TRANSACTIONS

OF THE

AMERICAN SOCIETY

OF

MECHANICAL ENGINEERS.

VOL. XVII.

XXXIId Meeting, New York, 1895.
XXXIIId Meeting, St. Louis, Mo., 1896.

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OFFICERS

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS,

1895–1896,

FORMING THE STATUTORY COUNCIL.

PRESIDENT.

John Fritz..........Bethlehem, Pa.

VICE-PRESIDENTS.

F. H. Ball..........New York City.
Jesse M. Smith..........Detroit, Mich.
M. L. Holman..........St. Louis, Mo.
Terms expire at Annual Meeting of 1896.

George W. Melville..........Washington, D. C.
Chas. H. Manning..........Manchester, N. H.
Francis W. Dean..........Boston, Mass.
Terms expire at Annual Meeting of 1897.

MANAGERS.

John B. Herreshoff..........Bristol, R. I.
L. B. Miller..........Elizabeth, N. J.
W. S. Russel..........Detroit, Mich.
Terms expire at Annual Meeting of 1896.

John C. Kafer..........New York City.
Chas. A. Bauer..........Springfield, O.
Arthur C. Walworth..........Boston, Mass.
Terms expire at Annual Meeting of 1897.

Norman C. Stiles..........Middletown, Conn.
E. D. Meier..........St. Louis Mo.
Geo. W. Dickie..........San Francisco, Cal.
Terms expire at Annual Meeting of 1898.

TREASURER.

Wm. H. Wiley..........No. 53 East 10th St., New York City.

SECRETARY.

Prof. F. R. Hutton..........No. 12 West 31st St., New York City.

HONORARY COUNCILLORS.

Past Presidents of the Society.

R. H. Thurston	1880—1882	Ithaca, N. Y.
E. D. Leavitt	1882—1883	Cambridgeport, Mass.
John E. Sweet	1883—1884	Syracuse, N. Y.
J. F. Holloway	1884—1885	New York City.
Coleman Sellers	1885—1886	Philadelphia, Pa.
Horace See	1887—1888	New York City.
Henry R. Towne	1888—1889	Stamford, Conn.
Oberlin Smith	1889—1890	Bridgeton, N. J.
Robert W. Hunt	1890—1891	Chicago, Ill.
Charles H. Loring	1891—1892	Brooklyn, N. Y.
Charles E. Billings	1895	Hartford, Conn.

[Note.—The former Presidents of the Society are members of the Council for life or during their retention of active membership in the Society.]

PAST OFFICERS.

(Executive.)

R. H. Thurston	*President*	April 7th, 1880—Nov. 3d, 1882.
E. D. Leavitt, Jr.	"	Nov. 3d, 1882—Nov. 3d, 1883.
John E. Sweet	"	Nov. 3d, 1883—Nov. 7th, 1884.
J. F. Holloway	"	Nov. 7th, 1884—Nov. 13th, 1885.
Coleman Sellers	"	Nov. 13th, 1885—Dec. 2d, 1886.
Geo. H. Babcock [*]	"	Dec. 2d, 1886—Dec. 1st, 1887.
Horace See	"	Dec. 1st, 1887—Oct. 18th, 1888.
Henry R. Towne	"	Oct. 18th, 1888—Nov. 22d, 1889.
Oberlin Smith	"	Nov. 22d, 1889—Nov. 14th, 1890.
Robt. W. Hunt	"	Nov. 14th, 1890—Nov. 20th, 1891.
Chas. H. Loring	"	Nov. 19th, 1891—Nov. 29th, 1892.
Eckley B. Coxe [†]	"	Nov. 29th, 1892—Dec. 4th, 1894.
E. F. C. Davis [‡]	"	Dec. 4th, 1894—Aug. 6th, 1895.
Chas. E. Billings [§]	"	Sept. 4th, 1895—Dec. 5th, 1895.
Lycurgus B. Moore	*Treasurer*	April 7th, 1880—Dec. 2d, 1881.
" " "	*Acting-Sec'y*	April 7th, 1880—Nov. 4th, 1880.
Thos. Whiteside Rae, [‖]	*Secretary*	Nov. 4th, 1880—March 1st, 1883.
Chas. W. Copeland [¶]	*Treasurer*	Dec. 2d, 1881—Nov. 7th, 1884.

MEMBERS OF PREVIOUS COUNCILS.

VICE-PRESIDENTS.

Henry R. Worthington,[**] Coleman Sellers, Eckley B. Coxe,[†] Q. A. Gillmore, Wm. H. Shock, Alex. L. Holley,[††] F. A. Pratt, W. P. Trowbridge,[‡‡] E. D. Leavitt, Jr., Chas. E. Emery, John Fritz, Henry Morton, Wm. Metcalf, S. B. Whiting, A. B. Couch, W. R. Eckhart, J. V. Merrick, Charles W. Copeland,[¶] Olin Landreth, Henry R. Towne, C. H. Loring, Horace See, Allan Stirling, Jos. Morgan, Jr., C. T. Porter, Horace S. Smith, W. S. G. Baker, H. G. Morris, C. J. H. Woodbury, Thos. J. Borden, Wm. Kent, Chas. B. Richards, Joel Sharp, Geo. W. Weeks, De Volson Wood, S. W. Baldwin, John F. Pankhurst, Alexander Gordon, Geo. I. Alden, E. F. C. Davis, Irving M. Scott, C. W. Hunt, Thos. R. Pickering, Edwin Reynolds, C. E. Billings, Percival Roberts, Jr., and H. J. Small.

MANAGERS.

W. P. Trowbridge,[‡‡] T. N. Ely, J. C. Hoadley,[§§] Washington Jones, Wm. B. Cogswell, F. A. Pratt, Chas. B. Richards, S. B. Whiting, J. F. Holloway, Geo. W. Fisher, Allan Stirling, Geo. H. Babcock, S. W. Robinson, Jno. E. Sweet, R. W. Hunt, Chas. T. Porter, C. J. H. Woodbury, W. F. Durfee, Oberlin Smith, C. C. Worthington, Wm. Lee Church, Wm. Hewitt, C. H. Morgan, H. A. Hill, Wm. Kent, S. T. Wellman, F. G. Coggin, J. T. Hawkins, T. R. Morgan, Sr., S. W. Baldwin, Fred'k Grinnell, Morris Sellers, Frank H. Ball, Geo. M. Bond, Wm. Forsyth, Jas. E. Denton, Carleton W. Nason, H. H. Westinghouse, Andrew Fletcher, Worcester R. Warner, Coleman Sellers, Jr., Jas. M. Dodge, Robt. Forsyth, Jesse M. Smith, Chas. H. Manning, C. W. Pusey, and John Thomson.

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[*] Died, Dec. 16, 1893.
[†] Died, May 13, 1895.
[‡] Died, Aug. 6, 1895.
[§] Unexpired term of Mr. Davis.
[‖] Died, May 27, 1893.
[¶] Died, Feb. 7, 1895.
[**] Died, Dec. 17, 1880.
[††] Died, Jan. 29, 1882.
[‡‡] Died, Aug. 12, 1892.
[§§] Died, Oct. 21, 1886.

NOTE.

THE considerable bulk of the annual volume of *Transactions* has induced the Publication Committee to direct that the full list of members of the Society should be omitted from the preliminary matter therein. The list which would have been published here is that which was corrected up to July, 1896, and was issued as a second edition of the Seventeenth Catalogue. The following summary records the number of members in each grade :

Honorary Members	16
Members	1,337
Associate Members	101
Junior Members	294
Total Membership	1,748
Life Members*	64

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* These Life Members are included in the total membership above, in the class to which they belong.

RULES OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

ART. 1. The objects of the AMERICAN SOCIETY OF MECHANICAL ENGINEERS are to promote the Arts and Sciences connected with Engineering and Mechanical Construction, by means of meetings for social intercourse and the reading and discussion of professional papers, and to circulate, by means of publication among its members, the information thus obtained.

ART. 2. All persons connected with engineering may be eligible for admission into the Society.

ART. 3. The Society shall consist of Honorary Members, Members, Associates, and Juniors.

ART. 4. Honorary Members, not exceeding twenty-five in number, may be elected. They must be persons of acknowledged professional eminence.

ART. 5. To be eligible as a Member, the candidate must be not less than thirty years of age, and must have been so connected with engineering as to be competent as a designer or as a constructor, or to take responsible charge of work in his department, or he must have served as a teacher of engineering for more than five years.

NOTE.—The Rules of the Society, adopted in 1880, were in force until 1884, when they received a general revision by a careful committee, whose report, distributed by letter ballot, was adopted November 5, 1884. In December, 1894, a similar extensive revision was made under direction of the Council, and the present rules are those of 1894. They include the amendments made in 1889, 1891, and 1893, which were the only changes since the revision of 1884.

Art. 6. To be eligible as an Associate, the candidate must be not less than twenty-six years of age, and must have the other qualifications of a member; or he shall have been so connected with engineering as to be competent to take charge of work, and to coöperate with engineers.

Art. 7. To be eligible as a Junior, the candidate must have had such engineering experience as will enable him to fill a responsible position, or he must be a graduate of an engineering school.

Art. 8. All Honorary Members, Members, and Associates shall be equally entitled to the privileges of membership. Juniors shall not be entitled to vote, nor to be officers of the Society.

Art. 9. Nominees for Honorary Membership must be proposed by at least five Members who are not officers of the Society. References shall not be required of a nominee for Honorary Membership, but the grounds upon which the application is made must be fully set forth in writing and signed by the proposers.

Art. 10. A candidate for admission to the Society, as a Member or as an Associate, must make an application on a form to be prepared by the Council, which shall contain a written statement giving a complete account of his engineering experience and an agreement that he will, if elected, conform to the laws, rules, and requirements of the Society. He must refer to at least five Members or Associates personally known to him. A candidate for admission to the Society as a Junior must make an application on the same form and refer to not less than three Members or Associates personally known to him.

Art. 11. The referees for each candidate for admission to the Society shall be requested to make a confidential communication on a form to be prepared by the Council, setting forth in detail such information, personally known by the referee, as shall enable the Council to arrive at a proper estimate of the eligibility of the candidate for admission to the Society. Such confidential communications shall be destroyed by the Secretary as soon as the vote has been officially declared.

Art. 12. All applications for membership must be presented to the Council, and this body shall consider each application, assigning to each, with the applicant's consent, the grade in the Society to which, in its opinion, his qualifications entitle him. The names of those candidates recommended for election by the Society shall be immediately printed on a ballot, and the ballot mailed at once by the Secretary to each voting member of the Society. Persons desiring to change their grade of membership from junior to associate or from associate to member shall make an application in the same manner and on the same form as that required for a new applicant.

ART. 13. A member entitled to vote may leave the name of any candidate on the ballot untouched to vote in favor of the admission of the candidate to the Society, or he may erase the name to vote against it. He shall enclose the ballot so approved by him in a sealed blank envelope, and enclose this envelope in a second envelope, on which he shall write his name, and mail the same to the Secretary of the Society. A ballot without such endorsement shall be rejected as defective. The rejection of a candidate by seven voters shall defeat his election.

ART. 14. The aforesaid envelopes containing the ballots shall be opened by the Council, at any meeting thereof, and the names of those elected shall be announced in the next meeting of the Society. The names of applicants not elected shall not be announced, nor recorded in the proceedings.

ART. 15. Endorsers of any applicant not elected may, within three months after such failure to be elected, lay before the Council written evidence that an error was then made. The Council may then, by a three-fourths vote, order another similar ballot by the Society, in which case thirteen negative votes shall be required to defeat the candidate.

ART. 16. Honorary members shall be elected by the unanimous vote of the Council, through a letter ballot, not less than sixty days subsequent to the proposal, a notice of which proposed election shall have been mailed at once by the Secretary to each member of the Council.

ART. 17. Each person elected, excepting honorary members, must subscribe to the Rules of the Society, and pay the initiation fee before he can receive a certificate entitling him to the rights and privileges of the Society, and to wear the emblem appropriate to his grade. If this payment is not made within six months of the election, the same shall be void, unless the time is extended by the Council. The emblems of each grade of membership shall be worn by those only who belong to that grade.

Art. 18. The initiation fee of a member or an associate shall be twenty-five dollars, and the annual dues shall be fifteen dollars, payable in advance. The initiation fee of a junior shall be fifteen dollars, and his annual dues ten dollars, payable in advance. A junior being promoted to any other grade of membership shall pay an additional initiation fee of ten dollars. Any member or associate may become a Life Member in the same grade, by the payment of two hundred dollars at one time, and shall not be liable thereafter to annual dues.

The Council shall have the power, for special reasons, by unanimous vote, through a letter ballot, to admit to life membership, without the payment of the sum above named, such person as for a long term of years has been a member or an associate, when such a procedure would in its judgment be for the best interests of the Society; provided that notice of such action shall have been given at a previous meeting of the Council.

Art. 19 Any member of the Society in arrears may, at the discretion of the Council, be deprived of the publications of the Society, or, when in arrears for one year, he may be stricken from the list of members. Such person may be restored to the privileges of membership by the Council on payment of all arrears.

Art. 20. The affairs of the Society shall be managed by a Council, consisting of a President, six Vice-Presidents, nine Managers, and a Treasurer, who shall also be the Trustees of the Society.

All past (ex) Presidents of the Society, while they retain their membership therein, shall be known as Honorary Councillors, and shall be entitled to receive notices of all meetings of the Council and may take part in any of its deliberations; they shall be entitled to vote upon all questions except such as affect the legal rights or obligations of the Society or its members.

Art. 21. The members of the Council shall be elected from among the members and associates of the Society at the annual meetings, and shall hold office as follows:

The President and the Treasurer for one year; and no person shall be eligible for immediate re-election as President who shall have held that office for two consecutive years; the Vice-Presidents for two years, and the Managers for three years; and no

Vice-President or Manager shall be eligible for immediate re-election to the same office at the expiration of the term for which he was elected.

ART. 22. A Secretary, who shall be a member of the Society, shall be appointed for one year by a majority of the members of the Council at its first meeting after the annual election, or as soon thereafter as the votes of a majority of the members of the Council can be secured for a candidate. The Secretary may be removed by a vote of twelve members of the Council, at any time after one month's notice has been given him by a majority of its members to show cause why he should not be removed, and he has been heard to that effect. The Secretary may take part in any of the deliberations of the Council, but shall not have a vote therein. His salary shall be fixed for the time he is appointed by a majority vote of the Council.

ART. 23. At each annual meeting, a President, three Vice-Presidents, three Managers and a Treasurer shall be elected, and the term of office of each shall continue until the end of the meeting at which their successors are elected.

ART. 24. The duties of all officers shall be such as usually pertain to their offices or may be delegated to them by the Council or by the Society. The Council may, in its discretion, require bonds to be given by the Treasurer.

ART. 25. The Council may, by vote of a majority of all its members, declare the place of any officer vacant, on his failure for one year, from inability or otherwise, to attend the Council meetings, or to perform the duties of his office. All such vacancies and those occurring by death or resignation shall be filled by the appointment of the Council, and any person so appointed shall hold office for the remainder of the term for which his predecessor was elected or appointed; *provided* that the said appointment shall not render him ineligible at the next annual meeting.

ART. 26. Five members of the Council shall constitute a quorum. Members of the Council absent from a meeting may vote by letter upon subjects stated in the call for the meeting, said vote to be deposited with the Secretary.

ART. 27. The President on assuming office shall appoint a Finance Committee and a Publication Committee and a Library Committee of five members each. The appointment of two members of each Committee shall expire at the end of each year. The Secretary shall, *ex officio*, be a member of all three committees.

Art. 28. The Finance Committee shall have power to order all ordinary or current expenditures, and shall audit all bills therefor. No bill shall be paid except upon their audit. When special appropriations are ordered by the Society, they shall not take effect until they have been referred to the Council and Finance Committee in conference.

Art. 29. It shall be the duty of the Publication Committee to receive all papers contributed, and to decide upon which papers or parts of the same shall be presented at the professional meetings of the Society. They shall see that all editorial revisions of the proceedings, papers, discussions, and reports are made; and to decide what parts of the same shall be published in the proceedings of the Society. The Council may at its discretion revise any action of the Publication Committee.

Art. 30. It shall be the duty of the Library Committee to take charge of the collection of all material for the Library of the Society, and to supervise all regulations for its use.

Art. 31. At the regular meeting preceding the annual meeting a nominating committee of five members, not officers of the Society, shall be appointed, and this committee shall, at least thirty days before the annual meeting, send to the Secretary the names of nominees for the offices falling vacant under the rules. In addition to such regularly appointed committee, any other five members or associates, not in arrears, may constitute an independent nominating committee, and may present to the Secretary, at least thirty days before the annual meeting, all the names of such candidates as they may select. All the names of such independent nominees shall be placed upon the ballot list, with nothing to distinguish them from the nominees of the regular committee, and the Secretary shall at once mail the said list of names to each member and associate in the form of a letter ballot, it being understood that the assent of the nominees shall have been secured in all cases.

Art. 32. In the election of Vice-Presidents, each member and associate may cast as many votes as there are Vice-Presidents to be elected. He may give all these votes to one candidate, or distribute them among more, as he chooses. Managers shall be voted for in the same way.

Art. 33. Any member or associate entitled to vote may vote by retaining or changing the names on said list, leaving names not exceeding in number the officers to be elected, and returning the list to the Secretary—such ballot inclosed in two envelopes, the inner one to be blank and the outer one to be indorsed by the voter. No member or associate in arrears since the last annual meeting shall be allowed to vote until said arrears shall have been paid

ART. 34. The said blank envelopes shall be opened by tellers at the annual meeting, and the person who shall have received the greatest number of votes for the several offices shall be declared elected.

MEETINGS.

ART. 35. The annual meeting of the Society shall be held on the first Tuesday in December of each year, in the City of New York, unless otherwise ordered, at which a report of proceedings and an abstract of the accounts shall be furnished by the Council. The Council may change the place of the annual meeting, and shall, in that case, give timely notice to members and associates.

ART. 36. Other regular meetings of the Society shall be held in each year at such time and place as the Council may appoint. At least thirty days' notice of all meetings shall be mailed by the Secretary to members, honorary members, associates and juniors.

ART. 37. Special meetings may be called whenever the Council may see fit; and the Secretary shall call a special meeting at the written request of twenty or more members. The notices for special meetings shall state the business to be transacted, and no other shall be entertained.

ART. 38. Any member, honorary member or associate may introduce a stranger to any meeting; but the latter shall not take part in the proceedings without the consent of the meeting.

ART. 39. Every question which shall come before the Society shall be decided, unless otherwise provided by these rules, by the votes of a majority of the members and associates present, provided there is a quorum.

ART. 40. At any regular meeting of the Society thirteen or more members and associates shall constitute a quorum.

Art. 41. Unless otherwise ordered, papers shall be read in the order in which their text is received by the Secretary. Before any paper appears in the *Transactions* of the Society, a copy of the paper shall be sent to the author, and, so far as possible, a copy of the reported discussion shall be sent to every member who took part in the same, with requests that attention shall be called to any errors therein.

Art. 42. The Society shall claim no exclusive copyright in papers read at its meetings, nor in reports of discussions, except in the matter of official publication with the Society's imprint, as its *Transactions*. The Secretary shall have sole possession of papers between the time of their acceptance by the Publication Committee and their reading, together with the drawings illustrating the same ; and at the time of such reading, or as soon thereafter as practicable, he shall cause to be printed, with the authors' consent, copies of such papers, " subject to revision," with such illustrations as are needed for the *Transactions*, for distribution to the members and for the use of technical newspapers, American and foreign, which may desire to reprint them in whole or in part. The policy of the Society in this matter shall be to give papers read before it the widest circulation possible, with the view of making the work of the Society known, encouraging mechanical progress, and extending the professional reputation of its members.

Art. 43. The author of each paper read before the Society shall be entitled to twelve copies, if printed, for his own use, and all members shall have the right to order any number of reprints of papers at a cost to cover paper and printing; *provided*, that said copies are not intended for sale.

Art. 44. The Society is not, as a body, responsible for the statements of fact or opinion advanced in papers or discussions, at its meetings; and it is understood that papers and discussions should not include matters relating to politics or purely to trade.

Art. 45. These rules may be amended, at any annual meeting, by a two-thirds vote of the members present; *provided*, that written notice of the proposed amendment shall have been given at a previous meeting.

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LIST OF ILLUSTRATIONS.

PAPERS

OF THE

NEW YORK MEETING

(XXXIId)

DECEMBER 3d TO 6th, 1895,

BEING ALSO THE SIXTEENTH ANNUAL MEETING OF THE SOCIETY.

DCLXIII.

PROCEEDINGS

OF THE

NEW YORK MEETING

(XXXIId)

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS,

December 3d to December 6th, 1895.

THE opening session of the sixteenth annual meeting differed from any of its predecessors in that the death of the elected President of the Society, Mr. E. F. C. Davis, while in office, had left a vacancy in the presidential chair and had made it necessary for the Council to appoint his successor under the rules. It was felt to be fitting that the appointee should be introduced to the meeting by one of the past presidents. This duty fell to the lot of Mr. J. F. Holloway, who spoke as follows:

For the first time in the history of our Society we meet to find the chair of our President made vacant by death; for the first time the Council has been called upon to appoint a person to fill the unexpired term of a President elected by the Society. This the Council has done, and later on it will be my duty as well as my pleasure to introduce to you the person whom it has appointed.

This is not the time, nor the place, in which to speak at length of the many charming qualities possessed by our late President, Mr. E. F. C. Davis; that will be done by another at the proper time. As the death of Mr. Davis was sudden, unexpected, and to some extent mysterious, and as many persons present did not have the opportunity of reading the city papers which contained all the information then obtainable of this sad affair, perhaps a brief recital of the facts concerning it, so far as they are known, will be of interest.

Mr. Davis, whose place of business was on Staten Island, was wont during the summer, and while his family were out of the city, to come to New York in the evening, and take rest and recreation by horseback riding in Central Park. He was the owner of a fine Kentucky riding horse, which he kept near the Park for this purpose. On the evening of August 6th, as was his practice, he called at the stable for his horse, and, mounting him, entered alone the bridle-path of the Park.

From his entrance to the Park until later it is not known that he was seen by any one until found dead by the roadside by a company of mounted police who were returning to their stations. The most reasonable theory by which to account for this lamentable accident was that his horse, from some cause or another, took a sudden fright, and, shying, threw its rider, who, in falling, struck a stone, which caused his death. While this is the most probable cause of the death of Mr. Davis it is, at the same time, a difficult one to understand, as he was reputed to be an expert rider.

While the death of such an estimable gentleman as was Mr. Davis is ever a great loss to the community at large, and a severe and sadly lamented one to the Society over which he had presided with such marked ability and dignity, who of us can estimate the feeling of utter loneliness, that sense of desolation, which such a death must bring to the home circle of which he was the honored and well-beloved head. And if the heartfelt sympathy of those who knew and admired him as their associate in the business affairs of this Society, of those who were his associates in its membership, could, in the slightest degree. serve to lighten the load of sorrow they bear, how kindly it would be tendered, and how sincerely it is!

Before introducing the gentleman appointed by the Council to fill the remainder of the term for which Mr. Davis was elected, I desire to say a few words indicative of my own feelings when first elected as the President of this Society, and what has been the feeling of all those who have followed me in that office, and what I know to be the desire of the gentleman who is now about to assume its obligations and duties.

In a Society having so large and so widely extended a membership as has the American Society of Mechanical Engineers, it is impossible for any incoming President to know personally very many of the members who may be in attendance at any of its meetings. This is a source of much embarrassment to the presiding officer, but it is one which can be greatly lessened by those present if they are so disposed, and I think the manner of doing it needs only to be pointed out to be adopted. The way to accomplish this is for each member, as opportunity may offer, to present himself to the President, make his acquaintance, and let him make yours. I am certain that this will be highly appreciated by your Presidents, and will certainly make each one more at home and more at ease.

I perhaps need not repeat what I have so often said about the duty of each member to do what he can to make each meeting as great a success socially, and an occasion for making and renewing acquaintance, and for promoting genial, kindly good-fellowship, as it is for bringing out and distributing useful knowledge in the various lines of our industries and professions. It is a well established and recognized fact that, while our Society has and is doing much to add to the world's stock of useful knowledge in matters technical and scientific, it is none the less renowned for the harmony and good feeling attending the transaction of its business affairs, and, above all, for a kindly regard, sympathy, and interest in the welfare of each other, which, after all, is the "one touch of nature that makes all the world akin."

Gentlemen, I take pleasure in introducing as your President Mr. Charles E. Billings, of Hartford, Conn.

At the close of Mr. Holloway's introduction, Mr. C. E. Billings took the chair as President, and called for the reading of the memorial minute prepared by the Council upon the death of President Davis. This was read by the Secretary, as follows:

IN MEMORIAM.

The American Society of Mechanical Engineers desires to place upon the records of the Society and of its Council a minute expressive of the respect and regard which its members feel and seek to make public upon the sudden and untimely death, from an accident, of their colleague, Mr. E. F. C. Davis, President of the Society.

The formal mould of memorial resolutions in which a corporate body ordinarily records its action seems inadequate for a proper voicing of the spirit which pervades the Society in the presence of the death of one whom its members had known so well and whom they had learned to admire and love. His wise and mature judgment, his business and professional knowledge, his conservative yet energetic counsel, and his courteous consideration for others, had made him one from whose administration of the Society's affairs the highest hopes had been entertained.

Although with such grief the stranger intermeddleth not, yet the Society would presume to express its heartfelt sympathy with those nearest and dearest to Mr. Davis, upon whom this blow has fallen so crushingly.

Resolved, That copies of this minute be furnished to the engineering journals, with a request that they give a publicity to it in such a way that it may serve to convey to the profession something of the sorrow and regret with which the American Society of Mechanical Engineers has heard of their loss in the death of their President.

This minute, moved as the sense of the Society, was unanimously adopted.

The President then addressed the Convention in the following words of salutation:

Gentlemen:—I extend to you a cordial and hearty welcome to the sixteenth annual meeting of the American Society of Mechanical Engineers.

The silent messenger of death has removed from us my predecessor, our friend and brother member, Mr. E. F. C. Davis, on whom this Society, at its last annual meeting, conferred the highest honor in its power to bestow, by electing him its President. Little did we anticipate then but what we should meet again at this time and listen to his words of wisdom and counsel; but the Almighty and Supreme Architect of the universe has willed otherwise.

Through our representatives, the Council, I was chosen to fill the vacancy caused by the death of our lamented friend. It was with extreme reluctance that I accepted the office, for I know full well that there are many among us better qualified for the position than myself; but duty is one great law we all recognize, inflexible as fate, exacting as destiny. Therefore, asking for your kind indulgence, I will endeavor to discharge the duties of the office for the remainder of the term to which I was elected.

Looking back over the time which has passed, it hardly seems that it will be sixteen years next January since a few gentlemen met in the office of the American Machinist Publishing Company at 96 Fulton Street, New York, and talked over the subject of forming such a society.

February 16, 1880, upon invitation of Prof. John E. Sweet, Prof. Robert H. Thurston, and Mr. Alexander L. Holley, about thirty gentlemen held a meeting and discussed the matter and laid plans for the formation of the Society. Complete organization was accomplished at the Stevens Institute, Hoboken, N. J., April 7, 1880. The first annual meeting was held in the Turf Club Theatre, New York, November 4, 1880. The attendance was nearly one hundred.

The seeds which the founders of this Society planted have taken deep root, and from the small beginning it has continued to increase in number and in its sphere of usefulness, until to-day its total membership, including members associate, life, and honorary, is nearly seventeen hundred, embracing in its ranks many of the brightest men, technically and practically, of the present time. Its pathway has ever been onward and upward. No record has ever been laid at its door, so far as my knowledge extends, which would be unbecoming to true and honorable gentlemen.

Many of the papers read, discussed, and published on mechanical subjects have been of great benefit, not only to our members, but to those that are not members, who have been fortunate enough to have had the opportunity to read them.

Our Society has done a great and good work in the past. The field grows broader and the opportunities greater for still more advanced work in the future.

Mr. Billings then read his address from the chair, bearing title of "Modern Improvements in the Drop-press." Messrs. Holloway, Fritz, Dean, Kent, and Hutton took part in the discussion which followed.

Topical discussions were then taken up, and the following questions were answered:

For filtering oil having very finely divided metallic particles in suspension, what have you found to be the best filtering material, either for one operation or in a series?

What information can you give as to the best method for the extraction of oil from condensed steam, where it is desirable to use the exhaust steam repeatedly for boiler-feed purposes?

Messrs. Kafer, Bang, Roelker, Langlotz, Kent, Darling, Bonner, Grimm, Woolson, McBride, Fritz, and Winship took part in the debate.

This first evening was intended rather as a preliminary opportunity for the assembling members to meet together to renew old friendships and begin new acquaintance. The rooms of the Society were open from an early hour, and, with smoking and light refreshment, the evening passed pleasantly. Just prior to adjournment the President appointed Messrs. W. T. Bonner and George W. Scott as tellers to count the ballots for officers, and to report at the morning session.

SECOND DAY. WEDNESDAY, DECEMBER 4TH.

The regular sessions of the annual meeting began with the session of this morning, at ten o'clock, in the auditorium. The registration of members, even at this early session, showed that the meeting was to be an unusually large one, and the record before the end of the meeting showed that the size and numerical success of the meeting were to be noteworthy. The plan was adopted of numbering the lines on the official register, and providing that the usual button badge worn at the Society's convention should bear a number corresponding to the number on the register. It will be seen that by this expedient every one could immediately ascertain the name of every one else without the embarrassment of a direct question to this end, and the practical result showed that the meeting was one of the most successful on the social side that had ever been held. The register showed the following persons in attendance from the list of members. The total registered, including guests, was four hundred and nineteen.

Alden, Geo. I.
Aller, A.
Almond, T. R.
Almy, D.
Ashley, F. M.
Baldwin, A. T.
Baldwin, S. W.
Ball, F. H.
Bang, H. A.
Bardwell, A. F.
Barnes, A. T.
Barr, H. P.
Barr, J. H.
Bauer, C. A.
Beardsley, A.
Billings, C. E. (President).
Birkenbine, Jno.
Bixby, W. H.
Boenig, R. W.
Bole, W. A.
Bond, Geo. M.
Bonner, W. T.
Bowden, J. H.
Boyer, F. H.
Bradley, W. H.
Bristol, W. H.
Brooks, M.
Brotherhood, F.
Bulkley, H. W.
Bullock, M. C.
Burchard, A. W.
Buzby, C. E.
Cadwell, W. D.
Cahoon, J. B.
Caldwell, A. J.
Canfield, H.
Carpenter, H. A.
Carpenter, R. C.

Cary, A. A.
Chase, H. S.
Cheney, W. L.
Childs, A. E.
Christie, W. W.
Clark, W. L.
Clarke, S. J.
Coffin, W. C.
Cogswell, W. B.
Colvin, F. H.
Colwell, A. W.
Connell, J. A.
Conover, E. K.
Corbett, C. H.
Cottier, Jos.
Crane, W. E.
Creelman, F. J.
Cremer, J. M.
Cruikshank, B.
Cruikshank, D. L.
Cullingworth, Geo. R.
Curtis, R. E.
Darling, E. A.
Darrin, D. H.
Davis, I. H.
Dean, F. W.
Deane, C. P.
Deck, H. S.
Dent, E. L.
Denton, J. E.
Dick, Jno.
Dinkel, Geo.
Du Bosque, F. L.
Durfee, W. F.
Eberhardt, F. L.
Emery, A. H.
Emery, C. E.
Estrada, E. D.
Faber, Du Faur A.
Fairbanks, R. N.
Farrand, D.
Fladd, F. C.
Flagg, S. G.
Flather, F. A.
Forbes, W. D.
Forney, M. N.
Forsyth, R.
Foster, E. H.
Francis, H. C.
Frevert, H. F.
Frith, A. J.
Fritz, John.
Gale, H. B.
Gantt, H. B.
Garfield, L. M.
Geoghegan, S. J.
Glenn, H. F.
Gnade, E. R.
Gobeille, J. L.
Goetze, F. A.
Goodale, A. M.
Goodell, J. M.
Gordon, Alex.
Goubert, A. A.
Gould, W. V.
Granger, A. S.
Graves, E.
Green, D. J.
Green, S. M.
Greene, A. M.
Greenleaf, G. E.
Griffin, C. L.
Grimm, P. H.
Guilford, W. M.
Hague, C. A.
Hale, R. S.
Hall, F. A.
Halsey, F. A.
Hamilton, J. F.
Hammett, H. G.
Hardy, G. F.
Hardy, G. R.
Hartness, Jas.
Haskins, H. S.
Hayward, F. H.
Hemenway, F. F.
Henderson, Alex.
Henning, G. C.
Herreshoff, J. B. F.
Higgins, C. P.
Hill, Wm.
Hill, W. E.
Hillmann, G.
Hirt, L. J.
Hoffecker, W. L.
Hollerith, H.
Holloway, J. F.
Holly, E. P.
Hopton, W. E.
Horton, J. A.
Hough, D. L.
Howell, E. I. H.
Hunt, C. W.
Hunt, W. F.
Huson, W. S.
Hutton, F. R.
Idell, F. E.
Illingworth, J. J.
Jacobus, D. S.
Jenkins, M. C.
Jenks, L. H.
Jenks, W. H.
Johnson, A. E.
Jones, H. C.
Jones, Washington.
Kafer, J. C.
Katté, E. B.
Keep, W. J.
Kelly, J. R. F.
Kent, Wm.
King, C. C.
Kingsbury.
Kirchhoff, C.
Kirk, R. H.
Knight, A. F.
Kretschmer, F. G.
Laforge, F. H.
Lager, C.
Lambert, A.
Langlotz, C.
Langlotz, R.
Larkin, A. C.
Le Van, W. B.
Lieb, J. W.
Longnecker, C. K.
Loring, C. H.
Low, F. R.
Lyall, W. L.
McBride, Jas.
McClelland, E. S.
McElroy, S.
McKee, J. J.
McMannis, W.
Magoun, H. A.
Matlack, D. J.
Matlack, Jno. R.
Manning, C. H.
Marble, H. M.
Marx, H.
Mason, F. S.

Mason, W. B.
Matton, F. V.
May, De C.
Meatz, J. F.
Melvin, D. N.
Messenger, F. M.
Mesta, Geo.
Meyer, H. C.
Meyer, H. C., Jr.
Miller, Alex.
Miller, F. J.
Miller, H. B.
Mirkil, T. H., Jr.
Monaghan, W. F.
Montgomery, H. M.
Moore, D. G.
Moore, M. F.
Morse, C. M.
Mossberg, F.
Moulthrop, L.
Müller, M. A.
Müller, T. H.
Mumford, E. H.
Nason, C. W.
Newcomb, C. L.
Newhall, J. B.
Nicoll, C. H.
Norris, H. M.
Norris, J. E.
Odell, W. H.
Otis, S.
Parker, C. H.
Parks, E. H.
Parsons, F. W.
Parsons, H. de B.
Partridge, W. E.
Paul, J. W.
Peabody, E. H.
Pearson, W. A.
Peirce, W. H.
Penney, E.
Phelps, F. A.
Phillips, Geo. H.
Platt, F. W.
Platt, Geo. H.
Platt, Jno.
Pomeroy, L. R.
Porter, Wm.
Rand, A. C.
Raqué, P. E.
Raynal, A. H.
Redwood, I. I.
Reeve, S. A.
Rettew, C. E.
Richards, F. H.
Richards, R.
Richmond, Geo.
Rickson, C. E.
Riddell, Jno.
Ridgway, J. T.
Ridsdale, T. W.
Roberts, P.
Roberts, Wm.
Robertson, R. A., Jr.
Robinson, J. M.
Rockwood, G. I.
Roelker, H. B.
Rowland, A. E.
Rowland, C. B.
Rowland, T. F., Jr.
Russell, C. W.
Sargent, J. W.
Sattler, W. R.
Scheffler, F. A.
Schoenborn, W. E.
Scholl, J.
Schumann, F.
Schutte, L.
Scott, G. H.
Scott, S. M.
Seavey, J. F.
Sergeant, C. H.
Serrell, J. A.
Sewall, M. W.
Shellenberger, L. R.
Shepherd, W. G.
Slater, A. B.
Smith, Geo.
Smith, H. W.
Smith, J. H.
Smith, J. M.
Smith, Oberlin.
Snell, H. J.
Sonnberger, E. C.
Southер, H.
Spaulding, H. C.
Spies, A.
Stangland, B. F.
Stiles, N. C.
Stillman, F. H.
Strong, Geo. S.
Suplee, H. H.
Svenson, Jno.
Swasey, A.
Taber, G. H.
Tabor, H.
Taylor, J. F.
Taylor, S.
Thomas, E. W.
Thomson, Jno.
Thurston, R. H.
Torrance, K.
Torrey, H. G.
Towl, F. M.
Towne, H. R.
Townsend, D.
Tremaine, E. G.
Trowbridge, A.
Tucker, W. B.
Uehling, E. A.
Vanderhoef, G. N.
Varney, W. W.
Waldron, F. A.
Wallace, D. A.
Walworth, A. C.
Ward, W. E.
Warner, W. R.
Warren, B. H.
Watson, Wm.
Webb, J. B.
Webber, S. W.
Weber, A. G.
Weber, Geo.
Webster, N.
Webster, W. R.
Weeks, Geo. W.
Weeks, J. D.
Weil, C. L.
Wellman, S. T.
Wells, J. L.
Weston, N. S.
Wheeler, F. M.
Wheeler, S.
White, J. J.
Whitehead, G. E.
Whiting, C. W.
Whittier, C.
Wiggin, W. H.
Wiley, W. H.
Williams, D. C.

Winship, J. G.
Wood, De V.
Wood, M. P.
Woolson, O. C.
Wright, J. Q.
Wright, L. S.
York, H. W.
Young, W. S.

Total.......................................346

The first order of business was the Annual Report of the Council to the Society under the Rules.

ANNUAL REPORT OF THE COUNCIL.

The Council must begin the Annual Report to the Society, of the business which has been transacted during the Society year, with the action taken upon the removal by death of those who have been honored by selection to the office of President.

The Society has already taken action upon the death of President E. F. C. Davis, but it has also experienced during the year just closed the loss of one who had but recently retired from presidential office. Mr. Eckley B. Coxe died at his home, Drifton, Pennsylvania, in May, and at the meeting of the Council first succeeding, the following minute was presented and entered upon its records. The Council, in reporting it to the meeting, desires in this way to make it the action of the Society as a whole.

The action was as follows:

" The Council of the American Society of Mechanical Engineers has learned with profound sorrow of the death of Hon. Eckley B. Coxe, former President of the Society. He had so recently retired from active participation in the business affairs of the Society, that the shock comes so much the nearer to those who had been associated with him.

" The long and honorable connection of Mr. Coxe with professional duties of the highest class, had given him a standing which shed a special lustre upon the office which he filled so acceptably; and his familiarity with legislative procedure, and with business affairs, made his advice and leadership most wise and judicious. But, more than all, the charming and affectionate geniality and frank-heartedness of the personality which lay behind the outward acts were the things which will remain long in the memory of his closer colleagues, and which give the poignancy to their regret at his loss. It is these qualities of the man which must make his death the sorer blow to those near to him in family and business, and which call for an outward expression of the sympathy which we feel in the great loss they have undergone.

"*Resolved,* That this minute be recorded in full upon the records of the Society, and of the Council."

The final revision of the proposed amendments to the rules which carried with them improvements in the blanks to be used by candidates for membership in the Society, was referred to the Council by the annual meeting of 1894, and the rules thus amended appear in the sixteenth catalogue, issued January 1, 1895.

The amended forms of application blanks, and particularly the amended forms of blanks used by those members to whom candidates have referred, have been in operation during the year, and with signal satisfaction. Particular advantage seems to have resulted from the change which made the Associate grade one in which an increasing number of persons might be classified under the rules, thus enhancing in a notable degree the value which attaches itself to the grade of Member of the Society.

To secure a more certain and positive knowledge concerning candidates for membership in the various grades, the Council had directed that the applications of candidates should be considered at frequent intervals by a committee of that body which has been designated as the Committee on Admissions. By the direction of this Committee the names of candidates are printed on a slip, which is mailed to the voting membership as an announcement that persons upon that list are seeking membership, and requesting them to communicate to the Council their views upon their eligibility and fitness. This procedure corresponds to the posting of candidates in the usual club methods, differing only in the fact that it is done by mail. The Committee on Admissions, receiving the replies of the voting membership, then presents the application in final form to the Council, who thereupon order the preparation of the official ballot. This threefold scrutiny has been found to work well, and should be a manifest safeguard in securing a high standard of membership.

In addition to its important functions with respect to scrutiny of applications for membership, the Council has been solicited by libraries, technical schools, and others, to supply the back sets of the Society's *Transactions*, and to list the libraries upon its records for the regular receipt of the annual volumes as issued. The calls for these early issues have become so numerous that it has been impossible to grant the request in every case for their presentation as a gift; but in cases where it seemed fitting, the right has been granted to the library to purchase the back volumes at the discount of fifty per cent. which is permitted to members of the Society desiring this procedure.

Among other institutions which have availed themselves of this privilege is to be mentioned the University of Glasgow, Scotland, in whose chair of engineering Professor W. J. M. Rankine sat for so many years.

The Council has elected to Honorary Membership by unanimous letter-ballot, under the rules, Sir William Arrol, builder of the Forth Bridge in Scotland, the Tower Bridge in England, and many other distinguished engineering works.

At the instance of certain interested members, both upon the Society's Committee on Standard Methods of Testing Materials and from the Society at large, the Council directed that an appropriation be made for the necessary expenses of a delegate from the Society and its committee to the International Convention of Engineers and Manufacturers at the city of Zurich, Switzerland, in the month of September. Mr. Gus. C. Henning, secretary of the Society's committee and its reporter, was the choice of the Council for this assignment; and the advantage to the repute of the Society from being thus represented at such a gathering has been neither small nor unrecognized. A report from the delegate will form part of the business of the annual meeting.

Pursuant to the action of the annual meeting of 1894, a committee of five members of the Society was appointed to take charge of the details of a series of reunions of members of the Society and others, in the Society's house, during the winter and spring of 1895. This Committee consisted of Messrs. Charles Kirchhoff, C. W. Baker, F. R. Low, B. H. Warren, and George L. Fowler.

As these meetings were distinctly local in character and were to be self-supporting so far as the report of the discussions, etc., were concerned, great care was taken that they should be regarded as reunions of individual members of the Society and not in any sense meetings of the Society as an organization. The name given to secure this end was "Monthly Engineering Evenings," and the only relation of the organization to the Society as a whole was the furnishing of a meeting place with its conveniences.

The subjects of the evenings of 1895 were, "The Gas Engine," "The Rapid Transit Problem in Large Cities," "The Electric Motor in the Machine Shop," "The Compound Locomotive," and the "Water Works Engineering of New York."

It was referred to the Council by a meeting of the Society at Detroit in June, 1895, to appoint a Committee who should consider the question of revising the Society's Code of Steam Boiler Trials reported in 1886. That committee consists of Messrs. Barrus, Coon, Dean, Emery, Hunt, Kent, Porter, Potter, and Thurston.

The question of the dates at which the semi-annual conventions of the Society are held has been under advisement, pursuant to a suggestion that as now selected the dates were not specially well chosen. It was the opinion of the Council, after taking advice, that the present dates seem to suit the convenience of the greatest number; and therefore no change was recommended.

They have further directed that at the sessions devoted to the presentation and discussions of professional papers, executive and administrative business shall be considered out of order; but that upon the programmes of the conventions, certain specially designated times shall be allotted for the presentation and consideration of such matters.

A series of communications from Mr. E. L. Corthell has been considered by the Council in which the proposer embodies certain ideas looking to the creation of an Institute of Engineers and Architects, which should be inclusive of the membership of the present national societies and should be aimed to become international in scope and character. Alternative to this idea was the suggestion that by common action the existing Societies should arrange to federate themselves for purposes of common interest to applied science and engineering, with a view to the holding at convenient intervals of joint meetings or congresses to which delegates from other countries should be invited to be present and contribute. If the Council was not ready for action of this comprehensive character it was requested to appoint committees to confer with the sister societies with a view to providing for such congresses without either federation or organic union. In view of the debate in Volume XI. of the *Transactions* of this Society, which showed an opinion and judgment distinctly antagonistic to the first scheme, and the obvious practical difficulties with respect to expense and the effects upon the present organizations of the two latter schemes, the matter has been laid upon the table with an expression of the opinion that the time is not yet ripe for the inauguration of such plans.

The Council would report for record the death since the last annual meeting of the following persons:

A. J. Shaw, C. L. Hoyt, Charles W. Copeland, L. Packard, John H. Webster, Thomas R. Pickering, E. C. French, Eckley B. Coxe, A. M. Wellington, James G. Dagron, William C. Mackinney, George Davidson, E. F. C. Davis, W. C. Jones, E. J. Whitaker, Herman Winter, R. H. Tweddell, and William A. Pike.

At the close of the Report of the Council, the second order of business was the Report of the Finance Committee, which was as follows:

The Finance Committee of the American Society of Mechanical Engineers would respectfully report to the Council the following statements of the receipts and expenditures on behalf of the Society, under their direction during the year, from November, 1894, to November, 1895:

ANNUAL REPORT.

Receipts.

Accounts.	Cash.	Bonds.	Total.
Initiation Fees	$2,540 00	....	$2,540 00
Current Dues	21,471 85	....	21,471 85
Past Dues	1,114 45	....	1,114 45
Advanced Dues	131 08	....	131 08
Sales of Publications	792 44	....	792 44
Binding	4 50	....	4 50
Meetings	25 00	....	25 00
Badges	487 65	....	487 65
Engraving	99 75	....	99 75
Life Membership	900 00	$300 00	1,200 00
Contingencies	17 00	....	17 00
Postage and Express	4 84	....	4 84
Interest on Investments	995 00	....	995 00
Office Expenses	6 35	....	6 35
Rent	7 50	....	7 50
Stationery and Printing	6 25	....	6 25
Travelling	3 50	....	3 50
Profit and Loss	1 52	....	1 52
	$28,608 68	$300 00	$28,908 68
Cash on Hand First of Year	60 21	....	60 21
	$28,668 89	$300 00	$28,968 89

Disbursements.

Accounts.	Cash.		Total.
General Printing and Stationery	$1,392 58	....	$1,392 58
Reprints and Publications	8,883 70	....	8,883 70
Postage and Express	2,028 82	....	2,028 82
Salaries	6,938 28	....	6.938 28
Office Expenses	311 13	....	311 13
Engraving	1,110 36	....	1,110 36
Contingencies	82 53	....	82 53
Binding	1,533 70	....	1,533 70
Meetings	716 65	....	716 65
House Supplies and Furniture	287 21	....	287 21
Badges and Certificates	313 78	....	313 78
Traveling	151 63	....	151 63
Insurance and Safe Deposit	17 00	....	17 00
Rent, Interest, and Taxes	2,775 65	....	2,775 65
Investment Bonds received as above	300 00	....	300 00
Investment Bonds purchased	1,550 00	....	1,550 00
Library (book purchase)	13 12	....	13 12
Work of Committee	276 95	....	276 95
Cash in Hand to Balance	285 80	....	285 80
	$28,968 89		$28,968 89

The receipts on account of Life Membership during this year were $1,200—$900 of this amount being cash, and $300 bonds of the Mechanical Engineers' Library Association which were received as cash in payment for such Life Membership.

The Finance Committee has directed a reduction of expenses for the ensuing year in the two largest items of expenditure in the foregoing statement, by so changing the salary account as to effect an economy of about $600; and in addition have recommended to the Publication Committee so to administer their important department as to reduce the outlay for publications in so far as it may be possible to do so without impairing the value of the volumes.

The original issue of the bonds of the Mechanical Engineers' Library Association amounted to $32,000, and of this issue the Council as Trustees for the Society held $19,000 at the time of the last report of the Finance Committee, November 15, 1894. During the past year the Council has acquired $1,900 worth of additional bonds ($1,600 by purchase and $300 by surrender for Life Membership), thus making the total of these bonds held by the Council, November 15, 1895, $20,900; and the Mechanical Engineers' Library Association has bought $500 of these bonds this year (see the report of the Mechanical Engineers' Library Association), which leaves outstanding $10,600.

The amount of dues and accounts still carried on the books of the Society as due from members and others at the end of this year is more than enough to pay all bills against the Society for its expenses of the year which have not been paid at the time of drawing up this report.

A memorandum was also presented for record as follows:

LIBRARY ASSOCIATION.

COPY OF THE ANNUAL REPORT OF THE TRUSTEES OF MECHANICAL ENGINEERS' LIBRARY ASSOCIATION, 1894–1895.

The summary of receipts and disbursements of the Trustees from November 10, 1894, to November 19, 1895, is appended below:

Receipts.

Balance on hand November, 1894		$199 38
Receipts Fellowship Fund	$232 00	
" Sinking Fund	610 50	
" Office Rent	4,710 00	
Gas and Electric Light	87 04	
Room Rent	1,807 15	
Contingencies	113 00	
Salaries	5 00	
Total Receipts		7,564 69
Total Cash		$7,764 07

Disbursements.

Interest on Mortgage		$1,471 24
" Bonds		1,600 00
Salaries		835 00
House Supplies and Furniture		542 46
Fuel		279 15
Lighting Gas	$184 47	
Lighting Electric Light	576 59—	761 06
Equipment		336 78
Laundry		220 00
Repairs		328 50
Binding		115 15
Book Purchase		118 87
Contingencies		18 20
Investment (Mechanical Engineers' Library Association Bonds bought)		500 00
Total Disbursement		$7,126 41
Cash in Hand to balance		637 66
		$7.764 07

Assets.

House and lot, 12 W. 31st Street, New York City	$65,000 00	
Furniture and equipment	5,000 00	
Books and MSS	10,100 00	
Bills Receivable (Office and Room Rent, uncollected)	349 51	
“ “ (Subscription to Fellowship Fund, uncollected)	122 00	
“ “ (Sinking Fund Subscription, uncollected)	554 50	
Second Mortgage Bonds held by Trustees as an investment	500 00	
Total Assets		$81,626 01

Liabilities.

First Mortgage held by N. Y. A. of M.	$33,000 00	
Second Mortgage held by Members of the A. S. M. E.	10,600 00	
Second Mortgage Bonds held by the Council of the A. S. M. E. as an investment	20,900 00	
Total Liabilities		$64,500 00
Excess of Assets over Liabilities		$17,126 01

The tellers of the Council also presented for record the following report:

REPORT OF THE TELLERS OF ELECTION.

The undersigned were appointed a committee of the Council to act as tellers (under Rule 13), to scrutinize and count the ballots cast for and against the candidates proposed for membership in the American Society of Mechanical Engineers, and seeking election before the thirty-second meeting, New York, 1895.

They have met upon the designated day, in the office of the Society, and have proceeded to discharge their duty. They would certify, for formal insertion in the records of the Society, to the election of the persons whose names appear on the appended list to their respective grades.

There were 455 votes cast of the blue ballot, of which 15 were thrown out because of informalities (the members voting having neglected to indorse the sealed envelope).

FRANK H. BALL,
JOHN C. KAFER, } *Tellers of Election.*
JOHN THOMSON,

MEMBERS.

Bell, James Richard.
Clements, John B.
Foster, Horatio A.
Heisler. Charles L.
Leland, Henry M.
Lobben, Peder.
McKean, Robert A.
Palmer. Courtlandt E.
Potter, William B.
Riddell, John.
Wilkes, Charles Mason.
Wilkinson, Alfred.

ASSOCIATES.

Carpenter, A. H.
Connolly, John H.
Connelley, Clifford B.
Hooper, George K.
Inglis, James.
Joy, Francis B.
Lighthall, John A., Jr.
Mallory, Harry C.
Olin, F. W.
Sayward, John F.
Towne, Thomas.
Weber, Frederick C.

PROMOTION TO FULL MEMBERSHIP.

Whiting, Charles W.

PROMOTION TO ASSOCIATE MEMBERSHIP.

Trask, George F. D.

JUNIOR MEMBERS.

Aisawa, Yakichi.
Alexander, Harry.
Barnum, D. D.
Bowen, H. S.
Church, Austin.
Church, Charles Thomas.
Colvin, Frederick H.
Gnade, Edward R.
Greene, A. M., Jr.
Goetze, Frederick A.
Hagar, Edward McKim.
Kirk, Robert H.
Larkin, A. C.
Phisterer, Frederick Wm.
Pilcher, John A.
Power, William M.
Trowbridge, W. B.
Trotter, W. F.
Williams, H. E.
Wilcox, George B.

The Tellers appointed on the previous evening to count the ballot for officers reported as follows:

Your Committee appointed to count ballots cast for officers of the American Society of Mechanical Engineers for the year 1895–6, begs to submit the following report:

Total ballots cast	520
Ballots thrown out on account of irregularities	19
Total votes counted	501

Of this latter number,

501 votes were cast for Mr. John Fritz for President.
501 " " Mr. William H. Wiley for Treasurer.
500 " " Mr. George W. Melville for Vice-President.
496 " " Mr. Charles H. Manning for Vice-President.
495 " " Mr. Francis W. Dean for Vice-President.
497 " " Mr. Norman C. Stiles for Manager.
500 " " Mr. E. D. Meier for Manager.
501 " " Mr. George W. Dickie for Manager.
1 vote was scattering.

Our count therefore shows that the entire ticket was elected.

Respectfully,

Wm. T. Bonner, }
Geo. H. Scott, } *Tellers of Election.*

The report was then called for from the delegate of the Society sent, by vote of the Council, to represent it and its Committee on Uniform Methods of Test and Testing Materials, at the International Conference of Engineers and Manufacturers at Zurich, in Switzerland, September, 1895. Mr. Gus. C. Henning, Secretary of the Committee and its Reporter, had been selected for this duty, and gave a short account of the conference, its objects and results. This report, with a translation of the official minutes, will form two of the papers of the meeting, to be found in the sequel.

At the close of the report a vote of thanks was moved, seconded, and carried, in recognition of the sacrifices made by the delegate, and the credit and distinction which the Society had received among the representatives at this conference by being thus represented among the technical societies of Europe.

There was no formal report from the Committee to consider the Revision of the 1886 Code of Rules for Conducting Steam Boiler Trials, but Mr. Kent, on behalf of the Committee, spoke as follows:

Mr. William Kent.—The Committee has no report to make at present, but it is making progress. Mr. Emery and myself, the New York members of the Committee, met soon after the appointment of the Committee, and intended to send a letter to all the other members, asking them to express their views. But Mr. Emery at that time was preparing a paper to send to all the members of the Committee, concerning some of the matters brought up in the discussion at Detroit, and at my request he made that a paper to be presented to the Society at this meeting, so that when the Committee finally comes together, which should be in a short time, it will have an expression of opinion from as many members of the whole Society as wish to make themselves heard. It is our intention to devote a great deal of time to the subject, and give everybody who has an interest in the matter a chance to express an opinion. I cannot promise that the final report of the Committee will be presented for a considerable time yet, because it requires a great deal of work, and there are some matters of controversy to be carefully studied.

From the Society's Committee upon the Conduct of Tests upon Fire-proofing Materials, the report of progress was as follows:

Mr. H. de B. Parsons.—As a member of the Society's Committee on Fire-proof Tests, I wish to present a report of progress. As the Society has already been informed, our Committee was appointed to act with Committees appointed by the Fire Underwriters of New York and the Architectural League of New York. The object of the tests is to determine the effect of fire upon modern iron and steel buildings—buildings of the so-called skeleton type. In order that the Committee's work may be of the greatest value, and in order to prevent criticism which might arise on account of the Joint Committee being composed of men entirely local to New York City, the Committee has associated with itself an Advisory Board of twenty. That Advisory Board has been appointed by the Joint Committee, and the names selected have been those of men who are prominently associated or connected with the subject, and who are geographically located throughout the country, so as to give the result of the Joint Committee's work a national character. From the interest which has already been manifested, and from the correspondence which we have already received, we are led to believe that the work will be one of considerable interest, not only to the United States, but to foreign countries as well. The Committee wishes to acknowledge the courtesies extended to it, first by the Continental Iron Works, who have kindly decided to allow the tests to be made upon their property in Brooklyn; to the Carnegie Steel Company, who have kindly offered to furnish the Committee with all the beams, channels, and all iron or steel built-up forms the Committee may wish. The Committee is in hopes of receiving a similar offer from manufacturers of cast-iron columns. The Committee wishes to acknowledge also the courtesies extended to it by Messrs. Sinclair and Babson, who have kindly offered to furnish free all the cement which the Committee desires; by the Messrs. Henry A. Maurer and others representing the fire-brick manufacturers, who have kindly notified the Committee that they will furnish all the fire-brick which may be needed at a "nominal cost;" and also by a syndicate of common-brick manufacturers, who will furnish all the common brick which is necessary for the construction of the Committee's furnaces.

The method which the Committee has proposed is first to construct a gas-producer, the gas being passed through a main, from which branch pipes are led to the burners. These burners will be situated in the floor of the furnace to be tested, which will represent a room. One furnace will test columns, outside walls, partition walls, and columns embedded in walls, either outside or partition. The other furnace will test the floor beams and floor construction. Both furnaces will be made on a large scale, the floor furnace being so constructed as to take floor beams 25 to 30 feet in length, and the column furnace being arranged to represent a room such as is found in the modern buildings of the type which we are testing, the columns varying from 11 to 14 feet in height. Provision has been made, however, to undertake tests of a greater length if so desired.

Our motto is that the Committee knows nothing, and that the rest of the world knows less. We have, therefore, determined that our first tests will be made upon naked iron and naked beams, so that the Committee may learn what can be accomplished with the furnaces as designed, and what changes may be necessary in order to obtain the desired results. Then, having established a certain amount of information for our own use, the Committee proposes to formulate a series of rules. The manufacturers may then cover the columns and the beams with their material, and the tests upon such covered iron and steel will be carried out uniformly in accordance with those rules, in order that comparative results may be obtained. Should, in the progress of the tests, the manufacturer or the Committee desire to make a test a little different from that as mapped out by the rules, such additional tests will be made.

The Secretary read the following petition, at the request of an absent member, explaining that, while the signing of such petition must be an individual matter with each member who might interest himself in it, yet the intent of the petition was to secure early action upon a matter of general and public concern to many interests represented in the Society as a body. The petition was as follows:

IMPORTANT PETITION TO CONGRESS RELATIVE TO THE PARIS EXPOSITION OF 1900.

To the Honorable the Senate and House of Representatives of the United States of America in Congress assembled:

We, the undersigned American manufacturers of products, the foreign trade of which gives promise of a very large increase, and we, the undersigned export commission houses of New York City, and we, the undersigned corporations, whose business interests are closely allied with the development of international commerce, hereby respectfully urge that immediate action be taken upon the invitation from the French Government to our country to take part in the International Exposition to be held in Paris in the year 1900, and relative thereto we hereby beg to respectfully call the attention of your honorable body to the following important points :

This Exposition has been projected on a grander scale than any previous International Exposition, and will therefore afford an exceptional opportunity for an immense and rapid development of trade relations between American exporters and manufacturers on the one hand, and foreign buyers from all parts of the world on the other hand.

It is a well-known fact that the United States section of the last International Exposition, held at Paris in the year 1889, presented an appearance which contrasted in a most humiliating way with the exhibits from other nations.

This lamentable condition of affairs was, to a great extent, owing to a corps of American Exposition officials being hastily organized at almost the last moment to represent our great industrial interests, and to a corresponding lack of time for working out proper preliminary plans for securing the attention and coöperation of all American industrial elements.

All the manufacturing nations of Europe always begin their preparations years in advance for any great exposition in Paris, which city is recognized by them as the world's central mart for international trading, and said nations of Europe are already actively engaged in the work of organizing for the Paris Exposition of the year 1900.

A period of four years is barely sufficient time for adequate preliminary work in order to secure a display of manufactured products that will prove a fair and true indication of the varied and comprehensive nature of American productions, and of their many advantages to the traders of the world in price, artistic design, workmanship, and finish.

We therefore further petition that an adequate sum be promptly appropriated for the purpose of organizing, on a thorough basis and an extensive scale, exhibits of American products for the International Exposition to be held in Paris in the year 1900, and that the President of the United States be forthwith authorized to appoint a Commissioner-General and an Assistant Commissioner-General, who shall both hold office until all the Exposition work in connection with American exhibits and American manufacturing interests shall be terminated after the final closing up of the Exposition.

Mr. J. F. Sorzano, member of the Society, had consented to take charge of the circulation of these petitions, and solicited the coöperation of all who were willing to help.

No general business being presented, the professional papers were taken up.

Messrs. Kent, Wood, and Aldrich discussed the paper by Samuel McElroy on the "Water Power of Caratunk Falls, Kennebec River, Maine ;" Messrs. Suplee and Aldrich presented additional matter upon the "Generation and Transmission of Water Power," a paper by Samuel Webber.

Topical discussions on "Oil Firing and Regulation of Oil-fired Boilers" filled the hour till the time for adjournment.

this sad affair, perhaps a brief recital of the facts concerning it, so far as they are known, will be of interest.

Mr. Davis, whose place of business was on Staten Island, was wont during the summer, and while his family were out of the city, to come to New York in the evening, and take rest and recreation by horseback riding in Central Park. He was the owner of a fine Kentucky riding horse, which he kept near the Park for this purpose. On the evening of August 6th, as was his practice, he called at the stable for his horse, and, mounting him, entered alone the bridle-path of the Park.

From his entrance to the Park until later it is not known that he was seen by any one until found dead by the roadside by a company of mounted police who were returning to their stations. The most reasonable theory by which to account for this lamentable accident was that his horse, from some cause or another, took a sudden fright, and, shying, threw its rider, who, in falling, struck a stone, which caused his death. While this is the most probable cause of the death of Mr. Davis it is, at the same time, a difficult one to understand, as he was reputed to be an expert rider.

While the death of such an estimable gentleman as was Mr. Davis is ever a great loss to the community at large, and a severe and sadly lamented one to the Society over which he had presided with such marked ability and dignity, who of us can estimate the feeling of utter loneliness, that sense of desolation, which such a death must bring to the home circle of which he was the honored and well-beloved head. And if the heartfelt sympathy of those who knew and admired him as their associate in the business affairs of this Society, of those who were his associates in its membership, could, in the slightest degree. serve to lighten the load of sorrow they bear, how kindly it would be tendered, and how sincerely it is!

Before introducing the gentleman appointed by the Council to fill the remainder of the term for which Mr. Davis was elected, I desire to say a few words indicative of my own feelings when first elected as the President of this Society, and what has been the feeling of all those who have followed me in that office, and what I know to be the desire of the gentleman who is now about to assume its obligations and duties.

In a Society having so large and so widely extended a membership as has the American Society of Mechanical Engineers, it is impossible for any incoming President to know personally very many of the members who may be in attendance at any of its meetings. This is a source of much embarrassment to the presiding officer, but it is one which can be greatly lessened by those present if they are so disposed, and I think the manner of doing it needs only to be pointed out to be adopted. The way to accomplish this is for each member, as opportunity may offer, to present himself to the President, make his acquaintance, and let him make yours. I am certain that this will be highly appreciated by your Presidents, and will certainly make each one more at home and more at ease.

I perhaps need not repeat what I have so often said about the duty of each member to do what he can to make each meeting as great a success socially, and an occasion for making and renewing acquaintance, and for promoting genial, kindly good-fellowship, as it is for bringing out and distributing useful knowledge in the various lines of our industries and professions. It is a well established and recognized fact that, while our Society has and is doing much to add to the world's stock of useful knowledge in matters technical and scientific, it is none the less renowned for the harmony and good feeling attending the transaction of its business affairs, and, above all, for a kindly regard, sympathy, and interest in the welfare of each other, which, after all, is the "one touch of nature that makes all the world akin."

Gentlemen, I take pleasure in introducing as your President Mr. Charles E. Billings, of Hartford, Conn.

At the close of Mr. Holloway's introduction, Mr. C. E. Billings took the chair as President, and called for the reading of the memorial minute prepared by the Council upon the death of President Davis. This was read by the Secretary, as follows:

IN MEMORIAM.

The American Society of Mechanical Engineers desires to place upon the records of the Society and of its Council a minute expressive of the respect and regard which its members feel and seek to make public upon the sudden and untimely death, from an accident, of their colleague, Mr. E. F. C. Davis, President of the Society.

The formal mould of memorial resolutions in which a corporate body ordinarily records its action seems inadequate for a proper voicing of the spirit which pervades the Society in the presence of the death of one whom its members had known so well and whom they had learned to admire and love. His wise and mature judgment, his business and professional knowledge, his conservative yet energetic counsel, and his courteous consideration for others, had made him one from whose administration of the Society's affairs the highest hopes had been entertained.

Although with such grief the stranger intermeddleth not, yet the Society would presume to express its heartfelt sympathy with those nearest and dearest to Mr. Davis, upon whom this blow has fallen so crushingly.

Resolved, That copies of this minute be furnished to the engineering journals, with a request that they give a publicity to it in such a way that it may serve to convey to the profession something of the sorrow and regret with which the American Society of Mechanical Engineers has heard of their loss in the death of their President.

This minute, moved as the sense of the Society, was unanimously adopted.

The President then addressed the Convention in the following words of salutation :

Gentlemen:—I extend to you a cordial and hearty welcome to the sixteenth annual meeting of the American Society of Mechanical Engineers.

The silent messenger of death has removed from us my predecessor, our friend and brother member, Mr. E. F. C. Davis, on whom this Society, at its last annual meeting, conferred the highest honor in its power to bestow, by electing him its President. Little did we anticipate then but what we should meet again at this time and listen to his words of wisdom and counsel; but the Almighty and Supreme Architect of the universe has willed otherwise.

Through our representatives, the Council, I was chosen to fill the vacancy caused by the death of our lamented friend. It was with extreme reluctance that I accepted the office, for I know full well that there are many among us better qualified for the position than myself; but duty is one great law we all recognize, inflexible as fate, exacting as destiny. Therefore, asking for your kind indulgence, I will endeavor to discharge the duties of the office for the remainder of the term to which I was elected.

Looking back over the time which has passed, it hardly seems that it will be sixteen years next January since a few gentlemen met in the office of the American Machinist Publishing Company at 96 Fulton Street, New York, and talked over the subject of forming such a society.

February 16, 1880, upon invitation of Prof. John E. Sweet, Prof. Robert H. Thurston, and Mr. Alexander L. Holley, about thirty gentlemen held a meeting and discussed the matter and laid plans for the formation of the Society. Complete organization was accomplished at the Stevens Institute, Hoboken, N. J., April 7, 1880. The first annual meeting was held in the Turf Club Theatre, New York, November 4, 1880. The attendance was nearly one hundred.

The seeds which the founders of this Society planted have taken deep root, and from the small beginning it has continued to increase in number and in its sphere of usefulness, until to-day its total membership, including members associate, life, and honorary, is nearly seventeen hundred, embracing in its ranks many of the brightest men, technically and practically, of the present time. Its pathway has ever been onward and upward. No record has ever been laid at its door, so far as my knowledge extends, which would be unbecoming to true and honorable gentlemen.

Many of the papers read, discussed, and published on mechanical subjects have been of great benefit, not only to our members, but to those that are not members, who have been fortunate enough to have had the opportunity to read them.

Our Society has done a great and good work in the past. The field grows broader and the opportunities greater for still more advanced work in the future.

Mr. Billings then read his address from the chair, bearing title of "Modern Improvements in the Drop-press." Messrs. Holloway, Fritz, Dean, Kent, and Hutton took part in the discussion which followed.

Topical discussions were then taken up, and the following questions were answered:

For filtering oil having very finely divided metallic particles in suspension, what have you found to be the best filtering material, either for one operation or in a series?

What information can you give as to the best method for the extraction of oil from condensed steam, where it is desirable to use the exhaust steam repeatedly for boiler-feed purposes?

Messrs. Kafer, Bang, Roelker, Langlotz, Kent, Darling, Bonner, Grimm, Woolson, McBride, Fritz, and Winship took part in the debate.

This first evening was intended rather as a preliminary opportunity for the assembling members to meet together to renew old friendships and begin new acquaintance. The rooms of the Society were open from an early hour, and, with smoking and light refreshment, the evening passed pleasantly. Just prior to adjournment the President appointed Messrs. W. T. Bonner and George W. Scott as tellers to count the ballots for officers, and to report at the morning session.

Second Day. Wednesday, December 4th.

The regular sessions of the annual meeting began with the session of this morning, at ten o'clock, in the auditorium. The registration of members, even at this early session, showed that the meeting was to be an unusually large one, and the record before the end of the meeting showed that the size and numerical success of the meeting were to be noteworthy. The plan was adopted of numbering the lines on the official register, and providing that the usual button badge worn at the Society's convention should bear a number corresponding to the number on the register. It will be seen that by this expedient every one could immediately ascertain the name of every one else without the embarrassment of a direct question to this end, and the practical result showed that the meeting was one of the most successful on the social side that had ever been held. The register showed the following persons in attendance from the list of members. The total registered, including guests, was four hundred and nineteen.

Alden, Geo. I.
Aller, A.
Almond, T. R.
Almy, D.
Ashley, F. M.
Baldwin, A. T.
Baldwin, S. W.
Ball, F. H.
Bang, H. A.
Bardwell, A. F.
Barnes, A. T.
Barr, H. P.
Barr, J. H.
Bauer, C. A.
Beardsley, A.
Billings, C. E. (President).
Birkenbine, Jno.
Bixby, W. H.
Boenig, R. W.
Bole, W. A.
Bond, Geo. M.
Bonner, W. T.
Bowden, J. H.
Boyer, F. H.
Bradley, W. H.
Bristol, W. H.
Brooks, M.
Brotherhood, F.
Bulkley, H. W.
Bullock, M. C.
Burchard, A. W.
Buzby, C. E.
Cadwell, W. D.
Cahoon, J. B.
Caldwell, A. J.
Canfield, H.
Carpenter, H. A.
Carpenter, R. C.

Cary, A. A.
Chase, H. S.
Cheney, W. L.
Childs, A. E.
Christie, W. W.
Clark, W. L.
Clarke, S. J.
Coffin, W. C.
Cogswell, W. B.
Colvin, F. H.
Colwell, A. W.
Connell, J. A.
Conover, E. K.
Corbett, C. H.
Cottier, Jos.
Crane, W. E.
Creelman, F. J.
Cremer, J. M.
Cruikshank, B.
Cruikshank, D. L.
Cullingworth, Geo. R.
Curtis, R. E.
Darling, E. A.
Darrin, D. H.
Davis, I. H.
Dean, F. W.
Deane, C. P.
Deck, H. S.
Dent, E. L.
Denton, J. E.
Dick, Jno.
Dinkel, Geo.
Du Bosque, F. L.
Durfee, W. F.
Eberhardt, F. L.
Emery, A. H.
Emery, C. E.
Estrada, E. D.
Faber, Du Faur A.
Fairbanks, R. N.
Farrand, D.
Fladd, F. C.
Flagg, S. G.
Flather, F. A.
Forbes, W. D.
Forney, M. N.
Forsyth, R.
Foster, E. H.
Francis, H. C.
Frevert, H. F.
Frith, A. J.
Fritz, John.
Gale, H. B.
Gantt, H. B.
Garfield, L. M.
Geoghegan, S. J.
Glenn, H. F.
Gnade, E. R.
Gobeille, J. L.
Goetze, F. A.
Goodale, A. M.
Goodell, J. M.
Gordon, Alex.
Goubert, A. A.
Gould, W. V.
Granger, A. S.
Graves, E.
Green, D. J.
Green, S. M.
Greene, A. M.
Greenleaf, G. E.
Griffin, C. L.
Grimm, P. H.
Guilford, W. M.
Hague, C. A.
Hale, R. S.
Hall, F. A.
Halsey, F. A.
Hamilton, J. F.
Hammett, H. G.
Hardy, G. F.
Hardy, G. R.
Hartness, Jas.
Haskins, H. S.
Hayward, F. H.
Hemenway, F. F.
Henderson, Alex.
Henning, G. C.
Herreshoff, J. B. F.
Higgins, C. P.
Hill, Wm.
Hill, W. E.
Hillmann, G.
Hirt, L. J.
Hoffecker, W. L.
Hollerith, H.
Holloway, J. F.
Holly, E. P.
Hopton, W. E.
Horton, J. A.
Hough, D. L.
Howell, E. I. H.
Hunt, C. W.
Hunt, W. F.
Huson, W. S.
Hutton, F. R.
Idell, F. E.
Illingworth, J. J.
Jacobus, D. S.
Jenkins, M. C.
Jenks, L. H.
Jenks, W. H.
Johnson, A. E.
Jones, H. C.
Jones, Washington.
Kafer, J. C.
Katté, E. B.
Keep, W. J.
Kelly, J. R. F.
Kent, Wm.
King, C. C.
Kingsbury.
Kirchhoff, C.
Kirk, R. H.
Knight, A. F.
Kretschmer, F. G.
Laforge, F. H.
Lager, C.
Lambert, A.
Langlotz, C.
Langlotz, R.
Larkin, A. C.
Le Van, W. B.
Lieb, J. W.
Longnecker, C. K.
Loring, C. H.
Low, F. R.
Lyall, W. L.
McBride, Jas.
McClelland, E. S.
McElroy, S.
McKee, J. J.
McMannis, W.
Magoun, H. A.
Matlack, D. J.
Matlack, Jno. R.
Manning, C. H.
Marble, H. M.
Marx, H.
Mason, F. S.

Mason, W. B.
Matton, F. V.
May, De C.
Meatz, J. F.
Melvin, D. N.
Messenger, F. M.
Mesta, Geo.
Meyer, H. C.
Meyer, H. C., Jr.
Miller, Alex.
Miller, F. J.
Miller, H. B.
Mirkil, T. H., Jr.
Monaghan, W. F.
Montgomery, H. M.
Moore, D. G.
Moore, M. F.
Morse, C. M.
Mossberg, F.
Moulthrop, L.
Müller, M. A.
Müller, T. H.
Mumford, E. H.
Nason, C. W.
Newcomb, C. L.
Newhall, J. B.
Nicoll, C. H.
Norris, H. M.
Norris, J. E.
Odell, W. H.
Otis, S.
Parker, C. H.
Parks, E. H.
Parsons, F. W.
Parsons, H. de B.
Partridge, W. E.
Paul, J. W.
Peabody, E. H.
Pearson, W. A.
Peirce, W. H.
Penney, E.
Phelps, F. A.
Phillips, Geo. H.
Platt, F. W.
Platt, Geo. H.
Platt, Jno.
Pomeroy, L. R.
Porter, Wm.
Rand, A. C.
Raqué, P. E.
Raynal, A. H.
Redwood, I. I.
Reeve, S. A.
Rettew, C. E.
Richards, F. H.
Richards, R.
Richmond, Geo.
Rickson, C. E.
Riddell, Jno.
Ridgway, J. T.
Ridsdale, T. W.
Roberts, P.
Roberts, Wm.
Robertson, R. A., Jr.
Robinson, J. M.
Rockwood, G. I.
Roelker, H. B.
Rowland, A. E.
Rowland, C. B.
Rowland, T. F., Jr.
Russell, C. W.
Sargent, J. W.
Sattler, W. R.
Scheffler, F. A.
Schoenborn, W. E.
Scholl, J.
Schumann, F.
Schutte, L.
Scott, G. H.
Scott, S. M.
Seavey, J. F.
Sergeant, C. H.
Serrell, J. A.
Sewall, M. W.
Shellenberger, L. R.
Shepherd, W. G.
Slater, A. B.
Smith, Geo.
Smith, H. W.
Smith, J. H.
Smith, J. M.
Smith, Oberlin.
Snell, H. J.
Sonnberger, E. C.
Souther, H.
Spaulding, H. C.
Spies, A.
Stangland, B. F.
Stiles, N. C.
Stillman, F. H.
Strong, Geo. S.
Suplee, H. H.
Svenson, Jno.
Swasey, A.
Taber, G. H.
Tabor, H.
Taylor, J. F.
Taylor, S.
Thomas, E. W.
Thomson, Jno.
Thurston, R. H.
Torrance, K.
Torrey, H. G.
Towl, F. M.
Towne, H. R.
Townsend, D.
Tremaine, E. G.
Trowbridge, A.
Tucker, W. B.
Uehling, E. A.
Vanderhoef, G. N.
Varney, W. W.
Waldron, F. A.
Wallace, D. A.
Walworth, A. C.
Ward, W. E.
Warner, W. R.
Warren, B. H.
Watson, Wm.
Webb, J. B.
Webber, S. W.
Weber, A. G.
Weber, Geo.
Webster, N.
Webster, W. R.
Weeks, Geo. W.
Weeks, J. D.
Weil, C. L.
Wellman, S. T.
Wells, J. L.
Weston, N. S.
Wheeler, F. M.
Wheeler, S.
White, J. J.
Whitehead, G. E.
Whiting, C. W.
Whittier, C.
Wiggin, W. H.
Wiley, W. H.
Williams, D. C.

Winship, J. G.	Woolson, O. C.	Wright, L. S.
Wood, De V.	Wright, J. Q.	York, H. W.
Wood, M. P.		Young, W. S.

Total..346

The first order of business was the Annual Report of the Council to the Society under the Rules.

ANNUAL REPORT OF THE COUNCIL.

The Council must begin the Annual Report to the Society, of the business which has been transacted during the Society year, with the action taken upon the removal by death of those who have been honored by selection to the office of President.

The Society has already taken action upon the death of President E. F. C. Davis, but it has also experienced during the year just closed the loss of one who had but recently retired from presidential office. Mr. Eckley B. Coxe died at his home, Drifton, Pennsylvania, in May, and at the meeting of the Council first succeeding, the following minute was presented and entered upon its records. The Council, in reporting it to the meeting, desires in this way to make it the action of the Society as a whole.

The action was as follows:

"The Council of the American Society of Mechanical Engineers has learned with profound sorrow of the death of Hon. Eckley B. Coxe, former President of the Society. He had so recently retired from active participation in the business affairs of the Society, that the shock comes so much the nearer to those who had been associated with him.

"The long and honorable connection of Mr. Coxe with professional duties of the highest class, had given him a standing which shed a special lustre upon the office which he filled so acceptably; and his familiarity with legislative procedure, and with business affairs, made his advice and leadership most wise and judicious. But, more than all, the charming and affectionate geniality and frank-heartedness of the personality which lay behind the outward acts were the things which will remain long in the memory of his closer colleagues, and which give the poignancy to their regret at his loss. It is these qualities of the man which must make his death the sorer blow to those near to him in family and business, and which call for an outward expression of the sympathy which we feel in the great loss they have undergone.

"*Resolved*, That this minute be recorded in full upon the records of the Society, and of the Council."

The final revision of the proposed amendments to the rules which carried with them improvements in the blanks to be used by candidates for membership in the Society, was referred to the Council by the annual meeting of 1894, and the rules thus amended appear in the sixteenth catalogue, issued January 1, 1895.

The amended forms of application blanks, and particularly the amended forms of blanks used by those members to whom candidates have referred, have been in operation during the year, and with signal satisfaction. Particular advantage seems to have resulted from the change which made the Associate grade one in which an increasing number of persons might be classified under the rules, thus enhancing in a notable degree the value which attaches itself to the grade of Member of the Society.

To secure a more certain and positive knowledge concerning candidates for membership in the various grades, the Council had directed that the applications of candidates should be considered at frequent intervals by a committee of that body which has been designated as the Committee on Admissions. By the direction of this Committee the names of candidates are printed on a slip, which is mailed to the voting membership as an announcement that persons upon that list are seeking membership, and requesting them to communicate to the Council their views upon their eligibility and fitness. This procedure corresponds to the posting of candidates in the usual club methods, differing only in the fact that it is done by mail. The Committee on Admissions, receiving the replies of the voting membership, then presents the application in final form to the Council, who thereupon order the preparation of the official ballot. This threefold scrutiny has been found to work well, and should be a manifest safeguard in securing a high standard of membership.

In addition to its important functions with respect to scrutiny of applications for membership, the Council has been solicited by libraries, technical schools, and others, to supply the back sets of the Society's *Transactions*, and to list the libraries upon its records for the regular receipt of the annual volumes as issued. The calls for these early issues have become so numerous that it has been impossible to grant the request in every case for their presentation as a gift; but in cases where it seemed fitting, the right has been granted to the library to purchase the back volumes at the discount of fifty per cent. which is permitted to members of the Society desiring this procedure.

Among other institutions which have availed themselves of this privilege is to be mentioned the University of Glasgow, Scotland, in whose chair of engineering Professor W. J. M. Rankine sat for so many years.

The Council has elected to Honorary Membership by unanimous letter-ballot, under the rules, Sir William Arrol, builder of the Forth Bridge in Scotland, the Tower Bridge in England, and many other distinguished engineering works.

At the instance of certain interested members, both upon the Society's Committee on Standard Methods of Testing Materials and from the Society at large, the Council directed that an appropriation be made for the necessary expenses of a delegate from the Society and its committee to the International Convention of Engineers and Manufacturers at the city of Zurich, Switzerland, in the month of September. Mr. Gus. C. Henning, secretary of the Society's committee and its reporter, was the choice of the Council for this assignment; and the advantage to the repute of the Society from being thus represented at such a gathering has been neither small nor unrecognized. A report from the delegate will form part of the business of the annual meeting.

Pursuant to the action of the annual meeting of 1894, a committee of five members of the Society was appointed to take charge of the details of a series of reunions of members of the Society and others, in the Society's house, during the winter and spring of 1895. This Committee consisted of Messrs. Charles Kirchhoff, C. W. Baker, F. R. Low, B. H. Warren, and George L. Fowler.

As these meetings were distinctly local in character and were to be self-supporting so far as the report of the discussions, etc., were concerned, great care was taken that they should be regarded as reunions of individual members of the Society and not in any sense meetings of the Society as an organization. The name given to secure this end was "Monthly Engineering Evenings," and the only relation of the organization to the Society as a whole was the furnishing of a meeting place with its conveniences.

The subjects of the evenings of 1895 were, "The Gas Engine," "The Rapid Transit Problem in Large Cities," "The Electric Motor in the Machine Shop," "The Compound Locomotive," and the "Water Works Engineering of New York."

It was referred to the Council by a meeting of the Society at Detroit in June, 1895, to appoint a Committee who should consider the question of revising the Society's Code of Steam Boiler Trials reported in 1886. That committee consists of Messrs. Barrus, Coon, Dean, Emery, Hunt, Kent, Porter, Potter, and Thurston.

The question of the dates at which the semi-annual conventions of the Society are held has been under advisement, pursuant to a suggestion that as now selected the dates were not specially well chosen. It was the opinion of the Council, after taking advice, that the present dates seem to suit the convenience of the greatest number; and therefore no change was recommended.

They have further directed that at the sessions devoted to the presentation and discussions of professional papers, executive and administrative business shall be considered out of order; but that upon the programmes of the conventions, certain specially designated times shall be allotted for the presentation and consideration of such matters.

A series of communications from Mr. E. L. Corthell has been considered by the Council in which the proposer embodies certain ideas looking to the creation of an Institute of Engineers and Architects, which should be inclusive of the membership of the present national societies and should be aimed to become international in scope and character. Alternative to this idea was the suggestion that by common action the existing Societies should arrange to federate themselves for purposes of common interest to applied science and engineering, with a view to the holding at convenient intervals of joint meetings or congresses to which delegates from other countries should be invited to be present and contribute. If the Council was not ready for action of this comprehensive character it was requested to appoint committees to confer with the sister societies with a view to providing for such congresses without either federation or organic union. In view of the debate in Volume XI. of the *Transactions* of this Society, which showed an opinion and judgment distinctly antagonistic to the first scheme, and the obvious practical difficulties with respect to expense and the effects upon the present organizations of the two latter schemes, the matter has been laid upon the table with an expression of the opinion that the time is not yet ripe for the inauguration of such plans.

The Council would report for record the death since the last annual meeting of the following persons:

A. J. Shaw, C. L. Hoyt, Charles W. Copeland, L. Packard, John H. Webster, Thomas R. Pickering, E. C. French, Eckley B. Coxe, A. M. Wellington, James G. Dagron, William C. Mackinney, George Davidson, E. F. C. Davis, W. C. Jones, E. J. Whitaker, Herman Winter, R. H. Tweddell, and William A. Pike.

At the close of the Report of the Council, the second order of business was the Report of the Finance Committee, which was as follows:

The Finance Committee of the American Society of Mechanical Engineers would respectfully report to the Council the following statements of the receipts and expenditures on behalf of the Society, under their direction during the year, from November, 1894, to November, 1895:

ANNUAL REPORT.

Receipts.

Accounts.	Cash.	Bonds.	Total.
Initiation Fees	$2,540 00	....	$2,540 00
Current Dues	21,471 85	....	21,471 85
Past Dues	1,114 45	....	1,114 45
Advanced Dues	131 08	....	131 08
Sales of Publications	792 44	....	792 44
Binding	4 50	....	4 50
Meetings	25 00	....	25 00
Badges	487 65	....	487 65
Engraving	99 75	....	99 75
Life Membership	900 00	$300 00	1,200 00
Contingencies	17 00	....	17 00
Postage and Express	4 84	....	4 84
Interest on Investments	995 00	....	995 00
Office Expenses	6 35	....	6 35
Rent	7 50	....	7 50
Stationery and Printing	6 25	....	6 25
Travelling	3 50	....	3 50
Profit and Loss	1 52	....	1 52
	$28,608 68	$300 00	$28,908 68
Cash on Hand First of Year	60 21	....	60 21
	$28,668 89	$300 00	$28,968 89

Disbursements.

Accounts.	Cash.		Total.
General Printing and Stationery	$1,392 58	....	$1,392 58
Reprints and Publications	8,883 70	....	8,883 70
Postage and Express	2,028 82	....	2,028 82
Salaries	6,938 28	....	6,938 28
Office Expenses	311 13	....	311 13
Engraving	1,110 36	....	1,110 36
Contingencies	82 53	....	82 53
Binding	1,583 70	....	1,583 70
Meetings	716 65	....	716 65
House Supplies and Furniture	287 21	....	287 21
Badges and Certificates	313 78	....	313 78
Travelling	151 63	....	151 63
Insurance and Safe Deposit	17 00	....	17 00
Rent, Interest, and Taxes	2,775 65	....	2,775 65
Investment (bonds received as above)	300 00	....	300 00
Investment (bonds purchased)	1,550 00	....	1,550 00
Library (book purchase)	13 12	....	13 12
Work of Committee	276 95	....	276 95
Cash in Hand to Balance	285 80	....	285 80
	$28,968 89		$28,968 89

The receipts on account of Life Membership during this year were $1,200—$900 of this amount being cash, and $300 bonds of the Mechanical Engineers' Library Association which were received as cash in payment for such Life Membership.

The Finance Committee has directed a reduction of expenses for the ensuing year in the two largest items of expenditure in the foregoing statement, by so changing the salary account as to effect an economy of about $600; and in addition have recommended to the Publication Committee so to administer their important department as to reduce the outlay for publications in so far as it may be possible to do so without impairing the value of the volumes.

The original issue of the bonds of the Mechanical Engineers' Library Association amounted to $32,000, and of this issue the Council as Trustees for the Society held $19,000 at the time of the last report of the Finance Committee, November 15, 1894. During the past year the Council has acquired $1,900 worth of additional bonds ($1,600 by purchase and $300 by surrender for Life Membership), thus making the total of these bonds held by the Council, November 15, 1895, $20,900; and the Mechanical Engineers' Library Association has bought $500 of these bonds this year (see the report of the Mechanical Engineers' Library Association), which leaves outstanding $10,600.

The amount of dues and accounts still carried on the books of the Society as due from members and others at the end of this year is more than enough to pay all bills against the Society for its expenses of the year which have not been paid at the time of drawing up this report.

A memorandum was also presented for record as follows:

LIBRARY ASSOCIATION.

COPY OF THE ANNUAL REPORT OF THE TRUSTEES OF MECHANICAL ENGINEERS' LIBRARY ASSOCIATION, 1894–1895.

The summary of receipts and disbursements of the Trustees from November 10, 1894, to November 19, 1895, is appended below:

Receipts.		
Balance on hand November, 1894		$199 38
Receipts Fellowship Fund	$232 00	
" Sinking Fund	610 50	
" Office Rent	4,710 00	
Gas and Electric Light	87 04	
Room Rent	1,807 15	
Contingencies	113 00	
Salaries	5 00	
Total Receipts		7,564 69
Total Cash		$7,764 07
Disbursements.		
Interest on Mortgage		$1,471 24
" Bonds		1,600 00
Salaries		835 00
House Supplies and Furniture		542 46
Fuel		279 15
Lighting { Gas	$184 47	
Lighting { Electric Light	576 59—	761 06
Equipment		336 78
Laundry		220 00
Repairs		328 50
Binding		115 15
Book Purchase		118 87
Contingencies		18 20
Investment (Mechanical Engineers' Library Association Bonds bought)		500 00
Total Disbursement		$7,126 41
Cash in Hand to balance		637 66
		$7,764 07

Assets.

House and lot, 12 W. 31st Street, New York City	$65,000 00	
Furniture and equipment	5,000 00	
Books and MSS	10,100 00	
Bills Receivable (Office and Room Rent, uncollected)	349 51	
" " (Subscription to Fellowship Fund, uncollected)	122 00	
" " (Sinking Fund Subscription, uncollected)	554 50	
Second Mortgage Bonds held by Trustees as an investment	500 00	
Total Assets		$81,626 01

Liabilities.

First Mortgage held by N. Y. A. of M.	$33,000 00	
Second Mortgage held by Members of the A. S. M. E.	10,600 00	
Second Mortgage Bonds held by the Council of the A. S. M. E. as an investment	20,900 00	
Total Liabilities		$64,500 00
Excess of Assets over Liabilities		$17,126 01

The tellers of the Council also presented for record the following report:

REPORT OF THE TELLERS OF ELECTION.

The undersigned were appointed a committee of the Council to act as tellers (under Rule 13), to scrutinize and count the ballots cast for and against the candidates proposed for membership in the American Society of Mechanical Engineers, and seeking election before the thirty-second meeting, New York, 1895.

They have met upon the designated day, in the office of the Society, and have proceeded to discharge their duty. They would certify, for formal insertion in the records of the Society, to the election of the persons whose names appear on the appended list to their respective grades.

There were 455 votes cast of the blue ballot, of which 15 were thrown out because of informalities (the members voting having neglected to indorse the sealed envelope).

FRANK H. BALL,
JOHN C. KAFER, } *Tellers of Election.*
JOHN THOMSON,

MEMBERS.

Bell, James Richard.
Clements, John B.
Foster, Horatio A.
Heisler. Charles L.
Leland, Henry M.
Lobben, Peder.
McKean, Robert A.
Palmer. Courtlandt E.
Potter, William B.
Riddell, John.
Wilkes, Charles Mason.
Wilkinson, Alfred.

ASSOCIATES.

Carpenter, A. H.
Connolly, John H.
Connelley, Clifford B.
Hooper, George K.
Inglis, James.
Joy, Francis B.
Lighthall, John A., Jr.
Mallory, Harry C.
Olin, F. W.
Sayward, John F.
Towne, Thomas.
Weber, Frederick C.

PROMOTION TO FULL MEMBERSHIP.

Whiting, Charles W.

PROMOTION TO ASSOCIATE MEMBERSHIP.

Trask, George F. D.

JUNIOR MEMBERS.

Aisawa, Yakichi.
Alexander, Harry.
Barnum, D. D.
Bowen, H. S.
Church, Austin.
Church, Charles Thomas.
Colvin, Frederick H.
Gnade, Edward R.
Greene, A. M., Jr.
Goetze, Frederick A.
Hagar, Edward McKim.
Kirk, Robert H.
Larkin, A. C.
Phisterer, Frederick Wm.
Pilcher, John A.
Power, William M.
Trowbridge, W. B.
Trotter, W. F.
Williams, H. E.
Wilcox, George B.

The Tellers appointed on the previous evening to count the ballot for officers reported as follows:

Your Committee appointed to count ballots cast for officers of the American Society of Mechanical Engineers for the year 1895–6, begs to submit the following report:

Total ballots cast	520
Ballots thrown out on account of irregularities	19
Total votes counted	501

Of this latter number,

501 votes were cast for Mr. John Fritz for President.
501 " " Mr. William H. Wiley for Treasurer.
500 " " Mr. George W. Melville for Vice-President.
496 " " Mr. Charles H. Manning for Vice-President.
495 " " Mr. Francis W. Dean for Vice-President.
497 " " Mr. Norman C. Stiles for Manager.
500 " " Mr. E. D. Meier for Manager.
501 " " Mr. George W. Dickie for Manager.
1 vote was scattering.

Our count therefore shows that the entire ticket was elected.

Respectfully,
Wm. T. Bonner,
Geo. H. Scott, } *Tellers of Election.*

The report was then called for from the delegate of the Society sent, by vote of the Council, to represent it and its Committee on Uniform Methods of Test and Testing Materials, at the International Conference of Engineers and Manufacturers at Zurich, in Switzerland, September, 1895. Mr. Gus. C. Henning, Secretary of the Committee and its Reporter, had been selected for this duty, and gave a short account of the conference, its objects and results. This report, with a translation of the official minutes, will form two of the papers of the meeting, to be found in the sequel.

At the close of the report a vote of thanks was moved, seconded, and carried, in recognition of the sacrifices made by the delegate, and the credit and distinction which the Society had received among the representatives at this conference by being thus represented among the technical societies of Europe.

There was no formal report from the Committee to consider the Revision of the 1886 Code of Rules for Conducting Steam Boiler Trials, but Mr. Kent, on behalf of the Committee, spoke as follows:

Mr. William Kent.—The Committee has no report to make at present, but it is making progress. Mr. Emery and myself, the New York members of the Committee, met soon after the appointment of the Committee, and intended to send a letter to all the other members, asking them to express their views. But Mr. Emery at that time was preparing a paper to send to all the members of the Committee, concerning some of the matters brought up in the discussion at Detroit, and at my request he made that a paper to be presented to the Society at this meeting, so that when the Committee finally comes together, which should be in a short time, it will have an expression of opinion from as many members of the whole Society as wish to make themselves heard. It is our intention to devote a great deal of time to the subject, and give everybody who has an interest in the matter a chance to express an opinion. I cannot promise that the final report of the Committee will be presented for a considerable time yet, because it requires a great deal of work, and there are some matters of controversy to be carefully studied.

From the Society's Committee upon the Conduct of Tests upon Fire-proofing Materials, the report of progress was as follows:

Mr. H. de B. Parsons.—As a member of the Society's Committee on Fire-proof Tests, I wish to present a report of progress. As the Society has already been informed, our Committee was appointed to act with Committees appointed by the Fire Underwriters of New York and the Architectural League of New York. The object of the tests is to determine the effect of fire upon modern iron and steel buildings—buildings of the so-called skeleton type. In order that the Committee's work may be of the greatest value, and in order to prevent criticism which might arise on account of the Joint Committee being composed of men entirely local to New York City, the Committee has associated with itself an Advisory Board of twenty. That Advisory Board has been appointed by the Joint Committee, and the names selected have been those of men who are prominently associated or connected with the subject, and who are geographically located throughout the country, so as to give the result of the Joint Committee's work a national character. From the interest which has already been manifested, and from the correspondence which we have already received, we are led to believe that the work will be one of considerable interest, not only to the United States, but to foreign countries as well. The Committee wishes to acknowledge the courtesies extended to it, first by the Continental Iron Works, who have kindly decided to allow the tests to be made upon their property in Brooklyn; to the Carnegie Steel Company, who have kindly offered to furnish the Committee with all the beams, channels, and all iron or steel built-up forms the Committee may wish. The Committee is in hopes of receiving a similar offer from manufacturers of cast-iron columns. The Committee wishes to acknowledge also the courtesies extended to it by Messrs. Sinclair and Babson, who have kindly offered to furnish free all the cement which the Committee desires; by the Messrs. Henry A. Maurer and others representing the fire-brick manufacturers, who have kindly notified the Committee that they will furnish all the fire-brick which may be needed at a "nominal cost;" and also by a syndicate of common-brick manufacturers, who will furnish all the common brick which is necessary for the construction of the Committee's furnaces.

The method which the Committee has proposed is first to construct a gas-producer, the gas being passed through a main, from which branch pipes are led to the burners. These burners will be situated in the floor of the furnace to be tested, which will represent a room. One furnace will test columns, outside walls, partition walls, and columns embedded in walls, either outside or partition. The other furnace will test the floor beams and floor construction. Both furnaces will be made on a large scale, the floor furnace being so constructed as to take floor beams 25 to 30 feet in length, and the column furnace being arranged to represent a room such as is found in the modern buildings of the type which we are testing, the columns varying from 11 to 14 feet in height. Provision has been made, however, to undertake tests of a greater length if so desired.

Our motto is that the Committee knows nothing, and that the rest of the world knows less. We have, therefore, determined that our first tests will be made upon naked iron and naked beams, so that the Committee may learn what can be accomplished with the furnaces as designed, and what changes may be necessary in order to obtain the desired results. Then, having established a certain amount of information for our own use, the Committee proposes to formulate a series of rules. The manufacturers may then cover the columns and the beams with their material, and the tests upon such covered iron and steel will be carried out uniformly in accordance with those rules, in order that comparative results may be obtained. Should, in the progress of the tests, the manufacturer or the Committee desire to make a test a little different from that as mapped out by the rules, such additional tests will be made.

The Secretary read the following petition, at the request of an absent member, explaining that, while the signing of such petition must be an individual matter with each member who might interest himself in it, yet the intent of the petition was to secure early action upon a matter of general and public concern to many interests represented in the Society as a body. The petition was as follows:

IMPORTANT PETITION TO CONGRESS RELATIVE TO THE PARIS EXPOSITION OF 1900.

To the Honorable the Senate and House of Representatives of the United States of America in Congress assembled:

We, the undersigned American manufacturers of products, the foreign trade of which gives promise of a very large increase, and we, the undersigned export commission houses of New York City, and we, the undersigned corporations, whose business interests are closely allied with the development of international commerce, hereby respectfully urge that immediate action be taken upon the invitation from the French Government to our country to take part in the International Exposition to be held in Paris in the year 1900, and relative thereto we hereby beg to respectfully call the attention of your honorable body to the following important points :

This Exposition has been projected on a grander scale than any previous International Exposition, and will therefore afford an exceptional opportunity for an immense and rapid development of trade relations between American exporters and manufacturers on the one hand, and foreign buyers from all parts of the world on the other hand.

It is a well-known fact that the United States section of the last International Exposition, held at Paris in the year 1889, presented an appearance which contrasted in a most humiliating way with the exhibits from other nations.

This lamentable condition of affairs was, to a great extent, owing to a corps of American Exposition officials being hastily organized at almost the last moment to represent our great industrial interests, and to a corresponding lack of time for working out proper preliminary plans for securing the attention and coöperation of all American industrial elements.

All the manufacturing nations of Europe always begin their preparations years in advance for any great exposition in Paris, which city is recognized by them as the world's central mart for international trading, and said nations of Europe are already actively engaged in the work of organizing for the Paris Exposition of the year 1900.

A period of four years is barely sufficient time for adequate preliminary work in order to secure a display of manufactured products that will prove a fair and true indication of the varied and comprehensive nature of American productions, and of their many advantages to the traders of the world in price, artistic design, workmanship, and finish.

We therefore further petition that an adequate sum be promptly appropriated for the purpose of organizing, on a thorough basis and an extensive scale, exhibits of American products for the International Exposition to be held in Paris in the year 1900, and that the President of the United States be forthwith authorized to appoint a Commissioner-General and an Assistant Commissioner-General, who shall both hold office until all the Exposition work in connection with American exhibits and American manufacturing interests shall be terminated after the final closing up of the Exposition.

Mr. J. F. Sorzano, member of the Society, had consented to take charge of the circulation of these petitions, and solicited the coöperation of all who were willing to help.

No general business being presented, the professional papers were taken up.

Messrs. Kent, Wood, and Aldrich discussed the paper by Samuel McElroy on the "Water Power of Caratunk Falls, Kennebec River, Maine ;" Messrs. Suplee and Aldrich presented additional matter upon the "Generation and Transmission of Water Power," a paper by Samuel Webber.

Topical discussions on "Oil Firing and Regulation of Oil-fired Boilers" filled the hour till the time for adjournment.

Messrs. Kent, Towl, Hill, Billings, Wood, Manning, Kingsbury, Winship, Nason, Raynal, and Spaulding were heard.

Following the usual custom of the annual meetings in New York City, luncheon was served in the house for the members and ladies at the close of the morning session, and many members remained to enjoy the reunion and social opportunity of the afternoon, for which no assignments had been made. This plan was found to work most agreeably.

THIRD SESSION. WEDNESDAY EVENING.

The professional papers of the evening were as follows:

C. E. Emery, "Means Adopted for Saving Fuel in a Large Oil Refinery;" James E. Denton, "The Reliability of Throttling Calorimeters;" A. A. Goubert and E. H. Peabody, "Some Experiments with the Throttling Calorimeter;" C. E. Emery, "Comparative Tests of Steam Boilers with Different Kinds of Coal."

In the discussions on these papers during the evening, and in the postponed discussion upon the last one of the series on the following morning, Messrs. Winship, Wheeler, Denton, Scheffler, Kent, Clark, Kingsbury, Rockwood, Woolson, Carpenter, Jacobus, Le Van, Spaulding, Strong, Dean, Boyer, Barr, and Cary took part.

FOURTH SESSION. THURSDAY MORNING.

The papers assigned to this session were:

Albert Kingsbury, "Experiments on the Friction of Screws;" W. F. M. Goss, "Tests of a Ten-horse-power De Laval Steam Turbine;" George W. Bissell, "Recording Device for Testing Machines."

Messrs. Kent, Holloway, Woolson, Whitehead, Denton, Newcomb, Schumann, Griffin, Oberlin Smith, Lieb, and Rockwood took part in comment upon them, and, at their close, discussion was resumed upon the topic of "Extracting Oil from Condensed Steam," which had already been presented. Messrs. Wheeler, Oberlin Smith, Rockwood, Raynal, Boyer, Newcomb, Jesse M. Smith, Pearson, and Winship contributed to it.

After luncheon, served as usual in the supper-room below the auditorium of the Society's house, an excursion party was organized for the works of the Pond Machine Tool Co., at Plainfield, N. J., to which quite a number attached themselves, while others remained at the house, or attended to their personal business in the city.

In the evening a very largely attended reception was held at Delmonico's, at which over four hundred and fifty persons were present. The President-elect and the retiring President formed the Reception Committee, and after supper there were music and dancing.

FIFTH SESSION. FRIDAY MORNING.

The concluding session was occupied by the reading and discussion of the following papers:

R. C. Carpenter, "Effect of Temperature on the Strength of Wrought Iron and Steel;" P. M. Chamberlain, "Some Data Relating to Forge-shop Design;" D. S. Jacobus, "Experimental Method of Determining the Effective Centre of the Light Emitted from a Standard Photometric Burner;" Jno. H. Barr, "The Proportions of High-speed Engines."

The discussions proceeded from Messrs. Henning, Parsons, Hutton, Snell, Weil, Woolson, Green, Suplee, Le Van, Kent, Thurston, Kingsbury, Aldrich, Oberlin Smith, and Schumann.

At the close of the discussion upon the papers, the Secretary called the attention of the Society to an easel upon the platform of the hall, which had been placed there only the afternoon before. On this easel was a framed drawing, forty-three inches long by thirty-three inches high, concerning which he had received the two letters from which he read the following extracts:

135 EAST 21ST STREET, GRAMERCY PARK,
December 5, 1895.

TO THE SECRETARY OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

Dear Sir:—I have in my possession the original drawing of the plans of the steamboat "Fulton" (scale one-quarter inch to the foot), of date March 1, 1813, designed by Robert Fulton. The drawing belonged to my father, the late Mr. George L. Schuyler, of this city, and was much valued by him.

* * * * *

Should it be agreeable to the Society of Mechanical Engineers to receive this drawing as a gift, it will give me much pleasure to send it to you at such hour and place as you may designate.

* * * * *

I regret that it is not in very good condition—after the lapse of eighty-two years.

* * * * *

As a possible convenience, I send also an easel upon which the picture may stand, * * * and I will ask you not to take the trouble to return it.

I have been reading the accounts of your Convention in the daily papers with much interest. * * * The man who brings the picture will fasten it upon the easel if you so desire.

Very truly yours,
LOUISA LEE SCHUYLER.

The Secretary continued:

I, therefore, on behalf of Miss Schuyler, Mr. Chairman, present to the Society of Mechanical Engineers the drawing and its mounting upon the platform, the drawing bearing the endorsement, apparently, I should judge, in Mr. Fulton's own handwriting: "These drawings $\frac{1}{4}$ of an inch to the foot to be returned when the boat shall be finished. Robert Fulton, March 1st, 1813." On the side is the memorandum, "The Sound steamboat called the *Fulton* navigated the Sound between Long Island and Manhattan Island, passing the dangerous Strait called Hell Gate, in which she is often exposed to the current running among rocks on every hand, at the rate of six miles an hour. She cost $87,000. Her boiler of copper cost more than $20,000. This boat is 327 tons, Custom House measure. In building the boat it was found necessary to put the water wheels some six feet farther aft than they are in the plan."

In Miss Schuyler's name, therefore, Mr. President, I present to the Society this drawing of Fulton's.

Mr. J. F. Holloway.—I move the adoption of the following resolution:

Resolved, That the thanks of the American Society of Mechanical Engineers are due, and hereby tendered to, Miss Louisa Lee Schuyler, of Gramercy Park, New York, for her gift to this Society of the original drawing of the steamboat *Fulton*, made by Robert Fulton, March 1, 1813, which highly prized drawing has, for many years, been in the possession of her family.

Our thanks are due Miss Schuyler not only for the gift, but for her kindly recognition of the fact that this is the proper Society to have among its treasures this handiwork of one of America's earliest mechanical engineers; and that in no other place would its value be more highly appreciated than in the home of our Society, which has hanging on its walls an original portrait of that famous engineer, and in its parlors the old colonial mahogany table of Robert Fulton, around which, in the days in which the propulsion of boats by steam was in its infancy, and an untried and bold venture, he, no doubt, not only entertained his friends with the well-known hospitality of those early times, but on which he doubtless described and discussed his plans and ideas, traced by his own hand, as shown by the drawing so kindly given us by Miss Schuyler, and which is now before us.

Commodore Charles H. Loring.—In seconding this resolution, which I do most heartily, I would refer, not only to the interest connected with this illustration of the beginning of the new era in naval construction which has culminated in our own time in those magnificent examples of inventive genius and mechanical skill, the *Monitor*, the *Columbia*, and the *Indiana*, but also I would recognize the gracious manner in which it has been presented to us; and I would wish that there might be a rising vote upon this resolution, and would further move that a copy of our action should be forwarded to Miss Schuyler, with a letter from the Secretary inviting her, at her pleasure, to visit the rooms and see upon our walls the drawing which she has so long viewed upon her own, that she may receive the assurance that it is not only prized by us, but that it will be properly cared for.

The resolution was then adopted unanimously with applause and by a rising vote.

Mr. William Kent.—I would suggest that when the Secretary puts this resolution of thanks into the minutes of the Society that he will also prepare an appendix to cover information about the history of this boat. It would be of interest for permanent record in the *Transactions* of the Society. In fact, I think it might be photographed and put in the *Transactions.*

Professor Hutton.—The Secretary will be very glad to carry out the suggestions, and I think an original of such value should be photographed anyway, in case of the possibility of its destruction.

Mr. Holloway.—The members have no doubt noticed on our walls the portrait of a former member of this Society, the late Capt. John Ericsson. That portrait has been secured through the ingenuity of our Secretary, and I think you would all be interested in hearing something of the story of how he found the portrait. It always adds interest to a picture to know something of its history. I think the Society will be very much indebted to Professor Hutton if he will give a short account of when and where he found the picture.

Professor Hutton.—It would give me great pleasure to answer Mr. Holloway's request, but there is very little in the story.

It was suggested to me by one of our members that in a second-hand store in an unlikely part of the city he had discovered a portrait in oil of Captain Ericsson, and he advised that I look at it with a view to securing it for the Society, if it seemed worthy of that distinction.

The address he gave me was that of a curio store maintained by a German, who had left the employ of one of the larger houses and had gone into business for himself in this out-of-the-way part of the city.

On examining the portrait closely, I recognized at once that it was an excellent one, and bore the name of the artist, Ballin, and the date 1862, which was the year in which Captain Ericsson was at the zenith of his popularity, because it was the year of the great achievement of his first *Monitor*.

The dealer told me he had picked the picture up at a sale of household effects in Brooklyn, and although it was soiled and the frame in bad condition, I saw that at the price he quoted we were really on the track of a prize.

I had been anxious to secure an oil portrait of one who had reflected so much distinction upon mechanical engineering at this critical period, but had almost despaired of success, because Captain Ericsson was so retiring a person that he had always been reluctant to sit to a painter. That we should be able thus to secure it is, in my mind, a rare piece of good luck; and you will observe that underneath it has been suspended the model of the original *Monitor*, on a scale of one-quarter of an inch to the foot, the gift to the Society by our life member, Mr. Thomas F. Rowland, the builder of the *Monitor*, at the Continental Iron Works.

Mr. H. B. Roelker.—I would like to mention, in confirmation of the value of this portrait as an original, that I remember to have seen it hanging in Captain Ericsson's parlor as long ago as 1863 and 1864. There was suspended beneath it a series of resolutions from representative New York citizens, and I think the portrait and resolutions came to him together.

I congratulate the Society on obtaining possession of it.

Mr. Norman C. Stiles.—I would like to add to the reminiscences of Ericsson's time a story which belongs to the days when I was an apprentice in Springfield at the American Machine Works.

At this time Ericsson's enormous engines, to be operated by hot air, were being constructed for the ship *Ericsson*, and part of the work was in progress at that establishment. The cylinders were fourteen feet in diameter, and they had no lathe in that establishment which could turn piston rings of that size; so they rigged up a couple of planers to plane them out in sections. The ring was fastened to the bed of one planer, which moved back and forth in the usual way. At the side of the planer was a stud set up, which served as a pivot of an arm, actuated by the other planer, so that the motion of the two beds caused the circle of the required diameter to be planed out on the ring, instead of being turned, as usual, in a lathe.

Mr. A. H. Raynal.—It occurs to me to say a word or two in connection with this picture of Captain Ericsson, and its becoming the property of the Society.

It was given to me to enjoy his personal acquaintance and his friendship, which I have always considered a very great pleasure and privilege. I admired the man exceedingly.

I have been surprised to learn that the Society has not, until now, a copy of a most remarkable work of his, which he called the History of his Inventions, published in 1876, at the time of the Centennial Exhibition in Philadelphia. Captain Ericsson was gracious enough to present me with a copy of that work, which I have prized very highly, and which it would seem eminently proper should be preserved under the guardianship of the Society.

If it is agreeable to the members, it will make me very happy to turn it over as a gift to the Library of the American Society of Mechanical Engineers. (Applause.)

The President.—On behalf of the Society, I take great pleasure in accepting Mr. Raynal's gift.

Mr. C. W. Hunt.—I move a vote of thanks to Professor Hutton for what he has done for the Society in securing this portrait of one whom we have delighted to honor, and to Mr. Raynal for this most highly appreciated gift of his copy of Captain Ericsson's Centennial work.

This motion, being seconded, was unanimously carried by a rising vote.

The President.—The motion to adjourn is about to be in order, but before we separate and go to our several homes it would seem proper for me to acknowledge, in leaving the chair, my appreciation of the honor which this Society has conferred upon me in selecting me to fill the vacancy in the presidential office.

I do appreciate the distinction very much, and I desire to tender you my thanks for your uniform courtesy while I have occupied this position.

I would bespeak for my successor, my friend Mr. John Fritz, the same courtesy and magnanimity which have been shown to me. (Applause.)

On motion the meeting then adjourned.

DCLXIV.*

PRESIDENT'S ADDRESS, 1895.

THE MODERN DROP-PRESS.

BY C. E. BILLINGS, HARTFORD, CONN.
(President Partial Term 1894-5.)

FROM 1847 to 1862, among the green hills of the State of Vermont, there was located one of the best equipped plants for the manufacture of machine tools in this country. It was there, in the years of 1854–55, that most of the machinery was built for the manufacture of the then celebrated Enfield Rifle for the English Government, on the interchangeable system. Previous to that time they had made their fire-arms on the "cut and try" plan, or what we would term, in this country, hand-work. The parts were made in different shops: for instance, one manufacturer was skilled in making the barrel; another, the stock; another, part of the lock; and so on through the list. The various parts were assembled at the Tower of London, and it was there that the "cut and try" plan commenced, filing a little here, chipping off a little there, with several trials before the parts would go together satisfactorily.

On the introduction of American machinery and tools, all this was changed, for it was possible to machine the pieces of the arms so that parts of the same kind would be exact duplicates of each other. Consequently the cost of production was reduced and the quantities in a given time increased over the old method. To America is thus due the credit of introducing the interchangeable system in the manufacture of fire-arms, sewing machines, watches, etc.

It was necessary to have uniform forgings so that they could be handled in special fixtures adapted to the different parts. The art of forging in dies at that date was the weak

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* Presented at the New York meeting (December, 1895) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

point. Drop-hammers had not come into use, and all the forgings was made by the old hand-swaging process. A base of cast iron was used with a suitable opening in the top for keying the guide stock and a lower die. The upper die was made to work freely up and down in the guide stock. In the faces of the two dies were cut the forms of the parts to be forged. The power used was hammer and sledge, wielded by the smith and helper.

So far as I have been able to learn, drop-hammers were first used by Col. Samuel Colt about the year 1853 in the manufacture of the celebrated Revolving Fire-Arm which bears his name.

The hammer of the Colt drop was raised by a vertical revolving screw. In the first year of the war, Golding & Cheney obtained a United States Patent on a drop-hammer, the principle feature of which was the raising the hammer by a leather belt between friction rolls. These friction rolls are in use to-day on what are considered the best hammers for drop-forging. In other respects there have been great improvements. Some of the latest of these improvements I will endeavor to explain.

First, *The Counter-Balanced Treadle* which is made from one piece of steel forging. The advantage of this construction is that it does not become "shackly" from wear; and when the pressure is put on one side, the opposite side acts simultaneously, and the mechanism on either side of the machine does its work as it was designed to do. Instead of springs to hold the treadle in a raised position, a counter-balance is provided which runs across the back of the base and is attached at either end to levers whose fulcrums are pins driven into the sides of the base. The short ends of the levers have projecting points extending underneath the sides of the treadle and holding it in the raised position desired.

The improvements claimed for the counter-balanced treadle are that the pressure required is the same at the start as at the finish of the movement of the treadle, and that the construction is such that repairs are not frequently needed as in the cases where springs, or pulleys and chains, are used.

Second, *The Compound Lever Device* for operating the lifting or head mechanism. This device was designed with a view to lessen the shock of the blow given to the "friction bar" by the hammer when in operation. It consists of a clamp on the friction bar having a projection on the inner side which acts as the fulcrum of the lever, whose short end is a fork which engages with pins projecting from the left-hand upright, and whose long end is actuated by a pin in the hammer. This pin is placed as near the right-hand side of the hammer as is practicable, in order to enable the long arm of the lever to be made of as great a length as possible, thereby reducing the speed of the movement given to the friction bar and incidentally the shock of the blow. (Figs. 1 and 2.) All of this tends to diminish the necessity of repairs as it reduces the tendency of the friction bar to become crystallized, and it imparts to all the friction mechanism a moderate, easy motion, which is conducive to the durability of that part of the machine.

Another feature of this device is the ease with which it is adjusted for the different heights from which the hammer falls. There is only one nut to turn; and when this is loosened, the clamp is perfectly free upon the bar and will drop by its own weight, or it can be raised with one hand. This one nut is sufficient to hold the clamp in place, as the latter is not subjected to a sharp blow as in the old method.

Third, *The Jointed Swing Head Construction.* The main idea of this construction is to lessen the expense of repairs. The two sides of the head are connected by a heavy web at the bottom edges, through which there is a rectangular hole to accommodate the board. The upper halves of the two sides are fastened to the main head-casting by a hinge-joint at the rear, and are primarily held in place by small swivel bolts such as are used on a lathe centre-rest, and incidentally by two of the head bolts which pass through the upper and lower parts of the head and through the top of the uprights. By removing two bolts and loosening two more, and swinging open the caps, it is possible to remove any part of the head in detail, thus obviating the necessity of taking off the entire head by means of blocks or hoists when repairs are needed.

On both sides of the machine, running horizontally through the upper part of the uprights and through the web of the lower part of the head and into the rectangular hole in the latter, good stout bolts are used which hold the upper part of the machine rigidly together, and relieve the head bolts proper from all shearing strain and also obviate the elongation of the holes in the uprights by wear. The eccentrics are made of steel castings, which are stronger and more durable than bronze

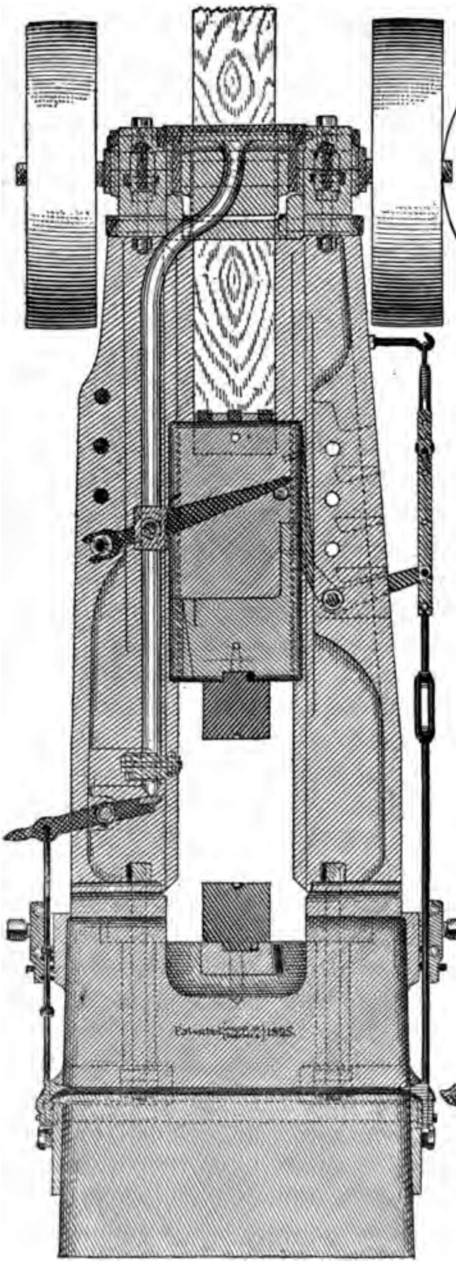

FIG. 1.

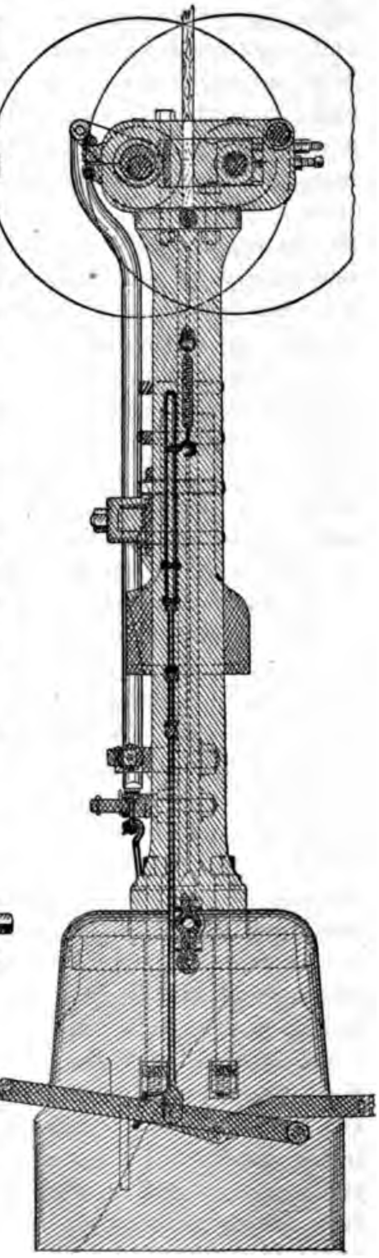

FIG. 2.

or gun metal. These are chambered and babbitt-lined, this lining being easily replaced when worn out.

The sliding rear boxes for adjusting the friction are operated in the usual way.

Fourth, *The Use of Paper Pulleys.* Experience has shown that iron pulleys are not reliable for drop-hammers. They become crystallized and break, and some one is likely to get hurt. Wood pulleys with iron hubs are very good, but the compressed paper pulleys give the best satisfaction. They are light as compared with their strength, are elastic, and give excellent belt surface.

Fifth, *The Method of Fastening the Board in the Hammer.* An oblong cavity from 4 inches to 8 inches long, and about 5 inches deep by 1½ inches wide, is machined in the top of the hammer. That side of the cavity which is toward the back of the hammer has a bevel of about 15 degrees, the cavity being smaller at the top than at the bottom. The front side of the cavity being straight, the rear side of the lifting board has a bevel corresponding to that on the rear side of the cavity. The board is dropped into the cavity, a steel plate placed against the front side of the board, and two or three steel wedges lightly driven with a hand-hammer between the board and the front side of the cavity. (Figs. 3 and 4.) At every blow of the hammer when the machine is working, these wedges become tighter and the board more firmly held.

Sixth, *The Foundations, and Incidentally the Ratio of the Base as Compared with Weight of Hammer.* There seems to be a variance of opinion in regard to the proper foundation for a drop-hammer. Several articles have appeared in the technical journals in regard to this subject. Some favor a rigid, rock-like foundation, and others favor an elastic construction. It seems to me that the weight of the base of the machine as compared to the weight of the blow given by the hammer should have more or less consideration in determining the construction of the foundation. It is apparent that if a man tried to do some hand-forging with an ordinary flat-iron held bottom up between his knees for an anvil, the results would not be altogether satisfactory; but if it were possible for him to hold a piece of iron weighing, say, 400 pounds on his knees, he would do more execution with his hammer and in addition could stand some pretty good blows from his helper's sledge. From this illustration I argue that if the base of a drop-hammer should be made heavy enough, no foundation whatever would be required. The inertia of the mass of metal would be sufficient to absorb the effects of the shock imparted by the blow of the hammer. The cost and difficulties of handling, however, make such construction out of the question. Within the past few years an increase in the weight of the bases of drop-hammers has been a move in the right direction. In deciding this point a certain ratio between the weight of the hammer proper and the base is considered. In former years the ratio of 6 or 8 to 1 was considered sufficient. This was increased by some machine builders to 10 to 1, and now the most modern practice advocates a ratio of 15 to 1.

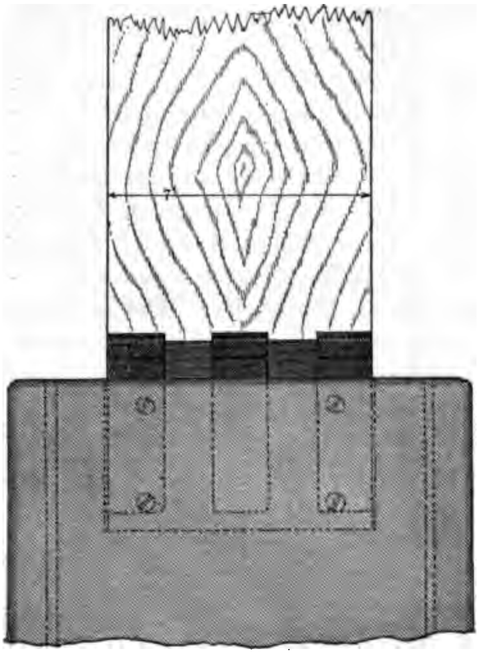

FIG. 3.

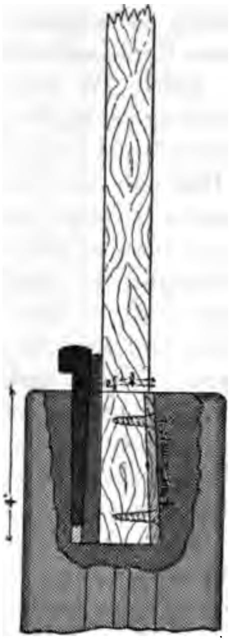

FIG. 4.

To return to the subject of foundations, I would not venture to say which construction will give the best results, owing in a measure to the variation of conditions, particularly the formation of the earth where the machine is to be located. In fairly hard ground, such as clay, or where "hard pan" can be reached within fifteen feet of the surface, the following construction will give satisfaction. At the bottom of the excavation put in two or three feet of broken stone and Portland cement; on top of that place chestnut timbers on end. These timbers are to be sawed on four sides and bolted together, and the section of this block should be of sufficient size to accommodate the base of the machine and to have about 4 inches margin. (Figs. 5 and 6.) It is preferable to have the upper end of the timbers several inches below the surface of the ground, as they will then be less liable to decay.

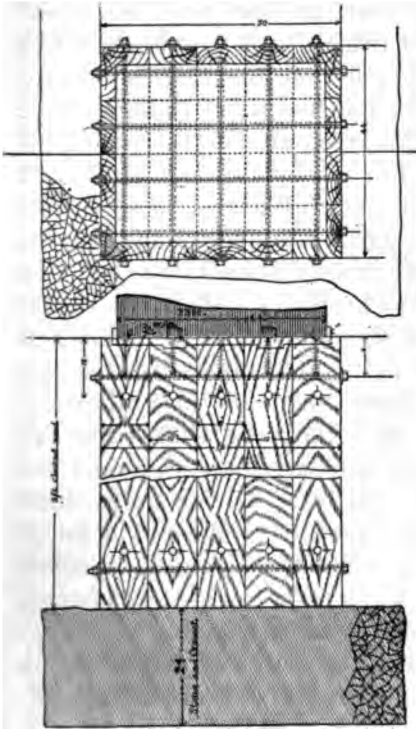

Fig. 6.

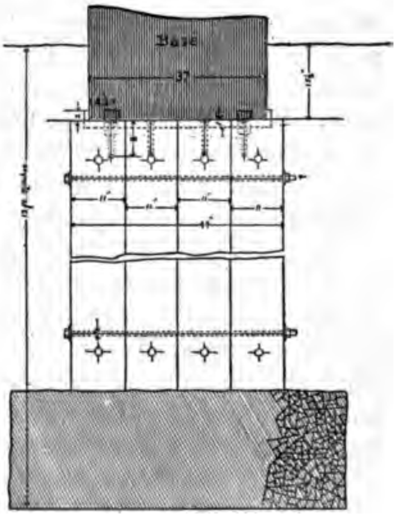

Fig. 5.

With a base of right proportion and a properly constructed foundation, the old method of fastening down the base with anchor bolts is unnecessary. Angle irons at the corners of the base fastened down to the foundation with lag screws will answer the purpose.

DISCUSSION.

Mr. J. F. Holloway.—I think that Mr. John Fritz has some experience in putting down foundations for drop-hammers. He has the largest hammer in the world.

The President.—We shall be pleased to hear from Mr. Fritz.

Mr. John Fritz.—The hammer which gave trouble weighed 125 tons. First we prepared a foundation about 60 feet square and drove it with piles until we could not drive them another inch or get in another pile. We covered the piles over with timbers 34 inches square; on top of that we put on forged beams somewhere about 35 feet long. Each of these beams weighed some 40 odd tons. The object was to catch the timbers so as to get the surface. Then we cross-timbered on top of that again, and then put on an anvil block which weighed about 1,500 tons. We ran the hammer but a short time and the foundation went down some 8 or 10 inches, and it unfortunately did not go level, which made it worse. There we were in a dilemma. What to do was the question. So I took the whole thing out down to the piles, and levelled the foundation up again, and put in two feet of shavings which we got from the car shops, such as are made with ordinary freight cars, etc. We put a lot of men on and tramped that down to about sixteen or eighteen inches thick and then placed the heavy timbers on top of the shavings, and the forged steel beams on them crosswise, and on top of the beams, ten-inch square timber, then about fifteen hundredweight of cast iron, and then covered the casting with three-inch plank, and then twelve inches of cork. On top of the cork ten inches of timber, and then the anvil block; and the hammer has simply worked magnificently.

The President.—What effect did the shavings have, Mr. Fritz?

Mr. Fritz.—We had to save the foundation, not the hammer. It was the foundation which was the trouble. If we had put the anvil on the foundation again it would have gone down. But the shavings took the severe blow on the foundations. It has been running four or five years. It has never gone down at all. We put the shavings on to save the foundation. It was something elastic which was required between the anvil block and the piles upon which it rested. If the foundations had been strong enough we would have simply put the fifteen hundredweight of iron on top of heavy timbers; but we were afraid to.

The President.—You believe that the elasticity of the shavings was what helped it?

Mr. Fritz.—Yes. The idea was not original. It came from the old forge hammers where they put brush under them to accomplish the same purpose to a great extent. They did it to get elasticity. I did not care about the elasticity for the hammer, but wanted it to save the foundation.

The President.—Mr. Dean must have had some experience with foundations for steam stamps while connected with Mr. Leavitt, and the Calumet and Hecla. We should be glad to hear from him as to their practice.

Mr. F. W. Dean.—It is some years since I have been connected with the Calumet and Hecla Mining Company; but that matter of the weight of the anvil has come up, and I understand that since I left the company the spring timbers have been entirely done away with. They tried one stamp with a solid rock-like foundation for the anvil, and the output of that stamp was so much greater than the others, that they have, I understand, made all stamp foundations solid. I understand the output is enormously increased thereby per stamp, and of course it is quite evident why it should be so. All the energy of the stamp is taken up in crushing the ore, instead of springing the timbers and all of the country about. In the houses within some distance of the stamp mills everything shook very badly, and all the windows rattled like those of a side-wheel steamer; and it was unsafe to leave a pitcher of water on a table at night, for it would be pretty sure to be on the floor by morning. The water in the lake had small wavelets all over it, and I believe the country the other side of the lake shook also; but since the solid foundations have been put in, that has all stopped.

Prof. F. R. Hutton.—I should like to ask the author about the breaking of these pins which trip the lever on the head, or the failure of them, rather, by crystallization from 'shock, and his statement that wood has served the purpose better than metal. Do the pins gradually break, or what happens to them?

The President.—They broke off close to the face of the hammer. We have used steel, Swedish and Low Moor iron, and two or three different kinds of alloys of bronze, and with the same result. A hickory wood pin stood the best of all.

Previous to using the wedges for holding the lifting board, we put bolts entirely through the hammer with nuts on end. Those nuts and bolt heads were constantly dropping off. No kind of metal we tried for the purpose would stand. The appearance of the fracture was crystalline. This led up to the system of holding the lifting board to the hammer with wedges as represented by drawing, Figs. 3 and 4. These have been in use now for many years with entire satisfaction.

DCLXV.*

WATER-POWER—ITS GENERATION AND TRANSMISSION.

BY SAMUEL WEBBER, CHARLESTOWN, N. H.
(Member of the Society.)

AN examination of the detailed schedule of subjects submitted by the Council, as desirable topics on which to prepare papers for the current year, has induced the writer to offer the following notes on the first portion of the data requested by said schedule, which, it seems to him, it is desirable to preserve in such permanent form as will be given them by a place in the *Transactions*.

The first topics suggested, the storage of water supply, and the cost of its development and maintenance, seem to belong more particularly to the civil than to the mechanical branch of the engineering profession; but as the utilization is mechanical, and the whole matter is intimately connected, it seems proper to offer a few general notes on the subject of the supply of water necessary for its mechanical utilization.

The engineers, who have been for many years engaged in the question of water-supply for large cities, have laid it down as an established fact that, by means of proper and complete storage basins, one-half the annual rainfall may be thus saved, the other half being either absorbed by vegetation or dissipated by evaporation.

This amount has been usually estimated for our northern cities as 1,000,000 gallons per day from each square mile of drainage area, or one-half an annual rainfall of 42 inches, which is a fair average for the larger part of the United States, east of Kansas and Nebraska, rising, according to Blodgett, as high as 50 and 55 inches, in parts of the southwestern States, but a safe estimate

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*Presented at the New York meeting (December, 1895) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

for the area of drainages from the great Appalachian range, which is as wide an area as we propose to consider in this paper.

It will be readily seen that this annual rainfall of 42 inches amounts to nearly 732,000,000 gallons on a square mile, so that 1,000,000 gallons per day is almost exactly half of it. To secure this half, however, requires the most complete and perfect system of storage basins possible, and it is not safe to calculate on such an amount as being available for water-power by any possible and economical means of storage.

It is possible, however, by practicable means of storage, to secure about one-third of the rainfall, and as water for power purposes is usually measured in cubic feet per minute, or per second, instead of gallons, we will now adopt that mode of computation.

An annual rainfall of 42 inches is equal to 267,409 cubic feet per day on a square mile, or 3.09 cubic feet per second, and if we take one-third of this, or 1 cubic foot per second, from each square mile of drainage area, we arrive at the supply which can usually, by the aid of storage, be relied upon.

The late James B. Francis, for many years the engineer of the Locks and Canals Company, at Lowell, on the Merrimac River, once gave me the following data, as the result of many years' observation of the flow of the Merrimac River, which, however, does not take in the few days of "spring freshets," when the snow is going off from the mountains, and the river so high and swollen as to be practically unmeasurable :

Spring flow.................... = 90 cubic feet per minute per square mile.
"June flow," about the average...55 " " "
Minimum flow in Aug. and Sept...30 " " "

The minimum flow has, however, been less than that once or twice in recent years, as, in 1881, it was only 26.7 cubic feet per square mile drainage area, or .445 cubic foot per second. This diminution has been due to the destruction of the forests around the head-waters of the river, and such forest destruction must be borne in mind by every engineer as a probability, when making estimates on a projected water-power.

It will be seen that this 30 cubic feet per minute, or 0.50 cubic foot per second, the minimum flow, is but one-sixth of the rainfall, and in order to secure the one-third, which I have considered as available, a sufficient "pondage" must be secured above the dam, at the proposed water-power, or in some other convenient location, to store the night flow, if the water is used in the daytime, or *vice versa*, so as to get a double quantity during working hours without too much diminution of the working head.

This is practically accomplished at Lowell, where the observations on the water-power of the Merrimac River have been longer continued and are more complete than any others of which I am aware, by the pond made by the dam. This pond is 18 miles long, with an average width of 500 feet. The drainage area of the Merrimac, above Lowell, is 4,093 square miles, and if we take the minimum flow as 0.50 cubic foot per second, we have a total flow of 2,000 cubic feet per second.

Col. James Francis, who has succeeded his father as agent and engineer of the Locks and Canals Company, informs me that, with 3 feet of "flash boards" on the dam, giving a fall of 34 feet, they can store in this pond, at a depth of 1.50 feet, 71,874,000 cubic feet of water, which, if drawn down the 18 inches in 10 hours, would give them 6,165 horse-power, which, added to the daily flow of the same 2,000 cubic feet, would give at low water a total of 12,330 horse-power. The original estimate of the power available at Lowell was 10,000 horse-power on 30 feet fall; but by raising the dam above, and removing obstructions below, this power has been increased, as shown.

The net effect of the present turbines in Lowell is here taken at 80 per cent. There are, however, in place, at Lowell, turbines enough to utilize 20,000 horse-power, for which water is furnished for a portion of the year, but which have to be supplemented by steam-engines, to supply the deficiency, when the water is reduced to the minimum flow, as above quoted.

In addition to this, the mills at Lowell, Lawrence, and Manchester, N. H., have also derived great benefit from the use of the water stored in Lakes Winnepesaukee and Winnesquam, in New Hampshire, where the outlets were deepened, and weirs and gates put in below, enabling the water-power companies to draw down these lakes in the summer to a depth of 12 feet below the full height in spring, or 6 feet below their normal summer level. The area of these lakes above the Lake Company's dam is 71.8 square miles; and Colonel Francis gives me the following data of the amount of water furnished by them for several consecutive years:

Year.	Horse-Power Furnished for 3 Months.	Depth Drawn at Lake.
1878.	659	4.20 feet.
1879.	809	5.16 "
1880.	1,299	8.28 "
1881.	1,600	10.20 "
1882.	1,506	9.60 "
1883.	282	1.80 "
1884.	1,845	11.76 "
1885.	69	0.44 "
1886.	1,067	6.80 "
1887.	0	0. "

The variation in seasons is seen to be considerable.

Leaving this branch of the subject, with the repetition of the statement that, by storage, one-third of the rainfall can be relied on for power for day *or* night, I now take up the question of turbines.

The modern turbine is the evolution of ages from two distinct types, one of which delivers the water in a tangential direction to radial arms or vanes, projecting from a central shaft, without confining it in any way; the other conveyed it in a closed tube to hollow radial arms, through which it passed, and, leaving them in a tangential direction, gave, by the reaction pressure, a rotary motion to the whole apparatus.

We can trace both systems back to such remote antiquity that it is useless to attempt to find the origin; and as the principal developments of both have been made within the present century, we need go back no farther. As we shall devote much less time to the second of these types, or the "outward discharge," we shall consider it first, and simply refer to the well-known "Barker Mill," or the "Whitelaw & Sterret," sometimes called the "Archimedean" wheel, as the first modern type of this style.

In 1827 Mr. Fourneyron applied this principle of the outward discharge from a pipe to a wheel with curved buckets placed outside of the apertures of discharge, so as to receive the water in a direction perpendicular to the first and inner element of the curve, which appears to be practically cycloidal, and which, revolving from the action of the water, finally discharged it at its outer element at the circumference, with its force exhausted; *i. e.*, the best results obtained from this form of turbine were shown by Mr. Francis, in his "Hydraulic Experiments," to be when the circumference of the wheel at the point of discharge had reached the velocity due to the water under the fall, or 62 per cent. of the theoretical velocity due the head, from the action of gravity, this being the result of what is known as the "contracted vein." At this velocity of the wheel the water falls away dead into the pit, to take a new direction due to the fall in the "tail-race."

In the Fourneyron turbine, the tube, or feeder, which supplied the water, was closed at the bottom by a concave cone surrounding the wheel shaft, which passed up through it in a pipe, and was not exposed to the water. This cone was surrounded by a number of guide plates, curved like the buckets, but in the opposite direction, and fastened to the cone; and these delivered the water to the buckets in the proper tangential direction. This first turbine of 1827 was followed by another, in 1834, of 7 or 8 horse-power, which worked at times under a head of only 9 inches.

Then came several others, under higher heads, of 63, 79, 126, and 144 feet respectively, giving from 71 to 87 per cent. net effect of the power of the water.

In 1837 came the celebrated one of St. Blasien, 20 inches in diameter, weighing 105 pounds, under a head of 72 feet, and this was followed by one of 13 inches diameter, under a head of 354 feet. The width of this wheel across the buckets was only 0.225 inch; and it made 2,200 to 2,300 revolutions per minute. It is said to have driven 8,000 cotton spindles, with the other accessory machinery, which would require from 100 to 120 horse-power, and to have given from 80 to 85 per cent. net effect. The apertures of the buckets were so small, however, that the water was all filtered before entering the feeder, to avoid clogging them.

The success of these wheels led to their introduction to this country by the late Uriah A. Boyden, who placed the first ones in Lowell, in 1844, and these were rapidly followed by others, until their use became almost general in the large manufacturing towns of New England. Those built under Mr. Boyden's instructions gave as high as 80 per cent. net effect, and he claimed to have got 88 per cent. at the Atlantic Mills in Lawrence.

Their manufacture was taken up by a number of builders, but they did not all obtain such high results, and owing to the multitude of buckets, with the small apertures, they were liable to become choked by chips and leaves and other floating obstructions, not to speak of fish; for at Fall River the first turbines are said to have been stopped by eels, on their annual migrations to the sea, from Watuppa Lake.

The net effect at partial gate was also very poor, owing to cutting off the water by the sharp edge of a cylinder, as shown by the writer in a paper presented to this Society, and included in Volume III. of the *Transactions.*[*]

Attempts have been made to obviate this by introducing diaphragms in the buckets, so that only a part of the bucket is affected by this sharp cut-off, and this is shown in the Swiss turbines, now being introduced at Niagara Falls, but this division only reduces the dimensions of the apertures, and renders them more liable to choke from obstructions. This form of wheel, as built by Mr. Boyden, was also enormously expensive, and they have generally given place, as they wore out, in forty or more years' use, to the "inward and downward flow" turbine, which we shall now proceed to trace. This, as we said in the outset, comes from the old "flutter-wheel" of radial vanes inserted in a central shaft, which supported a grindstone, or "millstone," on top of it, and which is one of the earliest traces of mechanical application of force to be found in history. India, Egypt, Syria, and Europe all appear to have used this primitive water-wheel to grind their corn. It is impossible to determine when the modifications of this form began, but, in 1804, a patent signed by Thomas Jefferson was granted to Benjamin Tyler, of Lebanon, N. H., for "an improvement in water-wheels," in which he claimed "hooping the wheel with iron hoops," and specified the proper angle at which to set the buckets, "made of winding timber."

Similar improvements were early made in the mountainous districts of France, where metal buckets, curved either vertically or horizontally, were bolted to a central shaft, and were known either as "*rouets a cuve*" or "*rouets volants,*" and in common parlance with us were known as "tub wheels." The water was applied to all these wheels "tangentially," by a trunk or spout which delivered it at the circumference. Next, this trunk was made in the form of an Archimedean scroll, which applied the water equally all around the wheel, the top being closed, and the discharge at the bottom. A wheel of this sort was patented by John Tyler, grandson of "Benjamin," above referred to, in 1855. I have no record of the dates of the European improvements in this direction, but, as early as 1843, Elwood Morris, of Philadelphia, experimented with and reported on what is generally known as the "Jonval turbine," in which the radial buckets are curved vertically, and the water directed to them by a set of stationary guides,

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[*] "Efficiency of Turbines as Affected by Form of Gate," Vol. III., p. 84, No. 61.

curved in the opposite direction, and fixed to the interior of the tube or feeder which supplied the water. This form of wheel has also been known as the "Koechlin," "Fontaine," and as the "Froment" turbine; the name of "Jonval," I believe, only applies properly to the "draught tube" arrangement, which was patented in this country by Zebulon and Amasa Parker, of Licking, O., in 1840.

These wheels were sometimes, in cases of low heads, set directly in the bottom of the wooden flume or forebay, in other cases supplied by an iron feeder pipe. The Froment turbine, which the writer saw in the London "Crystal Palace" of 1851, was of the former character, and the gates were a series of "plungers," which fitted down between the guides. J. P. Collins, of Norwich, Conn., has adopted this form of gate; others, as Mr. Geyelin, of Philadelphia, have used what is known as the register gate, a term derived from the common hot-air heating apparatus. Still another form has been a sliding telescopic tube, outside, which throttles the water after leaving the wheel, and seems to the writer objectionable, but has been applied to the turbines at Niagara.

This class of wheels, known as the "downward flow," has proved effective and economical, and they are particularly suited for large and constant powers at low heads, but are deficient at partial gate, if the gate is of the register or telescope pattern. The writer has obtained 84 per cent. net effect with two "Geyelin" turbines, in different localities, when at "full gate."

We must now turn to a different form of wheel, the "inward flow," patented in 1838 by Samuel B. Howd, of Geneva, N. Y. In this the action of the Fourneyron wheel is reversed, and the converging guides, which were straight, were placed outside the wheel, which had curved buckets, revolving inside the guides, and was, in fact, only one form of the old "tub wheel." Mr. Francis has stated (see "Hydraulic Experiments") that a similar wheel was suggested by General Poncelet, in 1826.

In the Howd wheel, the regulating gates were placed outside the guides or "chutes." The buckets were cast iron, fastened by bolts to wooden top and base plates, and the discharge was central.

In 1849 Mr. Francis took this matter up, and built, for the Boott Mills in Lowell, an inward discharge wheel, in which he employed the carefully designed curves of the "Boyden" wheel, and which gave excellent results, nearly equal to those of the outward discharge.

This type of inward discharge gave much greater facilities for operating the gates, and was followed by a number of variations, notably the "American Turbine," of Stout, Mills & Temple, of Dayton, O., in which the form of gate adopted gave much better results than were obtained when partially closed, by the cylinder between the guides and buckets, which Mr. Francis copied from Mr. Boyden. This wheel at the Boott Mills lasted until 1875, when it was replaced by a "Swain wheel." In 1855 A. M. Swain, a mechanic who had been employed at the Lowell machine-shop in the construction of the Boyden and Francis wheels, conceived an idea which produced the prototype and exemplar of all the modern American turbines. He combined the inward and downward flow wheels, curving the buckets both laterally and vertically, and discharging the water mainly downward, where a reversed curve in the base on which the wheel rested threw it outward again, so that the path of the water was a semicircle. He adopted a form of gate which, instead of cutting off the water abruptly, closed the orifice by which it entered the wheel, by lifting the lower side of the tube, so as to contract the passage, which still retained a rounded aperture. The result produced by this was marvellous; instead of 30 per cent. effect at part gate, or half water, he got 66 per cent., and 83.4 per cent. at full gate, when the wheel was finally perfected in 1875.

The Swain wheel had, however, given an excellent result as far back as 1862, and from that date down to about 1878 the number of turbines was legion, in all sorts of variations of curve of bucket and form of gate, but all containing the same general features of inward and downward discharge. Of these, the Leffel wheel combined both forms of bucket, separated by a diaphragm in the same wheel, and has given excellent effects.

The general result of this change from the Fourneyron type, as first introduced, has been to furnish the public with turbines of equal power in one-half the space and at one-fifth the cost, being single castings of iron or bronze, instead of built up of many parts. The general line of evolution, beginning with the Swain wheel, has been that of fewer and deeper buckets, with wider openings, to avoid obstruction by floating matter, and in some of the wheels, like the "Hercules," the narrow openings of the "chutes" have been retained, preventing such matter from entering the wheel itself.

This latter wheel brings us to the date of 1876, when what is known as the "new departure" wheels were introduced. The first of these was the "Hercules," designed by John B. McCormick, of Brookville, Pa., who brought it to the Holyoke Testing Flume to be tried, and the results were such that the Holyoke Machine Company at once entered into its manufacture.

The principal feature of this wheel was a much smaller diameter, with longer buckets and deeper openings, for any proposed amount of power.

This wheel was at once followed by the "Victor," made by Stilwell & Bierce, of Dayton, O., on the same general lines, but differing in form of bucket and gate; and many of the older wheels have been since changed or improved in the same direction, and the following table will show the difference in quantity of water used and power obtained by a number of wheels of nearly the same diameter, under the same head of 26 feet, beginning with the "Boyden Fourneyron," and ending with the "Victor;"

	Inches, Diameter.	Cubic Feet Water per Sec.	Horse-Power.
Boyden Fourneyron	36	22.95	55
Risdon	36	35.45	89
Risdon "L. C."	36	48.27	121
Risdon "D. C."	36	80	199
Leffel, Standard	35	40.45	96
Leffel, Special	35	60	148
Tyler	36	40.7	95.8
Swain	36	58.2	140
Hunt, "Swain bucket"	36	48.8	121
Hunt, New Style	30	98	239.74
Leffel, "Samson"	35	109.1	264
"Hercules"	36	107.6	253.5
"Victor"	35	108.8	266
New Swain	36	89.5	215

This enormous difference in productive effect in wheels of the same diameter shows the great economy of the later type of turbines, particularly as all the wheels above named have a *proved* efficiency of 80 per cent., and some of them have given more; such as 87 per cent. for the Risdon, tested by Mr. Edward Sawyer, of Boston, at Crompton, R. I., and by the writer at the Centennial; 87 per cent. for the "Hercules," tested by Professor Thurston; 84 per cent. for the Collins, by the same authority; 84 per cent. nearly for the Swain, by Mr. Francis; 84 per cent. for the Geyelin and the Hunt, tested by the writer, and 88 per cent. for a 15-inch

"Victor," by the same, but this was so small a wheel that the test cannot be depended on. Later tests of large wheels at the Holyoke Flume give over 80 per cent., and to these may be added the "Success" of E. Morgan Smith, York, Pa., and the "Humphrey," Keene, N. H., and the wheel of Gates Curtis of Ogdensburg, N. Y., also the "New American," of the Dayton Globe Iron Works, Dayton, O. Here all questions of selection must be governed by other reasons than that of mere efficiency, as all the above seventeen wheels have been proved to give 80 per cent. or over net effect. Nearly all these wheels have been adapted to horizontal shafts, for high heads, where the belt pulleys can be kept out of water, and so far as they have been tested show no difference in economy from that given on vertical shafts. A "Hunt" wheel, tested by Mr. Francis *in situ*, in a mill at Lowell, only varied a fraction of $\frac{1}{10}$ of 1 per cent. on a horizontal shaft, from the result obtained on a vertical one by Mr. Herschel, at the Testing Flume in Holyoke.

While the writer has expressed a preference for the "downward flow" wheel when the head was low, and bevel gears necessary, he would prefer the new type of small diameter wheels for horizontal shafts under high heads, as they give a greater initial velocity to the shafting, the friction of bevel gears is avoided, and if set in pairs, to thrust against each other, step friction, which is very destructive in muddy streams, is also done away with.

The first instance in which turbines were placed in pairs in this manner, in the writer's memory, was in 1875, when A. M. Swain installed a pair at Ticonderoga, N. Y., which were very successful. Since then all the prominent wheel builders have adopted it, and it has become very general in all cases where the head was sufficient to keep the pulleys out of water. It also gives the advantage of easy and immediate access to the wheel for examination or repairs, by a manhole in the case, if the head-gates to the feeder are closed. The writer installed a pair of Risdon turbines for the Nashua Manufacturing Company in this way some time since, and, asking the man who had charge of them, after two years' use, "If anything had been required to be done to them?" he answered, "Nothing but to oil the stuffing-boxes, and open and shut the gates." Like all other water-wheels, the turbine is somewhat slow in answering to regulation under a variable load, as it takes more time to open and close the gates than it does to trip the "cut-off" in a Corliss engine, but both the "Snow" and "Schofield" governors are very effective, and can be recommended.

Since writing the above a new hydraulic "Governor," the "Lombarde," has been introduced; but the writer has no personal knowledge of its efficiency, although it is highly commended.

Among the other points mentioned in the schedule is the testing of turbines "*in situ*," and in regard to this the writer would say that a few points need careful attention. The friction pulley should be flanged, to keep the brake in place, and amply strong, and a safe size for it is to allow 1 square foot of surface motion per second for every 3,000 foot-pounds per second lifted; this gives a pressure of a little over 20 pounds per square inch. The brake should be of timber, fitted to the pulley, one-third the circumference on each edge, leaving two openings of one-sixth circumference for lubrication. The best lubricant is strong, thick soapsuds, about the consistency of molasses, and this should be constantly fed from a can or cans in a stream the size of a quill, and may be diluted in use by a jet of cold water from a hose or pipe, played in through the openings, to cool the pulley. The brake lever is most convenient if made the radius of either a 33-foot or a 66-foot circle; that is, practically, 5 feet 3 inches or 10 feet 6 inches long from centre of shaft to point of attachment of weight. The whole apparatus should be perfectly balanced at rest before commencing operations.

With a worm shaft and gear, tapped in to the wheel shaft, so as to ring a bell every one hundred revolutions, the speed is ascertained, and the weight in the scale being known, the horse-power is quickly calculated. Professor Thurston's paper on "Turbine Testing," in Vol. VIII. of the *Transactions*, and Mr. Francis's "Hydraulic Experiments," give data as to the measurement of water, if the *net effect* of the wheel is also to be arrived at, but it would cover space unnecessarily to go into those details here.

When we come to the matter of cost, we find it to vary much in different localities, according to the expense of development. The cost at Lowell, when the first "mill powers" were opened, had been only $40 per horse-power, for dam, land, and canals. This was increased $50 per horse-power by the new canal, which gave more certain head, and enabled the mills to use the surplus water which ran to waste part of the year, and the total cost has probably been $100 per horse-power, to which another $100 is to be added for the expensive Boyden wheels and massive masonry pits. At Augusta, Ga., the canals, nine miles long, cost the city, which leases the power, $90 per horse-power. At Columbia, S. C., for five miles of canals the cost to the city has been $72 per horse-power.

In many cases of smaller enterprises it has been less than $50 per horse-power, and the total cost, including wheels and pits, less than $100, and we will now give the data of the cost of water-power as developed within recent years at three different points, showing the outlay, and a fair allowance for interest and running expenses.

The first instance we shall give is that of the Concord Water Power Company, on the Merrimac River, at Concord, N. H. Here the power developed is at a minimum 3,300 horse-power, on an average 5,000 horse-power from a fall of 22 feet. The wheels are "Rodney Hunt" turbines, set in pairs on horizontal shafts of 400 horse-power each. The cost has been as follows:

700 Acres Land, and Flowage Rights	$ 20,000
Dam and Abutments	141,015
Canal, 60 feet wide	27,368
Head Gates	16,675
Waste Weir	5,220
Making an investment for water of	$210,278

or $63.72 for the minimum amount of power, or $42.05 for the average amount of power. To this is to be added, pits and foundations put in for 2,000 horse-power, $15,000, or $7.50 per horse-power; wheels put in for 1,600 horse-power, $12,225, or $7.66 per horse-power—making a total, for the minimum flow of water, of $78.88 per horse-power, and for the average flow, of $57.75 per horse-power.

Now, if we base our calculation of cost on the minimum flow, and allow interest, 5 per cent., sinking fund, 2½ per cent., repairs, 1½ per cent., taxes, etc., 1 per cent., we get a total annual *cost* of 10 per cent., or $7.89 per horse-power, to which add oil and attendance, 75 cents, making $8.64.

As this power is to be transmitted, in part, at least, to Concord by electricity, the cost of such transmission, on which I do not assume to be authority, will have to be added to this. If, on the other hand, it is to be partially used near at hand, it is safe to say that the cost of transmission by shafts and belts would not increase it to over $10 per horse-power.

If we assume the average flow of 5,000 horse-power the cost of the power at the wheels would be only $5.72, but we should then require the additional expense of a steam plant, and its operation, to produce the 1,700 horse-power deficiency at low water.

We will now take a large southern mill, the John P. King, at Augusta, Ga. Here the water is purchased of the city at a rental of $5.50 per annum per gross horse-power.

The wheels are 3 Geyelin turbines, on vertical shafts with bevel gears, estimated at 1,835.5 gross horse-power. These wheels, by my own test *in situ*, netted 84 per cent. Calling the average 80 per cent., it gives 1,468 net horse-power. This cost of plant was for wheel-pits, 42 feet deep, in rock, head race, 200 by 40, tail race, 800 feet to river, about $25,000, and the wheels and jack shaft cost the same, or $50,000 in all. This, for 1,468 net horse-power, is $34.20 per horse-power, or, at 10 per cent., $3.42; water rent, $5.50 on 1,835.5 gross horse-power, equal, net, $6.88; attendance and oil, 75 cents; making a total cost of $11.05.

The next case is also a southern one, that of the Columbia Mills, at Columbia, S. C. Here the water is also leased, at a rental of $5 per horse-power. For quantities less than 500 horse-power, the charge is $7. The fall is 27 feet, and the power is furnished by "Victor" turbines, on horizontal shafts, and is transmitted by electricity to the mills.

Quicksands made the wheel-pits very expensive, by the quantity of concrete masonry required, so that for all expenses of pits, races, power-house, etc., we have $55,000 for 2,000 horse-power. The wheels cost $20,000 more, so that we have a total expenditure of $75,000 for 2,000 horse-power, or $37.50 per horse-power. This, at 10 per cent., as before, gives $3.75 per horse-power; water rent, $5 per horse-power; attendance and oil, 75 cents; making a cost at wheels of $9.50 per horse-power.

As the water rent paid in the last two cases covers interest and depreciation, while the cities which furnish the water also obtain their own supply for other purposes, it will be seen that it covers the cost, and that the estimate of Mr. Samuel Batchelder, fifty years ago, that the cost of water-power in Lowell, including land, was under $15 per annum per horse-power, was substantially correct, and will *cover* the cost of water-power with modern turbines, under fair circumstances, to-day, with plenty of room to spare for heating.

The writer trusts that these notes may be acceptable to the Society, and that they may draw from some of the other members, who have paid more attention to that question, fuller details as to the cost of "water storage," and possibly some other facts in the history of the turbine which have not come to his knowledge.

DISCUSSION.

Mr. H. H. Suplee.—Referring to the historical portion of this paper, I really do not think that sufficient mention has been made of the work of Mr. Emile Geyelin, of Philadelphia. He is mentioned here in regard to the turbines, at various times, but without any date. Mr. Geyelin was acquainted with Fourneyron, and subsequently with Jonval; and he came to this country, I think, about 1850. On page 50 the date is given from the author's memory, of 1875, for Mr. Swain's idea, placing two turbines opposing each other on the shaft.

I find that Mr. Geyelin constructed in 1854 what he believes to be the first pair of turbines working on a horizontal axis. These turbines were made for Mr. James Prince for a cotton-mill at Palitas, Mexico. His original intention had been to order at Manchester, England, an over-shot water-wheel, 100 feet in diameter, for which he expected to pay $25,000. He was dissuaded from doing so by Mr. Alexis Dupont, of Wilmington, who had already had favorable experience with turbine wheels designed by Mr. Geyelin. The problem was to build a turbine of 140 horse-power to operate under 160 feet head of water. Mr. Geyelin proposed to build a pair of horizontal-axis turbines, so arranged that the opposing pressures counteracted each other, the speed being reduced by means of gearing. The contract price was only $2,300, or less than one-tenth what Mr. Prince had expected to pay in England. The offer was accepted, and the wheels were built, and were most satisfactory in their operation, subsequent orders being also satisfactorily filled. These turbines were only eleven inches in diameter, and made 1850 revolutions per minute, the speed being geared down, so that the countershafts ran at 185 revolutions. Mr. Geyelin not long ago exhibited the original drawings and the agreement before the Engineer's Club of Philadelphia, so that the above is a matter of record. Mr. Geyelin is still in active service, and designed the large turbines for the paper mills in use at Niagara Falls, in advance of the Swiss turbines now in use there.

Mr. William S. Aldrich.—The utilization of water-power is certainly a mechanical subject, as Mr. Webber early points out. And we believe that the members of our Society need have no fear that the subject is likely to very soon run out into other branches of engineering. We would not go further than to paraphrase that which is only too often applied to another system of power transmission, and say that hydraulic transmission is yet in its infancy.

Some time ago we were called upon to design a system of hydraulic transmission mechanism, for the purpose of variable speed power transmission. As usual, these problems come up without precedent. Costly experimental work is necessary to obtain any data for the case in hand. What seems to lure the inventor on is the fact that hydraulic transmission must be very efficient, because hydraulic motors realize so much of the power delivered to them. Arguments will not avail. An experiment must be made; and history repeats itself. The inherent characteristic of an incompressible working fluid is shown to be either a great advantage or an insurmountable obstacle to the successful introduction of the principle. The desired efficiencies of water-wheels and motors are not realizable all along the line of their load variations. Consequently, at small loads, hydraulic gear will prove less efficient than somewhere near the maximum for which it was designed.

In fact, hydraulic motors are not so very different in their performance from turbine wheels. They may be designed to have maximum efficiency at almost any point, from half to full load. It is quite necessary to know at what point you are going to use the motor the most, in order to design it for that work at a given speed.

On the other hand, with a given motor it will be found possible to bring the point of maximum efficiency almost anywhere from half to full load, according to the relation between the best spouting velocity and speed. In the case of the Pelton motor, for instance, it has been found that the maximum efficiency is attained at or near the point where the circumferential velocity is 47 per cent. of the theoretical spouting velocity. So that with fixed head and given sized nozzle, fully open, it easy to determine at what speed you must run the motor in order to obtain the maximum efficiency at any given proportional part of the full load. At all loads under and over this, the efficiency falls so rapidly that it is likely to bring into disrepute the utilization of power transmitted by hydraulic pressure. The line losses, however, in such a transmission increase very slowly as the load is increased; so that up to the point of maximum efficiency of motor, increasing motor efficiency is met by decreasing line efficiency; and beyond, both motor and line efficiency fall off together. It is necessary to plot the curves to determine the resultant effect of these variable efficiencies throughout the range of loads.

Accumulator storage of water-power is coming into such extensive use that its installation requires a knowledge of its probable efficiency at various loads. One of the most complete series of tests was made at the Marseilles Docks, and quoted by Unwin, in his "Development and Transmission of Power." The efficiency of the storage reckoned from the indicated power of engine to work stored in accumulator, appears to fall off very slowly but almost uniformly from light loads to fully loaded condition. We required this information not long since, and were unable to obtain any data at all on the efficiency of accumulator storage, all of our representative builders reporting that no such tests had ever been made with their installations. Business competition and the demands for intelligent installation will certainly require future guarantees of performance in these pumping plants.

*Mr. Samuel Webber.**—I am very much obliged to Mr. Suplee for his addition to my reminiscences on the history of the turbine. Although I have enjoyed Mr. Geyelin's acquaintance, and I may say friendship, for fully twenty years, he had never mentioned this matter to me while discussing the subject of turbines; and the first horizontal shaft turbines of his, within my knowledge, were some he put in at Willimantic, some ten or twelve years ago, of which he sent me an illustration.

Professor Redtenbacher, of Carlsruhe, had put in a pair of Archimedean scroll wheels, on a horizontal shaft, prior to 1851, as stated by Professor Wedding; but these had no draft-tube and were simply "reaction wheels." Mr. Suplee does not say whether Mr. Geyelin's wheels had the draft-tube or not.

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* Author's closure, under the Rules.

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DCLXVI.*

WATER-POWER OF CARATUNK FALLS, KENNEBEC RIVER, MAINE.

BY SAMUEL McELROY, NEW YORK CITY.
(Member of the Society.)

In the winter of 1888–9 I made an examination of this power, on the Kennebec River, Maine, for some Boston capitalists, and, incidentally, of the power capacity of the river at and above Augusta.

Water-power being determined, in the main, by drainage area, rainfall, climate, relative storage, and local fall, from very careful statistics and examinations at my command I found the following conditions:

Catchment Basin.—The basin of the Kennebec is compact in form, bold in contours, abounds in lakes and forests, has a heavy and quite regular rainfall, a cold climate favorable to its stream flow, and is capable of large development in power.

The length of the river, from its head-waters of the "Moose" to "Moosehead Lake," is 72 miles; to Caratunk Falls, 137 miles; to Augusta, 184 miles; to the ocean, 227 miles. Its divides in the White Mountains rise to 3,113 feet above tide; Moosehead Lake being 1,023 feet, Caratunk Falls 316 feet, Skowhegan 220 feet, Kendall's mills 76 feet, Augusta dam 17 feet above tide.

The formation of the upper basin is granite, sandstone, and slate; thence to the ocean, mica-schist, clay, slate, and gneiss, as at Caratunk Falls.

The river basin is about 5,917 square miles. About 3,800 square miles are in forest.†

There are 311 lakes and ponds, somewhat more (311 to 290) than the mean lake distribution in the State; joint area, 450

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* Presented at the New York meeting (December, 1895) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

† In 112 miles to tide, the descent is 1,023 feet; about 9.1 feet per mile; a greater fall in a shorter distance than any other Maine river.

I am also in receipt of a letter from one fellow member, my friend Mr. John H. Cooper, asking me why I did not mention the "Pelton wheel"; to which my answer is, that I have never seen it, and only know of it by "hearsay." Nearly all the other wheels I have mentioned I have tested myself, and for those which I have not, I have the authority of either Messrs. Francis, Mills, or Thurston. I find that I also forgot to mention the "Burnham" wheel, very successful tests of which were witnessed by Professor Thurston and myself at Holyoke in 1872.

Mr. Cooper has kindly sent me a copy of the report of a committee of the Franklin Institute, published in their Journal for September, 1895, which gives the Pelton wheel a standing which certainly entitles it to a high mention; but as my paper was written the last of May it was impossible for me to use the information. I am very glad to read, in the supplement to the said report, the result of Mr. Cooper's own researches into the history of the "impulse" wheel, in Europe, and find the general confirmation of the now established fact that, in a turbine, "the water should enter without shock, and leave without velocity." Mr. Boyden explained this to me fifty years ago.

are here, then, a large natural pondage above the falls; a site already formed for race, wheel pit, and mills; a powerful fall on this immediate site, and an estuary directly obviating obstructions from flood back-water.

Area.—As outlined on the annexed map (Fig. 7), Caratunk Falls drains four great tributaries; the

Moose River	766.55	square miles.
Dead River	887.93	" "
Moosehead Lake	616.60	" "
Kennebec River	578.92	" "
Total	2,850.00	square miles.

The tributaries to the Augusta dam, below the falls, are the

Carrabasset	366	square miles.
Wesserunsett	167	" "
Sandy	666	" '
Sebasticook	1,088	" '
Total	2,287	square miles.

Rainfall.—From statistics collected by Henry Richards, Esq., at Gardiner, at the lower end of the river, the mean fall for 50 years—1839 to 1888 inclusive—is 44.494 inches. The quarterly season subdivisions show the usual uniformity; spring, 11.194 inches; summer, 10.550 inches; autumn, 10.500 inches; winter, 12.250 inches. The maximum fall in 1887, 54.64 inches; minimum, 1860, 33.71 inches.

Power Investment.—Without time to make a continuous gauge of the river, it was necessary to estimate its ordinary merchantable value, at this point, from a study of its hydrology. With 28 feet available flood fall (wheel-heads being usually reduced in freshets from back-water), and a mean rain of 44.494 inches, minimum 33.71 inches, on such a basin, a safe present plant outlay for 5,000 horse-power was determined from experience on this and other rivers.

There is sometimes a conservative and proper and sometimes an "intensely scientific" tendency to disparage stream flow for city supply and power use, because in every season there is a short time of extreme minimum flow, and at intervals a year of much reduced flow. A basin with a rain supply of 45 inches per year, or a mean of 3.315 cubic feet per second per day, may, for a few days, run as low as 0.22 cubic foot; the Kennebec sometimes down to 0.6 cubic foot for 20 to 25 days; the Merrimac, 0.31 cubic foot; Delaware, 0.30 cubic foot; Passaic, 0.22 cubic foot; Croton, 0.15 cubic foot. So the rainfall—with a mean for 50 years—on the Kennebec may vary from 54.64 inches, 1887, to 33.71 inches, 1890; but the mean of all the great basins shows these as exceptional years, with large flood waste in the wet months; which dictates the common sense of catchment and storage.

Authorities, like Professor Trowbridge, in "Water-Powers of the United States," p. 8, assert that the "total amount discharged by streams falls as low as 12 (0.885 cubic foot per second per square mile) or 15 inches (1.1 cubic feet) over the entire drainage basin, at intervals of from 5 to 10 years." Nothing can be clearer than the wisdom of adequate provision for exceptional years and weeks, but very great loss of mean available supply and power would follow the reduction of plant to extreme cases.

Merrimac River.—A carefully but not fully developed power like that of Lowell or Lawrence furnishes a valuable lesson.

At Lowell, with 4,085 square miles basin, with a mean of 44.89 inches rain, 19 to 27 years, an actual sale of standard power, on 33 feet extreme low-water fall, is about 3,596 cubic feet per second, or 0.8803 per square mile, for the usual working days of 11½ hours.

At Lawrence, with 4,553 square miles basin, the standard use is 4,200 cubic feet per second for the working day, the full day supply being a mean of about 2,400 cubic feet, or 0.5271 cubic foot per square mile per second, or 15.85 per cent. of the mean rainfall. Extra powers are largely furnished.

But the stream flow itself far exceeds this use, with rare cases below standard mill day supply; in 6 years no month below 2,400 cubic feet per day.

Dry month daily averages at Lawrence, in cubic feet per second:

YEAR.	May.	June.	July.	August.	September.	October.
1871	11.848	4.471	2.998	3.058	3.094	4.357
1872	9.260	10.528	4.922	9.014	9.559	9.164
1873	16.174	4.320	3.065	2.966	3.400	10.914
1874	19.091	11.230	11.126	5.389	3.152	3.195
1875	12.501	5.264	3.075	3.999	2.618	3.767
1876	17.398	6.792	2.994	2.791	.....	.....
Mean	14.328	7.161	4.697	4.356	3.637	5.233

For the storage control of daily supply ample provisions exist at each point; for that of minimum flow, ample and expensive provision has been, in 7 storage lakes of 103.48 square miles area, capacity of reserve, 7,483,283.544 cubic feet, on depths of 2 to 4 feet; but, while their existence doubtless regulates the river, their full use appears to be hampered by mills below them, so that practically little special use has been made of them. During these years—11 months in all—quantities 39 to 123 cubic feet per second; in one case, September, 1873, 277 cubic feet per second (Sudbury River case).

In these dry months the mean flow is 6,568 cubic feet per second, 1.442 cubic feet per square mile, 43.6 per cent. of the mean rainfall for these years. How much was wasted in the wet months is self-evident.

The Sudbury River, a contiguous basin, in 5 years, 1875–9, with about 78 square miles area, with a maximum rain of 57.93 inches, minimum 41.42, mean 47.68, gave actual measured flow of 49.94 per cent. mean, 57.9 per cent. maximum, 44.88 minimum.

The Mystic also, in 4 years, 1876–9, maximum rain 54.06, minimum 35.3, mean 44.86, gave 48.1 per cent. mean, 51.2 per cent. maximum, and 43.6 per cent. minimum.

The Croton, in geology and topography, better resembles the Kennebec. Its basin of 338.82 square miles, above the Croton dam, had a mean rain for 12 years, 1868–79, of 45.98 inches. Measured flow of "Boyd's Corner" basin, 20.57 square miles; mean, 70.98 per cent.; Croton dam, mean, 57.68 per cent.; lowest, 45 per cent. of 48.93 inches fall; highest, 74 per cent. of 50.33 inches.

The mean annual flow of the Connecticut is 1.86 cubic feet per square mile per second; Raritan, 1.72 cubic feet per square mile per second; Ramapo, 1.73 cubic feet per square mile per second; Potomac, 1.85 cubic feet per square mile per second.

Kennebec Power.—Applying these conditions, the relative value of the Augusta and Caratunk dams may be examined.

Augusta dam is 956 feet long, with a fall of 17 feet. It has a log chute on the east end, and a large mill on the west end, of 3,000 horse-power.

The measurements for low water show a mean in 1866, with 45.63 inches rain, of 2,916.6 cubic feet per second, or 0.494 cubic foot per second per square mile for July, August, and September.

I learned from an intelligent gate-house keeper, of long experito 0.6 cubic foot for 20 to 25 days; the Merrimac, 0.31 cubic foot; Delaware, 0.30 cubic foot; Passaic, 0.22 cubic foot; Croton, 0.15 cubic foot. So the rainfall—with a mean for 50 years—on the Kennebec may vary from 54.64 inches, 1887, to 33.71 inches, 1890; but the mean of all the great basins shows these as exceptional years, with large flood waste in the wet months; which dictates the common sense of catchment and storage.

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TABLE I.

Analysis of Mean Annual Rain, 1839 to 1888, 50 Years—Kennebec River, Gardiner, Maine.

Month.	Rain, Inches.	Rate per Annum, Inches.	Cubic Feet per Second per Square Mile.	Ratio Actual Flow, per cent.	Per Square Mile per Second.					
					Amount.	Days.	Above 50 per cent.		Below 50 per cent.	
							Per Day.	Per Month.	Per Day.	Per Month.
Jan.....	3.56	42.72	3.147	45	1.416	31	......	....	0.222	6.882
Feb.. ..	3.63	43.56	3.209	45	1.433	28	......	....	0.205	5.740
March..	3.98	47.76	3.518	90	3.145	31	1.507	46.717	......	....
April...	3.41	40.92	3.014	135	4.050	30	2.412	72.360	......	....
May. ..	3.82	45.84	3.377	75	2.530	31	0.892	27.652	......	....
June ...	3.27	39.24	2.890	60	1.734	30	0.096	0.288	......	....
July ...	3.38	40.56	2.988	45	1.344	31	......	....	0.294	9.114
Aug....	3.74	44.88	3.306	15	0.496	31	.....	....	1.142	35.402
Sept....	3.35	40.20	2.961	7.5	0.222	30	......	....	1.416	42.480
Oct.....	4.30	51.60	3.781	45	1.701	31	0.063	1.953	......	....
Nov....	4.30	51.60	3.781	67.5	2.529	30	0.891	26.730	......	....
Dec.....	3.75	45.00	3.315	90	2.967	31	1.329	41.199	......	....
Year. ...	44.49		3.277	60 50	23.592 1.966 1.638	365		216.899		99.618

TABLE II.

Kennebec River: Analysis Minimum Year, 1860, Gardiner, Maine.

Month.	Rain, Inches.	Rate per Annum, Inches.	Cubic Feet per Second per Square Mile.	Ratio Actual Flow, per cent.	Per Square Mile per Second.					
					Amount.	Days.	Above 60 per cent.		Below 60 per cent.	
							Per Day.	Per Month.	Per Day.	Per Month.
Jan.....	1.04	12.48	0.919	45	0.413	31	......	....	1.079	33.449
Feb	3.29	39.48	2.908	45	1.308	28	......	....	0.184	5.152
March ..	2.14	25.68	1.890	90	1.701	31	0.209	6.479	......	....
April...	1.31	15.72	1.158	135	1.562	30	0.070	0.210	......	....
May....	0.87	11.14	0.821	75	0.615	31	......	....	0.877	27.187
June . . .	2.36	28.32	2.086	60	1.651	30	0.159	4.770	......	....
July . . .	1.97	23.64	1.741	45	0.783	31	......	....	0.709	21.979
August .	4.70	56.40	4.155	15	0.623	31	......	....	0.869	26.939
Sept. ...	3.62	43.44	3.200	75	0.240	30	......	....	1.252	37.560
Oct. ...	3.80	45.60	3.359	45	1.511	31	0.019	0.589	......	....
Nov....	5.36	64.32	4.738	67.5	3.198	30	1.706	51.180	......	....
Dec	3.25	39.00	2.873	90	2.586	31	1.094	33.914	......	....
Year....	33.71		2.487	60		365		97.142		152.266
			1.492 ; 60 per cent.					63.8 per cent. of deficit.		

ence here, that in the lowest summer run of 20 to 25 days (common on other streams) the depth on the dam is about 6 inches, and the usual depth a foot, for the balance of the dry season, of about 80 to 90 days in all, before and after this reduction; and it was reported as exceedingly rare to have no flow on the dam.

With 3,000 horse-power in use, 6 inches flow equals 0.19 cubic foot per second per square mile, and the mill use, at 70 per cent. duty, is 0.4056 cubic foot, or a total of 0.5956 cubic foot per second. The usual use at Lawrence, very near stream low run, is 0.5271 cubic foot per second per square mile per day. A very low run August 21–26, 1876, gave 0.5 cubic foot.

The extreme low run assumed by State authorities ("W. P. Maine," p. 92) is 1,300 cubic feet per second, or 0.22 cubic foot per second per square mile. Applying this to the extreme year of 1860, the equation stands:

25	days at 0.22 cubic foot	5.50
60	" " 0.456 "	27.36
280	" (50 per cent. flow) at 1.2415 cubic feet	347.62
365		380.48

Per day, 1.042 cubic feet per second per square mile.

At one-foot flow (neglecting the waste at the log chute), the dam gives 0.538 cubic foot, and with the mill, 0.943 cubic foot per second per square mile.

The spring flood flow has been measured at 35,352 cubic feet per second for 5 feet depth on the dam, or 6 cubic feet per second per square mile. Other occasional floods have reached 7.1, and in one case 11.5 cubic feet. In these cases the flow is spasmodic, with a rapid rise for about 12 hours, a stand of 12, and a rapid fall.

The streams which supply this dam differ essentially in regimen. Those like the Carrabassett and Sandy, draining the 3,067 square miles below Caratunk Falls, are not well reservoired by natural lakes, and are subject to rapid rise and fall in heavy rains, while the basin above the falls abounds in such reservoirs, which greatly reduce flood waste and improve summer flow.

Caratunk Power.—In applying these observations to this fall, it is evident that its power conditions are much more favorable than Augusta, below it, or the Merrimac, at Lawrence.

To analyze the supply as to its capacity and as to its moderate mercantile value, basing one on the mean annual rain of 50 years, 1839 to 1888, and the other on the lowest record year, 1860, the following tables have been compiled:

and location, and with fivefold the proportionate storage reserve of the Merrimac, in a case where it seems to be little needed, from limited wheel use, this fall ought to command much greater supply in dry seasons.

It was evident, then, not only that this fall had a great prospective value which will place it in the front rank of great powers, but a present value, easily and cheaply developed, of not less than 5,000 horse-power, as a moderate result for full-power operation.

Site Advantages.—The rock gorge here, at and below the site of the dam, has unusual adaptation to cheap and strong dam, mill, and wheel-pit construction, and easy control of log chute and flood-wash by permanent masonry, while the formation on the east side is well adapted to store yards, employees' residences, and other structures. The completion of the Somerset Railroad to and across the falls relieved any question of easy and cheap receipt of machinery or supplies or delivery of products.

Improvements.—In the fall and winter of 1890–91 a dam was built by the Moosehead Pulp and Paper Company, under the superintendence of D. T. Mills, H. E., with a large pulp mill on the west side of the falls, intended to develop about 3,500 horse-power on that side. Three "new American" wheels of 850 horse-power each have been put in, 66-inch diameter; one "Special," 45-inch, 390 horse-power; a 16-inch "Electric," of 42 horse-power; and a pair of 13-inch horizontal, for a centrifugal pump of 80 horse-power, representing about 3,000 horse-power.

Measurements made through 1890, a very dry year, show a minimum flow of 6,000 horse-power (on 70 per cent. wheels), as reported to me.

Turbines.—The "centre vent," or "inward flow" wheel, with its carefully planned and adjusted scroll curbs and gates, has been the favorite of its class, originating in the "Wry Fly" of Benjamin Tyler, of 1804. Those of the "new American" type used here have shown high duty, especially in "part gate" work.

Tests at Holyoke, July 8, 1894, show results indicated as follows:

45″ "R. H." NEW AMERICAN TURBINE HOLYOKE TEST, JULY 9, 1894.

	Opening Per Cent.	Head.	Discharge Per Cent.	Revolutions Per Minute.	Cubic Feet Per Second.	Horse-power.	Efficiency Per Cent.
Maximum......	1.000	16.06	0.997	119.17	141.58	205.27	79.76
Minimum	1.000	16.13	0.983	127.75	140.02	200.04	78.26
Maximum.....	0.699	16.42	0.885	122.00	127.18	195.19	82.58
Minimum......	0.699	16.53	0.856	134.00	123.42	182.46	79.02
Maximum......	0.505	16.78	0.775	117.53	112.60	175.74	82.18
Minimum	0.505	16.86	0.725	133.50	105.56	154.51	76.71
Maximum......	0.382	17.03	0.661	111.83	98.12	149.99	79.31
Minimum......	0.382	17.24	0.621	136.25	91.40	129.87	72.82
Maximum......	0.293	16.88	0.563	113.67	82.07	118.40	75.52
Minimum......	0.293	17.04	0.521	145.50	76.19	89.15	60.67
Next	0.293	16.95	0.532	135.00	77.67	101.10	67.85

Relative Cost: Steam and Water-Power.—Estimates for cost of steam substitution are necessary in mill-power expert cases, and much difference of opinion is sometimes expressed.

Like all other engineering questions, this is to be determined by the principles involved, in which special local cases may differ, without affecting the general rule.

Obviously, power generated by the great steam-boiler of the globe itself, by which enormous bodies of water are precipitated on the earth, to seek sea-level under the influence of gravity, with a weight of 62⅓ pounds per cubic foot, is cheaper than ordinary steam-engine power.

There is also a material difference in plant cost between an 850 horse-power turbine fitted in place and an equal steam-engine plant in place.

There is also in attendance, wear, and other contingencies, insurance, etc., a material difference.

If, then, the location and the supply admit an economical application of power, all these conditions favor water-power.

In this case the outlay for dam, flume, head-gates, wheel-pit, etc., was about $15 per horse-power of 3,500 actually provided on the west side; the cost of wheels, for 3,000 horse-power, about $9, or $24 in all.

Similar steam-plant could not be furnished for less than $65 per horse-power, for boiler, engines, and buildings.

A fair estimate of its annual fixed expense is:

Depreciation, 4 per cent.; repairs, 4 per cent.; supervision, 1 per cent.; taxes, ½ per cent.; insurance, 1½ per cent.; interest, 5 per cent.; total, 16 per cent. on $65		$10 40

Annual operation for 3,000 horse-power, 300 full days per year (pulp mill), closely estimated:

Coal, 48 pounds per horse-power per day, 300 days, 14,400 pounds; 6.42 tons at $6		$38 52
Attendance, Engines	$10 00	
Boilers	18 00	
Cleaning	3 00	
Oil and Supplies	1 50	
	$32 50	
Three hundred days, $9,750 ÷ 3,000 horse-power		3 25
Total per horse-power		$52 17

Turbines, etc., fixed charges:

Depreciation, 2 per cent.; repairs, 2 per cent.; supervision, 1 per cent.; taxes, ½ per cent.; insurance, ½ per cent.; interest, 5, or 11 per cent. on $24	$2 64
Attendance per horse-power	2 00
Race, etc.	0 60
Total	$5 24

This shows, in a local case like this, a proximate comparison. Cotton and similar mills, unlike pulp mills, requiring careful heating, have in steam-plant the use of exhaust steam, and in other ways local cases will modify the results, but nothing can be more clear, in principle, than the superior economy of water-power *per se*.

As a practical comment on the cost of steam-power, the "Central Pacific" mill at Lawrence, with 29 mill-powers, or 1,740 horse-power in ordinary use, and with 1,000 horse-power steam-plant, has preferred to pay $12 per day per mill-power for surplus water, for months together, rather than run this expensive plant. This is about $50.40 per horse-power per year of 277 days.

The usual Lowell estimate of steam-power is $75 per horse-power per year, and $3 per week is the common price paid for it in New York and other cities where rented.

The Lowell rental of water-power at $1,200 per mill-power per year is for 277 days, $4.32 per day, or a mean of $20 per horse-power (shaft) per year.

Niagara Water-Power.—As a prominent instance of the superior economy of water-power in favorable localities, with economically constructed plant, the rates published for the New Hydraulic tunnel are for 5,000 horse-power or over, $10 per horse-power per year; 4,500, $10.50; 4,000, $11; down to small powers, 300, $21. On the old Hydraulic canal-powers have been leased as low as $4 for 600 to 1,000 horse-power, and $5.30 for 250 to 300. It is now proposed to furnish Buffalo with power at about $18, which now costs at least $50 for steam.

Commercial Value.—Lowell, with 4,085 square miles basin, worth, properly reservoired, at 50 per cent. 7,112 cubic feet per second, actually has sold and maintained as regular powers, 139.36 mill-powers, about 11,149 horse-power "penstock," and 8,363 "shaft," for which the rental value is about $1,200 per year per mill-power, or at 6 per cent., $20,000 capital, or $2,787,200. In addition there is a large sale of extra powers.

Lawrence, with 4,553 square miles basin, worth about 9,000 cubic feet per second, uses about 2,400 cubic feet (24 hours mean), and with 180 mill-powers now controlled, has maintained and sold 122, about 7,320 horse-power "shaft," worth at 6 per cent. capital, $2,440,000; and has also sold an average of about 20 extra powers, about 7 months' use, payment $1,280 (or $2,194 per year), or $21,336 at 6 per cent.; value $731,540; in all $2,866,720. In addition, there is a land income which makes the value of these powers about $35,000 to $40,000 each.

Controlling 180 mill-powers of 30 cubic feet per second, or a mean per day of 2,700 cubic feet, with a rainfall of 15,050, it can actually sell 18 per cent. of this mean supply on the entire basin without careful flood storage.

Anchor Ice.—In the second of the four modes of water motion, in which the particles move with the wave, in channel flow, there is a constant motion from the surface towards the bottom, proximating a cycloid curve, described by a point on the tire of a carriage wheel in motion. In very cold weather the effect is to submerge surface particles more or less below freezing temperature, and coming in contact with iron bars, valves, etc., a rapid accumulation of needle ice takes place when the stream surface near them is thus exposed; but when the current for some distance is protected from the air, the temperature is kept above freezing, and this action prevented. One sees in the races, above the mills in Maine, several hundred feet of floating, light, wood frames, intended to promote ice formation and prevent this surface-motion exposure.

At Caratunk Falls, the reach above the dam freezes for two miles up stream, with blue ice 24 inches thick, in winter; above this the stream is obstructed by this anchor ice, as it is below the falls, with an open stream, but this ice sheet effectually prevents it, and this suggests a valuable remedy for a very serious trouble on various rivers and races.

NOTE.—The Boston Sudbury River appropriation reduces the Merrimac basin about 78 square miles; and the Lowell and Lawrence statistics given in that case have been used as careful expert testimony.

DISCUSSION.

Mr. Wm. S. Aldrich.—The inward flow turbines of the "New American" type have certainly done well at Holyoke Testing Flume. Shortly afterward we obtained complete test sheets from the makers, copies of which we believe they were permitted to use in advertising their wheels. Analyses of the records of the 42-inch and 45-inch wheels were made, similar to that developed in the case of the 45-inch Hercules wheel, which formed the basis for determining the turbine performance in a former paper of mine, on "Power Losses in the Transmission Machinery of Central Stations."

Of the two "American" wheels, the best performance was shown by the 45-inch one. The maximum efficiency was attained, when the circumferential velocity of wheel was 70 per cent. of the theoretical spouting velocity of the water, at the following gates: 0.505, 0.699, and 1.00 per cent. of the full opening of the speed gate. At these gates the maximum efficiencies were respectively: 82.18 per cent, 82.58 per cent., and 79.76 per cent., as Mr. McElroy has given in his table, page 67.

We then reduced the performance of the 45-inch American wheel to a discharge basis, rating its performance at several proportional parts of the full hydraulic horse-power, upon the unit discharged at full gate and maximum efficiency. The whole purpose of this work was to determine at what proportional part of the full hydraulic horse-power the turbine gave its maximum efficiency at two selected speeds of 110 and 120 revolutions per minute. At the former speed this 45-inch wheel would do its best, with an efficiency of 84.6 per cent., when receiving 81 per cent. of the full available hydraulic power. At 120 revolutions per minute it would reach a maximum efficiency of only 81.5 per cent., and this when receiving 88.5 per cent. of the full available hydraulic power. Of course, and in the case of other prime movers, these curves may be plotted and the efficiency be obtained on the basis of the maximum obtainable brake horse-power—on the maximum output, instead of the input.

Rated on the basis of its maximum output, this 45-inch American wheel develops, at 110 revolutions per minute, a maximum efficiency of 84.6 per cent. when delivering 85.8 per cent. of its maximum possible horse-power at this speed. At 120 revolutions per minute it develops a maximum efficiency of 81.5 per cent. when delivering 92 per cent. of its greatest possible horse-power at that speed.

These ratings on the turbine output basis will be found especially valuable when planning the installation of electric plants to be driven by turbines. The builder of the dynamo states the speed at which his machine must be run, and asks you what is the maximum possible power you can ever expect to deliver to the dynamo. Turbines are prime movers with fixed maximum output, and in this respect differ from all others. With gate fully open and fixed head of water, giving maximum discharge, it would naturally be expected that these were the conditions for maximum delivered horse-power. But that depends upon the efficiency of the turbine at this point. Few turbines are working at maximum efficiency when developing their full power. We believe the best builders to-day recognize the value of wheels having maximum efficiency at part gate and therefore at some part load. Consequently, their performance must be analyzed and the efficiency curves plotted, for the given speed, on either hydraulic or brake horse-power—that is, on input or output base. From these may readily be found the greatest possible horse-power which the turbine can deliver at the given speed. This is the maximum input for the dynamo builder to figure upon. He has similar curves all worked out, or the data at hand for them, from the shop tests of all of his machines; so that the maximum horse-power which the dynamo will receive being stated, he will recommend putting in a dynamo which will be very largely overloaded at this point. Just what per cent. overload will be advisable, however, will depend somewhat upon the so-called "load factor" of the station, which it will be seen is a question to be settled very largely by the conditions of demand for electric power. Crompton introduced the term "load factor" to express the coefficient of fluctuation of rate of working. Unwin, in considering the influence of the variation of load on the efficiency of the plant, uses the load factor as the ratio of the average load during the day to the maximum load at any time during the day. Certainly the plant must be large enough for the maximum load. The importance of these considerations will be realized when planning turbine plants, which must of necessity have a certain fixed maximum delivered horsepower. Turbines cannot be overloaded like steam-engines, gas-engines, etc., using a compressible working fluid.

A Holyoke test gives such data that from that time forward the performance of that particular turbine is practically known for any given set of conditions. So accurately has the work come to be executed that the turbine is thenceforward its own water meter and dynamometer. But it will not enable one to predict the performance of another turbine made on exactly the same lines but another size. In the case of this 42-inch American turbine the plotted curves showed some erratic wanderings, compared with the 45-inch wheel. Still, for another 45-inch wheel, from the same patterns, the results would be found in very close agreement with the former test. In other words, each size and type of wheel should be tested at Holyoke, but not necessarily each wheel of the same size and type. It is best to guarantee the performance of turbine plants from actual tests of the turbines to be installed.

Mr. Charles T. Main.—I should like to correct some statements in connection with the "Central Pacific," mills now and for about fourteen years past known as the "Lower Pacific." What Mr. McElroy has said with reference to this mill is very ancient history. It refers to conditions existing over twenty years ago; at all events it must date back of 1875, for at this time the rate of $12 per mill-power a day was abolished, and at that time the mill did not possess an economical and adequate steam-plant.

After the rate of $12 per day a mill-power was abolished, the rates for surplus water in Lawrence were $4 a day a mill-power for 20 per cent. surplus, $8 between 20 per cent. and 50 per cent., and $4 over 50 per cent. In 1894 the rates were changed again to $4 a day up to 50 per cent. surplus and $3 for all over 50 per cent.

The lowering of rates speaks for itself. There was a reason for it, and the reason was simply that to meet present costs of steam-power it became necessary to make the reductions. The power owned by the mills has been paid for in part, but there is a perpetual rental which is supposed to amount to about $300 per year a mill-power or about $1 a day a mill-power.

The mills own eleven mill-powers or about 660 horse-power. The three water-wheels installed in 1883 will develop about 1,900 horse-power under twenty-eight feet head and in times of back-water much less. Two wheels only are run during ordinary stages of the river, the third being in reserve for back-water. The present engine was installed in 1885 as a cross compound with two cylinders with a nominal horse-power of 1,200. It was so designed that if future additions or changes should require more power, it could be made into a pair of tandem engines of 2,400 nominal horse-power. These two cylinders were added in 1891.

The total power required to run the mill is about 2,200 horse-power, showing that the engine must run, and it has run every day since its erection, and the amount of power which it develops is all that is required in excess of about 700 horse-power which is produced by the wheels. That it is cheaper in this particular case to run by steam-power than to pay the charges for surplus water I know from actual tests covering several weeks, ascertaining the costs under each set of conditions.

This is the more recent history of the use of steam and water-power at the Lower Pacific Mills. If any mill manager in Lowell thought to-day that his steam-power was costing him $75 a year a horse-power there would commence immediately an investigation to find out the cause. With compound condensing engine of 1,000 horse-power or thereabout and coal at $4.50 a ton, there is no good reason why the total cost of steam-power in mill-work per horse-power per year should exceed $25 for a fifty-eight to sixty hours a week run. The charges for small amounts of power produced or rented are no measure of the cost of the production of power in large amounts.

It may be possible that a power a long way off from the coal-fields may have great value for a special purpose, such as grinding pulp, where the raw material is at hand; but when its market value for other purposes is determined, it must be in comparison with the cost of power at some other equally good location for carrying on business where coal will not cost $6 a ton, but very much less.

Mr. M. P. Wood.—Mr. McElroy states that the cost of the Buffalo Steam-Power is $50 per year. This, I have seen detailed elsewhere, is for small plants under 500 horse-power, and is approximately correct. For large plants, 1,000 or over horse-power, the cost would be less; say $40 at the most. Good steam coal at Buffalo is rated at $1.50 per long ton in the report I have. I think Mr. Manning, agent of the Amoskeag Works, Manchester, N. H., who pays $4.25 to $4.50 for anthracite, and estimates his power in 1,000 horse-power units, for the same 10¼-hour duty would show a different result. In no estimates of the cost of steam-power have I ever seen any allowances for the cost of water, and the removal of the ashes included. To show how important these two items are in any estimate of the cost of power, I cite two cases in large manufactories at Scranton, Pa. (*Cassier's Magazine*, Industrial Supplement, p. vi., Nov., 1895.)

Cost of water	$2.34	$2.52
Cost of removal of ashes	2.45	0.95
	$4.79	$3.47

A fair estimate of the cost of these two items for compound condensing engines, and good boiler duty, is at least $2 per horse-power per year, and is as much a cost of the yearly cost of steam-power as the cost of the coal.

*Mr. Samuel McElroy.**—In reply to discussion points, it may be said, as to turbines, that analysis does not sustain the extravagant "table" duties sometimes advertised; and the reception, use, and delivery of water may each, if defective, reduce duty. Performance depends on weight of water applied; losses by friction, waste, and contraction of penstock, gates, wheel, or outlets; perfection of forms, materials, and workmanship; reduction of discharge velocity by absorption of power; and free tail race, or discharge outlet.

Weisbach makes the minimum of these losses 17 per cent. (overshot); Trowbridge, 16 per cent. (turbines).

As between the Fourneyron "outward flow," Jonval "parallel flow," or American, Swaine, etc. "centre-vent," the first have been less effective on "part gate," in a case where the concen-

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* Author's closure, under the Rules.

trated and continuous line of water motion is an important principle of economy.

As to the notes used for Lowell and Lawrence, referred to by Mr. Main, government reports, so recent as 1885, do not show any increased development of power; and an expert, naturally, in quoting estimates, will prefer to use carefully prepared, sworn testimony of selected witnesses, as was the case in the "Sudbury" appropriation for Boston.

As to the "Central Pacific" mill, so prominent a local authority as H. F. Mills, C. E. (p. 73), says: "This conclusion I did arrive at, that it was better for *the mills* (not one alone) to pay $12 per mill-power per day than to start their engines," and he, afterwards, gives that special case as occurring "months together." Where I took the rate at $4.32 for that date, Mr. Main gives it for 1894, at $4 (up to 50 per cent. surplus).

The same authority takes the cost of coal there at $7 per ton; F. W. Bacon (p. 250) makes coal at Caxonville $8 per ton.

As to the cost and operation of steam-plant, estimating at the great factory and coal centre of New York, an expert like Dr. Charles E. Emery, A. I. E. E., March, 1893, puts the cost of about 550 horse-power engines, high speed condensing, $54.71 per net horse-power; low speed, $59.51; compound low, $60.35; triple compound, $68 to $73; and the operation, respectively, 365 days, 20 hours, coal $5, at $66.55, $62.21, $57.35, $52.38, and $50.56.

I preferred to use a more conservative estimate, since the superior economy of water-power, *per se*, is a principle of very "ancient history."

DCLXVII.*

RECORDING DEVICE FOR TESTING MACHINES.

BY G. W. BISSELL, AMES, IOWA.

(Junior Member of the Society.)

IN Figs. 8, 9, and 10, accompanying this paper, are shown views of an autographic recording device attached to a 50,000 pound Olsen testing machine. Fig. 8 shows the instrument arranged for obtaining a record of either a transverse test or a punching test, or any other test in which the movement of the movable head of the testing machine may be taken without gross error as equal to the deformation of the test piece. *A* is a drum about 6 inches in diameter and 7 inches long, hollow, and supported on pivot bearings so as to rotate truly about its geometrical axis. The pivots are supported in the frame *B*, shaped from sheet steel, and bolted to the frame of the testing machine as shown. This frame *B* also serves to support a rod *C*, upon which slides freely the pencil carriage *D*, from which projects the pencil arm *E*, in

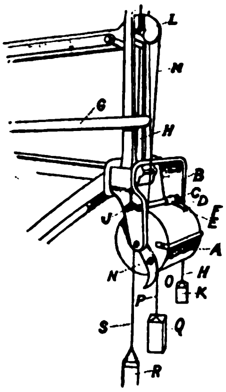

FIG. 8.

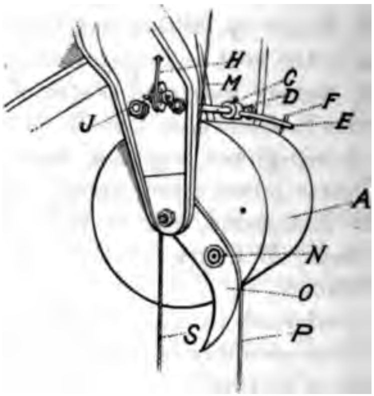

FIG. 9.

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* Presented at the New York meeting (December, 1895) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions.*

the end of which is the pencil point *F*. The rod *C* is parallel to the axis of the drum. Consequently the motion of the pencil is parallel to the axis of the drum. The motion of the pencil is obtained from the lever *G*, which is a simple multiplying lever, its ratio of multiplication depending upon the location of a knife edge fulcrum, not shown in Fig. 8, placed between the moving head of the testing machine, and the point of attachment to *G* of the cord *H*, which passes over a guide pulley *J* and another guide pulley on the frame *B*, not shown, and provided with a weight *K* to maintain the cord taut. This cord passes through a clamp on the pencil carriage, thus giving to the carriage the motion of the end of the lever *G*. The motion of the drum *A* is obtained from the scale beam *L* of the testing machine, the poise of which is set at zero, by means of a wire *M* fastened to

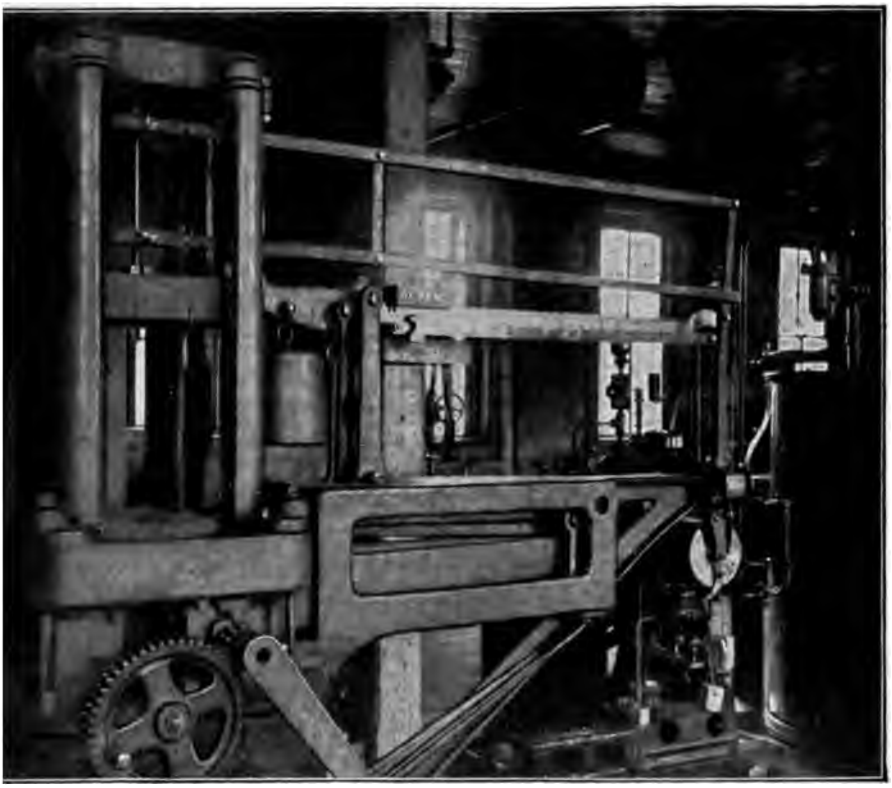

FIG. 10.

the end of *L*, which drops vertically from its point of attachment to *L* and passes around and is fastened to a grooved pulley concentric with the axis of the drum, and rigid in relation to the drum. Secured to the end of the drum by its axis and a thumb, screw *N* is a cam *O*, having in its edge a groove to receive a wire *P* carrying a weight *Q*. The shape of this cam is such that the

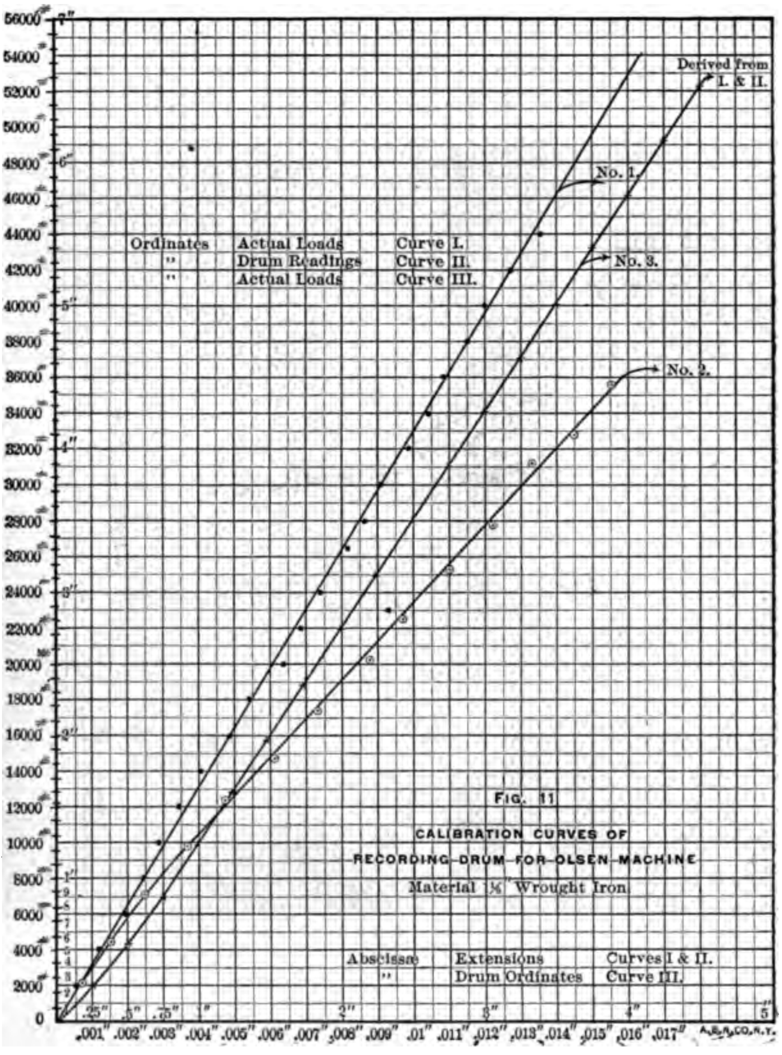

FIG. 11.

angular motion of the drum is exactly proportional to the motion of the end of the scale-beam *L* between its stops, the assumption being made that the leverage of the testing machine is constant during the small arc of vibration of the scale-beam. The weight *R* is attached by means of the cord *S* to a small grooved pulley upon the axis of the drum and serves to balance the weight *Q*. The drum *A* is provided with clips for holding the paper, as shown. Although the cam was laid out with very great care, it was deemed best to calibrate the device, and this was done as follows: A piece of wrought iron of such size that it could not be strained beyond its elastic limit by the full power of the testing machine was placed in the testing machine and fitted with micro-electric extensometers as if for taking observations within the elastic limit in a standard tension test. A series of observations of loads and extensions was then taken very carefully, the recording device being detached. A curve plotted from these observations is shown in Fig. 11. Then the recording device was attached, the poise of the machine was set at zero, and the same test piece was again stretched slowly and by such increments as to give as nearly as possible for each such increment a motion of one-quarter inch to the paper on the drum, the pencil being drawn by hand for each such increment, and corresponding micrometer readings being taken. The curve plotted from these observations is shown in Fig. 11; from these two curves a third is easily produced, showing the relation between loads and the ordinates on

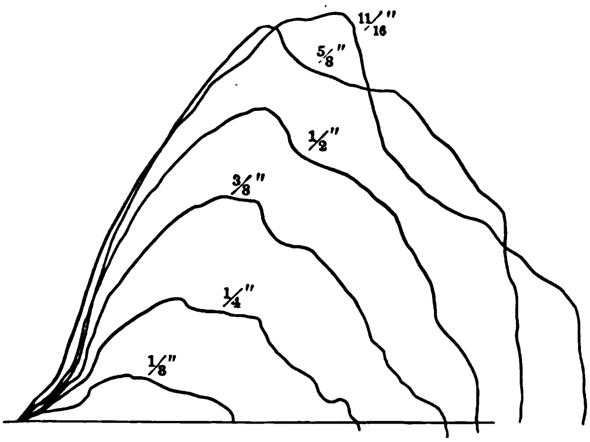

FIG. 12.

the paper. The weights R and Q, in use at present, give a diagram about 5 inches high for the full capacity of the machine. For lighter work, smaller weights R and Q could be used to advantage. Fig. 10 shows the method employed in getting autographic records of tension tests. The elongations are multiplied by two as the apparatus is now arranged. A greater degree of magnification necessitates a longer drum. Fig. 12 shows a series of diagrams obtained by putting a three-quarter inch spiral punch through plates of wrought iron, ranging in thickness from one-eighth inch to eleven-sixteenths inch.

DCLXVIII.*

TESTS OF A TEN-HORSE-POWER DE LAVAL STEAM TURBINE.

BY WILLIAM F. M. GOSS, LAFAYETTE, IND.
(Member of the Society.)

THE de Laval steam turbine experimented upon constitutes a part of the permanent equipment of the Engineering Laboratory of Purdue University, and the present paper is based upon data secured chiefly through the assistance of Charles E. Bruff, B.M.E.†

I.—DESCRIPTION OF THE ENGINE.

In the de Laval steam turbine, jets of steam, delivered from suitable nozzles, are made to impinge against the buckets of a light turbine wheel. The steam enters the buckets from one side of the wheel, and passing through, is discharged or "exhausted" from the opposite side. The arrangement of nozzle and wheel is shown by Fig. 13. The motion of the turbine shaft, which, under the action of the jets, is extremely rapid, is communicated by gearing to a heavier and slower-moving driving shaft carrying a fly-wheel of small diameter; from this wheel the power of the engine is delivered. Regulation of speed is secured by means of a throttling governor, which controls the pressure of the steam admitted to the nozzles.

The important moving parts, with approximate dimensions, are shown by Fig. 14. The turbine wheel is built up of sixty-three steel segments, each carrying a bucket and a portion of the light outside rim. The segments are held in place by means of suitable collars, which grip them on either side. The wheel is

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* Presented at the New York meeting (December, 1895) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

† "Tests of a Ten-Horse-Power de Laval Steam Turbine," a thesis by Charles E. Bruff, 1895.

mounted upon a long, slender shaft, having sufficient flexibility to allow the system at speed to revolve about its centre of gravity, even though this may not agree with the geometrical axis of the shaft. The gear upon the turbine shaft is of steel, solid with the shaft; that upon the drive shaft has its teeth formed in a bronze ring, which is carried by a solid iron centre. The smaller gear has twenty-one teeth, the larger one two hundred and eight teeth, giving a ratio of 1 to 9.90476.

The shafts run in bronze boxes completely lined with babbitt or other soft metal. To assist in the distribution of oil a spiral curve, the pitch of which is about half the diameter of the journal, is cut into the metal of the bearing. The outboard bearing on the turbine shaft is closed at the end, and a small pipe runs from the closed end to a point over the gears. The pumping action, resulting from the presence of the spiral oil-way, gives a constant, though small, supply of oil upon the gears. The gears do not dip in oil, though the case which encloses them receives drainage from all the bearings.

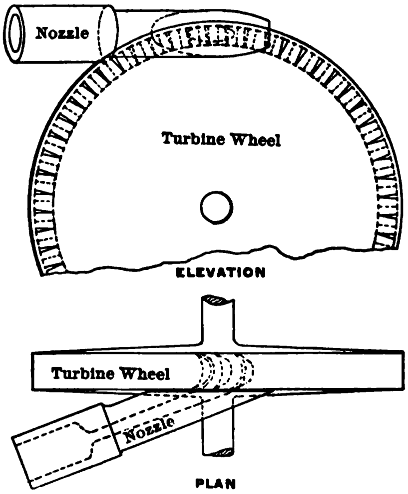

FIG. 13.

The governor is connected with the driving shaft, of which, at first sight, it appears to be but an extension. It is shown in detail in Fig. 14. The weights, *WW*, with their arms, *CC*, are in the form of a split cylindrical cup. Upon the outside and at the base of each weight a knife edge, *EE*, is formed, which bears

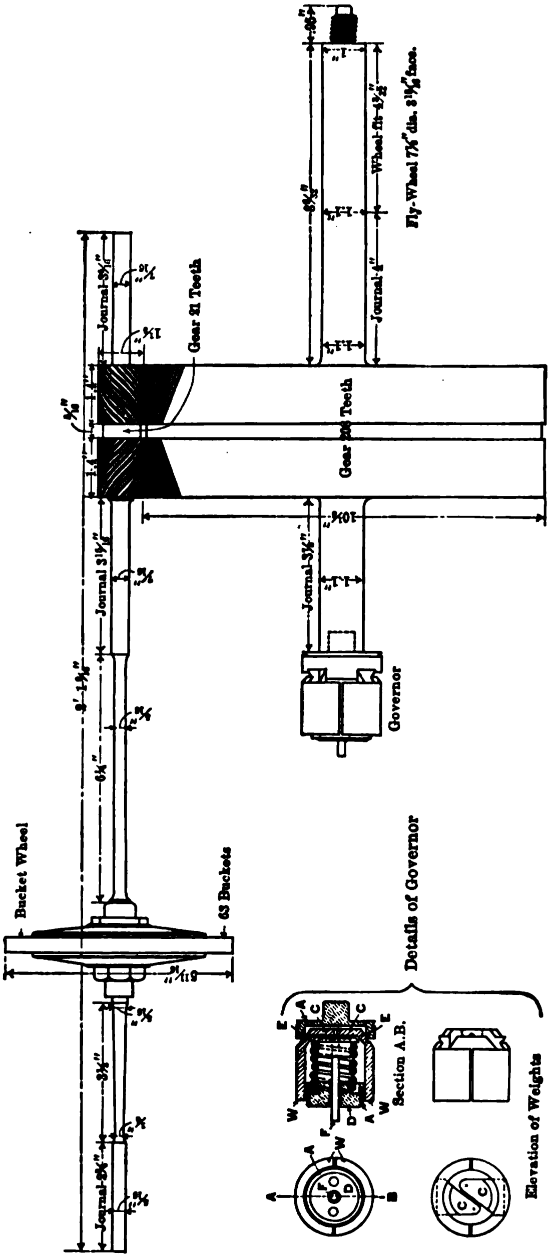
Bucket Wheel
63 Buckets
Gear 21 Teeth
Gear 206 Teeth
Governor
Fly-Wheel 7⅞" dia. 3 1⅝" face.
Wheel-fit
Journal
Details of Governor
Section A.B.
Elevation of Weights
A
B
C
D
E
F
W

FIG. 14.

upon a suitable surface in the governor frame, *AA*. A spiral spring is fitted at its inner end with two projecting pins, which bear upon the arms, *CC*, of the governor weights. The outer end of the spring is connected with the frame by the threaded plug *D*. When the governor is at rest the concave surfaces of the weights are in contact with the frame, and the tension of the spring keeps the knife edges upon their seat. When the governor is revolving at speed the weights are under centrifugal action and move outward, swinging upon their knife edges, against the resistance of the spring. The motion of the weights is taken up by the pin *F*, by which it is communicated, through suitable mechanism (not shown), to the governor valve above the engine.

The nozzles which serve to deliver steam to the wheel are four in number, and are so fixed in the frame of the engine as to act upon the turbine wheel at points which are equally distant from each other. Two of the four are provided with stop-cocks, which, when closed, put out of action the nozzles with which they are connected. By means of the stop-cocks, therefore, the engine may be run under the action of two, three, or four nozzles, at the will of the engineer.

The distinguishing feature of the engine, perhaps, is to be found in the form of the nozzles. All are diverging, the throat or smallest diameter being approximately 2 inches from the discharge end. Three have a diameter in the throat of 0.138 inch, and one a diameter of 0.157 inch.

It is assumed that the form of the nozzles is such that the pressure of the steam as it passes from the orifice will be that of the surrounding medium, and, since the flow is nearly adiabatic, it is clear that if this condition is realized all the energy of pressure is transformed into energy of motion before the steam is allowed to impinge upon the buckets of the turbine wheel. The medium surrounding the nozzles in the machine is practically that of the exhaust, so that the expansion from the pressure of the boiler to that of the exhaust is complete before the steam has contact with any moving part of the machine.

Lateral motion of the driving shaft is limited by contact between the large gear and the bearings on either side. With this shaft fixed, the double spiral of the gears makes lateral motion of the turbine shaft impossible. All forces, therefore, tending to displace the turbine wheel laterally are transferred to the slow-moving shaft, where ample rubbing surfaces can be provided without seriously impairing the efficiency of the machine through frictional losses—a happy solution of an otherwise difficult problem. When it is remembered that the parts shown (Fig. 14) are those of a machine capable of developing 10 horse-power, that the driving shaft under normal conditions makes 2,400 revolutions a minute and the turbine shaft practically ten times as many, the opportunity for the display of good design and workmanship may be better appreciated. Viewed as a piece of mechanism, the engine tested appears to merit high commendation, both as to design and workmanship, but the service which has thus far been obtained from it is not sufficient to show the effect of long-continued use.

II.—THE TESTS.

Arrangements for Testing.—Fig. 15, from a photograph, shows the engine with its auxiliary apparatus. The power of the engine was absorbed by a Prony brake, cooled by constant streams of water. The exhaust steam was piped to a Wheeler condenser, open to the atmosphere. The water resulting from condensation was drained into tin buckets, which were changed and weighed at regular intervals.

Gauges were used to show the steam pressure both above and below the governor throttle, the former giving the pressure available at the engine, and the latter the pressure under which, in consequence of the action of the governor, the steam was admitted to the nozzles. A manometer was also attached to the exhaust pipe, but as this pipe is large (3 inches diameter) and the connection with the condenser close, the observed pressure was never appreciably different from that of the atmosphere.

Conditions and Results.—The boiler pressure for all efficiency tests was 130 pounds by gauge, for which pressure the particular nozzles used were designed. The rated speed of the fly-wheel is 2,400 revolutions per minute (23,771 for turbine wheel), but this standard was not maintained for all the tests. The governor was adjusted several times as the work progressed, and it was not until several tests had been run that the proper speed was secured. It is believed, however, that the differences of speed recorded do not materially affect the value of results for purposes of comparison.

The tests are grouped into three series, the first including those for which all four nozzles were in action, the second those with three, and the third with two. The several tests in each series were intended to vary from each other only in amount of power delivered from the wheel. All tests were of thirty minutes' duration, and all observations were taken at five-minute intervals.

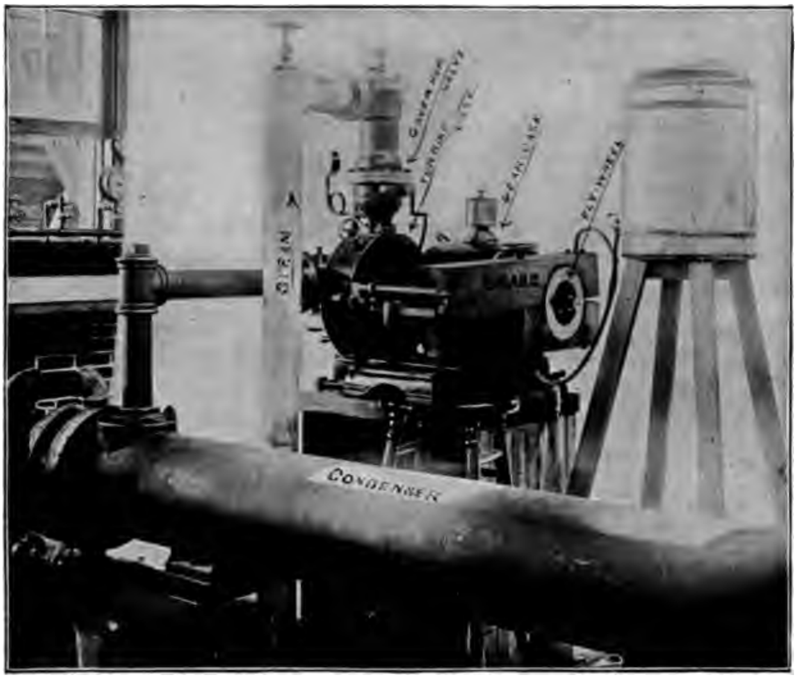

FIG. 15.

The conditions of each test were maintained with such uniformity that the observations of any five-minute interval were very nearly identical with the average of all observations taken for the test.

The observed and calculated results appear in tabulated form herewith (Table I.):

TABLE I.

A SUMMARY OF RESULTS OF TESTS.

Nozzles.	Number of Test.	Revolutions per Minute of Belt Wheel.	Brake Horse-power.	Steam Pressures by Gauge		Total Pounds of Steam per Hour.	Pounds of Steam per Brake Horse-power per Hour.
				In Boiler.	In Engine below Governor Valve.		
All four nozzles in action, three having a diameter in throat of 0.138 inch and one a diameter in throat of 0.157 inch.	1	2138	**0.00**	130	17.1	120.8	.....
	2	2545	**1.63**	130	42.2	210.3	**128.6**
	3	2038	**2.36**	130	48.5	230.8	**99.8**
	4	2118	**2.97**	130	55.6	254.6	**85.7**
	5	1917	**3.46**	130	61.9	275.5	**79.6**
	6	2072	**4.38**	130	70.8	313.0	**71.5**
	7	2128	**5.10**	130	76.9	328.5	**64.4**
	8	2576	**7.52**	130	99.6	403.0	**53.6**
	9	2453	**8.24**	130	104.4	422.8	**51.3**
	10	2411	**10.33**	130	126.3	491.8	**47.8**
Three nozzles in action, two having a diameter in throat of 0.138 inch and one a diameter in throat of 0.157 inch.	11	2584	**0.00**	130	31.3	121.4	....
	12	2112	**3.95**	130	83.6	267.8	**67.8**
	13	2125	**4.77**	130	93.4	286.0	**60.0**
	14	2490	**6.50**	130	111.7	346.3	**53.3**
Two nozzles in action, each having a diameter in throat of 0.138 inch.	15	2546	**0.00**	130	42.2	99.3	.....
	16	2049	**1.95**	130	83.5	162.6	**83.4**
	17	1909	**3.43**	130	121.1	222.9	**65.0**
	18	2412	**3.87**	130	127.0	229.6	**59.3**

It will be seen that, with all four nozzles in action, and with the engine developing a little more than its rated power, the steam consumption per horse-power per hour is as low as 47.8 pounds. In comparing this result with results obtained from other engines, the small size of the engine tested (10 horse-power) should be kept in mind, and also the fact that the rate of consumption stated is based upon brake-power. The efficiency of the engine falls off rapidly as the load is decreased, and, as would be expected, the effect is most marked when all the nozzles are in action. This may best be seen by means of the three heavy-lined curves given in Fig. 16. Assuming the nozzles to be cut out of action one at a time, as soon as the reduction of load becomes sufficient to permit the work to be done without them, the minimum steam consumption at different loads, for the boiler pressure and speed employed, is represented by the broken line *fgdebc*, Fig. 16. Again, if, instead of four nozzles, an infinite number could be employed, and if the governor could be arranged so as to regulate the number in action, rather than the pressure admitted to them, the steam consumption of the engine in question might be made to follow a line somewhat similar to the light broken line *gec*. But the heavy lines indicate the results which were actually obtained.

The engine requires very little attention and is almost noiseless in action. The governor is quick to act. and its speed regulation appears to be fair, except when changes of load are large and suddenly made. After such a change, the engine requires a little time before settling down to steady running under the new conditions.

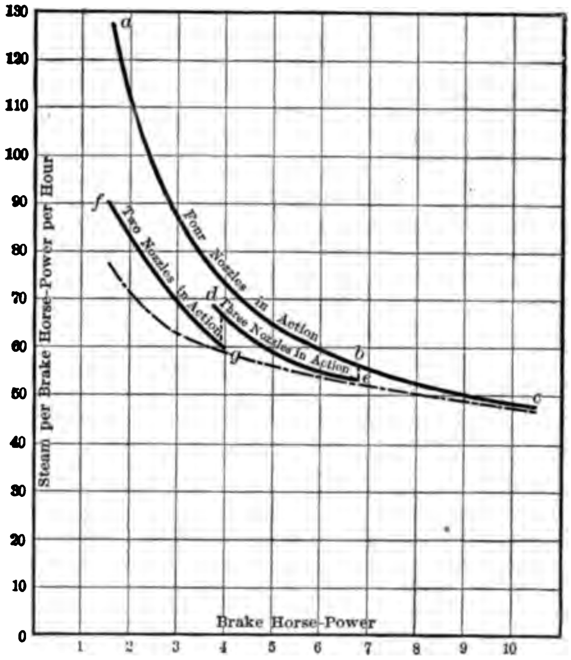

FIG. 16.

Starting-Power.—As the speed of the de Laval engine is high, it is evident that the force in action must be comparatively low. To determine the maximum resistance under which the engine might be expected to start, the brake was clamped upon the fly-wheel so that the latter could not turn within it. Steam was then admitted to the engine, and readings were taken from the scale under the brake arm. The result of this process, of course, depends upon the steam pressure and the number of nozzles in action. With all nozzles, and with a steam pressure of about 125 pounds by gauge, the maximum starting-power is equal to a force of 30 pounds acting at a radius of one foot. The following tabulated data (Table II.) gives the starting-power for different pressures, and when two, three, or four nozzles are in action.

TABLE II.

STARTING-POWER OF ENGINE.

	Four Nozzles in Action.		Three Nozzles in Action.		Two Nozzles in Action.	
Steam pressure by gauge	125.2	71.1	125.2	71.1	125.2	71.1
Effective radius of brake arm, feet	1.5	1.5	1.5	1.5	1.5	1.5
Reading of scale under brake arm, lbs.	20.0	12.1	14.1	9.0	9.5	6.0
Equivalent force in pounds, acting at a radius of one foot	30.0	18.2	21.2	13.5	14.3	9.0

DISCUSSION.

Mr. William S. Aldrich.—These tests, we believe, are the first which have been made on this steam turbine in this country. They have certainly been made with great care ; and, when the size of the machine is considered, the results compare favorably with those which have been obtained by Prof. I. E. Cederblom, of the Polytechnic College, at Stockholm, Sweden. The latter were from a 50 horse-power de Laval steam turbine, working from 108 to 122 pounds, gauge pressure, steam condensed by a Korting ejector condenser maintaining a vacuum of about twenty-six inches of mercury, and developing an average of 63.7 brake horse-power, with a steam consumption of 19. 73 pounds per brake horse-power per hour. This performance, when the turbine was developing over 25 per cent. of its rated load, will be seen to be at a more favorable point than the rated capacity, upon an inspection of the curve given in Professor Goss's paper. In other words, successively overloading the turbine results in a regularly decreasing steam consumption. This is a very important point and contrary to the [illegible] steam engine, in which Willan's law is [illegible]ptions, even at constant speed.

The total steam consumption, pe[illegible] plotted on the same base, of the brake horse-power, as given in Fig. 15. All of the plotted points fall so near a straight line that one is inevitably drawn into making the conclusion that the divergences above and below the straight line can be accounted for as errors of observation. We have taken the points for the run with four nozzles. The range of values in the other cases is not sufficient. We believe that this series of values given by Professor Goss furnishes the first graded determination of the performance of a steam turbine by which we are enabled to predict its fulfilment of Willan's law. That is to say, the curve of steam consumption, for the run with four nozzles, as plotted in Fig. 15, is practically an equilateral hyperbola.

It is not well to be hasty in drawing conclusions, especially from the first of a series of values. But, if we mistake not, the law will hold good for any steam turbine if it will hold good for this one. They have the one characteristic in common of using the working fluid continuously, and not intermittently, as in the ordinary steam engine. We think it therefore not illogical to paraphrase Willan's law, and say that, in the case of a steam turbine at a constant speed, the total weight in pounds of steam used per hour is given by a linear equation of the form,

$$w = a + b \times \text{brake horse-power}.$$

The constants a and b may be determined from any two runs of the series. We are aware that Willan's law is usually applied to the indicated horse-power; but this would only change the nature of the constants, in almost all cases of the ordinary steam engine, and cannot be applied in case of the steam turbine till we have some way of obtaining the indicated horse-power.

Noting Fig. 15 again, it will be seen that, for the case of the present turbine, of 10 horse-power rated capacity, the base may readily be converted into "per cent. brake horse-power." Steam consumption curves, plotted on this base, are well known to show the inherent rapidity of increase of steam consumption, at light loads. So that we are obliged to look at the light-load end of the curves to the disadvantage, apparently, of the turbine, because we cannot plot the same on the usual "per cent. indicated horse-power" base. Still its showing is not at all discreditable. It shows clearly that the increase of steam consumption per horse-power at light loads is much less than with ordinary steam engines, a feature which has previously been pointed out in connection with Ewing's tests of Parsons's steam turbine. This is not so very remarkable as it may appear, when we consider the regulation, by throttling, and the practical uniformity of the rate of flow of steam for the usual range of working pressures.

The flow of steam, as may be seen by examining Table I., is in close agreement with what is known as Napier's approximate formula; that is, that the weight of steam discharged from an orifice or tube, per second, is approximately equal to the area of the orifice in square inches, multiplied by the absolute pressure per square inch of the higher pressure, when discharging into a lower pressure, less than three-fifths of the higher. It is to be noted, also, that the difference of pressures was increased, in these tests, by raising the higher. The results agree with boiler practice, in which the flow increases into the atmosphere as the pressure in the boiler is increased. But the area of discharge orifice is not that which should be taken from the diameters, but some sectional area beyond the throat sections of the nozzles. Where to take this section still remains to be determined. What we wished to point out, however, was that in the case of a steam turbine it is its own meter of steam consumption, so to speak, as soon as we have recorded its performance through a range of values such as Professor Goss has here given us for the De Laval turbine.

The steam turbine which has been tested like this one becomes its own dynamometer also. For we may standardize it at constant speeds by such a test as this, determine the constant which it is necessary to use in connection with Napier's formula, thence determine the total steam used, under the given speed conditions and absolute pressure, from which we may determine the brake horse-power by the application of Willan's law. In short, after such a test as this, we are enabled to determine the brake horse-power from the reading of the steam gauge below the governor valve, and a tachometer on the shaft. At constant speed the record of a recording steam gauge, if integrated, would give the average for variable loads.

We should like to know the quality of the steam in all of this series of tests, however. No separator was used in these tests, nor calorimeter to determine quality of steam after passing separator and before entering nozzles. Will not the entrained water and that due to condensation during the assumed adiabatic expansion have the same effect as in a water turbine?

A series of runs, also, at regularly varied speeds, with other conditions constant, would give valuable data for further analysis of this interesting steam turbine.

This form of the turbine, that of the axial jet type, has been pointed out by Weisbach as having considerable loss due to the oblique impact of the stream line, in case of water. We believe the tangential type, similar to the Pelton wheel, will be finally adopted for this work. The form of nozzle must evidently be changed, to give a solid stream line for the issuing steam; this form has already been shown by Mr. Strickland L. Kneass, in his studies of the injector. The same is given by him in discussing Professor Webb's Paper: "Performance of a Steam Reaction Wheel."* If we accept the analogy between the steam turbine and water turbine, which Professor Webb has also pointed out in another former paper, "Note on

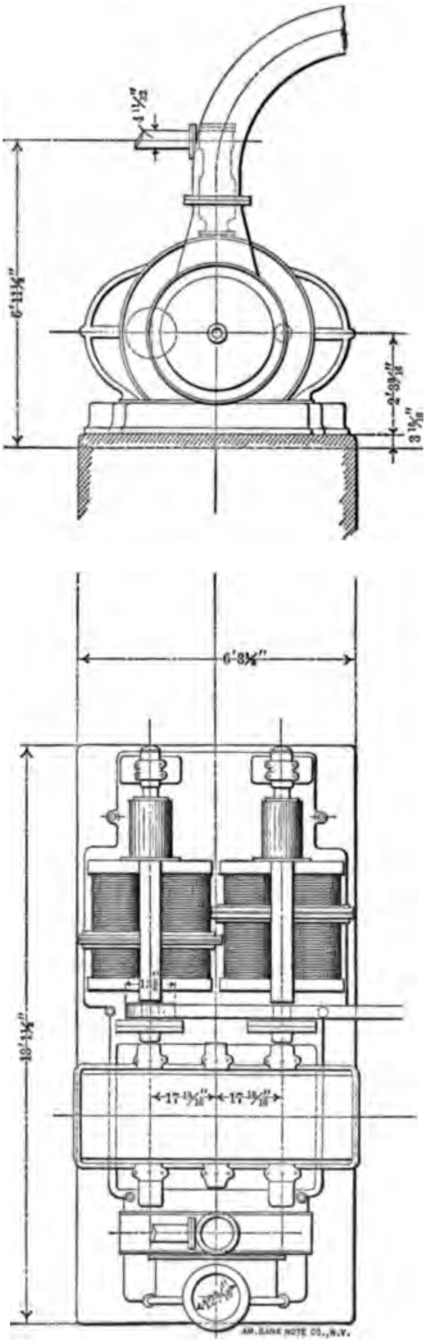

FIG. 17.—300 Horse-power De Laval Steam Turbine. Maison Breguet, Constructor, Paris.

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* *Transactions A. S. M. E.*, vol. xii., p. 897.

the Steam Turbine," * it would appear that we might determine the theoretical horse-power, from the equivalent gravity head of the weight of steam discharged, by Napier's rule. Though we must proceed with care in use of hydraulic analogies; for steam does not, like water, flow from an orifice with a velocity due to its gravity head.

Mr. J. W. Lieb, Jr.—It may be of interest to the members to learn that in a few weeks the Edison Electric Illuminating Company of New York will have in operation at one of its stations two 300 horse-power de Laval steam turbines with attached dynamos (Fig. 17). These turbines were built by the Maison Breguet, Paris, and are now on their way to this port. They were ordered under guarantee to comply with the following specifications:

Each 300 horse-power turbine is to drive two Desroziers dynamos, each of 100 kilowatts (133 horse-power) capacity. The turbine shaft is to run at 13,000 revolutions, driving at a speed of 1,300 revolutions, by means of helical gearing, two dynamo shafts situated on either side of the turbine shaft. Each dynamo is to be capable of generating continuously without undue heating 770 amperes at 130 volts, or 625 amperes at 160 volts. If the turbines are built to be operated either condensing or non-condensing, as a mongrel type, with a steam pressure of 10 kilos per square centimeter (142 pounds per square inch) at the throttle, and with a vacuum of 65 centimeters at the condenser, the steam consumption per brake horse-power is guaranteed not to exceed 8½ kilos (18.7 pounds); with a free exhaust the steam consumption is not to exceed 16 kilos (35.2 pounds). If it should be contemplated to operate the turbines ordinarily with a condenser, the guaranteed steam consumption will be reduced to 7½ kilos (16.5 pounds) per brake horse-power. In this case the turbine disk would have a diameter of 0.75 meter (29 inches), instead of 0.50 meter (19⅝ inches) for the mongrel type.

We hope at some future time to present to the Society for discussion the results of the test we shall make on these units under various conditions of load and steam pressure. The principal dimensions of the unit will appear from the accompanying general plan drawn to a scale $\frac{1}{20}$. The general plan of a 600 horse-power Parsons turbine, as proposed to the New York

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* *Transactions A. S. M. E.*, vol. xii., p. 888.

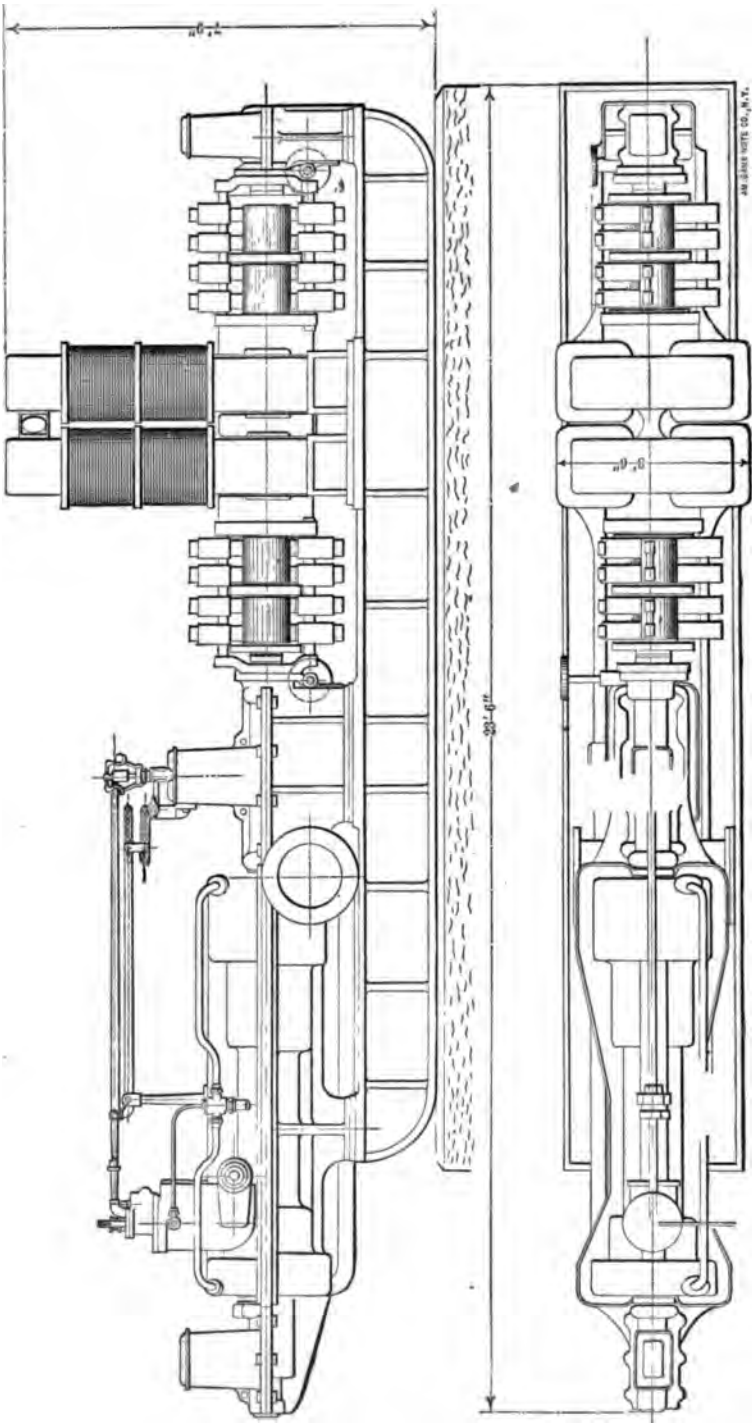

FIG. 18.—600 Horse-power Parsons Turbine. By C. A. Parsons, Newcastle.

Illuminating Company by C. A. Parsons & Co., of Newcastle-on-Tyne, is also submitted (Fig. 18).

Mr. George I. Rockwood.—The principles involved in the construction of one of these turbines of such large power as three hundred horse are not different, I believe, from those governing the construction of the little machine tested by Professor Goss, so far as economy in operation is concerned; that is, the case should be different from that of the reciprocating steam engine, in which, from purely geometrical considerations, the small engine will inevitably be less economical of steam than the larger engine. Though I am not informed about this, yet I suppose the speed of the buckets is the same for any size of turbine. At any rate, if I am correct in my premise that large turbines are no more economical than small ones, then it seems as if Professor Goss's experiments give but small promise of the fulfilment of the guarantee of nineteen pounds made to the Edison company by the foreign builders.

Possibly the investment in de Laval steam turbines may be justified if their use is confined to carrying the heaviest portions of the total load during the usually short periods when the station is called upon to put forth its utmost energy; but I do not suppose that the advantage is so apparent on average running loads.

DCLXIX.*

EXPERIMENTS ON THE FRICTION OF SCREWS.

BY ALBERT KINGSBURY, DURHAM, N. H.
(Member of the Society.)

WITHIN the past three years the writer has made several hundred experiments on the friction of metallic screw-threads under the conditions of very slow motion, free lubrication, and pressures varying from zero to 14,000 pounds per square inch of bearing surface.

The results sought were the minimum and the mean coefficients of friction under these conditions. No attempt was made to find a maximum coefficient; this would require trials without lubricants, and with rough surfaces. The maxima obtained under the given conditions were noted, however.

The tests were made upon a set of square-threaded screws and nuts of the following dimensions:

Outside diameter of screw	1.426	inch	
Inside diameter of nut	1.278	"	
"Mean diameter" of thread	1.352	"	
Pitch of thread	$\frac{1}{3}$	"	
Depth of nut	$1\frac{1}{16}$	"	(effective)

This depth of nut makes the area of thread approximately one square inch, so that the total axial load on the screw is also the pressure per square inch on the thread surface.

The nuts fit the screws very loosely, so that all friction is excluded, except that on the faces of the threads directly supporting the load. The threads were cut carefully in the lathe, and had been worn to good condition by trials previous to those here recorded. Screw No. 5 was not quite so smooth as the others.

The machine used for the experiments was designed for the purpose. It was built in the New Hampshire College shops in 1891–92,

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* Presented at the New York meeting (December, 1895) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

and now forms part of the laboratory equipment of the college. It is used by students for experiments similar to these; also for testing materials in torsion and in compression. The only changes involved in its several uses are in the loose jaws receiving the test pieces. The machine is shown in front view in Fig. 19, in which the pendulum is swung forward about 45 degrees, and in section (upper part only) in Fig. 20.

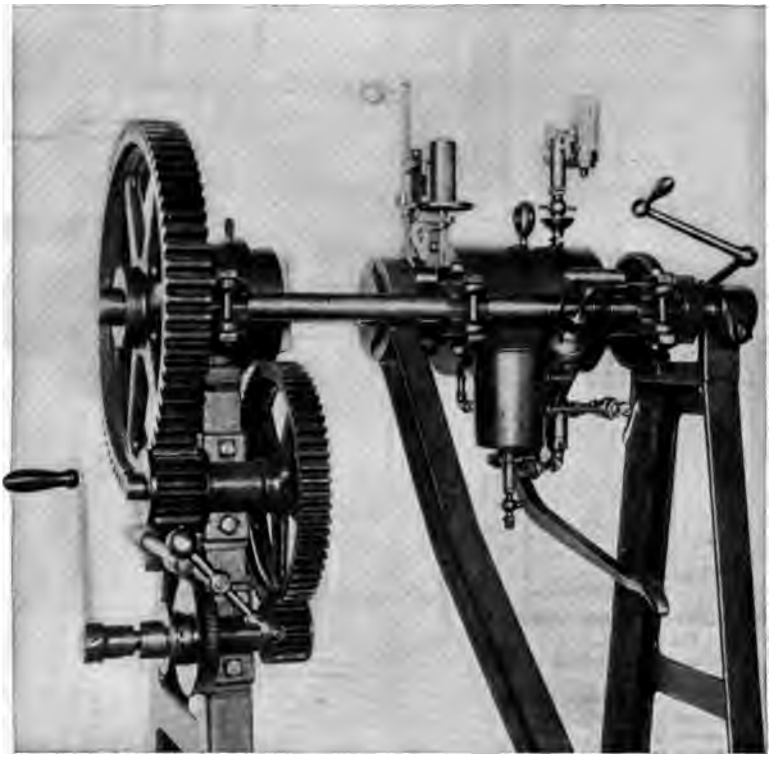


FIG. 19.

The construction of the machine is clearly shown in the section. The gearing at the left serves to turn the test screw, the thrust being received by the ball bearing. The nut is carried by the pendulum, co-axial with its hardened steel spindle, which turns and moves endwise freely in its ball bearing. The moment required to turn the nut is indicated by the amount by which the pendulum swings out from the vertical as the screw is turned. The thrust of the nut is transmitted through the spindle of the pendulum to the trunk piston in the heavy cylinder, the oil confined behind the piston forming a frictionless thrust bearing, upon which the piston turns with the spindle, while the rise of the pencil of the indicator shows the total pressure on the piston, which is the load on the screw. (In the section, the piston is at the extreme right of its $\frac{1}{8}$-inch motion.) The piston is close-fitting, without packing of any kind, and its motion is practically frictionless

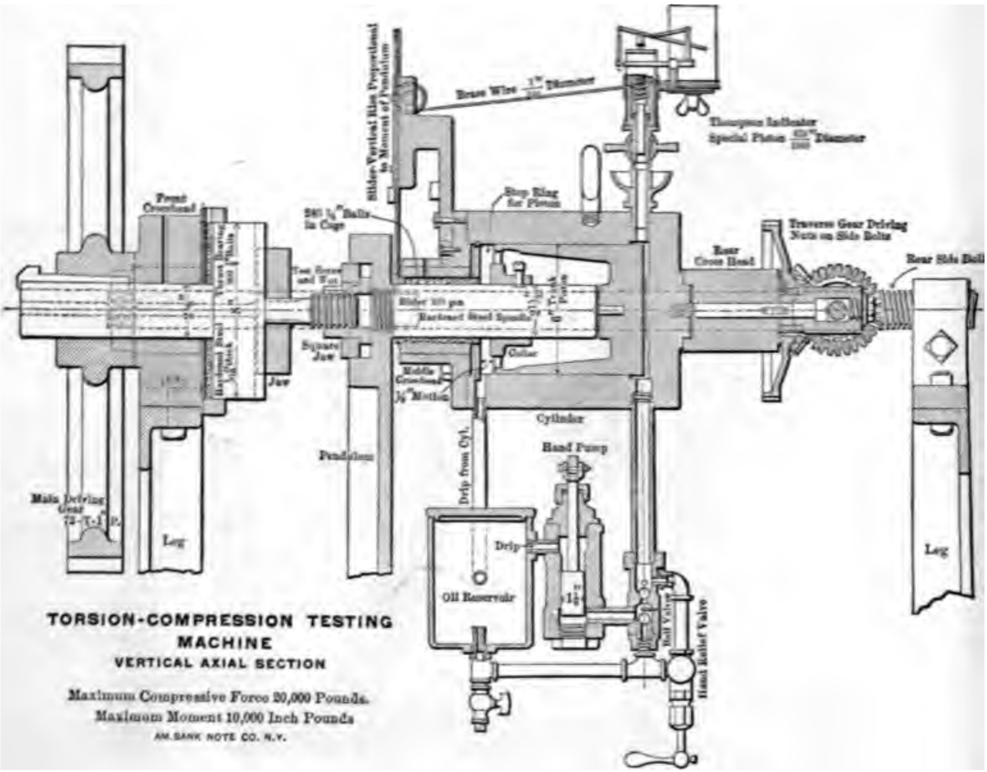


FIG. 20.

at slow speeds. Thus the swing of the pendulum is that due to the action at the threads of the test screw, and that only, to a reasonable degree of exactness.

The thrust is ultimately taken up by tension in the long side bolts passing through the front and rear crossheads. The cylinder, with its attached parts, slides along these bolts to adjust for different lengths of test pieces, the motion being obtained by means of the geared nuts back of the rear crosshead.

An autographic record of each test is obtained by means of the indicator. As the screw is turned, setting up pressure in the oil in the cylinder, the pencil rises an amount proportional to the pressure. At the same time, as the pendulum swings out, a pin at its back lifts the slider above it a distance proportional to the moment of the pendulum, and by the wire this motion is transmitted to the drum of the indicator. Thus any point on the line traced by the pencil indicates, by its ordinate, the pressure on the screw, and by its abscissa the moment required to turn the nut under that load. The hand-pump serves to replace the oil from the front to the back side of the piston, past which the oil gradually leaks under pressure. When the machine is used for simple compression tests, the pump is used to apply the pressure.

The screws and nuts used in the test were as follows:

SCREWS.

No.	MATERIAL.
1	Mild Steel.
2	Common Wrought Iron.
3	Cast Iron.
4	Cast Bronze.
5	Mild Steel—Case-hardened.

NUTS.

No.	MATERIAL.
6	Mild Steel.
7	Common Wrought Iron.
8	Cast Iron.
9	Cast Brass.

Four sets of tests were made with lubricants and pressures, as follows:

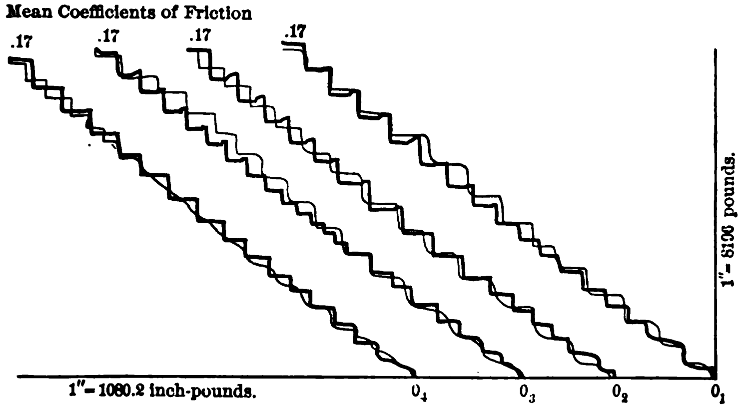
No. of Set.	Lubricant.	Maximum Load.
1	Heavy Machinery Oil	14,000 lbs.
2	Winter Lard Oil	14,000 "
3	Heavy Machinery Oil and Graphite, in equal volumes	14,000 "
4	Heavy Machinery Oil	4,000 "

The "Heavy Machinery Oil" was a purely mineral oil of specific gravity .912. The "Winter Lard Oil" had a specific gravity of .919.

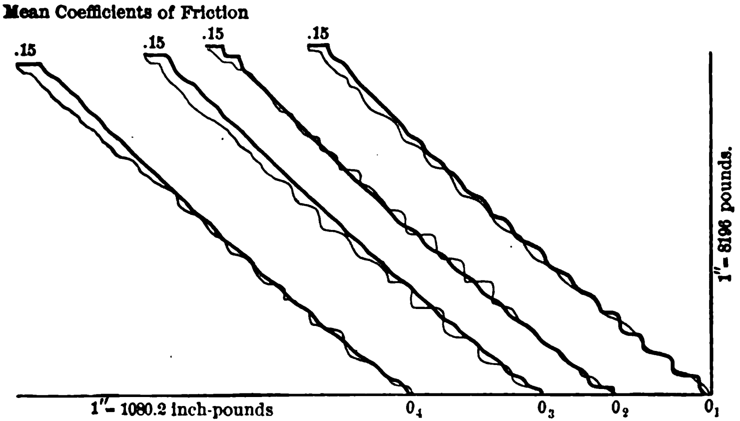
In each set of tests, screw No. 1 was tested with nuts Nos. 6, 7, 8, and 9, successively; then screw No. 2, with the same nuts, in the same order, and so on. In the first set eight cards were taken from each pair; but as the mean of the first four cards taken throughout was identical with the mean of all, it was considered that four cards each would suffice in the remaining sets. Set No. 3 is a duplicate of a previous set, with the exception that the pressure was carried to 8,000 or 10,000 pounds only in the first trial, while in the second (the one tabulated), the pressure was carried to 14,000 pounds. The mean results of the two sets were practically identical. The screws and nuts were flooded with oil when placed in the machine; the four or eight cards were then taken without re-oiling, except as the oil was redistributed each time the pressure was relieved; and when taken out, both screw and nut were thoroughly cleaned in dry sawdust before interchanging, except in set 3, in which they were not cleaned.

The method of testing was as follows: The test pieces being placed in the machine, the gearing was turned by hand, driving the screw at a very slow rate (not more than one revolution in two minutes), until the pressure was raised to the desired amount, the pendulum meanwhile being swung out by the moment required to turn the nut. The relative motion of screw and nut during this time was very slight, being only that due to spring of parts of the machine, and the slight displacement of oil in the cylinder; so that the action between screw and nut was quite similar to that taking place in ordinary machine bolts when tightened upon comparatively unyielding material. The motion was usually rather irregular, the screw and nut being relatively at rest from ten to twenty times during the tightening, as is well shown by the cards. This was partly due to the jar of the gearing.

When the maximum pressure was reached, the gearing was locked, and the hand relief valve was opened slightly; as the pressure fell the pendulum slowly descended, turning the nut on the screw in the same relative direction as before, but *reversing* all the motions of the machine, which, by their friction, might affect the card. Thus, if the piston did not turn freely, it would make the "up" line on the card too high, and the "down" line too low; and for friction in the indicator piston and other parts there would be corresponding deviations in the lines. But in most tests the "up" and the "down" lines coincided very closely, showing either almost total absence of friction, or compensation of the errors. In those cards in which the lines did not sensibly coincide, the true card was assumed to lie midway, as this would give the proper mean, whether the deviations were due to friction in the machine or to change of the coefficient at the screw. Usually the "down" line was the smoother, the jar of the gears being absent.



Heavy Machinery Oil—Cast Iron Screw—Brass Nut.



Heavy Machinery Oil—Wrought Iron Screw—Brass Nut.

FIG. 21.

The general form of the cards is that of a curve closely approximating a straight line, with small irregularities throughout, as shown in Fig. 21. The curvature is usually in the direction indicating a smaller coefficient at higher pressures; a straight-line card would indicate a constant coefficient, or "friction proportional to pressure."

The coefficients given in the first three tables were taken at 10,000 pounds load on the screw. The fourth set was made with much lighter indicator spring and pendulum, to get a large card at low pressures. As the average result of this set, read at 3,000 pounds, was practically identical with that of the first set, read at 10,000 pounds, it was assumed that each card might be considered as a "straight-line" card.

The labor of computation from the cards was reduced to a minimum by plotting on a piece of transparent celluloid a series of straight-line cards with a common origin, and for coefficients varying by .02 from .04 to .24, and involving all corrections shown to be necessary by a careful calibration of all parts of the machine and indicator. The celluloid sheet being placed over the actual card, the proper average coefficient for that card could be read off.

The computations were based upon the formula

$$Q = P\frac{p + \mu\pi d}{\pi d - \mu p},$$

in which

Q = tangential force necessary to turn the nut, applied at the mean radius of the thread.
P = total axial load.
p = pitch of thread.
d = mean diameter of thread.
μ = coefficient of friction.

The comparatively low coefficients frequently obtained in set No. 3 were also made evident by the "overhauling" of the screw when pressure was applied by the hand-pump—the highest coefficient at which this can occur being about .076 for these screws. The graphite and oil were well distributed between the nut and the screw, the looseness of the fit making this possible.

TABLE I.

MEAN COEFFICIENTS FOR HEAVY MACHINERY OIL.

(Actually read at 10,000 pounds pressure per square inch. Each figure is the average for eight cards.)

SCREWS.	NUTS.			
	6 Mild Steel.	7 Wrought Iron.	8 Cast Iron.	9 Cast Brass.
1 Mild steel	.141	.16	.136	.136
2 Wrought iron	.139	.14	.138	.147
3 Cast iron	.125	.139	.119	.171
4 Cast bronze	.124	.135	.172	.132
5 Mild steel, case-hardened	.133	.143	.13	.193

Mean of all, .1426.

Highest for a single card (screw 5, nut 9) .... .20
Lowest " " (screw 3, nut 8) .... .11

TABLE II.

MEAN COEFFICIENTS FOR LARD OIL.

(Actually read at 10,000 pounds pressure per square inch. Each figure is the average for four cards.)

SCREWS.	NUTS.			
	6	7	8	9
1	.12	.105	.10	.11
2	.1125	.1075	.10	.12
3	.10	.10	.095	.11
4	.1150	.10	.11	.1325
5	.1175	.0975	.105	.1375

Mean of all, .1098.

Highest for a single card (screw 4, nut 9) .... .25
Lowest " " (screw 3, nut 8) .... .09

TABLE III.

MEAN COEFFICIENTS FOR HEAVY MACHINERY OIL AND GRAPHITE.

(Actually read at 10,000 pounds pressure per square inch. Each figure is the average for four cards.)

NO. OF SCREWS.	NUTS.			
	6	7	8	9
1	.111	.0675	.065	.04
2	.089	.07	.075	.055
3	.1075	.071	.105	.059
4	.071	.045	.044	.036
5	.1275	.055	.07	.035

Mean of all, .07.

Highest for a single card (screw 5, nut 6) .... .15
Lowest " " (screw 5, nut 9) .... .03

TABLE IV.

MEAN COEFFICIENTS FOR HEAVY MACHINERY OIL.

(Actually read at 3,000 pounds pressure per square inch. Each figure is the average for four cards.)

NO. OF SCREWS.	NO. OF NUTS.			
	6	7	8	9
1	.147	.156	.132	.127
2	.15	.16	.15	.117
3	.15	.157	.14	.12
4	.127	.13	.13	.14
5	.155	.1775	.1675	.1325

Mean of all, .1433.

Highest for a single card (screw 5, nut 7) .... .19
Lowest " " (screw 2, nut 9) .... .11

The conclusions which the results seem to warrant are :

That for metallic screws in good condition, turning at extremely slow speeds, under any pressure up to 14,000 pounds per square inch of bearing surface, and freely lubricated before application of the pressure, the following coefficients of friction may be used :

COEFFICIENTS OF FRICTION.

LUBRICANT.	Minimum.	Maximum.	Mean.
Lard oil	.09	.25	.11
Heavy machinery oil (mineral)	.11	.19	.143
Heavy machinery oil and graphite, in equal volumes	.03	.15	.07

The writer does not consider that the tests prove that any one of the metals used develops less friction than any of the others, under the methods of testing employed, although such results might be inferred from Table III., for instance, in which the coefficients for the brass nut are uniformly lower than for any of the others. Nor does he believe that the method of testing employed is the best possible; a number of cast-iron nuts and screws tested by themselves, and a number of steel nuts and screws similarly tested, might give results showing less variation than is evident in the records given above, and hence more definitely comparable with each other.

Addendum.—In using the machine for testing materials in torsion, a graduated arc and a pointer are attached directly to the ten-inch test piece at points eight inches apart. The two-inch drum above the head of the pendulum (shown in the photograph only) is used for obtaining "semi-autographic" records. For equal intervals in the angle of torsion, as read on the graduated arc, the drum is turned by hand a fixed number of teeth on its ratchet-wheel, while the pencil, carried on an arm of the slider, rises a distance proportional to the moment of the pendulum. The record thus obtained gives virtually a number of points in the true card, from which both strain and stress may be scaled; or the strain may be referred directly back to the graduations on the arc. After the stress has been carried sufficiently beyond the elastic limit, the rotation of the drum is discontinued, and the maximum moment is autographically recorded by the vertical rise of the pencil. The angle of torsion at rupture is determined, in ductile materials, from the fractured specimen, marks being made for the purpose before testing. With brittle materials the angle of torsion at rupture may best be determined from the initial and final positions of the heads carrying the jaws, the reading arc and pointer being removed before fracture. The cards obtained as above are on a large scale to a point somewhat beyond the elastic limit; the maximum stress is determined accurately, and the maximum strain is determined with sufficient accuracy for any practical purpose.

DISCUSSION.

Prof. R. H. Thurston.—Professor Kingsbury is to be complimented on the ingenuity and efficiency of his apparatus, as well as upon his experimental results, obtained in a field as yet very little explored. When working up this subject, years ago, in collecting material afterwards published in *Friction and Lost Work*, it became evident that almost nothing of the small quantity of experimental matter then available could be relied upon to give correct data; and this is, I think, the only considerable work done since which gives us reliable information relative to this particular case of friction of lubrication of heavily loaded screws or of very high-pressure friction of lubrication of any kind. The machine employed and the facts collected are welcome contributions to our experimental apparatus and to our literature of friction and lost work in machinery. Many modifications and numberless applications have been made of the "autographic recording torsion mechanism," the first, I think, ever made use of in testing machinery of any kind, but none that I have seen seems to me better planned or better suited to a special investigation for which it has been devised. It has, hitherto, been next to impossible to obtain satisfactory measures of the coefficient of friction at such great pressures; these fill a long-existing hiatus in our tables.

The reported results appear to confirm deductions which have been previously only provisional and uncertain, and to show that, at pressures measured by tons on the square inch, the friction-coefficient, even for rest, may be kept down to usual and moderate figures—provided abrasion is avoided. At least, that is the apparent deduction from the fact that lard oil acts better than "heavy machinery oil," and graphite mixed with oil gives the best results of all. It would be interesting to secure figures for sperm oil, which I have usually found better—if pure—than lard, under exceptionally heavy work. I have, for many years, advised the introduction of graphite of fine grades, and specially purified, wherever these great loads are to be carried on heavy and slow-moving machinery, as under the main centres of large engine-beams, and under the pivots of swing-bridges; assuming that its interposition between the rubbing surface will greatly aid in insuring smooth and uninterrupted operation, by giving safety against abrasion. Oils, and even greases, may be driven out by pressure, but not usually graphite. I hope that Mr. Kingsbury will give us some figures, later, on the friction of the heavy greases, like "Albany grease," for example, under these pressures. Such lubricants, probably always undesirable under light loads, may be found satisfactory under very high intensities of pressure, even on the score of moderate coefficients of friction.

The superiority of cast iron on cast iron, in some of these experiments, may perhaps be due to the spongy constitution of the metal, insuring retention of the lubricant, and, to some extent, thus securing the ultimate effect of use of graphite. The superiority of the combination of graphite and the brass surface, in Table III., is, I am inclined to think, not accidental. It has been customary, with many engine-builders, for a generation and more, to use brass piston-rings where a soft cylinder gives rise to danger of injury by abrasion; and good bronze has always been found useful in heavy work; though under light pressure cast-iron on cast-iron, and, on hard-driven machinery, as at sea, white-metal surfaces are often required under parts liable to spring.

Mr. William S. Aldrich.—The application of the principles of the torsion testing machine have been admirably worked out for the experiments in this new field. The almost frictionless movement of the trunk piston, in the heavy cylinder of Professor Kingsbury's apparatus, is due to a happy adaptation of the well-known principle that the frictional resistance is reduced to a minimum in such case when rotatory motion is combined with the axial movement. The next step would have been to provide that the indicator piston should have the same kind of helical motion.

Indicators will no doubt have this feature introduced in their construction. We shall then see no more the accumulation of zig-zag expansion lines due to sticky indicator piston, on series of consecutive cards taken at intervals too short for oiling up.

We do not mean to say that the zig-zag lines in the diagrams shown in the paper are due to this cause: this characteristic is there explained as being due to the intermittent method of running the test, as well as to the gearing used. But we notice some kinks on these lines for which there is possibly some other explanation, notwithstanding the small scale on which they are drawn.

The hydraulic transmission of the pressures by the piston method, it is admitted, is accompanied with leakage. Such losses increase with the pressures. They will not compensate each other on the "up" and "down" runs, as the losses due to mechanical friction are recognized to do. The hydraulic transmission is on what has been termed a "closed system." Therefore, leakage occurring on the "up ' run vitiates very slightly that record; while on the "down" run there is certainly less oil present in the system, introducing an initial error, followed by diminishing leakage as the pressure is relieved on this "down" run. The losses due to this cause are not extensive enough to alter materially the long-run average. We wish to point out that the indicator cannot be depended upon for very accurate quantitative work when recording pressures transmitted, as in this case, in a closed hydraulic system. Such records show comparative pressures of considerable use in qualitative experimental work, however.

The inherent failure of the indicator in this connection was also reported upon by Professor Carpenter in discussing a previous paper of mine, on the "Use of the Indicator for Continuous Records in Dynamometric Testing." In that paper I advocated the diaphragm method of receiving the pressure, and hydraulically transmitting the same to a diaphragm pressure-recording gauge, or one of the closed-tube type. While these are made for rectangular as well as circular diagrams, the latter would be especially useful in the present case. The angular motion of the chart could be made to correspond exactly with that of the pendulum of the torsion-testing machine.

These experiments on the friction of screws have some valuable practical applications in the common screw-jack.

Graphite is shown to reduce greatly the coefficient of friction when used with heavy machinery oil. Taking the case of a mild steel screw working into a cast-brass nut, the use of graphite with the oil will enable a man to lift the same weight with only 60 per cent. of his applied force required without graphite. This is from the only tabulated results with graphite, at 10,000 pounds pressure per square inch. We should like to see similar comparative data at other pressures, as well as the coefficient of friction with use of graphite alone. A slight modification of the machine would adapt it to experimental work in determining the friction of collar and ring thrust bearings.

Mr. William Kent.—I would like to ask Professor Kingsbury what coefficient he would advise using in designing machinery for very heavy work. Should we be safe to take .15 as the coefficient of friction, which is the maximum given with machinery oil? I would also suggest future experiments to see if forced lubrication could be applied to a screw. I know it would be very difficult to get oil at 14,000 pounds to the square inch upon the surface, but I think a proper apparatus could be got up to do that. We might possibly get a small current of oil flowing through a very fine orifice in the screw itself into the nut, so as to lubricate the nut under great pressure.

Mr. J. F. Holloway.—I think the gentleman is to be congratulated on having gotten up a very nice machine; just what it shows, whether the friction of the screw, or the value of the lubricant, I have not yet quite made out. It is rather a laboratory experiment on a large scale. Those of us who have occasion to use nuts and bolts in ordinary practice are often at a loss to know what pressure is produced by screwing down a nut. Some here have no doubt struggled in trying to screw a nut on a bolt, and finding it go very hard, have hit it a few blows with a hammer on the corner of the nut and then run it down with their fingers, thus showing that the friction of nuts is often due to mechanical and accidental conditions. I cannot see how a test on such an apparatus as described would help us to know whether the friction of the nut was due to mechanical defects, want of area, or imperfect lubrication. It is doubtless known to many here that in making very large bolts, where the thread is cut in a lathe, that if the tap is cut on the same pitch precisely as that of the bolt, the difference in the shrinking of the tap, when a large and long one, is enough to make a difference in the pitch of the thread to such an extent as very often to make the nut go very hard unless made a loose fit, and it is the practice in some places where this has been observed, to cut the tap with a slight difference in the pitch from the bolt, which helps to make the nut and bolt move much more easily, and fit very much better.

As I said before, I congratulate the gentleman on building a very nice machine, but I do not see how we people who have to use these things practically are going to derive very much benefit from the action of the apparatus shown.

Mr. O. C. Woolson.—I would like to ask the gentleman bath of oil. Now in designing this screw the question of the coefficient of friction was of course a very important one, and the assumption was made that a screw acting under the given conditions would have a coefficient of friction of somewhere in the vicinity of eight and ten per cent. That was merely a guess, however. When the crane was put in operation and worked under a load, the guess proved to be somewhere near right. Now if we could have determined beforehand positively what the coefficient of friction would have been with certain grades of oil, it would have assisted us very much to a closer power calculation.

I do not see why this question of the coefficient of screws should not be distinctly applicable to worms and worm wheels running in a bath of oil. Now in the crane business, although I believe that it is usually considered that the worm-wheel crane is somewhat a thing of the past, yet at the same time there are special cases where the worm wheel will work in very nicely. In that case they are usually kept in a continuous bath of oil, and the motion is quite slow. But so far as I know the only data which we have at hand to determine what is the coefficient of friction, and consequently the efficiency of the worm wheel, embrace simply each man's own individual opinion on the subject. It seems to me that this question of the coefficient of friction is very important, and that any investigation which tends to define its limits, especially in the simple case of a slow-moving screw, is to be highly valued.

Mr. Oberlin Smith.—I too think that this machine is a very ingenious one and valuable for finding out what it has found out. But as has been said, the conditions are so different from average ones with a very slow motion, with everything perfectly favorable to keeping the oil in its place, etc., that it does not give us very much practical knowledge. What we want is to have such experiments supplemented in a very much more careful way. We should have tests of the actual nuts and screws used for hoisting and for pressing substances, and of worm gearing, running in a bath of oil, as it is usually easy enough to arrange, and also running under ordinary conditions of lubrication, such as the first-named screws are subjected to. I think none of us realize, until we try it, what a variation there is in the friction of our machinery in general. I have made some rough tests recently with fly-wheels weighing from 500 to 1,500 pounds running loose on stationary shafts. They had long cast-iron hubs, smoothly reamed out, two or three inches in diameter, running on forged steel shafts, turned as average lathe work. No special pains were taken to polish the surfaces, and ordinary lubricating oils were used. I have been surprised to find the coefficient of friction running as high as 35 per cent.—all the way from 10 to 35—but this high rate must have been due to slow starting and a short arc of motion without giving time for tho oil film to properly adjust itself. I have no doubt that the variation in the friction is as great in almost all of our transmission machinery. I do not see why the conditions on the screw-thread should be different from those of ordinary journals; as we all want to use screws, it would be very interesting if we could have some more practical experiments, so as to know what we actually are losing in friction. As I understand it, this paper does not attempt to deal with the abstract question of the relative efficiency of the different screws. That, of course, is easily found by knowing the pitch and pressure, etc. We want, however, to get the friction coefficients just as low as we possibly can, because screws are a very inefficient device at best, and with the very best conditions of service and lubrication we still lose a good deal of energy with every screw we use.

Professor Denton.—I would like to ask Mr. Smith if he ever tried spinning his wheel and letting it stop?

Mr. Smith.—No; the experiments were tried with a rope wrapped around the fly-wheel rim and a spring-balance attached. The moment at the friction surfaces was of course obtained by finding the inverse ratio between the radius of the wheel and the radius of the shaft. The static friction in starting from a state of rest, when the wheel had been standing some time, reached in some cases the maximum figure named, but fell from 25 to 50 per cent. after getting thoroughly in motion. That is, it would start off with a coefficient of 25 to 35, and get down to a rate of 15 to 25 while being moved at the rim, through the spring-balance, about as fast as a man would naturally pull, perhaps 3 or 4 feet a second. I did not make any tests running at high speed.

*Prof. Albert Kingsbury.**—The trend of the discussion indicates that the results of the experiments are a beginning in a direction in which much more information is needed by engi-

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* Author's closure, under the Rules.

neers. The writer has long been aware of this as the result of his own experience; and while he has projected a variety of additional experiments, for which the apparatus seems adapted, he has chosen to present at this time his results thus far obtained.

Dr. Thurston, Mr. Woolson, and Mr. Newcomb have raised various questions regarding the lubrication. Short tests have been made with nearly all the lubricants suggested—sperm oil, soap, heavy greases, dry graphite, paraffine, and possibly others; but in none of these have the tests been extensive enough to warrant publication of the figures.

The graphite used in the tests was Dixon's "Perfect Lubricator." A short test was made with some of this graphite which the writer had attempted to purify specially, on the assumption that silicates might be present in the commercial article; but no conclusive results were obtained.

Professor Aldrich thinks there is some error in the cards, due to leakage of the oil in the cylinder. Even if this leakage were of considerably greater extent than that which actually occurs, it is not evident to the writer that either the "up" or the "down" line could be affected by it in the least degree. The indicator, except as influenced by its own friction, registers without error the pressure on the oil in the cylinder; and only an extremely minute local drop in the pressure could exist. The leakage was mentioned by the writer only because it would prevent sustaining the load on a compression test-piece long enough to make a micrometric test of the shortening of the test-piece.

The indicator was adopted for the recording apparatus primarily because it was the only thing of the kind at hand; but it would probably prove more desirable than the Bourdon gauge or the diaphragm gauge, on account of facility in changing springs and in calibration by dead loads. If a circular chart or card were used, showing angular motion of the pendulum, this would involve another factor in the computations. The device used, giving the moments directly, is quite simple and easily calibrated.

It is undoubtedly true that a coefficient of friction would be of little use in case of a tight nut, as suggested by Mr. Holloway; nor would it be of use in any other case in which the load is wholly unknown.

The question as to the mathematics of the formula, as raised by Mr. Schumann, was not overlooked when the computations were begun; but the ordinary formula here used, taking the mean radius to the middle of the thread-surface, introduces no error which is worthy of consideration at all in a test of this kind, where the result sought itself varies so widely.

Mr. Griffin suggests the applicability of the results to the case of worm gearing used for hoists. For worms running at extremely slow speeds this would probably be permissible; but for ordinary speeds the coefficients would be of doubtful utility. The friction of worms and wheels has been quite extensively experimented upon by Mr. Wilfred Lewis, and his results are recorded in Vol. VII. of the Transactions of this Society.* Dr. Thurston, in his book on "Friction and Lost Work," gives the results of his own tests of worm gearing. Both the records referred to give the results as *efficiencies*, and the friction includes that of the bearings of worm and wheel. Yale & Towne have also experimented on the subject of worm gearing, and their results are given in the discussion of Mr. Lewis' paper.

Mr. Kent asks what coefficient is best to use in designing screws. That depends upon the object of the design. If the screw is to be made so that it could not overhaul under the most favorable conditions, with either lard oil or heavy machinery oil, probably 8 per cent. would be the highest allowable coefficient; and for a certain margin of safety, a somewhat lower figure. If the driving mechanism is to be designed with a view to making the screw turn, even if perfectly dry, probably 35 or 40 per cent. would be the figure. If the amount of power likely to be lost in the long run is what is wanted, probably 15 per cent. would be a safe coefficient for everyday work; this might be reduced to 10 per cent. with lard oil under the best conditions, and at the speeds used in these experiments.

As a matter bearing upon the subject of lubrication, it may be said that some interesting phenomena were observed in connection with the work of fitting the six-inch piston into the cylinder. The cylinder is cast closed at the back end. It was bored out in the lathe and finished by grinding with emery on a cast-iron lap. The piston was roughed off in the lathe and finished nearly to size by grinding, the final touches being given by fine emery paper. The cylinder was about eight ten-thousandths of an inch larger than the piston. Placing the cylinder in an upright position, the piston was dropped into it nearly to the bottom, both piston and cylinder being perfectly clean and dry;

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* Vol. vii., p. 273, No. 198.

then the air vent (the indicator hole) being closed, the piston was supported on the confined air. Thus supported, and given a whirl with the hand (the initial speed being about 120 revolutions per minute), the piston ran for about five and one-half minutes, its motion being gradually reduced by the friction of the air, and ending so very slowly that the precise instant of stopping could be determined only by the closest inspection. The piston ran without touching the cylinder at all, as was evidenced by the absolute quietness of the motion, the piston being surrounded by a film of air four ten-thousandths of an inch thick, acting as a lubricant and preventing contact of the surfaces. It is not suprising that this should be possible with the cylinder in an upright position; but it was also found that nearly the same results were obtained with the cylinder in a *horizontal* position, the entire weight of the piston (22 pounds) then being supported by the film of air, instead of by the deep cushion as in the first case. In the second case, however, the motion stopped quite suddenly after slowing down very gradually for a time; a lower speed having been reached which was not sufficient to maintain the distribution of the air in the film, the metals came into contact, which at once ended the motion. Of course, while running in this position, longitudinal traverse of the piston was very easy; it was very difficult to level the cylinder so that the piston would not travel one way or the other; but by closing the air vent the piston could be kept in any desired place. The lightest available oil (kerosene), if substituted for the air film, while offering very slight resistance to slow motion, would not permit the piston to make more than five or six revolutions after it was given an impulse as in the previous cases. This "damping" effect was, of course, more marked with heavier oils; and with the oil actually used in the machine (the same "heavy machinery oil" as used for lubricating the test screws), served the useful purpose of retarding, to some extent, the vibration of the pendulum during the tests, which arises from the variations of friction at the threads of the test-screw.

Mr. Wm. Kent.—I would suggest that an explanation for that curious phenomenon of the film of air may be found in capillary action. When you reduce the clearance down to a few ten-thousandths of an inch, the air may have considerable capillary force and insert itself between the surfaces and keep them apart.

DCLXX.*

THE PROPORTIONS OF HIGH-SPEED ENGINES.

BY JOHN H. BARR, ITHACA, N. Y.
(Member of the Society.)
F. F. GAINES, SOUTH EASTON, PA., AND H. E. WILLIAMS, ALBANY, N. Y.

Introductory Note.—Mathematical formulas are not in great favor among builders for proportioning the parts of such machines as the steam-engine. It may be possible to justify the limited use of such formulas in these cases; but the exercise of "judgment" in selecting a factor of safety which will give dimensions suited to the requirements of actual operation is often equivalent to relying upon the judgment of the designer without any computation whatever.

Notwithstanding the probability that the use of definite rules is, and must continue to be, the exception (otherwise than as a check), there is a rather striking general agreement among builders of standard engines of any type as to the proportions of many of the parts, making due allowance for differences of conditions. That is, practice has settled down to somewhat definite lines, not, however, without exhibiting occasional freaks.

It occurred to the writer, some two or three years ago, that it might be possible to derive formulas which would express, more or less closely, the general conclusions arrived at as the result of experience in high-speed engine construction. These formulas are necessarily empirical in the sense that they are adjusted to agree with observations; but they should be, whenever possible, rational in form. That is, the variables should enter the formulas as they would enter purely analytical formulas; while the constants would be derived from practice, and not from assumed working strength, bearing pressures, etc. In other words, the engine in actual operation takes the place of the laboratory testing machine in supplying data for design.

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* Presented at the New York meeting (December, 1895) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

The advantages of using expressions of the rational form, rather than purely empirical formulas, are: first, that working stresses, factors of safety, etc., can be deduced from their constants, and that these constants can be intelligently modified to meet new conditions; second, that they can be applied with greater safety somewhat beyond the range of data from which they are obtained.

In order to begin the proposed examination, it was first necessary to secure data as to dimensions and weights found essential, desirable, and satisfactory in practice; which required the co-operation of established builders of engines of the class to be examined. It was expected that this would present a serious obstacle, as many builders are very properly cautious about distributing such detailed information. In order to reduce the labor, on the part of the makers, to a minimum, a printed form was prepared in which the desired data could be inserted. This form with a personal letter, and a circular explaining the scheme, was mailed to numerous representative builders. While some of these did not see fit to comply with the request, a good number of others responded very liberally. It was considered best to limit the investigation, at least for the time, to high-speed engines of moderate capacity. Should opportunity offer, it is hoped to extend the range of the work.

The examination was carried out by Messrs. Gaines and Williams as the basis of a thesis presented upon graduation at Sibley College, Cornell University. This thesis, and the abstract prepared by these gentlemen for the *Sibley Journal of Engineering* (June, 1895), furnish the substance of the present paper.

J. H. B.

METHOD AND RESULTS.

Data for the examination of high-speed engine proportions, as described in this paper, were obtained from leading engine builders, who very kindly furnished blue-prints, and filled out such a form as is shown (abbreviated) herewith.

FORM FOR ENGINE DATA.

School of Mechanical Engineering,
and of the Mechanic Arts.

R. H. THURSTON, Director.

SIBLEY COLLEGE, CORNELL UNIVERSITY,

Machine Design.

JOHN H. BARR.

Data on.................. ....*Steam Engines*, 189..

1	Diameter of Cylinder............								
2	Length of Stroke								
4	Revolutions per Minute..........								
6	Rated Horse-Power..............								
18	Face of Piston..................								
19	Diameter of Piston Rod..........								
20	Material " "								
22	Mid-Section of Connecting Rod...								
27	Diameter of Crank Pin.....								
28	Length " "								
30	Area of Crosshead Shoes.........								
32	Diameter of Main Journal								
33	Length " "								
35	Length of Shaft; c. to c. Bearings								
36	Material of Shaft.....								
39	Diameter of Fly-Wheel..........								
40	Face of Fly-Wheel..............								
41	Total Weight of Fly-Wheel								
42	Weight of Rim of Fly-Wheel								
52	Weight of Complete Engine......								

The data secured in this way were quite complete, covering about 75 engines of about twelve different builders; the sizes of engines ranging from 25 to 225 rated horse-power. The information obtained was first classified and arranged for comparison. Thus, for example, in the examination of crank-pin dimensions the engines with overhanging cranks were separated from those with inside or centre cranks; while in dealing with piston-rod diameters such a division is not necessary.

The following notation is used throughout this paper:

D = diameter of piston; A = area of piston; L = length of stroke; S = steam pressure, taken at 100 pounds per square inch above exhaust, as a standard pressure; $H.\text{-}P.$ = rated horse-power; N = revolutions per minute; C = a constant. All dimensions in inches, unless stated to the contrary. Other notation is explained as used.

The general method employed in deriving the various expressions may be illustrated by reference to that used for the diameter of the crank shaft at the main bearings.

Crank Shaft.—d = diameter of shaft. The formula for the diameter of a shaft which is subjected to torsion is:

$$d = C\sqrt[3]{H.\text{-}P. \div N};$$ if the moment of torsion is constant.

Crank shafts are subject to variable combined bending and twisting moments; but these moments, when their magnitude and variation are known, can be reduced to an equivalent twisting moment; hence an expression of the above form applies to the case in hand, if the ratios between bending to twisting moments and between maximum and mean moments are constant. In the engines examined, there is a general agreement as to these ratios.

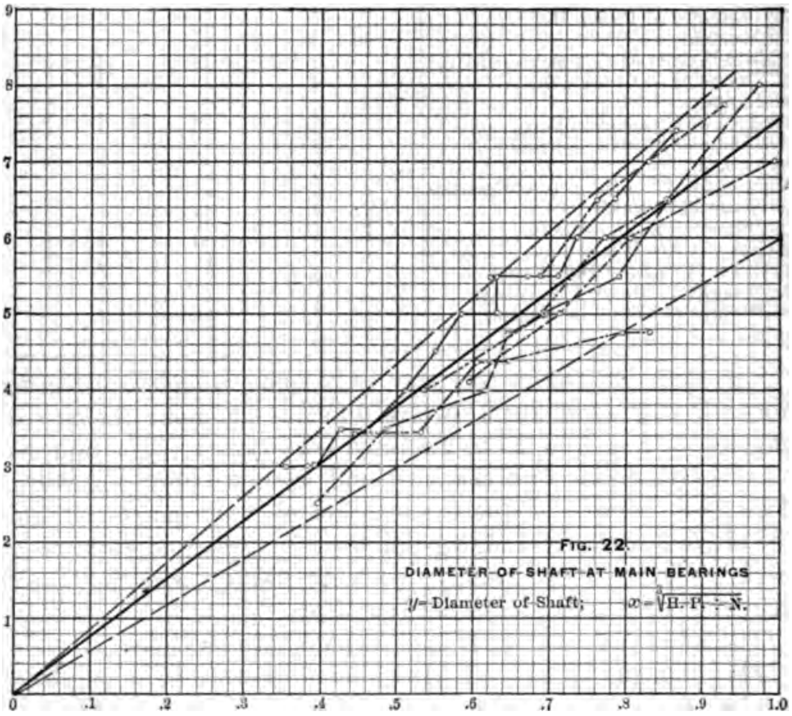

FIG. 22.

In the centre-crank engines the ratio of crank throw to distance between bearings and the ratio of maximum to mean moments showed a general agreement.

From the data at hand, points were plotted on cross-section paper with given values of d as ordinates, and the corresponding values of $\sqrt[3]{H.P. \div N}$ as abscissas. Points located in this way are indicated by small circles in Fig. 22, and if two points, derived from different engines, coincide, a double circle is used. All points obtained from the engines of one maker are connected by a conventional line. The broken appearance of some of the lines representing the dimensions of a single builder, may be accounted for, in part, by the use of common fractions of an inch and by the frequent practice of using the same frame, crank shaft, etc., with different cylinders.

The heavy full line is drawn to represent the average of the observations, and lines are also drawn to embrace the extreme points. From the equations of these lines formulas are derived which represent the average and extremes of practice, as shown by the engines examined. The three formulas thus obtained differ only in the values of the constants.

The constants found as above give:

$$d = 7.56\sqrt[3]{H.\text{-}P. \div N} \text{ for the mean,}$$
$$= 8.76\sqrt[3]{H.\text{-}P. \div N} \text{ `` `` maximum,}$$
$$= 5.98\sqrt[3]{H.\text{-}P. \div N} \text{ `` `` minimum.}$$

For example: If an engine develops 100 horse-power at 250 revolutions per minute, the first of these formulas gives

$$d = 7.56\sqrt[3]{100 \div 250} = 7.56\sqrt[3]{.4} = 7.56 \times .737 = 5.57 \text{ inches,}$$

or say $5\frac{1}{2}$ inches.

The other formulas would give 6.46 inches and 4.41 inches, respectively. Or the range of sizes is about from $4\frac{1}{2}$ inches to $6\frac{1}{2}$ inches for such an engine as that assumed for the illustration.

Piston Rod.—The expression derived for the diameter of piston rods is based upon the Euler formula for a long strut: $P = cEI \div l^2$, in which P is the load, E the modulus of elasticity, I the moment of inertia of the section, and l the length of the strut, and c is a constant. P equals steam pressure times the area of the piston; hence it is proportional to the square of the piston diameter (D^2), for any given pressure, as 100 pounds per square inch.

$I = \frac{1}{64}\pi d^4$ for a circular section of diameter d; l is taken equal to the length of stroke, L; for the unsupported length of rod is not much in excess of the stroke, and would bear nearly a constant ratio to the stroke in the different engines of this class. Collecting the constants, steam pressure, E, $\frac{1}{64}\pi$, etc., in one constant C, and solving for d, the following expression is obtained;

$$d = C\sqrt[4]{D^2L^2} = C\sqrt{DL}.$$

Using values of d given by the data as ordinates, and the corresponding values of the radical $\sqrt{D\,L}$ as abscissas, points are located as in Fig. 23. The equation of the mean line gives .145 as the value of C, while the extreme lines give .119 and .177 as the minimum and maximum values, respectively.

Connecting Rods are first treated as long struts, then the allowance for flexure stresses due to inertia is examined. For resistance to buckling in the plane of motion, the connecting rod is treated as pin connected, or round ended; for flexure in a plane at right angles to this, the strut is square ended. Hence (neglecting inertia) the thickness or breadth (b) of a rod of rectangular mid-section should be one-half the height (h). The formula for breadth is: $b = C\sqrt{D\,L'}$, in which L' is the length of the rod.

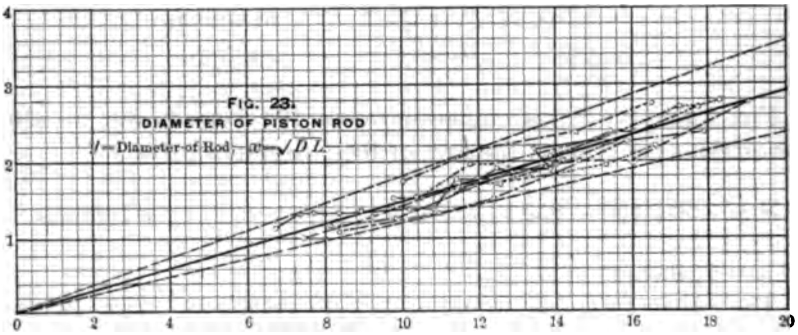

FIG. 23.

The data examined gives .0545 as the mean value of C, with .0433 and .0693 as the minimum and maximum values.

The excess of h over $2b$ may be considered as a provision for the stresses due to inertia. To show this allowance points were plotted having corresponding values of b and h for the coördinates. This curve shows that h is from 2.18 to 4 times b; the mean value being 2.73 b.

Main Journals.—The diameter of the crank shaft at the main journals has already been discussed.

The length of journal to prevent undue heating was examined upon the basis of the formula, $l = C\,\frac{H.\text{-}P.}{L}$, but the data is insufficient (with the varied proportions of the different builders) to clearly locate the general direction and position of the mean line.

For projected area of each main bearing, the formula is: $dl = C'SA = CA$ (taking a standard steam pressure).

The examination gives values of C ranging from .367 to .739, the mean value being .489.

If p is the pressure per square inch of projected area,

$$2p\,d\,l = SA\,;\ \text{hence}\ \frac{2p\,d\,l}{S} = \frac{d\,l}{C}\,;\ \text{or}\ p = \frac{S}{2C}.$$

With steam pressure of 100 pounds per square inch this gives about 100 pounds as the pressure per square inch of projected area, using the mean value of C, while the minimum and maximum values of C give about 140 and 70 as the extreme values of p.

Crank Pin.—The length of crank pin, l, was investigated upon the basis of the formula $l = C\frac{H.\text{-}P.}{L}$, plotting l as ordinates and $\frac{H.\text{-}P.}{L}$ as abscissas. As in the similar case for main bearings, the points located were very irregular. Fig. 24 shows the diagram obtained and also the lines drawn for the mean, minimum, and the maximum practice. The equations derived from these lines are, respectively:

$$l = .333\left(\frac{H.\text{-}P.}{L}\right) + 2.2\ \text{inches,}$$

$$l = .192\left(\frac{H.\text{-}P.}{L}\right) + .88,\ \text{and}$$

$$l = .417\left(\frac{H.\text{-}P.}{L}\right) + 3.92.$$

These expressions do not accord in form with the fundamental formula, and it is evident that more data should be obtained before trying to establish formulas for this case. The two extreme lines have been determined upon the proportions of only two makers, differing widely from the general practice, and should be changed unless substantiated by additional data. The lines indicating the general practice should be curves instead of the straight lines shown in Fig. 24. The principal interest attaching to this diagram is in exhibiting the peculiarities of practice, as exemplified by the highest set of points, and as showing the necessity of much data in drawing conclusions. The first of the above formulas probably represents practice approximately within the limits examined, but it is not offered as satisfactory in all respects.

The projected areas of the crank pins were found to be represented by the expressions:

$$d\,l = .22\,A \text{ for the mean.}$$
$$= .07\,A \text{ " " minimum.}$$
$$= .44\,A \text{ " " maximum.}$$

These values give pressures per square inch of projected area (for steam pressure of 100 pounds per square inch of piston) as about 450, 1,400, and 225, mean, maximum, and minimum, respectively.

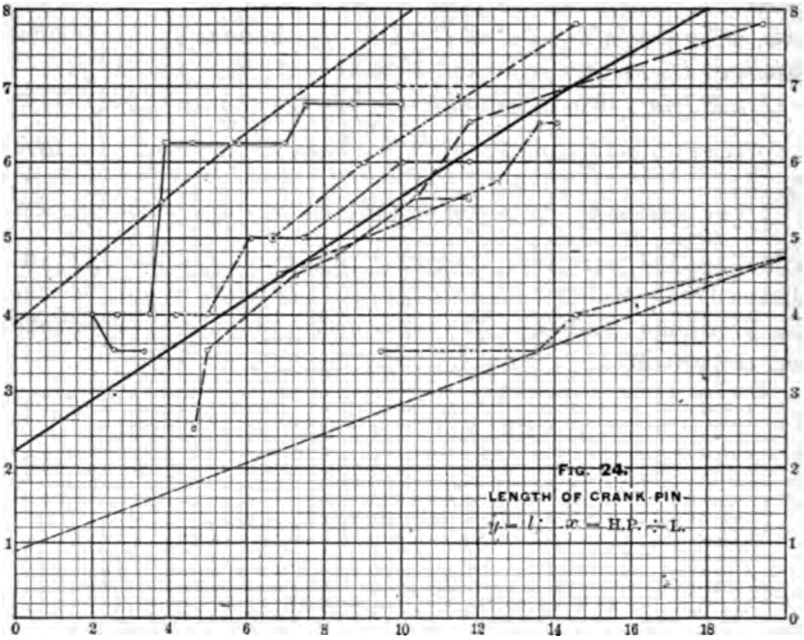

FIG. 24.

Face of Piston.—As would be expected, a wide divergence was noted in the ratio of diameter to face of piston. The following relations were obtained:

$$\text{Face} = .437\,D, \text{ for the mean.}$$
$$= .300\,D, \text{ " " minimum.}$$
$$= .650\,D, \text{ " " maximum.}$$

These expressions are, of course, purely empirical.

Crosshead Pin.—Projected area of crosshead pin varies from .066 A to .346 A; the mean value, as observed, being about $dl = .105\ A$.

The length of crosshead pin was found to vary from d to $2d$; the mean being $l = 1.33\ d$.

Fly-Wheel.—The weight of rim, W, should be proportional to $\frac{H.\text{-}P.}{D_1^2\ N^3}$ (in which D_1 is diameter of wheel in inches), for engines on similar service, steam distribution, etc. A wide range of weights is to be looked for here, and this expectation is justified by the examination. The expressions obtained are:

$$W = 833{,}000{,}000{,}000\ \frac{H.\text{-}P.}{D^2 N^3} \text{ for the mean.}$$

$$= 341{,}000{,}000{,}000\ \frac{H.\text{-}P.}{D^2 N^3} \text{ `` `` minimum.}$$

$$= 2{,}780{,}000{,}000{,}000\ \frac{H.\text{-}P.}{D^2 N^3} \text{ `` `` maximum.}$$

As in the other cases, the general practice lies comparatively close to the mean; the extreme values of the constants covering the widest range observed, which is approached by but few of the engines examined.

The linear velocity of rims of wheels was treated thus: The average velocity of each maker was found, then the mean of these averages was determined. This general mean is about 4,200 feet per minute.

Weight of Reciprocating Parts.—For engines having similar compression, smoothness of running (in passing the dead-points) indicates that the weight of reciprocating parts, W, should be proportional to $\frac{D^2}{L\,N^2}$. Taking the reciprocating parts as made up of the piston, piston rod, crosshead, and one-half the connecting rod, the diagram of Fig. 25 was obtained by plotting the weight of these parts as abscissas, and the corresponding values of $\frac{L\,N^2}{D^2}$ as ordinates. By using the reciprocal of $\frac{D^2}{L\,N^2}$ for y, the mean curve takes the form of the equilateral hyperbola, $xy = C$, and the value of C is found to be 1,850,000; hence

$$W = 1{,}850{,}000\ \frac{D^2}{L\,N^2}.$$

Weight of Entire Engine per Horse-Power.—It is probable that some of the engine weights, as furnished, are not very exact; but the data given show that the average weight of engine, W, among the engines examined, is $W = 117$ (H.-P.–7), or $W = 117$ (H.-P.)–820 pounds.

In all cases involving the steam pressure, this has been taken at 100 pounds per square inch above exhaust pressure. The Appendix gives the values of the constants (mean, minimum, and maximum) corrected for other usual steam pressures.

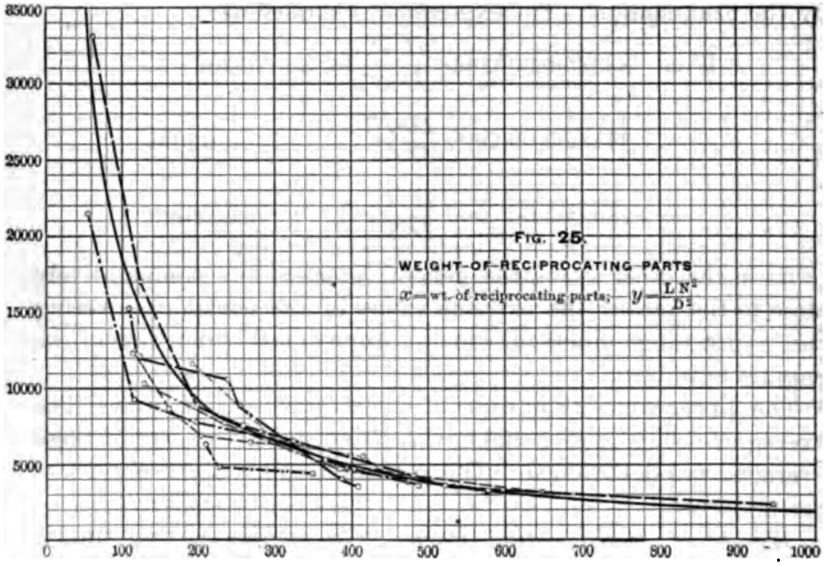

FIG. 25.

In conclusion, it may be said that many features of the high-speed engine, other than those reported here, were investigated. As this paper has for its object simply an explanation of the general method pursued, many of these are omitted.

The authors fully appreciate that this paper is very deficient in many respects. The data at hand are insufficient, in most cases, for a satisfactory investigation; but it is hoped that other engine builders may feel disposed to remedy this source of weakness, should it appear that the work will have any real value.

We take this opportunity to express our thanks to those who so cheerfully assisted us in the investigation.

APPENDIX.

The following table gives values of the constants to be used in the appropriate cases, when designing for pressures other than 100 pounds per square inch, which was taken as the standard pressure in this work:

VALUES OF MEAN CONSTANTS AT VARIOUS PRESSURES.

STEAM PRESSURE	80	90	100	110	120
Diameter of piston rod	.137	.141	.145	.149	.152
Breadth (thickness) connecting rod	.0515	.0532	.0545	.0558	.0570
Crank pin (projected area)	.176	.198	.220	.242	.264
Crosshead pin (projected area)	.084	.094	.1045	.115	.125

DISCUSSION.

Prof. R. H. Thurston.—This is one of a number of somewhat similar investigations which have been carried on, of late, looking toward the rationalization of practice in construction, and the elimination of the empirical and of the "factor of ignorance." Its real purpose and result are, as I take it, to secure a sound basis for constructive formulas in correct mathematical forms, and, then, the derivation, from results of experience as illustrated in practice, of the values of constant multipliers—of constants in the formulas—which shall be at once safe and economical. The use of the facts thus presented is not merely to exhibit variations in common practice, but to derive good bases for a better and more uniform practice in each of the several special lines of construction studied. It is not to show that good builders vary from 100 to 150 pounds in weights of engine, per horse-power, in building high-speed engines, but to derive safe weights from acknowledged successful practice.

The variations here shown come, presumably, from a number of kinds of variation in knowledge and in judgment on the part of designers and builders. The "factor of safety" illustrated includes not only a true factor of safety, to cover inevitable variations of quality of material and defects of workmanship, as well as unavoidable occasional excess of load on the machine or on a part, but also that "factor of ignorance," of quite another sort, which measures the designer's distrust of his own knowledge, or his actual ignorance of his business.

I was once attached to a ship in which a pair of thirty-inch steam cylinders, eighteen-inch stroke of piston, driven by a gauge pressure of only twenty-five pounds, were fitted with rods five inches in diameter. The reason given by a friend of the designer was that, at that time, it was impossible to secure good workmanship, and, in illustration of this fact, he stated that he had been startled, in a case of breakdown by fracture of a rod, to see a bolt drop out of the interior of the rod, which bolt had formed a part of the original pile out of which the forging had been drawn down, and which had not been welded into the surrounding mass when the rod was made. I knew a case in which a designer made his flat steam-chest tops an inch thick on a variety of sizes of engines, and, unable to compute the right thickness, increased the depth of metal only when he found that some of his larger makes were springing visibly under steam. It is more than likely that some of the excessive sizes noted in this work come in a somewhat similar way—as, perhaps, by experiencing a wreck due to water coming over from the boiler—not realizing that engines cannot be designed to meet successfully that sort of contingency.

I have known designers to design iron shafts of ten inches diameter and one-inch rods alike, on the assumption that the breaking stress may be taken as 50,000 pounds per square inch, never dreaming that the same metal may break at 35,000 in large shafts, or, drawn into one-inch rod, at 60,000, or, in wire, at 100,000 pounds per square inch. A designer of rock-drills was continually enlarging the size and increasing the number of his cylinder-head bolts, which as steadily continued breaking under blows of the piston; failing utterly, until given a special lecture on the subject, and taught to lengthen the body of the bolt and reduce its diameter below that of the bottom of its threads, to appreciate the fact that strength without extensibility, in such places, means inevitable fracture under impact. Thus, where we see an exceptionally large rod, or a peculiarly heavy crank, it is apt to prove the case that the last of that pattern broke through some accident, and the designer makes the next a little larger that it may stand in the same contingency, when, very probably, the cause was one which should have not the slightest influence upon the proportions of the part or of the engine.

With one of the old forms of Corliss crosshead, for example, piston rods were continually breaking, and as constantly being enlarged by unobservant designers; until, after a time, it was discovered that the springing of the rod through the tilting of the crosshead was the source of trouble, and an improved design of the defective part put an end to all trouble of that sort and again reduced sizes of rods to their proper minimum. Precedent may serve to regulate practice in the courts, but it is apt, if not checked by thorough knowledge and good judgment, to make engineering very costly.

On the whole, it seems very probable that the constants to be used in good practice are likely to fall under, rather than over, the average values there revealed. Engines break down oftener through malproportion of parts, and accidents having no bearing upon their proportions, than from actual weakness or lightness due to the adoption of too small a factor of safety. Some of the best and most successful designers build the lightest engines, and in the navy, for example, the reduction of weights one-half, during the last generation, has not apparently increased liability to accident. Could absolutely safe materials be secured by correct specification and inspection; could symmetry and uniformity in proportioning be attained by intelligent designing; could parts be adapted with equal success to resistance of stresses, both static and dynamic; and could skill and care in management be insured, it seems to me extremely probable that a factor of safety of four would prove ample for all ordinary work in steam-engine designing. The settlement of this question, so far as practicable, by this sort of comparison of experience among the best builders of the world, is the true end in view in such investigations as these.

It is encouraging to find, as we have in this case, that all the leaders in modern construction have so much wisdom and liberality, and have so little of the old abominable selfishness and jealousy of their fellows in the business, as to join heartily in the investigation of such matters of professional and scientific importance as this, for example, is admitted to illustrate.

I would say a word further. In the attempt to secure information relative to the costs of parts, we have met one difficulty, at least I have met one difficulty, in seeking such information as this, and that has only come from the fact that builders have very frequently supposed that we were seeking market prices, which they did not care to give out, and not the costs of parts which might be compared in order to secure the final result of getting a given piece of designing done in a proper way at least cost of work finally accomplished in dollars and cents expended in its final running. But when that impression is removed I have no doubt it will be perfectly possible to make comparisons in a somewhat similar way to this in the economics of steam-engine design, a subject which from that point of view has never, so far as I know, been taken up in any formal way.

Mr. William S. Aldrich.—The comparison of an engine in operation to a laboratory testing machine, though unique in its way, we believe should not be pushed to its limit. Of all the members of a steam engine, the piston rod alone has perfectly determinate stresses while in motion, which the indicator card may be said to weigh. Moreover, the destructive testing of full-sized members has its legitimate place in structural work subjected to statical loads; but engine builders are not yet educated up to the point of determining the strength (or weakness) of their designs, of a fly-wheel, for instance, by destructive test of the same to find at what dynamic loads it gave way.

An inspection of the diagrams given in Professor Barr's valuable paper will convey a better idea, we think, than any comparison of numerical values for mean and extreme points. We could wish that the variations in the proportions of the several members could all have been presented by plotted diagrams rather than by giving only the constants for mean and extreme values. The Society will surely find room for more of these diagrams, if the author wishes to place them on record. We could scarcely appreciate the value of the numerical extremes for length of crank pin till we had carefully inspected the diagram, showing some sort of a satisfactory clustering of values about a general average. This is in a field of design on which builders usually reserve the right to pass judgment; introducing questions of friction, wear, lubrication, and being independent of the strength of the material, it cannot be subjected to rational analysis. The same may be said of area of slides, area of face of piston, and lengths of crosshead pin and main bearings, of which we should like to see the plotted diagrams.

Examining all curves given which involve design by purely rational formulæ, we note a remarkably satisfactory clustering about the general average. The structural design of the crank shaft and piston rod, involving the strength of the material alone, in the final analysis, and the dynamic design for weight of reciprocating parts, show an adherence in the long run to an average, whose lessons are obvious.

The formulæ of our forefathers for structural design must be made more rational, however, by using the coefficient of safety, based on the elastic limit, rather than the factor of safety, based on the breaking load. The present very general interest in the accurate determination of the elastic limit makes it almost criminal to design further by the breaking-limit factor. No one cares to be around any structure with internal stresses beyond the elastic limit; why, then, use a factor based on the behavior of the metal beyond this point?

The internal resisting stresses of all materials are coming to be more accurately determined every day. The point of application, direction, and magnitude of the externally applied forces may be readily determined in most cases of steam-engine design. So that it does appear unnecessary, in all such cases, to depart from rational methods of designing.

The weights of fly-wheel and of reciprocating parts are properly treated by purely rational methods. Here, too, an inertia indicator card may be said to take the place of the testing-machine diagram. When fly-wheels come to be built like bicycle wheels, in which material is provided for weight and strength where most needed, perhaps an inertia instrument of some type will show different constants from those in the paper, which have a phenomenal range, though in the billions. Such a fly-wheel inertia indicator, by making a continuous record, and being required by law, would provide an invaluable aid to the coroner's jury, in the absence of the engineer.

Prof. R. C. Carpenter.—It strikes the writer that this paper forms a very valuable addition to the literature relating to the design and proportion of engines, and it is to be hoped that the field of research may be extended so as to ascertain the practice in this respect of the builders of low-speed engines. The writer has had reason in a number of cases to lament the fact that there was no standard to which builders of engines were confined. The great variation in practice of different builders was illustrated in a series of proposals for several engines to be of 900 horse-power each, which the writer was called on to examine in the capacity of consulting engineer. In these proposals for the same engines, working at the same speed, and between the same limits of pressures, the size of main shaft proposed varied in diameter from 16 to 22 inches, the sizes of crank pin from 7 to 9 inches, and other working parts accordingly. The makers were not accordant as to the size of cylinders required for producing the same power, when working at the same speed and between the same limits of temperature. The variation in power estimated by taking the product of volume passed through by piston, into probable M. E. P., would range from 80 to 140 per cent. of that demanded. The want of uniformity in practice and the want of a rational basis on which to establish engine proportions are patent. To the writer it would seem that in many instances the makers were simply vying with each other to see which could put in the heaviest parts, regardless of the requirements of the plant in question, and this view was considerably strengthened by a conversation with the selling representatives. There is little doubt but that certain proportions of parts of engines are required to meet the conditions under which the work is to be performed, and furthermore, for such service as electric-railroad work, where the variation is almost instantaneous from no load to 50 per cent. overload, these parts must be much heavier than in an engine designed for a steady load; but it also seems probable that some of the builders in attempting to meet this demand have taken proportions which are unreasonably large and not required under any conditions. The same lack of harmony is also to be seen in the proportions which are proposed for steam piping, some builders being content with a pipe which will deliver steam at the rate of 100 feet per second, and others requiring one, two, or in some cases three times as great an area.

Prof. Albert Kingsbury.—I wish to add a word of commendation to that which has already been said in favor of the paper. I think that Professor Barr has undertaken, and to a large extent has carried out, a valuable work. I look at this matter from the same standpoint as Professor Barr—that of a teacher of machine design. It is to such a man very distressing sometimes to give a student a problem in designing in the solution of which he has to use the formula and the constants given him in his text-books, and after the student has worked out the dimensions of the crank pin of the engine very nicely, and has expressed them in thousandths or ten-thousandths of an inch, to say to him "That is very good—but I think we must add half an inch to the diameter, and an inch and a half to the length, in order to make it look right." The teacher very frequently is at a loss to give the student reasons for such an exercise of judgment, and the lack of sufficient evidence to back him up is a confusing thing to the student, and may perhaps offset the careful teaching which has preceded the work in hand. The lack of just such data as Professor Barr has undertaken to acquire is a serious difficulty in the matter of teaching. There is really no substitute for your own experience. The next best thing to have is the experience of the other fellow. One of the difficulties which Professor Barr has found in acquiring data for his paper has been the lack of responses to his circular letters. We all know why these responses have been few; press of business, imaginary self-interest, or something else interferes with the impulse to answer promptly; but I think that, even for his own interest, every builder ought to submit such information if he has it, and I hope that if Professor Barr undertakes to carry out this work further, he will receive a great many more answers to his letters than he has already received. It seems to me, however, that a certain amount of critical inspection should be given the data received. I do not think that the dimensions submitted by all builders should be received with the same weight. I remember a case in which a builder who made large steam presses, the steam cylinder having a diameter of about four feet, and perhaps four-feet stroke, was requested to make a press of the same diameter with no changes except an additional length of stroke, making the stroke six feet instead of four. From a rational point of view, about the only change in the original machine which would be necessary would be an increase in the length of the piston rods—there were three of them—and the length of struts connecting the steam cylinder with the cylinder in which the work was done, with an increase in their diameters to produce the requisite stiffness. The maker did this, but he went further; he added an extra inch to the thickness of the metal in the steam cylinder and the cylinder-heads, and so on, making changes which were wholly unnecessary throughout the machine. If the data submitted to Professor Barr were taken from such a machine as this, it is quite evident that they ought to receive no value whatever. It is evident that the work already done has involved a considerable amount of labor, and it is further evident that to collect and formulate the data for a complete work on machine design, of the magnitude of Professor Unwin's, for instance, would involve an amount of time which no otherwise busy man is likely to have for the work. I hope the authors of the paper may find time to do more of the work, and give us the results as soon as possible.

Mr. Oberlin Smith.—I think this paper has great value (aside from its evident intrinsic value as pertaining to the special subject on which it is written) as an object lesson of more to come of the same kind of literature—a kind which we ought to have, and of which I hope we will have a good deal in the future. I hope to see the time when this Society and other societies will have special committees for just such work as this. There is a lamentable ignorance among us of the average proportions of actual machines of a great many kinds, which are good machines and are in constant use, but which are made with the same great variation between different makers which high-speed engines have. Such work consists in getting a consensus of opinion, so to speak, of the practice of manufacturers of actual machines, tabulating it, formulating it, finding averages as carried on, not only with steam engines, but with printing presses, looms, locomotives, boats, and all sorts of things about which it would be of enormous value to the community to know more. One illustrative case in point was the standardizing of the screw-threads of the country by the Franklin Institute in connection with the Messrs. Sellers and the Navy Department. Their system has been the United States standard ever since, and has been of enormous use to the country. The work was done in the same way as in this case under consideration. Circulars were sent out and information was gotten from a great number of people who were using threads, and a general average was struck. Some theoretical considerations were incorporated and the various series were "evened up," so to say, with a view of getting the best practical screw-threads possible, although not expecting to reach perfection. In this age, therefore, which we may perhaps call the beginning of *the age of standards*, wherein we shall learn to standardize our manufactured goods far more than we ever have in the past, such a paper as this is very interesting.

Mr. Francis Schumann.—The paper of Professor Barr reminds me of an experience which happened to me several years ago.

In looking up data relating to the transmission of heat I obtained translations of the work of Peclet and Morin in which the theories were correctly and clearly elucidated by formulæ, and in which, for practical application, a coefficient K continually appeared. I sought back and forth to discover the value of this coefficient, but without success.

Now this coefficient which was lacking in the heat formulæ is what Professor Barr is seeking for use in computing the proportions of the parts of a steam engine. We speak of rational formulæ; how can we hope to obtain them when we have none even for a simple column, or strut?

The application of theory in designing a commercial machine is yet in an unsatisfactory state, because of the lack of information regarding the special purposes, conditions, and forces to which it may be subjected. Take for instance a student who would attempt to determine the proportions of an engine, based upon the knowledge as it is now taught him, without the advantage of the numerous empirical methods now made use of by the older practitioner, in lieu of the rational formulæ not yet found. A rolling-mill engine is subject to shocks and wear entirely different from those appertaining to one used for a woollen mill. Those constants which change the proportions of an engine so that it will be suited to either purpose respectively, are what we still need. Is there any one of us, who has designed, made the drawings for, erected and tested an engine for some special purpose, who has not modified, finally, the theoretical proportions by this previously lacking coefficient K? Has he not, as Professor Kingsbury said, added half an inch here and there?

It is true that ultimately we may establish rational formulæ, but at present we must rely on those constants or coefficients which Professor Barr has, so happily for us practitioners, commenced to formulate as a substitute for those missing links in the rational design of an engine, and I believe Professor Barr's work, when completed, and, I hope, extended to other machines, will be of the greatest value.

Mr. William Kent.—I did not notice in Professor Barr's paper any statement of the difference in the proportions of crank shafts when the fly-wheel is overhung or when it has an outboard bearing.

Professor Barr.—I will state that the engines examined and reported in this paper, so far as the crank shaft is concerned, are all of the centre-crank type with no outboard bearing. In considering piston rods, we have taken some engines of the other type.

Mr. Kent.—I have no doubt that the formulæ for crankshaft diameter will be different for engines provided with an outboard bearing. I have noticed in some engines with outboard bearings the fly-wheel seemed to be wobbling in a most dangerous manner. In an electric-light place some time ago, I was really afraid to stand near the fly-wheel. I asked the engineer if there was not some danger of that breaking. He said, "No; there is no danger at all; the other one did break about six months ago." I would also say that I have been told that one firm has recently enlarged the diameters of an outboard-bearing engine shaft from five inches to eight inches. I do not think any theory will come in to explain that, except that they found that the five-inch shafts were breaking, and they made up their minds that they would make them so strong that they would not.

Prof. Charles L. Weil.—I was very much interested in what Professor Kingsbury had to say about the unfortunate position of the instructor in machine design. When I was at Lehigh University, it was the custom, in teaching engine design, to take the class to New York City, and make measurements upon some twenty-five engines, something after the manner mentioned in this paper. When engaged in this work one thing struck me as unfortunate, and that was, that by the time the technical-school men had gathered data for constants, for what might be termed a certain style of engine, there came a change of requirements in the commercial world—in regard to speed, for instance—in the case of that class, which would so influence proportions as to have a very pronounced effect on the values of the constants previously determined. Too often our constants in machine-design work are for a style that is passing into disuse.

Mr. H. H. Suplee.—The remarks made remind me of a statement which I think holds good in a great many such cases; that is, that the work of the professors is very good in its way, but very often it is just a little too late. I think if we could get it in such a shape as to anticipate and get data from new designs of engines as they are being planned—of course we all know how difficult that is—the information would not be too late to be utilized.

Mr. Oberlin Smith.—I agree with Mr. Porter, one of the original "anvil" missionaries, that an engine-bed should be just as heavy as we can afford to make it, and independent of the probable purpose of the engine; and the heavier the better. We cannot make it too heavy for practical use. Of course, reciprocating parts, like pistons, crossheads, etc., should follow more the idea of getting plenty of strength, but having as little weight as possible. But we do not, by any means, want to do that in beds.

*Prof. John H. Barr.**—In comment upon the remarks of members, I would refer first to the suggestion of Dr. Thurston, that the best proportions are probably somewhat under the mean. I should agree that the best practice would be, probably, to adopt proportions under the average, rather than above it; this is an important point which we neglected to bring out in the paper.

As to the factor which has been referred to under the general name of factor of safety, the factor which has been derived from investigations of this kind is not a factor of safety with respect to strength alone, but is based also on rigidity and various contingencies of service which affect the proportions of the different parts.

The formulæ which we have derived are not rational, except in form. They are formulæ of rational antecedents. The factors are derived from practice, and include elements which have been taken into account by different builders.

In reply to the suggestion that we should give different percentage values to the proportions adopted by different builders, I would say that this would be rather a difficult thing to do. If I were at liberty to give the names of the builders whose data have been used, it would be admitted, perhaps without exception, that all were entitled to much respect and were of equal value. Of course I cannot give such names.

The builder who would be likely to build an engine whose piston rod was forged out of a pile of old bolts represents the type of man who keeps his trade secrets to himself, and declines to help such inquirers as ourselves.

The investigation has been entirely confined to high-speed engines, and in most cases to the centre-crank engines. We are going to begin on the slow-speed engine men next, and afterwards hope to get round to the builders of machine tools.

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* Author's closure, under the Rules.

I am glad to be assured of Mr. Smith's coöperation in furnishing us information in this latter field.

Mr. Oberlin Smith.—I should be very glad to give it, and hope to get some of the other fellows to do the same thing when it is wanted.

Professor Barr.—The opening paragraph of Professor Aldrich's discussion seems to show a misunderstanding of the position taken by the authors of this paper. It is not intended to advocate the substitution of the steam engine in operation for the laboratory testing machine in making *destructive* tests of materials. What is intended is simply the use of the proportions found desirable and necessary in actual engines in deriving the safe working stresses; or using the engine in operation to measure the effects of the various contingencies which we have not, so far, been able to determine by analysis and the common experimentally determined constants.

The stresses due to dynamic action (other than those resulting from the useful load transmitted, and the more readily calculated incidental effects), such as the effects of repeated variations in stress, etc., have made it necessary to use factors of safety of 8, 10, 12, or even more, in place of the real factor of safety of 3 or 4, which should be sufficient if all conditions were accurately known and provided for. These factors contain so much of the element of ignorance that it seems necessary to resort to comparison of the proportions of "good" engines in order to get a proper factor for each part. This may not be the most scientific method of approaching the problem, as it does not assign to each of the various causes its separate effect; but it appears to be an expedient which will give a result more nearly in accordance with the requirements than is attained by the method of selecting some one factor of safety to be used for all members of the same machine. As Professor Aldrich remarks, the stresses on a piston rod can be ascertained somewhat closely, and this is evidently an instance where the intelligent designer would determine these actions as nearly as practicable, and then use a *real* factor of safety, which should be low.

It is suggested that more of the diagrams should be presented. It is very true that these diagrams alone are of much more value than are any deductions and conclusions which the authors can derive from them. The present paper was not presented as in any way comprehensive; but it was offered in its very incomplete form in order to get the "sense of the meeting" as to the desirability of further investigation along this line; and with the hope that many more builders would consent to furnish data when shown that it could be used without divulging their proportions. While the limited data already secured have enabled us to observe the general trend of practice in certain instances, it is realized that much more is required in order to draw any important conclusions. Should the builders agree to coöperate more generally—and they will certainly have the opportunity—and should the matter be considered of sufficient value to occupy the attention of the Society further, more of these diagrams may be offered later.

The writer agrees with Professor Aldrich in his strong appeal for abandonment of the breaking limit as the basis of design, and hopes that we may be able in the near future to advance far enough to base our design upon the stress which a member will stand under indefinitely repeated application of such stresses as it is called upon to endure in operation. The researches of Wöhler and Bauschinger have indicated the importance of much more extended investigation along this line; but in the absence of adequate information as to the behavior of materials under these conditions, less scientific methods may be utilized to meet the immediate necessities. Certainly "rational" methods of designing are best, unless they end up in an irrational factor of ignorance.

Professor Weil cites the rapid changes in requirements, and the corresponding alterations of proportions which are apt to occur, and which tend to vitiate the value of examination made upon current practice. We can hardly hope to arrive at standard proportions for the members of a steam engine, and to have these standards retain their value indefinitely. However, it may be well to call attention to the fact that the type of engine here considered is a new one, and that extreme variations of proportions are inevitable during the experimental period. Furthermore, the past decade, with its marvellous electrical development, has produced a revolution in the requirements of the steam engine such as we may hardly expect to witness again in many years. These circumstances are sufficient to account for the diversity of practice observed in the present case. It is not difficult to agree with the recent prediction of the editor of one of our engineering papers that an examination similar to this, if made ten years from now, will reveal no such wide range of practice as we see to-day.

Mr. Suplee refers to the advantage to be derived from examining the newest designs in advance of their actual application. This would doubtless be very desirable, if sufficient data of this nature could be obtained; but it would probably not show, in the general case, much departure from the latest preceding practice of the same designer. This method would be taking the judgment of the designer, rather than his experience, as our basis, and this judgment is formed by his past experience. The last designer would show his effort to correct previous errors of judgment, as well as his allowance for new conditions, presumably. Many of the proportions employed are the result of a compromise between what is necessary and desirable in the opinion of the designer, and commercial considerations such as using the same frame, crank shaft, etc., for different sizes of engines, or for different speeds. It would be interesting to obtain from these same designers the proportions which they would adopt for each size of engine if not hampered by the usual limitations, and this might afford a basis for deducing standard proportions which would satisfy the purely mechanical requirements to a high degree.

DCLXXI.*

MEANS ADOPTED FOR SAVING FUEL IN A LARGE OIL REFINERY.

BY CHARLES E. EMERY, NEW YORK.
(Member of the Society.)

ONE of the most interesting professional engagements during the past year has been the study of conditions obtaining in the large oil refinery of the Tidewater Oil Co., at Bayonne, N. J., with a view of recommending means to obtain a saving of fuel. An incredibly large amount of steam is required in such a place. It is used for power to operate the engines for the various manufacturing establishments, such as barrel, can, and box factories; to operate steam pumps to transfer the oil and finished products to different parts of the yards; to press out the paraffine or wax from the heavier oils; to operate hydraulic presses for higher pressures; to pump water in large quantities for cooling purposes, ammonia for refrigeration, etc. Some steam power is also required for electric lighting. A very large part of the steam supply is, however, required for various heating operations connected with refining. In the refinery referred to there were 5,500 horse-power of boilers installed in four boiler houses in different parts of the grounds, which boilers were originally forced much beyond their capacity a great deal of the time. The coal consumption for steam purposes amounted to about 64,000 tons per year, independent of which a very large quantity was consumed directly under oil stills. The question of the saving of fuel had been agitated before the writer was consulted, and some savings made by separating the boilers for two different departments in the refinery, so that each could be held responsible for its own consumption. It had also been considered that there were some connections between the different boiler houses which could be simplified, as it had been

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* Presented at the New York meeting (December, 1895) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

found necessary to keep all the boiler houses in operation nearly all the time. The executive officers had also entertained a proposition from the prominent electric companies to erect a central electric plant for generating alternating current, it being proposed to substitute alternating motors for all of the steam engines in the establishment, of course putting in new pumps adapted for operation in this way. The cost seemed so large that the writer was consulted as to the best method desirable under the circumstances. It was found that the executive officers at the refinery had studied the problem very thoroughly, and that they knew in a general way the causes of the large consumption of steam. One of the same had some time before sent to the writer for a copy of experiments which he had made on the cost of steam power with ordinary steam pumps, which led to an investigation of the cost of power with the large pumps of the refinery, the method generally adopted being to ascertain the weight of exhaust steam delivered through a temporarily arranged surface condenser, or, in some cases, the extra weight caused by exhausting directly into a vessel of water, the water used being compared directly with the theoretical power obtained from the gallons pumped and the pressure of delivery. It was found that many of the steam pumps were using as high as 240 pounds of water per net horse-power per hour, and only in exceptional cases could one be found which could deliver a horse-power as low as 80 pounds of feed-water. The general impression seemed to be that the steam pumps were requiring on the average 150 pounds of water per horse-power per hour. The advantages of using exhaust steam were also appreciated to a certain extent, as exhaust steam pipes were being erected and connected so as to keep the various stills and tanks warm during the winter.

The preliminary report of the writer, which was not based on full knowledge of all that had been done before, corroborated the opinions of the officers as to the causes of the large consumption of steam, but considerably modified the suggestions as to the methods of reducing the same. The large electric plant was not approved. A smaller electric transmission was recommended to reach various outlying points where steam had to be transmitted a long distance at very great expense in condensation independent of the power developed, since it was necessary in winter and desirable in summer to keep the pipes warm all the time, although the power was at many of the points only used occasionally. An extension of the exhaust system was recommended even if it became necessary to increase the back pressure, and it was recommended that a number of power stations be established in which would be erected good high-pressure non-condensing engines operating power pumps to take the place of the numerous steam pumps in different parts of the works, the exhaust from such engines to enter the exhaust mains and to be used for heating purposes. It was pointed out as desirable that the changes be made somewhat slowly, so that experience gained at one plant could be applied at another, and so that the class of engine best adapted for the purpose could be determined. Evidently if all the exhaust would eventually be required a cheap form of engine could be used, and if the contrary was the case good compound condensing engines could be used at some of the locations.

The suggestions were adopted, and considerable work has been done under the immediate direction of the executive officers in consultation with the writer. At the present time the system of local plants operated by high-pressure steam engines and power pumps has been applied at two points in neighborhoods where the least exhaust steam is required, and the exhaust steam from nearly all the engines and the large number of wasteful pumps has been collected and used at a pressure of about 10 pounds in the steam stills, the results showing that nearly all of it could be utilized. The result of the work thus far accomplished has been to reduce the coal consumption for steam purposes fully one-half, or about 32,000 tons per year. The saving has gradually increased from the time the work was commenced, and has been 54 per cent., compared with the previous year, for the last three months, though the entire work laid out is not yet complete. One of the four boiler houses has been closed, and experiments are in progress to ascertain how many more boilers can be shut down without forcing the remainder above the economical limit. The principal part of the saving has been due to the use of exhaust steam. Its application in steam stills required experiment, so the results could not have been accomplished without the hearty coöperation of the executive officers of the establishment. Before the changes the yards were overhung by clouds of escaping steam; now hardly any is visible. In comparison, it seems like Sunday, or as if the work was stopped, whereas, actually, the output is at times greater than before. The fact that so much exhaust steam could be utilized has somewhat modified the original plans of dispensing with all the steam pumps. At points where there is little condensation due to exposure, evidently the lack of efficiency is of minor importance, as the heat passes on and is utilized for heating purposes. In outlying districts, however, there was a large amount of condensation in pipes and pumps necessarily located out in the air in many cases, to avoid danger from fire. A number of these pumps have been housed so as to save loss by condensation, and power pumps will be substituted for others in another sub-station, thus reducing the surplus of exhaust steam, when improvements will be stopped for a time until experience indicates the desirability of further change.

The question may be asked why it was decided to give up the electric-power system. The principal reason was that it was quite expensive, and, moreover, not warranted by a balance of the advantages for a location where much of the exhaust steam could be used for heating purposes. Even if interest on first cost were neglected, the quantity of exhaust steam which could be utilized for heating purposes would be many times as much as the steam required to operate the dynamos. This last steam had to be supplied as well as the first, and, if supplied through steam engines, the power could be developed with only the extra cost due to heat lost in the performance of work, which is comparatively trifling in such a place, and the heat lost by radiation during transmission. So long as the heat lost by radiation was less than the cost of the power in the best compound engines, the use of the latter was not warranted even on economical considerations, and when the cost of the electric plant was considered, the balance was decidedly in favor of the plan finally decided upon. It does not follow that this decision would apply as a general rule. Every case must be decided on its own merits, but in making such decision great pains must be taken to obtain the probable results in practice rather than those which have been shown under experimental conditions. The small electric-transmission plant previously referred to is now in operation. It is a three-phase alternating system, put in by the General Electric Company. A 75-kilowatt 550-volt generator is provided, it having been decided on consultation to make it large enough to furnish all the incandescent lights then supplied from three small plants in different parts of the yard. There are about 60 horse-power of motors distributed at outlying points, the units varying from 5 to 30 horse-power.

The electric conductors displace about 2,000 feet of steam pipe of various sizes which it was necessary to keep hot winter and summer. In locations where gases exist that a spark would light, the variable starting resistance has been omitted from the motors, and the switch blades are immersed in oil, so that the electric apparatus is absolutely sparkless. The change has improved the electric lighting, and the motors are also operating quite satisfactorily.

DISCUSSION.

Mr. J. G. Winship.—I am especially interested in the part of Dr. Emery's paper relating to steam pumps. In the infancy of the oil refineries, when a party wished to purchase a steam pump to do a certain work, it was particularly specified that the pressure would be liable to drop 25 or 30 pounds and the proportions of the cylinders must be arranged to suit the conditions. Consequently, a much larger steam cylinder had to be provided than would have been necessary if a steady pressure of steam had been maintained; thus causing an increased consumption of steam in running the pumps. Then, in the beginning the companies had their fortunes to make, and the first cost was of more consequence than now.

From the first, the firm with which I am connected has furnished a portion of the pumping plant of the various refineries, and has always recommended the adoption of high-duty pumps. The Standard Oil Company began the use of economical pumps about six or eight years ago, and, finding the results so gratifying, have installed the same style in all their refineries. The consumption of steam was over 50 per cent. less than with the old type. In the case of the Tidewater Oil Company a large saving is made by utilizing exhaust steam in place of live steam, and also in the use of power pumps driven by an automatic cut-off engine.

The policy of concentrating so much of their plant in one unit is questionable, for no piece of machinery is infallible, and a serious break in the motive power would be disastrous in disorganizing the work of the plant. I think it would be better to divide up the work in more units, and adopt the most economical type of steam pumps.

Mr. F. Meriam Wheeler.—I am not surprised to learn by Dr. Emery's paper that the saving in steam is about one-half, for I remember some tests which I made years ago for the Standard Oil Company where we secured even greater saving than that amount. In the case I refer to about half a dozen steam pumps were employed for furnishing the supply of water for the condensers of the refinery, the quantity of water required amounting to several million gallons per day. They were using several makes of pumps, of the single and duplex types, and I remember that the consumption of steam was very great. As some of the pumps, especially the duplex, did not make even seven-tenths of their rated stroke, you can readily imagine what the loss from clearance alone would amount to. One particular pump had an adjustable valve gear, thus making it possible to get a full stroke, but this advantage was entirely overlooked and neglected. This lot of steam pumps was afterwards replaced by a more economical type built by our company, namely, a compound condensing pump. This pump was installed on a guarantee of a saving of its entire cost in fuel within one year, that being the amount we were to receive in payment. Before many months had elapsed our clients were glad to cancel the contract and pay the regular price of the pump, as it was very evident that we would exceed our guarantee by a considerable amount, and thus secure more than the usual price of the pump.

The consumption of steam in an ordinary steam pump is far beyond what it is generally supposed to be. Even engineers and others who are directly interested in the subject do not realize how high the rate of steam really is in the average pump, especially of the duplex type. As Dr. Emery says, some pumps require as high as 200 to 300 pounds weight of steam per indicated horse-power per hour. I recently read in one of the technical papers an article written by a well-known authority (Mr. Barr) wherein he quoted a case where the consumption of steam was as high as from 500 to 600 pounds per indicated horse-power per hour, but he remarked that in the case of the duplex pump referred to it was not in good working order, although it was a new pump.

Dr. Emery mentions 80 pounds as a fair rate of steam consumption for pumps. Even that seems very high, compared with the economy of the modern steam engine. Why cannot we have the same refinements in pump practice at least approaching what has been accomplished in steam-engine practice?

It is certainly remarkable that large corporations such as those named have been so long in adopting a more economical type of steam pump, especially where large quantities of liquids are handled day and night.

However, to come back to the subject to which I first referred: As I remarked, there was installed one large compound pump, by the use of which the consumption of steam was reduced from about 150 pounds to 35 pounds weight of steam per indicated horse-power per hour—quite a saving!

Also take the blowing engines used by the refineries of these companies, by which they agitated the oil. It has been the custom to use the direct-acting type of blowing engines, or what they term "blowers" (and they do blow a fearful amount of steam away, to no good purpose!). These so-called "blowers" will consume, on an average, at least 120 pounds weight of steam per indicated horse-power per hour. Now, any one familiar with machinery for compressing air or gases knows that the direct-acting type is the last system to adopt for the purpose. For pumping water or other liquids the direct-acting steam pump is all right, but when it comes to handling air or gases the crank and fly-wheel system is the only proper one to employ. About five years ago I persuaded certain officials of the oil company mentioned to discontinue the use of their direct-acting blowing engines, assuring them they could save at least 60 per cent. of the steam by adopting the fly-wheel type. I designed a blowing engine of this kind, and when it was installed a careful test was made by a committee of experts especially appointed by the company, and it was shown that a saving was secured even greater than the amount guaranteed. Since that time the company have used no other type of blowing engine.

It does seem strange that corporations and others who have extensive steam plants will overlook the subject of steam economy in steam pumps and other auxiliary engines, and yet will be so very discriminating in regard to their regular steam engines in the matter of economy, giving a great deal of attention and time in deciding on the best type for highest economy.

Now take the matter of pumps for elevator service: It is an astonishing fact that to-day in New York City thousands of dollars' worth of coal is wasted every day unnecessarily. Take one street alone, Broadway, and the steam which is wastefully used by the steam pumps in the large buildings is something enormous. The loss of steam, measured in dollars, means quite a fortune. I only wish I had the amount represented by this loss as an income! It would enable me to retire in a few years. This statement may surprise many, but it is nevertheless true.

However, we are slowly getting around to a more economical system of steam pumps, particularly in those of small size. Even in pumps developing only 2 or 3 horse-power a great saving of steam can be secured. Take a pump of this size, and by compounding it you can save its entire cost in a little over one year's time in saving of fuel, over that required by a simple pump, such as are commonly sold in the market.

Any one present can readily see this by the following illustration: The case in point was at an electric-light plant in Ohio, where they had been using a 6 x 4 x 6 duplex pump developing about three indicated horse-power. A compound (non-condensing) pump of the single type, having a 6-inch diameter high-pressure steam cylinder, 10-inch diameter low-pressure steam cylinder, 5-inch diameter water cylinder and 10-inch stroke, was substituted, with the result that a saving of steam at the rate of 120 pounds per indicated horse-power per hour was accomplished. Figuring on 10 hours a day, and 300 working days to the year, this shows a saving of over a million pounds of steam. Now it is a good boiler which will average 8 pounds evaporation per pound of coal, and on this basis the coal saving would amount to 135,000 pounds, or 60 tons, per annum. With coal, say, at $3 per ton, this represents a saving of $180 the first year, which, by the way, is about the price of the compound pump. This illustration is one taken from everyday practice, and shows conclusively that although the first cost of the more economical pump may have been twice the price of the other pump, the former was decidedly the cheaper pump in the end.

Certainly this subject of steam economy in steam pumps of moderate size deserves more attention than has been given to it by the average user of such pumps.

Prof. James E. Denton.—I desire to ask Dr. Emery if, in closing, he will not say if pumps of 10 horse-power or more would consume 45 pounds of steam per indicated horse-power per hour, how much saving could have been effected by their use. We made a very careful test of the 10 horse-power compound direct-acting air pumps on the *Bremen*, one of the Hoboken ferry boats, to determine its consumption, and we found that a direct-acting non-condensing pump of 10 horsepower would consume 40 pounds of water per horse-power per hour.

Mr. H. de B. Parsons.—The subject of fuel-saving is one which is always of the greatest interest to both the user and the engineer. Many years ago there was in use in a certain iron mine a battery of two boilers, which supplied steam to a number of rock drills, and a large old-fashioned pump. The capital of the company was small, and it therefore could not undertake the expense of reducing the cost of pumping by replacing the old machine with a more economical one. The quantity of coal used in this battery, however, was large, and it was necessary, if possible, to reduce the amount. Against great opposition on the part of many of the directors, it was recommended that a third boiler be added to the battery of two, for the purpose of reducing the fuel consumption. After considerable argument, the opposing directors agreed to try the experiment, and while the piping, drills, and pump remained the same, the saving in fuel after the three boilers were put in use was very large. I have not at hand the exact percentage of this saving, but my recollection is that it amounted to about 25 to 30 per cent. The coal used was anthracite.

Mr. F. A. Scheffier.—If, as Dr. Emery states in his paper, the average water consumption of the pumps before he made the changes was 150 pounds of water per horse-power per hour, and he cut down the fuel consumption to one-half the annual amount, is it not true that the present plant is operating at about 75 pounds, and that there is a pretty good opportunity for cutting that down?

*Dr. Emery.**—The discussions as to the economy of steam pumps have been very full and interesting, but a prominent feature thereof has not been fully appreciated by some of the speakers. The fact is that the exhaust steam from all the engines, except one large compound pumping engine, is utilized for heating purposes, so the power costs practically nothing. As the paper states, it was finally found that so much exhaust steam could be utilized that very many of the original steam pumps were retained, and simply moved into buildings to re-

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* Author's closure, under the Rules.

duce the loss by condensation in pipes and steam cylinders to a minimun, as evidently any losses of heat by external radiation could not be recovered. With such apparatus the steam not utilized for power in the engine simply passes to the exhaust pipes and is used for heating, and the kind of pumps or other engines used is of no consequence. We have therefore a direct answer to the question of several parties, that in general no saving would be made by using more economical pumps. This statement is, however, only true under the conditions obtaining at this particular location. The considerations which have been so ably presented by Mr. Winship and Mr. Wheeler, and implied in the questions of Professor Denton and others, would apply in very many cases, but do not to this particular one.

A Member.—I would like to ask Dr. Emery if there is any free exhaust left after the steam passes around through the heating pipes, and also about what was the size of the units used in the steam engines of the power pumps.

Dr. Emery.—There is practically no free exhaust in the yards at all. Whatever exhaust is left goes into a large tank to heat the feed-water. There is some waste from the surface of this tank in the summer time, so that we are planning to cover it, and to put in another pumping plant operated by economical engines to reduce the consumption in summer, with the expectation that a little live steam will be required in winter, which will be warranted by the saving during the rest of the year. Mr. F. W. Edwards, the very able superintendent of the works, has, however, suggested that a large compound condensing engine used for pumping salt water through the yards can be run high pressure, and the exhaust utilized during the winter, which will be conducive to economy, if the conditions another season warrant it. As I have already stated in the paper, the success of this method is largely due to the zealous coöperation of the executive officers of the refinery, among whom should be mentioned, besides the superintendent, above referred to, Mr. P. R. Gray, superintendent of the P. & L. Department, and Mr. J. E. Morse, the chief engineer of the establishment.

DCLXXII.*

SOME EXPERIMENTS WITH THE THROTTLING CALORIMETER.

BY AUG. A. GOUBERT, NEW YORK CITY
(Member of the Society),

AND E. H. PEABODY
(New York City, N. Y.).

In the course of their experience in making boiler tests, the authors of this paper, in common with most engineers who have been engaged in that line of work, have found the determination of the amount of moisture in steam, even by the most approved methods, exceedingly unsatisfactory.

The invention of the throttling calorimeter was hailed with delight, as it was at first supposed that, with boilers working within the limits of good practice, the exact condition of the steam could be ascertained readily and continuously.

It was soon found, however, that a great difficulty lay in the obtaining of the true average sample of steam.

Many have been the experiments and discussions on this subject, and controversy has waxed hot even in the meetings of this Society as to form and location of sampling nipple, whether it should be plain and open-ended, slotted, or perforated, with holes large or small, until finally a method has been suggested involving the testing of the entire amount of steam furnished by the boiler. But in all these methods it is assumed that the correct sample of steam once obtained, the throttling calorimeter will give an accurate reading of its condition.

That this is not the case with the accepted mode of using the instrument the following experiments seem to demonstrate.

In these experiments, which were conducted for the Babcock & Wilcox Company, at their works, Elizabethport, N. J., unusual facilities were afforded, as the boiler at our disposal was under

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* Presented at the New York meeting (December, 1895) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

our absolute control, and the pressure and rate of evaporation could be varied at will—the steam being discharged through a bleeder directly to the atmosphere. But nothing was done to increase or decrease the percentage of moisture in the steam, as this was foreign to the purpose of the investigation.

Great care was used in the selection and standardizing of instruments.

Having in a preliminary test ascertained the wonderful sensitiveness and reliability of the Bristol recording thermometer, an order was placed with the manufacturers for two of these, with the proviso that they should read exactly alike through the whole range of the diagram or chart. Tests in water for the lower temperatures and in heated oil for the higher, showed them so sensitive that they would be at variance whenever the liquid was left undisturbed, and so accurate that as soon as the liquid was thoroughly stirred they would read exactly alike.

The mercury thermometers were all compared to one which had been standardized by the maker, and as they all agreed within less than one-half degree, they were considered sufficiently correct. Sometimes during the experiments two or three of these would be placed together in the same well for comparison, and readings found almost absolutely alike.

The thermometer wells were of iron, specially made, the walls being one sixty-fourth of an inch thick; they were three inches long and filled with mercury.

A Bristol recording gauge and an Ashcroft test gauge, both standardized by comparison with a mercury column, were also used to record pressures of steam.

In the accompanying charts the results will be found carefully plotted with all corrections made.

Three calorimeters were used, and it was thought best to have them all of the same construction, as shown in Fig. 26; this being the form of apparatus recommended by Mr. Barrus.

Two of them, marked respectively *A* and *B* on the drawing, were made practically alike and connected with open-ended nipples directly opposite each other in the vertical portion of the steam main on top of the boiler.

The third calorimeter *C* was connected closer to the boiler drum, but with a longer and somewhat crooked arrangement of piping.

The orifices of throttling diaphragms were $\frac{1}{16}$ inch in diameter.

The recording gauge was connected at *E*, Fig. 26, close to the sampling nipples of calorimeters *A* and *B*, the test gauge being placed on the steam pipe at *U*. For comparison the test gauge was also tried at *M*, as shown by dotted lines on the figure, no difference being found in the readings.

The first part of the investigation was conducted with a view to determine whether or not it is absolutely necessary in practice to correct the readings of the calorimeter for radiation and loss of heat through the walls of the instrument when it is properly clothed with non-conducting covering.

Having as yet experimented with only the Barrus form of apparatus, we limit our remarks accordingly; but that for this instrument a calibration is a necessity, will appear on reference to Charts I., II., III., and IV. (Figs. 27 to 30).

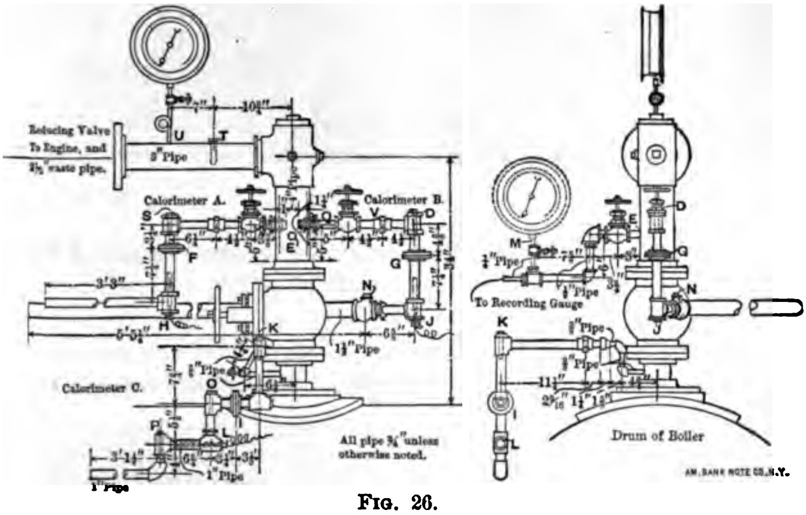


FIG. 26.

In the experiment recorded on Chart I. (Fig. 27), calorimeter *C* was connected to another boiler in such manner as to obtain wet steam. Mercury thermometers were placed at *O* and *P* (Fig. 26), a recording thermometer being connected between these two at *L*. Minute readings were taken instantaneously on the stroke of a gong. It will be seen that there is a wide divergence between the readings of the three thermometers.

In the experiment shown on Chart II. (Fig. 28), and in which the intention was to test the sensitiveness of the apparatus, the calorimeter was connected to the safety valve nozzle and variations prowrapped, the orifices the same size, calorimeter *A* gives readings from 10 degrees to 18 degrees higher than *C*, this being probably due to the longer connections.

That all these causes of error are eliminated when a proper calibration of the instrument is made is true, but they undoubtedly show also its necessity.

And now arises the question: How should such a calibration be made?

On page 794, Vol. XI., of the *Transactions* of this society, Mr. Barrus advises that readings be taken "at a time when the pressure is steady and the pipe contains nothing but dead steam, there being no current," this calibration being of course made at the average pressure—that is, that ordinarily the pressure existing previous to such calibration must be increased or decreased until it reaches the point of such average.

A series of such calibrations at various pressures will be found on Chart V. (Fig. 31).

It will there be seen that when the point of steady average pressure is reached by allowing the pressure to go down, the lower thermometer will read in some cases 20 degrees higher than when the average pressure is reached in rising from a lower one.

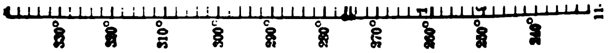
A somewhat more elaborate method which has been used by the authors consists in closing the stop valve and allowing the pressure to rise until the safety valve is about to blow, then opening the furnace doors, and, as the pressure is slowly decreasing, taking readings for every pound during the fall of pressure.

The correction for radiation is then made by comparing each calorimeter reading with the calibration for the pressure corresponding, but reference to Chart IV., which illustrates this method, will show that the readings taken on a falling pressure vary just as much from those on a rising pressure as they do on Chart V., and that such calibration is just as erroneous.

The only explanation of this that we can thus far offer is that when the pressure is falling, the walls of the instrument having been heated to the higher temperature, impart heat to the small volume of steam flowing through, the contrary taking place on a rising pressure.

Probably a more correct method of calibration is that shown on Chart VI. (Fig. 32).

In this experiment a short portion of the inlet pipe to calo-


330°
320°
310°
300°
290°
280°
270°
260°
250°
240°

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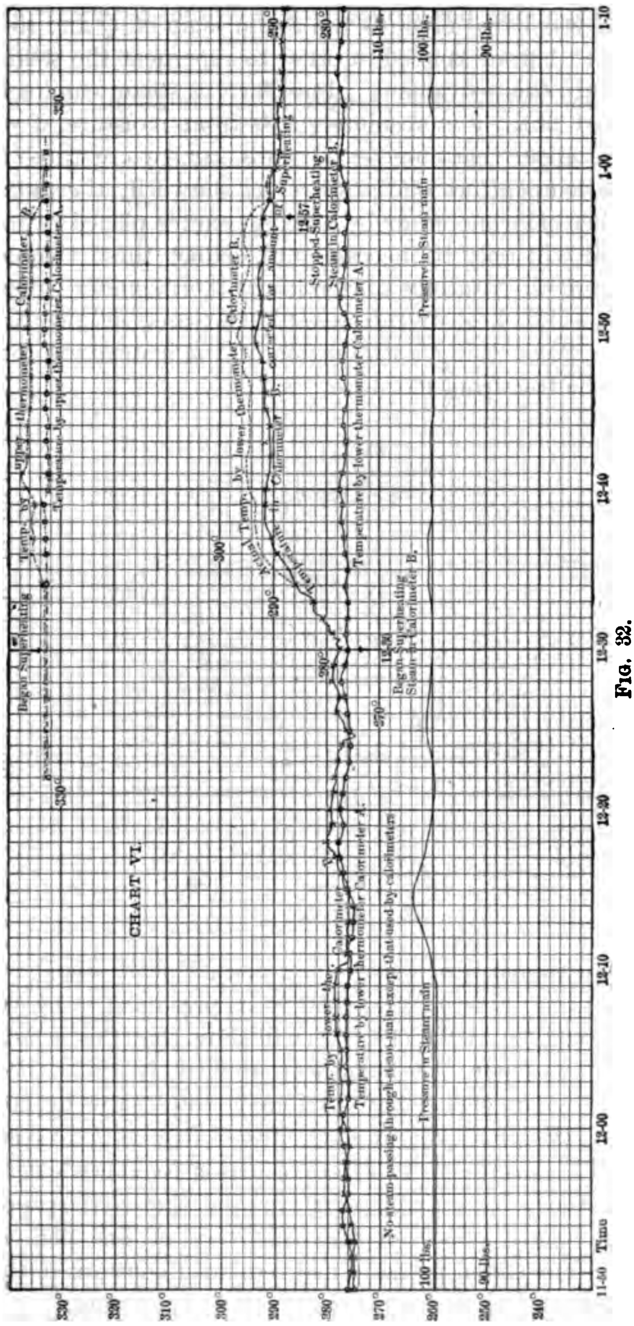
CHART VI.
Began Superheating
Temp. by upper thermometer Calorimeter B.
Temperature by upper thermometer Calorimeter A.
Actual Temp. by lower thermometer Calorimeter B.
Temperature in Calorimeter B. corrected for amount of Superheating
12.57 Stopped Superheating Steam in Calorimeter B.
Temperature by lower thermometer Calorimeter A.
12.30 Began Superheating Steam in Calorimeter B.
Temp. by lower the Calorimeter B.
Temperature by lower thermometer Calorimeter A.
No steam passing through steam main except that used by calorimeters
Pressure in Steam main
110 lbs.
100 lbs.
90 lbs.
330°
320°
310°
300°
290°
280°
270°
260°
250°
240°
11-50
Time
12-00
12-10
12-20
12-30
12-40
12-50
1-00
1-10

FIG. 32.

rimeter *B* was bared close to the steam main at *Q* and the flame of a Bunsen burner applied in order to superheat the steam at its entrance into the instrument. Inasmuch as steam cannot become superheated until it is absolutely free from moisture, if we heat it until the upper thermometer *D* reads, say, two or three degrees above the temperature of the steam as shown by thermometer *S* in the other calorimeter or by a thermometer placed in the main as at *T*, it will only be necessary to deduct these two or three degrees from the readings of the lower thermometer—presuming that the specific heat of the steam is the same at the two pressures—the result being a calibration of the instrument for steam known to be free from moisture.

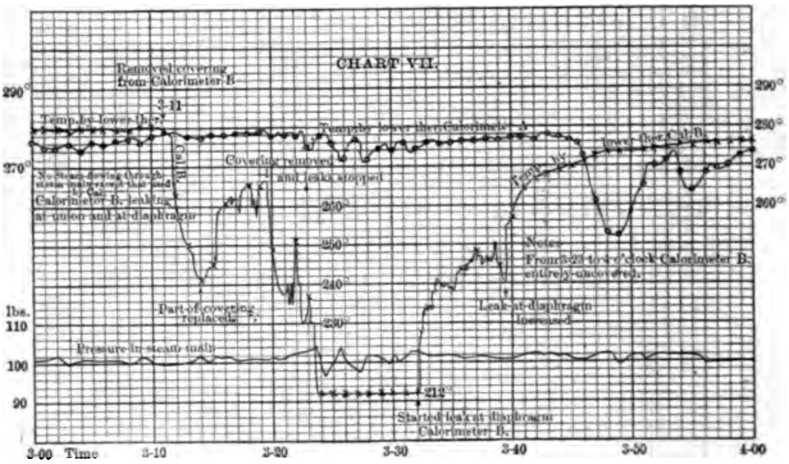

FIG. 33.

This experiment was carried on with "dead steam," which, according to Mr. Barrus, "may fairly be presumed to be dry."

Reference to Chart VI. (Fig. 32) will show that this is not a safe assumption, as when the flame was applied at 12:30 the upper thermometer remained steady for four minutes, showing no superheat, while the lower thermometer rose 8 degrees, and continued rising until the temperature, after correction for superheat, showed 14 degrees above the starting point; in other words, the supposedly dry steam contained about three-quarters of one per cent. of moisture. The steam pressure had remained constant in this case for one and one-half hours previous to the experiment.

The following table gives the readings of the lower thermometer of calorimeter A for different pressures and different methods of calibrating:

CALIBRATIONS OF CALORIMETER A AT DIFFERENT PRESSURES AND BY DIFFERENT METHODS.

Pounds Pressure by Recording Gauge.	TEMPERATURE IN DEGREES FAHR. BY LOWER THERMOMETER OF CALORIMETER A.							
	Pressure Changed.						Constant Pressure.	
	Quickly and Held at Different Points for 8 to 10 minutes.		Quickly and Continuously.		Slowly and Continuously.		Dead Steam Used.	Superheated Steam Used.
	Falling.	Rising.	Falling.	Rising.	Falling.	Rising.		
160	....	....	....	....	290–297	....	....	....
140	....	....	....	....	291–299	286–295	....	....
126	....	290	292	....	293–299	278–292	....	....
123	292	....	292	....	298	277–289	....	....
105	....	282	293	281	295½	278	....	....
104	294	....	292½	280	295½	268–282	....	....
100	....	....	292½	279	294	270	278	292
84	290	271	295	275	291	262–272	....	....
68	284	....	294½	277	283	277	....	....
66	....	263	294	277	281	277½	....	....
44	277	....	281½	281	....	....	....	....
43	....	260	....	....	....	....	....	....

It is worthy of notice that the calibrations with falling pressures approximate very nearly to those made with superheated steam, the radiation from the walls of the instrument evidently being sufficient to dry the steam before it reaches the diaphragm. But as this would vary with the size of orifice, amount of metal in the instrument, and pressure of steam, it cannot fairly be relied upon to give a correct calibration.

Another experiment, although having no direct bearing on the subject, is illustrated on Chart VII. (Fig. 33), and will be found somewhat interesting.

With a view to determine the effect of slight leaks upon the reading of the instrument, the union *V* and flange *G* of calorimeter *B*, Fig. 26, were loosened. It was expected that the leakage of steam in wetting the covering would cause the calorimeter to show less superheat than before.

Contrary to expectation, the reading was higher, and further investigation brought out some curious results.

The experiment was begun with both calorimeters *A* and *B* covered with hair felt one inch thick, and calorimeter *B* leaking as above mentioned.

At 3:11 the covering was removed from calorimeter *B*. At 3:14 part of it was replaced, and again removed at 3:19, the instrument remaining uncovered during the rest of the experiment. By 3:24 all leaks had been stopped and the temperature had fallen to 212 degrees. At 3:32 a leak was started at the diaphragm, and the temperature immediately rose some 30 degrees. At 3:39½ the leak was increased, and by 3:45 the temperature had risen another 30 degrees. From then until the end of the test, at 4 o'clock, the temperature continued to rise slowly and the phenomenon was observed of an entirely uncovered calorimeter with a leak at the diaphragm showing more superheat than a calorimeter protected by an inch thickness of hair felt, the leaky calorimeter under these conditions evidently acting as a separator.

This record of a few experiments undertaken by the writers with a view to throw some light on discrepancies arising in the use of throttling calorimeters is submitted to the Society in order to invite discussion.

The adoption by this body of a standard method of conducting such tests would seem advisable, as certainly the results obtained by different engineers cannot be compared unless the methods employed are exactly the same; and the determination of the percentage of moisture in boiler trials will always be in discredit as long as " doctors disagree."

DISCUSSION.

Prof. R. C. Carpenter.—I am very much interested in this paper, as we have been making a similar line of experiments, and I presume have obtained a similar difference in thermometer readings arranged as shown in the paper.

My explanation of this difference, however, is very different from that given by Mr. Goubert, and, as I have some facts to back up my explanation, I think my reasoning is sound in this respect. For instance, the authors find a difference in the reading of the thermometers when they are arranged in a certain way. His conclusion from that fact is not that the reason is due to variation in the sample, but that the calorimeters themselves disagree and give inharmonious results. Now, it is that conclusion which I contest. I am certain that the reason of this variation is not due to any discrepancy in the instruments themselves, but it is due to the fact that the sample which passed into these two instruments was not the same. In some experiments in Sibley College we arranged a vertical pipe with glasses in the side so that we could observe the steam as it was flowing through the pipe. Similar constructions were tried both in a vertical and a horizontal pipe. In nearly every case when we would find a thermometer in a calorimeter to vary up or down we could trace the cause to a drop of water which had gotten in the sampling pipe and entered the calorimeter. I think the author would have found that the cause of the apparent change in the reading of the thermometers was entirely due to corresponding variations of the quality of steam in the instrument, and in no case to the instrument itself.

It seems to me that in the use of the throttling calorimeter we should follow out as nearly as possible the method laid down by Professor Peabody in his first description of the instrument. We may need to correct for any condensation in the instrument. We may need to correct for our readings of the thermometers. It is impossible to get a thermometer, as we ordinarily would place them, at least, which will read the correct temperature of the steam, because of the radiation of heat from the glass stem. The instrument itself when these corrections are made is not one which requires calibration. We should measure that heat accurately before and after it has passed the throttling orifice, and from these results compute the quality. It seems to me that it is hardly fair to assume that any one condition of the steam is one to which all results should be referred. Regarding the loss of heat from thermometers: it may be said that this is quite marked, as, for example, in trying two thermometers in two separate calorimeters, one of which was entirely immersed in steam, and the other clothed with felt two or three inches thick; the difference was never less than three degrees in the reading.

Now, as to the amount of error made by the difference in the readings of these thermometers. Professor Denton has very ably shown that there is likely to be a great variation in the samples of steam. I think there is quite certain to be such a variation. It should be noted that with this instrument you can have a very large difference in the reading of the thermometer without a very great difference in the quality of the steam. For instance, a difference of ten degrees in thermometers, when the steam is 380, makes a difference of less than a half per cent. in our results. So you see that this thing, while it looks big on the thermometer, is in reality very small when we figure out the effect on the quality of the steam. My own notion is, from the results of our experiments, that the instrument itself is thoroughly reliable, but that it is possible to get into it samples of steam which do not represent even approximately the average in the steam pipe.

Mr. William Kent.—In the light of Professor Denton's experiments, which show that the great difficulty with small throttling calorimeters is not due so much to inaccuracy of these instruments themselves as to the impossibility of obtaining a true average sample of the steam from the main steam pipe, it would appear at least possible that the variations in the results found by Messrs. Goubert and Peabody were due to the variations in the quality of the steam which entered the two calorimeters. Because the nozzles supplying the two calorimeters were inserted opposite to each other in the vertical steam pipe, it by no means follows that the quality of the steam collected by them was identical. In some experiments which I made in 1892, reported in an article in the *American Machinist* of August 4 in that year, I made a comparison between a Barrus and a Heisler calorimeter. A perforated nozzle was inserted into the vertical steam pipe leading from the boiler, and the half-inch pipe leading from it was fitted a short distance from the pipe with a Y branch, to which was attached by short nipples the two calorimeters. By this contrivance it was expected that the samples received by the two calorimeters would be identical. In 22 tests the highest apparent percentage of moisture found was 0.57 per cent., and the lowest – 0.01 per cent.; that is, a very trifling superheating. The maximum difference at any time observed between the connected readings of the thermometers of the two calorimeters was 4 degrees Fahr., which would represent a difference of 0.21 per cent. in the moisture, but the average difference was only 0.3 degree, representing only about 0.015 per cent. moisture. The results obtained by the two calorimeters were therefore practically identical.

Prof. D. S. Jacobus.—There are two ways of calculating the percentage of moisture indicated by the Barrus calorimeter. One is that recommended by Mr. Barrus, and the other is the way which Professor Carpenter has just described, in which the theoretical formula is used. We have employed both methods. The method which is recommended by Mr. Barrus is to calibrate the instrument with steam which he called "dead steam," or steam obtained from a pipe open to the boiler shut off at a point beyond the calorimeter, so that the steam in the pipe is practically in a state of rest, and call the reading of the lower thermometer under these conditions the reading for dry steam, or the "normal reading." The other way, as I have just stated, is to employ the theoretical formula, which is based on the fact that the total heat of the mixture of steam and entrained water on the high-pressure side of the orifice is equal to the total heat of the superheated steam on the low-pressure side. If the work is carefully done, the two methods agree with each other to within one-fifth of one per cent.

The method recommended by Mr. Barrus is the most convenient and reliable, because the normal reading, when properly obtained, includes all radiation effects, and corrects for any constant error there may be in the thermometer used to measure the temperature of the superheated steam on the low-pressure side of the orifice; whereas, if the theoretical formula is used, the effects of radiation and the errors of the thermometers must be determined separately and allowed for.

In obtaining the normal reading by experiment, the nipple which furnishes steam to the calorimeter must be arranged so that there is no possibility of moisture entering it along with the steam. We have obtained reliable readings with a nipple with no side holes, which projected upward for several inches into a horizontal pipe. We have also obtained reliable readings by attaching the calorimeter to the separator which Mr. Barrus furnishes with his calorimeter, the separator being furnished with steam which does not contain over five per cent. of moisture. In several cases we have endeavored to obtain reliable readings by means of nipples projecting into a vertical pipe, but have failed, probably on account of moisture which trickled down the sides of the pipe, or fell through the steam in such a way as to be drawn into the nipple.

Having determined the normal reading, the percentage of priming is found by dividing the difference in degrees between the normal reading and the temperature registered by the lower thermometer, by the quotient of the latent heat in B. T. U. per pound of saturated steam at the initial pressure ÷ 48.

If the theoretical formula is used all the measurements must be made with great refinement, otherwise there will be a considerable error in the result. The radiation of the calorimeter is an important factor, and has to be determined independently.

We have determined the radiation of the calorimeter, or the "heat gauge"—as Mr. Barrus calls it in the description of his Universal Calorimeter—in two ways: The first was to place a mercury well in the pipe leading to the calorimeter of exactly the same pattern as the well used for the thermometer placed in the steam after passing the orifice, and determine the loss of superheat in superheated steam when passed through the calorimeter. The superheated steam was passed through the calorimeter at the same rate at which steam flowed through it when it was in service. To do this the orifice plate was removed, and the steam leaving the calorimeter was throttled so as to give the desired flow at some pressure slightly less than that which existed when the calorimeter was in use. When the steam was superheated it was brought to about the temperature of the steam which passed through the calorimeter under ordinary conditions. Tests made in this way indicated that the radiation of the heat gauge used in the tests given in my paper on calorimeters amounted to 2 degrees Fahr. of superheating, or one-ninth of one per cent. of priming.* In this case the heat gauge was covered with about 1½ inches of hair felt, and the temperature of the air which surrounded it averaged about 120 degrees Fahr. The radiation of 18 inches of horizontal half-inch covered pipe leading to the heat gauge was found in the same way to be equivalent to 1.7 degrees Fahr., or one-tenth of one per cent. of priming.

In a test made at a recent date it was found that with no circulation of air, and a temperature of 97 degrees Fahr., the radiation of the heat gauge and the short length of pipe—six inches long—leading from the separator to the heat gauge was equivalent to 2¼ degrees of superheating. In this case the heat gauge and pipe were covered with about 2½ inches of felting.

In another series of tests, with the same amount of felting, in which there was a gentle circulation of air about the calorimeter, and the temperature of the air was about 85 degrees Fahr., the radiation of the heat gauge and pipe leading to the separator was 3.8 degrees Fahr. The orifice in all of the above tests was

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* See table, Volume XVI., *Transactions A. S. M. E.*, page 461.

one-eighth of an inch in diameter, and the weight of steam discharged at 80 pounds pressure was about one pound per minute. In the calorimeters experimented on by the authors of the paper the orifices were one-sixteenth of an inch in diameter, so that the radiation under similar conditions would be equivalent to about four times the number of degrees of superheating that is shown by my experiments.

A second way of determining the radiation of the calorimeter, which we have employed as a check on the method just described, is to remove the orifice plate from the calorimeter of which the radiation is to be determined, and place the calorimeter between a steam-supply nipple and a second calorimeter. The supply nipple was arranged so that no water could drip into it, by employing a vertical nipple with no side holes, projecting upward in a horizontal pipe, and the reading of the lower thermometer of the second calorimeter was determined for saturated steam at a given pressure. The calorimeter of which the radiation was to be determined was then removed, and the second calorimeter was placed directly on the supply nipple, and a second set of readings taken for saturated steam at the same temperature as before. The difference of temperature of the exit steam of the second calorimeter for the two conditions gave the radiation of the heat gauge. There was a slight correction to be made on account of the fact that a portion of the radiation of the pipe which surrounded the lower thermometer of the heat gauge did not affect the reading of the lower thermometer, and after this was done the results agreed with those obtained by the first method.

The radiation of the separator portion of the Barrus Universal Calorimeter was determined by means of superheated steam, as has been described in my paper on calorimeter,* and also by noting the condensation of steam when the exit from the separator was closed. By the first method the radiation amounted to 4 degrees Fahr. of superheating, which is equivalent to the condensation of $2\frac{1}{8}$ ounces of steam per hour, or one-fifth of one per cent. of priming. The temperature of the air was about 100 degrees Fahr. With a gentle circulation of air at 75 degrees Fahr. about the separator the radiation determined by the second method, or that of condensation, was found

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* *Transactions*, Volume XVI., page 452.

to be equivalent to 3¾ ounces per hour. With a temperature of air of about 100 degrees Fahr., and no draught acting on the separator, the radiation by the second method was exactly the same as that determined by the first method, or equivalent to the condensation of 2⅛ ounces of steam per hour.

The pressures at the inlet and exit must be accurately measured, and the latent heat values in the theoretical formula must be those corresponding to the pressures.

The temperatures registered by the mercury thermometer placed in the exit steam must be corrected so as to correspond to those registered by an air thermometer, in order to apply the theoretical formula. To do this the mercury well in which the thermometer is placed may be surrounded with saturated steam at known pressures, and, therefore, at known temperatures by an air thermometer, as given in steam tables, and corrections may be obtained for all points of the scale. If it is inconvenient to employ the identical well in which the thermometer is to be used for such a test, another well of exactly the same size may be used. There may be a large variation in the readings of a mercury thermometer for different depths of immersion. For example, a Fahrenheit thermometer in which the 32-degree mark was 1¾ inches from the bottom of the bulb, and the 350-degree mark was about 13½ inches from the bulb, read 7¼ degrees too low when immersed in a mercury well 1¾ inches deep which was surrounded with saturated steam at 120 pounds per square inch above the atmosphere; 6¾ degrees too low in a well 2½ inches deep; 5¾ degrees too low in a well 3¾ inches deep; 4¾ degrees too low in a well 5¾ inches deep; 2¼ degrees too low in a well 9¾ inches deep, and read correctly when entirely immersed. Special tests were made which indicated that all of the wells were of the same temperature, or that of the saturated steam, to within less than one-quarter of a degree Fahr., so that the above errors are entirely due to the fact that the stem of the thermometer was not immersed.

The above errors are about equal to the theoretical errors calculated by assuming that the temperature of the mercury in the portion of the stem which projects above the well is equal to the temperature of the air which surrounds the stems. These large discrepancies show how very misleading the results may be if the readings of the thermometers are not corrected for the column of mercury in the stems which are exposed to the air, and which consequently are not heated to the maximum temperature.

The indications of the Bristol thermometer used by the authors are not altered by the heating or cooling of the small tube which leads to the bulb, so that it has an advantage of a mercury thermometer in this respect. The Bristol thermometer might also be graduated so as to record temperatures by an air thermometer.

With superheated steam there will be larger discrepancies than with saturated steam, because in addition to the errors caused by not heating the stems of the thermometers, there will be errors due to the fact that the wells will not indicate the exact temperature of the superheated steam. The form and thickness of the wells cause a difference in the case of superheated steam, and a well having a thin neck and an enlarged end in the steam space may give a higher temperature in the case of superheated steam than an ordinary well of the same depth. It is for this reason that the mercury wells used for measuring the temperature of superheated steam in my tests to determine radiation were made of precisely the same form and size. In the case of saturated steam it is necessary to take into account the depth only of the wells, as no appreciable difference is found for wells of various patterns and thicknesses.

At this point it may be well to explain our present method of calibrating thermometers by means of steam at various pressures. The apparatus is shown in Fig. 34.

A is a reservoir formed of a length of 6-inch pipe, the top of which is closed with a cap. Seven mercury wells of various lengths, four of which are marked *a*, *b*, *c* and *d* in the sketch, are inserted in the cap. Steam is brought to a known pressure in the reservoir *A*, and in entering passes through water at the bottom of the reservoir. The water-glass *C* indicates the height of the water in the reservoir. The pressure is measured by means of the plug-and-weight device *B*. The bottom of the plug is on the same level as the pipe *R*. *D* is a gauge which is used to show the approximate pressure. The U-shaped pipe *H* is filled with oil. Before measuring the pressure the pet-cock *F* is opened slightly in order to remove any air that may be lodged in the small pipe leading to the pipe *H*. The siphon *P* is cooled by water contained in the can *O*. The pet-cock *J* is used to remove any water that may collect at the lower part of the pipe *H*, after which the pipe is refilled with oil at *F*. The accumulation of water in *H* is caused by leakage of oil around the plug of the weight device, and as this is a small amount there is but little water drawn from the pet-cock *J*. The valve *M* is opened slightly during the tests, so that steam is circulated continuously throughout the apparatus. The steam pressure is adjusted by means of the throttle-valve *K*. The plug *N* is removed for calibrations at atmospheric pressure. The valve *L* is used to adjust the water level. *S* is a vessel to receive any mercury that may overflow from the wells.

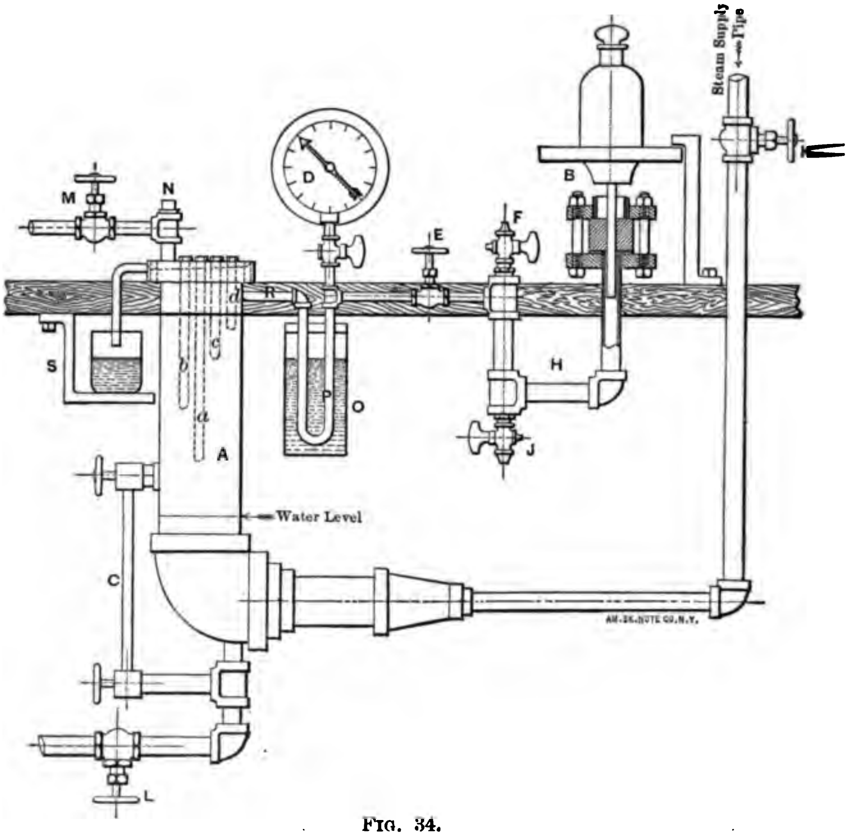

FIG. 34.

In measuring the pressure by means of the weight-device *B* the pan is spun around so as to eliminate the effect of friction. The diameter of the plug is 0.5 of an inch, and of the hole 0.5005 of an inch, both being ground true. The average diameter of the hole and plug is used in calculating the pressure. The difference in the pressure, if the diameter of the plug or the diameter of the hole were employed instead of the average diameter, would amount to about one-tenth of a pound in one hundred, and the corresponding variation in temperature would be about one-sixteenth of a degree Fahr.

The weights, which are sealed bottles filled with shot, were adjusted so as to correspond with a standard set of kilogramme weights, which were in turn compared with weights made by the Fairbanks Company.

Special experiments have been made which show that the temperature indicated by a 3-inch, or longer, well filled with mercury is the same as that of the saturated steam which surrounds it, and that the error of using a well as short as 1¾ inches which projects one inch into the steam space is less than one-quarter of a degree Fahr. for ordinary steam pressures. These experiments will be published at a future date.

It is interesting to note how nearly the readings of mercury thermometers in use to-day agree with the readings of the mercury thermometers used by Regnault for measuring the temperature of saturated steam. Table I. gives the results obtained with six thermometers manufactured by Mr. H. J. Green. These thermometers were selected at random, and all, with the exception of No. 817, had been used in previous tests. The readings given in the table are corrected for any discrepancy at 212 degrees, due to long use. All the thermometers were raised and lowered in temperature a number of times before taking the readings, so as to produce the corresponding amounts of depression and insure constant readings at given temperatures. It is seen that, taking the average of the four thermometers in which the degree marks were the longest, and which, therefore, allowed closer readings to be made, the largest discrepancy is about one-half of a degree Fahr., which is the same as the possible error due to reading the thermometers, as they could not be read closer than one-quarter of a degree Fahr. The thermometers were, of course, immersed to the full depth of the mercury in the stems, so that all the mercury in the thermometers was brought to the maximum temperature.

TABLE I.

READINGS OF MERCURY THERMOMETERS IN DEGREES FAHRENHEIT CORRESPONDING TO VARIOUS STEAM PRESSURES. COMPARISON OF READINGS OF THERMOMETERS MADE BY H. J. GREEN WITH READINGS OF MERCURY THERMOMETERS USED BY REGNAULT IN MEASURING THE TEMPERATURE OF SATURATED STEAM.

Number of Thermometer.	Pressures in pounds per square inch above atmosphere at which readings were taken. Pressure of atmosphere, 14.70 pounds.				
	120	100	80	60	40
1	1	3	4	5	6
817	351¾	339¼	325¼	308½	287¾
900	351¼	338¼	324¼	307¾	287¼
463	351¾	338¾	324¾	308	287¼
461	351¼	338½	324½	308	287¼
* { 831	350½	338	324¼	308	287
* { 821	351	338¾	324¾	308½	287½
Average of first four.......	351.5	338.7	324.7	308.1	287.4
Reading of Regnault's thermometers. Mercury.	351.6	339.1	324.8	308.1	287.4
Reading of Regnault's thermometers. Air †....	349.8	337.6	323.7	307.1	286.5

Thermometer No. 817 has a stem about 19 inches long, graduated from 27 to 430 degrees Fahr.
" " 900 " " " 16 " " " " 15 " 450 " "
" " 463 " " " 17½ " " " " 94 " 406 " "
" " 461 " " " 11½ " " " " 192 " 406 " "
" " 831 " " " 15½ " " " " 90 " 610 " "
" " 821 " " " 16 " " " " 80 " 680 " "

* Not included in average, as the graduations were closer together than in the other thermometers, and the probable error of reading was therefore greater.

† The temperatures measured by the air thermometers are those given in the ordinary steam tables.

The matter which I have presented shows how difficult it is to obtain correct readings with a calorimeter when all the conditions are constant. If the conditions are variable, as was the case in some of the tests made by Messrs. Goubert and Peabody, reliable readings cannot be obtained. When in their tests the steam pressure was raised and lowered there were considerable discrepancies, caused partly by the fact that the heating or cooling of the walls of the calorimeter produced a retarding effect, and partly by the fact that when the pressure was lowered in the steam pipe the walls of the pipe tended to impart heat by conduction to the steam which it contained. In their tests to determine the normal reading by means of superheated steam there may have been an error in the reading of the thermometer used on the high-pressure side of the orifice to indicate the point at which superheating began. We have found considerable variation under such conditions with different forms of wells. If the temperature at which the steam began to superheat was accurately determined, the normal reading which they obtained should have been higher with the superheated than with the saturated steam, by an amount equal to 3 degrees Fahr., plus the equivalent of the heat radiated from the small pipe leading from the steam main to the calorimeter. These two factors will account for a portion of the difference which they found. If the experiments were made correctly, there would be a difference of about 3 degrees Fahr. in the normal reading for saturated steam which is slowly condensing and steam just at the point of superheating, and the 3 degrees given above is to allow for this difference.

Mr. George I. Rockwood.—It appears that in the future no moisture tests are to be received as accurate unless made by the use of a separator on the main steam pipe itself.

This is a new and a very important step which is here being taken, and it ought to be very fully realized what an important bearing it has on tests of the performance of engines and boilers which we have heretofore regarded as quite accurate, tests which now must be thrown out as uncertain.

Mr. W. B. Le Van.—I have heard a great deal to-night about the amount of moisture in the steam, and a great deal of fine work being done to arrive at its percentage. Seven-eighths of the commercial boilers in use make wet steam and one-eighth dry steam. Now, if all this intelligence and time were spent in improving the wet-steam boilers, I think we would have no necessity for all this fine work and standardizing of calorimeters.

There are several boilers made which produce dry steam, the Harrison, for instance. If the object of this Society is to benefit its members we ought to turn our attention to making dry steam in place of wet. I would suggest that the Harrison or similar boilers be recommended, of which there is a number.

A Member.—I have just been testing a Harrison boiler, and it threw off 10 per cent. of moisture.

Mr. Le Van.—I find that at the International Exhibition at

Philadelphia in 1876 the following-named boilers made dry superheated steam:

Wiegand	13.40	degrees	superheated
Harrison	2.27	"	"
Firmenich	26.70	"	"
Rogers & Black	43.95	"	"
Andrews	52.59	"	"
Root	37.81	"	"
Lowe	9.80	"	"

It will be seen from the above that boilers can be built to produce superheated steam in place of saturated steam, if it is desired.

I insist and maintain that if a boiler is properly constructed and erected, superheated steam can be produced and maintained, especially in view of statements made by Professors Carpenter and Jacobus during the discussion on calorimeters.

Mr. H. C. Spaulding.—Will Professor Carpenter kindly explain his statement regarding the presence of superheated steam in contact with water, and state under what circumstances this may occur?

Mr. Carpenter.—I think the thing is entirely reasonable, if we only think of the nature of superheated steam; it is practically a gas, and is a poor conductor of heat.

Mr. Jacobus.—That is so.

*Mr. A. A. Goubert.**—In closing this discussion I would say that Mr. Kent's remarks are evidently founded on a misapprehension. Calorimeters *A* and *B*, which were identical and connected opposite each other, taking steam from the centre of the steam pipe, always gave results practically alike; but calorimeter *C* is the one whose results are shown to be different, due evidently to longer connections, and the variations as shown on Charts I. and II., between the readings of the three thermometers at *O*, *L*, and *P*, all on the same or low-pressure side of the diaphragm, point to the necessity of a calibration. Every one of these thermometers will give correct results, providing that the instrument is calibrated with that thermometer.

In regard to Professor Carpenter's remarks, it seems that the same answer applies: *A* and *B* always read alike except when a change is made in the one such as adding extra covering.

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* Author's closure, under the Rules.

Repeated experiments have shown the same results even when the sampling nipple of one of the calorimeters was introduced vertically into the horizontal pipe in the way recommended by Professor. Denton.

The purpose of this paper is to invite discussion. It is not intended to tell you how to make a calorimeter test, for that is what I want to find out myself. The fact is that I have repeatedly had my attention called to calorimeter tests made by different engineers and in different places, and in which the results have been extraordinary, to say the least. I have in mind one instance where the sampling nipple was placed on the inner bend of a long vertical elbow, with the result that it was claimed the steam contained 47 per cent. of moisture, while a test made on the same boiler with the nipple located in a different place gave perfectly dry steam.

In another instance the calorimeter was connected at the end of a three-quarter-inch pipe, 18 feet long, and covered with a single thickness of burlap.

So that in view of Professor Denton's paper on the proper method of sampling steam, and our experiments showing how easily error in the readings can result from different methods of handling the instrument, I think myself justified in suggesting to you the necessity of adopting a standard method of making calorimeter tests if we desire comparable results.

Mr. F. W. Dean.—I presume I know the tests to which Mr. Goubert refers, in which he says a great amount of moisture was found, and which he says is easily accounted for. I did not make the tests, but I know something about them, and I do not think the difficulty is so easily accounted for. Some distance from the side of the main pipe there was a collar on the sampling pipe, and the holes which took the steam were drilled in such a way as to sample the steam equally from the different layers of the main pipe. We may imagine that through the centre of the main pipe a cylinder of steam went along, and then outside of it a hollow cylinder of steam, and so on, until the pipe was entirely taken care of. Now, if that large collection of moisture ran down the side of the pipe, it would be impossible for it to get on to the sampling pipe, because the collar would prevent it. All those difficulties were foreseen and provided for, and the whole apparatus was very carefully inspected by several different engineers, and they were unable to criticise it. The amount of moisture given in that case varied with the forcing of the boiler. As the boiler was forced more and more, the amount of moisture increased.

Personally I have never been able to get any such amounts of moisture from the same kind of boiler, even when forced about as much; but I am unable to see that any blunder was made in this case.

Mr. Boyer.—I would like to speak about the result of several tests made where calorimeters were used. In making the first test we placed one so that the steam came into the sampling pipe, as shown by Mr. Dean. I think we got about 1.6 per cent. of moisture. The result was criticised. It was said that our tests were all wrong. Professor Schwamb inserted his calorimeter in the opposite direction, and he got two-tenths of one per cent. more than we did.

Mr. Dean.—The boilers were on a lower level, and about 20 feet above the boilers the calorimeters were inserted, and the steam moved upwards. Now, as I say, if any moisture tended to run back on the main pipe, it was hardly probable that it could pass the collar. The tendency was to sweep everything upwards.

Mr. Kent.—What was the maximum moisture?

Mr. Dean.—I think it was 47 per cent. I did not take any part in those experiments, but I think that was it. It varied from 1 per cent. up to 47.

Mr. Kent.—Wasn't it the foaming in the boilers?

Mr. Dean.—I do not know of any reason why the boiler should have foamed. I tested a boiler of the same kind, a Babcock & Wilcox boiler, and got only a little over one per cent. of moisture.

Mr. Kent.—I made the statement a while ago that I never got over 3 per cent. of moisture. There was one case where I got an enormous amount of moisture, and that was because the boiler was supplying steam to a tremendous plant which was not using the steam, so there was a large amount of condensation, and that water was all running back into the boiler; but that was an unusual case. There may have been some similar conditions in this case.

DCLXXIII.*

THE RELIABILITY OF "THROTTLING CALORIMETERS."

BY JAS. E. DENTON, HOBOKEN, N. J.
(Member of the Society.)

The object of this paper is to present the complete† results of an investigation of this subject, undertaken at the request of a leading firm of builders of boilers ‡ to determine:

First. Whether it is, or is not, true that the proportion of moisture in steam as determined by the accepted methods of using a "throttling calorimeter" may be considerably in excess of the true proportion of such moisture.

Second. The conditions under which "throttling calorimeters" should be used, or the precautions necessary in using them, in order to insure practically accurate conclusions regarding the proportion of moisture in the steam under examination.

The investigation has divided itself into the following parts:

I.

The entire output of steam from a seventy-five horse-power boiler was made to contain known amounts of moisture while flowing through a three-inch pipe, the determination of the true percentage of moisture being made to depend entirely on actual weighings of the steam and water involved. (See Fig. 35.)

The outlet from the three-inch pipe was connected with a seventy-five horse-power separator, and with a large throttling chamber, so that the principle of the small "throttling calo-

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* Presented at the New York meeting (December, 1895) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

† The experimental data covering parts of the investigation have been presented to the Society, in two papers, by Prof. D. S. Jacobus; Volume XVI., pages 448, 1017.

‡ The Babcock & Wilcox Co. of New York.

rimeters with separator attached" could be applied to the *entire* amount of steam mixture flowing through the pipe. Thereby it was determined that the *principle* of the "throttling calorimeter" was entirely reliable as a means of determining the percentage of moisture of any mixture which *passed through it.* (See Table A.)

II.*

Small "throttling calorimeters" were applied to the three-inch pipe, with the ordinary arrangement of perforated nipple, and it was found that the percentage of moisture shown by them varied considerably from the true percentage, when the conditions were such as to make it probable that the moisture was separated from the steam or was not distributed throughout the latter when it collided with the nipple of the calorimeter. For instance, when the true moisture was 21 per cent. and 17.6 per cent. respectively, the small calorimeter showed 54.6 per cent. and 50.8 per cent.

III.*

Small calorimeters were applied to the three-inch pipe at the exit from the 75 horse-power separator, with the drip-pipe to the separator closed, under conditions which fairly insured the thorough distribution of the moisture throughout the current of steam when the latter collided with the calorimeter nipple, and it was found that, while the percentage of moisture shown by them was still liable to exceed the true percentage, the discrepancy was much less than when the conditions were such as to favor the accumulation of the moisture at some part of the surface of the pipe. For instance, when the true moisture was 0.5 per cent., 0.8 per cent., 1 per cent., 1.6 per cent., 2.5 per cent., and 19.1 per cent., respectively, the calorimeter showed 1 per cent., 1.5 per cent., 2.2 per cent., 3.6 per cent., 5.5 per cent., and 31.8 per cent. (See Table B.)

CONCLUSIONS FROM I., II., AND III.

The results of I., II., and III. made it evident that, while the small "throttling calorimeter" might be relied upon to determine correctly the amount of moisture in the sample of steam and

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* See paper by Prof. D. S. Jacobus, *Transactions American Society of Mechanical Engineers*, Volume XVI., p. 448.

water which is drawn into the instrument from the larger volume of mixture in a steam main, the percentage of moisture in such a sample may largely exceed the percentage in the steam main, if the moisture in the latter separates itself from the steam so as to accumulate at the point of connection of the calorimeter. It became necessary, therefore, to determine whether, under the usual conditions of good boiler practice—that is, for conditions where the moisture does not exceed one and one-half per cent.—there can be such a separation of the moisture from the steam so as to cause the erratic indication of the calorimeter.

IV.

To investigate this question two sets of experiments were made, namely:

(*a*) Two* small Barrus calorimeters were arranged with an open-ended nipple working through a stuffing-box by means of a screw, so that the end of the nipple could be moved radially in a steam main. One calorimeter was attached to the 12-inch horizontal main of a 500 horse-power boiler, at its bottom, and the other at about four inches along the circumference away from the bottom point. By one of the screws controlling the nipples, the inner open end of the latter could be located anywhere in the pipe, from flush with its inside surface to seven inches beyond the latter. When the boiler was known, by means of the absence of drip from a separator, beyond the calorimeters, to be generating dry steam, the bottom calorimeter showed dry steam when the end of its nipple was more than one and three-quarters inches away from the side of the pipe, and from 35 per cent. to 47 per cent. of moisture when it was at less than this distance away; while the other calorimeter showed no moisture at all possible positions of its nipple. (See Table Part IV.[*a*].) The actual weight of water which passed through the calorimeter when it indicated 47 per cent. of moisture, represented only about one-third per cent. of moisture in the output of the boiler. The results, therefore, confirmed the hypothesis that less than one-half per cent. of moisture in a steam main might separate itself from the steam, and accumulate at the bottom of a pipe in a stream which would impinge against a calorimeter nipple in its path so as to flow up the side

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* See Appendix.

and into the orifice of the latter, thereby causing the indications of the instrument greatly to exaggerate the true percentage of moisture in the main. Evidently, if this hypothesis was correct, the extent to which moisture could separate itself between the outlet for steam from a boiler to the point where a calorimeter was attached would depend upon the velocity in the steam main, the diameter of the latter, and the distance from the boiler outlet to the calorimeter. In other words, the moisture, in dropping out of the steam in a horizontal pipe, would probably roughly follow the law of a falling body, and to ascertain how far this was the case we undertook experiment

(*b*) The same apparatus was used as described above in connection with I., II., and III., except that the 75 horse-power separator was omitted * (see Fig. 37), and the small "throttling calorimeter" was connected with an open nipple, whose inner end was flush with the inside of the three-inch pipe. The moisture was created in the steam by circulating cold water through a pipe located within the three-inch steam main. After passing the small calorimeter the steam was throttled in the drum *N*, and from the indications of the latter, and those of the small calorimeter, the per cent. of the total moisture in the three-inch main was accurately determined. The amounts of moisture created in the three-inch main were confined to from one-half to ten per cent., and the velocity of flow was varied from 15 to 65 feet per second by varying the rate of steam generated by the boiler from 20 to 90 horsepower.

The results (Table C) clearly indicate that, in travelling a little more than twice the distance in the three-inch main—which would be necessary in order for a body to fall by gravity through the diameter of the pipe—*practically all* of the moisture in the steam main would escape through the calorimeter.

Conclusions.

These results afford, I think, a key for the explanation of the erratic indications of "throttling calorimeters" in practice, which all extensive users of them have met to a greater or less extent. Variations in the proportions and arrangement of nipples, in the rate of evaporation, relative location of calorimeter, and position

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* See paper DCLII., by Prof. D. S. Jacobus, *Transactions American Society of Mechanical Engineers*, Volume XVI., p. 1017.

of steam mains leading to the point of attachment of the latter, will give rise to an infinite variety of results in the degree of the error which may be involved in the use of the instrument.

All parts of the surface of any form of nozzle inserted in the steam main will act as a collector for moisture, which will adhere to the metal so as to resist being detached by the comparatively swift main current of steam, but which will allow itself to be gradually drawn into the nozzle by the gentler current of steam which flows into the calorimeter, because the latter has only to overcome the resistance to sliding of the water along the metal.

Under this view there seems to be no possible method of depending solely upon small "throttling calorimeters" to determine with certainty the percentage of moisture in a steam main. By using several instruments simultaneously, with the orifices of the nipples located at different parts of the cross-section of the main, or by making the nipple of a single instrument movable so as to explore the interior of the pipe, an approximately correct judgment may be made regarding the average moisture, which will be sufficiently complete for commercial purposes.

By combining a single calorimeter with a separator acting on the whole current in the steam main, however, the source of error in the calorimeter may be so far eliminated as to make its indications reliable. This method is based upon the fact that, by using a separator of sufficiently large proportions to confine the velocity of flow within certain limits, the moisture in the steam leaving the separator can be reduced from any probable amount to a small fraction of one per cent. For example, in the case of the three-inch Stratton separator, if the velocity of flow is not more than one thousand feet per minute, with twenty-seven per cent. of moisture in the steam entering the separator, there is practically no moisture in the steam which leaves it. If, therefore, a small "throttling calorimeter" be applied to the steam main at the exit from such a separator, the small amount of moisture there, and the fact that it will be thoroughly intermingled with the steam, make it reasonably certain that its indications will be correct for any arrangement of nipple, and, by combining these with the determinations of drip from the separator, the moisture in the steam generated by the boiler may be completely and reliably determined.

APPENDIX.

GENERAL ARRANGEMENT OF APPARATUS FOR EXPERIMENTS.

The principal arrangements for the investigation are shown by Fig. 35.

Steam was drawn from boilers by a three-inch pipe *A*. The latter was enlarged to six inches at *B*, whereby the velocity of the flow of steam was made sufficiently low to enable its temperature to be accurately determined by means of the thermometers *C* and *D*. As the steam flowed past the points *G* and *F*, a stream of water was injected into it by means of the pump *W*, from a reservoir W_1, the rate of injection being regulated by means of the water meter G_1. When the water was injected at *G* it issued against the steam in an unbroken stream through small orifices; but when it was injected at *F* two streams of water, at an angle, were made to impinge against each other so as to spatter into a fine spray.*

The mixture of steam and water then passed a three-inch Stratton separator *K*. The water was withdrawn from the latter by the valve K_2, whence it passed into the weighing barrels *Y* and Y_1, the level in the water-glass K_1 being maintained at about one inch above its lower end.

The steam leaving the separator passed through the globe valve *M* into a drum *N*, twelve inches in diameter and about five feet long, the valve *M* being regulated so that while at *J* the desired boiler pressure was maintained, the pressure in *N*, as shown by pressure gauge *U*, would not be more than a fraction of a pound above that of the atmosphere. The temperature of the steam being given by the thermometers *O*, *P*, and *Q*, this drum constituted a "throttling calorimeter" adapted to receive the whole amount of steam operated upon.

The small calorimeters to be tested were applied at *S* and *H*, the separating attachment and throttling device being both used for these two positions. The throttling device was also used alone at position *S*.

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* It was thought that the injection of the water as spray would be necessary to enable it to have acquired the temperature of the steam before it left the separator, but it was found that both methods of injection were equally effective in this respect.

From *N* the steam flowed to a surface condenser *R*, in which it was condensed so as to be weighed in the barrels *T* and T_1.

All parts of the apparatus were well insulated with canvas-covered hair felt.

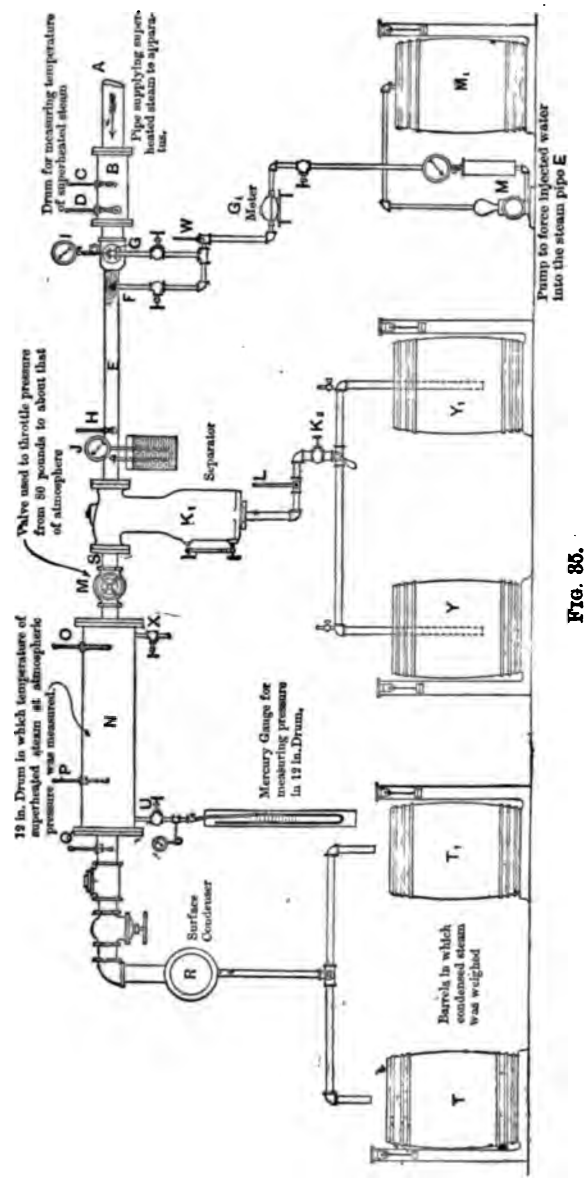

FIG. 85.

PART I.

EXPERIMENTS PROVING RELIABILITY OF PRINCIPLE OF "THROTTLING CALORIMETER."

With the small calorimeters disconnected so that all of the steam from the boiler flows to the Stratton separator, the latter separator combined with the throttling drum *N* represents a "throttling calorimeter," with separator attachment, which operates upon the whole current of steam under examination.

The total weight of mixed steam and water entering the separator is the sum of the weights collected in *Y* and Y_1, *T* and T_1. If the steam at *B* is slightly superheated, its condition as received from the boiler is determined by the thermometer *C* or *D*. Then, knowing the weight of water injected from W_1, and that the latter is heated to the temperature corresponding to the pressure of the steam at *J*, by means of the thermometers *H* and *L*, the percentage of moisture in the separator is determinable. Therefore, the proportion of this moisture eliminated by the separator, or the percentage of the moisture in the steam leaving the latter, is determinable from the amount of water collected in *Y* and Y_1.

The result of this determination of moisture, based upon absolute weights, being compared with the indication of the drum *N* used as a "throttling calorimeter," enables the truth of the "throttling" principle to be tested free of any question as to whether the sample of the steam acted on by the calorimeter represents the quality of the whole.

The results of this comparison are given by Table A, which shows that the true percentage of moisture of the steam leaving the calorimeter (column 4), determined by weight, agrees with that determined from the drum (column 5), by the usual process of estimating the moisture from the temperatures and pressures, the differences being within about two-tenths of a per cent. of the average of the two methods. This difference is within the accidental error of either method.

An example of the steps involved in calculating the percentage of moisture from an experiment is appended.

We may conclude, therefore, that a "throttling calorimeter" with its separating attachment will correctly indicate the proportion of moisture in any mixture which is made to pass through it. Hence the question of the erratic indication of small calorimeters which act upon a portion, or sample, only of the total steam under examination is reduced to this: *Can the sample of mixture of steam and water which a small "throttling calorimeter" draws through itself in a given time, out of a steam pipe or reservoir, differ considerably in quality from that of the whole quantity of mixture which flows through the pipe in the same time?*

To answer this question we made the following experiments:

PART II.

EXPERIMENTS TO DETERMINE THE DIFFERENCE BETWEEN THE QUALITY OF A SAMPLE OF STEAM DRAWN FROM A THREE-INCH PIPE BY A "THROTTLING CALORIMETER" AND THAT OF THE TOTAL QUANTITY OF STEAM FLOWING THROUGH A PIPE.

A "throttling calorimeter," with its separator attachment, of the standard Barrus proportions, carefully calibrated for radiation with superheated steam, was attached at *H*, Fig. 35, by a vertical half-inch nipple tapped into the bottom of the three-inch pipe. The nipple projected two and one-half inches into the three-inch pipe. It was closed at its inner end, and perforated on its cylindrical surface with twelve one-eighth-inch holes, the lower row of holes being three-eighths of an inch within the pipe. Steam from the boiler at 78.5 pounds pressure, which was superheated 30 degrees when passing *B*, received water at *G* at 60 degrees Fahr., so that the total mixture flowing at *E* was 1,916 pounds per hour.

Assuming* that the injected water was raised to the temperature corresponding to the pressure, the per cent. of moisture at *H* was 21.0 per cent.; but the calorimeter gave the moisture at 54.6 per cent.

In the second experiment, in which 2,044 pounds of mixture flowed through the three-inch pipe per hour, the correct maximum moisture was 17.6 per cent., and by calorimeter 50.8 per cent. In these experiments the water was injected at *G* in a broken stream through one thirty-second of an inch perforations. It is probable, therefore, that the majority of it lay upon the bottom of the pipe.

These two experiments may, therefore, be taken as examples of

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* This assumption makes the true moisture a maximum, and it therefore insures a minimum value for the discrepancy of the calorimeter.

the current 1.2 per cent. of moisture in the steam caused the calorimeter to indicate 2.5 per cent.

Again, in lines 16 to 19, with a horizontal nipple with 6 holes seven thirty-seconds of an inch in diameter, with from 0.5 to 1.6 per cent. of actual moisture, the calorimeter showed from 1.0 per cent. to 3.6 per cent.

PART IV. (*a*).

ABSTRACT OF RECORD OF TWO CALORIMETERS WITH MOVABLE NIPPLES APPLIED TO TWELVE-INCH MAIN DELIVERING ABOUT 500 HORSE-POWER.

CALORIMETER No. 1 AT BOTTOM OF PIPE.						Inches Inner End of Nipple was above Inside of Pipe.	CALORIMETER No. 2, WITHOUT SEPARATOR.		
Duration of Test, Minutes.	Boiler Pressure, Pounds.	CORRECTED TEMPERATURES, DEGREES FAHR.		Pounds of Drip from Separator per Hour.	Per cent. of Priming.		CORRECTED TEMPERATURES, DEGREES FAHR.		Percentage of Priming.
		Upper.	Lower.				Upper.	Lower.	
1	2	3	4	5	6	7	8	9	10
20	90	331	283	3.39	5.2	0	331	280	0.55
10	96	335	284	57.36	47.0	0.33	.....	.....	.....
10	99	338	286	30.00	32.0	0.66	338	287	0.13
10	96	334	285	11.73	15.5	1.00	335	287	0.05
10	94	334	286	0	0*	1.66	.....	.....	.....
2	90	330	284	0	0*	2.33	.....	.....	.....
3	95	334	286	0	0*	3.33	.....	.....	.....
3	95	335	286	0	0*	4.33	.....	.....	.....

* Radiation of calorimeter, 0.4 per cent.

PART IV. (*b*).

EXPERIMENTS MADE TO PROVE THAT AS LITTLE AS ONE PER CENT. OF MOISTURE WILL SEPARATE ITSELF FROM STEAM IN A HORIZONTAL PIPE, AND, FLOWING ALONG THE BOTTOM OF THE LATTER, WILL ESCAPE THROUGH A "THROTTLING CALORIMETER," AND THEREBY TEND TO CAUSE THE PER CENT. OF MOISTURE SHOWN BY THE LATTER TO VARY CONSIDERABLY FROM THE TRUE AVERAGE PERCENTAGE IN THE STEAM MAIN.

The general arrangement of apparatus for conducting the tests on the three-inch horizontal pipe is represented in Fig. 37. The results are given in Table C.

Superheated steam entered at *A* and passed through a three-inch pipe surrounding a cooling pipe *B*. The cooling water entered at *C* and passed off at *G*. After passing the cooling pipe

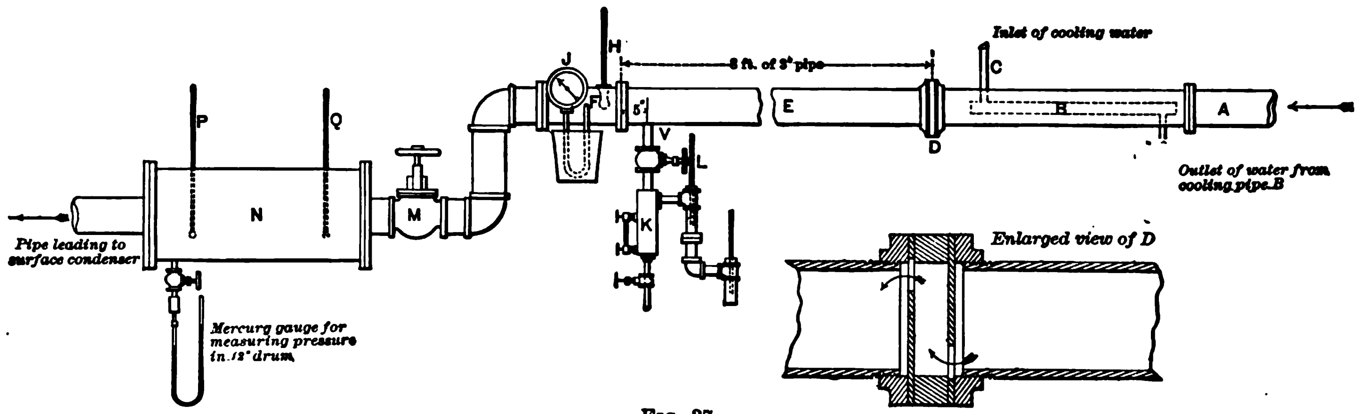
Inlet of cooling water
C
H
J
8 ft. of 3" pipe
5'
B
A
E
D
V
L
K
F
P
Q
N
M
Outlet of water from cooling pipe B
Enlarged view of D
Pipe leading to surface condenser
Mercury gauge for measuring pressure in 12" drum

FIG. 87.

the current 1.2 per cent. of moisture in the steam caused the calorimeter to indicate 2.5 per cent.

Again, in lines 16 to 19, with a horizontal nipple with 6 holes seven thirty-seconds of an inch in diameter, with from 0.5 to 1.6 per cent. of actual moisture, the calorimeter showed from 1.0 per cent. to 3.6 per cent.

Part IV. (*a*).

ABSTRACT OF RECORD OF TWO CALORIMETERS WITH MOVABLE NIPPLES APPLIED TO TWELVE-INCH MAIN DELIVERING ABOUT 500 HORSE-POWER.

Calorimeter No. 1 at Bottom of Pipe.						Inches Inner End of Nipple was above Inside of Pipe.	Calorimeter No. 2, without Separator.		
Duration of Test, Minutes.	Boiler Pressure, Pounds.	Corrected Temperatures, Degrees Fahr.		Pounds of Drip from Separator per Hour.	Per cent. of Priming.		Corrected Temperatures, Degrees Fahr.		Percentage of Priming.
		Upper.	Lower.				Upper.	Lower.	
1	2	3	4	5	6	7	8	9	10
20	90	331	283	3.39	5.2	0	331	280	0.55
10	96	335	284	57.36	47.0	0.33	.....	.....	.....
10	99	338	286	30.00	32.0	0.66	338	287	0.13
10	96	334	285	11.73	15.5	1.00	335	287	0.05
10	94	334	286	0	0*	1.66	.....	.....	.....
2	90	330	284	0	0*	2.33	.....	.....	.....
3	95	334	286	0	0*	3.33	.....	.....	.....
3	95	335	286	0	0*	4.33	.....	.....	.....

* Radiation of calorimeter, 0.4 per cent.

Part IV. (*b*).

EXPERIMENTS MADE TO PROVE THAT AS LITTLE AS ONE PER CENT. OF MOISTURE WILL SEPARATE ITSELF FROM STEAM IN A HORIZONTAL PIPE, AND, FLOWING ALONG THE BOTTOM OF THE LATTER, WILL ESCAPE THROUGH A "THROTTLING CALORIMETER," AND THEREBY TEND TO CAUSE THE PER CENT. OF MOISTURE SHOWN BY THE LATTER TO VARY CONSIDERABLY FROM THE TRUE AVERAGE PERCENTAGE IN THE STEAM MAIN.

The general arrangement of apparatus for conducting the tests on the three-inch horizontal pipe is represented in Fig. 37. The results are given in Table C.

Superheated steam entered at *A* and passed through a three-inch pipe surrounding a cooling pipe *B*. The cooling water entered at *C* and passed off at *G*. After passing the cooling pipe

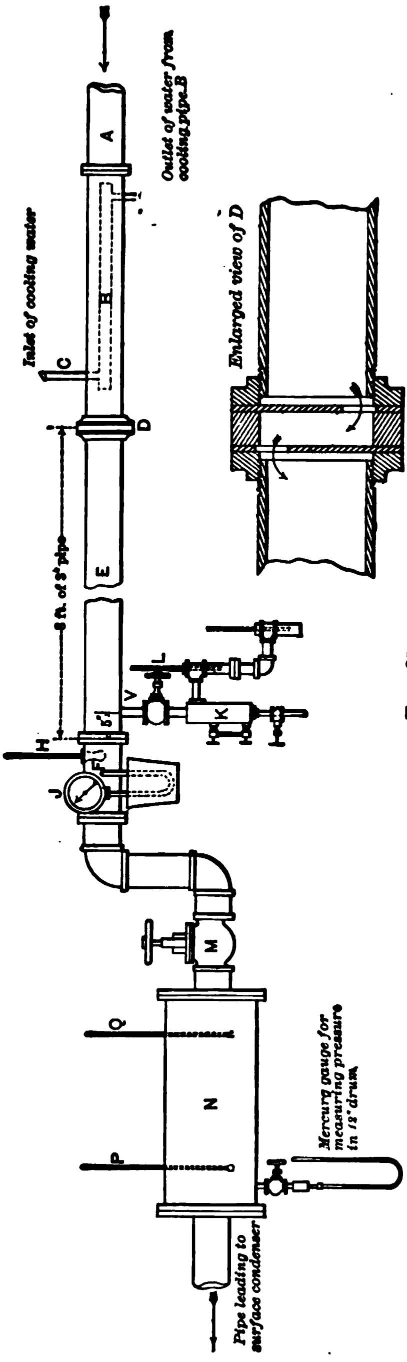
Outlet of water from cooling pipe B
Inlet of cooling water
A
C
H
D
Enlarged view of D
6 ft. of 3" pipe
E
5"
H
F
J
V
L
K
M
Q
N
P
Mercury gauge for measuring pressure in 12" drum
Pipe leading to surface condenser

FIG. 87.

the steam passed through a device at *D* which thoroughly mixed the steam with the water. This consisted of two plates placed about one inch apart, in which were two holes about seven-eighths of an inch in diameter. The hole in the first plate encountered by the steam was at the bottom of the pipe, so that all moisture in the steam would be drawn from the bottom of the pipe. The steam and moisture then passed upward between the plates, and out of the hole in the second plate. The hole in the second plate was placed near the top so as to introduce the steam and moisture near the top of the three-inch pipe *E*. The calorimeter was attached at *V*. *K* is the separator portion of the calorimeter, and *L* the heat gauge. The temperature and pressure of the steam were measured on leaving the pipe *E* by means of the thermometer *H* and the pressure gauge *J*. The thermometer *H* was placed in a mercury well having an enlargement at its lower end and a thin neck. The steam was throttled by means of the valve *M* from a pressure of about 80 pounds above the atmosphere in the pipe *E* to about the pressure of the atmosphere in the twelve-inch drum *N*. The temperature of the steam after throttling was measured by a thermometer *Q*, placed in a mercury well, and by a thermometer *P* which came in direct contact with the steam. The pressure in the drum *N* was measured by means of a mercury gauge. The steam flowing into the drum *N* was led to a surface condenser, and finally weighed.

The amount of moisture in the steam passing through the valve *M* was indicated by the amount of superheating in the twelve-inch drum *N*. This moisture, added to the moisture in the steam entering the Barrus calorimeter, gave the total moisture contained in the steam passing through the three-inch pipe. Corrections, determined directly by experiment, were made for all radiation. The factor of 0.48 for the specific heat of steam was employed in calculating the percentage of moisture; and special experiments were made to show how nearly this method would agree, in the case of the twelve-inch drum, with the experimental normal reading for dry steam. These experiments, from the nature of the apparatus, could be made only with steam just at the point of superheating, or with slightly superheated steam.

Three series of tests were made. In the first there was no mixing device placed at *D*. In these it was found that the thermometer *H* would indicate superheating with considerable moisture entering the calorimeter nozzle *V*. The second series of tests were made after adding the mixing device *D*. In the third series of tests the three-inch pipe containing the cooling pipe *B* was lowered, together with the mixing device *D*, and the steam was made to pass through an S-shaped connection of three-inch pipe into the pipe *E*. This caused the steam which was admitted to *E* to pass upward through a vertical pipe, then turn through an elbow into the pipe *E*. The object of the latter arrangement was to make the mixture of steam and water enter the pipe *E* at the same velocity at which it flowed through the pipe *E*. When the steam and moisture entered the three-inch pipe directly from a seven-eighths-inch hole in the mixing device *D*, it was initially at a much greater velocity than the average velocity in the pipe *E*, but it was considered best to make tests in this way so as to have one set of tests in which the conditions were as severe as possible.

In all these tests no pains or expense were spared to secure accuracy. Green's thermometers were used, and were carefully calibrated in regard to their indications when immersed to the particular depths at which they were used in mercury wells. The standards of temperature were established by Regnault's steam tables, the necessary steam pressures being determined by three different bases. The radiation losses were determined with great care, and the question of the applicability of Regnault's value for the specific heat of steam was considered by a study of his memoirs and by special experiments.

The details of these operations are given in papers by Prof. D. S. Jacobus, *Transactions American Society of Mechanical Engineers*, Volume XVI., pages 448 and 1017, which, however, inadequately show the amount of painstaking labor and rare skill which he has supplied during the investigation.

METHOD OF COMPUTING THE TRUE PERCENTAGE OF MOISTURE IN THE STEAM ENTERING AND LEAVING THE SEPARATOR.

For Part I.

The method which has already been described consisted in determining the percentage of moisture in the mixture of steam and the known weight of injected water. The data and calculations in detail for test, Group 8, Table A, are as follows:

1.	Duration for selected interval for which the average data are obtained, in minutes	31
2.	Total steam and entrained water leaving the separator K, in pounds, per hour	3,040
3.	Water drawn from separator, in pounds, per hour	248.2
4.	Total weight of steam and entrained water entering separator, in pounds, per hour $= W$	3,288.2
5.	Water injected at P, in pounds, per hour $= w$	232.0
6.	Temperature of water injected at F, in degrees Fahr. $= t'$	69
7.	Pressure of steam at J, in pounds, per square inch above atmosphere	80
8.	Sensible heat of steam corresponding to pressure at J in B.T.U. $= h$	326.9
9.	Temperature of steam corresponding to pressure at J, in degrees Fahr. $= t''$	323.6
10.	Latent heat of steam corresponding to pressure at J, in degrees Fahr. $= L$	885.7
11.	Temperature of superheated steam before injecting water, as registered by the thermometer D, in degrees Fahr. $= t'''$	351.3
12.	Weight of steam condensed by the water injected in pounds $= \dfrac{w(h-t') - 0.47(t'''-t'')(W-w)^{*}}{L}$	22.6
13.	Total weight of water in the mixture of steam and water = line 5 + line 12	254.6
14.	Percentage of moisture in steam entering the separator = line 13 × 100 ÷ line 4	7.7
15.	Water remaining in steam leaving separator, in pounds, per hour = line 13 − line 3	6.4
16.	True percentage of moisture in steam leaving the separator = line 15 × 100 ÷ line 2	0.21

CALCULATION OF THE PERCENTAGE OF MOISTURE INDICATED BY THE SUPERHEATING OBSERVED IN THE TWELVE-INCH DRUM.

For Experiment: Group 8, *Table A.*

1.	Pressure of steam before throttling, in pounds, per square inch above atmosphere $= p_1$	80.0
2.	Pressure of steam after throttling, in pounds, per square inch above atmosphere $= p_2$	3.2

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* The factor of 0.47 was determined by experiment so as to include all radiation effects.

3. Sensible heat above zero, degrees Fahr., corresponding to pressure $p_1 = h_1$ 326.9
4. Latent heat corresponding to pressure $p_1 = L_1$ 885.7
5. Total heat above zero, degrees Fahr., corresponding to pressure $p_2 = H_2$ 1,181.7
6. Temperature corresponding to pressure $p_2 = t_2$ 222.1
7. Temperature of superheated steam after throttling $= S_2$ 281.4
8. Quality of steam $= \frac{H_2 + 0.48\,(S_2 - t_2) - h_1}{L_1}$ 0.997
9. Percentage of priming = 100 (1 − line 8) 0.3

DISCUSSION.

Dr. Charles E. Emery.—In a test of a boiler which had two outlets, so that the quality of the steam was necessarily about the same in both, a calorimeter was placed on each outlet. Referring to accompanying sketch, Fig. 38, the steam from the boiler passed upward through the run of a flanged tee, on the top of which was placed a safety valve, and the steam for the engine passed through a side outlet. The boiler manufacturers connected a calorimeter to an outlet *a* at the centre of the tee. I, however, had a connection made to the other outlet at a point *b* near the bottom flange of the tee. The steam from the upper outlet showed less moisture than that from the lower one, though in neither case was the percentage of moisture very high. It will be seen that the less moisture obtained at the point *a* corresponds well with the experiments of Professor Denton, as it was nearly out of the current of steam.

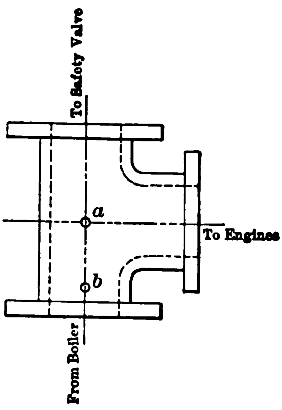

FIG. 38.

Prof. R. C. Carpenter.—I would like to ask Professor Denton if he has made any experiments at all in getting samples from different kinds of vertical pipes.

Mr. Kent.—Professor Denton says that if we use the large separator the little calorimeter afterwards shows whether we have taken the moisture out or not. Now suppose we did not take out all the moisture, but within one or two per cent. of it, according to Professor Denton's experiments that calorimeter might show us anything. I would like to have the Professor give us directions how to place that little calorimeter, after the separator, in order to have it tell the truth.

Mr. Albert Kingsbury.—There is a point in the paper which seemed clear to me when I read it, but some obscurity has since arisen about it. How is it possible to know what percentage of water is in this steam beyond the point where the cold water is introduced? The amount of water introduced can be determined, but it immediately changes the quality of the steam which remains, reducing the temperature, producing condensation, and hence making some uncertainty as to the exact amount of water remaining in the steam.

Mr. George I. Rockwood.—I would like to ask if the whole structure of calorimetry is upset by these experiments. I would like to have it stated definitely whether we are to make calorimetric experiments in the future in testing boilers, or whether we are to give up that department of steam engineering.

Mr. William Kent.—I will speak on the same side as Mr. Rockwood. Some fifteen or twenty years ago we were told by steam-boiler experts that no boiler experiments were worth anything unless a calorimeter test was made; that boilers gave too much evaporation if not checked by the calorimeter. They produced figures showing that boilers would give fourteen pounds of water per pound of coal, if tested ordinarily, but if you applied the calorimeter you would get the true result. Then the barrel calorimeter was brought in, and later the coil and the throttling calorimeter. In a great number of experiments which I have made, using the barrel, the throttling and also the coil calorimeter with many different kinds of boilers, I was never able to get more than three per cent. of moisture, whenever the water level was anywhere near the proper place; that is, whenever the water was in sight in the gauge glass, and never over one and one-half per cent. as an average of a series of tests. I then came to the conclusion that all boilers which had horizontal shells and were of the ordinary kind did give a commercially dry steam; that is, steam which did not have over three per cent. of moisture in it. Now Professor Denton tells us that the steam will drain itself in a pipe, so that within a distance of eight or ten feet that pipe will have dry steam, the water being all concentrated at the bottom of the pipe. I think, in answer to Mr. Rockwood's question, that we shall have to throw away the calorimeter as being unnecessary, and come to the conclusion that boilers will give dry steam unless they are foaming or unless there is some defect in their construction. If we take the separator as being correct, say within one-fifth of one per cent., what is the use of a calorimeter, except for scientific purposes?

Mr. O. C. Woolson.—I understood the author to say that this test pipe, if placed on the bottom and flush with the inside of the steam pipe, gave an excess of moisture, but if inserted two inches or more gave no moisture, and that it made no difference whether that pipe entered from the bottom or anywhere around the circumference of that pipe; the results would be the same: dry steam if inserted a little way and wet steam if inserted flush with inside of steam pipe.

*Prof. James E. Denton.**—Dr. Emery's case I judge to be simply in the line of my own findings. The first question is Professor Carpenter's about the vertical pipes. If the water runs along the bottom of a horizontal pipe leading to the top of a vertical pipe, it will splash about in the pipe so as to fall on the calorimeter nipple and cause unreliable results from the latter. If the steam rises through the vertical pipe, then the water which is due to radiation, collecting on the sides, may trickle down over the nipple.

In answer to Mr. Kingsbury's question I would say that we made allowance for the moisture due to heating the injected water to the temperature of the steam. The calculations for this allowance are given at the end of the paper.

Mr. Kent asks where to place a calorimeter, used in conjunction with a separator, and how the calorimeter can be relied upon to show the true moisture, even when used in this way. My proposition to use the instrument beyond a separator assumes that the latter is known to be capable of removing any amount of moisture in the steam to such an extent that the greatest amount which the calorimeter will show, if placed within, say, one foot of the outlet from the separator, may be acceptable as a satisfactory performance of the boiler. With a separator of proper proportions the moisture passing it will be so small a fraction of one per cent. that the most exaggerated result from the calorimeter will not reach one per cent.

In reply to a question as to what a commercially dry steam is, I believe it may be defined to be the per cent. of moisture which is equivalent to the accidental error of a boiler or engine

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* Author's closure, under the Rules.

test. The performance of a boiler by duplicate tests under identical conditions varies about three per cent., or the average accidental error is, say, one and one-half per cent., and the similar error for water-consumption tests of engines is probably no less. I believe, therefore, that for capacity tests of boilers and tests of engines, commercially dry steam may be taken to be steam which contains not more than one and one-half per cent. of moisture, and for economy tests of boilers, steam containing a larger amount of moisture in proportion to the ratio of the heat in the water in the form of steam to that represented by a pound of boiling water.

I think the conclusion that calorimeters are shown to be of no value is unjust to the intrinsic merits of the instrument, as we need the calorimeter to show that the separator has done its duty.

Professor Carpenter.—The reason for asking Professor Denton in regard to trials on the vertical pipes was to bring out another point which he has not mentioned. We made some experiments last year in this line of work, and they are not finished yet. We had a sample of steam flowing both downward and upward. Flowing downward we found streams of water flowing, as Professor Denton has described, and we would get samples of varying amounts, ranging sometimes to nearly 100 per cent. of moisture. We afterwards put in a glass so that we could see the stream. When we arranged the pipes in a little different manner, so that the current of steam was ascending, then those objections in a large measure disappeared, although at the present time I am not able to say that we found a perfect way of getting a sample of steam, especially when there was very much moisture in it. Certainly the variation in the percentage of moisture was very much less, and we got pretty fairly good samples with the ascending current. With the horizontal pipe we had the same experience which Professor Denton has described, and when we had a high velocity of steam we also succeeded in getting pure water from the top of the pipe, which was due, perhaps, to the peculiar arrangement of pipes which we had. To me the question is of very great interest, and I fully agree with Professor Denton in his general conclusions

Professor Denton.—I would say that I think the way to secure the best results is to have the steam passing upward in a vertical pipe.

Mr. Woolson.—I do not think the Professor has answered my question yet.

Professor Denton.—I did not say that it made no difference where the nipple was placed, but that when inserted at any point above the bottom we found no moisture.

Mr. Woolson.—Doesn't it depend on the separator which you are using? Isn't it a fact that some separators will show you a moisture on top of the pipe?

Professor Denton.—I have great confidence in separators. I believe there is some velocity at which all good separators will remove all moisture. Of course, that is something yet to be proved, perhaps.

DCLXXIV.*

EFFECT OF TEMPERATURE ON STRENGTH OF WROUGHT IRON AND STEEL.

BY R. C. CARPENTER, ITHACA, N. Y.
(Member of the Society.)

The investigation described in the following pages was conducted in the spring of 1895, in the Testing Laboratory of Sibley College.†

The tests were performed on an Emery Testing Machine, having a maximum capacity of 200,000 pounds. This machine is of the horizontal type, and was built by William Sellers & Co. for the Columbian Exposition, 1893, and is especially well adapted for tests of this character.

The method employed in making the tests differed from that employed in ordinary testing, simply in the provision for heating the test-piece to a specified temperature and maintaining it at that point throughout the test. Various schemes were tried before a successful method was found. The methods of heating tried and rejected as impracticable, involved first the use of a vessel filled with oil or some metal having a melting point so low that it could be maintained in a liquid condition, surrounding the test-piece and situated so that it could be heated. Difficulty with leakage at stuffing boxes finally led to the adoption, as a substitute for the liquid, of a solid block of cast iron made in two halves and held in position by clamps, as shown in the lower part of Fig. 39. This block was heated externally and transmitted its heat to the test-piece. The temperature was measured by a mercurial thermometer, the upper part of which was filled with nitrogen to prevent vaporization of the mercury at high temperatures; it

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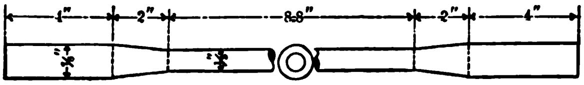
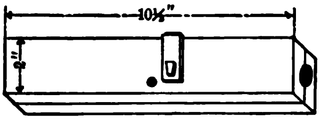
* Presented at the New York meeting (December, 1895) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

† Thesis investigation of O. R. Wilson and R. L. Gordon, to which I am largely indebted for results.

was graduated to 900 degrees Fahr. The bulb of the thermometer was put in direct contact with the test specimen, and was partly surrounded by the solid metal of the cast-iron jacket. The length of the jacket was about 2 inches greater than the gauged length of the test specimen.



TEST PIECE



METALLIC JACKET

FIG. 39.—TEST-PIECE AND METALLIC JACKET.

The iron jacket when in position on the test specimen was heated by a Bunsen burner having four jets, the apparatus being as represented in Fig. 40, in which *T* is the thermometer, *aa* the ends of the test-pieces, *JJ* the cast-iron jacket, *B* the burners, and *HH* the pulling heads of the testing machine.

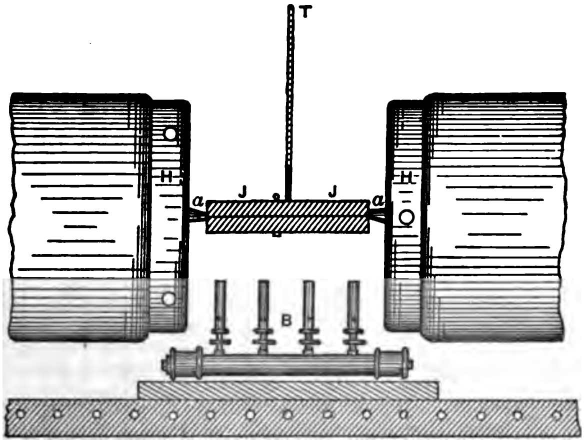


FIG. 40.—TEST-PIECE AND JACKET IN POSITION.

This method of heating the test-piece proved very satisfactory, and, as will be seen by consulting the tables and curves, gave very uniform results. There may have been a small error in the measurement of temperature, due to the fact that the thermometer was not entirely surrounded by the metal of the test-piece, but n readings were taken until several minutes after the thermomete indicated a stationary temperature, and such error was not larg and would not affect results sensibly. Correction was made fo radiation from the stem.

The specimens tested were turned to dimensions as shown i Fig. 39, and those belonging to each class, wrought iron, too steel, and machinery steel, were as nearly uniform in quality a could be obtained from the stock in Sibley College. The tool an

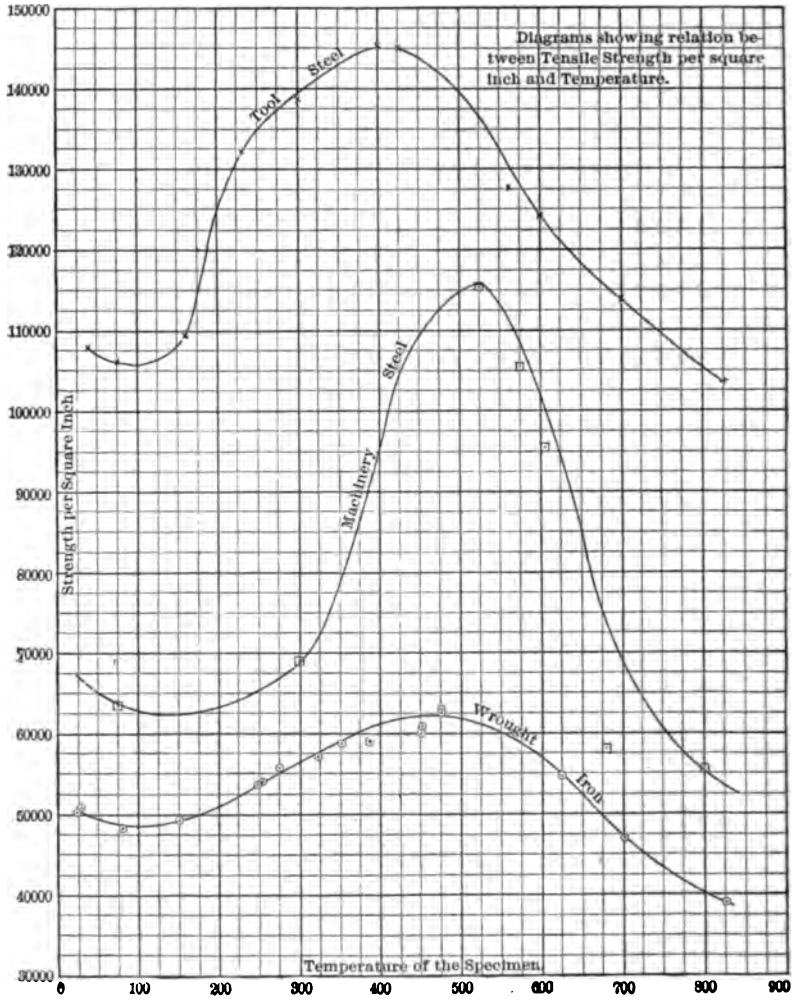


FIG. 41.

machinery steel was purchased from the Crescent Steel Company of Pittsburgh, and the wrought iron of the Burden Iron Company of Troy, N. Y., for use in the college shops. The chemical composition of each piece is not accurately known; the uniformity of the results shows that this is a matter of little importance. Two specimens of tool steel, numbered 10–0 and : : :-0, gave decidedly different results from the others; these results are given in the logs, but are not plotted. About thirty specimens of wrought iron were tested and about twenty-five of steel, the temperatures varying in each test from 22 degrees to 825 degrees the lowest temperature being obtained by use of a freezing mixture, the highest temperature as explained. The method of heating the specimen prevented the use of appliances for measuring extension while under stress, so that information could not be obtained from which the elastic limit or modulus of elasticity could be computed.

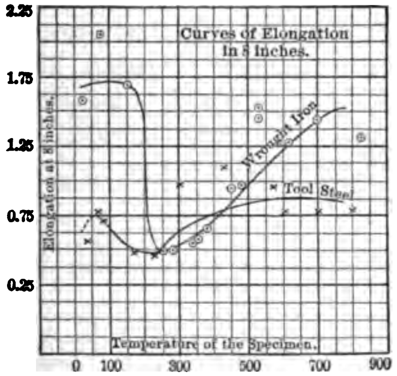


FIG. 42.

Results.—The general results of the test are shown on the curves accompanying the report, from which it will be noted that all the curves have a point of contra-flexure at about 70 degrees Fahr. and another at a temperature not far from 500 degrees. The maximum strength is found at temperatures of 400 to 550 degrees Fahr. At temperatures higher than this, all the materials show a rapidly decreasing strength. The variation in strength with change of temperature is marked; thus, for instance, with wrought iron, if we represent the strength at the temperature of 75 degrees Fahr. as 100, that at 22 degrees to 25 degrees is 103 to 104, at 500 degrees is 126, while at 825 degrees it would be represented by 80.7, which is 63 per cent. of the maximum strength ; beyond this point the strength steadily decreases.

The curve for tool steel has the same general form, the temperature of maximum strength being, however, about 400 degrees. That for machinery steel is similar, but no experiments were made at low temperatures and no critical point was observed.

The elongation in 8 inches of length for the tool steel and wrought iron, is shown on the curves in Fig. 42, from which it is noted that these curves are of the same general form, and agree in showing smallest elongation when at a temperature about equal to the boiling point of water. There is considerable variation in the results given by individual specimens, especially for the tool steel; and there is, for this reason, doubt as to the exact position and form of the curve. A large portion of the discrepancy is no doubt due to the methods which had to be employed in measuring the elongation.

RESULTS OF TESTS OF WROUGHT-IRON SPECIMENS.

Temperature, Degrees Fahr.	Identifying Mark.	Maximum Load, Pounds.	Diameter in Inches.	Area in Square Inches.	Tensile Strength, Pounds per Square Inch.	Per Cent. of Normal.	Elongation in 8 Inches.
							Inches.
23	2	9,900	.4991	.19555	50,500	103.0	....
25	G	10,300	.5073	.20210	50,980	103.8	1.63
82	.	9,300	.4925	.19051	48,820	100.0	2.10
150	. .	9,000	.4815	.18205	49,430	100.7	1.54
250	H	10,350	.4935	.19120	54,010	110.6	....
250	J	10,550	.4956	.19291	54,690	112.2	.50
275	7	10,600	.4906	.18908	56,070	114.6	.52
320	0	11,200	.4934	.19120	57,240	116.9	.59
350	I	10,600	.4791	.18021	58,820	120.2	.62
385	D	11,600	.5003	.19665	58,980	120.3	.67
450	A	11,700	.4986	.19524	59,920	122.5	.92
450	9	11,800	.4964	.19354	60,970	124.8	....
475	+	11,700	.4878	.18689	62,610	128.0	.95
525	E	10,700	.4667	.17114	62,520	125.6	1.52
530	3	11,700	.5001	.19644	59,840	122.3	1.40
625	8	10,400	.4931	.19095	54,450	111.1	1.27
700	C	8,650	.4855	.18513	46,720	95.8	1.40
825	F	7,600	.4960	.19322	39,330	80.5	1.3

Note.—Normal is here taken as strength at 70 to 80 degrees Fahr.

machinery steel was purchased from the Crescent Steel Company of Pittsburgh, and the wrought iron of the Burden Iron Company of Troy, N. Y., for use in the college shops. The chemical composition of each piece is not accurately known; the uniformity of the results shows that this is a matter of little importance. Two specimens of tool steel, numbered 10–0 and : : :–0, gave decidedly different results from the others; these results are given in the logs, but are not plotted. About thirty specimens of wrought iron were tested and about twenty-five of steel, the temperatures varying in each test from 22 degrees to 825 degrees the lowest temperature being obtained by use of a freezing mixture, the highest temperature as explained. The method of heating the specimen prevented the use of appliances for measuring extension while under stress, so that information could not be obtained from which the elastic limit or modulus of elasticity could be computed.

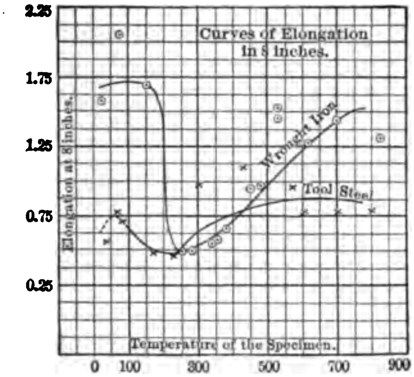


FIG. 42.

Results.—The general results of the test are shown on the curves accompanying the report, from which it will be noted that all the curves have a point of contra-flexure at about 70 degrees Fahr. and another at a temperature not far from 500 degrees. The maximum strength is found at temperatures of 400 to 550 degrees Fahr. At temperatures higher than this, all the materials show a rapidly decreasing strength. The variation in strength with change of temperature is marked; thus, for instance, with wrought iron, if we represent the strength at the temperature of 75 degrees Fahr. as 100, that at 22 degrees to 25 degrees is 103

TOOL STEEL.

Identifying Mark.	Temperature, Degrees Fahr.	Fracture.		At Point of Fracture.		
		Color.	Character.	Diameter in Inches.	Area in Square Inches.	Area of Fracture in Per Cent. of Original Area.
.... 0	28	Normal.	Gran. Flat.	.4756	.1769	91 0(?)
· : : : 0	73	"	" "	.4540	.1626	79.2
10 0	75	"	Gran. & Crys. Flat.	.4214	.1395	77.5
N 0	75	"	Gran. and Crys.	.4460	.1562	84.0
... 0	160	"	" "	.4337	.1477	77.0
.. 0	230	"	Gran.	.4394	.1517	79.4
9 0	300	"	Gran. and Crys.	.4436	.1544	74.1
8 0	400	Light Straw.	" "	.4905	.1874	94.0(?)
3 0	425	Dark Straw.	Silky.	.4327	.1470	75.5
: : : 0	560	Blue Black.	"	.3870	.1238	63.6
11 0	600	Deep Blue.	Silky-necked.	.3400	.0908	44.8
12 0	700	" "	Silky.	.3693	.1071	54.8
: · : 0	825	Blue Black.	Silky-nkd. & Crys.	.2880	.0629	32 1

RESULTS OF TESTS OF MACHINERY-STEEL SPECIMENS.

Temperature, Degrees Fahr.	Identifying Mark.	Maximum Load, Pounds.	Diameter in Inches.	Area in Square Inches.	Tensile Strength, Pounds per Square Inch.	Per Cent. of Normal.	Elongation in 8 Inches.
							Inches.
73	X	12,850	.5073	.2025	63,650	100.0	1.7
300	4	12,700	.4853	.1849	68,680	107.5	.53 B. O.
420	1	16,200	.5120	.2052	78,680	123.0	B. O.
525	5	23,400	.5061	.2011	116,370	183.0	"
575	6	19,650	.4866	.1860	105,660	166.5	1.02
680	2	10,500	.4797	.1807	58,120	91.4	1.22
800	7	10,400	.4886	.1875	55,460	87.1	1.42

MACHINERY STEEL.

Identifying Mark.	Temperature, Degrees Fahr.	Fracture.		At Point of Fracture.		
		Color.	Character.	Diameter in Inches.	Area in Square Inches.	Area of Fracture in Per Cent. of Original Area.
X	73	Normal.	Silky.	.3100	.0757	37.5
4	300	"	"	.3520	.0973	52.5
1	425	"	Silky-necked.	.3855	.1166	57.1
5	525	Dark Bronze.	Gran. and Crys.	.4395	.1517	75.5
6	575	Deep Purple.	Silky Well Nkd.	.2860	.0628	33.7
2	675	Deep Blue.	Silky Fine Crys.	.2740	.0590	30.0
7	800	" "	Silky Well Nkd.	.2665	.0557	29.7

WROUGHT IRON.

Identifying Mark.	Temperature, Degrees Fahr.	Fracture.		At Point of Fracture.		
		Color.	Character.	Diameter in Inches.	Area in Square Inches.	Area of Fracture in Per Cent. of Original Area.
2	23	Normal.	Silky.	.3215	.0811	41.4
G	25	"	"	.3260	.0835	41.2
.	82	"	Fibrous.	.3320	.0867	45.4
. .	150	Bluish.	"	.3290	.0855	46.9
J	250	"	Silky.	.3760	.1111	58.0
7	275	"	"	.3790	.1128	60 0
0	320	Normal.	Silky Crys.	.....	.....	....
1	350	"	" "	.3782	.1123	62.9
D	385	"	Silky Slt. Crys.	.4060	.1295	66.1
9	450	"	Silky.	.4943	.1918	99.0(?)
†	475	Dark Bronze.	"	.3416	.0917	49.0
E	525	Deep Purple.	Fibrous.	.3546	.0988	57 5
3	530	Dk. Purp. Bronze	"	.3892	.1188	60.7
8	625	Dark Bronze.	"	.3385	.0901	47.3
C	700	Dark Blue.	Fibrous-necked.	.3685	.1054	57.0
F	825	Blue Black.	Silky.	.3614	.1026	53.1

RESULTS OF TEST OF TOOL-STEEL SPECIMENS.

Temperature, Degrees Fahr.	Identifying Mark.	Maximum Load, Pounds.	Diameter in Inches.	Area in Square Inches.	Tensile Strength, Pounds per Square Inch.	Per Cent. of Normal.	Elongation in 8 Inches.
							Inches.
28	 0	21,000	.4976	.19447	107,990	101.8	.62
73 (*a*)	: : : . 0	26,600	.5054	.20063	132,590	125.0	.77
75 (*a*)	10 0	25,300	.4796	.18065	140,080	132.0	.66
75	N 0	19,800	.4877	.18678	106,000	100.0	.71
160	... 0	21,100	.4950	.19244	109,650	103.4	.47
230	.. 0	25,400	.4944	19198	132,310	124.8	.45
300	9 0	28,900	.5163	.20928	138,100	130.3	.97
400	8 0	29,000	.5046	.19998	145,020	136.8	B. O.
425	3 0	28,400	.4993	.19572	145,200	137.0	1.10
560	: : : 0	24,900	.4990	.19557	127,340	120.0	.94
600	11 0	24,300	.5074	.20210	120,170	113.4	.78
700	12 0	22,400	.4996	.19603	114,270	107.6	.86
825	: . : 0	20,300	.4991	.19572	103,740	98.6	.81

NOTE.—(*a*) These specimens were hard, and not of same character as remainder in this set; for this reason these results are not plotted.

B. O. signifies broke outside gauged length.

TOOL STEEL.

Identifying Mark.	Temperature, Degrees Fahr.	Fracture.		At Point of Fracture.		
		Color.	Character.	Diameter in Inches.	Area in Square Inches.	Area of Fracture in Per Cent. of Original Area.
.... 0	28	Normal.	Gran. Flat.	.4756	.1769	91 0(?)
· ::: 0	73	"	" "	.4540	.1626	79.2
10 0	75	"	Gran. & Crys. Flat.	.4214	.1895	77.5
N 0	75	"	Gran. and Crys.	.4460	.1562	84.0
... 0	160	"	" "	.4337	.1477	77.0
.. 0	230	"	Gran.	.4394	.1517	79.4
9 0	300	"	Gran. and Crys.	.4436	.1544	74.1
8 0	400	Light Straw.	" "	.4905	.1874	94.0(?)
3 0	425	Dark Straw.	Silky.	.4327	.1470	75.5
::: 0	560	Blue Black.	"	.3870	.1238	63.6
11 0	600	Deep Blue.	Silky-necked.	.3400	.0908	44.8
12 0	700	" "	Silky.	.3693	.1071	54.8
: · : 0	825	Blue Black.	Silky-nkd. & Crys.	.2830	.0629	32 1

RESULTS OF TESTS OF MACHINERY-STEEL SPECIMENS.

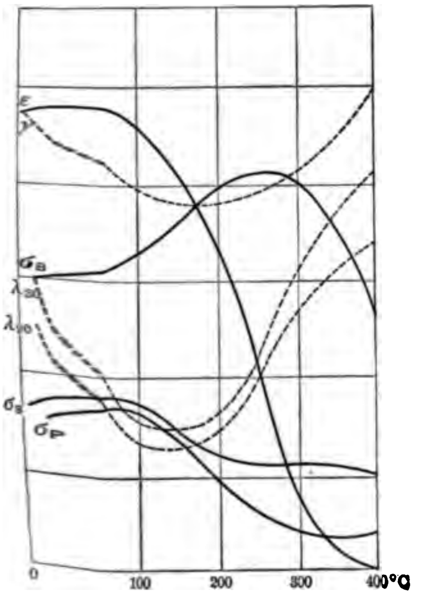
Temperature, Degrees Fahr.	Identifying Mark.	Maximum Load, Pounds.	Diameter in Inches.	Area in Square Inches.	Tensile Strength, Pounds per Square Inch.	Per Cent. of Normal.	Elongation in 8 Inches.
							Inches.
73	X	12,850	.5073	.2025	63,650	100.0	1.7
300	4	12,700	.4853	.1849	68,680	107.5	.53 B. O.
420	1	16,200	.5120	.2052	78,680	123.0	B. O.
525	5	23,400	.5061	.2011	116,370	183.0	"
575	6	19,650	.4866	.1860	105,660	166.5	1.02
680	2	10,500	.4797	.1807	58,120	91.4	1.22
800	7	10,400	.4886	.1875	55,460	87.1	1.42

MACHINERY STEEL.

Identifying Mark.	Temperature, Degrees Fahr.	Fracture.		At Point of Fracture.		
		Color.	Character.	Diameter in Inches.	Area in Square Inches.	Area of Fracture in Per Cent. of Original Area.
X	73	Normal.	Silky.	.3100	.0757	37 5
4	300	"	"	.3520	.0973	52.5
1	425	"	Silky-necked.	.3855	.1166	57.1
5	525	Dark Bronze.	Gran. and Crys.	.4395	.1517	75.5
6	575	Deep Purple.	Silky Well Nkd.	.2860	.0628	33.7
2	675	Deep Blue.	Silky Fine Crys.	.2740	.0590	30.0
7	800	" "	Silky Well Nkd.	.2665	.0557	29.7

plotted all the results obtained by Rudloff relating to wrought iron and steel, taken from tables A and B, also given, and they can be compared with the curves of similar material tested by Professor Carpenter, and the results are similar. A comparison of the curves and data given in the paper with those I give will show the similarity clearly. He says wrought iron and mild steel show a decrease of elastic limit of about 50 per cent. up to 570 degrees as differing from the temperature of the room. That is, an elevation of temperature of 570 degrees; while the tenacities increase about 40 per cent. up to 570 degrees temperature; that is, at the 570-degree temperature line, where the maximum strength is observed, the loss of ductility is very considerable. It appears that the harmful influence of heating up to that temperature of 570 degrees on the possibility of working the material, which was illustrated by the previous tests by Professor Martens, also exists for the ordinary low or mild steels; temperatures above 600 degrees show a decrease of strength, as Professor Carpenter has demonstrated. The elongation up to rupture grows very considerably, while in

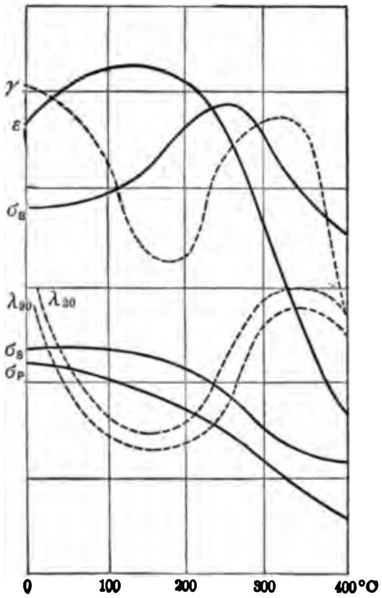
Chart 1.



WROUGHT IRON

FIG. 43.

Chart 2.



MARTIN STEEL

FIG. 44.

TABLE A.

MATERIAL.	Temperature ° C.	Means of Heating.	Diameter *d*.	Sectional Area *F*.	Modulus of Elasticity *E*.	Elastic Limit δ *P*.	Yield Point δ *S*.	Tanacity δ *B*.	PR. CT. OF ELONGATION		Reduction of Area.
									In λ 30.	In λ 90.	
Wrought Iron.	14.6	Watery	.3858	.1169	29,508,000	25,450	28,870	50,200	35.3	30.3	55.0
	96	Vapor.	.3858	.1169	29,195,000	27,440	29,010	55,170	19.0	16.1	47.9
	218	Naphthaline	.3898	.1193	26,640,000	14,080	19,340	67,260	20.0	17.7	45.7
	292	Vapors.	.3898	.1193	23,080,000	7,395	18,490	68,820	34.4	29.9	49.3
	400	Metallic Bath.	.3898	.1193	21,330,000	6,400	16,920	45,790	49.6	40.2	59.3
Martin Steel (for Staybolts).	15	Watery	.3937	.1217	29,295,000	36,550	38,820	63,710	34.4	30.2	59.6
	96	Vapor.	.3898	.1193	30,148,000	33,560	38,390	66,270	19.3	16.8	51.1
	216	Naphthaline	.3937	.1217	29,720,000	27,720	33,990	79,350	19.3	17.3	40.8
	306	Vapors.	.3937	.1217	26,920,000	18,340	23,320	75,220	33.6	30.1	55.4
	398	Metallic Bath.	.3898	.1193	24,032,000	9,670	18,910	58,450	31.6	28.6	30.8

TABLE B.

RELATIVE VALUES OF WROUGHT IRON AND STEEL.

	Temperature.	Elastic Limit.	Yield Point.	Tenacity.	Elong. 30 Pr. Ct.	Reduction.
Wrought Iron.....	100	108	100	110	54	87
	200	55	67	134	57	83
	300	29	64	138	94	90
	400	25	59	91	140	109
Steel...	100	92	99	108	56	86
	200	76	88	125	56	69
	300	50	60	118	98	93
	400	26	48	92	92	52

the case of steel it again decreases after 700 degrees. It is not only an increase of elongation, for when you get up to 700 degrees, beyond where Professor Carpenter's tests stop, the curve drops down again very quickly, which is important. The apparatus has been used for many years and is fully shown in *Stahl und Eisen*, and it is pointed out that that mirror apparatus is used for elongation because that is about the only apparatus which can be used for that purpose. Nothing is attached to the test-piece except two bars with a spring clamp, and the elongation of those two bars under the temperature changes can be calculated. The extension of the mirror which is outside the heated chamber is not affected at all, and the correction can easily be made for the two springs which transmit the extension of the test-piece to the reflecting mirrors from which the reflected scales are read. I am sure Professor Carpenter ought to try to get this apparatus.

Now in regard to the general conclusions of Professor Carpenter referring to low temperature, papers presented by Professor Steiner and Dr. Gollner at Zurich show that for abnormally low temperature—we do not talk of 20 degrees below—the strength of the iron and steel increases immensely, so that it is material such as we do not know of at the present time for ordinary use. They have, however, no ductility whatever; not one-half per cent. ductility at, say, 200 degrees below zero. The point of beginning of curves by Professor Carpenter should be about 70 degrees; then the strength decreases at 100 degrees, and then it begins to increase again. Now, if these tests had been made a little lower down, we should have found a slight increase, and then what comes between 50 degrees above and 20 below zero we do not know. Unfortunately the most important point of the qualities of materials which we have talked about so much, and investigated so much, we know nothing about. When we come to this diagram, away back here to 60 degrees below zero, we know what the changes in the material are under the effect of abnormally low temperatures, but we do not know what happens under moderate temperatures, because all the tests that have been made are absolutely valueless on account of not taking sufficient pains in investigating. One man will observe one thing and another man another, and because each omits just the other part of the investigation his results are really worthless. Now, if the elongation and the elasticity of the material were observed, say, from 100 degrees down as a minimum, and then to about 50 degrees below freezing, which are temperatures which can easily be reached in the laboratory, then we will get the most valuable information about what are called abnormal fractures of rails, say, or other materials in use.

Mr. H. de B. Parsons.—Perhaps it would be interesting to some of the members of the Society to hear the result of some experiments which have been made at my suggestion by the Committee on Fire-Proofing Tests, of which I have the honor to be a member. We made some experiments at the Carnegie Steel Company's Works, on the expansion and contraction of steel beams under high temperatures, and the results were much higher than had been expected. It appears that at temperatures of about 2,000 degrees Fahr. steel beams will expand and contract from 1.6 to 1.9 per cent. of their length, which would represent in a 30-foot beam an expansion of from 5¾ to 7 inches—rather more than most people think. A full account of the experiment and the extensions obtained will appear in the committee's report. This is a little digression, perhaps, from the purport of the paper, but it is rather interesting in connection with the subject, because it bears upon the behavior of the metal under high temperatures.

Mr. Henning.—I would like to call attention to the fact that those experiments are identically in line with those made by Mr. Keep; that we found about two per cent. expansion at those temperatures with steel. We have not yet concluded the experiments, however. I suppose that you did not keep a record of the changes of expansion during the temperatures; did you?

Mr. Parsons.—No. We were after the total expansion. The investigation was started to determine the expansion which could be expected in steel beams in so-called skeleton-construction buildings, in order to determine how much the expansion would be in a floor beam subjected to the heat of a hot fire. We did not take measurements at different temperatures.

Mr. Henning.—This change of length is due to crystallographic changes of material, because at those high temperatures the metal of your steel beam becomes mobile, and the curve that should have been observed instead of following simple maximum elongation would have been quite different. The beam begins to expand, and then expands at a certain point very rapidly, and then the expansion would cease, and the beam would shorten considerably, and then there would be another expansion, and with a slight rise of temperature would reach the melting point. This expansion would be two per cent. While if this expansion were measured at a point only 100 degrees higher than this maximum expansion would be less. Further on it would be greater again. The expansion ought to be observed continuously so as to find out what the variation is at different temperatures, because those expansions are due to crystallographic changes in the material, and there is no telling whether the material will hold together or not when a load is applied. We have found that iron is almost amorphous. If, when in that condition, it is struck or picked up with tongs, it will fall to pieces at such high temperatures. It is the same with cast iron. We have taken bars of cast iron, and by simply picking them up with a pair of tongs they would break in two.

A Member.—What is that temperature?

Mr. Henning.—That varies according to the material. In cast iron it is probably 1,200 or 1,300 degrees; in steel it is higher. In wrought iron it is something less again. It depends entirely on the particular material you are investigating, because that depends on the crystallographic structure and somewhat upon some of the elements contained therein.

Professor Carpenter.—I do not know that there is anything particular to be said, as all of the discussion has been confirmatory of the general results given here. I might say more distinctly that the difficulties experienced in measuring extension during the application of heat were quite serious; Mr. Henning has referred to that. Our difficulties were due, of course, to the fact that we did not have the kind of apparatus described by him, which is a form recently designed, and which I believe has been perfected in this country; this will, no doubt, show such changes during process of heating. It seems to me that we may logically conclude, since the general results with a variety of test-pieces are so nearly alike, that the composition of the material does not have a very great effect. No doubt the exact temperature at which the maximum strength is found differs a little with different materials, but nevertheless the same general law as to variation in strength with changes of temperature seems to hold, whether the material contains little or considerable carbon—in other words, is pure iron or steel; so that I think the general results described in the paper will be confirmed by later and more complete investigations; indeed, Mr. Henning has shown they have been confirmed by the experts in this line of work in Germany.

DCLXXV.*

EXPERIMENTAL METHOD OF DETERMINING THE EFFECTIVE CENTRE OF THE LIGHT EMITTED FROM A STANDARD PHOTOMETRIC BURNER.

BY D. S. JACOBUS, HOBOKEN, N. J.
(Member of the Society.)

[NOTE.—As many engineers have to supervise photometric measurements, and the burner described herein is of the form often used for such work, the following method of determining the effective centre of such a burner is considered of sufficient interest to many members of the Society to warrant presentation.]

IN tests of car lamps made by the Department of Tests of the Stevens Institute during the past spring and summer, it was necessary to employ a burner of about six-candle power as a standard of light. The burner selected was a Sugg Argand gas burner, size *D*, fitted with an opaque screen of the Edgerton pattern, which passed over a glass chimney. The opening for the emission of light was arranged so that the top and the lower part of the flame were obscured from view, as shown in Fig. 45; whereas the horizontal width of the slot was made greater than the diameter of the flame. The horizontal width, *AB*, of the slot was one and one-half inches, and its height, *CD*, was thirteen thirty-seconds of an inch. The diameter of the opaque screen was one and seven-eighths inches. The back of the screen opposite the slot was cut away so as to prevent reflected light from being thrown back and through the slot.

In this class of a screen and burner the distances employed in calculating candle-power measurements are often measured to the geometrical centre of the flame. Any error so involved will be a small one, if the illuminated disc of the photometer is used at a considerable distance from the burner, and in about the same position which it occupied when the burner was calibrated by

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* Presented at the New York meeting (December, 1895) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

means of candles. In our tests, however, the burner had to be used in positions near to, as well as far away from, the disc; so that it was necessary to determine the effective centre of the light which it emitted.

The method of determining the effective centre was as follows: The photometer disc was set at A_1 in Fig. 46, at a distance c_1 from the candles C, and the standard burner was brought to a position, B_1, at which there was an equal illumination on the two sides of the photometer disc at A_1. The distance, b_1, from the disc to the geometrical centre of the burner was then recorded. The disc was then moved to another position, A_2, at the distance c_2 from the candles, and the corresponding distance, b_2, from the disc to the burner was recorded. The disc was then set back to its first position at A_1, and a second reading of b_1 obtained. It was then moved to A_2, and then back to A_1, and so on until a number of readings of b_1 and b_2 were obtained. After a sufficient number of readings was taken to eliminate any irregularity due to variations of light emitted from the candles, the results were averaged, and the distance, x, of the effective light centre from the geometrical centre of the flame was found by means of the formula :—

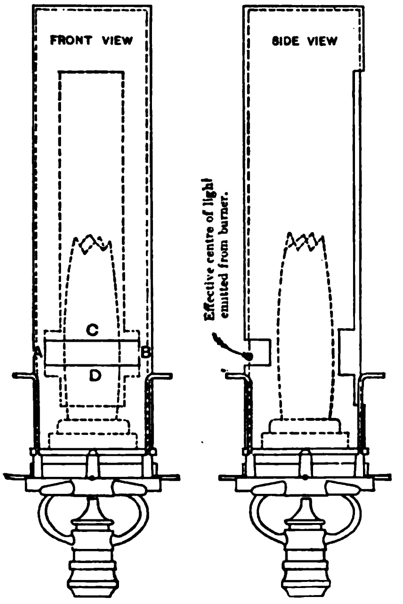

FIG. 45.

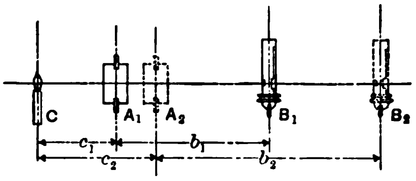

FIG. 46.

$$x = b_1 - \frac{b_2 - b_1}{\frac{c_2}{c_1} - 1}$$

The results of the experiments are given in Table I., and show that the effective light centre of the burner was about nine-tenths

In the case of the blast:
Where $t = 131.66$ degrees,
$p = 29.92$ inches,
$h = .7$ inch,
$V = 59.04$ feet per second.
In the case of the exhaust:
Where $t = 252$ degrees,
$p = 29.92$ inches,
$h = .6$ inch,
$V = 59.95$ feet per second.

In neither case is the coefficient for contraction or friction taken into account; this may vary in value from 90 to 99 per cent. in the case of the blower, and probably not far different in the case of the exhaust.

The combined area of the twenty tuyeres of twenty-five ¼-inch holes = .1704 square foot.

The combined area of the ten 5-inch smoke-pipes = 1.363 square feet.

Cubic feet of air handled for the blast = 59.04 × .1704 = 10.06 cubic feet per second.

Cubic feet of smoke and gases handled by the exhaust fan = 59.95 × 1.363 = 81.71 cubic feet per second.

Taking the weight of 1 cubic foot of air, at 252 degrees, as .05575 pound, the fan would have handled 4.555 pounds per second.

Taking the weight of 1 cubic foot of air, at 131.66 degrees, as .0671 pound, the blower would have handled .675 pound per second. The ratio of air for blast to exhaust is thus about 1 to 8 by volume, and about 1 to 7 by weight. For the two hours' run, 7,200 seconds, the blower, according to the above assumptions, would have handled 72,432 cubic feet, or 4,860 pounds, of air.

The exhaust fan would have handled 588,312 cubic feet, or 32,798 pounds, of air.

For each pound of coal consumed, 278.6 cubic feet at 131.66 degrees, or 18.7 pounds, of air, were supplied; and 2,263 cubic feet at 252 degrees, or 126.1 pounds, exhausted.

Taking the theoretical calorific value of the coal at 12,000 heat units per pound, and the specific heat of the exhaust gases, smoke, and air at .24, which is approximately correct, adding 75 per cent. of the weight of fuel to the air handled, making a total of 32,993 pounds, we would detect [32,798 + (.75 × 260)] × .24 (252 – 80)

	REVOLUTIONS.		DRAFT IN INCHES OF WATER.						BLAST IN INCHES OF WATER.						TEMPERATURES FAHRENHEIT.							
	Blower.	Exhaust Fan.	Blast-pipe at						Smoke-pipe at						Blast-pipe at						Inlet to Blower.	Smoke-flue at
			A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F		G
1.........	1,000	900	⅝	½	½	⅜	½	½	⅞	½	½	⅜	½	¾	- 98	98	99	100	101	98	68	173
2.........	1,200	900	¾	⅝	⅝	½	¾	⅝	1	½	½	½	⅝	¾	104	108	110	112	113	114	73	218
3.........	1,400	1,050	⅞	¾	¾	⅝	¾	¾	⅞	¾	¾	⅜	⅝	⅝	110	122	132	140	144	145	83	275
4.........	1,200	1,000	¾	⅝	⅝	½	⅝	⅝	1	1	¾	½	⅝	¾	116	120	126	132	134	148	83	260
5.........	1,400	1,070	⅞	½	½	½	⅝	⅝	¾	½	½	⅜	½	½	128	136	142	150	156	152	83	291
6..... ...	1,500	1,000	1	¾	¾	¾	¾	⅝	⅞	¾	½	⅞	⅜	½	128	138	146	152	156	148	83	265
7.	1,400	1,000	⅞	¾	¾	⅝	¾	⅝	¾	⅝	⅜	⅜	⅜	⅝	132	142	150	153	159	160	84	264
8.........	1,600	1,030	1⅛	1″	1¼	1	⅞	¾	¾	½	½	¼	¼	⅜	130	140	148	154	150	152	84	270
Average..	1,337	994	.85	.69	.85	.58	.62	.64	.85	.64	.55	.45	.51	.58	118	125	132	137	139	139	80	252
			.7						.6						131.66							

Run of two hours.
Readings taken every fifteen minutes.
Two hundred and sixty pounds of coal consumed.
Average temperature of room, 80 degrees.

centre experimentally than to rely on a theoretical computation.

Mr. H. H. Suplee.—I would like to ask Professor Jacobus if the theory which he has just explained is not practically identical with the proper location of the diaphragm in a photographic lens. There the exact focal distance is governed somewhat by the location of the diaphragm, especially when the spot is very small, while a very large spot in the lens practically eliminates this effect altogether. I refer especially to simple lenses with the diaphragm in front of the lens.

Professor Jacobus.—It would appear to be the same thing. Although I have never examined the theory of the lens, I can see what you refer to is similar to the action which occurs in the burner.

DCLXXVI.*

SOME DATA RELATING TO FORGE-SHOP DESIGN.

BY PAUL MELLEN CHAMBERLAIN, AGRICULTURAL COLLEGE, MICH.
(Junior Member of the Society.)

DURING the winter of 1893–94 a new forge shop was erected for the mechanical department of the Michigan Agricultural College. Some features of its arrangement and data regarding air blast and suction for smoke expulsion may prove of interest. The floor of the shop is 30 feet by 40 feet, and is set with twenty forges in pairs as per plan view, Fig. 49. A general view is reproduced from a photograph in Fig. 48. The forges were not designed for the arrangement, but ten of them being on hand they were used, and the hoods and duplicate forges were for the most part made by the students. The hoods and smoke-flues could not be suspended from above in the usual manner without cluttering up the room and obstructing the instructor's view. The smoke hoods and pipes were consequently arranged as shown in elevation in Fig. 50 —a scheme which was thought by the writer at that time to be entirely new. The blower and exhaust fan were placed on a platform, as shown, to save floor space, and for like reason a bracket engine was used. Correspondence with builders of fans elicited such conflicting advice as to capacities necessary, that some crude experiments were undertaken, which resulted in deciding on using a blower with an outlet six inches in diameter which had been used in the old shop, a present from the B. F. Sturtevant Company to the college some years ago, and an exhaust fan, having an inlet fifteen inches in diameter, purchased from the Boston Blower Company. The blower has since been removed to supply the cupola, and replaced with a nameless blower having an outlet of five inches. The hoods are made of cast iron and fitted with gates. Different heights for hood above the fire were tried up to twelve inches, showing little decrease of

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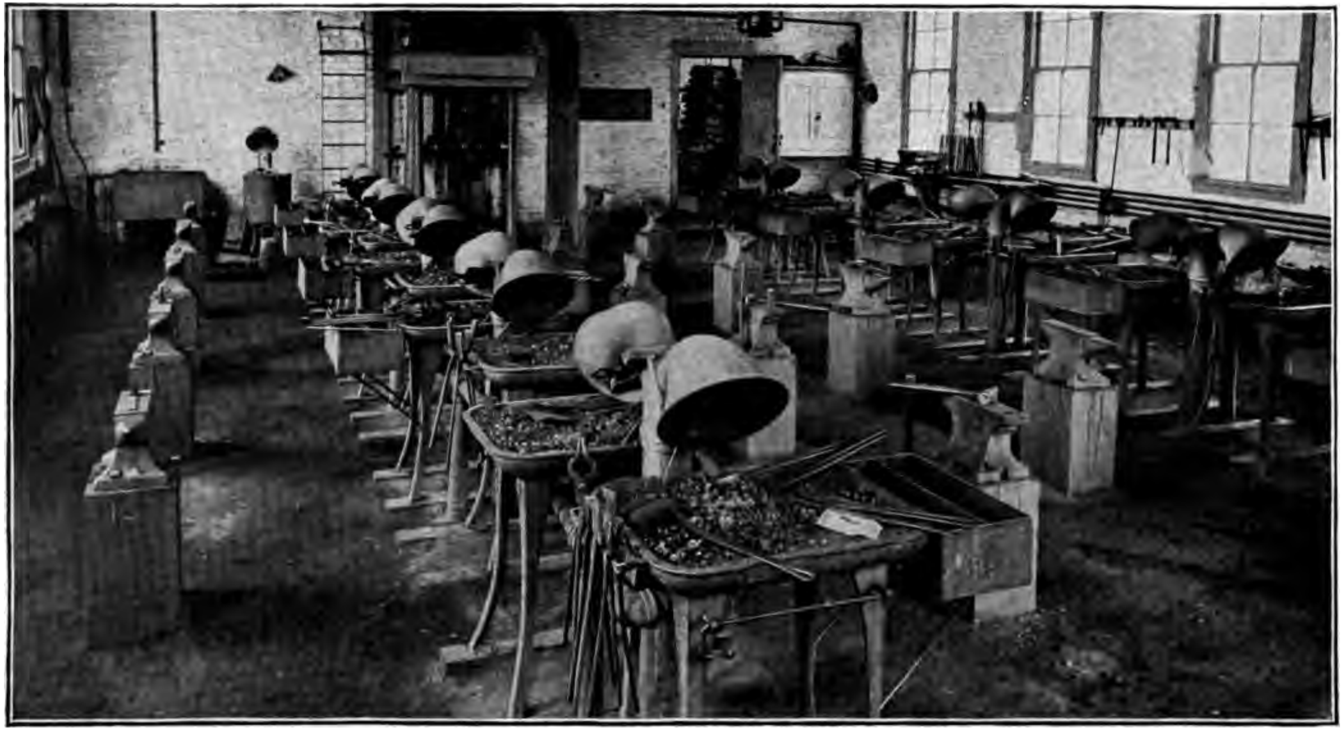
* Presented at the New York meeting (December, 1895) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.



General View of Fig. 50.—Fig. 48.

blower, with a main pipe of nine inches diameter, would have been the proper selection in this case.

There are probably in use to-day, in this country alone, at least 100,000 blowers and exhaust fans, and if, by proper application, only one horse-power each can be saved in the power used in driving them, then 100,000 horse-power would be saved, which, at a cost of $50 per horse-power per annum, amounts to $5,000,000 annually. This estimate, in my opinion, is actually below the facts if they could be known. Let me make a suggestion right here that the proper selection of a blower is one which has a capacity equal to all the discharge openings and the size of pipes made to carry the required volume of air with a minimum loss by friction. This is the view taken by manufacturers when they proportion the size of their outlets, and while the outlet greatly exceeds the effective area of terminal discharge, it serves its purpose well in determining the size of main pipes for lengths not exceeding, say, 100 feet.

The author says he corresponded with different manufacturers of fans about the size of pipes, and their replies were so at variance with each other it was determined to follow the design shown. I do not know with whom this correspondence was carried on, but probably a variation of opinion among the different manufacturers as to the greatest advisable loss of pressure due to friction was the reason for differences of opinion as to size of pipes.

In reference to the size of fan and pipes used in the exhausting arrangement it is quite evident, if the system designed for the blast is correct, that for the exhaust must be really too large, as the work to be done in the one case is only exceeded in the other by the introduction of gas, due the consumption of coal, and the expansion of air supplied by heating.

The principles governing the capacity of an exhaust fan are identical with those of a blast blower, and no exhaust fan and system of piping is correctly applied when the sum total of the area of all inlets is not within its capacity. Capacity is a technical word adopted by manufacturers, and means the number of square inches of outlet for a blast fan, and the number of square inches of inlet of an exhaust fan, which the fan will supply without any appreciable loss from the pressure due the speed of the fan; when designed within these limits, the opening or closing of any of the branches will have no effect on the pressure and consequent volume of air discharged per square inch from any other branch.

Prof. C. L. Weil.—With regard to drainage, the trenches, boxes, and piping are kept dry by means of porous tiling laid beneath the boxes. With regard to any inconvenience arising from the stopping up of the pipes, I only need to state that no such trouble has occurred. This plant has been running two years, and the piping is practically free from sediment or dirt. This is a school shop, and it was necessary to use a blower that was on hand, the authorities only granting permission to purchase an exhaust fan, and thus the size of the blower was limited by financial considerations. The blower was considered at the time of installation somewhat small for the purpose for which it was employed.

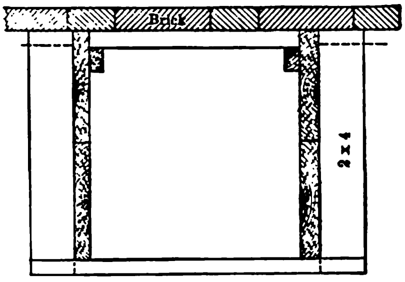
I would like to have some information in regard to proper sizes of pipes for such work, particularly in view of the correspondence with makers mentioned in the paper. The recommendations for size of exhaust pipe, made by three of the prominent concerns of this country, differed very much, the sizes recommended being 15-inch, 30-inch, and, I believe, 20-inch. We were under the impression that we did not know so very much about this matter ourselves, but on comparing the areas of 15-inch and 30-inch pipe, felt we had better make some experiments. When the makers recommended pipes for the same work varying as four to one, we felt the makers also needed to investigate this matter.

While it is acknowledged that a larger blower would work somewhat more economically, still the present blower does the work in a very satisfactory manner.

Mention has been made of the shape of the hood, which is a matter of considerable importance, and I desire to state that the interior of the shop was whitened and painted in light colors nearly two years ago, and although the shop is run nearly every afternoon of the college year, the interior is not discolored by smoke, but remains clear and white, which fact, I believe, goes to show that the smoke and gases do not escape the hoods to any great extent.

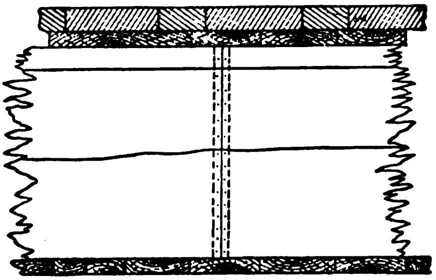
With regard to placing piping under ground, I desire to state that this is a desideratum in school shops, particularly when limited for space, where the instructor needs to have a clear view of the men and their work from any part of the shop.

necessary pressure in the pipe. The revolutions stated in the table were determined in a separate run when the blower was open, and speeded down to give the pressures indicated in the table. The run reported herewith was of two hours' duration, and readings taken every fifteen minutes of the temperatures, revolutions, and pressures. Readings were taken only on six sets of forges, as presumably representing a fair average selected in the positions indicated on Fig. 49 by *A*, *B*, *C*, *D*, *E*, *F*. The fires were first put in prime condition by a practical smith, who was instructed to obtain the requisite blast for a good forging fire, as large as would be practicable with the size of tuyere and forge, and maintain the fire throughout the run, keeping account of the weight of coal used during the run. The fires were about eighteen inches in diameter. The writer has Mr. A. L. Westcott to thank for assistance in taking readings. The blast was very much less in pressure in the pipes than is the usual practice, but was all the fires would stand with the gates wide open. The fires undoubtedly consumed more coal than they would in ordinary use, but the consumption of coal seems to the writer to be the only basis for comparison.



CROSS SECTION OF TRENCH

FIG. 51.



LONGITUDINAL SECTION OF TRENCH

FIG. 52.

Taking the averages of revolutions, pressures, and temperatures as shown on page 225, we can calculate the cubic feet of air and gas handled.

Where V = velocity in feet per second,
t = temperature,
h = height of water in inches in draught gauge, and
p = barometric pressure in inches of mercury,

$$*V = 352\sqrt{\left(1 + .00203\ (t - 32)\right) \times \frac{h}{p}}.$$

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* *A Manual of Rules, Tables, and Data*, D. K. Clark.

brazing furnace. There is a light wrought-iron bar around the edge of a fire-brick block, fitting into a groove and clamped there to hold it, and this brick is suspended by a rod which goes a short distance up into the hood, and then comes out and is attached to a lever arm, so that the suspended fire-brick can be raised or lowered from without. The band-saw is an endless strip of steel, and has to be brought around underneath the forge and back and the scarfed joint laid on top of the fire. The blast comes from below, and the reflected heat from above should, if possible, be nearly as strong as that from the blast underneath. To do this the saw is placed in position, and then the fire-brick is gradually lowered to within two or three inches of the surface of the band-saw. The moment that the temperature has reached the proper degree, the saw must be almost instantly removed and pressure brought to bear upon it, and to do that this fire-brick must be promptly taken out of the way, and the whole saw drawn out and a screw pressure placed upon it, forcing the brass solder out and brazing the parts together. This form of furnace has been found very successful in the establishment referred to. In other respects the furnace is very much as Mr. Woolson describes.

Mr. W. Barnet Levan.—Something has been said here in regard to the area of the pipe carrying from the blower to the furnace. About twenty-five years ago Mr. Corliss built a new foundry, and to save time he utilized an old chimney underground flue which was four times the area of the outlet of the flue of the blower, and he found that he got an increased volume of air and an increased blast with the same old blower. I only mention this to show that an air-flue of large area acts similarly to the reservoir of water-works.

Mr. Snell.—The speaker stated that in answers received from different blower manufacturers some recommend 15-inch diameter for the main pipe, and others said as high as 30. I fail to see any discrepancy in such answers, as it all depends upon how we look at it. A 15-inch pipe will carry the volume of air with a certain velocity and loss from friction due that velocity; a 30-inch pipe will carry the same volume of air with less velocity and less loss for friction. The 30-inch pipe costs more money, but saves in running expenses, and, independent of financial reasons, the larger the pipes for conveying air, provided they are tight, and the terminal reduced to or within

	REVOLUTIONS.		DRAFT IN INCHES OF WATER.						BLAST IN INCHES OF WATER.						TEMPERATURES FAHRENHEIT.							
	Blower.	Exhaust Fan.	Blast-pipe at						Smoke-pipe at						Blast-pipe at						Inlet to Blower.	Smoke-flue at
			A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F		G
1.........	1,000	900	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{7}{8}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	- 98	98	99	100	101	98	68	173
2.........	1,200	900	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{8}$	1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	104	108	110	112	113	114	73	218
3.........	1,400	1,050	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	110	122	132	140	144	145	83	275
4.........	1,200	1,000	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{8}$	1	1	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	116	120	126	132	134	148	83	260
5.........	1,400	1,070	$\frac{7}{8}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{1}{2}$	128	136	142	150	156	152	83	291
6.........	1,500	1,000	1	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{2}$	128	138	146	152	156	148	83	265
7.........	1,400	1,000	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{5}{8}$	132	142	150	153	159	160	84	264
8.........	1,600	1,030	$1\frac{1}{8}$	1″	$1\frac{1}{8}$	1	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{8}$	130	140	148	154	150	152	84	270
Average..	1,337	994	.85	.69	.85	.58	.62	.64	.85	.64	.55	.45	.51	.58	118	125	132	137	139	139	80	252
			.7						.6						131.66							

Run of two hours.
Readings aken every fifteen minutes.
Two hundred and sixty pounds of coal consumed.
Average temperature of room, 80 degrees.

cial considerations had a strong influence in making a choice of blower—in fact, necessitated the use of a blower then on hand.

In regard to choice of exhaust pipe, I presume there is a limit to the size of pipe one can afford to purchase, admitting that the larger pipes are the more economical when operating, with respect to first cost. No doubt the makers are willing to disregard such a limit, and would be satisfied to have one purchased which I would consider an extremely large pipe for its purpose.

Mr. Woolson.—I have noticed since my former remarks that this design of the forge shop is for a college. It did not occur to me when addressing the meeting, therefore I want to say to the author of the paper that I thought it was for ordinary, everyday smith-shop business, where furnaces are running continually, and I want to take back any criticisms I made of his design, and to say that I think a design similar to his for shops in colleges is better in many respects than the sketch I put on the board. Permit me to say one thing more. I made a remark about the economy of a furnace of the kind I have sketched. Mr. Hill of the Collinsville Company has just said to me that they are using several furnaces similar to that, and they find that they are saving at least 50 per cent. of coal.

Prof. P. M. Chamberlain.[*]—The experiments which this paper records were undertaken to determine the amounts of air and smoke handled per pound of coal in forging operations, and incidentally to trace the disposition of the heat, very little of which, as is well known, being used in heating the work. To make the data comparable with other conditions, a description of the plant was desirable.

The selection of blower and exhaust fan for such work is a simple matter when it is known how much air must be supplied and how much mixed air and smoke taken away. Within certain limits it is, from the financial side, the one usually considered, a question of saving in power by using the larger machines and pipes, versus the interest and depreciation on the greater first cost.

The design is not presented as a model of perfection in this or any other respect, but was, with the data and money at our disposal, the best we could contrive, and has proved satisfactory.

The machines used are handling the work without great loss

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[*] Author's closure, under the Rules.

become filled to the extent of fifty per cent. of their original cross section, and the blower failed to do the work required of it from this cause alone.

Second, in reference to the hoods shown in the illustrations to the paper. The reason for adopting the underground pipe is given in the paper as affording the instructor an unobstructed view of the work of the students. If this is of paramount importance it should not be made the subject of criticism, but, for the benefit of those of our members who are interested in the practical working of forge shops, and, incidentally, in cases of large operations of tempering in oil, where large volumes of smoke are to be carried off, let me suggest a good plan for hoods sometimes adopted.

The illustration (Fig. 53) shows the ordinary conical form of hood as seen in all forge shops, with the addition of a smaller cone attached within it. This smaller cone reduces the area of entrance for the gases, yet permits of the spreading of the outer cone over the fire to collect the smoke and bring it under the control of the exhaust fan. It will readily be perceived that the contraction of inlet increases the suction per square inch around the periphery of the cone, and prevents the smoke from escaping around the edge of it, and away from the influence of the fan. The opening in the top of the inner cone permits of a suction at this point which tends to relieve the hood and cause currents toward the centre of it. This fact will be recognized : that with a suction of, say, about one-half inch of water in the pipe *D*, the velocity of flow through it will be about 2,788 feet per minute (vide *Kent's Mechanical Engineers' Hand Book*, page 514), and if the circular area *B* plus the area of the annular space *C* equals the area of pipe *D*, the velocity at these points will be the same; now, if the inner cone *A* be removed, and the diameter of cone equal four times the diameter of the pipe, or sixteen times the area, not an unusual proportion, the mean velocity at the base of the cone becomes $\frac{2788}{16}$, equal only to 120 feet per minute. The foregoing demonstration is based upon the equal suction of

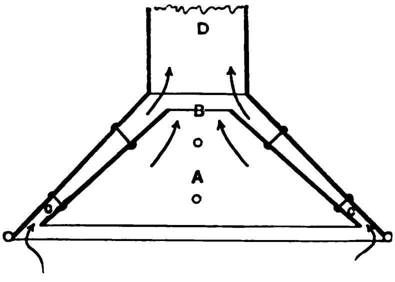

FIG. 53.

My observation of smoke exhausting from an open fire will not enable me to agree with Mr. Snell when he says that the work done by the exhaust fan exceeds that of the blower only by the introduction of gas due to the consumption of coal and the expansion of air supplied by heating. In the case in hand the exhaust fan is speeded as low as it will thoroughly carry away the smoke and gases; and on page 225 we find the ratio of exhaust to blast to be eight to one. Mr. Snell's statement would hold only with a closed furnace.

The forges described by Messrs. Woolson, Suplee, and Kent are without doubt superior for commercial purposes, but would not, I am inclined to think, so well answer the purpose of instruction as the ordinary open fire.

We have in our shop a forge for tempering in lead and sand baths, which in some respects resembles those described.

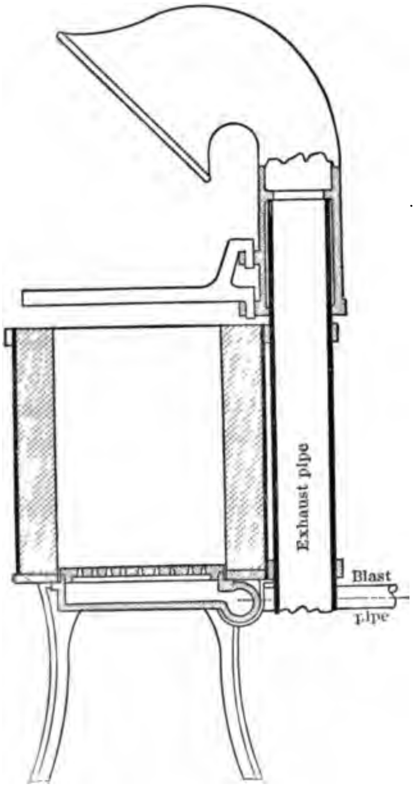

FIG. 54.

A feature of the tuyere box, the idea of Mr. Paul Theadore, proves so satisfactory that I present here a sectional view of it (Fig. 54). The blast-pipe is connected to the tuyere box, which is also the bottom of the furnace, by means of a hinge, and the bottom may be dropped at any time without disconnecting the blast-pipe. The top can be lifted out and the box cleaned very conveniently.

blower, with a main pipe of nine inches diameter, would have been the proper selection in this case.

There are probably in use to-day, in this country alone, at least 100,000 blowers and exhaust fans, and if, by proper application, only one horse-power each can be saved in the power used in driving them, then 100,000 horse-power would be saved, which, at a cost of $50 per horse-power per annum, amounts to $5,000,000 annually. This estimate, in my opinion, is actually below the facts if they could be known. Let me make a suggestion right here that the proper selection of a blower is one which has a capacity equal to all the discharge openings and the size of pipes made to carry the required volume of air with a minimum loss by friction. This is the view taken by manufacturers when they proportion the size of their outlets, and while the outlet greatly exceeds the effective area of terminal discharge, it serves its purpose well in determining the size of main pipes for lengths not exceeding, say, 100 feet.

The author says he corresponded with different manufacturers of fans about the size of pipes, and their replies were so at variance with each other it was determined to follow the design shown. I do not know with whom this correspondence was carried on, but probably a variation of opinion among the different manufacturers as to the greatest advisable loss of pressure due to friction was the reason for differences of opinion as to size of pipes.

In reference to the size of fan and pipes used in the exhausting arrangement it is quite evident, if the system designed for the blast is correct, that for the exhaust must be really too large, as the work to be done in the one case is only exceeded in the other by the introduction of gas, due the consumption of coal, and the expansion of air supplied by heating.

The principles governing the capacity of an exhaust fan are identical with those of a blast blower, and no exhaust fan and system of piping is correctly applied when the sum total of the area of all inlets is not within its capacity. Capacity is a technical word adopted by manufacturers, and means the number of square inches of outlet for a blast fan, and the number of square inches of inlet of an exhaust fan, which the fan will supply without any appreciable loss from the pressure due the speed of the fan; when designed within these limits, the opening or closing of any of the branches will have no effect on the pressure and consequent volume of air discharged per square inch from any other branch.

Prof. C. L. Weil.—With regard to drainage, the trenches, boxes, and piping are kept dry by means of porous tiling laid beneath the boxes. With regard to any inconvenience arising from the stopping up of the pipes, I only need to state that no such trouble has occurred. This plant has been running two years, and the piping is practically free from sediment or dirt. This is a school shop, and it was necessary to use a blower that was on hand, the authorities only granting permission to purchase an exhaust fan, and thus the size of the blower was limited by financial considerations. The blower was considered at the time of installation somewhat small for the purpose for which it was employed.

I would like to have some information in regard to proper sizes of pipes for such work, particularly in view of the correspondence with makers mentioned in the paper. The recommendations for size of exhaust pipe, made by three of the prominent concerns of this country, differed very much, the sizes recommended being 15-inch, 30-inch, and, I believe, 20-inch. We were under the impression that we did not know so very much about this matter ourselves, but on comparing the areas of 15-inch and 30-inch pipe, felt we had better make some experiments. When the makers recommended pipes for the same work varying as four to one, we felt the makers also needed to investigate this matter.

While it is acknowledged that a larger blower would work somewhat more economically, still the present blower does the work in a very satisfactory manner.

Mention has been made of the shape of the hood, which is a matter of considerable importance, and I desire to state that the interior of the shop was whitened and painted in light colors nearly two years ago, and although the shop is run nearly every afternoon of the college year, the interior is not discolored by smoke, but remains clear and white, which fact, I believe, goes to show that the smoke and gases do not escape the hoods to any great extent.

With regard to placing piping under ground, I desire to state that this is a desideratum in school shops, particularly when limited for space, where the instructor needs to have a clear view of the men and their work from any part of the shop.

dence to the contrary was at an early date overwhelming, and it was claimed by many that the commercial value of coal of all kinds was practically proportioned to the carbon element alone. From the weight of evidence, it appears to the writer that this simple rule is, in a general sense, as nearly accurate as any other that has been suggested for a number of varieties of coal burned with ordinary apparatus and management (§ 42).

§ 5. It has also been suggested that the practical evaporation bears a definite relation to the proportion of "fixed combustible," or that remaining after the volatile matter in the coal has been distilled off; but from the weight of evidence it appears to the writer that this proposed rule is not generally applicable, though it should be borne in mind that the proportions of fixed and volatile combustible matter are used universally as a means of identifying and classifying different kinds of fuel. A well-established result of this classification is that the evaporative efficiencies of anthracite and semi-bituminous coals containing less than 20 per cent. of volatile combustible are, in a general sense, nearly equal, independent of chemical composition; though, as a rule, the theoretical calorific value increases considerably, and the practical evaporation slightly, with the increase of volatile matter within these limits. On the contrary, as the proportion of volatile matter increases above such limits, the percentage of the total calorific value of the fuel utilized is, as a rule, reduced materially with ordinary apparatus and management. It is true that the calorific value of many coals reduces as the percentage of volatile matter is increased; but this is not always the case, particularly with the coals of this country. The percentage of efficiency is, however, in general decreased with the increase of volatile matter above the limits mentioned.

§ 6. Most of the coals used on the seaboard and in the eastern

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in which h = the calorific value; C = the weight of carbon, with a calorific value according to Fabre and Silberman of 14,500 British thermal units; H = weight of hydrogen, with a calorific value by the same authority of 62,032 units. Dulong's original formula, as quoted in another reference (*j* 505)*, reduced to same units and notation, is practically the same, being

$$h = 14{,}544\ C + 62{,}032\left(H - \frac{O}{8}\right).$$

Minor variations of these values have been suggested, based on changes in the calorific value due to differences in the densities of the elements (§§ 7 and 24).

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* See list of references, §48.

part of the United States have less than 20 per cent. volatile matter in their composition, and, in a general sense, with conditions favorable to each, give substantially like evaporative results (§ 16). Each, however, has peculiarities of its own, so that, with ordinary apparatus and management, the results vary somewhat, and the mechanical structure of the coal (§ 7) seems to have more influence on the result than the chemical composition. The practical results for the softer coals of the same class, substantially alike in appearance and composition, also vary in much the same way; but in general all show a falling off in evaporative efficiency when the volatile matter is greater than 20 per cent.

§ 7. The above will serve to give a general impression of the information available on the subject. The explanations that have been made of various observed phenomena are more or less conflicting because based on experiments limited in number, or carried out in a manner which did not develop all the conditions. One difficult question to explain has been the variations in practical result shown by coals of substantially the same chemical composition. These differences have frequently been referred to a less percentage of refuse, and to differences in the refuse as respects the formation of clinkers, etc., whereby less labor was required to handle the fires, the fire-doors were opened less, and there was less heat carried away in the refuse itself. All these practical questions are of importance; but it is probable that the more important variations in result are due to the different way in which the components are united chemically, and, as stated, to a difference in mechanical structure of the coal. It is known that a difference even in the allotropic form of the element affects the calorific value, Berthelot finding nearly 5 per cent. difference in calorific value due to the combustion of carbon in the form of a diamond, and of amorphous wood charcoal (*k* 101).* It is known that in comparing coals of very similar composition, some will smut the hands and others will not; some have little cohesion, like rotten wood, others are like stone. The suggestion that the calorific value may vary with the mechanical structure is, therefore, very probable. It has occurred to the writer that these differences may be very much akin to those resulting from the mixtures and combinations of carbon and iron, resulting in cast iron, malleable iron, soft and hardened steel, etc.

§ 8. In burning coal with a large proportion of volatile matter

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* See list of references, § 48.

there results a combined combustion and wasteful distillation of the volatile products, which latter are not consumed in ordinary furnaces, but escape to the chimney. The experiments show, as stated, that the loss of heat increases with the proportion of volatile products, and Rankine (*a* 292) gives the carbon value of losses on the several assumptions: First, that hydrogen only is wasted; second, that the carbon is combined with hydrogen in the same proportion as in "marsh gas" and the product wasted; and third, that the combination is in the same proportion as in "olefiant gas" and the product wasted. This would seem to imply that, at the temperature of the furnace, carbon and hydrogen unite to form hydro-carbons, but this is probably not the case. Any hydro-carbons that appear are doubtless condensed and combined as a part of the coal itself, released as gases by the heat of the furnace, and in the main carried away, wasting the heat due to their chemical composition, which it is interesting to note is less than the sum of the calorific values of the elements (§ 24). The imperfect combustion resulting from driving off the volatile matter can, in part at least, be explained by the great volumes of gases disengaged, which prevent a proper admixture with the air supplied, and which, moreover, absorb a portion of the heat of the combustible consumed.

§ 9. Those of us who were in the United States naval service during the late war, appreciate the great services rendered the profession by the very numerous and elaborate investigations participated in or made under the direction of Chief Engineer B. F. Isherwood, United States Navy, before and during the time he was Engineer-in-Chief of the Navy. His publications contain the details of very many excellent and carefully conducted tests with boilers of different types and fuel of different kinds. Analyses were made of typical coals employed in the naval service, and the corresponding calorific values compared with the actual results obtained in practice. In his early writings he urged that the commercial value of coal was measured entirely by the carbon element, as was the early belief; but afterwards, in testing one of the Pittsburg coals with a large percentage of volatile matter, he considered that the hydrogen showed in practice about half the calorific value of carbon, instead of upwards of four times that value as shown by combustion in oxygen (*d* I. 151). This, however, was with a coal richer in hydrogen than any other that has been reported (See ‡, Table I.).

TABLE I.

SHOWING PROXIMATE AND ORGANIC ANALYSES OF DIFFERENT COALS AND THEIR THEORETICAL AND PRACTICAL EVAPORATIVE EFFICIENCIES AS DETERMINED BY ISHERWOOD AND JOHNSON.

1			A		B		C		D		E		F	
2			ISHERWOOD (c. II. 3).		ISHERWOOD (c. II. 3).		ISHERWOOD (c. II. 3).		ISHERWOOD (d. I. 145).		ISHERWOOD (d. I. 145).		JOHNSON (b. 292).	
3			Blackheath Anthracite, Pa.		Treverton Semi-Anthracite, Pa.		Cumberland Semi Bituminous, Md.		Ormsby Bituminous, Pa.		Lehigh Anthracite, Pa.		Cambria Co. Bituminous, Pa.	
4	Proximate Analysis.	Fixed carbon	Not given.		85.66	92.77	80.75	86.14	53.72	57.92	72.00	91.17	69.590	77.46
5		Volatile matter, exclusive of water			6.67	7.23	13.00	13.86	39.03	42.08	6.97	8.83	20.255	22.54
6		Water expelled at 212°			0.84	......	1.25	......	1.25	......	2.50	......	1.105	......
7		Ashes			6.83	......	5.00	......	6.00	......	18.53	......	9.050	......
8					100.00	100.00	100.00	100.00	100.00	100.00	100.00	100 00	100.000	100.00
9	Organic Analysis.	Carbon	......	93.89	90.661	97.310	86.50	92.27	67.57	73.68	73.41	94.12	......	91.955
10		Hydrogen	......	3.55	1.726	1.853	4.75	5.07	21.47	23.41	2.23	2 86	......	5.867
11		Oxygen	......	2.56	0.780	0.837	2.50	2.66	2.67	2.91	2.36	3.02	......	2.178
12		Nitrogen	......	......	0.001	......	......	......	1.04	......	0.97	......	.. ..	......
13		Water	......	......	......	.. ...	1.25	......	1.25	......	2.50	......	......	......
14		Ash	......	......	6.721	......	5.00	......	6.00	. ....	18.53	......	......	......
15		Loss	......	......	0.111	......	......	......	......	......	.. ..	......	......	......
16			......	100.00	100.000	100.00	100.00	100.00	100.00	100.00	100.00	100.00	......	100.000
17	Calorific value, B.T.U.		15,619		15,195		16,821		24,968 ‡		15,390		16,806	
18	Relative practical evaporation without air over fire		1.000		1.107		1.134		......		......		.....	
19	With air over fire		1.000		. 1.127		1.118		......		......		......	
20	Water evaporated from and at 212° per pound of combustible		......		......		......		9.512		10.126		10.92	
21	Efficiency or calorific value utilized during test, per cent		......		......		......		86.772		63.559		02.77	

of efficiency, as calculated by the Sturtevant Blower Company's tables, and it is doubtful, according to calculations I have recently made, whether an increase of efficiency by using larger machines would counterbalance the interest on the increased cost. While the design was for a school shop, I believe the down-draft feature, doing away with suspended hoods and pipes, would be appreciated in many of the regular business shops.

The cast-iron hoods are more expensive than those made of wrought iron, but are, I believe, economical, as wrought iron is very short-lived under the direct action of the gases and cinder from a forge fire.

A number of the speakers have condemned underground pipes, but our experience with them, in this instance, has been very satisfactory. With proper design they may be made quite as accessible as overhead ones. The objection urged against underground blast-pipes becoming clogged by reason of the precipitated moisture, does not hold in a case where the smoke-flues occupy the same trench. This may be readily seen by noting that, as given on page 225, the air in the blast was raised from 80 degrees to 131.66 degrees between the blower and forges.

In reply to Professor Hutton's question, I would say that when the plant was designed, it was expected that it would be necessary occasionally to remove the trench covers at the extremities of straight runs of pipe, and introduce a sweeper operated by either a chain or wire. With two years' use this has not been found necessary, the velocity of the air being such as to carry along with it pieces of coke even as large as a hickory nut when thrown within the hood. It would be interesting to know how low a velocity of exhaust would be sufficient for this self-cleansing process, for in a down-draft arrangement such a point would limit the area of the pipe for any given quantity of air handled.

I wish to correct the misapprehension of Mr. Snell regarding the comparative area of the tuyere openings and the blast-pipe. The area of the main blast-pipe is 28.27 inches, and the combined area of the tuyeres 24.5 inches when all are open wide, a condition that would seldom exist. As the plant runs when in ordinary use, it is not unlikely that the blower would handle, instead of 10·06 cubic feet per second, perhaps only two-thirds of that amount or less.

My observation of smoke exhausting from an open fire will not enable me to agree with Mr. Snell when he says that the work done by the exhaust fan exceeds that of the blower only by the introduction of gas due to the consumption of coal and the expansion of air supplied by heating. In the case in hand the exhaust fan is speeded as low as it will thoroughly carry away the smoke and gases; and on page 225 we find the ratio of exhaust to blast to be eight to one. Mr. Snell's statement would hold only with a closed furnace.

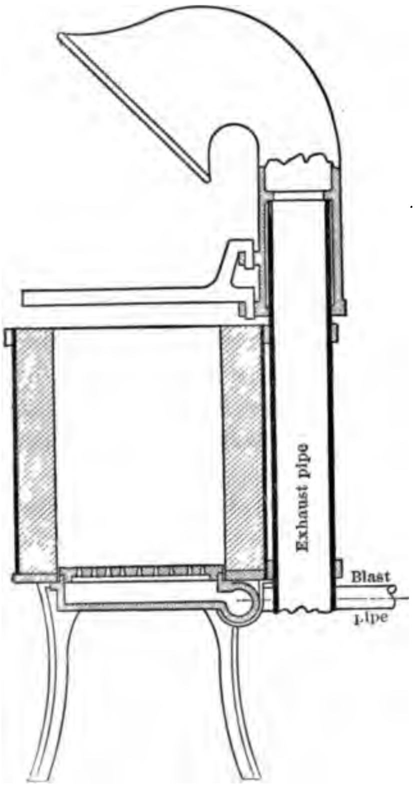

FIG. 54.

The forges described by Messrs. Woolson, Suplee, and Kent are without doubt superior for commercial purposes, but would not, I am inclined to think, so well answer the purpose of instruction as the ordinary open fire.

We have in our shop a forge for tempering in lead and sand baths, which in some respects resembles those described.

A feature of the tuyere box, the idea of Mr. Paul Theadore, proves so satisfactory that I present here a sectional view of it (Fig. 54). The blast-pipe is connected to the tuyere box, which is also the bottom of the furnace, by means of a hinge, and the bottom may be dropped at any time without disconnecting the blast-pipe. The top can be lifted out and the box cleaned very conveniently.

DCLXXVII.*

COMPARATIVE TESTS OF STEAM BOILERS WITH DIFFERENT KINDS OF COAL.

BY CHARLES E. EMERY, NEW YORK, N. Y.
(Member of the Society.)

§ 1. THE meeting of another prominent engineering society in the same week as the Detroit meeting of this Society, unfortunately prevented the writer from examining and discussing the paper of Mr. F. W. Dean on the "Efficiency of Boilers: A Criticism of the Society's Standard Code of Reporting Boiler Trials." As a member of the original committee of 1886, the writer has recently been appointed a member of the new committee in accordance with the suggestion brought out in the discussion of Mr. Dean's paper. The primary object of the present paper was to acquaint the new members of the committee with some of the considerations which governed the writer individually in the action formerly taken, and to invite the other members to similarly contribute their views in advance of a meeting for oral discussion. Mr. William Kent, on whom, as the originator of the movement in 1886, has devolved the duty of calling the new committee together for organization, suggested, however, that the paper be put in such shape that it could be presented to the entire membership of the Society, and that written discussions be invited to be acted on at the first meeting of the committee, and with this object turned over to the writer copies of his previous writings on the subject. An attempt to carry out the suggestion has been made with some hesitation, as it is impossible to discuss the subject exhaustively in a single paper; but we have endeavored to give a digest, with references, of the information available in regard to the more important suggestion of Mr. Dean, which will show, in some degree, the difficulties to be overcome, and hope that any deficiencies in treatment will be corrected or supplemented by a free discussion.

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*Presented at the New York meeting (December, 1895) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

§ 2. The paper of Mr. Dean criticises the standard code of 1886 from the fact that it provides to compare the efficiency of boilers by the actual evaporation per unit of combustible. The paper claims that "combustible, as well as coal, varies in heat value per pound;" and urges that boiler trials should be reported on the "basis of efficiency," which is defined to be "the ratio between the total heat which any given coal can generate by complete combustion, and that part of it which is absorbed by the water, and steam heated and generated." He adds: "There are two methods of obtaining the heat value of coal; one by burning a representative sample in some kind of oxygen calorimeter, and the other is to analyze the coal, and equate the elements with their heat values."

§ 3. It would be strange, indeed, if there were not omissions in the original "Report on a Standard Method of Steam-Boiler Trials." Specifications of ordinary machines and structures are improved every year to keep up with the progress of thought and experience. On the same principle, additions may be desirable to the code of rules for testing boilers, but investigation shows that the standard above proposed involves so many irregularities that, at the best, it can only be employed to supplement, rather than supplant, that already established. Conclusions drawn by reason from accepted elementary facts are not always correct, because the combinations, so easily made mentally, involve actually many unknown physical conditions. Many such conclusions are so evident that they are suggested again and again. For instance, nothing is apparently more reasonable than the recommendation in Mr. Dean's paper "to analyze the coal and equate the elements with their heat values," but it was known over fifty years ago that this method did not give the practical value of fuel for the purposes of generating steam.

§ 4. Experimentally, hydrogen burned in oxygen has over four times the calorific value of carbon. It seems evident, therefore, that the value of the fuel should be greater, the larger the proportion of hydrogen it contains, but such is not the case.* The evi-

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* This general statement implies that no oxygen is present, or refers to the weight of hydrogen in excess of that required to form water with the combined oxygen. The theoretical calorific value of a fuel as given by Rankine (*a* 272)* is

$$h = 14{,}500\left(C + 4.28\left(H - \frac{O}{8}\right)\right),$$

dence to the contrary was at an early date overwhelming, and it was claimed by many that the commercial value of coal of all kinds was practically proportioned to the carbon element alone. From the weight of evidence, it appears to the writer that this simple rule is, in a general sense, as nearly accurate as any other that has been suggested for a number of varieties of coal burned with ordinary apparatus and management (§ 42).

§ 5. It has also been suggested that the practical evaporation bears a definite relation to the proportion of "fixed combustible," or that remaining after the volatile matter in the coal has been distilled off; but from the weight of evidence it appears to the writer that this proposed rule is not generally applicable, though it should be borne in mind that the proportions of fixed and volatile combustible matter are used universally as a means of identifying and classifying different kinds of fuel. A well-established result of this classification is that the evaporative efficiencies of anthracite and semi-bituminous coals containing less than 20 per cent. of volatile combustible are, in a general sense, nearly equal, independent of chemical composition; though, as a rule, the theoretical calorific value increases considerably, and the practical evaporation slightly, with the increase of volatile matter within these limits. On the contrary, as the proportion of volatile matter increases above such limits, the percentage of the total calorific value of the fuel utilized is, as a rule, reduced materially with ordinary apparatus and management. It is true that the calorific value of many coals reduces as the percentage of volatile matter is increased; but this is not always the case, particularly with the coals of this country. The percentage of efficiency is, however, in general decreased with the increase of volatile matter above the limits mentioned.

§ 6. Most of the coals used on the seaboard and in the eastern

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in which h = the calorific value; C = the weight of carbon, with a calorific value according to Fabre and Silberman of 14,500 British thermal units; H = weight of hydrogen, with a calorific value by the same authority of 62,032 units. Dulong's original formula, as quoted in another reference (*j* 505)*, reduced to same units and notation, is practically the same, being

$$h = 14{,}544\ C + 62{,}032 \left(H - \frac{O}{8}\right).$$

Minor variations of these values have been suggested, based on changes in the calorific value due to differences in the densities of the elements (§§ 7 and 24).

* See list of references, §48.

management, for it is known that there are important differences in the behavior of different coals in the furnace, and that some require very much more careful manipulation than others, to secure satisfactory results. The semi-bituminous coals averaged better than the anthracites, but this Mr. Isherwood attributed to the proportions of the boiler, and claimed that, with a boiler properly proportioned to burn anthracite, the results would be the same, and other experiments show such a result. Unfortunately, analyses were not made of the several kinds of coal at this time, but it is assumed that the anthracites were substantially of the same composition as the Blackheath anthracite given in Table I., and the bituminous coal substantially the same as the Cumberland semi-bituminous given in the same table, which is probably true in a general sense.

§ 17. The fact that the greater part of the Isherwood experiments were made at atmospheric pressure may be criticised, but the discharge openings were very large, and, moreover, the experiments correspond well one with another, and with other experiments with the same coal. For instance, during the experiments with the machine-shop boiler the average evaporation from and at 212° per pound of combustible for twelve kinds of anthracite coal was 10.868 pounds, and for two kinds of semi-bituminous coal 10.916 pounds, being 2.2 per cent. higher for the latter. The average of six experiments with the new boilers on steamers was, for the anthracite, 11.02 pounds, and for the semi-bituminous 11.264 pounds, or slightly greater, but the average of the semi-bituminous results was 2.2 per cent. better than for the anthracite, as before. In the Johnson experiments, with a small boiler referred to hereinafter, the corresponding average result from eight kinds of anthracite coal was 11.235 pounds, and from eleven kinds of semi-bituminous coal 11.597 pounds, or substantially the same absolute results; the latter showing 3.03 per cent. superiority, though tested under entirely different conditions.

§ 18. The earliest experiments of note made in this country, and in some respects the most remarkable, were conducted under authority of an Act of Congress approved September 11, 1841. The experiments were made by Prof. Walter R. Johnson, of Philadelphia. His preliminary report to the Secretary of the Navy was dated November 28, 1843, and, with a final report dated June 6, 1844, was published as Document 386, Twenty-eighth Congress, First Session. Professor Johnson states that the inves-

TABLE I.—*Continued.*

1			G		H		J		K		L		M		N	
2			JOHNSON (b. 421).		JOHNSON (b. 499).		JOHNSON (b. 364).		JOHNSON (b. 515).		JOHNSON (b. 535).		JOHNSON (b. 539).		JOHNSON (b. 539).	
3			Midlothian Coking Bituminous, Va.		Newcastle Bituminous, England.		Clover Hill Bituminous Coking, Va.		Scotch Cannel Bituminous.*		Caseyville and Cannelton Bituminous, Ind.†		Osage River Bituminous, Miss.		Pure Bitumen.	
4	Proximate Analysis.	Fixed Carbon	56.40	62.74	56.996	61.55	56.831	64.19	60.342	62.94	44.493	59.18	51.16	55.02	24.799	25.50
5		Volatile matter, exclusive of water	33.49	37.26	35.597	38.45	31.608	35.81	35.586	37.06	30.669	40.82	41.83	44.98	72.439	74.50
6		Water expelled at 212°	0.67	......	2.007	......	1.339	......	1.365	......	1.151	......	1.67	......	......	......
7		Ashes	9.44	......	5.400	......	10.132	......	2.707	......	23.687	......	5.34	......	2.762	......
8			100.00	100.00	100.000	100.00	100.000	100.00	100.000	100.00	100.000	100.00	100.00	100.00	100.000	100.00
9	Organic Analysis.	Carbon	......	93.620	81.371	84.157	......	83.393	79.574	82.952	57.375	76.335	......	81.855	......	77.679
10		Hydrogen	......	5.739	5.439	5.626	......	4.958	5.378	5.607	5.008	6.663	......	6.168	......	8.023
11		Oxygen	......	0.641	9.879	10.217	......	11.649	10.976	11.441	12.779	17.002	......	11.977	......	14.298
12		Nitrogen	......	......	......	......	......	......	......	......	......	......	......	......	......	......
13		Water	......	......	1.461	......	......	......	1.365	......	1.151	......	......	......	......	......
14		Ash	......	......	1.850	......	......	......	2.707	......	23.687	......	......	......	......	......
15		Loss	......	......	......	......	......	......	......	......	......	......	......	......	......	......
16			......	100.000	100.000	100.000	......	100.000	100.000	100.000	100.000	100.000	......	100.000	......	100.000
17	Calorific value, B.T.U		17,087		14,902		14,265		14,620		13,885		14,768		15,184	
18	Relative practical evaporation without air over fire		......		......		......		......		......		......		......	
19	With air over fire		......		......		......		......		......		......		......	
20	Water evaporated from and at 212° per pound of combustible.		10.43		9.79		9.16		8.23		8.25		......		......	
21	Efficiency or calorific value utilized during test, per cent.		58.97		63.46		62.03		54.38		57.40		......		......	

* The ultimate analysis was of cannel coal. The evaporative test was made with mixed cannel and other coal as delivered.
† The evaporative test was made with Cannelton ; the analysis was of Caseyville coal from same coal field.
‡ This high calorific value is due to the hydrogen, which is reported so large as to cause doubt as to the accuracy of the analysis, though stated in great detail (c. II. 3).

the oxygen with compounds which yielded it readily, and collected and weighed the gaseous products of combustion, thus inferring the weight of oxygen absorbed. He states that this is "no other than the method of analysis so successfully applied of late years to discover the composition of organic substances among which *coal* is undoubtedly to be ranked. The quantity employed in analyses of this kind seldom or ever exceeds ten grains." He states: None of the above-described methods appear to fulfil the conditions required in a practical determination of the evaporative power of the several kinds of coal, and adds, "Preference was therefore given to what had to a limited extent been employed" by parties he mentions in Scotland and England and "by Dr. Dana, Mr. Hayes, and Mr. Francis, in this country." "This method consists in burning the coals under a steam boiler so arranged and furnished with apparatus as to be capable of complete regulation. The water delivered to the boiler and the coal supplied to the furnace are determined both by weight and measure. The supply of air, the rate of combustion, the pressure and temperature of steam, the proportion and character of the products of combustion, both fixed and volatile, whether left on the grate or passing through the flues, are subject to careful observation and experiment." The results are reported in terms of the weight of water evaporated from and at 212 degrees per pound of combustible.* Bear in mind that this is not a modern report, but was published fifty-two years ago.

§ 20. The experiments were conducted in this way with forty-one samples of coal. Nine were anthracites from Pennsylvania, which, as seen in Table IV., presented herewith, then bore names still familiar, one being from the Lykens Valley Coal Company, Dauphin County, which, "though possessing the principal features of anthracites, also contains more than the usual amount of volatile matter, gives a considerable quantity of luminous flame, burns with more freedom than the generality of anthracites, and hence constitutes a proper link of transition to the next class, or that of the free-burning or semi-bituminous coals," of which twelve samples were tried, six from Maryland and six from Pennsylvania. In addition to the above there were eleven samples of Virginia

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* Johnson actually used 1,030 heat units as the latent heat of steam at atmospheric pressure, instead of 966, now acknowledged as the unit of evaporation, so all of his results must be increased 6⅝ per cent. to compare with modern practice.

greàt pains taken to make the conditions as nearly the same as possible. The general results are shown in Table II.

TABLE II.

SHOWING RESULTS OF EXPERIMENTS WITH MACHINE-SHOP BOILER, NAVY YARD, NEW YORK, TO TEST THE EVAPORATIVE EFFICIENCIES OF DIFFERENT KINDS OF COAL.

KIND OF COAL.		Percentage of Refuse.	Evaporation from and at 212° per Pound of Combustible.	Relative Evaporative Efficiency.
		Per Cent.	Pounds.	
Anthracites from Luzerne Co., Pa.	Lackawanna	17.54	11.187	.991
		17.04	10.914	.967
	Scranton	17.25	10.125	.897
	Boston	20.95	11.136	.986
	Hazleton	15.03	10.419	.923
	Pittston	17.45	10.452	.928
	Council Ridge	10.80	10.812	.958
	Spring Mountain.	13.76	10.640	.942
Anthracites from Schuylkill Co., Pa.	Locust Mountain	19.72	10.819	.958
	Unknown	14 16	10.240	.907
	Broad Mountain.	19.36	10.204	.904
	Blackheath	17.29	11.284	1.000
Semi-Anthracite	Glen Carbon	17.66	11.184	.990
Semi-Bituminous from Huntington Co., Va.	Broadtop	13.88	11 604	1.028
Semi-Bituminous from Allegbany Co., Md.	Cumberland	8.39	10.228	.995
Bituminous from Clinton Co., Pa.	Eagleton	13.03	10.701	.948

§ 16. The result of these experiments showed that the practical evaporative efficiencies of the different kinds of coal available for steam purposes in the navy were remarkably near to being alike. Mr. Isherwood expressed the opinion that probably, if very much larger quantities of coal had been burned, the average results for each of the different anthracites would have been practically the same, though different experiments might vary 10 per cent. from each other, or 5 per cent. each side of the average. It is not thought that so broad a generalization is warranted. It is, indeed, surprising that the different coals gave results so closely approximating each other, but this must have been largely due to skilful the oxygen with compounds which yielded it readily, and collected and weighed the gaseous products of combustion, thus inferring the weight of oxygen absorbed. He states that this is "no other than the method of analysis so successfully applied of late years to discover the composition of organic substances among which *coal* is undoubtedly to be ranked. The quantity employed in analyses of this kind seldom or ever exceeds ten grains." He states: None of the above-described methods appear to fulfil the conditions required in a practical determination of the evaporative power of the several kinds of coal, and adds, "Preference was therefore given to what had to a limited extent been employed" by parties he mentions in Scotland and England and "by Dr. Dana, Mr. Hayes, and Mr. Francis, in this country." "This method consists in burning the coals under a steam boiler so arranged and furnished with apparatus as to be capable of complete regulation. The water delivered to the boiler and the coal supplied to the furnace are determined both by weight and measure. The supply of air, the rate of combustion, the pressure and temperature of steam, the proportion and character of the products of combustion, both fixed and volatile, whether left on the grate or passing through the flues, are subject to careful observation and experiment." The results are reported in terms of the weight of water evaporated from and at 212 degrees per pound of combustible.* Bear in mind that this is not a modern report, but was published fifty-two years ago.

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coal, one from Sidney, Nova Scotia, one of Scotch, one of Liverpool, and two of Pictou coals; also one from Cannelton, Indiana, and another sample of a similar coal not definitely located. Tests were also made of natural coke from Virginia, of mixtures of anthracite and bituminous coals, of two kinds of artificial coke, and of pure wood. Incidentally, the value of the softer coals for smithery purposes was ascertained in the shops of the Navy Yard. The adaptability of all the coals for use on a house grate was also tested.

§ 21. The evaporative experiments were made in a small flue boiler, specially constructed for the purpose, which was 3½ feet in diameter and 30 feet long, arranged with direct and return passages for the products of combustion outside the shell in connection with the flues. The grate was 3 feet 3 inches by 5 feet. It was reduced in length 8 inches when air bridge was used, and still more when a coking plate was employed. The grates were 9 inches from the centre of boiler in front and 10 inches at the rear. The air for the furnace passed on the way to the ash-pit, through passages 6 feet deep and 9 inches wide in the side walls, by which means heat ordinarily lost by radiation was utilized in heating the air for combustion. The steam pressure was about 7 pounds. The feed-water was introduced from an elevated tank through an intermediate chamber or water lock. One to six experiments, each of twenty-four hours and upward, were made with each variety of coal, according to the quantity furnished, the evaporative efficiency being, however, referred only to five to eight hours of each run, when the log showed that the average conditions were maintained in respect to rate of firing, admission of water, etc.; all questions as to losses in stopping and starting being thus eliminated. A proximate analysis was made of all the different kinds of coal, and all were tested by the method of M. Berthier, to ascertain the quantity of metallic lead reduced from a mass of litharge by a definite quantity of coal roasted in connection therewith. These results are directly compared with those made similarly by M. Baudin on French coals. The general conclusion from these experiments was that the reduction was practically all accomplished by the carbon element. The comparative results of the evaporation and litharge tests agree very closely for the anthracite coals, but vary somewhat for the bituminous coals, having different ratios of fixed and volatile combustible (*b.* 585). Professor Johnson and his assistant, Dr. King, also made complete organic analyses of a number of the coals tested. A remarkable feature of these analyses was that for a number of coals the actual results obtained by evaporation, when the chimney losses were included, corresponded almost precisely with the calorific value of the carbon element as determined by organic analysis (*b.* 586), thus so far confirming the old impression. He refers also to the total calorific values assigned to Pennsylvania anthracite and English Newcastle coal by foreign writers, and shows that by his experiments Lehigh coal tested gave superior results to Newcastle, although showing very considerably less total calorific value (*b.* 586).

§ 22. Professor Johnson's report is a compendium of useful information on the general subject. His work was carried out on a fair scale, was quickly and economically completed, and reported in detail with great clearness. It is well worth the study of any one proposing any extensive series of investigations, even those not confined to this particular line. An abstract of these experiments was made by Mr. William Kent, member of the committee, and published in 1891 (*j.* 430, *et seq.*), which will be found of interest to those who have not access to the original work. Mr. Kent criticised the apparatus in several particulars, such as the use of a flue boiler and the small distance between the grate bars and boiler. As he says, however, the flue boiler was undoubtedly good practice at the time and it may be observed that though the grate was close to the centre of the boiler there was necessarily much more room in the spandrel spaces each side. Moreover, the large chambers incident to a flue boiler may have been an advantage rather than otherwise in burning some of the bituminous coals. It appears possible, however, as Mr. Kent says, that in testing Lehigh coal the fire was not thick enough to prevent excessive air dilution. Mr. Kent considered also that the conditions were not calculated to obtain the best results from some of the other coals tested, referring particularly to Western coals, and cites instances in more modern practice where much higher results have been obtained. In a later discussion of the subject (*k* 104), in comparing the results with the tests of similar coals made in France, he acknowledges that the efficiency was on the average as low as shown in the Johnson tests. This shows that both series of tests were made under the conditions of average or ordinary practice, which, on the whole, is better, as evidently no general laws can be ascertained by comparing the average practice in one case with those obtained under special conditions in another.

§ 23. In connection with the review of Professor Johnson's experiments by Mr. Kent, a similar review is made in the same paper (*j* 504) of a carefully conducted and extensive series of tests of European coals made by Scheurer-Kestner and Ch. Meunier as presented in an excellent study of these tests with others by M. L. Gruner. Tables of comparison of results from Gruner's paper and Johnson's report are presented, and are plotted on a diagram in connection with the theoretical heating value of the coals by Dulong's law and the apparent heating value ascertained by Messrs. Scheurer-Kestner with a Favre & Silberman calorimeter, which tables and diagram will be referred to later in connection with another paper by Mr. Kent. The review of the paper of M. Gruner points out some important discrepancies in the so-called "industrial" results or practical evaporative efficiencies of different coals and the calorific values of the same determined from chemical analysis, and states that from a study of the various results M. Gruner concludes that "the real value of the coal may better be determined by a proximate than an elementary analysis," which we will show later only applies to the particular coals tested. It also states that the "heating power increases and decreases with the proportion of fixed carbon," adding that "this is true at least for bituminous coals, but not always for anthracites and lignites." As an example, two coals are selected from the tables practically identical in composition, in which the one lowest in volatile matter gives the highest evaporation. Then another illustration is taken in which the contrary is the case. It is stated that the latter result is probably due to the fact that the volatile elements are not always combined in the same manner. It is then argued by Mr. Kent that some of these explanations are not in accordance with the view that elements in a less condensed state have a higher calorific value.

§ 24. One reference is made in Mr. Kent's review of M. Gruner's paper (*j* 506) which explains the discrepancies between the results obtained by calculating the calorific value of a coal and those shown by a calorimeter, it being stated in effect that Favre & Silberman had discovered that isometric and ternary hydrocarbons had less calorific value than was due to the components, and it is further stated, though not clear by whom, that "all heat set free in the act of condensation is lost beyond recovery by the

TABLE III.

HEATING POWER OF COALS.

According to Scheurer-Kestner and others, as collated by Gruner. Arranged in order of per cent. of fixed carbon in dry fuel free from ash. (Kent.)

DESCRIPTION OF FUEL.	Per cent. Fixed Carbon per 100 Fuel.	ELEMENTARY COMPOSITION.			HEATING POWER.			
		C.	H.	O + N.*	Actual.†	By Dulong's Law.	Industrial.	
					Calories.	Cal.	In Boilers.	Per ct. Total.
Anthracite coal from the Creusot..	88.1	92.36	3.66	3.98	9456	8552	....	....
Gruner's Class 5. Dry or semi-bituminous anthracite coals.....	82–90	90–93	4.5–4	5–5.3	9200–9500	....	5760–6080	63.9
Dry-burning coal. St. Paul du Creusot..........................	84.2	90.79	4.24	4.97	9263	8683	....	....
Short-flaming or flat coal. Chaptal du Creusot..	80.4	88.48	4.41	7.11	9622	8363	....	....
Gruner's Class 4. Short-flaming, caking or coking................	74–82	88–91	5.5–4.5	6.5–5.5	9300–9600	....	5888–6400	65.0
Caking coal. Anzin..............	77.2	84.47	4.21	11.32	9257	7789	....	....
Caking coal. Rouchamp.........	73.0	88.32	4.79	6.89	9077	8494	....	....
Gruner's Class 3. True caking coals, or Smith's coals	68–74	84–89	5–4.5	11–5.5	8800–9300	....	5376–5888	62.2
Caking coal. Denain.............	70.3	83.94	4.43	11.63	9050	7810	....	....
Long-flaming coal. Sultzbach....	64.4	83.55	5.17	11.48	8603	8024	....	....
Gruner's Class 2. Long-flaming, caking or gas coals..............	60–68	80–85	5.8–5	14.2–10	8500–8800	....	4864–5312	58.8
Long-flaming, caking coal. Duttweiler........................	63.5	83.82	4.60	11.58	8724	7858	....	....
Long-flaming, dry coal. Montceau	60.6	78.58	5.23	16.19	8325	7455	....	....
Very long-flaming coal. Von der Heydt..........................	60.4	81.56	4.98	13.46	8462	7727	....	....
Long-flaming, dry coal. Louisenthal..............................	59.0	76.87	4.68	18.45	8215	7082	....	....
Long-flaming, semi-coking coal. Friedrichstall..................	58.5	78.97	4.67	16.36	8457	7287	....	....
Gruner's Class 1. Long-flaming, dry coals.......................	50–60	72–80	5.5–4.5	19.5–15	8000–8500	....	4288–4800	55.1
Highly bituminous lignite. Bohemia..........................	55.0	76.58	8.27	15.15	7924	8387	....	....
Dry lignite. Rocherbleu..........	52.0	72.98	4.04	22.98	6480	6300	....	....
Bituminous wood................	51.4	67.60	4.55	27.85	6311	5831	....	....
Fossil wood, passing into lignite..	50.4	66.51	4.72	28.77	6358	5760	....	....
Fat lignite, Manosque............	48.8	70.57	5.44	23.99	7363	6542	....	....
Dry lignite, Manosque	46.8	66.31	4.85	28.84	7006	5788	....	....
Cellulose. $C_{12}H_{10}O_{10}$............	28–30	44.44	6.17	49.39	3622	3590	....	....

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* The nitrogen rarely exceeds one per cent.

† These are the results with calorimeter used by Scheurer-Kestner.

§ 26. A table not herein presented shows the results of tests with the Mahler calorimeter of thirty-one samples of coal of different kinds, together with seven samples of lignite turf and wood stated in connection with the theoretical heating power derived from Dulong's formula previously stated, and a modified form of the same by Mahler, giving substantially the same results. The table showing Mahler's results is not here reproduced, as he made no tests with steam boilers, but confined his resent the heating powers in calories.* The upper line of the diagram shows the calorific value by calorimeter of the coals tested by Scheurer-Kestner. The five numbered stars in the line show the position of the averages of Gruner's classes. The third

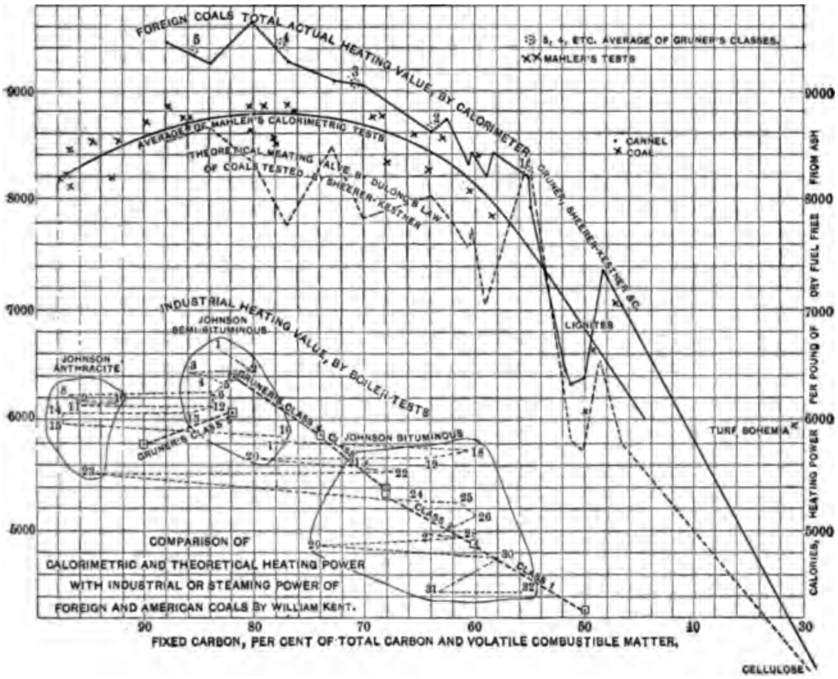

FIG. 55.

line from the top of diagram shows the theoretical heating value, according to Dulong's law, of the coals tested by Scheurer-Kestner. The intermediate curve shows the average of Mahler's calorimeter tests plotted in relation to the percentage of fixed carbon.

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* The formula of Dulong is given in foot-note § 4 in terms of B. T. U. The calorie referred to equals $\frac{9}{5}$ of 1 B. T. U.

TABLE III.

HEATING POWER OF COALS.

According to Scheurer-Kestner and others, as collated by Gruner. Arranged in order of per cent. of fixed carbon in dry fuel free from ash. (Kent.)

DESCRIPTION OF FUEL.	Per cent. Fixed Carbon per 100 Fuel.	ELEMENTARY COMPOSITION.			HEATING POWER.			
		C.	H.	O + N.*	Actual.†	By Dulong's Law.	Industrial.	
					Calories.	Cal.	In Boilers.	Per ct. Total.
Anthracite coal from the Creusot..	88.1	92.36	3.66	3.98	9456	8552	....	....
Gruner's Class 5. Dry or semi-bituminous anthracite coals.....	89-90	90-93	4.5-4	5-5.3	9200-9500	....	5760-6080	63.9
Dry-burning coal. St. Paul du Creusot.....................	84.2	90.79	4.24	4.97	9263	8683	....	....
Short-flaming or flat coal. Chaptal du Creusot..	80.4	88.48	4.41	7.11	9622	8363	....	....
Gruner's Class 4. Short-flaming, caking or coking..............	74-82	88-91	5.5-4.5	6.5-5.5	9300-9600	....	5888-6400	65.0
Caking coal. Auzin..............	77.2	84.47	4.21	11.32	9257	7789	....	....
Caking coal. Rouchamp.........	73.0	88.82	4.79	6.89	9077	8494	....	....
Gruner's Class 3. True caking coals, or Smith's coals	68-74	84-89	5-4.5	11-5.5	8800-9300	....	5376-5888	62.2
Caking coal. Denain.............	70.3	83.94	4.43	11.63	9050	7810	....	....
Long-flaming coal. Sultzbach	64.4	83.55	5.17	11.48	8603	8024	....	....
Gruner's Class 2. Long-flaming, caking or gas coals..............	60-68	80-85	5.8-5	14.2-10	8500-8800	....	4864-5312	58.8
Long-flaming, caking coal. Duttweiler..........................	63.5	83.92	4.60	11.58	8724	7858	....	....
Long-flaming, dry coal. Montceau	60.6	78.58	5.23	16.19	8325	7455	....	....
Very long-flaming coal. Von der Heydt........................	60.4	81.56	4.98	13.46	8462	7727	....	....
Long-flaming, dry coal. Louisenthal............................	59.0	76.87	4.68	18.45	8215	7082	....	....
Long-flaming, semi-coking coal. Friedrichstall..................	58.5	78.97	4.67	16.36	8457	7287	....	....
Gruner's Class 1. Long-flaming, dry coals..........................	50-60	72-80	5.5-4.5	19.5-15	8000-8500	....	4288-4800	55.1
Highly bituminous lignite. Bohemia............................	55.0	76.58	8.27	15.15	7924	8387	....	....
Dry lignite. Rocherbleu..........	52.0	72.98	4.04	22.98	6480	6300	....	....
Bituminous wood......	51.4	67.60	4.55	27.85	6311	5831	....	....
Fossil wood, passing into lignite..	50.4	66.51	4.72	28.77	6358	5760	....	....
Fat lignite, Manosque............	48.8	70.57	5.44	23.99	7363	6542	....	....
Dry lignite, Manosque	46.8	66.31	4.85	28.84	7006	5788	....	...
Cellulose. $C_{12}H_{10}O_{10}$............	28-30	44.44	6.17	49.39	3622	3590	....	....

* The nitrogen rarely exceeds one per cent.
† These are the results with calorimeter used by Scheurer-Kestner.

§ 26. A table not herein presented shows the results of tests with the Mahler calorimeter of thirty-one samples of coal of different kinds, together with seven samples of lignite turf and wood stated in connection with the theoretical heating power derived from Dulong's formula previously stated, and a modified form of the same by Mahler, giving substantially the same results. The table showing Mahler's results is not here reproduced, as he made no tests with steam boilers, but confined his attention to a comparison of calorific values determined by calorimeter, and calculated from ultimate analysis—which two methods agreed very closely. The results of proximate analyses are also given in the table.

TABLE IV.

JOHNSON'S RESULTS CORRECTED AND COMPARED BY PER CENT. OF FIXED CARBON TO TOTAL COMBUSTIBLE. (KENT.)

Number of Coal.	Order of Excellence.	NAME OF COAL.	Evaporation per Pound Combustible.*	Fixed C.; Per Cent. Total C. and Volatile Matter.	Volatile Matter: Per Cent. Total C. and Volatile Matter.	Evaporation,† Equivalent, Calories.
		Anthracites, Pennsylvania:				
1	15	Beaver Meadow Slope, No. 3	11.15	97.4	2.6	5,988
2	14	" " " " 5	11.29	97.2	2.8	6,063
3	9	Forest Improvement	11.52	95.6	4.4	6,186
4	8	Peach Mountain	11.59	96.8	3.2	6,224
5	23	Lehigh	10.26	94.4	5.6	5,509
6	11	Lackawanna	11.47	95.7	4.3	6,159
7	10	Lykens Valley	11.50	92.4	7.6	6,176
		Semi-Bituminous:				
8	3	New York & Maryland Mining Co., Md.	11.95	85.6	14.4	6,417
9	13	Neff's, Cumberland, Md	11.30	85.5	14.5	6,068
10	7	Easby's, Md.	11.66	83.6	16.4	6,261
11	1	Atkinson & Templeman, Md	12.39	83.2	16.8	6,653
12	5	Easby & Smith's, Md	11.76	82.7	17.3	6,315
13	4	Dauphin and Susquehanna, Pa	11.91	84.3	15.7	6,396
14	6	Blossburg, Pa	11.68	83.2	16.8	6,272
15	12	Lycoming Creek, Pa	11.43	83.8	16.2	6,138
16	2	Quin's Run, Pa	12.02	80.1	19.9	6,455
17	20	Karthaus, Pa	10.54	79.1	20.9	5,660
18	16	Cambria Co., Pa	10.91	77.2	22.8	5,859
		Bituminous, United States:				
19	17	Barr's Deep Run, Va	10.81	77.5	22.5	5,805
20	21	Crouch & Snead, Va	10.38	71.1	28.9	5,574
21	18	Midlothian (screened), Va	10.63	60.9	39.1	5,708
22	19	Chesterfield Mining Co., Va	10.55	64.3	35.7	5,665
23	28	Tippecanoe, Va	9.15	61.3	38.7	4,914
24	24	Creek Co., Va	9.82	65.0	35.0	5,273
25	27	Clover Hill, Va	9.15	63.8	36.2	4,914
26	26	Pittsburgh, Pa	9.54	59.9	40.1	5,123
27	31	Cannelton, Ind	8.24	63.2	36.8	4,425
		Bituminous, Foreign:				
28	22	Picton, N. S	10.85	67.2	32.8	5,558
29	29	Sidney, N. S	9.06	73.9	26.1	4,865
30	30	Liverpool, Eng	8.80	57.8	42.2	4,726
31	25	Newcastle, Eng	9.78	61.4	38.6	5,252
32	32	Scotch, Scotland	8.23	54.9	45.1	4,419
33	33	Dry Pine Wood	5.02	....	....	2,696

* Evaporation from and at 212 degrees F. per pound combustible.
† Johnson's figures corrected by multiplying by 1.066.

§ 27. The paper states, referring to diagram Fig. 55, that "Johnson's tests group themselves in three distinct classes. They are numbered from one to thirty-two in the order of their steaming values." (See also Table IV.) The extreme irregularity of these tests is clearly shown by the position of the numbers. The five short, inclined lines included among Johnson's groups represent the range of the industrial value of Gruner's five classes. (See also Table III.) "They show as close an agreement as can be expected with the results of Johnson, and indicate that the efficiency of coals in actual trial, upon which Gruner's figures are based, was about as low on an average as the efficiency shown in Johnson's tests. This efficiency, as shown in the last column of Table III., ranges from 65 per cent. down to 55 per cent. of the total heating value."

§ 28. It will be seen that calorific values by Mahler's calorimeter, compared with the percentage of fixed carbon, plot comparatively near the average curve given. Mr. Kent therefore concludes: "Knowing, therefore, the percentage of fixed carbon in the dry coal free from ash, we may, in the case of all coals containing over 58 per cent. of fixed carbon, predict the heating value within a limit of error of about 3 per cent.;" and prepares a table, herein presented as Table V., taken from the curve on diagram, Fig. 55, marked "Average of Mahler's Calorimeter Tests." The plotted results from the curve are very interesting, and for the first time, perhaps, give a fair general idea of one of the relations to be considered. It will be shown later, however, that this particular curve is only true for the particular experiments.

§ 29. Mr. Kent states that below 50 per cent. of fixed carbon the law apparently does not hold, and continues:

> "The comparison of the industrial or steaming power by Johnson's and Gruner's tests with the heating value as determined by a calorimeter, strongly emphasizes the fact that in the burning of highly bituminous coals under ordinary steam boilers, a greater percentage of heat is lost than in the burning of anthracite and semi-bituminous coals. There is but little difference in the calorimetric heating power of coals containing respectively 70 and 85 per cent. of fixed carbon, but in industrial practice the latter gives from 15 to 20 per cent. higher results. This is simply due to the great difficulty in ordinary boiler furnaces of burning the excess of volatile combustible matter which passes out of the chimney in smoke and unburned gases."

§ 30. Mr. Kent continues:

> "It is greatly to be desired that tests similar to those made by Scheurer-Kestner, Mahler and others on European coals should be made on the coals of the United States. The calorimetric apparatus used by Mahler is all that can be desired for determining total heating value. If our western coals which are now being wasted in steam-boiler furnaces to the extent of many million dollars per year could be tested calorimetrically by this apparatus, and the results compared with those of actual boiler tests we should then realize the enormous extent of the waste that is taking place, and inventors would be encouraged to devise improved boiler furnaces by the use of which a large percentage of the coal now wasted might be saved."

TABLE V.

APPROXIMATE HEATING VALUE OF COALS. (KENT).

Percentage of Fixed Carbon in Dry Coal and free from Ash.	HEATING VALUE.		Percentage of Fixed Carbon in Dry Coal and free from Ash.	HEATING VALUE.	
	Calories.	British Thermal Units.		Calories.	British Thermal Units.
97	8,200	14,760	63	8,400	15,120
94	8,400	15,120	60	8,100	14,580
90	8,600	15,480	57	7,800	14,040
87	8,700	15,660	54	7,400	13,320
80	8,800	15,840	51	7,000	12,600
72	8,700	15,660	50	6,800	12,240
68	8,600	15,480			

§ 31. The papers of Mr. Kent furnish a creditable and highly interesting compendium of the work done in the calorimetric, analytic, and practical evaporative tests during the investigations referred to, and the opinions of a number of scientific men on the subject. The results he has collated can, however, only be used, in connection with those from other available experiments, as evidence to aid us in the investigation of the particular problem which has brought about this discussion; viz., whether or not the practical evaporation of steam boilers should be compared on the basis of evaporation per pound of combustible, or with the calorific value of the fuel as determined by the calorimeter or ultimate analysis.

§ 32. If a new comparison is available it should enable us to compare the results of a test of a particular boiler, using a particular coal having certain characteristics, with those from another boiler using a different coal—either directly or by comparing the results of each with some standard. Let us try and find such a standard. If we compare directly by the efficiency, or the percentage of the total calorific value of the fuel utilized in a particular case, we find that this percentage varies with different coals, as shown in the last line of Table I. and by the last column of Table III., repeated in column 11 of Table VIII.

§ 33. The relations between the fixed and volatile combustible of the coal have long been supposed to have something to do with the matter, so these relations were ascertained for the experiments of Johnson fifty-two years ago, as well as for the previous experiments of Gruner in 1842 to which he refers (*b* 307). Naturally therefore the earlier experiments have been plotted by Mr. Kent (see Fig. 55) with the percentage of fixed combustible compared to the sum of the fixed and volatile combustible as a base, and the total and practical calorific values as ordinates. So far as efficiency is concerned, the base assumed simply separates the results of different experiments so that they may be studied. The same result would have been secured if any variable in the composition of the coal had been taken as a base. The shape of the approximate curves would have been varied, but without changing the efficiencies, for they are shown for a particular case by the position of the total and practical calorific values on a vertical ordinate. The average curves traced through such points are not parallel or of the same form. Therefore the relations between the two, or the efficiencies, are not constant, as already shown by the figures above given.

§ 34. Mr. Kent shows that for the Mahler experiments the calorimetric values bear a fairly definite relation to the fixed carbon as represented by the Mahler curve on the diagram and in Table V. derived therefrom; but this does not help us as to the relation which the practical evaporation bears to the calorific value or to the elementary composition of the coal, as Mahler made no boiler experiments. Moreover, it appears that the Mahler curve applies only to the particular coals tested by him, as explained in this and the two succeeding sections. It is true that the Mahler calorimeter gave results as closely resembling those calculated from chemical composition as could be expected, particularly when it is known, as before explained (§ 24), that the carbon and hydrogen which are chemically combined in hydrocarbons have together less calorific value than the elements separately. Within moderate limits, however, the results by calorimeter appear to correspond with the heating power calculated from chemical analysis; and the Mahler curve, Fig. 55, therefore represents approximately the mean results of both methods. By similar reasoning the calorimetric results obtained by Scheurer-Kestner were evidently too high. The results should have plotted with those calculated from the elementary composition, and the upper broken line in Fig. 55 would have taken practically the position of the broken line third from the top, when a smooth curve averaging the results would have shown both the average heating power by calorimeter and that calculated from the analysis, within reasonable limits, the same as the Mahler curve.

§ 35. The difference in the positions of the Mahler curve and the third one from the top, which represent respectively the calorific values of the coals tested by Mahler and by Scheurer-Kestner, indicates a very considerable difference in the qualities of the coals tested, so the comparison shown by Mr. Kent in Table V. is not applicable to the coals tested by Scheurer-Kestner. Many of the coals tested in both cases contain sufficient oxygen to carry off during combustion a large proportion of the hydrogen combined with oxygen to form steam. It therefore follows that the calorific value of these coals is very nearly represented by the carbon alone, and this will be shown more clearly by a comparison hereafter. There are a number of coals in the United States which have, as shown in Table I., a fair proportion of hydrogen and very little oxygen; which, therefore, have a high calorific value, and should plot in a curve above the Mahler curve in Fig. 55. Moreover, some of the bituminous coals of the United States and England contain a considerable proportion of oxygen—the Caseyville coal (*L*, Table I.) having 17 per cent., Clover Hill 11.6 per cent., and Newcastle and Scotch coal 10 to 11 per cent., with 59 per cent. to 64 per cent. of fixed combustible, so coals of this class would probably plot as low as, or in some cases lower than, the Mahler curve; and as both kinds of coal are found in the United States, it would probably be necessary to construct a different curve for each of the several different varieties of coal, as all kinds would depart so widely from any average. Until, therefore, a thorough investigation is made of all kinds of American coals by calorimetric tests, chemical analysis, and practical evaporation, we cannot infer the calorific value of such coals from the percentages of fixed combustible, derived from a simple proximate analysis, with any reasonable accuracy; and the evaporative efficiency involves so many more elements of doubt that it would in general be impossible to approximate it by any such method.

§ 36. The above considerations are emphasized by recent experiments of Professor Carpenter (*n*) with an improved form of calorimeter, the results of which, rearranged by him to apply to dry coal, and by the writer according to the percentages of fixed combustible, to compare with Mr. Kent's tables, are herewith presented in Table VI. It will be seen by comparing columns *i* and *h* that there is no direct relation between the percentage named and the calorific value, nor is there a general trend toward a curve like that given in Mr. Kent's paper. The anthracites, compared

TABLE VI.

SHOWING CALORIFIC VALUES AND PERCENTAGES OF FIXED COMBUSTIBLE OF VARIOUS COALS. (CARPENTER.)

Number for Reference.	MINE.	LOCALITY.	a. Volatile Matter.	b. Ash.	c. Fixed Carbon.	d. Specific Gravity.	e. Heat Units per Pound Dry Coal.	f. Pounds of Water Evaporated from and at 212°.	Per Cent. Combustible Matter in Black Smoke.	g. Heat Units per Pound of Fixed Carbon.	h. Heat Units per Pound of Combustible.	$i = \frac{100c}{a+c}$ Percentage of fixed Combustible compared with the Sum of the Fixed and Volatile Combustibles.
	Anthracite Coal, Dry.											
1	Buck Mountain	Cross Creek, Pa. (Slate removed)	3.17	4.42	92.41	1.56	14,220	14.72	......	15,350	14,700	96.68
2	Mammoth (Buckwheat)	Drifton, Pa. (Slate removed)	3.44	5.97	90.59	1.55	13,720	14.20	......	15,020	14,500	96.34
3	Woodward	Scranton, Pa.	4.06	14.07	81.87	1.42	12,554	13.	......	15,280	14,555	95.28
4	Oxford	Scranton, Pa.	4.49	5.45	90.07	1.415	13,433	13.91	......	14,700	14,200	95.25
5	D., L. & W.	Unknown	5.	11.	84.	.....	12,400	13.13	......	14,700	13,900	94.38
6	Forty-Foot	Scranton, Pa.	5.07	10.01	84.92	1.41	13,045	13.49	......	15,480	14,450	94.37
7	L. V. Buckwheat	Unknown	5.	14.	81.	.....	11,800	12.22	......	14,600	13,550	94.19
8	Avondale	Avondale, Pa.	6.	6.91	87.78	1.44	13,218	13.71	......	15,000	14,150	93.60
9	Continental	Scranton, Pa.	5.78	10.03	84.19	1.615	13,107	13.57	......	14,680	14,550	93.58
10	Manville Shaft	Scranton, Pa.	6.12	7.38	86.5	1.42	13,064	13.54	......	15,100	14,050	93.39
11	Jermyn Stove	Schuylkill Co., Pa.	6.08	11.02	82.90	1.425	12,316	13.05	......	14,800	13,850	93.17
12	Cayuga	Scranton, Pa.	6.50	9.12	84.38	1.49	12,413	12.77	......	15,550	13,600	92.85
13	L. V. Buckwheat	Wilkesbarre, Pa.	6.21	15.5	78.29	1.3	11,959	12.38	......	15,541	14,100	92.65
14	L. V. Buckwheat	Unknown	6.8	13.	80.2	.....	12,000	12.42	......	14,970	13,680	92.18
15	Mt. Pleasant	Scranton, Pa.	7.63	10.78	81.59	1.42	12,458	12.90	......	15,300	14,200	91.45
16	L. V. Pea	L. V. Region	7.49	16.23	76.28	1.52	11,920	12.37	......	15,000	14,050	91.06
	Bituminous Coal, Dry.											
17	Antrim	New Blossburg, Pa.	18.54	11.30	70.16	1.42	13,695	14.18	0.27	19,210	15,350	79.10
18	Eureka	Clearfield Co., Pa.	23.79	5.82	70.39	1.32	13,897	14.39	0.43	20,000	14,700	74.74
19	Reynoldsville	Reynoldsville, Pa.	24.67	5.37	69.96	1.34	15,134	15.67	0.33	21,500	15,900	73.93
20	Leisenring	Connellsville, Pa.	29.26	6.25	64.49	1.34	15,285	15.82	0.92	24,000	16,200	68.79
21	Cooperstown	Nova Scotia	30.75	4.09	65.16	1.345	15,435	15.98	0.5	24,000	15,950	67.94
22	Nova Scotia	No. 2 Slope, U. S.	32.38	4.11	63.61	1.31	15,324	15.86	0.27	24,000	15,950	66.27
23	Jackson Hill, Slack	Jackson Co., O.	30.6	10.2	59.2	.....	12,100	12.5	....	20,380	13,350	65.92
24	Bernmont (Va.)	Monongahela River, Pa.	32.	8.04	59.90	1.275	13,424	13.9	1.04	22,500	14,550	65.18
25	Turtle Creek	Monongahela River, Pa.	34.95	4.33	60.72	1.28	14,450	14.96	0.30	24,000	15,050	63.47
26	Little Pittsburg	Morgantown, W. Va.	37.5	6.6	55.9	.....	12,800	13.3	....	23,000	13,700	59.85
27	Gillespie	Gillespie, Ill.	36.26	12.33	51.41	1.26	10,902	11.28	0.56	21,400	12,540	58.64
28	Auburn Screenings	Sugar Creek, Ill.	37.5	15.2	47.3	.....	11,200	11.6	....	23,700	12,950	55.78

by thermal units per pound of coal (column *e*), show on the average lower calorific values than the bituminous coals, but the latter show no regular decrease in calorific value as the percentage of fixed combustible is increased. While there are wide differences in result, all taken together show roughly an equality in the calorific value of the different kinds of American coals, independent of the percentage of fixed combustible. The widest variation in the calorific values of the combustible of the various anthracites is only about three per cent. from the mean, and for the bituminous coals the results shown in the last two lines, for which the fixed combustible is below fifty-nine per cent., are the only ones which fall off greatly compared with the others.

§ 37. Referring to column *g* of the table, Professor Carpenter writes: "The heat units per pound of fixed combustible average somewhat higher than the theoretical value of the carbon, which I think indicates that in the oxygen calorimeter the volatile matter has some combustible value." It should be observed that the above conclusion does not modify that already stated (§ 4), to the effect that the evaporation of many coals is proportioned to the total contained carbon by ultimate analysis, as the weight of such carbon is necessarily greater than the so-called fixed carbon shown by proximate analysis, as will be seen by examining the first columns of the several analyses given in Table I. The volatile matter, being composed of hydrocarbons, carries off with it a portion of the carbon, and with many coals the effective result is represented by the weight of carbon, whether combined with hydrogen or not.

§ 38. It is suggested that the results of proximate analyses be stated in terms of "fixed combustible" and "volatile combustible," which were used by Johnson many years ago. It is not at all certain that the residue after roasting the coal is all carbon, even though the ashes be weighed back after such residue is consumed, but with such correction the residue is undoubtedly fixed *combustible*, and the term would therefore seem to be more accurate.

§ 39. In this general connection attention is called to the paper of Mr. George M. Barrus, member of the Society, on "The Coal Calorimeter," *Transactions*, Vol. XIV., page 816. The results of his experiments are not directly applicable for the purposes of this investigation, from the fact that neither ultimate nor proximate analyses are given of the particular coals tested. One interesting

TABLE VIII.

COMPARISON OF VARIOUS FOREIGN COALS AS CLASSIFIED BY GRUNER. (See Table III.)								AVERAGE REDUCTIVE POWERS OF AMERICAN AND FOREIGN COALS AS TESTED WITH LITHARGE BY JOHNSON.		
1	2		4	6	8	10	11	4a	6a	10a
No. of Line.	Description of Coal.		Average Carbon by Ultimate Analysis.	Average Fixed Combustible.	Average Calorific Value by Calorimeter.	Average Practical Evaporation.	Average Efficiency or Calorific Value utilized during Test.	Average Metallic Lead reduced from Litharge.	Average Fixed Combustible.	Average Practical Evaporation.
			Relative.	Relative.	Relative.	Relative.	Per cent.	Relative.	Relative.	Relative.
1	*Gruner's Class* 5. Dry or semi-bituminous anthracitic coals..............	....	100.00	100.00	100.00	100.00	63.9	......	......	......
2	....	*Johnson.* 8 Pennsylvania anthracites and natural coke	......	......	......	......	......	100.00	100.00	100.00
3	*Gruner's Class* 4. Short flaming caking or coking	....	97.81	90.70	101.07	102.90	65.0	......	......	......
4	....	*Johnson.* 11 Maryland and bituminous free burning coals............	......	......	......	......	......	97.60	86.62	103.00
5	*Gruner's Class* 3. True caking coals	....	94.54	82.56	96.79	94.34	62.2	......	......	......
6	*Gruner's Class* 2. Long flaming caking or gas coals	....	90.16	74.42	92.51	85.23	58.8	......	......	......
7	....	*Johnson.* 10 Virginia bituminous coals.	......	......	......	......	......	86.71	70.13	90.38
8	....	*Johnson.* 8 Foreign and Western highly bituminous coals............	......	......	......	......	......	85.31	68.98	82.67
9	*Gruner's Class* 1. Long flaming dry coals..............	....	83.61	63.75	88.23	76.11	55.1	......	......	......

between 59 and 63.5 per cent. Comparing columns 10 and 4, it is seen that the practical evaporation for the first six lines referring to coals tested for evaporation, is not fairly proportioned to the carbon by ultimate analysis; but Johnson, referring to the same coals (*b* 586), shows that if the heat expended on the products of combustion be added to that utilized by the evaporation, the modified results correspond almost identically with the calorific value of the carbon element.* For the experiments with the last four coals completely tested (H, J, K, L), the practical evaporation is also roughly proportioned to the fixed combustible; in fact, with the exception of results from the Midlothian coal, the progression is kept up through the whole list. Evidently no exact relations exist in either case, except between the percentage of carbon and the results of the boiler tests when the heat expended on the products of combustion is added, as above referred to (§ 21).

§ 42. It can hardly be expected that the results of tests of individual coals will show close agreement. When a large number of coals of similar kinds are averaged together approximate laws can be more readily traced. All the coals in Table VII. would be averaged in two classes. The first part of Table VIII. shows the comparison of various foreign coals as classified by Gruner. The proportional quantities only are given, as the others are available in Table III. In this table the calorific value by calorimeter, column 8, and the average carbon by ultimate analysis, column 4, show very nearly the same progression; which is explained by the fact previously referred to (§ 35), that the coals tested by Scheurer-Kestner and classified by Gruner contained in general sufficient oxygen to carry off during combustion a large proportion of the hydrogen combined with oxygen to form steam, so that the carbon had the governing influence on the calorific value. Most of the American coals contain less oxygen, but as those given in Table VII. correspond to Gruner's last two classes only, a comparison of the results is difficult. The average practical evaporation of the coals classified by Gruner is for the whole series less proportionally than shown by the proportion of carbon, but greater proportionally than the progression shown by the average fixed combustible.

§ 43. There is also given in Table VIII. the average effective power of American and foreign coals as tested with litharge by Johnson (*b* 585), the proportional results only being given. Johnson concludes that the carbon is principally effective in making the reductions in this way (*b* 584), and as the practical evaporation is also roughly proportioned to the carbon we find a very fair identity in the progressions shown in columns 4*a* and 10*a*. This part of Table VIII. also shows comparative results throughout the whole range of Johnson's experiments—which is not the

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* The results as given in his work require to be corrected for the unit of evaporation and the calorific value of carbon as now accepted.

case in Table VII.; and we see that the results by evaporation (column 10*a*) are proportionally higher than the relation shown by average fixed combustible (column 6*a*). The slight advantage shown by the American semi-bituminous coals in practice is shown in column 10*a*, line 4, and the same advantage appears in Gruner's class 4, line 3. The approximate identity shown between the results obtained by assaying coal with litharge, column 4*a*, as compared with practical evaporation, column 10*a*, suggests that it would be interesting and, perhaps, desirable to use the method of M. Berthier for testing coal used on boiler trials. The litharge tests are very readily made with simple apparatus.*

§ 44. The general conclusion to be derived from the study of the numerous experiments, with coals varying considerably in the percentage of volatile matter, seems to be that, while the average results of evaporative tests with a number of coals from a given region may indicate an approximate general law, the individual experiments vary so much among themselves, or even

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* The carbon in the coal should reduce 34 times its own weight of metallic lead from pure litharge (*b* 106). It is necessary to obtain the litharge pure, as a slight admixture of red oxide is quite common, and, as it contains more oxygen, it increases the relative results. Johnson (*b* 181) states the precautions which he observed in conducting experiments of this kind.

"The coals in their raw state were reduced to an impalpable powder. A separate experiment was made, to ascertain the quantity of moisture which they contained; and then on another portion, also in the raw state, the trial with litharge was made. The powder, generally not exceeding 20 grains, was very intimately mixed with about forty times its weight of good English litharge, and placed in the bottom of a clean Hessian crucible of such capacity that, when the mixture was covered with 500 or 600 grains of pure litharge, it was not more than half filled. The crucible thus charged was placed on a brick support in the centre of the small furnace . . . in which the fire had been previously lighted, and suitably covered to prevent the danger from particles of combustible matter falling into it. The heat was gradually brought up to redness, at which it was maintained for some ten or fifteen minutes, or until the ebullition of the mass had nearly abated. The heat was then pretty rapidly augmented until all the litharge resting above the charge was in complete fusion, at which it remained a few minutes to allow so much action on the silica of the crucible as to facilitate the subsequent detachment of the button of lead from the unreduced oxide, as well as from the crucible itself, and to obviate error from the intermixture and adhesion of litharge. Wherever there was reason to believe that an imperfect result had been obtained, a repetition of the experiment was resorted to. It is obvious that all comparisons of this method of determining heating powers with the practical one by evaporation, ought to be made after deducting the proportion of waste or incombustible matter from the total weight of coal submitted to trial in each case."

from the average, that they cannot be accurately compared with each other either directly or by any fixed law of progression, and this will be particularly the case when a highly bituminous coal is used in one case and an anthracite or semi-bituminous in the other. These limitations are particularly emphasized by the fact that the results of the tests presented can only be compared with those made with customary apparatus and customary management. Mr. Kent points out that much better results have been obtained in practice with Western coals than those given by Johnson, though he found that the foreign and American tests corresponded well with each other. Now if, by the use of a better furnace or better management, the evaporative results can be improved in a certain locality, such result would plot on a diagram like that represented in Fig. 1 above the general trend of the experiments dotted on the lower part, and this result would bear a different relation to the curve derived from calorimetric tests above, which latter would itself be changed by the difference in the composition of American coals; so in order to test the relative efficiencies of different boilers in different locations, using different coals under different conditions, it would be necessary to ascertain the value of the improved furnace and of the improved care exercised in making a particular test, in addition to such information as was available about the theoretical and practical calorific value of the coals employed. Even then no accurate comparisons could be made unless the practical evaporative efficiency under standard conditions of the coal used had been previously determined; and in determining the relative value of the coals still another difficulty is encountered, to wit, the variations in the efficiencies of the boilers themselves. The efficiency of the boiler is usually the very question to be settled in a boiler test; but to ascertain the comparative calorific value of different fuels, in order to use them in standard tests, allowance must be made for the difference in efficiency if different boilers are used or if the rate of combustion is varied.

§ 45. The writer, in the preparation of the General Report of Group XX., Centennial Exhibition (*m* 69), presented curves and tables based on experiments made in the United States Navy which very satisfactorily show the variations in the evaporative efficiency of a boiler due to different rates of combustion.* The

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* Since the report above mentioned is not generally accessible, the curves and formulæ developed by the writer are herewith presented. The experiments were

results there stated may be applied with confidence to tests of boilers that have been designed for economy by insuring a thorough distribution of the products of combustion over all the heat-

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made on marine boilers of the horizontal return tubular and the Martin vertical tubular types. The latter showed higher efficiencies. In Figs. 56 to 58 the curve *O* shows, for the vertical tubular boiler, the number of pounds of water evaporated from and at 212 degrees per pound of combustible for varying rates of combustion expressed in "Pounds of combustible consumed per square foot of heating surface

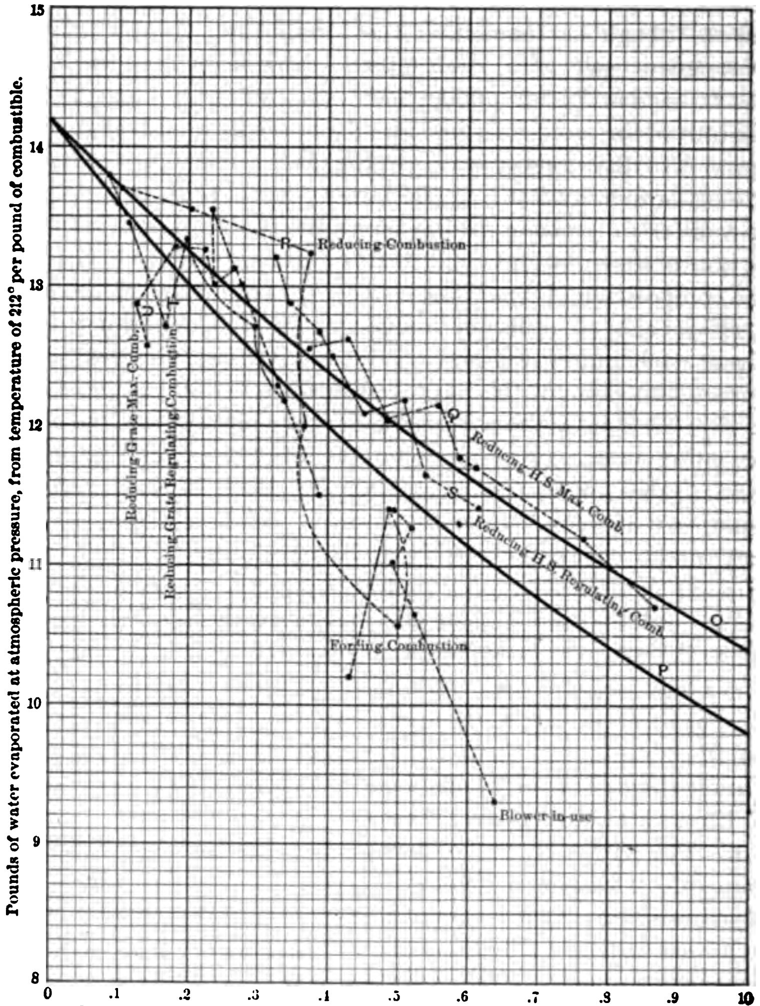

FIG. 56.

ing surfaces. Such a boiler cannot be forced much above its capacity without the use of artificial draught, and is therefore only adapted for positions where the load is comparatively steady. When the demands vary at short intervals it is necessary that the boiler be constructed so that it will burn coal freely when required. With such construction it is possible to obtain considerable difference in capacity, and this fact makes such a boiler of no better or even lower efficiency at comparatively small powers, thus reversing the rule compared with boilers proportioned for economy.

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per hour." The curve *P* applies similarly to the horizontal tubular boiler. The maximum evaporation possible under conditions stated, considering losses in chimney gases, is assumed to be 14.2 pounds, and the higher point of each curve terminates with this value. Calling *E* the evaporation in pounds of water from and at 212 degrees, and *c* the corresponding number of pounds of combustible

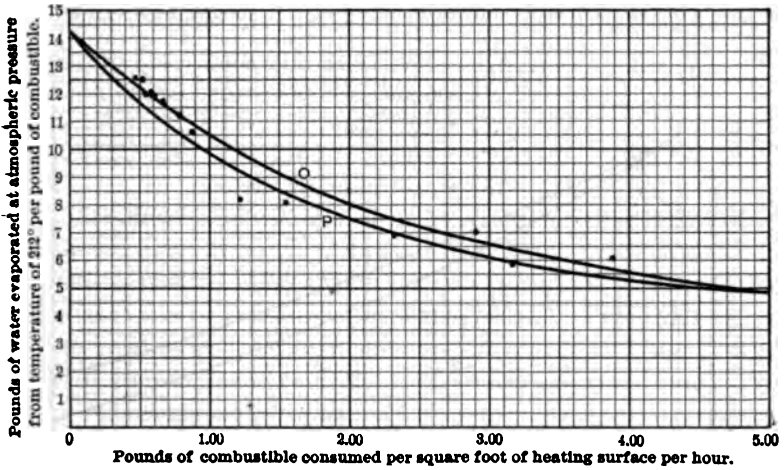

FIG. 57.

burned per square foot of heating surface per hour, the curves *O* and *P* are represented by the following formulæ:

$$E_o = \frac{46.045}{c + 3.016} - 1.067$$

$$E_p = \frac{27.287}{c + 2.04} + 0.824$$

On Fig. 56 are plotted a number of experiments relied upon to determine the higher limits of the curves. Fig. 57 shows some of the principal experimental values through wide limits. Fig. 58 shows that the boilers tested at the Centen-

§ 48. The above incident should not be considered as evidence that no benefit can be obtained from a knowledge of the proportion of carbonic acid in the products of combustion. An instrument of the kind might, in some cases, be very valuable as a substitute for the skilled observation of a good fireman. It is understood that manufacturers of instruments of this kind have so impressed their value on steam users that a premium is offered to firemen who will show the highest per cent. of carbonic acid. From what has been said, however, in the preceding pages it will be seen that the greatest losses occur from the fact that only the carbon in the coal is fairly well consumed, and the hydrogen, though of a higher calorific value, has little or no influence on the result. It is believed that this is a condition of things which needs further investigation with the view of improvement.

§ 49. It is a maxim in making tests of all kinds to arrange all the conditions alike except the particular one to be examined. In applying this principle to the matter in hand it becomes evident, in view of the varying results obtained with coals of similar composition, that if the comparative evaporative efficiencies of different boilers are to be tested with superlative accuracy it should be with the same variety of coal burned in furnaces of like construction under standard conditions. The value of improvements in furnaces should not only be tried with the same coal, but with the same or exactly similar boilers. Tests of the efficiency of different coals offer more difficulty, as furnaces of a particular form and boilers of particular proportions are not strictly adapted for obtaining the best results from all varieties. It would seem, therefore, necessary in comparing different coals to make changes of detail suited to each, but the same rate of evaporation per square foot of heating surface should be maintained. If other than ordinary details or boilers of unusual proportions are used, the experiments made with the same would not be strictly comparable with tests made of the same coal with different details or in boilers of different proportions, and this of itself is sufficient to prevent in general any accurate comparison of boiler tests made with different kinds of coal in different parts of the country.

§ 50. The difficulties in comparing the results of tests with steam boilers are very much reduced if such tests are made with the better grades of anthracite or semi-bituminous coals ordinarily sold in the market, as the difference in results between the very high evaporative results from ordinary boilers with rich bituminous coals; but the best efforts seem only to bring such results up, or nearly up, to those obtained with anthracite. Mr. Kent (*j* 507) hints that hot gas and air, or the conditions obtaining with a regenerative furnace, are necessary.

§ 47. With the expectation that mere regulation of the air supply would secure great economy of fuel, there has been invented abroad an instrument called the "dasymeter" to indicate the percentage of carbonic acid in the products of combustion, compared with pure air. The indication depends on the weight of a vessel through which gases are being continually drawn from the chimney of a steam boiler. It is stated that with practice the stoker "learns what alterations of the damper or fire-door or thickness of fuel on the grate are necessary, or whether a permanent alteration of grate area is desirable." Comparative experiments of ten hours' duration were made with a boiler having sixteen square feet of grate surface and 1,076 square feet of heating surface, with the following results:

Coal per 1,000 pounds of steam.	Percentage CO_2 by dasymeter.	Chimney loss.
152.6	6.8	33
125	13.1	13

At first blush these results seem to show the great value of the dasymeter, and, indeed, a distinguished gentleman abroad has allowed himself to speak in enthusiastic terms of a device which will enable the percentage of carbonic acid to be continually read off "as readily as the steam pressure on a gauge;" but it is the office of the engineer to look at the facts presented in a critical way. It seems suspicious to have the evaporation stated in terms of coal per 1000 pounds of water, and by taking the reciprocal so that the results appear in the customary way, we find that the boiler only evaporated 6.55 pounds of water per pound of coal without the dasymeter, and 8 pounds with it. The first result is altogether too low for any conditions, those actually obtaining not being mentioned, whereas the second result is about what should be expected under ordinary conditions; thus raising the suspicion that the trials were made in the interests of the inventor of the particular dasymeter, but, once published, reached the eye of one always on the lookout for improvements, who kindly attributed to others the same honesty of purpose as himself without thinking of conditions which unavoidably enter into commercial transactions.

§ 48. The above incident should not be considered as evidence that no benefit can be obtained from a knowledge of the proportion of carbonic acid in the products of combustion. An instrument of the kind might, in some cases, be very valuable as a substitute for the skilled observation of a good fireman. It is understood that manufacturers of instruments of this kind have so impressed their value on steam users that a premium is offered to firemen who will show the highest per cent. of carbonic acid. From what has been said, however, in the preceding pages it will be seen that the greatest losses occur from the fact that only the carbon in the coal is fairly well consumed, and the hydrogen, though of a higher calorific value, has little or no influence on the result. It is believed that this is a condition of things which needs further investigation with the view of improvement.

§ 49. It is a maxim in making tests of all kinds to arrange all the conditions alike except the particular one to be examined. In applying this principle to the matter in hand it becomes evident, in view of the varying results obtained with coals of similar composition, that if the comparative evaporative efficiencies of different boilers are to be tested with superlative accuracy it should be with the same variety of coal burned in furnaces of like construction under standard conditions. The value of improvements in furnaces should not only be tried with the same coal, but with the same or exactly similar boilers. Tests of the efficiency of different coals offer more difficulty, as furnaces of a particular form and boilers of particular proportions are not strictly adapted for obtaining the best results from all varieties. It would seem, therefore, necessary in comparing different coals to make changes of detail suited to each, but the same rate of evaporation per square foot of heating surface should be maintained. If other than ordinary details or boilers of unusual proportions are used, the experiments made with the same would not be strictly comparable with tests made of the same coal with different details or in boilers of different proportions, and this of itself is sufficient to prevent in general any accurate comparison of boiler tests made with different kinds of coal in different parts of the country.

§ 50. The difficulties in comparing the results of tests with steam boilers are very much reduced if such tests are made with the better grades of anthracite or semi-bituminous coals ordinarily sold in the market, as the difference in results between the same is, as shown by the elaborate Isherwood experiments, very small (§ 16). As clearly pointed out, the practical evaporations are not accurately proportioned to the calorific values shown by calorimeter or chemical composition, but they can be compared with a fair degree of accuracy by stating the results in units of evaporation per pound of combustible. It does not appear, everything considered, that for tests of different boilers with different coals of the same general character any other plan will give results any more accurate. There will be some variations in particular samples of the different coals, even of the better grades, which will affect the results for comparison with other boilers tested with different samples; but these minor differences can only be eliminated by the adoption of the suggestion that in all standard tests of boilers, where great accuracy is required, a particular kind of fuel be employed, which, from the experience of engineers in general, is quite uniform in quality, as regularly delivered in the market. A modification of this would be to compare the boilers in a given location by their relative performances with a fair sample of a particular fuel available in that particular locality, when a careful comparison of the standard fuel adopted in one section with that employed in another would enable the performances of all boilers in different sections to be compared.

§ 51. *LIST OF REFERENCES.*

a. Rankine on "The Steam Engine," 5th edition.

b. Johnson on "American Coals": A report to the Navy Department published in 1844, as Senate Document 386, Twenty-eighth Congress, 1st Session.

c. "Engineering Precedents," Chief-Engineer B. F. Isherwood, U. S. N.: two volumes, published by Balliere Brothers, New York, 1859.

d. "Experimental Researches in Steam Engineering," by Chief Engineer B. F. Isherwood, U. S. N.: two volumes, published by William Hamilton, Philadelphia, 1863 and 1865.

g. "The Evaporative Power of Bituminous Coals": a paper by William Kent, Esq., M.E., published in the Transactions of the American Society of Mechanical Engineers, IV., 249, 1883.

h. "Testing the Relative Value of Different Coals": article by William Kent, Esq., M.E., "Engineering and Mining Journal," July 19, 1890, p. 76.

j. "Critical Review of Efficiency Tests of Coals," by William Kent, Esq., M.E., "Engineering and Mining Journal." (I.) Oct. 10, 1891, p. 430. (II.) Oct. 17, 1891, p. 450. (III.) Oct. 24, 1891, p. 476. (IV.) Oct. 31, 1891, p. 504.

k. "Tests of the Heating Power of Coals," by William Kent, Esq., M.E., R. P. Rothwell's "Mineral Industry," Vol. I., p. 97.

for some time been collecting the results of all the principal boiler tests which I could find, and I have tried to tabulate them systematically for ready reference. I am sorry to say that I have found them, with but a few exceptions, of but very little value for my purpose. A great majority of them fail to state items of the utmost importance, such as information regarding the character of the coal used, the moisture it contained, its size, its calorific value, etc.; and the most important items of furnace construction, peculiarity of setting, and method of stoking are very seldom noted.

Dr. Emery has spoken of having different furnaces for different grades of fuel. That, I am afraid, would hardly be practical, as I know from experience that it is very hard to get boiler users to adopt special furnaces, and so we would seldom find the exact kind of furnace required when we go to a plant to run a boiler test. Another objection would be found in cases where steam users changed from one grade of coal to another to take advantage of the lowest market prices, and for other reasons. The furnace suited for one grade of fuel might be entirely unfitted for the other. We find certain mechanical stokers and special furnaces giving excellent results in certain parts of the country using certain grades of coal; but take these same stokers or furnaces to other sections, or change the grade of coal, and you will find them giving much poorer results than those obtained from the old-fashioned hand-stoking.

To cite an instance in this connection, I know of a certain mechanical stoker which will handle Pittsburg coal, and most of those found in Ohio, northern Indiana, and also the semi-bituminous coals, and give excellent results, but when it is called upon to handle coals containing a perceptibly greater amount of volatile matter, such as are found in southern Illinois, in Kansas, and in Iowa, it is almost a complete failure.

This variation of success is by no means confined to this one stoker. All are alike in this respect, and the same can be said of all special furnace-settings; and for this reason we find one kind of furnace-setting or stoker a great favorite in one section of the country, while in another section, where it has been equally well represented, it has but comparatively few users.

This variety of results obtained from each of the various stokers and furnaces, using different grades of coal, should be carefully studied by all mechanical engineers advising steam

For the water tube it was like this: $y = 14.3 - 4.5\sqrt{x}$; for the tubular boiler $y = 14.3 - 5\sqrt{x}$. I think the rate of combustion is an element which will affect the results in every single case; and in testing a boiler this should be given considerable weight.

Regarding the table which Dr. Emery referred to as showing the analyses made at Sibley College last year, I think, perhaps, that table is a little misleading in one respect. Those values, as originally published, are per pound of coal and not per pound of combustible. We found that the values of the anthracite coals plotted per pound of combustible gave very nearly a straight line, but for the curve of the bituminous coals we could find no such relation. I will furnish Dr. Emery with a more complete table of results. (See Table VI.)

Prof. John H. Barr.—The paper presented at the Detroit meeting by Mr. Dean, and the present paper by Dr. Emery, emphasize the importance of a method for comparing the fuels used in different boiler trials. The plan suggested by Dr. Emery, of adopting standard grades of coal for each of the different sections of the country, seems only partially to meet the requirements, though, perhaps, it is the best thing which can be done.

It occurred to me in this connection that *coke* might possibly be adopted as the standard fuel for determining the performance of the furnace and boiler. It is readily obtained in almost all localities; dry cokes from very dissimilar coals differ practically only in the percentage of ash; and the heating value, actual as well as computed, should be approximately proportional to the weight, less the ash and the moisture, both of which are readily ascertained in a fuel free from "volatile matter."

Objections can be urged to this scheme, no doubt; such as the claim that furnaces specially adapted for burning bituminous coals would be at a disadvantage with a fuel consisting only of fixed carbon. It seems, however, that this artificial fuel might serve as the standard in comparing furnaces and boilers in most cases, making provisions, of course, to govern the procedure when for any reason this fuel could not be used to advantage.

Mr. A. A. Cary.—In this matter of establishing a new standard I can see many difficulties standing in the way of this committee. I am often called upon to make boiler guarantees and tests in all sections of this country, and for the sake of having practical information at hand to assist me in making guarantees I have passes through the boiler front out into the boiler room, and it is through this cylinder that the coal is fed into the furnace.

One method of feeding the coal is accomplished by placing a steel conveyer-screw in the 8-inch cylinder, and continuing it along the bottom of the U trough, the screw gradually tapering towards the rear end of the furnace (Fig. 61).

Another manner of accomplishing this result is found in the shape of a piston ram, which also works in the 8-inch cylinder,

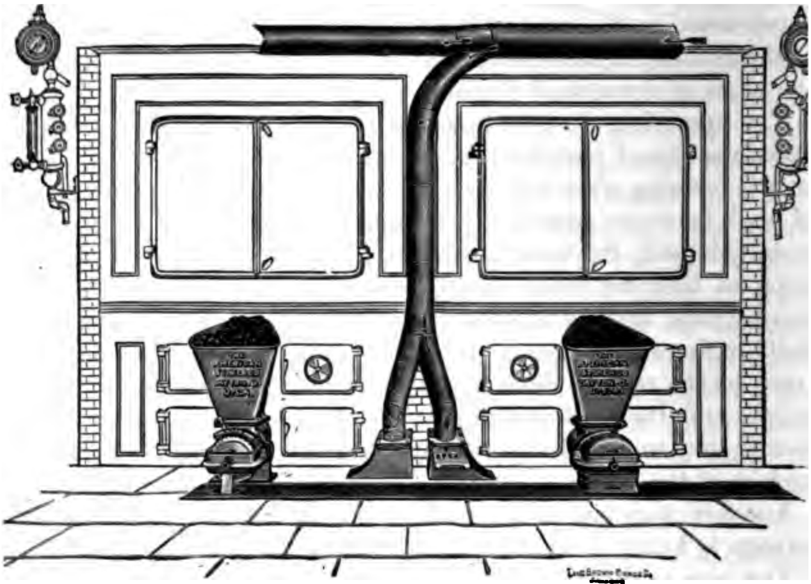

FIG. 60.

the ram being driven by a steam cylinder placed directly behind it, in a similar manner to a direct-acting pump.

Now let us fill our U trough with coal and start a fire on our side grates, which, with the aid of our air supply, delivered through the tuyeres, can be made to burn also over the U trough. We soon have an incandescent bed of coal, and then we begin to feed in the supply of coal.

The trough being full, the coal must find some method of escape, which it does by heaping up in the centre, finally taking the shape of a mound. The whole surface of this mound is now in an incandescent state, and as the fresh coal is fed up from underneath it soon reaches the lower part of the incandescent bed, its volatile matter is distilled off, and it burns rapidly, and

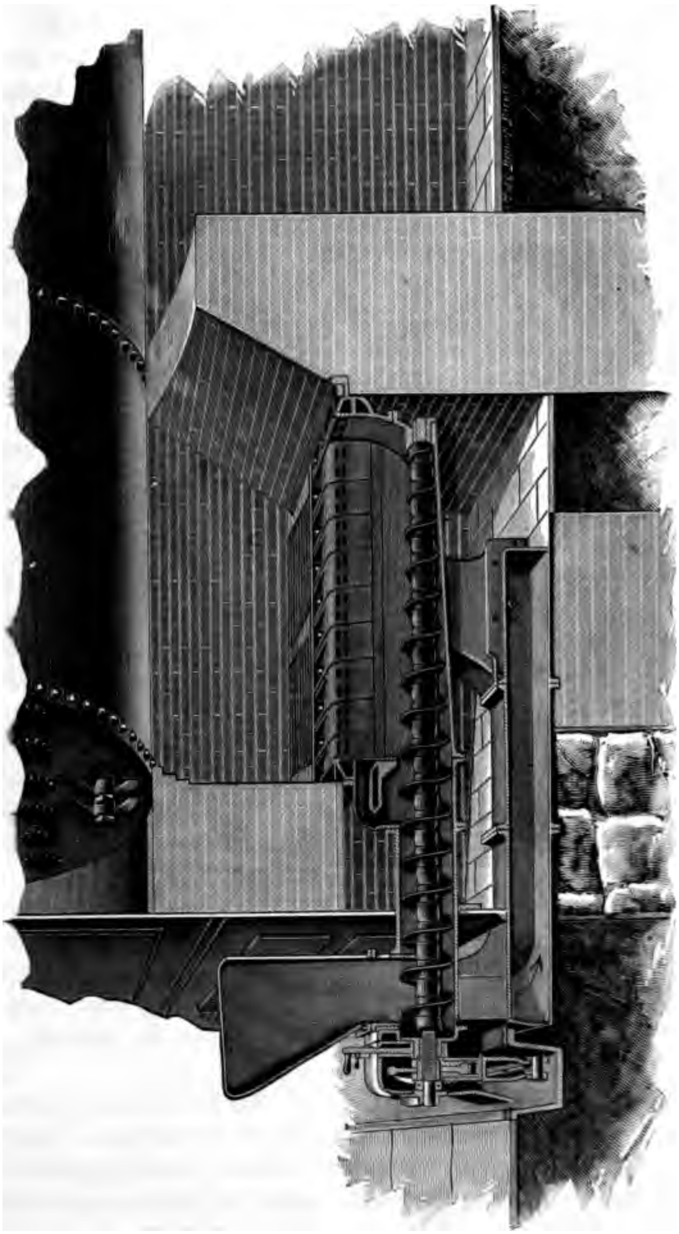

FIG. 61.

practically completes its whole combustion before it escapes from the surface of the mound, from whence it passes upward in a natural manner to the heating surface of the boiler.

As soon as the volatile matter is distilled off from the coal there is practically nothing but coke left (along with the incombustible impurities of the coal); and it is this coke burning, along with the volatile gases, which forms the very hot surface fire.

The incombustible matter finally rolls down the two sides of the central mound, in the form of slag or clinker, on to the side grates, from whence it is removed easily by the clinker hook.

This form of stoker is probably the best of any, when a varying rate of combustion is required, especially the stoker with the conveyer-screw feed, as the speed of this screw can easily be varied at will; and the fan blast, supplying the tuyeres, can also be regulated easily to suit.

The extreme Western coals, excepting those which refuse to burn to a coke, and those which run like melted molasses candy, seem to work better with this gas-producer type of stoker than any of the other types, and the coals above excepted can also be handled in this type of stoker if they are mixed with other coals having a tendency to counteract their faults.

They are also extremely efficient with the coals further east which will form a good coke, although carrying not over from 16 to 18 per cent. volatile matter.

The stokers of the Roney, Murphy, and Brightman type do not depend so much on the coking qualities of the coal they burn for successful working, but careful watching will show that they are far more successful in handling certain grades of coal than they are in handling others.

In burning the true bituminous coals there are many very successful furnaces in existence depending entirely on brick arches which are sprung over the grates, and they generally have advantageous points to admit air over the fire. I have known the application of these brick arches to increase the efficiency of the boiler 10 per cent.

The arrangement of the setting of any individual boiler to suit the different fuels is one of the utmost importance. During the past year I was called upon to examine a plant of water-tube boilers in the West, where it was alleged that certain mysterious troubles had appeared. The owners of this plant had bought one boiler of certain make, and it had given them such excellent satisfaction that they were led to purchase others from the same makers, but, for some strange reason, these other boilers did not begin to give the satisfaction obtained from the first one.

After a little examination I found that the makers had placed their grates much nearer the tubes in the last boilers than they did in the first one, so I had the tubes raised about fourteen inches, and since then the same satisfaction has been obtained from the new boilers as from the first one.

You will see from this that the true efficiency of any boiler cannot be determined by a test unless its setting is in every way adapted to the fuel used; and so it seems to me very necessary, in reporting a boiler test, that its method of setting, with measurements, should be carefully stated, otherwise a fair comparison cannot be made with any other boiler test.

We often note that special boilers manufactured in certain localities are more successful in fuel economy in their own immediate locality than they are further away from home. This is now easily explained. The boiler and setting has been specially designed to use the fuel in its neighborhood; and when this boiler goes to a distance and has other grades of fuel to handle, until the makers become thoroughly familiar with the new conditions to be met, their competitors are going to lead them, and sometimes very decidedly.

Dr. Emery spoke of arranging the conditions alike. From what I have said it will be seen that it is almost impossible to do this. Take the matter of having several standard fuels for different parts of the country. This would certainly be very desirable if the fuel ran sufficiently uniform. It has, however, one drawback, and that is, the extra expense it adds to many boiler tests. There are a number of plants where I have made tests which are somewhat off the main line of travel, and so the freight rates are very high; and besides, in manufacturing plants manufacturers want results from the coal they intend to burn every day. But these are comparatively unimportant exceptions, and I certainly hope that standard coals *will* be adopted: and this seems to be the only way we will be able to get at results of any value from which to make comparisons.

Mr. William Kent.—Before saying what I have to say about Dr. Emery's paper, I would just make a remark on what Mr. Barr has stated, that I consider coke would be very objectionable as a standard fuel, for the reason that it is porous, which makes it carry moisture, and it would be next to impossible to know what the average moisture of the whole body of coke was. The moisture would vary in every part of the pile, and it would be extremely hazardous to use it as a standard on that account. I think large egg anthracite, which can carry very little moisture, would be a much better standard if one coal is going to be adopted.

In regard to Dr. Emery's paper, I would say that I am entirely in accord with the conclusions reached by him, and expressed on the last pages of his paper.

The argument there against using efficiency as a standard for steam boilers I think is a very strong one, and I can supplement it by several other reasons, but I will not take up the time of the meeting by giving them, but will give them to the test committee, and have them thoroughly discussed there.

On page 247 Dr. Emery quotes Isherwood's experiments, and gives the figures of 12.412 for evaporation for anthracite, and another test of 13.865 pounds of water from and at 212 degrees per pound of combustible. I think these experiments from Isherwood should not be mentioned without condemning them. We cannot at all accept any such figures as those with regard to the combustion of anthracite coal. The criticism by Dr. Emery of the analysis of the Ormsby coal in footnote of Table I is well taken. The coal is stated to have given 24,988 British Thermal Units, calculated from the analysis, which analysis gives 21.47 per cent. of hydrogen—a simply impossible coal. There never was such a coal in the world, nor can there be. If you will look through the geological reports of Pennsylvania you will find many thousands of coal analyses, and I do not think you will find a single one that has half as much hydrogen as this. If that coal was marsh gas—CH_4—it would have only 25 per cent. hydrogen in it, and if it was petroleum, liquid fuel, it would have only about 15; so it is simply impossible it could have 21 as a solid coal. That statement should not be brought into a paper like this except for the purpose of condemning it.

Mr. F. W. Dean.—I have a few figures which I would like to present. In the discussion of the paper which I presented last year, advocating a change in the method of reporting boiler trials, basing the performance upon efficiency rather than upon evaporation per pound of combustible, I advocated the analysis of the coal for the reason that I thought it was rather a more perfect method than the method of calorimeter determination;

and I was under the impression, and I think it is a fact, that persons were endeavoring to make the coal calorimeter approximate more closely to the results derived from the analysis of the coal; and that process of bringing the calorimeter up to a greater state of perfection is still going on. However, I did not present it in any dogmatic way, and I do not now adhere to it in that way. In making tests during the last few years, I have in a number of cases had the coal analyzed, and have also had the same samples subjected to a calorimeter test, and I think it would be interesting in this connection to call attention to some of the records:

KIND OF COAL.	ANAL.	CAL.	PER CENT.
New River	15,083	14,026	93
Pocahontas	15,655	14,092	90
"	13,952	13,450	96
"	14,423	13,604	94
G. C. Cumberland	14,241	13,463	95
Pocahontas	15,756	14,654	93
"	14,666	13,680	93
Clinch Valley	14,332	13,401	93
G. C. Cumberland	14,977	14,092	94
" "	14,400	13,452	93
Pittsburg	13,453	13,104	97
Average			93.73%

In the second column we have the results by analysis, and in the third by the Thomson coal calorimeter, and the last column gives the percentage of one to the other. These analyses and calorimeter determinations were made by the same person, a chemist in Boston whom I always employ, and you will see that the percentages run quite uniform. There is an occasional irregularity. If it comes to a question of choice between the two methods, it would seem to be quite unimportant which is adopted, as they run parallel. I think any one in making a boiler test is rather desirous of having an analysis of the coal, and if that would answer the purpose without any further expense it would be a good thing. But I suppose it will be urged that the calorimeter is rather more practical, and approximates more closely to the performance which goes on under the boiler, and from that point of view it would be justifiable of course to take the calorimeter.

My chief reason last year for advocating the efficiency basis was, as I stated in the paper, that coal varies in heat value per pound of combustible. Mr. Barrus has paid great attention to this matter, and has published, I think, in the Transactions of this Society, a list of such determinations, and you will find that they vary considerably, something like six or seven per cent. Of course, therefore, if you base your determination upon combustible simply you take no account whatever, as I then said, of the different heat values of pounds of combustible. That to my mind was sufficient argument in favor of the efficiency method, and I think that even in Dr. Emery's paper there is just about as much proof in favor of that method as there is in favor of the pound-of-combustible method. I made, some time ago, two tests at a mill in Lawrence of the same boiler and with the same grate and fired by the same man. The tests were separated by about a month, and were made to determine the value of a certain cob-house arrangement of fire-brick in the fire-box, which was called a fuel economizer, for which the claim was made that there was a saving produced of anywhere from twenty to thirty per cent. of coal. I think if any one were to see the structure put in, and to see what a poverty of brick-work there was, he could not think it very effective. I will put down the results. The rate of combustion in the first test was 21.40 pounds of coal per square foot of grate, and the next one 21.70; and the evaporation per pound of coal from and at 212° in the first case, which was the plain boiler, was 10.46, and in the other case 10.71; and by analysis the heat values of the coals were 13,916 and 14,360, and the efficiencies determined by them were 72.59, 72.08. Now, the advocate of the fuel economizer immediately said that he had made the saving which is indicated by these different rates of evaporation, which would be $10.71 - 10.46 \div 10.71$, which would be two and something per cent.; but the real saving by the fuel economizer would be just the other way about, for where the evaporation was the greatest the efficiency was the least; therefore I reported that there was practically no saving by the use of the economizer; in fact, it might be shown that there was a little loss, and I felt satisfied that that was the proper way to show it. And then, I have found out that I could rate boilers better in that way than I could in any other. I could get very uniform results. For instance, I have found from the results of various tests that the

In the reaction with most oils there is a certain quantity of gas released which agitates the oil and still further aids purification. The compound has no perceptible effect on absolutely pure oil other than to give it additional polish. I have used it extensively AS AN OIL TEST. It readily seeks out and detects such adulterations as rosin, gum, paraffine, etc.

No. 678—126.

What information can you give as to the best method for the extraction of oil from condensed steam, where it is desirable to use the exhaust steam repeatedly for boiler-feed purposes?

Mr. John C. Kafer.—I do not know of any one subject which is of more importance to steamship owners than that of filtering oil out of exhaust steam, and preventing it from going into the boiler, and if there is any one in the Society who has had experience in successfully extracting oil or grease from exhaust steam or feed water, it would be of great importance to every one who uses a surface condenser on shipboard to hear how it is done. There are various appliances for extracting oil and grease from the feed water—some by floating the grease out of the condensed steam, others by interference, and some by filtering through cloths of various kinds. On some of the Sound steamers, I think they have used for many years straw or hay. That will extract the oil quite well. The slightest amount of grease on the top of the furnace of a boiler will keep the water from that surface, and numbers of furnaces, corrugated as well as others, have gone down, and all due to grease on the surface of the metal. Not only does it injure the boiler, but it interferes with the efficiency of the boiler by preventing the transmission of heat. I think there are a number of gentlemen here who have had some experience with grease extractors, and I would also like to hear some one speak as to the effect on the condenser tubes, if steam going into the condenser deposits this grease on the surface of the tubes and interferes with the transmission of the heat to the condensing water.

Mr. H. A. Bang.—Some years ago, while I was engineer for one of the filter companies, we used the ordinary sand filter for this purpose, and we had to use in addition to it a slight trace of alum, which was fed automatically into the water before

Mr. Hale.—Did not they all three use different calorimeters and all three different formulæ?

Mr. Kent.—They all doubtless used the same formula (Dulong's), but different calorimeters.

Mr. Dean.—I must plead ignorance on these details. I left the matter wholly to the chemist. I am not a chemist, and I do not intend to become one.

Professor Denton.—The Mahler calorimeter condenses all the products of combustion, allowing all the heat of the hydrogen to be accounted for. Mr. Dean's calorimeter does not, as I think it allows the products of combustion to escape, and some of the heat due to the combustion of the hydrogen is carried off as moisture in the excess of oxygen above the amounts required for combustion.

The error due to this fact would probably not reach one per cent.

It should also be noted in studying these figures that the calorific values given with a Mahler calorimeter agree with those calculated from analyses only when the latter are derived from the following particular formula,

$$\text{Heat of combustion} = 14652C + 62100\left(H - \frac{O + N - 1}{8}\right),$$

which may not be the one employed by Mr. Dean.

*Dr. Charles E. Emery.**—The subject is so complex that in closing I can only discuss a few points which have arisen in the discussion. Professor Carpenter has referred to the variations in efficiency due to different rates of combustion, and presents curves he has plotted from information given in the second volume of Wiesbach's *Mechanics* (American edition). These experiments were made at the New York Navy Yard under Mr. Isherwood's general directions, and I called the attention of Mr. Buel, who annotated the second volume of Wiesbach, to them, by a reference to my paper on the subject of "Boiler Proportions," in the report of the judges of Group XX., Centennial Exhibition (*m*), for which he gives due credit. Referring to this report, it will be found that, as stated in § 45 of this paper, I then gave curves plotted from such experiments, and formulæ based thereon. The function used by Professor Carpenter in plotting his curves must be criticised, as evidently the evaporation shown by formulæ would have a negative value

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* Author's closure, under the Rules.

would during the service fill with grease so that they were all matted together, looking more like dirty liver or raw rubber than sponges, but still the water which had passed through them was almost clean. It had a rather unpleasant taste, but one could drink it, and it looked practically clean.

Mr. Charles Langlotz.—I was about to remark, the same as the previous speaker, that on the Atlantic liners they use sponges, and these are fitted with an automatic by-pass to feed around the box rather than through it when they become foul. I have used pulverized coke, however, with considerable success, as it does not require the attention which sponges do.

Mr. William Kent.—I would like if these gentlemen who have spoken about sponges would give us some idea of the size of the vessel in which the sponges are kept. Also, how big a sand filter should you have, say, for 1,000 horse-power?

Mr. Roelker.—For 2,000 horse-power one would generally use two boxes about 18 inches high, 2 feet wide, and 12 feet long, with open tops. The water passes through them longitudinally. Two are used so that one may be cleared while the other is working.

Mr. E. A. Darling.—I learned the other day of a filtering material used on some of the Sound boats which meets with considerable success, and that is the ordinary "excelsior" wood fibre. The point about it is that it absorbs the oil much better than does straw or hay. Its cost is little more, and it may be burned when foul.

Mr. William T. Bonner.—I think there is one motto that would serve very well for all of the appliances suggested thus far, which is, that eternal vigilance is the price of safety. In my experience I have found that the ammonia-alum filters are very nice in theory, but unless they are carefully watched, that small trace of alum soon becomes quite a large amount. This is due to several causes, but principally to corrosion and gradual enlargement of the opening through the connection between the chemical tank and filter. In two of three instances where we tried that system we found that in a very short time the feed pipes to the boiler were all eaten out. It could not be accounted for in any other way than that there must have been a surplus of alum in the feed water beyond the filter. At other plants which I have in mind they attempted to filter grease from the water, but it was only a short time before the sand bed became so foul that it was given up as impracticable. There are places where it is possible to use pressure filters for work of that kind, but the impurities must first be thoroughly coagulated by the use of chemicals and the precipitate removed from the sand bed by frequent washing. In addition the filter should be opened from time to time, and the top of the sand bed scraped off, or else the sand bed should be taken out entirely, and replaced by fresh material.

I have also seen straw and excelsior used. In my experience that has proved a very cheap and effective means of taking out oil, but, like everything else, it needs to be watched. It requires but a short time for the straw and excelsior to become coated over and to clog up; and unless it is thrown out and replaced, the oil passes through the same as before. If anything, it is worse; because you are not only passing the oil through, but you are also carrying along the rotten material, as it seems to disintegrate and go through in small particles with the feed water, getting under the valve seats, clogging up passages, and causing no end of trouble.

Mr. Kafer.—What was the material of the feed pipe, copper or iron?

Mr. Bonner.—It was iron. The plant which I had in mind was very well arranged, and received careful attention; yet, as I remember, the pipes were all eaten out in something like four months. There they used a pressure filter with an automatic injection of ammonia-alum, the latter being intended to precipitate the lime in the water. The apparatus was put in by one of the prominent filter companies of that time, under a strong guarantee. It worked very well for a time, but it seemed impossible to regulate automatically the supply of alum, owing to gradual enlargement of the openings by corrosion. Brass pipes have been used for connections between the chemical tank and the filter, and in some cases also for connecting the filter to the main pipe system; but the alum would generally attack the first iron pipes it reached, and even in some cases corroded the brass pipes.

Mr. Kafer.—There is one method of preventing grease in boilers that has not been spoken of yet, and I think it is the best known; that is, not to put any oil in the cylinder. (Laughter.) That practice has been adopted on a number of steamships with success. Care must be taken to have the right kind of metal in

TABLE IX.

PROXIMATE ANALYSES OF DIFFERENT KINDS OF COAL. (GALE.)

DESIGNATION OF COAL.	Per cent. Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
Anthracite:					
Beaver Meadow, Penn	1.5	2.38	88.94	7.11	.01
Peach Mountain, Penn	1.9	2.96	89.02	6.13	.01
Lackawanna, Penn	2.12	3.91	87.74	6.35	.12
Lehigh, Penn	3.01	3.28	88.15	5.56	.5
Welsh, Wales	1.2	6.25	88.	4.55	.92
Semi-Anthracite:					
Natural Coke, Virginia	1.12	12.44	75.08	11.38	.47
Cardiff, Wales	1.25	12.85	81.9	4.	.76
Lycoming Creek, Penn	.67	13.84	71.53	13.96	.03
Arkansas, No. 16, Geol. Survey	1.35	14.93	74.06	9.66	....
Semi-Bituminous:					
Blossburg, Penn	1.34	14.78	73.11	10.77	.85
Mexican	1.0	14.86	55.7	28.44	4.53
Fort Smith, Arkansas	1.07	17.2	73.05	8.68	....
Cliff, New South Wales, Australia	.85	17.7	71.8	9.65	1.26
Skagit River, State of Washington	1.19	18.8	71.66	8.35	....
Cumberland, Maryland	.97	19.87	72.26	6.12	.77
Cambria County, Penn	2.46	20.52	69.37	9.15	1.5
Mount Kembla, New South Wales, Aus	1.2	20.93	66.96	10.91	2.33
Fire Creek, West Virginia	.74	22.42	75.5	.8	.54
Arkansas, No. 12 Geol. Survey	.89	24.66	58.2	16.26	
Bituminous:					
Wilkeson, Pierce County, Washington	1.33	25.88	66.75	6.04	Trace.
Cowlitz, Washington	1.16	26.12	61.9	10.69	0.13
New River, West Virginia	.67	26.64	70.66	1.53	.5
Picton, Nova Scotia	2.57	27.83	56.98	13.39	.77
Big Muddy, Illinois	7.12	29.5	54.64	8.74	1.01
Bellingham Bay, Washington	3.98	29.54	59.9	6.	.58
Midlothian, Virginia	2.46	29.86	53.01	14.74	.06
Connellsville, Penn	1.26	30.10	59.61	8.23	.78
Illinois, Average	8.93	30.14	45.93	15.	5.
Carbon Hill, Washington	2.16	31.73	55.8	10.31	2.33
Clover Hill, Virginia	1.34	32.21	56.83	10.13	.51
Wellington, Vancouver Island, B. C.	2.15	34.15	54.85	8.85	.27
Franklin, Washington	3.5	34.27	54 23	8.	
Rocky Mountains	7.55	34.65	42.85	14.95	1.1
Newcastle, England	1.5	34.7	59.3	4.5	.23
Mokihinui, Westport, New Zealand	3.96	34.94	57.92	3.18	....
Brunner Mine, Greymouth, New Zealand	1.59	35.68	56.62	6.11	....
Pittsburg, Penn	1.7	36.	55.	7.3	.16
Nanaimo, Vancouver Island, B. C.	2.25	36.05	51.95	9.75	2.39
Hocking Valley, Ohio	6.95	36.15	51.3	5.56	.67
Pleasant Valley, Utah	5.43	37.73	49.40	7.44	1.28
Kentucky	2.	37.89	56.01	4.1	....
Ellensburg, Washington	2.	39.1	54.4	3.4	1.1
Olympic Mountains, Washington	5.1	39.15	47.01	7.77	.97
Scotch, Scotland	3.01	39.19	48.81	9.34	.36
Roslyn, Washington	3.1	39.7	52.65	4.55	Trace.
Cook's Inlet, Alaska	1.25	39.87	49.89	7.82	1.2
Kootznahoo Inlet, Admiralty I., Alaska	3.74	37.02	45.15	14.09	.72
Liverpool, England	.89	39.96	54.9	4.62	.38
Calispel, Washington	2.39	41.18	42.92	13.21	.3
Carbonado, Washington	1.8	42.27	52.11	3.82	Trace.
Upper Yakima, Washington	1.2	42.47	52.21	4.12	Trace.
Methow, Washington	2.5	43.71	49.27	4.26	.26
Newcastle, King County, Washington	2.12	46.7	43.9	7.15	.13
Black Diamond, King County, Washington	3.11	47.19	45.11	4.58	.01
Black Diamond, Mt. Diablo, California	14.69	33.89	46.84	4.58	
Lignites:					
Otago (Kaitangata Cr.), New Zealand	19.61	37.25	39.41	3.73	....
Gilman, Washington	4.8	47.07	37.19	10.06	.88
Coos Bay (Newport Mine), Oregon	15.45	41.55	34.95	8.05	2.58
Alaska	14.6	44.85	31.2	9.35	1.15
Huron, Fresno County, California	11.7	51.73	19.63	16.94	2.73
Ione, Amador County, California	42.58	34.88	17.42	5.12	Trace.

works, where the object was to get the condensed steam back again for the sake of the distilled water for boiler feed, instead of using a lime water, and the exhaust steam was used for heating cold water, and simply passed through a system of coils (see sketch). I have not heard of anything which would work successfully on the exhaust steam after being used in the heating of a building; perhaps the same thing might answer the purpose. It might answer in a closed cylinder.

I know that a water filter is about the best thing I have ever found for separating oil from water, if you give it time enough to separate; of course there is a little heat lost by radiation, but the question is, whether the small amount of heat lost had not better be lost than to damage the boiler with grease, or to affect injuriously the heating surfaces.

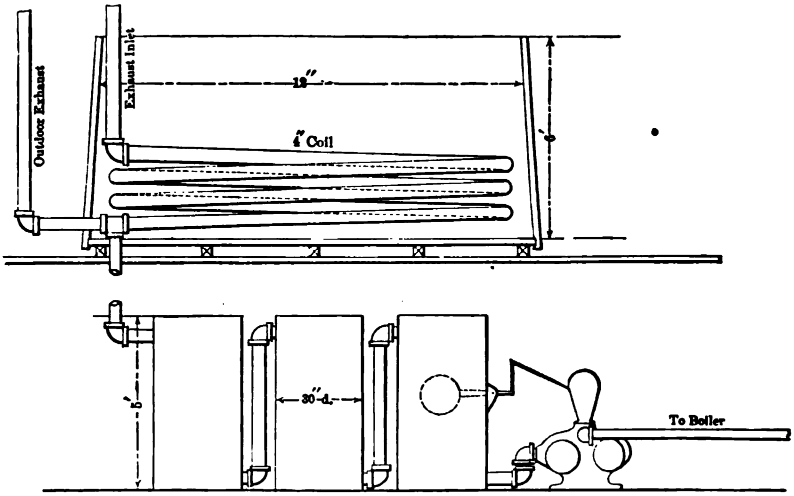

FIG. 62.

Mr. Kafer.—That is the system of the Wass grease extractor.

Mr. O. C. Woolson.—The experience which I had with this question was in the early seventies, at which time there was being introduced through the West a square, homely heater, with a chamber at the bottom for closely packed hay, through which all the feed water had to pass, and as the heater worked on the jet condenser principle, a purifying chamber was necessary; and from my experience that was a very practical heater.

Mr. McBride.—I think the suggestion of Mr. Kafer a very sensible one in regard to using less oil in cylinders.

DCLXXVIII.

TOPICAL DISCUSSIONS AND INTERCHANGE OF DATA.

XXXIId MEETING.

No. 678—125.

For filtering oil having very finely divided metallic particles in suspension, what have you found to be the best filtering material, either for one operation or in a series?

Mr. G. W. Bissell.—The writer uses an oil filter consisting of two shallow rectangular tin trays and some wide lamp-wicks. One of the trays, slightly smaller than the other, is supported within it on two blocks, which raise it an inch or so from the bottom of the larger pan. The wicks are laid in the upper pan so as to hang over its edges into the lower pan.

The oil to be filtered is poured into the upper pan. A drip cock in the lower pan, and a cover for the whole, complete the apparatus. No quantitative tests have been made, but the results, as far as the eye can judge, are good.

Mr. P. J. Tracy. *—Machinery oil used for lubrication, after passing through the bearings seems not only to become contaminated with non-lubricating matter, such as fine metallic particles, carbon, dust, etc., but it seems also to lose, in a great many cases, a large percentage of its valuable elements. It thus becomes less volatile and more difficult to restore to its original purity and value, and the attempts by filtration in most cases have not been satisfactory to the practical engineer.

It is not the heavy deposit of foreign matter which injures machinery, as such material is easily and readily removed, but it appears to be fine particles. often invisible to the naked eye, which become so incorporated into the body of the oil as to cause the heating and cutting with which operators are familiar. The heat would also seem in many cases to affect the structure of the bearings, as well as to increase consumption of the fuel.

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* Of Racine, Wisconsin. Contributed by letter to the Publication Committee.

The complete removal of the finely divided metallic matter cannot be effected by passing it through many of the so-called filtering mediums, such as mineral or animal wool, bone dust, vegetable or animal charcoal, hair felt, absorbent cotton, and the like, nor can much of this material be precipitated readily by heat.

What may be called the anti-lubricating substances continue in the oil, and comparatively little real purification is effected by such filtration, except when the material is quite new, and even an expert will find it hard to tell when the filtering medium is exhausted unless he applies frequent quality tests. My effort has been to find some material, if possible, which would be both certain in its results and be safe to place in the hands of inexperienced operators. The solution which I have found for the problem is, to devise a chemical preparation which should act as a coagulant, a deodorizer and disinfectant, and at the same time facilitate precipitation. It can be used in the simplest kind of apparatus, which I often arrange as follows:

A clean, empty oil barrel has its top head taken out, and there is substituted for it a reasonably dust-proof removable cover, having an overlapping flange. Through the centre of the cover, in an inch and a quarter hole, insert a pipe, passing down inside the barrel to within three inches of the bottom, and provide at its upper end a funnel and strainer, and at the bottom a strainer 2½ inches deep, 12 inches in diameter, open at the bottom, and with its side made of finely perforated sheet metal.

The object of this peculiar construction is to provide for a precipitation and to break up the oil from drops into a fine spray, thus presenting more surface to reaction with a compound.

About two tablespoonfuls of the filtering compound dissolved in a pail of tepid water is then poured into the barrel through the funnel, and water and compound added in above proportions, according to the condition and quantity of oil to be purified, until the solution stands nine inches high in the barrel, and the dirty oil is poured in and allowed to stand a few hours before using. A glass water-gauge and two molasses faucets enable the relative position and condition of the re-agent solution to be observed, and the clean oil or the precipitant can be drawn off as required.

not. Being directly interested in that line I am naturally very anxious to see a good filter produced, because many troubles have occurred on account of the oil in the feed water. As we all know, the item of cost for a supply of feed water is a very important one in large towns and cities where the water is taken from the regular water-works supply. If I remember correctly, in New York city it costs for feed water about one dollar per year per engine horse-power; it is a small electric light and power plant which will not use, at the above price, several thousand dollars' worth of feed water in a year; and as 90 per cent. of that amount can be saved by the use of surface condensers, a satisfactory filter would really be a great boon. Now the question is, How can we best get rid of the trouble of oil in the feed water?

My attention was called a few years ago to a very interesting paper and discussion on this subject, brought before one of the British engineering societies. Mr. Mudd, Mr. Rankin, and Mr. Edmiston, all well known in marine circles, together with other prominent engineers, discussed the subject pretty thoroughly. My brother happened to be abroad about a year ago, and at my request investigated the different filters in use in England, and which were mentioned in the paper and discussion referred to. They seem to give this subject more attention in Europe than has been the case in this country. Surface condensers are not as largely used here as there, and, except in connection with marine engines, you might say that there are but a few thousand in use in this country. I have found many builders and users of stationary engines in this country more or less prejudiced against surface condensers, founded on the results of carelessness and ignorance in handling—in other words, want of proper attention to the subject of filtering feed water from oil. I can cite cases where the men in charge of the filter box did not appreciate the importance of thoroughly looking after it, and allowed it to be neglected. They were also indifferent about renewing the water in the boilers every week. In short, they were so accustomed to the jet system of condensers that they did not give the surface condenser the same care as the marine engineer is in the habit of doing.

To give the gentlemen present the result of my brother's investigations on this subject, I would say that he found the best filters abroad—at least in England—are those known as the

Rankin, the Harris, the Reeves, and the Edmiston. They are all based upon mechanical effect—no chemical action whatever. By the way, I would like to say here that there are a number of well-known filters in this country—so-called quartz or sand filters—where they use more or less chemical treatment of the water. They do their work very well in eliminating oil, but the chemicals used are very apt to cause pitting in the boilers. It would therefore seem that we must rely on mechanical effect, which means filters where strainers especially adapted for the purpose are used.

We are all familiar with the ordinary filtering box, which, if roomy enough, and provided with sufficient number of compartments and the proper kind of filtering material, frequently renewed, gives very good results. But the average stationary engineer seems to begrudge the room required and the trouble necessary to attend properly to such a filter. There is, therefore, a necessity for a compact filter, with ready means for easily cleaning it, and that is how the filters named came to be introduced abroad.

Now, the Harris filter (one of those previously mentioned) is nothing more nor less than a combination of cylinders, in each of which there is a piston, and by the use of an attached hand screw the oil and other impurities can be compressed out of the sponges used, thus providing a ready means for keeping up the efficiency of the filter.

The Reeves filter is somewhat of the same construction, only that sawdust is the filtering material.

The Rankin filter is a very ingenious arrangement, and is known as the "cartridge" system. The cartridge is nothing more nor less than a cylinder wrapped in coarse towelling. This cylinder, or cartridge, is firmly held in proper position in the casing by means of a set-screw, adjustable by hand. This filter is a very simple device, and it does its work well.

The only trouble with all the filters named, however, is the limit of the filtration effect.

The system devised by Mr. Edmiston is really the most ingenious arrangement of all, and is in successful use to-day on a large number of vessels, including the British, Italian, and Russian navies. It is also in use on the steamers of one of the principal transatlantic lines. Mr. Edmiston is a marine engineer of wide experience, and he seems to have given this subwould during the service fill with grease so that they were all matted together, looking more like dirty liver or raw rubber than sponges, but still the water which had passed through them was almost clean. It had a rather unpleasant taste, but one could drink it, and it looked practically clean.

Mr. Charles Langlotz.—I was about to remark, the same as the previous speaker, that on the Atlantic liners they use sponges, and these are fitted with an automatic by-pass to feed around the box rather than through it when they become foul. I have used pulverized coke, however, with considerable success, as it does not require the attention which sponges do.

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These cloths are conveniently secured at the outer edges of the perforated plates by metal rings. After the plates and filtering material are placed in position they are securely held in place by set-screw *a*, which is screwed up tightly from outside by means of a wrench, thus water-tight joints are readily secured, so that the feed water must pass through each series of filtering material. The scum chamber *H*, on top of the filter, is provided with a blow-off cock *J*, which is opened when the glass water gauge indicates an accumulation of oil.

The soda cup *K*, shown at the other end of the filter, is provided with a steam connection for the purpose of removing oil and dirt from the filtering diaphragms by boiling and blowing out of same through the blow-off cock at the lowest end of the sludge pocket. A pressure gauge (not shown) indicates the pressure in the filter, the normal pressure being from 2 to 5 pounds above boiler pressure. When the pressure exceeds the amount named the by-pass connection should be opened and the inlet and outlet valves closed, thus allowing the feed water to flow to the boiler direct without going through the filter, while the latter is being cleaned. The whole operation is very simple; and when it becomes necessary, the filtering cloths can readily be renewed. On a steamer in ordinary service these cloths would not have to be removed more than once in every week or two. Of course it is necessary to boil out the filter with soda and steam, and clean these cloths quite frequently—say three or four times a day. Live steam is admitted through the soda cock shown; by this handy arrangement you can keep up the efficiency of the filter—an important feature.

Mr. Edmiston seems to have carried out this idea more elaborately than his competitors. I know that they have no trouble in eliminating practically 90 per cent. of the oil and impurities from the feed water.

Mr. Oberlin Smith.—Tell us, please, what is the scale of the drawing, and what would be the size of the filter for an ordinary steamer.

Mr. Wheeler.—The size of the filter shown is about 16 inches in diameter, and is ample for a 300 horse-power plant.

The filters used on the big transatlantic steamers are arranged in pairs, so that one filter can be cleaned while the other is in use.

the cylinder and valve surfaces, and a softer metal in the packing rings; but it can be arranged so that the engine will work satisfactorily and not use any oil in the cylinders at all, and that is the sure way of getting rid of the oil in the boilers.

Mr. Paul H. Grimm.—The methods thus far proposed for eradicating this evil, or preventing it, seem all to be in the interest of steamship companies and steamship boilers. I have not heard any remedy mentioned yet for the evil as it exists in land or stationary practice.

In many of our large buildings here in the city, where exhaust steam is used for heating purposes, and afterwards for feeding the boilers (that is, the condensation from this steam), I have known of considerable damage having been done by grease in the feed water. It is a well-known fact that in buildings where they have elevator engines, which live on oil generally, and the oil is attempted to be extracted by so-called grease extractors, which do almost everything but extract grease, the oil seems to get into the piping of the heating system, and comes back with the water of condensation to the boiler, with the result of filling up the tubes, if it is a water-tube boiler, or getting on to the crown or fire sheets of some other boiler; and I was in hopes that some one might advance a good remedy for that evil. I have myself come in contact with this thing to a considerable extent, and found that where the object is simply to recover the water of condensation for the sake of the water—for the sake of having the soft water—and where the temperature of this water is not any greater than say 212 degrees, I have used apparatus which perhaps others have used, though I have never heard of its being used before. In one case I have used two chambers, in another case three chambers, of water, consisting of cylinders about 5 feet high and 30 inches in diameter (Fig. 62). The water of condensation is first passed into one of these until it fills up to within six inches of the top of this cylinder; put in a pipe which leads to the bottom of the next cylinder; then that fills up, and from the top of that one, or near the top, another pipe down to the bottom of the next one, being a series of three; and my experience has been that from the first cylinder I could skim off oil which would be really fit to use again—quite a thick film of oil; and the second cylinder would have less, and the third one scarcely any. This is an apparatus which I have used very successfully in a Western starch works, where the object was to get the condensed steam back again for the sake of the distilled water for boiler feed, instead of using a lime water, and the exhaust steam was used for heating cold water, and simply passed through a system of coils (see sketch). I have not heard of anything which would work successfully on the exhaust steam after being used in the heating of a building; perhaps the same thing might answer the purpose. It might answer in a closed cylinder.

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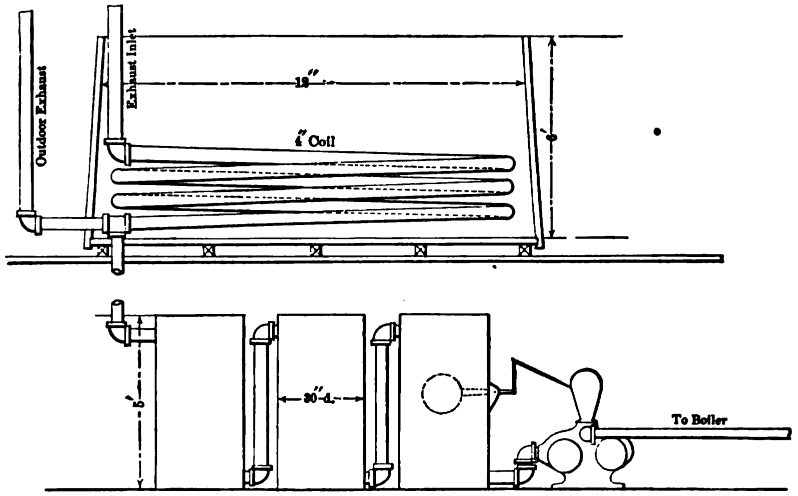

FIG. 62.

Mr. Kafer.—That is the system of the Wass grease extractor.

Mr. O. C. Woolson.—The experience which I had with this question was in the early seventies, at which time there was being introduced through the West a square, homely heater, with a chamber at the bottom for closely packed hay, through which all the feed water had to pass, and as the heater worked on the jet condenser principle, a purifying chamber was necessary; and from my experience that was a very practical heater.

Mr. McBride.—I think the suggestion of Mr. Kafer a very sensible one in regard to using less oil in cylinders.

their engines; this means very careful fitting of valves, etc. It is quite true that as a rule too much oil is used in most steam engines, especially in the auxiliary engines. I know of one case where the exhaust steam from the auxiliaries is allowed to go to waste just because the use of oil is so much greater in these engines than it is in the main engines. There is no doubt but what there is quite a field for improvement in the building of engines adapted to work without oil. When this is accomplished, the surface condenser will be more largely used than it is now; but until that time comes, we must rely on the best feed-water filters we can find.

Mr. Rockwood.—In the case of the Syracuse boiler plant to which I just referred, I am told that they experienced trouble at first, owing to the use of ordinary cylinder oils in the engines. The oil they now use with success is a purely mineral stock oil.

Mr. A. H. Raynal.—I would say in encouragement to Mr. Wheeler, in introducing filters of this kind, that they will be useful for eliminating not only the oil, but also little particles of solid matter. A few years ago, right in the city of New York, where I had charge of some large boilers, I was much annoyed by the solid matter baking on the crown sheet. The boilers could not be changed, and I had to get rid of this difficulty. I tried several filters for the feed water, and among others the Johnson filter, which is probably known to you, and by interposing three layers of cotton flannel I succeeded very well in keeping that matter out. It is probably known to many of you that the Croton water has a large amount of this solid vegetable matter in suspension, so finely subdivided that you cannot filter it out with an ordinary filter. It requires a close woven fabric to filter it. So far as the oil is concerned, it is of course very advisable to use as little as possible. It is well known to marine engineers that it is one of the great advantages of the vertical engine that you can use cylinders of large dimensions with a small amount of oil. But in stationary engine practice, when horizontal cylinders are employed, of say 52 or 56 inches diameter, you have to use large amounts of lubricants. In cotton mills this question of oil has often been quite a bugbear, as also has been the quantity of feed water used.

Mr. Boyer.—I am very glad to hear Mr. Wheeler speak on this question. We have got 800 horse-power engines running. We put in a 1,000 horse-power Wheeler condenser. Then I put in a Cochrand separator. We are on tide level, where we have to pump our exhaust, being so low down that we could not locate our condenser so as to get a flow of condensing drip by gravitation, and I put on a good pump for the exhaust lines and separator in addition to the air pump. I had my men in charge of the engines take samples from that water every hour and put them on my desk. The water was as clear as crystal to the eye. There was no criticism. We ran along in that condition, I should think, about three months. I had the boilers opened several times to watch the results for oils, using the mineral oil on the engines; and right here I will deviate a bit to say how we use the oil. When we first started, I found that our men were using eight drops of oil for a revolution on the engine, two 32-inch, one 17-inch cylinder, and we reduced it down to one drop of oil in the same lubricator to eight revolutions, instead of eight drops to one revolution, and it was under the latter circumstances that these conditions were noted. We had under the boilers a series of feed-water heating pipes, through which the water passed, located in the fire-box, and after we had run about four months my fireman came to me one day and said, "Those pipes under the boilers are dropping down." Upon examination it was found that on two sides of each boiler the pipes were bent down about 2½ inches. We were running refrigerating machinery and could not stop. I immediately shut down three boilers, and took the pipes out and examined them. While the inside of the shell of the boilers was clean, for there was no deposit, there was no appearance of oil in the feed-water pipes that had fallen down. I sent a sample of this water and had it analyzed by the State chemist, and his report came back that there were traces of oil, but not enough to define its quantity. Well, that of course made us feel quite content. But the result was that we lost all the coils under the six boilers—had to take them out and replace them. We have since stopped using this water and have had no trouble. Now, if there is any person who knows any way by which we can save this water, 130 tons daily, so that we can get it back and use it, I shall be glad to hear from him. We are running a condensing service anywhere from 25 to 26 inches of vacuum. I would say, in reference to the oil that went through the cylinder for lubricating, I put in a device to collect it after it had passed through the engines, and I found it in such a condition that about the only thing it not. Being directly interested in that line I am naturally very anxious to see a good filter produced, because many troubles have occurred on account of the oil in the feed water. As we all know, the item of cost for a supply of feed water is a very important one in large towns and cities where the water is taken from the regular water-works supply. If I remember correctly, in New York city it costs for feed water about one dollar per year per engine horse-power; it is a small electric light and power plant which will not use, at the above price, several thousand dollars' worth of feed water in a year; and as 90 per cent. of that amount can be saved by the use of surface condensers, a satisfactory filter would really be a great boon. Now the question is, How can we best get rid of the trouble of oil in the feed water?

My attention was called a few years ago to a very interesting paper and discussion on this subject, brought before one of the British engineering societies. Mr. Mudd, Mr. Rankin, and Mr. Edmiston, all well known in marine circles, together with other prominent engineers, discussed the subject pretty thoroughly. My brother happened to be abroad about a year ago, and at my request investigated the different filters in use in England, and which were mentioned in the paper and discussion referred to. They seem to give this subject more attention in Europe than has been the case in this country. Surface condensers are not as largely used here as there, and, except in connection with marine engines, you might say that there are but a few thousand in use in this country. I have found many builders and users of stationary engines in this country more or less prejudiced against surface condensers, founded on the results of carelessness and ignorance in handling—in other words, want of proper attention to the subject of filtering feed water from oil. I can cite cases where the men in charge of the filter box did not appreciate the importance of thoroughly looking after it, and allowed it to be neglected. They were also indifferent about renewing the water in the boilers every week. In short, they were so accustomed to the jet system of condensers that they did not give the surface condenser the same care as the marine engineer is in the habit of doing.

To give the gentlemen present the result of my brother's investigations on this subject, I would say that he found the best filters abroad—at least in England—are those known as the

Rankin, the Harris, the Reeves, and the Edmiston. They are all based upon mechanical effect—no chemical action whatever. By the way, I would like to say here that there are a number of well-known filters in this country—so-called quartz or sand filters—where they use more or less chemical treatment of the water. They do their work very well in eliminating oil, but the chemicals used are very apt to cause pitting in the boilers. It would therefore seem that we must rely on mechanical effect, which means filters where strainers especially adapted for the purpose are used.

We are all familiar with the ordinary filtering box, which, if roomy enough, and provided with sufficient number of compartments and the proper kind of filtering material, frequently renewed, gives very good results. But the average stationary engineer seems to begrudge the room required and the trouble necessary to attend properly to such a filter. There is, therefore, a necessity for a compact filter, with ready means for easily cleaning it, and that is how the filters named came to be introduced abroad.

Now, the Harris filter (one of those previously mentioned) is nothing more nor less than a combination of cylinders, in each of which there is a piston, and by the use of an attached hand screw the oil and other impurities can be compressed out of the sponges used, thus providing a ready means for keeping up the efficiency of the filter.

The Reeves filter is somewhat of the same construction, only that sawdust is the filtering material.

The Rankin filter is a very ingenious arrangement, and is known as the "cartridge" system. The cartridge is nothing more nor less than a cylinder wrapped in coarse towelling. This cylinder, or cartridge, is firmly held in proper position in the casing by means of a set-screw, adjustable by hand. This filter is a very simple device, and it does its work well.

The only trouble with all the filters named, however, is the limit of the filtration effect.

The system devised by Mr. Edmiston is really the most ingenious arrangement of all, and is in successful use to-day on a large number of vessels, including the British, Italian, and Russian navies. It is also in use on the steamers of one of the principal transatlantic lines. Mr. Edmiston is a marine engineer of wide experience, and he seems to have given this subbatteries; we have nineteen boilers altogether. We only tried the experiments on No. 3 battery—a battery of eight boilers. I first put a large oil feeder, the same as a lubricator of an engine, which would hold a gallon and a half of kerosene oil, so that I could feed it drop by drop. I ran about a week or ten days, and was feeding on an average of about two drops a minute, and the result of about ten days' trial was that I lost the lubrication on my engines. I heard the engines commence to give trouble. What to do I did not know. In fact, I did not know what was the cause, but thought the oil was the trouble. I stopped my engines and blew out my boilers; cleaned them out thoroughly, and found that my engines lubricated properly. We started again to use oil by putting a gallon in whenever we have the boiler open, and as the water flows in it raises the oil on its surface and would deposit a little film on the side of the boilers; the result is that the inside sheets of our boilers are just as clean to-day as when they were first used. I have never known a joint, a rivet, or a seam to start; but I would not dare to feed it in drop by drop. I know it would be disastrous. I approve highly of using kerosene oil for keeping boilers free from scale. It has got to be used with a good deal of discretion. It is a good servant, but it is a terrible master.

Mr. Raynal.—I would like to ask Mr. Wheeler—although I know that the question is not directly pertinent to the subject—whether this filter has been used for the purpose of filtering oil and drawing from it the particles of metallic substances where the oil has been used for lubricating. It is only a couple of weeks ago that one of my friends in charge of a very large electric plant asked me what I knew about filtering oil. Of course I had to plead ignorance, and since that time I know that others in the same line of business have made extensive series of experiments in that direction and found it a very difficult subject to handle. In electric light stations they use oil very profusely, finding it cheaper in order to be sure of no disaster from dry bearings. But this oil should be regained, and of course all the particles of abrasion have got to be removed; and if Mr. Wheeler's filter will do that, I believe it will be a great help to all the engineers using oil.

Mr. Wheeler.—In answer to this question, I consider this filter is even more valuable for extracting particles of oxides or other impurities held in suspension. In the discussion the percolator [illegible] filtering [illegible]

These [illegible] the percolator [illegible] filtering material [illegible] position [illegible] in place [illegible] sides [illegible] water-tight [illegible] secured [illegible] of filtering material [illegible] is provided [illegible] glass water gauge [illegible]

The [illegible] vided with [illegible] and [illegible] out of [illegible] the [illegible] pressure gauge [illegible] pressure [illegible] pressure [illegible] pounds above [illegible] pressure. [illegible] amount [illegible] the [illegible] while [illegible] [illegible]

Mr. [illegible] this idea more [illegible] that they have in [illegible] of the oil and [illegible]

Mr. [illegible] What is the scale of the [illegible] for an ordinary [illegible]

Mr. W[illegible] about 16 inches [illegible] horse-power plant.

[illegible] are arranged [illegible] while the other is in use.

I am surprised that so little is known about the Edmiston filter in this country, as there are many engineers and steam users who are seeking for something of this kind—*i.e.*, something that is compact and easily taken care of.

Mr. George I. Rockwood.—This question is, perhaps, asked in view of the fact that an ordinary oil separator may be efficient enough in separating oil from the exhaust steam of a non-condensing engine, when it will do no good at all on a condensing. It seems to me a singular fact, not generally known, and to which attention ought to be directed. I have found that it will not do to close the valve in the drip-pipe from a separator applied to a non-condensing engine, or to even impede the free exhaust of the drip by interposing a siphon barrel between the separator and the sewer, with a view to recovering the cylinder oil for use the second time. If the experiment be tried it will be found that the separator will no longer act as such, but that the oil will pass right along with the exhaust steam in nearly its original quantity.

Now, while I am not going to propound the theory that I have in my mind as a certain conclusion, still, it is something which I am going to try. It is this: that the oil can only be separated when a good draft is maintained down the drip-pipe, whether the engine is a condensing or a non-condensing engine. Some separators do better than others when there is no draft, but none of them do even moderately well if sole reliance is to be placed upon them for rendering the feed harmless. I am going to try the expedient of discharging the oil from the separator into a separate small surface condenser having its own air pump, by which I shall expect to maintain a slightly better vacuum than is in the regular condenser, and it now appears to me as if I would meet with success in eliminating the oil in this manner.

But even if the oil is not all eliminated in the steam separator, I see no reason why the condensed steam may not be absolutely cleansed of oil by passing the feed water through the filter just referred to by Mr. Wheeler.

Mr. Wheeler.—Mr. Rockwood, do I understand that the oil was separated in each case, and the question was to draft it off?

Mr. Rockwood.—No, sir; it will not separate.

Mr. Wheeler.—Then you mean to say that you do not get the

the furnace where you introduce the gas or the liquid the amount of air should be definitely controlled, and at the other end there should be a free escape; that is, you can control the amount of gas or the amount of liquid you put in under the boiler, and at the same time put in just enough air to give that the proper amount of combustion; that pressure given to the air also furnishes the draught, together with the pull of the chimney, and you should not vary the chimney draught in case you wanted to change the conditions as to the steam evaporated, but you should simply vary the amount of gas or fuel put in, and the amount of air supplied. These should be varied by the cocks or valves at the front of the boiler, and not by the damper at the rear.

Mr. Forrest M. Towl.—I have made a number of experiments with both gas and oil, and I do not believe there is any advantage in damper regulation with gas, if your flues and stack are properly proportioned. Sometimes it is handy to close off a little of your draught to regulate the fire. You can do it at times better than you can by closing off the air in front. I think the same thing applies to liquid fuel, but not to so great an extent. Your burners generally handle the amount of air, oil and gas, or it can be regulated by the men who are handling it, but it is very difficult with either to tell just what is the point when the proper amount of air is going into the furnace. That can hardly be obtained without very careful experiments. I think there would be a difference of 8 or 10 per cent. economy with a properly regulated air supply.

Mr. Kent.—I would suggest that if you want to make a good scientific experiment it should be done with a pyrometer at the bridge wall. The best conditions of combustion are at the times when you obtain maximum temperature. That maximum temperature should be measured by the pyrometer.

Mr. Towl.—I have experimented considerably with oil, and I do not think that the maximum economy is when you obtain the maximum temperature at the bridge wall. I have tested the temperature at the bridge wall. I think a temperature of about 1,500 degrees Fahr. at the bridge wall will give a better economy for boiler purposes than a temperature of 1,800 degrees.

Mr. Kent.—If that is the case, it must be because at the higher temperature there is some other condition introduced—a lack of their engines; this means very careful fitting of valves, etc. It is quite true that as a rule too much oil is used in most steam engines, especially in the auxiliary engines. I know of one case where the exhaust steam from the auxiliaries is allowed to go to waste just because the use of oil is so much greater in these engines than it is in the main engines. There is no doubt but what there is quite a field for improvement in the building of engines adapted to work without oil. When this is accomplished, the surface condenser will be more largely used than it is now; but until that time comes, we must rely on the best feed-water filters we can find.

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Mr. Carleton W. Nason.—The matter, as I understand it, is largely, if not simply and purely, a question of how many heat units can be bought for a dollar or a cent. Assuming, in order to give oil every possible advantage, that coal is as high as $3 per ton of 2,240 pounds, and assuming that with a theoretical heating capacity of 14,000 heat units there are to be 10,000 heat units absorbed under a well-constructed boiler, we then have $\frac{2{,}240 \times 10{,}000}{300} = 74{,}666$ heat units for one cent obtained from coal burned.

With oil (Lima) having a specific gravity of .792 we have $8.355 \times .792 = 6.617$ pounds per gallon, and with an assumed retention under a similar boiler of 17,000 heat units out of a possible 20,000 theoretic, there will be $6.617 \times 17{,}000 = 112{,}489$ heat units absorbed from each gallon.

Then $\frac{112{,}489}{74{,}666} = 1\frac{507}{1000}$ cents as the price per gallon for which oil would have to be bought to compete with coal at $3 per ton.

This estimate does not take into consideration any labor for coal stoking or removal of ashes, and as the labor of feeding oil is largely automatic, one man being quite able to control the supply for a plant of large size, it is very probable that there are many instances on this seaboard where there would be an economy in the use of oil at two cents per gallon.

Professor Hutton.—I was interested, Mr. Chairman, in being be in accord with the practice in the West, not of removing oil from the steam boiler, but of putting oil into it. It is not an uncommon practice there, for the purpose of removing scale from a boiler, to put in a certain quantity of ordinary black fuel oil. It is a very common practice to introduce kerosene drop by drop, through a sight-feed lubricator, for the purpose of removing scale and putting the boilers in better condition. I know that the use of kerosene in boilers has the effect of removing scale and of putting the inner face of the shell in much better condition than it was before, and up to the present, after an experience of probably three or four years, there seems to be no difficulty from the use of kerosene in that way. It sometimes removes the scale about a poorly made joint so that it leaks. But aside from showing up bad workmanship in boilers there is no difficulty whatever.

Mr. Raynal.—I plead guilty to the same crime of putting oil in our boilers now, and my neighbors do the same.

Mr. Wheeler.—Mr. Newcomb's remarks about the quality of oil bring us face to face with the main question, and we will always have trouble so long as owners of steam plants will not buy the best quality.

Mr. W. A. Pearson.—I think that in using the water from surface condensers over again it is impracticable for engineers to do so unless they put a filter in between condensers and boilers. We have settled on a special brand of cylinder oil at Schenectady after testing a number of different brands, and it is giving very good results. All of our materials are bought after being tested, and frequently we get a barrel of oil which does not give good results. We do not test every barrel of oil which is received, and I do not believe that any concern in the country is doing so. If oil is to be used in boilers it should be tested, and I think all will agree that it should be of a very crude nature; purely mineral. I have found that it is impossible to put oil in a boiler to clean it, but what it will find its way out through every joint if used long enough, and have come to the conclusion that it is good policy to keep the boiler as free from oil of all kinds as possible..

Mr. Boyer.—I think when the members speak of using oil in boilers they ought to specify how they use it. Now I have had a deal of experience in that, and I have had good results in running four years on a battery of eight boilers. We have three batteries; we have nineteen boilers altogether. We only tried the experiments on No. 3 battery—a battery of eight boilers. I first put a large oil feeder, the same as a lubricator of an engine, which would hold a gallon and a half of kerosene oil, so that I could feed it drop by drop. I ran about a week or ten days, and was feeding on an average of about two drops a minute, and the result of about ten days' trial was that I lost the lubrication on my engines. I heard the engines commence to give trouble. What to do I did not know. In fact, I did not know what was the cause, but thought the oil was the trouble. I stopped my engines and blew out my boilers; cleaned them out thoroughly, and found that my engines lubricated properly. We started again to use oil by putting a gallon in whenever we have the boiler open, and as the water flows in it raises the oil on its surface and would deposit a little film on the side of the boilers; the result is that the inside sheets of our boilers are just as clean to-day as when they were first used. I have never known a joint, a rivet, or a seam to start; but I would not dare to feed it in drop by drop. I know it would be disastrous. I approve highly of using kerosene oil for keeping boilers free from scale. It has got to be used with a good deal of discretion. It is a good servant, but it is a terrible master.

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PAPERS

OF THE

ST. LOUIS MEETING

(XXXIIId)

MAY 19th TO MAY 22d, 1896.

DCLXXIX.

PROCEEDINGS

OF THE

ST. LOUIS MEETING

(XXXIIId)

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS,

May 19th to May 22d, 1896.

GENERAL COMMITTEE OF LOCAL MEMBERS.

M. L. HOLMAN, Chairman.
WM. H. BRYAN, Secretary.
H. A. WHEELER, Treasurer.

SUB-COMMITTEES:

Finance.

M. L. HOLMAN, Chairman.
E. D. MEIER.
W. B. POTTER.
J. B. CLEMENTS.
G. PANTALEONI.
J. H. KINEALY.

Reception.

E. D. MEIER, Chairman.
J. B. CLEMENTS.
M. L. HOLMAN.
J. A. LAIRD.
FRANK H. POND.
A. SIEBERT.
H. A. WHEELER.
W. H. BRYAN.
EDWARD FLAD.
J. B. JOHNSON.
G. PANTALEONI.
W. B. POTTER.
JAMES P. SNEDDON.
J. H. KINEALY.

Committee on Ladies.

J. B. JOHNSON, Chairman.
J. A. LAIRD.
EDWARD FLAD.
E. D. MEIER.

Committee on Printing.

W. H. BRYAN, Chairman.
NILS JOHNSON.
C. E. JONES.
O. E. OVERPECK.

Committee on Local Information.

Edward Flad, Chairman.
W. H. Bryan.
J. B. Johnson.
C. E. Jones.
J. A. Laird.
G. R. Olshausen.
Frank H. Pond.
A. Thacher.
W. S. Brown.
J. L. Hornig.
Nils Johnson.
Julius Kraus.
E. D. Meier.
G. Pantaleoni.
James P. Sneddon.
S. E. Freeman.

Committee on Excursions.

J. A. Laird, Chairman.
J. L. Hornig.
G. R. Olshausen.
M. L. Holman.
Julius Kraus.
O. E. Overpeck.
W. E. Lindsay.

Committee on Accommodations.

W. B. Potter, Chairman.
J. B. Johnson.
J. B. Clements.
H. A. Wheeler.

Committee on Badges.

H. A. Wheeler, Chairman.
W. S. Brown.
G. Pantaleoni.

Executive Committee.

M. L. Holman, Chairman.
Edward Flad.
J. A. Laird.
W. B. Potter.
W. H. Bryan.
J. B. Johnson.
E. D. Meier.
H. A. Wheeler.

The XXXIIId meeting of the American Society of Mechanical Engineers was convened in the city of St. Louis, Mo., on Tuesday, May 19, 1896. The convention room was the large parlor of the Southern Hotel, on Walnut Street, between Fourth and Broadway, and an adjoining parlor was made into a convenient headquarters, placed in telephonic connection with the city system by the courtesy of the Bell Telephone Company.

The opening session was called to order by Col. E. D. Meier, chairman of the Reception Committee, with a few words of welcome to the city and to the courtesies which it was to extend, to which the President of the Society made brief response. The meeting then resolved itself into an opening reception, at which the hosts and guests were presented to each other, and at the close a collation was served in headquarters.

the Society to hear of a case recently mentioned to me by an engineer in Minnesota. A street-railway company in putting up its plant arranged entirely for burning oil, being quoted a satisfactory price by the Standard Oil Company, and everything went on very happily until one day its agent called upon them and stated that after a certain date the price of oil would be raised quite an appreciable amount. He had not been many minutes outside the office before they got their engineers together and made all the arrangements necessary for putting in a coal-burning plant. This becoming known, within a few days after that the agent again called upon them and stated that the company had reconsidered its decision; and they got their oil at the old price and for all I know are still using it. The moral in that case seemed to be, as the engineer stated, that it was cheaper to use oil when you could afford to maintain a coal-burning plant for exhibition purposes.

PAPERS

OF THE

ST. LOUIS MEETING

(XXXIIId)

MAY 19th TO MAY 22d, 1896.

this Society, requesting this Society to meet in Nashville in May, 1897. Many of you were present in 1888 at the meeting held there, and the people of Nashville have such kindly feelings toward this Society, and remember with so much pleasure that meeting, that they are anxious that the Society should return and give them another chance to show them the improvements which they have made in the past nine years, as it will be then, and to offer them some more Southern hospitality. These invitations having been duly presented to the Society, I would move you, Mr. President, that this matter be referred to the Council for its action.

Mr. William Kent.—Mr. Magruder having just spoken in favor of Nashville as the place of meeting next year, I rise to second the motion, and I wish to say that I have had two experiences of conventions in Nashville before this time—one in 1877, at the meeting of the American Association for the Advancement of Science, and one in 1888, at the meeting of this Society. On both these occasions we found Nashville a most pleasant place at which to meet. The citizens were exceedingly hospitable, the climate was delightful in the month of May, and we have no reason to go anywhere else, I think, than Nashville, when they give a National Exposition in that year; so I second the motion to refer the matter to the Council.

The motion to refer the matter to the Council was carried.

No other business of general character being presented, the professional papers were taken up, as follows:

That by Mr. W. J. Keep, of Detroit, entitled "Strength of Cast Iron," discussed by Messrs. Benjamin, Kent, and Henning.

That by Mr. William Kent, of New York, entitled "The Efficiency of a Steam Boiler; What is It?" discussed by Messrs. Barrus, Meier, Bryan, Rockwood, Cary, Potter, LeVan, Kinealy, and Blood.

That by Mr. A. Eldridge, of Ithaca, on "Tests of a Four Cylinder Triple-Expansion Engine and Boiler," discussed by Messrs. Kent, Suplee, Mansfield, and Laird.

That by Mr. R. S. Hale, on "Determining Moisture in Coal," discussed by Messrs. Bryan, Kinealy, Kent, Suplee, Henning, Cary, and Nason.

In the afternoon the party were the guests of one of the street railway lines for conveyance to the station of the Lindell Railway in Forest Park, of the city, where carriages were in waiting for a drive through that beautiful and artistically planned reservation. The party were set down at The Cottage in the park for a light luncheon, and after being driven to another entrance were met by special cars for the run back to the city.

THIRD SESSION. WEDNESDAY, MAY 20, 8 P.M.

The only paper taken up at this session was that by Mr. H. F. J. Porter, of Chicago, on "Hollow Steel Forgings." Mr. Porter had taken the trouble to reduce the illustrations of his paper to lantern slides, which were projected upon a screen while the descriptive matter was being read. President John Fritz made some explanations and additions at the end of the paper, and the session then adjourned.

FOURTH SESSION. THURSDAY, MAY 21, 10 A.M.

The papers of the morning and the participants in debate were as follows:

That by Prof. W. F. M. Goss, on the "Effect upon Diagrams of Long Pipe Connections for Steam Indicators," discussed by Mr. A. F. Hall.

That by Mr. J. B. Hoffman, entitled a "Hydraulic Dynamometer," discussed by Messrs. Henning, Nason, and Suplee.

That by Mr. C. W. Kettell, discussed by Professor Benjamin.

That by Prof. R. C. Carpenter, on a "New Form of Steam Calorimeter," discussed by Mr. Bryan.

That by Mr. George R. Henderson, entitled "Spring Tables."

Two papers by Mr. Jay M. Whitham, on the "Effect of Retarders in Fire Tubes of Steam Boilers," and upon "Experiments with Automatic Mechanical Stokers." The discussion was participated in by Messrs. Baker, Barrus, Kent, Rockwood, Wallace, Bryan, Herr, Kinealy, and Cary.

That by Mr. William H. Bryan, on "Western River Steamboats," discussed by Messrs. Rockwood, Holman, Kent, and Holloway.

Just previous to adjournment, which took place at this point, the President of the Society, acting under Article 31 of the rules, which calls for the appointment of a committee to nominate officers of the Society, made the following appointments:

George W. Weeks	Clinton, Mass.
H. H. Suplee	Philadelphia, Pa.
W. F. M. Goss	Lafayette, Ind.
W. J. Keep	Detroit, Mich.
J. F. Holloway	Buffalo, N. Y.

In the afternoon the members and the guests of the Local Committee were conveyed by the river steamer *City of Vicksburg* up the Mississippi to a point slightly above the Chain of Rocks Pumping Station of the City Water Works; thence back for a visit to that station, and for a brief sail below the city and back to the landing. Luncheon was served on board, and the hosts had provided an excellent orchestra.

In the evening, in the parlors of the convention hotel, a charming reception with supper was given to the members and their ladies by the citizens of St. Louis, with music and dancing.

FINAL SESSION. FRIDAY, MAY 22, 10 A.M.

The professional papers of the closing session were as follows:

By R. H. Thurston, on "Superheated Steam," discussed by Mr. Rockwood.

By Mr. L. R. Alberger, on "A Self-Cooling Condenser," discussed by Messrs. Emery, Kent, Meier, Bryan, and Goss.

By Prof. F. R. Hutton, entitled "A Classification and Catalogue System for an Engineering Library," discussed by Messrs Blood, Chamberlain, Suplee, and Kent.

By Thomas E. Murray, on "A Steel Plate Fly Wheel," discussed by Messrs. Kent, Henning, Suplee, and Blood.

The "Topical Discussion" and paragraphs of experience were then taken up until the series was exhausted which had been prepared for this meeting. The Secretary explained the slight change which had been made in the method of preparing these Topical Discussions for the meeting, which consisted in getting the proposer of the query to contribute one or two paragraphs to open the subject, with the view that thereby discussion might be more directly and pertinently brought to bear upon the question in hand. The first contribution gave data upon the "Holding Power of Clamp Fits," by Mr. William Sangster, and also by the same gentleman the paragraphs upon the "Power Required to

Second Session. Wednesday, May 20.

The business session was called to order at 10 A.M. The register in headquarters showed the following members in attendance:

Alberger, L. R.,
Barrus, Geo. H.,
Basford, Geo. M.,
Bauer, Chas. A.,
Bissell, G. W.,
Blauvelt, A.,
Blood, J. B.,
Brown, Alex. T.,
Brown, Chas. S.,
Brown, W. S.,
Bryan, Wm. H.,
Buchannan, A. W.,
Cary, A. A.,
Chamberlain, P. M.,
Cheney, W. L.,
Clements, J. B.,
Connell, Jas. A.,
Davis, W. C.,
Flad, Edward,
Foster, C. H.,
Freeman, S. E.,
Fritz, John, *President*,
Gabriel, Wm. A.,
Goss, W. F. M.,
Hagar, Edw. McKim,
Hartness, James,
Haskins, H. S.,
Henning, Gus C.,
Herr, E. M.,
Hoffman, J. D.,
Holloway, J. F.,
Holman, M. L.,
Hoppes, J. J.,
Hornig, J. L.,
Hutton, F. R.,
Johnson, J. B.,
" Nils,
Jones, C. E.,
Keep, W. J.,
Kent, Wm.,
Kinealy, J. H.,
Kirchhoff, Chas.,
Kraus, Julius,
Laforge, F. H.,
Laird, J. A.,
Lane, H. M.,
Low, F. R.,
Magruder, W. T.,
McGill, Chas. F.,
Malvern, L. K.,
Maury, D. H.,
Meier, E. D.,
Mesta, Geo.,
Miller, F. J.,
Mirkil, T. H., Jr.,
Moore, D. G.,
Nason, C. W.,
Olshausen, G. R.,
Overpeck, O. E.,
Pantaleoni, G.,
Parks, E. H.,
Paul, J. W.,
Pell, H. S.,
Pond, F. H.,
Porter, H. F. J.,
Potis, S., Jr.,
Potter, W. B.,
Prosser, J. G.,
Reynolds, I. H.,
Robinson, A. W.,
Rockwood, G. I.,
Rumely, W. N.,
Siebert, A.,
Slater, A. B.,
Slater, H. C.,
Smart, R. A.,
Smith, G. H.,
Sneddon, J. P.,
Stiles, N. C.,
Stone, H. B.,
Street, C. F.,
Suplee, H. H.,
Thacher, Arthur,
Waldo, L.,
Warner, W. R.,
Warner, C. M.,
Warrington, Jesse,
Weeks, G. W.,
Wheeler, H. A.,
Whitehead, Geo. E.,
Whitham, Jay M.,
Wiley, W. H.

A considerable number of St. Louis engineers and technical gentlemen were registered as guests of the Society during its stay, making with the members and their ladies a total of two hundred and thirty-seven.

The first business was the report of the tellers of the Council who canvassed the ballot for members. Their report was as follows:

REPORT OF THE TELLERS OF ELECTION.

The undersigned were appointed a committee of the Council to act as tellers (under Rule 13) to scrutinize and count the ballots cast for and against the candidates proposed for membership in the American Society of Mechanical Engineers, and seeking election before the XXXIIId Meeting, St. Louis, 1896.

They have met upon the designated day, in the office of the Society, and have proceeded to discharge their duty. They would certify, for formal insertion in the records of the Society, to the election of the persons whose names appear on the appended list, to their respective grades.

There were 462 votes cast on the lavender ballot, of which eleven were thrown out because of informalities (the members voting having neglected to indorse the sealed envelope).

JOHN C. KAFER,
F. H. BALL, } *Tellers of Election.*
J. F. HOLLOWAY,

NO. 1 OR LAVENDER BALLOT, 1896.

XXXIIId Meeting, St. Louis, Mo.

MEMBERS.

Alta, Lucas N.,
Aslakson, Baxter,
Bagg, S. F.,
Blauvelt, Albert,
Booth, E. H.,
Brown, Wm. C.,
Fleming, John B.,
Freeman, S. E.,
Gordon, H. D.,
Harding, F. W.,
Jones, Horace K.,
Kinealy, John H.,
Lange, P. A.,
Leverich, Gabriel,
Lufkin, E. C.,
McGill, C. F.,
Nichols, O. F.,
Nourse, Franklin,
Pell, H. S.,
Pratt, Chas. R.,
Rasch, Peter,
Reynolds, I. H.,
Rohrer, A. L.,
Rose, H. M.,
Rowley, H. W.,
Ryan, H. J.,
Sabin, A. H.,
Sargeant, W. D.,
Sawyer, Harry,
Seaman, H. B.,
Smith, J. W.,
Sparrow, E. P.,
Turner, John,
Warner, C. M.,
Wood, J. L.,
Woolson, I. H.

ASSOCIATES.

Campbell, J.,
Carlton, Newcomb,
Coster, E. L.,
Dodd, Daniel,
Ely, S. B.,
Gibbs, L. T.,
Morehouse, Wm. S.,
Scott, S. M.,
Thayer, Winthrop,
Wallace, F. A.,
Weber, George A.,
Williams, Franklin.

PROMOTION TO FULL MEMBERSHIP.

Brill, George M.,
Dawes, Robert,
Hopton, Walter E.,
Merriam, H. P.,
Paul, John W.,
Waldron, Fred A.

JUNIOR MEMBERS.

Bayless, C. T.,
Cutter, G. A.,
Deck, H. S.,
Dollar, Wm. M.,
Eastment, W. H.,
Elmer, Wm., Jr.,
Glanville, J. G.,
Goldsborough, W. E.,
Greene, D. J.,
Johnson, J. E., Jr.,
Johnson, R. DeO.,
Ladd, G. T.,
Lenssen, G. A., Jr.,
Mackintosh, Fred'k,
Messenger, W. H.,
Newton, James D.,
Rennie, Robert,
Straw, Charles A.,
Tenney, A. B.,
Thacher, Arthur,
Van der Willigen, T. A.

The President then called for the usual reports of progress from the Society's committees upon professional subjects. From the Committee on the Consideration of a Revision of the Society Code for Conducting Steam Boiler Trials, the report was:

Mr. Wm. Kent.—We can only report progress. There was one meeting of the committee held in New York some time ago, and there has been a great deal of correspondence carried on among the members. That correspondence is still unfinished, and at present we can only say the work is proceeding as rapidly as possible.

On behalf of the Committee on Standard Methods of Test and Testing Materials, the report was as follows:

Mr. Gus. C. Henning.—I will say on behalf of this committee that we are still working upon the tests which we have planned to settle some uncertain points which have arisen, and that the tension tests of cast-iron have given us so much trouble that we have not been able to complete them. It has taken all the time of an expert investigator with most improved appliances and machines to do even a part of the work, which will indicate to you the difficulties which are to be overcome. If, as we now expect, the experimental work is completed by next October, the committee can thereafter consider and summarize the results and be able to decide whether further work will still be necessary to reach data for a conclusive report. Very few realize how much labor is necessary and has to be expended, both in preparing apparatus and in computations of results, which must be given as the reasons why we have been unable to complete a report for this meeting. At the annual meeting in December we shall hope to bring forward some final conclusions.

General and new business being then in order, the Society was invited to hold its spring convention of 1897 in the city of Nashville, Tenn., as follows:

Prof. W. T. Magruder.—The State of Tennessee was the third State to be admitted into the union of States, and proposes to celebrate its admission to the Union by holding a Centennial Exposition, the inaugural ceremonies of which will be held on June 1st and 2d of this year. The Exposition will be opened on May 1, 1897, and will continue six months. Invitations from the Governor of the State, the Mayor and Common Council of the city of Nashville, and the Engineering Association of the South, of which I am a member, have been presented to the Council of this Society, requesting this Society to meet in Nashville in May, 1897. Many of you were present in 1888 at the meeting held there, and the people of Nashville have such kindly feelings toward this Society, and remember with so much pleasure that meeting, that they are anxious that the Society should return and give them another chance to show them the improvements which they have made in the past nine years, as it will be then, and to offer them some more Southern hospitality. These invitations having been duly presented to the Society, I would move you, Mr. President, that this matter be referred to the Council for its action.

Mr. William Kent.—Mr. Magruder having just spoken in favor of Nashville as the place of meeting next year, I rise to second the motion, and I wish to say that I have had two experiences of conventions in Nashville before this time—one in 1877, at the meeting of the American Association for the Advancement of Science, and one in 1888, at the meeting of this Society. On both these occasions we found Nashville a most pleasant place at which to meet. The citizens were exceedingly hospitable, the climate was delightful in the month of May, and we have no reason to go anywhere else, I think, than Nashville, when they give a National Exposition in that year; so I second the motion to refer the matter to the Council.

The motion to refer the matter to the Council was carried.

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FOURTH SESSION. THURSDAY, MAY 21, 10 A.M.

The papers of the morning and the participants in debate were as follows:

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That by Mr. J. B. Hoffman, entitled a "Hydraulic Dynamometer," discussed by Messrs. Henning, Nason, and Suplee.

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That by Prof. R. C. Carpenter, on a "New Form of Steam Calorimeter," discussed by Mr. Bryan.

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Two papers by Mr. Jay M. Whitham, on the "Effect of Retarders in Fire Tubes of Steam Boilers," and upon "Experiments with Automatic Mechanical Stokers." The discussion was participated in by Messrs. Baker, Barrus, Kent, Rockwood, Wallace, Bryan, Herr, Kinealy, and Cary.

That by Mr. William H. Bryan, on "Western River Steamboats," discussed by Messrs. Rockwood, Holman, Kent, and Holloway.

Just previous to adjournment, which took place at this point, the President of the Society, acting under Article 31 of the rules, in Washington I have received a number of copies of the literature on the subject, the bill itself, and discussions by certain prominent engineers. I have laid those copies out in the anteroom where any member may get them. I trust you will avail yourselves of them, and after reading them will do what you think is right in the matter, in the way of writing to those representatives in Congress who have something to say in the matter, so as to urge them to pass the bill. I think that your unanimous conclusion will be that that bill should be passed. Sometimes effects grow up from small causes entirely different from what had been intended; so that I will not lay the status of the naval engineer to-day to any particular cause, but the effect is there all the same, and that effect may be summed up in very few words by saying that the legal status of the engineer in the navy to-day is an insult to the profession. (Applause.)

Mr. J. F. Holloway.—I desire to add only a few words to what Colonel Meier has so well said. As stated by him, this is a matter which cannot be fully discussed in the limited time now at our disposal. There is, however, something which every member of this Society can do, which will be far more effective than simply talking, and that is, he should as far as possible inform himself in regard to the rank and position which his brother engineers now have in the navy of the United States. Upon investigation, it will be found that naval engineers hold to-day the same position as to rank and authority while in charge of these magnificent battle ships, of which we are all so proud, as they did in those early days when a little bit of a screw propeller was first put in the hull of a brig or schooner, thus transforming it into a "man-of-war." We all know that the modern naval vessel is a mechanical fighting machine from stem to stern post; that it is filled with the most powerful, costly, and intricate mechanism that can anywhere be found within the same space; and if there is any place in the wide world where an engineer is anything of a fellow it is on board of a modern battle ship; and if there is any position which requires the highest mechanical skill, the greatest courage, and the best executive ability it is the position held by the engineer-in-chief of such a complicated machine as is a modern man-of-war, and it is a slight upon the profession of engineering, and a disgrace to our country, that the men who have charge of and are responsible for this mass of fighting mechanism do not have a more important position and a higher

Drive Disk Fans." This latter was discussed by Messrs. Kent and Kinealy.

The paragraphs upon the "Effect of Fire on Machinery," by Prof. W. F. M. Goss, were discussed by Messrs. Suplee, Warner, and Fritz.

The discussion by Mr. John H. Cooper, on the "Advisability of Locating the Condenser of a Steam Engine Close to the Cylinder or at a Distance from it," was continued by Messrs. Rockwood and Kent.

A letter of invitation was read from Mr. Frederick M. Crunden, extending to the Society the privileges of the Public Library of St. Louis, and a paper by Mr. James Dredge, of London, honorary member of the Society, concerning the early history of the Bessemer steel process, was read by title, in order to make its presentation a matter of record.

This being the assigned time for general business, Mr. Blood presented the resolution to which he had referred in his discussion on the paper on an Engineering Classification, and moved that it be referred to the Council of this Society to appoint a committee of five to take up the matter of systematic classification of engineering literature and material, either as a matter of the American Society of Mechanical Engineers alone, or, better still, in conjunction with conference committees appointed by the societies representing other departments of engineering. This motion, being duly seconded by Mr. Alberger, was voted and carried.

Mr. Holloway then presented the following preamble and resolutions, which were seconded by Mr. Henning and unanimously adopted:

Whereas, The American Society of Mechanical Engineers, assembled in convention at St. Louis, in May, 1896, has a pleasant remembrance of a delightful meeting of the Society held in Montreal in 1894, and of the hospitality there shown by its most prominent citizens: they remember especially the courtesies extended to them by the Trustees and Governors of McGill University in opening up that famed institution for inspection, and in furnishing the commodious hall therein in which to hold the meeting;

And whereas, It has come to the knowledge of the Society that McGill University has recently been further enriched by extremely liberal gifts from two of its generous patrons—Mr. W. C. McDonald and Sir Donald A. Smith (both of whom conferred special favors and kind attention upon the Society while in Montreal)—which gifts are for the further upbuilding of a splendid institution of learning in which the science and art of engineering hold an important place;

Therefore be it Resolved, That the congratulations of the American Society of

Mechanical Engineers be and are hereby tendered to McGill University upon the continuance of that good fortune which has so marked its history. Our appreciation of the generosity of the gentlemen named is largely due to the fact that by this and former donations they have expressed the high regard which they feel for engineering as a profession, and because they recognize its value as a means to extend the limits of civilization, to confer comforts and benefits upon all, and because they recognize the prominent part which it has in making of one blood all the nations of the earth.

In seconding the resolutions Mr. Henning said: "You will all remember the pleasant surprise that was awaiting us when we visited the engineering schools and laboratories of McGill University, and the delightful manner in which the Society was received by the faculty on the occasion of our spring meeting at Montreal two years ago. It can but please us to hear of the repeated good luck which has befallen McGill University, as such gifts are a benefit to all engineers on this continent. Prof. H. T. Bovey, when in New York two weeks ago, told me that these very liberal gifts were to be devoted mainly to the Engineering Department, and as everything improving the condition of our Canadian confrères helps us as well, I most heartily second the motion just offered."

On motion it was agreed that this resolution be suitably engrossed and forwarded by the Secretary to the authorities of McGill University.

The following series of resolutions of thanks were then passed by the Society in recognition of the courtesies which the members had enjoyed at the hands of the local Committee of Arrangements and those whom they had enlisted for their help. The resolutions were passed with enthusiasm.

To Mr. George W. Baumhoff, General Manager Lindell Railway, the thanks of the Society are due for the courtesies extended on Wednesday afternoon in the excursion by electric railway to and from Forest Park, by means of which the visiting members obtained, in the most pleasant manner possible, an idea of the prosperity and beauty of St. Louis, the Future Great.

Through the kindness of Capt. Robert McCulloch, General Manager of the Southwestern Railway, the members of our Society are given free transportation for the excursion planned for us this afternoon. *Resolved*, That the American Society of Mechanical Engineers manifest its appreciation of this kind hospitality by a vote of thanks to Captain McCulloch.

Resolved, That the hearty thanks of this Society be rendered to the Engineering Club of St. Louis, and especially to its honored president, Mr. G. A. Ockerson, for the courtesies extended through the use of its comfortable house and valuable library.

Resolved, That the thanks of the Society be given to the Cupples Real Estate Company and the Imperial Building Company for the invitation kindly extended by them to visit their unique and interesting buildings.

Resolved, That the thanks of the Society be extended to the managers of the St. Louis Public Library for the privilege of the use of the library.

Resolved, That the thanks of the Society be sent to the Bell Telephone Company for the use of the instrument in headquarters.

Whereas, The Broderick-Bascom Wire Rope Company have tendered the American Society of Mechanical Engineers cordial invitations to visit their works, to give the members more opportunity of studying wire-rope making, and have also presented each member with a handsomely mounted piece of wire rope to be used as a paper-weight;

Therefore, be it Resolved, That a vote of thanks be tendered the Broderick-Bascom Wire Rope Company.

Whereas, The Christy Fire-Clay Company have tendered the American Society of Mechanical Engineers cordial invitations to visit their plant, and have also prepared a souvenir showing the fine quality, grain, and uniformity of their product;

Therefore, be it Resolved, That a vote of thanks be tendered the Christy Fire-Clay Company.

Whereas, The A. S. Aloe Company have extended to the American Society of Mechanical Engineers a cordial invitation to visit their extensive stock of engineers' supplies, and have furthermore presented a very useful souvenir in the shape of a nicely divided boxwood scale;

Therefore, be it Resolved, That a vote of thanks be tendered the A. S. Aloe Company for their invitation and valuable souvenir.

Resolved, That the members of the American Society of Mechanical Engineers in the St. Louis Convention assembled, hereby express their sense of obligation to the St. Louis Brewing Association and to the Anheuser-Busch Brewing Company for the kind and freely given invitations to visit their famous and well-appointed breweries; and

Resolved, That a copy of these resolutions be sent to the St. Louis Brewing Association and to the Anheuser-Busch Brewing Company.

The visiting members of the American Society of Mechanical Engineers desire to pay a tribute of thanks to the members of the Local Committee, the Reception Committee, and to the chairmen of the sub-committees for the effective and graceful manner in which they have performed their various duties, and to express their pleasure at the cordiality which has marked their efforts in our behalf. St. Louis will be remembered with gratitude, and should any of our hosts honor us by a visit to the East we will give them a welcome which may lack the warmth as to temperature of the St. Louis welcome, but will not be lacking in fervor and hearty welcome to those who have done so much, and so successfully, to add to our pleasure and comfort.

The mover of this final resolution would seek on behalf of the visiting ladies to convey to the ladies of St. Louis the hearty thanks which the former are not present to offer for themselves, for the assiduity which their hostesses have shown in attending upon them during their pleasant stay in this city, and would ask that the relatives and friends of the St. Louis ladies will make themselves

THICKNESS OF STEEL, $\frac{1}{16}$ INCH.

L	f		Values of P for Varying Values of nb.								
	Half.	Full.	1	2	3	4	5	6	7	8	9
3	.09	.19	69.4	139.0	208.0	278.0	347.9	416.0	486.0	555.0	625
4	.16	.34	52.0	104.0	156.0	208.0	260.0	312.0	364.0	416.0	468
5	.25	.53	41.7	83.4	125.0	167.0	209.0	250.0	292.0	334.0	375
6	.35	.77	34.7	69.4	104.0	139.0	174.0	208.0	243.0	278.0	312
7	.48	1.04	29.8	59.6	89.4	119.0	149.0	179.0	209.0	238.0	268
8	.63	1.36	26.0	52.0	78.0	104.0	130.0	156.0	182.0	208.0	234
9	.80	1.73	23.1	46.2	69.3	92.4	116.0	139.0	162.0	185.0	208
10	.98	2.13	20.8	41.6	62.4	83.2	104.0	125.0	146.0	166.0	187
11	1.19	2.58	18.9	37.8	56.7	75.6	94.5	113.0	132.0	151.0	170
12	1.42	3.07	17.4	34.8	52.2	69.6	87.0	104.0	122.0	139.0	157
13	1.66	3.60	16.0	32.0	48.0	64.0	80.0	96.0	112.0	128.0	144
14	1.92	4.17	14.9	29.8	44.7	59.6	74.5	89.4	104.0	119.0	134
15	2.21	4.79	13.9	27.8	41.7	55.6	69.5	83.4	97.3	111.0	125
16	2.52	5.45	13.0	26.0	39.0	52.0	65.0	78.0	91.0	104.0	117
17	2.83	6.16	12.2	24.4	36.6	48.8	61.0	73.2	85.4	97.6	110
18	3.18	6.90	11.6	23.2	34.8	46.4	58.0	69.6	81.2	92.8	104

THICKNESS OF STEEL, $\frac{1}{8}$ INCH.

L	f		Values of P for Varying Values of nb.								
	Half.	Full.	1	2	3	4	5	6	7	8	9
5	.12	.27	167.0	334.0	501	668	835	1,002	1,169	1.336	1,503
6	.18	.39	139.0	278.0	417	556	695	834	973	1.112	1,251
7	.24	.52	119.0	238.0	357	476	595	714	833	952	1,071
8	.31	.68	104.0	208.0	312	416	520	624	728	832	936
9	.40	.87	92.5	185.0	278	370	463	555	648	740	833
10	.49	1.06	83.3	167.0	250	333	417	500	583	666	750
11	.59	1.29	75.8	152.0	227	303	379	455	531	606	682
12	.70	1.54	69.5	139.0	209	278	348	417	487	556	626
13	.83	1.80	64.2	128.0	193	257	321	385	449	514	578
14	.96	2.10	59.6	119.0	179	238	298	358	417	477	536
15	1.10	2.40	55.6	111.0	167	222	278	334	389	445	500
16	1.25	2.73	52.2	104.0	157	209	261	313	365	418	470
17	1.41	3.08	49.1	98.2	147	196	246	295	344	393	442
18	1.59	3.46	46.4	92.8	139	186	232	278	325	371	418
19	1.77	3.85	43.9	87.8	132	176	220	263	307	351	395
20	1.96	4.26	41.6	83.2	125	166	208	250	291	333	374

it has been deemed proper and wise to call your attention as citizens and engineers to the bills now before Congress known as the "Wilson-Squire Bills," Senate No. 785, House of Representatives No. 3618. These have for their object and aim a revision of the rules and regulations of the navy as they effect the authority and status of the engineers: first, by an increase of the number of the corps, which shall be in proportion to the increase of naval vessels; second, the admission of graduates from civilian engineering schools to the corps; third, the establishment of an engineering experimental station; and finally, the transfer to the Engineer Corps of certain engineering duties now in other hands.

As is doubtless known to you, there have been no important changes in these rules as they relate to engineers since the time when steam was introduced into the navy as a mere auxiliary or an aid to the sail. It is scarcely necessary to remind members of our profession of the great difference which exists between the naval vessels of to-day as compared with those of the time referred to, nor to explain how in so many ways the duties, cares, and responsibilities of those who are in charge of the immense and complicated machines which fill them, have been enlarged, increased, and intensified.

It would be unpatriotic and unwise for any one to foster or encourage differences among naval officers which simply refer to precedence and rank, irrespective of responsibilities. It is, however, in the opinion of your Council, not only proper but the duty of every one, and especially so of the engineers of our country, by all proper means to bring their individual influence to bear upon those whose province it is to make the laws of the land, urging them so to amend the rules and regulations of the navy that they shall conform to existing conditions, and shall accord to the Engineer Corps a rank and a position which will correspond with the responsibilities now resting upon them, due to the great changes which have taken place in the construction and equipment of our new navy. Should the matter thus briefly referred to commend itself to your good judgment, you can greatly aid in bringing about this desired result by at once addressing a letter to the senator from your state, and the representative from your district, requesting their aid in passing the bills above refered to. In so doing you will not only confer a benefit upon our brother engineers in the navy, but you will contribute in bringing the profession of engineering into greater prominence the world over.

As this bill is likely to be called up at any time, prompt action only will be of service.

On behalf of the Council,

F. R. HUTTON, *Secretary*. JOHN FRITZ, *President*.

In connection with this action the following remarks were made:

Col. E. D. Meier.—I want to call attention to the foregoing—a matter on which the Council took action in New York about three or four weeks ago. It refers to the status of the naval engineer, and the bill known as the Squire bill now pending in the Senate; it is called the Wilson-Squire bill. There is nothing I could say in so short a time, because if I were to commence to explain the bill and the evils which it intends to correct I would have to keep you here unduly. But through the courtesy of one of my friends in Washington I have received a number of copies of the literature on the subject, the bill itself, and discussions by certain prominent engineers. I have laid those copies out in the anteroom where any member may get them. I trust you will avail yourselves of them, and after reading them will do what you think is right in the matter, in the way of writing to those representatives in Congress who have something to say in the matter, so as to urge them to pass the bill. I think that your unanimous conclusion will be that that bill should be passed. Sometimes effects grow up from small causes entirely different from what had been intended; so that I will not lay the status of the naval engineer to-day to any particular cause, but the effect is there all the same, and that effect may be summed up in very few words by saying that the legal status of the engineer in the navy to-day is an insult to the profession. (Applause.)

Mr. J. F. Holloway.—I desire to add only a few words to what Colonel Meier has so well said. As stated by him, this is a matter which cannot be fully discussed in the limited time now at our disposal. There is, however, something which every member of this Society can do, which will be far more effective than simply talking, and that is, he should as far as possible inform himself in regard to the rank and position which his brother engineers now have in the navy of the United States. Upon investigation, it will be found that naval engineers hold to-day the same position as to rank and authority while in charge of these magnificent battle ships, of which we are all so proud, as they did in those early days when a little bit of a screw propeller was first put in the hull of a brig or schooner, thus transforming it into a "man-of-war." We all know that the modern naval vessel is a mechanical fighting machine from stem to stern post; that it is filled with the most powerful, costly, and intricate mechanism that can anywhere be found within the same space; and if there is any place in the wide world where an engineer is anything of a fellow it is on board of a modern battle ship; and if there is any position which requires the highest mechanical skill, the greatest courage, and the best executive ability it is the position held by the engineer-in-chief of such a complicated machine as is a modern man-of-war, and it is a slight upon the profession of engineering, and a disgrace to our country, that the men who have charge of and are responsible for this mass of fighting mechanism do not have a more important position and a higher

THICKNESS OF STEEL, $\frac{7}{16}$ INCH.

L	f		Values of P for Varying Values of nb.								
	Half.	Full.	1	2	3	4	5	6	7	8	9
24	.81	1.76	426	852	1,278	1,704	2,130	2,556	2,982	3,408	3,834
26	.95	2.06	393	786	1,179	1,572	1,965	2,358	2,751	3,144	3,537
28	1.10	2.38	365	730	1,095	1,460	1,825	2,190	2,555	2,920	3,285
30	1.26	2.74	341	682	1,023	1,364	1,705	2,046	2,387	2,728	3,069
32	1.43	3.12	319	638	957	1,276	1,595	1,914	2,233	2,552	2,871
34	1.62	3.52	301	602	903	1,204	1,505	1,806	2,107	2,408	2,709
36	1.81	3.95	284	568	852	1,136	1,420	1,704	1,988	2,272	2,556
38	2.03	4.40	269	538	807	1,076	1,345	1,614	1,883	2,152	2,421
40	2.24	4.88	255	510	765	1,020	1,275	1,530	1,785	2,040	2,295
42	2.47	5.37	243	486	729	972	1,215	1,458	1,701	1,944	2,187
44	2.71	5.90	232	464	696	928	1,160	1,392	1,624	1,856	2,088
46	2.96	6.45	222	444	666	888	1,110	1,332	1,554	1,776	1,998
48	3.22	7.00	213	426	639	852	1,065	1,278	1,491	1,704	1,917
50	3.49	7.60	204	408	612	816	1,020	1,224	1,428	1,632	1,836
52	3.78	8.25	197	394	591	788	985	1,182	1,379	1,576	1,773
54	4.08	8.90	189	378	567	756	945	1,134	1,323	1,512	1,701

THICKNESS OF STEEL, $\frac{1}{2}$ INCH.

L	f		Values of P for Varying Values of nb.								
	Half.	Full.	1	2	3	4	5	6	7	8	9
30	1.10	2.40	444	888	1,332	1,776	2,220	2,664	3,108	3,552	3,996
32	1.25	2.72	416	832	1,248	1,664	2,080	2,496	2,912	3,328	3,744
34	1.41	3.07	392	784	1,176	1,568	1,960	2,352	2,744	3,136	3,528
36	1.58	3.45	372	744	1,116	1,488	1,860	2,232	2,604	2,976	3,348
38	1.76	3.84	350	700	1,050	1,400	1,750	2,100	2,450	2,800	3,150
40	1.95	4.25	333	666	999	1,332	1,665	1,998	2,331	2,664	2,997
42	2.16	4.68	317	634	951	1,268	1,585	1,902	2,219	2,536	2,853
44	2.37	5.15	303	606	909	1,212	1,515	1,818	2,121	2,424	2,727
46	2.58	5.62	290	580	870	1,160	1,450	1,740	2,030	2,320	2,610
48	2.82	6.13	277	554	831	1,108	1,385	1.662	1,939	2,216	2,493
50	3.06	6.65	266	532	798	1,064	1,330	596	1,862	2,128	2,394
52	3.30	7.19	256	512	768	1,024	1,280	1,536	1,792	2,048	2,304
54	3.57	7.75	247	494	741	988	1.235	1,482	1,729	1,976	2,223
56	3.88	8.35	238	476	714	952	1,190	1 428	1,666	1,904	2,142
58	4.12	8.95	230	460	690	920	1,150	,380	1,610	1,840	2,070
60	4.40	9.58	222	444	666	888	1,110	1,332	1,554	1,776	1,998

HELICAL SPRING TABLES.

The following tables are intended to give the "solid load" and the ratio of "free height" to "solid height" for all practical varieties of helical springs. Springs designed by these tables will come solid at a fibre strain of 80,000 pounds per square inch (torsional) in the bar, equivalent to 100,000 pounds direct strain. (In practice the solid load will generally be from 5 to 15 per cent. greater than the stated values, which are deduced theoretically, and are based on a maximum strain of 80,000 pounds.) The most generally preferred ratio for size is: $D = 5d$ where D = outside diameter of coil.

The free height for any solid height can be found by simple addition, using the values under the nine digits; thus free height of spring of $\frac{11}{16}$-inch steel, 4 inches outside diameter and 12 inches high, solid, =

Value under 1 (point moved to right)........................	14.6
" " 2..	2.93
Free height..	17.53

It is customary to make the static load about one-half the solid load.

The following formulæ were used in constructing the tables:

P = Load when spring is down solid, in pounds.
S = Maximum shearing fibre strain in bar, taken at 80,000 pounds.
d = Diameter of steel in inches.
R = Radius of centre of coil in inches.
l = Length of bar before coiling, in inches.
G = Modulus of shearing elasticity, taken at 12,600,000.
f = Deflection of spring under load in inches.
H = Height of spring free in inches.
h = Height of spring solid in inches.
π = 3.1416.

Then:

$$P = \frac{S\pi d^3}{16R}; \; f = \frac{32PR^2l}{G\pi d^4}; \; h = \frac{ld}{2\pi R} \text{ and } H = h + f.$$

Eliminating and reducing, we have $f = \frac{4S\pi R^2h}{Gd^2}$, and substituting the proper constants, $f = .08\frac{R^2h}{d^2}$, and $H = h\left(1 + .08\frac{R^2}{d^2}\right)$; also, $P = 15{,}714\frac{d^3}{R}$.

DIAMETER OF STEEL, $\frac{1}{16}$ INCH.

D	R	P	VALUES OF H FOR VARYING VALUES OF h.								
			1	2	3	4	5	6	7	8	9
$\frac{1}{4}$	.094	41.00	1.18	2.36	3.54	4.72	5.89	7.08	8.25	9.44	10.62
$\frac{5}{16}$	.125	30.70	1.32	2.64	3.96	5.28	6.60	7.92	9.24	10.58	11.90
$\frac{3}{8}$	.156	24.55	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50
$\frac{7}{16}$	.188	20.30	1.72	3.44	5.16	6.78	8.60	10.32	12.04	13.76	15.48
$\frac{1}{2}$	.219	17.55	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82
$\frac{9}{16}$	.250	15.35	2.28	4.56	6.84	9.12	11.40	13.68	15.96	18.24	20.52
$\frac{5}{8}$	.281	13.65	2.62	5.24	7.86	10.48	13.10	15.72	18.34	20.96	23.58
$\frac{11}{16}$	.313	12.30	3.00	6.00	9.00	12.00	15.00	18.00	21.00	24.00	27.00
$\frac{3}{4}$	.344	11.20	3.42	6.84	10.26	13.68	17.10	20.52	23.94	27.36	30.68
$\frac{13}{16}$	.375	10.20	3.88	7.76	11.64	15.52	19.40	23.28	27.16	31.04	34.92
$\frac{7}{8}$	.406	9.45	4.38	8.76	13.14	17.52	21.90	26.28	30.66	35.04	39.42
$\frac{15}{16}$	.438	8.75	4.91	9.82	14.73	19.64	24.55	29.46	34.37	39.28	44.19
1	.469	8.15	5.50	11.00	16.50	22.00	27.50	33.00	38.50	44.00	49.50

DIAMETER OF STEEL, $\frac{1}{8}$ INCH.

D	R	P	VALUES OF H FOR VARYING VALUES OF h.								
			1	2	3	4	5	6	7	8	9
$\frac{1}{2}$	.188	164.0	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
$\frac{9}{16}$	.219	140.5	1.25	2.49	3.74	4.98	6.24	7.48	8.73	9.97	11.22
$\frac{5}{8}$	.250	123.0	1.32	2.64	3.96	5.28	6.69	7.92	9.24	10.56	11.88
$\frac{11}{16}$	.281	109.5	1.41	2.81	4.22	5.62	7.03	8.48	9.84	11.24	12.65
$\frac{3}{4}$	.313	98.5	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50
$\frac{13}{16}$	.344	89.5	1.61	3.21	4.82	6.42	8.03	9.63	11.24	12.84	14.45
$\frac{7}{8}$	.375	82.0	1.72	3.44	5.16	6.88	8.60	10.32	12.04	13.76	15.48
$\frac{15}{16}$	.406	75.5	1.85	3.69	5.54	7.38	9.24	11.08	12.93	14.77	16.63
1	.438	70.0	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82
$1\frac{1}{16}$	.469	65.5	2.12	4.24	6.36	8.48	10.60	12.72	14.84	16.96	19.08
$1\frac{1}{8}$	.500	61.5	2.28	4.56	6.84	9.12	11.40	13.68	15.96	18.24	20.52
$1\frac{3}{16}$	.531	58.0	2.45	4.90	7.35	9.80	12.25	14.70	17.15	19.60	22.05
$1\frac{1}{4}$	.563	54.5	2.62	5.24	7.86	10.48	13.10	15.72	18.34	20.96	23.58

DIAMETER OF STEEL, $\frac{3}{16}$ INCH.

D	R	P	VALUES OF H FOR VARYING VALUES OF h.								
			1	2	3	4	5	6	7	8	9
$\frac{3}{4}$	.281	368	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
$\frac{13}{16}$	.313	332	1.22	2.45	3.67	4.89	6.12	7.34	8.56	9.78	10.91
$\frac{7}{8}$	.344	302	1.27	2.54	3.80	5.07	6.34	7.61	8.88	10.14	11.41
$\frac{15}{16}$	.375	276	1.32	2.64	3.96	5.28	6.69	7.92	9.24	10.56	11.88
1	.406	255	1.38	2.75	4.13	5.50	6.88	8.25	9.63	11.00	12.38
$1\frac{1}{16}$	.438	237	1.44	2.87	4.31	5.74	7.18	8.61	10.05	11.48	12.92
$1\frac{1}{8}$	.469	221	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50
$1\frac{3}{16}$	.500	207	1.57	3.14	4.71	6.28	7.85	9.42	10.99	12.56	14.13
$1\frac{1}{4}$	.531	195	1.64	3.28	4.92	6.56	8.20	9.84	11.48	13.12	14.76
$1\frac{5}{16}$	.563	184	1.72	3.44	5.16	6.88	8.60	10.32	12.04	13.76	15.48
$1\frac{3}{8}$	.594	175	1.80	3.60	5.40	7.20	9.00	10.80	12.60	14.40	16.20
$1\frac{7}{16}$	.625	166	1.89	3.78	5.67	7.56	9.45	11.34	13.23	15.12	17.00
$1\frac{1}{2}$	.656	158	1.98	3.96	5.94	7.92	9.90	11.86	13.86	15.84	17.82

DIAMETER OF STEEL, $\frac{1}{4}$ INCH.

D	R	P	VALUES OF H FOR VARYING VALUES OF h.								
			1	2	3	4	5	6	7	8	9
1	.375	656	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
$1\frac{1}{16}$	.406	605	1.21	2.42	3.63	4.84	6.05	7.26	8.47	9.68	10.89
$1\frac{1}{8}$	.438	562	1.25	2.49	3.74	4.98	6.23	7.47	8.72	9.96	11.21
$1\frac{3}{16}$	.469	525	1.28	2.56	3.84	5.12	6.40	7.68	8.96	10.24	11.52
$1\frac{1}{4}$	.500	490	1.32	2.64	3.96	5.28	6.69	7.92	9.24	10.56	11.88
$1\frac{5}{16}$	.531	463	1.36	2.72	4.08	5.44	6.80	8.16	9.52	10.88	12.24
$1\frac{3}{8}$	.563	437	1.41	2.81	4.22	5.62	7.03	8.43	9.84	11.24	12.65
$1\frac{7}{16}$	.594	414	1.45	2.90	4.35	5.80	7.25	8.70	10.15	11.60	13.05
$1\frac{1}{2}$	.625	394	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50
$1\frac{5}{8}$	.688	358	1.61	3.21	4.82	6.42	8.03	9.63	11.24	12.84	14.45
$1\frac{3}{4}$	.750	328	1.72	3.44	5.16	6.88	8.60	10.32	12.04	13.76	15.48
$1\frac{7}{8}$	.813	302	1.85	3.69	5.54	7.38	9.23	11.07	12.92	14.76	16.61
2	.875	281	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

Diameter of Steel, $\frac{5}{16}$ Inch.

D	R	P	Values of H for Varying Values of h.								
			1	2	3	4	5	6	7	8	9
1¼	.469	1,020	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
1⅜	.531	903	1.23	2.46	3.69	4.92	6.15	7.38	8.61	9.84	11.07
1½	.594	810	1.29	2.58	3.87	5.16	6.45	7.74	9.03	10.32	11.61
1⅝	.656	730	1.35	2.70	4.05	5.40	6.75	8.12	9.48	10.83	12.19
1¾	.719	668	1.42	2.85	4.27	5.70	7.12	8.54	9.97	11.39	12.82
1⅞	.781	614	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50
2	.844	570	1.59	3.17	4.76	6.34	7.93	9.51	11.10	12.68	14.27
2⅛	.906	530	1.68	3.36	5.03	6.71	8.39	10.07	11.75	13.32	15.00
2¼	.969	495	1.77	3.54	5.32	7.09	8.86	10.63	12.40	14.18	15.95
2⅜	1.031	465	1.87	3.74	5.61	7.48	9.35	11.22	13.09	14.96	16.83
2½	1.093	439	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82
2⅝	1.156	415	2.11	4.22	6.33	8.44	10.55	12.66	14.77	16.88	18.99
2¾	1.218	394	2.22	4.44	6.66	8.88	11.10	13.32	15.54	17.76	19.98

Diameter of Steel, ⅜ Inch.

D	R	P	Values of H for Varying Values of h.								
			1	2	3	4	5	6	7	8	9
1½	.563	1,470	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
1⅝	.625	1,330	1.22	2.44	3.67	4.89	6.11	7.33	8.55	9.78	11.00
1¾	.688	1,210	1.27	2.54	3.80	5.07	6.34	7.61	8.88	10.14	11.41
1⅞	.750	1,100	1.32	2.64	3.96	5.28	6.69	7.92	9.24	10.56	11.88
2	.813	1,020	1.38	2.75	4.13	5.50	6.88	8.25	9.63	11.00	12.38
2⅛	.875	948	1.44	2.87	4.31	5.74	7.18	8.61	10.05	11.48	12.92
2¼	.938	883	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50
2⅜	1.000	830	1.57	3.14	4.71	6.28	7.85	9.42	10.99	12.56	14.13
2½	1.062	780	1.64	3.28	4.92	6.56	8.20	9.84	11.48	13.12	14.76
2⅝	1.125	736	1.72	3.44	5.16	6.88	8.60	10.32	12.04	13.76	15.48
2¾	1.187	698	1.80	3.60	5.40	7.20	9.00	10.80	12.60	14.40	16.20
2⅞	1.250	653	1.89	3.78	5.67	7.56	9.45	11.34	13.23	15.12	17.00
3	1.312	631	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

DIAMETER OF STEEL, $\frac{7}{16}$ INCH.

D	*R*	*P*	VALUES OF *H* FOR VARYING VALUES OF *h*.								
			1	2	3	4	5	6	7	8	9
1¾	.656	2,000	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
1⅞	.719	1,830	1.22	2.43	3.65	4.86	6.08	7.29	8.51	9.72	10.94
2	.781	1,680	1.26	2.51	3.77	5.02	6.28	7.53	8.79	10.04	11.30
2⅛	.844	1,560	1.30	2.60	3.89	5.19	6.49	7.79	9.09	10.38	11.68
2¼	.906	1,450	1.35	2.69	4.04	5.38	6.73	8.07	9.42	10.76	12.11
2⅜	.969	1,360	1.39	2.78	4.18	5.57	6.96	8.35	9.74	11.14	12.53
2½	1.031	1,270	1.44	2.89	4.33	5.77	7.22	8.66	10.10	11.54	12.99
2⅝	1.093	1,200	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50
2¾	1.156	1,140	1.56	3.11	4.67	6.22	7.78	9.34	10.89	12.45	14.00
2⅞	1.218	1,080	1.62	3.24	4.85	6.47	8.09	9.71	11.33	12.94	14.56
3	1.281	1,030	1.68	3.37	5.05	6.74	8.42	10.10	11.79	13.47	15.16
3¼	1.406	935	1.83	3.65	5.48	7.30	9.13	10.95	12.78	14.60	16.43
3½	1.531	858	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

DIAMETER OF STEEL, ½ INCH.

D	*R*	*P*	VALUES OF *H* FOR VARYING VALUES OF *h*.								
			1	2	3	4	5	6	7	8	9
2	.750	2,600	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
2⅛	.813	2,400	1.21	2.42	3.63	4.84	6.05	7.26	8.47	9.68	10.89
2¼	.875	2,250	1.25	2.49	3.74	4.98	6.24	7.48	8.72	9.97	11.21
2⅜	.938	2,100	1.28	2.56	3.85	5.13	6.41	7.69	8.97	10.26	11.54
2½	1.000	1,970	1.32	2.64	3.96	5.28	6.69	7.92	9.24	10.56	11.88
2⅝	1.062	1,850	1.36	2.72	4.08	5.44	6.80	8.16	9.52	10.99	12.24
2¾	1.125	1,750	1.41	2.81	4.22	5.62	7.03	8.43	9.84	11.24	12.65
2⅞	1.187	1,660	1.45	2.90	4.35	5.80	7.25	8.70	10.15	11.60	13.05
3	1.250	1,580	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50
3¼	1.375	1,430	1.61	3.21	4.82	6.42	8.03	9.63	11.24	12.84	14.45
3½	1.500	1,310	1.72	3.44	5.16	6.88	8.60	10.32	12.04	13.76	15.48
3¾	1.625	1,210	1.85	3.69	5.54	7.38	9.23	11.07	12.92	14.76	16.61
4	1.750	1,130	1.98	3.96	5.94	7.92	9 90	11.88	13.86	15.84	17.82

DIAMETER OF STEEL, $\frac{9}{16}$ INCH.

D	*R*	*P*	VALUES OF *H* FOR VARYING VALUES OF *h*.								
			1	2	3	4	5	6	7	8	9
2¼	.844	3,300	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
2⅜	.906	3,100	1.21	2.42	3.62	4.83	6.04	7.25	8.46	9.66	10.87
2½	.969	2,900	1.24	2.47	3.71	4.95	6.19	7.42	8.66	9.90	11.13
2⅝	1.031	2,700	1.27	2.54	3.81	5.08	6.35	7.62	8.89	10.16	11.43
2¾	1.093	2,550	1.30	2.60	3.90	5.20	6.50	7.80	9.10	10.40	11.70
2⅞	1.156	2,400	1.34	2.67	4.01	5.35	6.69	8.02	9.36	10.70	12.03
3	1.218	2,300	1.37	2.75	4.12	5.50	6.87	8.24	9.62	10.99	12.37
3¼	1.243	2,100	1.46	2.91	4.37	5.82	7.28	8.73	10.19	11.64	13.10
3½	1.468	1,910	1.54	3.09	4.63	6.17	7.72	9.26	10.80	12.34	13.89
3¾	1.593	1,760	1.64	3.28.	4.92	6.56	8.20	9.84	11.48	13.12	14.76
4	1.718	1,630	1.75	3.49	5.24	6.98	8.73	10.47	12.22	13.96	15.71
4¼	1.843	1,520	1.86	3.72	5.58	7.44	9.30	11.16	13.02	14.88	16.74
4½	1.968	1,420	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

DIAMETER OF STEEL, ⅝ INCH.

D	*R*	*P*	VALUES OF *H* FOR VARYING VALUES OF *h*.								
			1	2	3	4	5	6	7	8	9
2½	.938	4,100	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
2⅝	1.000	3,800	1.21	2.41	3.62	4.82	6.03	7.23	8.44	9.64	10.85
2¾	1.062	3,600	1.23	2.46	3.69	4.92	6.15	7.38	8.61	9.84	11.07
2⅞	1.125	3,400	1.26	2.52	3.78	5.04	6.30	7.56	8.82	10.08	11.34
3	1.187	3,200	1.29	2.57	3.86	5.15	6.44	7.72	9.01	10.30	11.58
3¼	1.312	2,900	1.36	2.70	4.06	5.41	6.76	8.11	9.46	10.82	12.17
3½	1.437	2,650	1.42	2.85	4.27	5.69	7.12	8.54	9.96	11.38	12.81
3¾	1.562	2,450	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50
4	1.687	2,300	1.58	3.17	4.75	6.33	7.92	9.50	11.08	12.66	14.25
4¼	1.812	2,100	1.67	3.34	5.01	6.68	8.35	10.02	11.69	13.36	15.03
4½	1.937	1,980	1.77	3.54	5.31	7.08	8.85	10.62	12.39	14.16	15.93
4¾	2.062	1,860	1.87	3.74	5.61	7.48	9.35	11.22	13.09	14.96	16.83
5	2.187	1,760	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

DIAMETER OF STEEL, $\frac{11}{16}$ INCH.

D	R	P	VALUES OF H FOR VARYING VALUES OF h.								
			1	2	3	4	5	6	7	8	9
2¾	1.031	4,900	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
2⅞	1.093	4,700	1.20	2.40	3.61	4.81	6.01	7.21	8.41	9.62	10.82
3	1.156	4,400	1.23	2.45	3.68	4.90	6.13	7.35	8.58	9.80	11.03
3¼	1.281	4,000	1.28	2.56	3.83	5.11	6.39	7.67	8.95	10.22	11.50
3½	1.406	3,600	1.33	2.67	4.00	5.34	6.67	8.00	9.34	10.67	12.01
3¾	1.531	3,300	1.40	2.79	4.19	5.59	6.99	8.38	9.78	11.18	12.57
4	1.656	3,100	1.46	2.93	4.39	5.86	7.32	8.78	10.25	11.71	13.18
4¼	1.781	2,850	1.54	3.07	4.61	6.15	7.69	9.22	10.76	12.30	13.83
4½	1.906	2,650	1.61	3.23	4.84	6.46	8.07	9.68	11.30	12.91	14.52
4¾	2.031	2,500	1.70	3.39	5.09	6.79	8.49	10.18	11.88	13.58	15.27
5	2.156	2,350	1.79	3.57	5.36	7.14	8.93	10.71	12.50	14.28	16.07
5¼	2.281	2,250	1.88	3.76	5.64	7.52	9.40	11.28	13.16	15.04	16.92
5½	2.406	2,100	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

DIAMETER OF STEEL, ¾ INCH.

D	R	P	VALUES OF H FOR VARYING VALUES OF h.								
			1	2	3	4	5	6	7	8	9
3	1.125	5,900	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
3¼	1.250	5,300	1.22	2.44	3.67	4.89	6.11	7.33	8.55	9.78	11.00
3½	1.375	4,800	1.27	2.54	3.80	5.07	6.34	7.61	8.88	10.14	11.41
3¾	1.500	4,400	1.32	2.64	3.96	5.28	6.69	7.92	9.24	10.56	11.88
4	1.625	4,100	1.38	2.75	4.13	5.50	6.88	8.25	9.63	11.00	12.38
4¼	1.750	3,800	1.44	2.87	4.31	5.74	7.18	8.61	10.05	11.48	12.92
4½	1.875	3,500	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50
4¾	2.000	3,300	1.57	3.14	4.71	6.28	7.85	9.42	10.99	12.56	14.13
5	2.125	3,100	1.64	3.28	4.92	6.56	8.20	9.84	11.48	13.12	14.76
5¼	2.250	2,950	1.72	3.44	5.16	6.88	8.60	10.32	12.04	13.76	15.48
5½	2.375	2,800	1.80	3.60	5.40	7.20	9.00	10.80	12.60	14.40	16.20
5¾	2.500	2,700	1.89	3.78	5.67	7.56	9.45	11.34	13.23	15.12	17.00
6	2.625	2,550	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

DIAMETER OF STEEL, 13/16 INCH.

D	R	P	Values of *H* for Varying Values of *h*.								
			1	2	3	4	5	6	7	8	9
3¼	1.218	6,900	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
3½	1.343	6,300	1.22	2.44	3.65	4.87	6.09	7.31	8.53	9.74	10.96
3¾	1.468	5,800	1.26	2.52	3.78	5.04	6.30	7.56	8.82	10.08	11.34
4	1.593	5,300	1.31	2.61	3.92	5.23	6.54	7.84	9.15	10.46	11.76
4¼	1.718	4,900	1.36	2.71	4.07	5.42	6.78	8.14	9.49	10.85	12.20
4½	1.843	4,600	1.41	2.82	4.23	5.64	7.05	8.46	9.87	11.28	12.69
4¾	1.968	4,300	1.47	2.93	4.40	5.86	7.34	8.80	10.27	11.74	13.20
5	2.093	4,000	1.53	3.06	4.59	6.12	7.65	9.18	10.71	12.24	13.77
5¼	2.218	3,800	1.59	3.18	4.78	6.37	7.96	9.55	11.14	12.74	14.33
5½	2.343	3,600	1.67	3.33	5.00	6.66	8.33	9.99	11.66	13.32	14.99
5¾	2.468	3,400	1.74	3.47	5.21	6.95	8.69	10.42	12.16	13.90	15.65
6	2.593	3,300	1.81	3.62	5.43	7.24	9.05	10.86	12.67	14.48	16.29
6¼	2.718	3,100	1.89	3.78	5.67	7.56	9.45	11.34	13.23	15.12	17.00
6½	2.843	3,000	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

DIAMETER OF STEEL, ⅞ INCH.

D	R	P	Values of *H* for Varying Values of *h*.								
			1	2	3	4	5	6	7	8	9
3½	1.312	8,000	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
3¾	1.437	7,300	1.22	2.43	3.65	4.86	6.08	7.29	8.51	9.72	10.94
4	1.562	6,700	1.25	2.51	3.76	5.02	6.27	7.52	8.78	10.03	11.29
4¼	1.687	6,200	1.30	2.59	3.89	5.18	6.48	7.78	9.07	10.37	11.66
4½	1.812	5,800	1.34	2.68	4.03	5.37	6.71	8.05	9.39	10.74	12.08
4¾	1.937	5,400	1.39	2.78	4.18	5.57	6.96	8.35	9.74	11.14	12.53
5	2.062	5,100	1.44	2.88	4.33	5.77	7.21	8.65	10.09	11.54	12.98
5¼	2.187	4.800	1.50	3.00	4.49	5.99	7.48	8.98	10.48	11.97	13.47
5½	2.312	4,600	1.55	3.11	4.66	6.22	7.77	9.32	10.88	12.43	13.99
5¾	2.437	4,300	1.62	3.23	4.85	6.46	8.08	9.69	11.31	12.92	14.54
6	2.562	4,100	1.69	3.37	5.06	6.74	8.43	10.11	11.80	13.48	15.17
6½	2.812	3,800	1.83	3.66	5.49	7.32	9.15	10.98	12.81	14.64	16.47
7	3.062	3,400	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

DIAMETER OF STEEL, $\frac{15}{16}$ INCH.

D	*R*	*P*	VALUES OF *H* FOR VARYING VALUES OF *h*.								
			1	2	3	4	5	6	7	8	9
3¾	1.406	9,200	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
4	1.531	8,500	1.21	2.43	3.64	4.86	6.07	7.28	8.50	9.71	10.93
4¼	1.656	7,800	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00	11.25
4½	1.781	7,300	1.29	2.58	3.87	5.16	6.45	7.73	9.02	10.31	11.60
4¾	1.906	6,800	1.33	2.66	3.99	5.32	6.65	7.98	9.31	10.64	11.97
5	2.031	6,400	1.38	2.75	4.13	5.50	6.88	8.25	9.63	11.00	12.38
5¼	2.156	6,000	1.42	2.84	4.26	5.68	7.10	8.52	9.94	11.36	12.78
5½	2.281	5,700	1.47	2.95	4.42	5.89	7.37	8.84	10.31	11.78	13.26
5¾	2.406	5,400	1.53	3.06	4.58	6.11	7.64	9.17	10.70	12.22	13.75
6	2.531	5,100	1.58	3.16	4.74	6.32	7.90	9.48	11.06	12.64	14.22
6½	2.781	4,700	1.71	3.41	5.12	6.82	8.53	10.23	11.94	13.64	15.35
7	3.031	4,300	1.84	3.67	5.51	7.34	9.18	11.01	12.85	14.68	16.52
7½	3.281	3,900	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

DIAMETER OF STEEL, 1 INCH.

D	*R*	*P*	VALUES OF *H* FOR VARYING VALUES OF *h*.								
			1	2	3	4	5	6	7	8	9
4	1.500	10,500	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
4¼	1.625	9,700	1 21	2.42	3.63	4.84	6.05	7.26	8.47	9.68	10.89
4½	1.750	9,000	1.25	2.49	3.74	4.98	6.24	7.48	8.73	9.97	11.22
4¾	1.875	8,400	1.28	2.56	3.85	5.13	6.41	7.69	8.97	10.26	11.54
5	2.000	7,900	1.32	2.64	3.96	5.28	6.69	7.92	9.24	10.56	11.88
5¼	2.125	7,400	1.36	2.72	4.08	5.44	6.80	8.16	9.52	10.99	12.24
5½	2.250	7,000	1.41	2.81	4.22	5.62	7.03	8.43	9.84	11.24	12.65
5¾	2.375	6,600	1.45	2.90	4.35	5.80	7.25	8.70	10.15	11.60	13.05
6	2.500	6,300	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50
6½	2.750	5,700	1.61	3.21	4.82	6.42	8.03	9.63	11.24	12.84	14.45
7	3.000	5,200	1.72	3.44	5.16	6.88	8.60	10.32	12.04	13.76	15.48
7½	3.250	4,800	1.85	3.69	5.54	7.38	9.23	11.07	12.92	14.76	16.61
8	3.500	4,500	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

DIAMETER OF STEEL, $1\frac{1}{16}$ INCHES.

D	*R*	*P*	VALUES OF *H* FOR VARYING VALUES OF *h*.								
			1	2	3	4	5	6	7	8	9
4¼	1.593	11,800	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
4½	1.718	10,900	1.21	2.42	3.63	4.84	6.05	7.26	8.47	9.68	10.89
4¾	1.843	10,200	1.24	2.48	3.72	4.96	6.20	7.44	8.68	9.92	11.16
5	1.968	9,500	1.28	2.55	3.83	5.10	6.38	7.65	8.93	10.20	11.48
5¼	2.093	8,900	1.31	2.62	3.93	5.24	6.55	7.86	9.17	10.48	11.79
5½	2.218	8,400	1.35	2.70	4.04	5.39	6.74	8.09	9.44	10.78	12.13
5¾	2.343	8,000	1.39	2.78	4.17	5.56	6.95	8.34	9.73	11.12	12.51
6	2.468	7,600	1.43	2.86	4.29	5.72	7.15	8.58	10.01	11.44	12.87
6½	2.718	6,900	1.52	3.04	4.56	6.08	7.60	9.12	10.64	12.16	13.68
7	2.968	6,300	1.63	3.25	4.88	6.50	8.13	9.75	11.38	13.00	14.63
7½	3.218	5,800	1.73	3.46	5.19	6.92	8.65	10.38	12.11	13.84	15.57
8	3.468	5,400	1.85	3.70	5.55	7.40	9.25	11.10	12.95	14.80	16.65
8½	3.718	5,000	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

DIAMETER OF STEEL, $1\frac{1}{8}$ INCHES.

D	*R*	*P*	VALUES OF *H* FOR VARYING VALUES OF *h*.								
			1	2	3	4	5	6	7	8	9
4½	1.687	13,300	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
4¾	1.812	12,400	1.21	2.42	3.62	4.83	6.04	7.25	8.46	9.66	10.87
5	1.937	11,600	1.24	2.47	3.71	4.95	6.19	7.42	8.66	9.90	11.13
5¼	2.062	10,900	1.27	2.54	3.81	5.08	6.35	7.62	8.89	10.16	11.43
5½	2.187	10,300	1.30	2.60	3.90	5.20	6.50	7.80	9.10	10.40	11.70
5¾	2.312	9,700	1.34	2.67	4.01	5.35	6.69	8.02	9.46	10.70	12.03
6	2.437	9,200	1.37	2.75	4.12	5.50	6.87	8.24	9.62	10.99	12.37
6½	2.687	8,300	1.46	2.91	4.37	5.82	7.28	8.73	10.19	11.64	13.10
7	2.937	7,600	1.54	3.09	4.63	6.17	7.72	9.26	10.80	12.34	13.89
7½	3.187	7,000	1.64	3.28	4.92	6.56	8.20	9.84	11.48	13.12	14.76
8	3.437	6,500	1.75	3.49	5.24	6.98	8.73	10.47	12.22	13.96	15.71
8½	3.687	6,100	1.86	3.72	5.58	7.44	9.30	11.16	13.02	14.88	16.74
9	3.937	5,700	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

DIAMETER OF STEEL, $\frac{11}{16}$ INCH.

D	R	P	VALUES OF H FOR VARYING VALUES OF h.								
			1	2	3	4	5	6	7	8	9
2¾	1.031	4,900	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
2⅞	1.093	4,700	1.20	2.40	3.61	4.81	6.01	7.21	8.41	9.62	10.82
3	1.156	4,400	1.23	2.45	3.68	4.90	6.13	7.35	8.58	9.80	11.03
3¼	1.281	4,000	1.28	2.56	3.83	5.11	6.39	7.67	8.95	10.22	11.50
3½	1.406	3,600	1.33	2.67	4.00	5.34	6.67	8.00	9.34	10.67	12.01
3¾	1.531	3,300	1.40	2.79	4.19	5.59	6.99	8.38	9.78	11.18	12.57
4	1.656	3,100	1.46	2.93	4.39	5.86	7.32	8.78	10.25	11.71	13.18
4¼	1.781	2,850	1.54	3.07	4.61	6.15	7.69	9.22	10.76	12.30	13.83
4½	1.906	2,650	1.61	3.23	4.84	6.46	8.07	9.68	11.30	12.91	14.52
4¾	2.031	2,500	1.70	3.39	5.09	6.79	8.49	10.18	11.88	13.58	15.27
5	2.156	2,350	1.79	3.57	5.36	7.14	8.93	10.71	12.50	14.28	16.07
5¼	2.281	2,250	1.88	3.76	5.64	7.52	9.40	11.28	13.16	15.04	16.92
5½	2.406	2,100	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

DIAMETER OF STEEL, ¾ INCH.

D	R	P	VALUES OF H FOR VARYING VALUES OF h.								
			1	2	3	4	5	6	7	8	9
3	1.125	5,900	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
3¼	1.250	5,300	1.22	2.44	3.67	4.89	6.11	7.33	8.55	9.78	11.00
3½	1.375	4,800	1.27	2.54	3.80	5.07	6.34	7.61	8.88	10.14	11.41
3¾	1.500	4,400	1.32	2.64	3.96	5.28	6.69	7.92	9.24	10.56	11.88
4	1.625	4,100	1.38	2.75	4.13	5.50	6.88	8.25	9.63	11.00	12.38
4¼	1.750	3,800	1.44	2.87	4.31	5.74	7.18	8.61	10.05	11.48	12.92
4½	1.875	3,500	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50
4¾	2.000	3,300	1.57	3.14	4.71	6.28	7.85	9.42	10.99	12.56	14.13
5	2.125	3,100	1.64	3.28	4.92	6.56	8.20	9.84	11.48	13.12	14.76
5¼	2.250	2,950	1.72	3.44	5.16	6.88	8.60	10.32	12.04	13.76	15.48
5½	2.375	2,800	1.80	3.60	5.40	7.20	9.00	10.80	12.60	14.40	16.20
5¾	2.500	2,700	1.89	3.78	5.67	7.56	9.45	11.34	13.23	15.12	17.00
6	2.625	2,550	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

DIAMETER OF STEEL, 13/16 INCH.

D	*R*	*P*	VALUES OF *H* FOR VARYING VALUES OF *h*.								
			1	2	3	4	5	6	7	8	9
3¼	1.218	6,900	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
3½	1.343	6,300	1.22	2.44	3.65	4.87	6.09	7.31	8.53	9.74	10.96
3¾	1.468	5,800	1.26	2.52	3.78	5.04	6.30	7.56	8.82	10.08	11.34
4	1.593	5,300	1.31	2.61	3.92	5.23	6.54	7.84	9.15	10.46	11.76
4¼	1.718	4,900	1.36	2.71	4.07	5.42	6.78	8.14	9.49	10.85	12.20
4½	1.843	4,600	1.41	2.82	4.23	5.64	7.05	8.46	9.87	11.28	12.69
4¾	1.968	4,300	1.47	2.93	4.40	5.86	7.34	8.80	10.27	11.74	13.20
5	2.093	4,000	1.53	3.06	4.59	6.12	7.65	9.18	10.71	12.24	13.77
5¼	2.218	3,800	1.59	3.18	4.78	6.37	7.96	9.55	11.14	12.74	14.33
5½	2.343	3,600	1.67	3.33	5.00	6.66	8.33	9.99	11.66	13.32	14.99
5¾	2.468	3,400	1.74	3.47	5.21	6.95	8.69	10.42	12.16	13.90	15.65
6	2.593	3,300	1.81	3.62	5.43	7.24	9.05	10.86	12.67	14.48	16.29
6¼	2.718	3,100	1.89	3.78	5.67	7.56	9.45	11.34	13.23	15.12	17.00
6½	2.843	3,000	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

DIAMETER OF STEEL, 7/8 INCH.

D	*R*	*P*	VALUES OF *H* FOR VARYING VALUES OF *h*.								
			1	2	3	4	5	6	7	8	9
3½	1.312	8,000	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
3¾	1.437	7,300	1.22	2.43	3.65	4.86	6.08	7.29	8.51	9.72	10.94
4	1.562	6,700	1.25	2.51	3.76	5.02	6.27	7.52	8.78	10.03	11.29
4¼	1.687	6,200	1.30	2.59	3.89	5.18	6.48	7.78	9.07	10.37	11.66
4½	1.812	5,800	1.34	2.68	4.03	5.37	6.71	8.05	9.39	10.74	12.08
4¾	1.937	5,400	1.39	2.78	4.18	5.57	6.96	8.35	9.74	11.14	12.53
5	2.062	5,100	1.44	2.88	4.33	5.77	7.21	8.65	10.09	11.54	12.98
5¼	2.187	4,800	1.50	3.00	4.49	5.99	7.48	8.98	10.48	11.97	13.47
5½	2.312	4,600	1.55	3.11	4.66	6.22	7.77	9.32	10.88	12.43	13.99
5¾	2.437	4,300	1.62	3.23	4.85	6.46	8.08	9.69	11.31	12.92	14.54
6	2.562	4,100	1.69	3.37	5.06	6.74	8.43	10.11	11.80	13.48	15.17
6½	2.812	3,800	1.83	3.66	5.49	7.32	9.15	10.98	12.81	14.64	16.47
7	3.062	3,400	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

Diameter of Steel, $\frac{15}{16}$ Inch.

D	R	P	Values of H for Varying Values of h.								
			1	2	3	4	5	6	7	8	9
3¾	1.406	9,200	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
4	1.531	8,500	1.21	2.43	3.64	4.86	6.07	7.28	8.50	9.71	10.93
4¼	1.656	7,800	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00	11.25
4½	1.781	7,300	1.29	2.58	3.87	5.16	6.45	7.73	9.02	10.31	11.60
4¾	1.906	6,800	1.33	2.66	3.99	5.32	6.65	7.98	9.31	10.64	11.97
5	2.031	6,400	1.38	2.75	4.13	5.50	6.88	8.25	9.63	11.00	12.38
5¼	2.156	6,000	1.42	2.84	4.26	5.68	7.10	8.52	9.94	11.36	12.78
5½	2.281	5,700	1.47	2.95	4.42	5.89	7.37	8.84	10.31	11.78	13.26
5¾	2.406	5,400	1.53	3.06	4.58	6.11	7.64	9.17	10.70	12.22	13.75
6	2.531	5,100	1.58	3.16	4.74	6.32	7.90	9.48	11.06	12.64	14.22
6½	2.781	4,700	1.71	3.41	5.12	6.82	8.53	10.23	11.94	13.64	15.35
7	3.031	4,300	1.84	3.67	5.51	7.34	9.18	11.01	12.85	14.68	16.52
7½	3.281	3,900	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

Diameter of Steel, 1 Inch.

D	R	P	Values of H for Varying Values of h.								
			1	2	3	4	5	6	7	8	9
4	1.500	10,500	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
4¼	1.625	9,700	1.21	2.42	3.63	4.84	6.05	7.26	8.47	9.68	10.89
4½	1.750	9,000	1.25	2.49	3.74	4.98	6.24	7.48	8.73	9.97	11.22
4¾	1.875	8,400	1.28	2.56	3.85	5.13	6.41	7.69	8.97	10.26	11.54
5	2.000	7,900	1.32	2.64	3.96	5.28	6.69	7.92	9.24	10.56	11.88
5¼	2.125	7,400	1.36	2.72	4.08	5.44	6.80	8.16	9.52	10.99	12.24
5½	2.250	7,000	1.41	2.81	4.22	5.62	7.03	8.43	9.84	11.24	12.65
5¾	2.375	6,600	1.45	2.90	4.35	5.80	7.25	8.70	10.15	11.60	13.05
6	2.500	6,300	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50
6½	2.750	5,700	1.61	3.21	4.82	6.42	8.03	9.63	11.24	12.84	14.45
7	3.000	5,200	1.72	3.44	5.16	6.88	8.60	10.32	12.04	13.76	15.48
7½	3.250	4,800	1.85	3.69	5.54	7.38	9.23	11.07	12.92	14.76	16.61
8	3.500	4,500	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

DIAMETER OF STEEL, 1$\frac{1}{16}$ INCHES.

D	*R*	*P*	VALUES OF *H* FOR VARYING VALUES OF *h*.								
			1	2	3	4	5	6	7	8	9
4¼	1.598	11,800	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
4½	1.718	10.900	1 21	2.42	3.63	4.84	6.05	7.26	8.47	9:68	10.89
4¾	1.843	10,200	1.24	2.48	3.72	4.96	6.20	7.44	8.68	9.92	11.16
5	1.968	9,500	1.28	2.55	3.83	5.10	6.38	7.65	8.93	10.20	11.48
5¼	2.093	8,900	1.31	2.62	3.93	5.24	6.55	7.86	9.17	10.48	11.79
5½	2.218	8,400	1.35	2.70	4.04	5.39	6.74	8.09	9.44	10.78	12.13
5¾	2.343	8,000	1.39	2.78	4.17	5.56	6.95	8.34	9.73	11.12	12.51
6	2.468	7,600	1.43	2.86	4.29	5.72	7.15	8.58	10.01	11.44	12.87
6½	2.718	6,900	1.52	3.04	4.56	6.08	7.60	9.12	10.64	12.16	13.68
7	2.968	6,300	1.63	3.25	4.88	6.50	8.13	9.75	11.38	13.00	14.63
7½	3.218	5,800	1.73	3.46	5.19	6.92	8.65	10.38	12.11	13.84	15.57
8	3.468	5,400	1.85	3.70	5.55	7.40	9.25	11.10	12 95	14.80	16.65
8½	3.718	5,000	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82

DIAMETER OF STEEL, 1⅛ INCHES.

D	*R*	*P*	VALUES OF *H* FOR VARYING VALUES OF *h*.								
			1	2	3	4	5	6	7	8	9
4½	1.687	13,300	1.18	2.36	3.54	4.72	5.90	7.08	8.26	9.44	10.62
4¾	1.812	12,400	1.21	2.42	3.62	4.83	6.04	7.25	8.46	9.66	10.87
5	1.937	11,600	1.24	2.47	3.71	4.95	6.19	7.42	8.66	9.90	11.13
5¼	2.062	10,900	1.27	2.54	3.81	5.08	6.35	7.62	8.89	10.16	11.43
5½	2.187	10,300	1.30	2 60	3.90	5.20	6.50	7.80	9.10	10.40	11.70
5¾	2.312	9,700	1.34	2.67	4.01	5.35	6.69	8.02	9.46	10.70	12.03
6	2.437	9,200	1.37	2.75	4.12	5.50	6.87	8.24	9.62	10.99	12.37
6½	2.687	8,300	1.46	2.91	4.37	5.82	7.28	8.73	10.19	11.64	13.10
7	2.937	7,600	1.54	3.09	4.63	6.17	7.72	9.26	10.80	12.34	13 89
7½	3.187	7,000	1.64	3.28	4.92	6.56	8.20	9.84	11.48	13.12	14.76
8	3.437	6,500	1.75	3.49	5.24	6.98	8.73	10.47	12.22	13.96	15.71
8½	3.687	6,100	1.86	3.72	5.58	7.44	9.30	11.16	13.02	14.88	16.74
9	3.937	5,700	1.98	3.96	5 94	7.92	9.90	11.88	13.86	15.84	17.82

roll, for instance, would be worked down from 48-inch and 72-inch ingots respectively. Ingots of these sizes are liable to contain "blow holes," "piping," and "segregation." The upper and central portion, being the locality of last cooling, is the place where these defects are apt to occur. As a precautionary measure, therefore, ingots are made from 25 to 30 per cent. longer than necessary, so that if any defects should happen to occur, the part containing them can be cut off. Of all the various methods that have been devised to secure ingots which are solid and homogeneous and free from all of the above defects, the most efficient and most to be depended upon is the "Whitworth process of fluid compression." This consists in subjecting the metal in the mould, while fluid, to hydraulic pressure up to 7,000 tons if necessary (Fig. 64). This pressure is continued until the metal is solid throughout, great care being taken to cool the ingot slowly and equally on all sides to prevent strains or cracks forming from unequal contraction (Fig. 65). After it has cooled, the upper part is cut off, and a hole nearly the size required in the finished forging is bored through it (Fig. 66). This cutting off of the top and boring out of the centre take away those portions of the ingot where impurities may have concentrated and where there may have been a tendency toward "piping," and we now have a piece of steel which is as nearly perfect as can be produced, and it is ready for the forging process.

First, it must be reheated, and as much care has to be taken in this process as was taken in its cooling, one being simply the reverse of the other. The heat must penetrate it slowly and uniformly, and its hollow shape now assists in accomplishing this result. In reheating a solid ingot, cracks are apt to form in the centre, owing to the expansion of the exterior from more rapid heating. The hole in the centre of the hollow forging, however, allows the interior and exterior to expand together, and relieves this tendency to crack. After being reheated, a mandrel of the proper size to fit loosely into the hole is inserted, and the piece is taken to the press, where the metal is drawn out over the mandrel to the required dimensions (Fig. 67).

One of the primal requisites in forging is the proper selection of forging tools, suitable in design and power for the work in hand. The pressure applied in shaping a body of steel should be sufficient in amount and of such character as to penetrate to the centre and cause flowing throughout the mass. As

DCLXXXI.*

HOLLOW STEEL FORGINGS.

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(Member of the Society.)

BY this name I do not refer to steel forgings that have been forged solid under a hammer or press and subsequently bored, but to forgings which have been "forged hollow."

In order that I may not be misunderstood, I will briefly describe the process of making the type of forging referred to. Supposing that we have designed a hollow shaft or roll or cylinder of outside diameter D, inside diameter D^1, length L, and solid volume $\frac{1}{4}\pi D^2 L$, an ingot must be cast solid on end to forge it from, having a diameter $2D$, volume equal to $\frac{3}{8}\pi D^2 L$, but with length L^1. From the upper part of this ingot 25 per cent. is cut off and rejected, and a hole of diameter D^1 is bored through the longitudinal axis of the remainder. The ingot is then reheated, a mandrel of diameter D^1 is run through the axial hole, and then the mass is forged down under a hydraulic press from $2D$ and length L^1 to D and L, the inside diameter D^1 remaining the same.

The reasons for adopting this method of producing hollow forgings are many and various and the result of long experimenting. In the first place, as the walls of hollow forgings are comparatively thin, the metal must be absolutely without flaw or defect of any kind, homogeneous throughout, and thoroughly worked. For this purpose, therefore, only open-hearth steel is used, and of a grade that will best insure satisfactory working. Its carbon may vary according to the purposes to which the forging will finally be applied, but its phosphorus and sulphur should not exceed .04 per cent. In order that the metal should be sufficiently worked to give it strength and toughness, the best practice requires that the ingot should be at least twice the diameter of the finished forging. A 24-inch or 36-inch shaft or

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* Presented at the St. Louis meeting (May, 1896) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

this flowing of the metal requires a certain amount of time, the required pressure should be maintained throughout a corresponding period. The hydraulic press instead of the hammer is therefore used to work it into shape. Under its action the forging is slowly operated upon and the pressure distributes itself evenly throughout the mass, whereas under the high velocity of impact of the hammer the metal does not have time to flow, and thus internal strains and possibly cracks are caused. The latter would be fatal defects, for, as steel has not the property of welding, they cannot be remedied. Besides the undesirability of using the hammer on steel for the above reasons, it is a very difficult matter to make a forging of this character exeept by the use of the hydraulic press. A slow and even pressure is absolutely necessary to draw out the thin cylindrical walls equally and make a forging that is straight and symmetrical throughout. The varying impact of the hammer works the metal so unevenly that the mandrel is apt to stick fast in the hole. For this type of steel forging, therefore, it is practically imperative that the press be used, and thus the metal is unavoidably subjected to the best method of treatment.

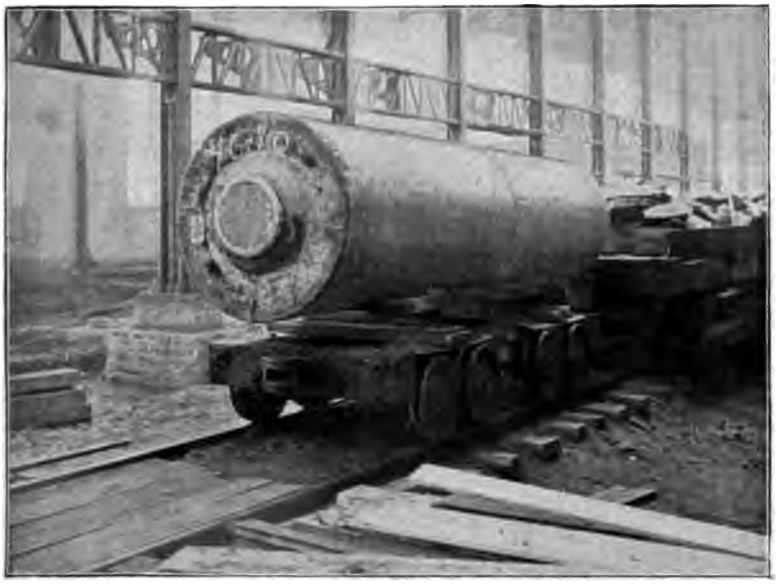

Fig. 65.—Ingot solid as coming from the mould.

During this process of working down the metal from 2D to D

and extending it from L^1 to L (Fig. 68), it is probable that the entire piece, or at least the end of it which is being worked upon, will have to be reheated from time to time. Operating on metal which has become too cold to flow would injure it by disturbin the continuity of its structure, and thus establishing lines and planes of weakness.

Considering all the manipulation to which the piece has bee subjected during the process of shaping it to the proposed design together with its frequent partial heatings and irregular coolings, it undoubtedly has strains set up in it. To relieve thes

FIG. 66.—Bored ingot.

strains it must be subjected to a final treatment of "annealing." This treatment consists in heating the forging slowly in a furnace and then allowing the latter to cool down slowly with th forging in it. *All* forgings, whether hollow or not, should b annealed, otherwise there is a certainty of "forging strains" developing into weakness after they have been in service, causing them to get out of true, with a possibility of their breaking particularly if subjected to alternating stresses as in heavil weighted shafts or connecting rods, and especially piston rods which are subjected to changing temperature. Annealing no

H. F. J. PORTER.

and modifies the physical properties by increasing the elastic limit and adding toughness. Forgings must be hollow to be tempered successfully, to allow the heat to be drawn from their interior as rapidly as from their exterior when they are subjected to the cooling effect of the bath, otherwise strains may be induced which result in weakening instead of strengthening them.

Authorities on machine design (*vide* Unwin, Seaton, *et al.*) say that solid shafts up to 10 inches in diameter may be subjected to a fibre strain of 9,000 pounds in wrought iron and 12,000 pounds in steel. Above 10 inches in diameter, however, iron shafts must not be subjected to more than 8,000 pounds, and steel shafts to more than 10,000 pounds. The reason assigned is, that forges do not possess hammers heavy enough to affect the centre of shafts larger than 10 inches in diameter; or if by top steam or long drop they are able to be felt through the whole forging, the effect is produced by velocity of impact rather than by weight of falling mass. This, however, damages the surface, having a tendency to draw it out, and leave the central portion behind, thus producing a tearing strain on the core, causing at times actual cavities. Heavy shafts forged under light hammers show the effect of this treatment in having concave ends (Fig. 69), while shafts forged under sufficiently heavy hammers or under the hydraulic press show bulging ends, the metal in the centre, where it is hottest and softest, being pressed out (Fig. 70). Another reason why authorities place a higher safety factor on large shafts, especially of steel, is on account of the liability of steel ingots to have "piping" and other defects in their centre.

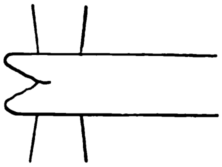

FIG. 69.

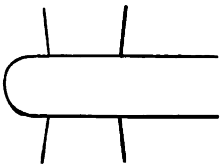

FIG. 70.

With hollow forgings manufactured under the processes here described, these objections are met by using fluid compressed steel and subsequently taking out the possibly defective centre altogether. By substituting for the centre, during the process of forging, a mandrel, the latter acts as an internal anvil, and by this flowing of the metal requires a certain amount of time, the required pressure should be maintained throughout a corresponding period. The hydraulic press instead of the hammer is therefore used to work it into shape. Under its action the forging is slowly operated upon and the pressure distributes itself evenly throughout the mass, whereas under the high velocity of impact of the hammer the metal does not have time to flow, and thus internal strains and possibly cracks are caused. The latter would be fatal defects, for, as steel has not the property of welding, they cannot be remedied. Besides the undesirability of using the hammer on steel for the above reasons, it is a very difficult matter to make a forging of this character except by the use of the hydraulic press. A slow and even pressure is absolutely necessary to draw out the thin cylindrical walls equally and make a forging that is straight and symmetrical throughout. The varying impact of the hammer works the metal so unevenly that the mandrel is apt to stick fast in the hole. For this type of steel forging, therefore, it is practically imperative that the press be used, and thus the metal is unavoidably subjected to the best method of treatment.

FIG. 65.—Ingot solid as coming from the mould.

During this process of working down the metal from $2D$ to D

Twisting moment Tr = moment of resistance $= \frac{\pi d^3 s}{16}$, and

$$Tr = .1963 d^3 s, \text{ and } d = \sqrt[3]{\frac{5.1\, Tr}{s}}.$$

(2) When the shaft is subject to *bending* only,

Let B = bending force in pounds.
l = distance between supports in inches.
t = safe tensile resistance of the metal in pounds per square inch.

Bending moment Bl = moment of resistance $= \frac{\pi d^3 t}{32}$, and

$$Bl = .0982 d^3 t, \text{ and } d = \sqrt[3]{2\left(\frac{5.1\, Bl}{t}\right)}.$$

And for hollow shafts, letting d and d' = the outside and inside diameters in inches, as $d^3 = \frac{(d^4 - d'^4)}{d}$, by substituting in the above we have,

$$(3) \qquad Tr = .1963 \frac{(d^4 - d'^4)s}{d}. \quad d = \sqrt[3]{\frac{5.1\, Tr}{\left(1 - \frac{d'^4}{d^4}\right)s}}.$$

$$(4) \quad Bl = .0982 \frac{(d^4 - d'^4)t}{d}. \quad d = \sqrt[3]{2\left(\frac{5.1\, Bl}{\left(1 - \frac{d'^4}{d^4}\right)t}\right)}.$$

(5) When the shaft is subjected to both twisting and bending simultaneously, the combined strain may be measured by calculating what is called the equivalent twisting moment T'.

If Tr = the twisting moment and Bl = the bending moment as above, the equivalent twisting moment

$$T' = Bl + \sqrt{(Bl)^2 + (Tr)^2}.$$

Assuming that steel less than 10 inches in thickness may be submitted to a fibre strain of 12,000 pounds per square inch, and when 10 inches thick and thicker it must not be submitted to a greater strain than 10,000 pounds per square inch, we may so reduce the thickness of metal operated upon in shafts of larger diameter than 10 inches, by hollow-forging them, that the walls will be less than 10 inches in thickness.

By the above formulas, hollow-forged shafts are shown to be as strong or stronger than solid shafts of the same diameter. Taking for example the shaft above mentioned, 32 inches outside diameter, 16 inches inside diameter, we find that when compared with a solid shaft of the same size it has lost 25 per cent. in weight and gained 12 per cent. in strength.

With the substitution of steel for wrought iron in the trades for engine and miscellaneous forgings, the tendency has naturally been to use a mild or soft steel approaching iron as regards physical qualities and in the ease with which it can be machined. Wrought iron has a low elastic limit, averaging about 20,000 pounds per square inch in large sections, where proper care is taken in its production. Its strength is apt to be impaired by imperfect welds and porous spots enclosing slag and scale.

Although mild steel, when of good quality, is superior to wrought iron in strength, toughness, homogeneity, and freedom from danger of such defects, still it does not possess the very desirable quality of high elastic strength combined with ductility or toughness in as great a degree as can be obtained without danger in a harder steel, when proper precautions are taken in its manufacture. In other words, in the use of ordinary mild steel, only a partial advantage is taken of the most desirable qualities of steel which are easily within reach. In some instances where the amount of machine work in finishing is very great and there is ample margin of safety in the design—as, for instance, is often the case with connecting rods—the use of mild steel may be advisable. Such steel contains about .20 to .25 of one per cent. carbon, and can be guaranteed to show, in specimens ½ inch diameter and 2 inches long between measuring points, cut from full-sized prolongations of forgings or from representative pieces, a tensile strength of not less than 57,000 pounds per square inch, and an elastic limit of not less than 27,000 pounds per square inch, with an average elongation of 25 per cent.

For the general run of engine forgings, however, a harder steel should be used in which a tensile strength of about 75,000 pounds and an elastic limit of 35,000 pounds per square inch can be obtained, together with an average elongation of 20 per cent.

When proper precautions are employed, forgings can be made with perfect safety of a still higher grade of steel, and this is especially recommended for crank and cross-head pins and for machine parts subject to severe alternating strains and wearing action. In this grade of steel a tensile strength of about 85,000 pounds and an elastic limit of about 40,000 pounds per square inch can be obtained, with an elongation of 15 per cent.

If steel forgings are tempered they will possess still higher qualities than those above mentioned, and can be furnished with a tensile strength of 85,000 to 90,000 pounds and an elastic limit of 45,000 to 55,000 pounds per square inch, and an elongation of 20 to 15 per cent.

By introducing about 3 per cent. of nickel into the composition of steel, a finely granular or amorphous condition is obtained in forgings, and the very highest quality of steel is attained.

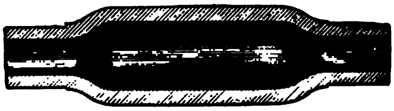

FIG. 72.—A hollow shaft or roll.

By the combination of hollow-forging and tempering this nickel steel, a material is obtained excelling all others known in elastic strength and toughness. As an example of this can be mentioned shafts made for the United States war-ship *Brooklyn*. These showed in specimens cut from full-sized prolongations a tensile strength of 94,245 pounds, an elastic limit of 60,775 pounds per square inch, an elongation of 25.55 per cent., and a contraction of area of 60.58 per cent.

Professor Merriman is quoted, in a paper read before the Society of Naval Architects and Marine Engineers in 1893 by R. W. Davenport, as estimating the strength of these shafts compared to solid shafts as follows, when strained to one-half their elastic limit:

1. Propeller shaft United States steamship *Brooklyn*, nickel steel, hollow forged, outside diameter 17 inches, inside diameter 11 inches, weight 19,112 pounds.

and when 10 inches thick and thicker it must not be submitted to a greater strain than 10,000 pounds per square inch, we may so reduce the thickness of metal operated upon in shafts of larger diameter than 10 inches, by hollow-forging them, that the walls will be less than 10 inches in thickness.

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FIG. 72.—A hollow shaft or roll.

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1. Propeller shaft United States steamship *Brooklyn*, nickel steel, hollow forged, outside diameter 17 inches, inside diameter 11 inches, weight 19,112 pounds.

a. Horse-powers transmitted at 50 revolutions per minute, 15,780.

b. Load in pounds at middle of a span of 12 feet on two supports, 276,200.

FIG. 73.—Field ring for 5,000 horse-power dynamo.

2. Simple steel shaft, solid, 13 inches diameter (same weight and sectional area as above).

a. Horse-powers transmitted under similar conditions, 5,130.

b. Load in pounds under similar conditions, 89,000.

Comparative strength of these two shafts as 3 to 1.

3. A solid shaft of simple steel of the same strength as the hollow-forged nickel-steel shaft would be 18.9 inches diameter, and weigh 53 per cent. more.

Hollow-forged fluid-compressed steel of .40 to .45 of one per cent. carbon, and more especially nickel steel, oil-tempered, is markedly adapted for piston rods of rock drills, mining machines, and hydraulic presses, and for drop-hammer rods, stamp stems, cam shafts, and similar pieces that are subjected to stress alternating between tension and compression, or of either kind, frequently repeated. By substituting steel of this grade, which would have an elastic limit of about 60,000 pounds per square inch, for wrought iron or mild steel, which is generally used for the purpose, and by so proportioning the cross section that the metal is not strained beyond one-half the elastic limit, so-called "crystallization" from shock or vibration does not occur and its life is prolonged indefinitely.

Undoubtedly the best type of hollow forging, and one which is gradually being adopted both for shafts and rolls, is where the walls are of the same thickness throughout, the outside and inside diameter varying together, both being greatest at the centre, where the strength is required, and smallest at the bearings (Fig. 72). Such a shaft is built on the principle of a girder, and offers the greatest strength for the least amount of metal.

The ability to produce forgings of this hollow variety has led to their adoption in many places where castings, both of iron and steel, have previously been used. This substitution has resulted in considerably lightening the dimensions of such pieces and also the parts in which they rest or move.

Prominent among hollow forgings are the Ferris wheel shaft, 32 inches outside diameter, 16 inches inside diameter, 45 feet long, weighing 89,320 pounds; and shafts for the steamers *Puritan, Plymouth,* and *Pilgrim* of the Old Colony Steamboat Company, 20½ inches outside diameter, 9 inches inside diameter, and weighing 65,832 pounds each. Shafts for the navy are made hollow, and those for the steamers *New York, Paris, St. Louis,* and *St. Paul,* of the International Line, are 21 inches in diameter, crank pins 22 inches diameter, with a 10-inch hole through both. Field rings of nickel steel were hollow-forged for the 5,000 horse-power Westinghouse dynamos at Niagara the discharge chamber, or cap, as it is sometimes called. This latter should be semicircular, as shown in section (Fig. 74), since, in that case, the metal will be brought into simple tension only, and the only force which the cap can bring upon the cylinder will be a vertical one, as will be shown farther on.

This being settled, we come to the cylinder itself; and first we will say that the valve decks must be strong enough to resist the bending action due to the pressure upon their upper surfaces, and the lower deck must also withstand the direct tension due to the pressure upon the side walls of the cylinder.

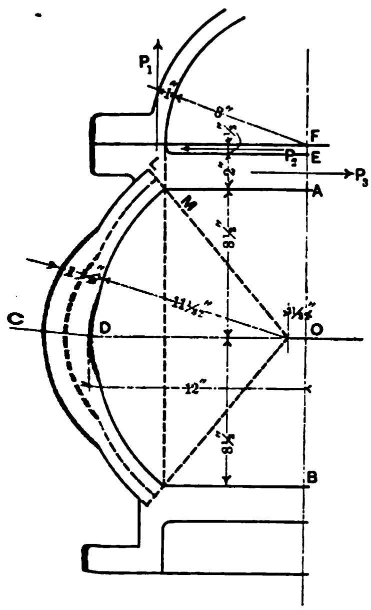

FIG. 74.

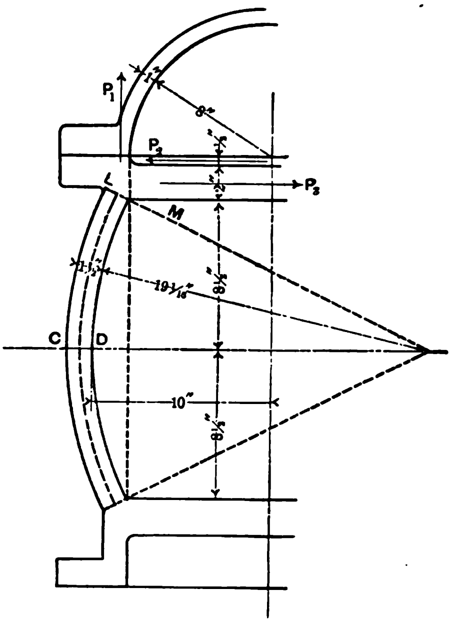

FIG. 75.

The lower deck is thus subjected to bending stress and direct tension simultaneously; but the upper deck is not, for the following reason. When the end of the cylinder under consideration is brought under pressure—*i.e.*, when it is the discharging end—the upper valves are open, and hence the pressure is the same upon the upper and lower surfaces of this upper deck, which is, therefore, not subjected to bending stress, but only to the direct tension coming from the pressure upon the side walls of the cylinder. On the other hand, when the discharge valves are closed, there is no pressure in the part of the cylinder under

DCLXXXII.*

A STUDY OF THE PROPER METHOD OF DETERMINING THE STRENGTH OF PUMP CYLINDERS.

BY CHARLES W. KETTELL, CAMBRIDGE, MASS.
(Member of the Society.)

ANY one who has had to do with the designing of machinery, or structures of any sort which are to be subjected to pressure, must have felt the difficulty of ascertaining the stresses to which the several members are subjected, and for which they should be properly proportioned. In many cases it is impossible to determine the proper dimensions of the various parts, except by the exercise of the judgment given by long practice, or by comparison with existing structures which have stood the test of time. In some cases, however, it is possible to determine the stresses with more or less mathematical accuracy; and in others, again, it is possible to apply mathematical processes for the sake of obtaining results by which the judgment shall finally be guided. In all cases where such processes are used, they must be preceded by a rigid analysis of the problem, so as to determine the actual extraneous forces, since otherwise no inference whatever can be drawn from the results obtained.

These remarks are especially applicable to the case of castings of complex form, and it is the purpose of this article to indicate a method of analysis which may be applied to the determination of the stresses in long horizontal pump cylinders. Such cylinders are usually made with an upper and a lower valve deck, as shown in the sections here given (Fig. 74). The sides are usually drawn with some simple curve, but are sometimes straight; and sometimes, to meet peculiar requirements, they are of more complex form.

We will suppose the cylinder to be of indefinite length, and analyze the stresses on a section one inch long.

Before taking up the cylinder itself, we shall have to consider

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* Presented at the St. Louis meeting (May, 1896) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

the discharge chamber, or cap, as it is sometimes called. This latter should be semicircular, as shown in section (Fig. 74), since, in that case, the metal will be brought into simple tension only, and the only force which the cap can bring upon the cylinder will be a vertical one, as will be shown farther on.

This being settled, we come to the cylinder itself; and first we will say that the valve decks must be strong enough to resist the bending action due to the pressure upon their upper surfaces, and the lower deck must also withstand the direct tension due to the pressure upon the side walls of the cylinder.

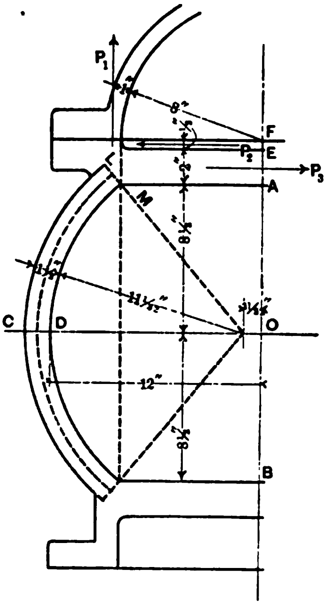

Fig. 74.

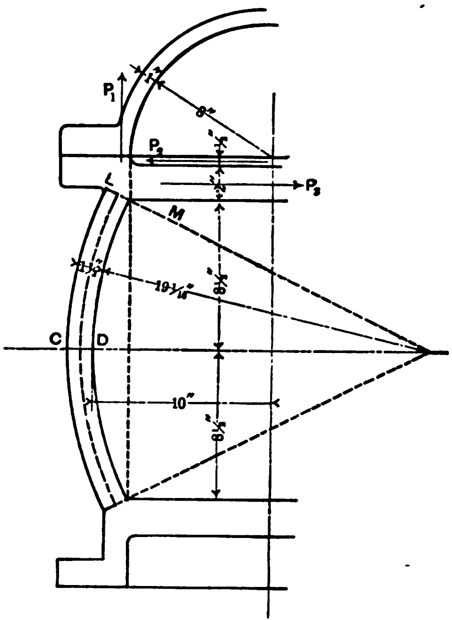

Fig. 75.

The lower deck is thus subjected to bending stress and direct tension simultaneously; but the upper deck is not, for the following reason. When the end of the cylinder under consideration is brought under pressure—*i.e.*, when it is the discharging end—the upper valves are open, and hence the pressure is the same upon the upper and lower surfaces of this upper deck, which is, therefore, not subjected to bending stress, but only to the direct tension coming from the pressure upon the side walls of the cylinder. On the other hand, when the discharge valves are closed, there is no pressure in the part of the cylinder under them, and the upper deck is then subjected to bending stress, but not to direct tension.

All this, however, is contingent upon the supposition that the tension in the valve decks acts at the centres of gravity of these decks. If, however, there is a bending moment in the side wall, where it joins the upper and lower decks, of such a character as to displace the centres of action of these tensions from the centres of gravity of the decks, then the upper deck will be subjected to a bending stress besides, and simultaneously with, its direct tension; and the lower deck, also, may have this additional bending stress.

Now suppose the cylinder and cap both to be under pressure, and let us consider the forces acting on a section of the cylinder one inch long.

Referring to Fig. 74, let us suppose that the resultant of the extraneous forces acting on any section *CD* is a couple *M* and an oblique force whose component normal to the section is *G*. Then we have for the maximum fibre stress caused by the couple,

$$f_1 = \frac{My_0}{I},$$

in which I is the moment of inertia of the section, and y_0 is the distance of the extreme fibre from the axis.

For the stress caused by the normal force G we have $f_2 = \frac{G}{A}$, in which A is the area of the section.

Hence for the total stress we have

$$f = f_1 + f_2 = \frac{My_0}{I} + \frac{G}{A}.$$

Now the extraneous forces acting on any section as $C - D$ are four in number:

First. We have the uniform pressure p upon the side walls between the decks.

Second. We have the horizontal pressure P_2 acting upon the vertical face *EF*.

Third. We have the action of the cap upon the cylinder, and this can be reduced to the force P_1 acting at the centre of the shell. For, the cap being semicircular in section, the stress on the metal is, as before stated, simply a direct tension throughout, and hence at the joint this tension is vertical, and equal to

$$P_1 = p \times c,$$

in which p is the unit pressure, and $2c$ is the inside width of the cap, the point of application of P_1 being taken at the centre of the shell, as shown in Fig. 74.

As the cap is attached to the cylinder by bolts, it might be thought that its centre of action ought to be taken at the centre of the bolts, instead of the centre of the shell. But that this is not the case can be shown in two ways:

1. When pressure is brought upon the cap, which is thus forced away from the cylinder, the cap pulls upon the bolts, but it also presses the outer edge of its flange against the flange of the cylinder, and the action of the cap is reduced to a vertical pull at the bolts and a downward pressure at the edge; the resultant of these two forces being a single force equal to the difference of the two, and lying inside of the bolts—*i.e.*, at the centre of the shell.

It may be observed that the tension of the bolts is thus greater than $P_1 = pc$ by just this additional pressure mentioned as occurring at the outer edge, besides the pressure necessary to secure a tight joint—which last pressure does not, of course, affect the strength of the cylinder, and is not to be taken into consideration in the present discussion.

2. In the second method of proving the correctness of the location assumed for the centre of action of the cap upon the cylinder, we will suppose that we take a radial section of the cap just above the flange, as $a-a'$, Fig. 77. We can then leave the joint entirely out of consideration, and we shall have for the forces acting upon the cylinder the direct tension $P^1 = pc$, which is not vertical, and the pressure upon the curved portion ab of the shell; the resultant of these two being again the *vertical* force $P_1 = pc$ acting at the centre of the shell.

Fourth. The last of the extraneous forces to be considered is the tension P_3 in the upper valve deck, the amount and centre of action of which depend upon the change of form that the cylinder undergoes under pressure. As to its amount, it is fair to assume that P_3 is equal to half the whole pressure upon the vertical face AB plus the pressure P_2, although it is perfectly conceivable that the upper deck should be so elastic as to

$$B_1 = \frac{1}{I} + \frac{1}{Ar_2^2}, \text{ and } B_2 = \frac{1}{Ar_2}.$$

Fig. 76 we have

$$\begin{aligned} \ldots \quad M = {} & P_4 r_2 (\sin.\alpha - \sin.\varphi) \\ & + P_1 r_2 (\cos.\alpha - \cos.\varphi) \\ & - 2pr_1r_2 \sin.^2\left(\frac{\alpha - \varphi}{2}\right) \\ & + M_0 ; \end{aligned}$$

M_0 is the unknown moment at LM.
om the same Fig. 76 we get

$$G = P_4 \sin.\varphi + P_1 \cos.\varphi + 2pr_1 \sin.^2\left(\frac{\alpha-\varphi}{2}\right).$$

ucing these values of M and G into equation (2) and
ng, we have

$$\begin{aligned} \Delta\varphi = B_1 \Big[& P_4 r_2(\varphi \sin.\alpha + \cos.\varphi) + P_1 r_2(\varphi \cos.\alpha - \sin.\varphi) \\ & - pr_1 r_2 [\sin.(\alpha - \varphi) - (\alpha - \varphi)] + M_0 \varphi \Big] \\ + B_2 \Big[& - P_4 \cos.\varphi + P_1 \sin.\varphi + pr_1 [\sin.(\alpha - \varphi) \\ & - (\alpha - \varphi)] \Big] + C. \end{aligned}$$

ssume that the rib is "fixed" at the upper and lower
the deflection is also zero at the middle section. Then
nes zero for $\varphi = 0$; $\varphi = \alpha$; and $\varphi = -\alpha$, and we get

$$\begin{aligned} & [P_4 r_2 - pr_1 r_2(\sin.\alpha - \alpha)] + B_2 [- P_4 + pr_1 (\sin.\alpha - \alpha)] \\ & + C = 0. \end{aligned}$$

$$\begin{aligned} & [P_4 r_2 (\alpha \sin.\alpha + \cos.\alpha) + P_1 r_2 (\alpha \cos.\alpha - \sin.\alpha) \\ & \qquad + M_0 \alpha] + B_2 [-P_4 \cos.\alpha + P_1 \sin.\alpha] + C = 0. \end{aligned}$$

$$\begin{aligned} & [P_4 r_2 (\cos.\alpha - \alpha \sin.\alpha) + P_1 r_2 (\sin.\alpha - \alpha \cos.\alpha) \\ & - pr_1 r_2 (\sin.2\alpha - 2\alpha) - M_0 \alpha] \\ & + B_2 [-P_4 \cos.\alpha - P_1 \sin.\alpha + pr_1 (\sin.2\alpha - 2\alpha)] + C = 0. \end{aligned}$$

As the valve decks are usually quite deep compared with the thickness of the shell, and are often stiffened by ribs, and have well rounded corners where they join the walls, the second case is much more nearly realized in practice, and probably represents quite well the actual condition of the cylinder.

The problem is, therefore, now reduced to the discussion of a curved piece, as shown in Fig. 76, subjected to a uniform normal pressure p, to a known force P_1, to a force P_4, which we will assume unknown, and lastly to a bending moment M_0, likewise unknown, but which includes the moments of the couples required to transfer the forces P_1 and P_4 from their actual centres of action to the end of the centre line of the curved rib.

As the theory of flexure is given in so many text-books of mechanics, it would be a matter of no interest to elaborate any part of it here, and therefore we will assume the following general formula* for the change of direction of the tangent of a curved piece subjected to a bending action and an oblique force at the same time:

$$(1) \quad . \quad . \quad . \quad . \quad E\Delta\varphi = \int\left[\frac{M}{I} + \frac{M}{Ar_2^2} + \frac{G}{Ar_2}\right] ds,$$

in which

E = modulus of elasticity;
A = area of section;
I = moment of inertia of section;
M = bending moment at any point;
G = resultant force at the same point, normal to the section;
r_2 = radius of the neutral axis;
$\Delta\varphi$ = deflection of the tangent;
ds = element of neutral line.

Tension is positive, and so also are those bending moments which tend to increase the curvature.

As r_2 is constant in our case, and $ds = r_2 d\varphi$, we can write equation (1) in this form:

$$(2) \quad . \quad . \quad . \quad \frac{E}{r}\Delta\varphi = B_1\int M\cdot d\varphi + B_2\int G\cdot d\varphi,$$

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* *The Elements of Graphical Statics*, A. J. Du Bois, vol. ii., p. 274.

no bending action whatever in the walls, which act as part of a cylinder only, and are subjected throughout to a uniform tension,

(15) . . . . $G = pr_1$.

It now remains to determine the centre of action of the tension in the upper and lower decks.

If x_1 and x_2, taken positive to the right and up, are the distances of the lines of action of the forces P_1 and P_2, and x_3 is the distance of the centre of gravity of the upper deck from and above the centre of gravity of the radial section LM; and, lastly, if x_0 is the displacement of the force P_3 below the centre of the deck, we have

(16) . . . $-P_1x_1 - P_2x_2 + P_3(x_3 - x_0) = M_0$.

(17) . . . . $x_0 = \dfrac{P_3x_3 - P_1x_1 - P_2x_2 - M_0}{P_3}$.

The upper deck is, therefore, subjected simultaneously to the uniform tension P_3, and to the uniform bending moment P_3x_0; and the maximum fibre stress is

(18) . . . . $f = \dfrac{P_3}{A_1} + \dfrac{P_3x_0y_0}{I}$,

in which

A_1 is the area of the section;

I is the moment of inertia;

y_0 is the distance of the extreme fibre from the neutral axis.

It should be observed that the length of section to be considered in this case is not one inch, but is to be determined by the distance between the valve seats.

Similarly for the lower deck, if x_1^1 and x_2^1 are the horizontal and vertical distances of the centre of the lower radial section from the centre of gravity of the middle section of the lower deck, we have for the bending moment at the centre of this deck

(19) . . . $M = P_1x_1^1 - P_4x_2^1 - \dfrac{pc^2}{2} + M_0$;

and for the displacement of the centre of action of the tension P_4 below the centre of gravity of the deck, we have

$$(20) \quad . \quad . \quad . \quad . \quad x_0 = \frac{P_1 x_1{}^1 - P_4 x_2{}^1 - \frac{pc^2}{2} + M_0}{P_4}.$$

This supposes that the whole of the bending moment M_0 comes upon the lower deck, which is hardly ever the case; and it may be well, in any actual example, to take advantage of the fact that, by its connection with the suction chamber or base, the lower deck is enabled to throw upon this base more or less of the bending action coming from the side walls. In fact, equations (19) and (20) are wholly based upon the supposition that the above connection is left out of consideration.

Let us apply our formulæ to the cylinder shown in Fig. 74, determining the stresses in two sections CD and LM, first under the assumption that M_0 is zero, and, secondly, that M_0 has a value to be determined by the method indicated above.

First. Side walls free, section CD:

$$M_0 = 0; \quad P_4 = pr_1 \sin. \alpha; \quad P_1 = 8p.$$

$$M = 4.12p; \quad G = 12p$$

$$I = \tfrac{9}{32}; \quad \frac{I}{y} = \tfrac{3}{8}; \quad A = 1\tfrac{1}{2}$$

$$\therefore f_1 = 10.99\,p$$

$$f_2 = 8\,p$$

$$f_1 + f_2 = 18.99\,p$$

For the section LM we have

$$M = M_0 = 0; \quad G = 11.65p;$$

$$\therefore f = f_2 = 7.76p.$$

Second. Suppose that the cylinder walls are "fixed" at their junction with the valve decks.

Then we have from equation (12)

$$M_0 = 2.52p,$$

and for the section *CD*

$$
\begin{aligned}
M &= (4.12 + 2.52)p; \\
&= 6.64p; \\
\therefore\ f_1 &= \tfrac{8}{3} \times 6.64p = 17.7p \\
f_2 &= \underline{\ 8\ \ p\ } \\
f &= f_1 + f_2 = 25.7p.
\end{aligned}
$$

For the section *LM* we have

$$M = M_0 = 2.52p;$$

$$
\begin{aligned}
\therefore f_1 &= \tfrac{8}{3} \times 2.52p = \ \ 6.72p \\
f_2 &= \qquad\qquad\ \ = \underline{\ 7.76p\ } \\
f &= f_1 + f_2 \ = 14.48p.
\end{aligned}
$$

If the centre of the curve had been taken at 0, making the radius of the inner surface $r_1 = 11.67$, the sides would have been subjected to a uniform tension of

$$11.67p.$$

For the form of cylinder shown in Fig. 75 we have

First. For the section *CD*, side walls "free,"

$$M_0 = 0;\ P_4 = 8.5p;\ P_1 = 8p;$$

$$M = 18.8p;\quad G = 10p;$$

$$I = \tfrac{9}{32};\ \frac{I}{y} = \tfrac{3}{8};\ A = 1\tfrac{1}{2};$$

$$
\begin{aligned}
\therefore f'_1 &= 50.13p \\
f'_2 &= \underline{\ 6.67p\ } \\
f' = f'_1 + f'_2 &= 56.8p.
\end{aligned}
$$

For the section *LM* we have

$$M = M_0 = 0;\ G = 10.95p;$$

$$\therefore f = f'_2 = 7.3p.$$

Second. Suppose that the cylinder walls are "fixed."

Then we have from equation (12)

$$M_0 = -12.47p,$$

and for the displacement of the centre of action of the tension P_4 below the centre of gravity of the deck, we have

$$(20) \quad . \quad . \quad . \quad . \quad x_0 = \frac{P_1 x_1{}^1 - P_4 x_2{}^1 - \frac{pc^2}{2} + M_0}{P_4}.$$

This supposes that the whole of the bending moment M_0 comes upon the lower deck, which is hardly ever the case; and it may be well, in any actual example, to take advantage of the fact that, by its connection with the suction chamber or base, the lower deck is enabled to throw upon this base more or less of the bending action coming from the side walls. In fact, equations (19) and (20) are wholly based upon the supposition that the above connection is left out of consideration.

Let us apply our formulæ to the cylinder shown in Fig. 74, determining the stresses in two sections CD and LM, first under the assumption that M_0 is zero, and, secondly, that M_0 has a value to be determined by the method indicated above.

First. Side walls free, section CD:

$$M_0 = 0; \quad P_4 = pr_1 \sin. \alpha; \quad P_1 = 8p.$$

$$M = 4.12p; \quad G = 12p$$

$$I = \tfrac{9}{32}; \quad \frac{I}{y} = \tfrac{3}{8}; \quad A = 1\tfrac{1}{2}$$

$$\begin{aligned} \therefore f_1 &= 10.99\,p \\ f_2 &= 8\,p \\ f_1 + f_2 &= 18.99\,p \end{aligned}$$

For the section LM we have

$$M = M_0 = 0; \quad G = 11.65p;$$

$$\therefore f = f_2 = 7.76p.$$

Second. Suppose that the cylinder walls are "fixed" at their junction with the valve decks.

Then we have from equation (12)

$$M_0 = 2.52p,$$

reason or another, the method here indicated should be applied to several sections; if for nothing else, as a basis to guide the judgment in determining the thickness of metal.

In this discussion the length of the section has been assumed as one inch, but in any real case the length to be considered will be determined by the distances between the valve seats, measured lengthwise of the cylinder; and any other variations of the method to suit an actual case will be readily made.

If the centre of the curve of the side wall is not taken midway between the decks, or if the walls are made with reversed curves, the method here given can still be followed; but the formulæ become too cumbersome for use in their general form.

DISCUSSION.

Prof. C. H. Benjamin.—During the past year I have conducted some experiments on cast-iron cylinders, the results of which I hope at some future time to present to the Society.

So far the experiments go to prove that but little reliance can be placed on existing formulas for thin shells and cylinder walls.

The uncertain nature of the material is always a disturbing factor, any little flaw or blow-hole which would otherwise be unnoticeable, serving as a starting point for a crack.

The flanges of the cylinder seem to exert more influence than has commonly been allowed.

In several instances the cylinder has cracked around a circumference near the flange instead of splitting longitudinally as it was expected to do, showing that on a cylinder of ordinary proportions the flange exerts a restraining influence on the metal of the whole cylinder to prevent splitting.

The stretching of the bolts which held the heads was one of the serious practical difficulties, but it effectually disposed of the theory that the tension due to screwing up should be added to the tension due to internal pressure.

Incidentally the experimenters learned nearly as much about the failings of various highly recommended packings as about the strength of cast-iron.

*Mr. C. W. Kettell.**—The engineering profession cannot fail to welcome any good and reliable experiments in the line of their

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* Author's Closure, under the Rules.

work, and the writer, therefore, hopes that Professor Benjamin will present to the Society at an early date the results of his labors. Formulas, however, will always have to be used more or less, because one cannot always subject a design to test until it has been actually carried out. But the use of formulas must always be governed by the sound judgment given by experience.

DCLXXXIII.*

THE WESTERN RIVER STEAMBOAT.

BY WILLIAM H. BRYAN, ST. LOUIS, MO.
(Member of the Society.)

In a public address delivered in 1895 at a convention of engineers a distinguished speaker made use of the following language:

"The advances in lake marine have been almost as great as those in ocean marine, but all this time our Western rivers are navigated by boats which differ little from those which ran upon them fifty years ago. They still have the wooden hulls, the long-stroke, high-pressure horizontal engine, the big separate side wheels, and the battery of small boilers; their machinery is a little better than it was at first, the pressure they carry a little higher, but the changes are so slight as to be insignificant. The channels of the principal Western rivers are being constantly improved under the direction of the general government, but as yet no response has been made to these improvements by the radical improvements which ought to come in the boats and their engines. Much is said of the decline of river business; it has declined because land transportation has given better and cheaper facilities. Until the boats on the Western rivers make the same advance that other tools of transportation have made, this business must continue to decline."

I rise to the defence of the Western river steamer. It seems proper that something be said in reply to such criticisms as these.

There are some minor points in which the Western river steamer may be improved, but in its general design and construction it is admirably fitted for the peculiar work which it has to do. Considered, therefore, strictly from an engineering standpoint, it is a creditable structure.

From my earliest days I have been closely associated with

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* Presented at the St. Louis meeting (May, 1896) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

ery. The average life of a steamer is so short, the rates of insurance so high, and the period of employment during the season so limited, as to make it imperative that the investment be kept at a minimum.

Experiment has demonstrated that the saving in fuel due to improved machinery does not, as a rule, compensate for the drawbacks accompanying its use, such as increased weight, space occupied, greater first cost, and less reliability.

Personally I am an advocate of the use of iron or steel hulls. They are already becoming common on Western rivers, and would be used almost universally if the first cost were not so great. A few years ago the cost was about double that of wooden hulls, but at the present low price of iron I believe the cost would be but little, if any, greater, if built in yards specially equipped with proper tools for the work. They certainly add to the steamer's life, and reduce its draught.

Long-stroke engines and side or stern wheels are necessary on account of the low depth of the channel.

Two forms of adjustable cut-offs have been introduced on the standard poppett-valve engine in recent years with considerable success, the "California" or "Cross," and the "Rees." Instead of the usual fixed cut-off of one-half, five-eighths, or three-fourths, it is adjustable at any point throughout the entire length of stroke. While it is an excellent feature to be able to vary the point of cut-off at will, an early cut-off is not always desirable, as it necessitates larger cylinders, greater weight and first cost, to do the same work. Furthermore, the usual fly-wheel cannot be employed. This drawback is to some extent remedied on stern-wheel steamers where the two engines are coupled at right angles. I see no reason, however, why some substitute for the fly-wheel—such, for instance, as the Worthington high-duty attachment—could not be employed on side or even stern-wheel steamers, in connection with the adjustable cut-off, to great advantage.

I cannot agree with the critic that the decline of river transportation is due to lack of improvement in the steamers, and that the introduction of lake and ocean machinery would rehabilitate river traffic. In my opinion it is due to other easily discernible causes, and the remedy must be found in other directions.

Accompanying this paper are some characteristic indicator

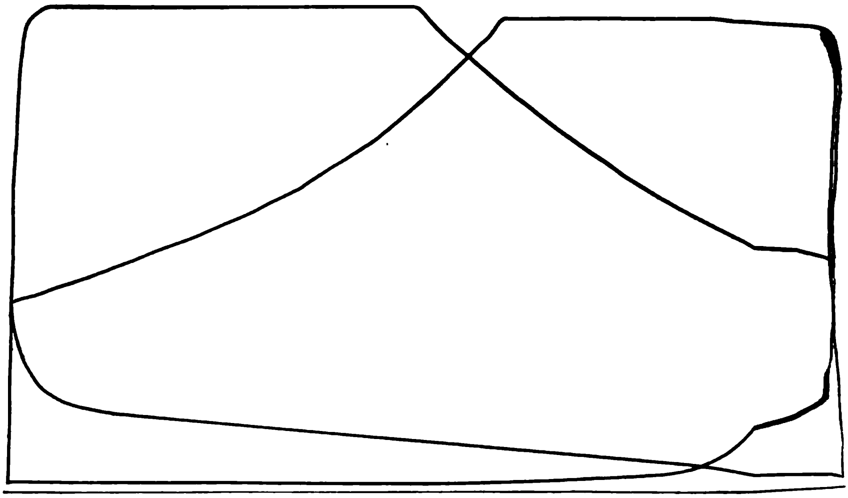

FIG. 80.—Rees cut-off. Pressure 157 pounds. Cylinders 15¼" x 7'. U. S. Steamer "Wm. Stone."

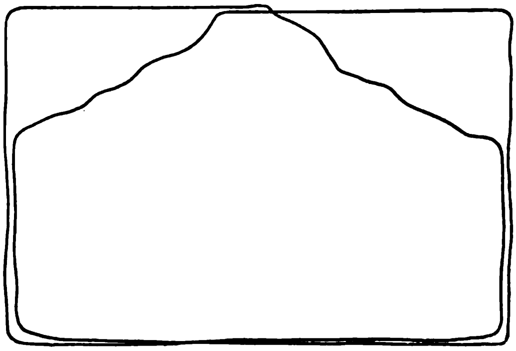

FIG. 81.—Larboard Engine, "Phil. E. Chappell." Revs. 23, Gauge 163, Scale 100. Cylinders, 12" x 36".

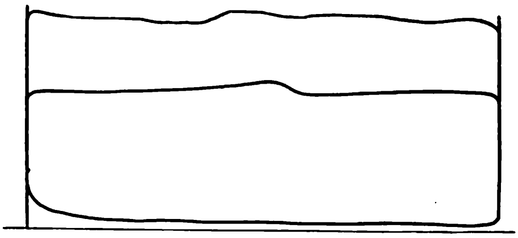

FIG. 82.—Scale 100, Gauge 142. Same Steamer. Running full stroke, and also on "slow" bell.

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Experiment has demonstrated that the saving in fuel due to improved machinery does not, as a rule, compensate for the drawbacks accompanying its use, such as increased weight, space occupied, greater first cost, and less reliability.

Personally I am an advocate of the use of iron or steel hulls. They are already becoming common on Western rivers, and would be used almost universally if the first cost were not so great. A few years ago the cost was about double that of wooden hulls, but at the present low price of iron I believe the cost would be but little, if any, greater, if built in yards specially equipped with proper tools for the work. They certainly add to the steamer's life, and reduce its draught.

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I cannot agree with the critic that the decline of river transportation is due to lack of improvement in the steamers, and that the introduction of lake and ocean machinery would rehabilitate river traffic. In my opinion it is due to other easily discernible causes, and the remedy must be found in other directions.

Accompanying this paper are some characteristic indicator

DISCUSSION.

Mr. George I. Rockwood.—I notice in the paper that the author seems to commend the practice of bleeding a little live steam into the low-pressure cylinder in order to get more speed out of the engine. Would he also approve of the practice of charging fat hams into the boiler furnace and seating members of the crew on the lever of the safety valve?

Mr. M. L. Holman.—As an older practitioner on the river, I will answer Mr. Rockwood's question with the author's permission. The principal consideration for all hands in Mississippi navigation is to get up the river in the shortest possible time.

Mr. William Kent.—The author's paper seems to me a work of supererogation, since the Mississippi steamboat needs no defence before this Society. Since Mr. Sweeney read his paper in 1888 at our Nashville meeting, no one in this Society has ever attacked the Western river practice; and he so completely answered those outside who may have criticised it that nothing more has ever been heard from them, until the address from which the author quotes on his opening page. *We* don't need to be told how commendable it is.

Mr. J. F. Holloway.—I desire to add something to what Mr. Bryan has said in his paper about the "Steamboats on the Western Rivers," thus availing of the privilege of subsequently continuing a discussion which for want of time during the meeting was curtailed. It is often considered quite the thing, by many persons, to speak in a derogatory manner in reference to what has been accomplished in the West, especially in matters pertaining to engineering, and of the men there engaged therein, and this, too, without a full understanding of the circumstances under which the work was done, or the service which it was expected to perform. Any one familiar only with the steamboats now in use on the Eastern rivers and Long Island Sound, and who had little or no acquaintance with the navigable rivers in the West, might, perhaps, be excused for any disparaging remarks they might be disposed to make when for the first time they see and examine a "Western river steamboat," for the reason that, as the splendid boats with which they are familiar are the outgrowth of many years of change and improvement, they cannot understand why the Western steamboats have been exempt from similar changes, and why to-day they bear so close a resemblance as they do, to the boats which floated on the same waters thirty or forty years ago. Having several years ago had opportunities of observing navigation as conducted on the Ohio, Cumberland, Tennessee, and Mississippi Rivers, I learned something of the difficulties with which the old-time engine builders and the builder of their hulls had to contend, and I also learned that as there had been no change in these rivers (except for the worse) since the early days when steam-driven boats first began there their struggles against strong currents, were swung around their abrupt bends, or were dragged over their shallow bars, that there could be little or no change now made either in the hulls of the present boats or in the engines that propel them. To comprehend the reasons which govern the design and construction of steamboats for use on Western rivers, one should have an acquaintance with the rivers themselves. It would be an easy task to build a boat which would navigate them when their channels are filled with water to a depth of from twenty to fifty feet; it is quite another matter to make the same boats carry any considerable cargo when these waters have fallen to a depth of from twenty to fifty inches, or even less. The apparent want of change or improvement in the construction of these river steamboats, and which in all respects are so unlike the changed and improved steamers which now float upon the deep Hudson or the adjacent Sound, is not due to the stupidity or want of skill in the engineers and builders of the present, but is due rather to the skill and ingenuity of the engineers and builders of the past, who did their work so well that no considerable improvement is now possible.

The problem of carrying the largest possible load on the shallowest water is one which permits of no question, either as to the model, or as to the construction of the boat as a whole. The model must be one which will displace the largest amount of water for each foot, or inch, of submergence, within the limit of the length and beam given, and the hull must be made of the lightest, scantiest material possible, and still hold together. All such stiffening devices used in other hulls, and known as main, centre, sister or side-keelsons, are unknown as such in the Western river steamboats, and indeed would be a disadvantage, as they would make the hull too stiff and rigid to allow of being dragged over sand bars by the use of derrick spars, much as a lame man makes progress by the aid of crutches under his arms. The economy of weight in the hull is also observable in the constructions of the cabin, whose stateroom partitions and other parts are all made up of the thinnest boards obtainable, and where the wood brackets, ornamental or otherwise, are examples of what a scroll saw can do and still leave something visible. In order to get the most power with the least weight, horizontal boilers having in them large return flues are used, which hold but little water, and whose small shells are made out of as light plate as can be used and pass inspection under the high pressure which they carry.

Were it not that the water used in these boilers is often very muddy, other and still lighter types of boilers would no doubt be used. The same controlling conditions permit the use of non-condensing engines only, and as the steam cylinders of these engines are the heaviest part of the engine, they are supported on long wooden frames or bed-plates, which rest upon the floor timbers of the boat, and are notched on them, and thus carry their weight much as one would use a long ladder to carry a weight over thin ice which otherwise would break under the load. The long wooden connecting rods, or "pitmen," as they are called on the Western rivers, are made out of the lightest, driest pine to be had, and are strapped on either side with the thinnest iron allowable, and they convey in a horizontal position the power of the steam cylinders to the cranks on the shafts of the side or stern wheels. These wooden "pitmen" have long been a standing object for criticism, and a topic for ridicule with many "new engineers," as a relic of engineering barbarism, and yet I fancy no possible combination resulting from engineering refinements can construct a substitute which will produce as good results in the same place, for anything like the same weight, stiffness, and cost. The valve gear of these engines, when compared with the elegant and exact devices employed on modern engines of the Corliss type, or those using elaborate and costly cams, or wipers, it must be confessed do look crude, inaccurate, and rough, and yet under conditions where the most refined modern valve gear would prove a lamentable failure, these old and crude devices are a success. The reason which induced the builders of engines for these Western river boats to adopt such peculiar construction could hardly be made clear without a careful description of a resemblance as they do, to the boats which floated on the same waters thirty or forty years ago. Having several years ago had opportunities of observing navigation as conducted on the Ohio, Cumberland, Tennessee, and Mississippi Rivers, I learned something of the difficulties with which the old-time engine builders and the builder of their hulls had to contend, and I also learned that as there had been no change in these rivers (except for the worse) since the early days when steam-driven boats first began there their struggles against strong currents, were swung around their abrupt bends, or were dragged over their shallow bars, that there could be little or no change now made either in the hulls of the present boats or in the engines that propel them. To comprehend the reasons which govern the design and construction of steamboats for use on Western rivers, one should have an acquaintance with the rivers themselves. It would be an easy task to build a boat which would navigate them when their channels are filled with water to a depth of from twenty to fifty feet; it is quite another matter to make the same boats carry any considerable cargo when these waters have fallen to a depth of from twenty to fifty inches, or even less. The apparent want of change or improvement in the construction of these river steamboats, and which in all respects are so unlike the changed and improved steamers which now float upon the deep Hudson or the adjacent Sound, is not due to the stupidity or want of skill in the engineers and builders of the present, but is due rather to the skill and ingenuity of the engineers and builders of the past, who did their work so well that no considerable improvement is now possible.

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DCLXXXIV.*

THE EFFECT, UPON THE DIAGRAMS, OF LONG PIPE-CONNECTIONS FOR STEAM-ENGINE INDICATORS.

BY W. F. M. GOSS, LAFAYETTE, IND.

(Member of the Society.)

THE experiments which serve as a basis for this paper were developed in the engineering laboratory of Purdue University by Mr. Paul W. Covert, † to whom, also, the writer is indebted for many courtesies.

The facts presented are grouped under several heads, as follows: I., Purpose of the Work; II., Apparatus and Methods; III., Analysis of Results; IV., Conclusions.

I. PURPOSE OF THE WORK.

The excellence of the modern steam-engine indicator, and a growing appreciation of its value, have operated in recent years greatly to extend its use. It serves the designer of a proposed engine by disclosing to him the performance of those already existing, its aid is a guide in the adjustment of the new engine, and its record is an important factor in a determination of the power and efficiency of the completed machine. The record of the indicator is, also, often accepted as conclusive in the settlement of important matters of business, and in the development of interesting questions in science. It is well, therefore, that every condition affecting its accuracy be known and appreciated.

It is commonly assumed that any one understanding the action of the indicator is competent to apply it and to interpret the results which it gives; and it is true that, viewing the instrument as an educational means, its widest use is justifiable. But reliable results with the indicator are not obtained by chance, nor by dependence upon fine mechanism alone, but

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* Presented at the St. Louis meeting (May, 1896) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

† *Thesis*—"Effect of Pipe Connections on the Form of Indicator Cards," by Paul W. Covert, B.M.E., Purdue University, 1895.

rather by an intelligent application of the instrument and by watchful and painstaking manipulation. As has been said of liberty, so it may be said of reliable indicator cards—their price is "eternal vigilance." In general, one is not justified in accepting a diagram as a basis for safe conclusions unless very much more is known about it than the information given by its outline.

Errors in indicator diagrams may arise from several causes, one of which is the pipe connecting the indicator with the engine cylinder. It is admitted that, under the conditions of ordinary practice, the presence of the pipe does not constitute the most prolific source of error, but it can be shown that it does cause serious distortion in the form of the diagram, and it is believed that this fact merits more careful consideration than has heretofore been accorded to it. The writer has already called attention to the fact that in road tests of locomotives, where the indicator is attached to a length of pipe sufficient to bring the instrument to the top of the valve box (a length of 3½ feet or more), a true card can be obtained only at slow speeds; and has shown that, for a speed of 300 revolutions per minute, the area of the diagram is likely to be in error as much as 17 per cent.* These early experiments were further used as the basis of a discussion concerning the precise character of the influence exerted by the pipe.† They have now been followed by a more extended series of experiments, the results of which are herewith presented.

II. Apparatus and Methods.

All experiments were made in connection with a 7¾-inch by 15-inch Buckeye engine. The power of this engine was absorbed by an automatic friction brake, by means of which a very constant load was obtained. The head end of the engine cylinder was tapped with two holes (*a* and *b*, Fig. 84), both in the same cross section, and hence equally exposed to the action of the steam in this end of the cylinder. One of these holes (*a*) was made to serve for the indicator *A*, the cock of which was placed as close to the cylinder as possible. The hole *b* was made to receive one end of a U-shaped pipe, the other end of which entered a coupling fixed in the angle-plate *c*. The cock of a

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* Proceedings of Western Railway Club, March, 1894, p. 257.

† *American Machinist*, January 25, 1894, p. 6.

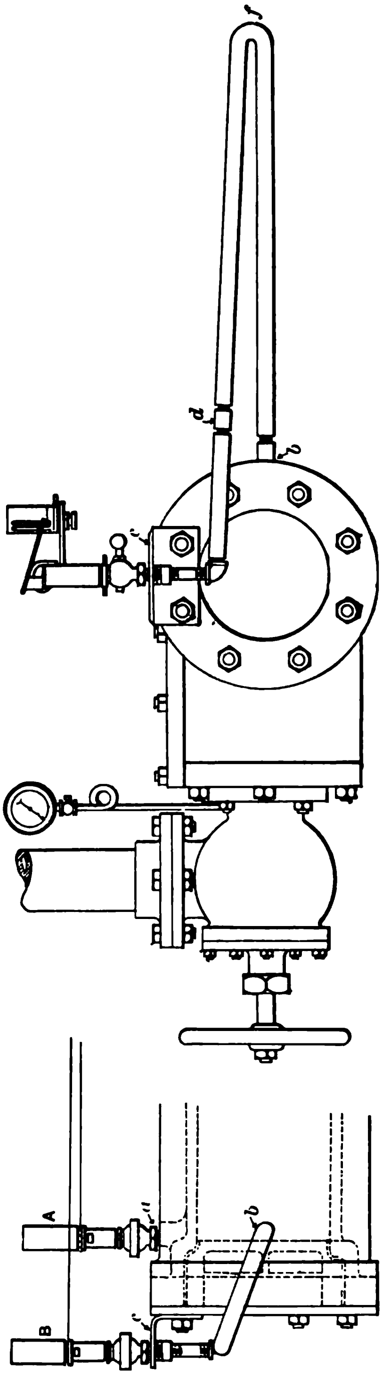

FIG. 84.

rather by an intelligent application of the instrument and by watchful and painstaking manipulation. As has been said of liberty, so it may be said of reliable indicator cards—their price is "eternal vigilance." In general, one is not justified in accepting a diagram as a basis for safe conclusions unless very much more is known about it than the information given by its outline.

Errors in indicator diagrams may arise from several causes, one of which is the pipe connecting the indicator with the engine cylinder. It is admitted that, under the conditions of ordinary practice, the presence of the pipe does not constitute the most prolific source of error, but it can be shown that it does cause serious distortion in the form of the diagram, and it is believed that this fact merits more careful consideration than has heretofore been accorded to it. The writer has already called attention to the fact that in road tests of locomotives, where the indicator is attached to a length of pipe sufficient to bring the instrument to the top of the valve box (a length of 3½ feet or more), a true card can be obtained only at slow speeds; and has shown that, for a speed of 300 revolutions per minute, the area of the diagram is likely to be in error as much as 17 per cent.* These early experiments were further used as the basis of a discussion concerning the precise character of the influence exerted by the pipe.† They have now been followed by a more extended series of experiments, the results of which are herewith presented.

II. Apparatus and Methods.

All experiments were made in connection with a 7¾-inch by 15-inch Buckeye engine. The power of this engine was absorbed by an automatic friction brake, by means of which a very constant load was obtained. The head end of the engine cylinder was tapped with two holes (*a* and *b*, Fig. 84), both in the same cross section, and hence equally exposed to the action of the steam in this end of the cylinder. One of these holes (*a*) was made to serve for the indicator *A*, the cock of which was placed as close to the cylinder as possible. The hole *b* was made to receive one end of a U-shaped pipe, the other end of which entered a coupling fixed in the angle-plate *c*. The cock of a

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* Proceedings of Western Railway Club, March, 1894, p. 257.

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EFFECT OF LONG PIPE-CONNECTIONS FOR INDICATORS.

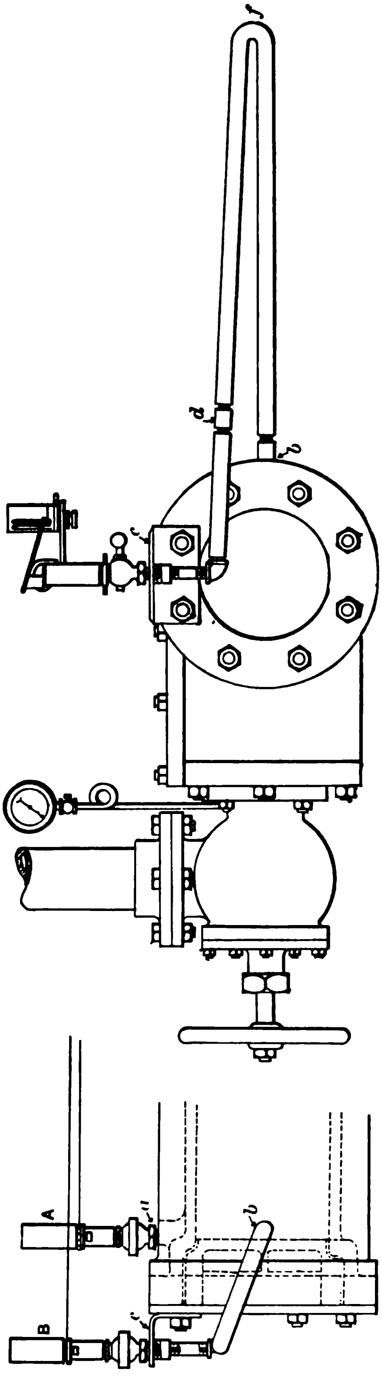

FIG. 84.

second indicator, *B*, was screwed to this coupling. A single system of levers supplied the drum motion for both indicators. The closely-connected indicator, *A*, will hereafter be referred to as the "cylinder-indicator," and the cards obtained from it as "cylinder-cards." It is assumed that this indicator recorded the actual conditions of pressure existing in the cylinder. In like manner the indicator *B* will be referred to as the "pipe-indicator," and cards obtained from it as "pipe-cards." It is assumed that this indicator gave a record which, when compared with that given by the cylinder-indicator, demonstrated the effect of the pipe.

The pipe fittings were all half-inch. A right-and-left coupling at *d* allowed the U-shaped section *d f b* to be removed at will and replaced by a similar section of different length. Pipe lengths of 5, 10, and 15 feet were used, length being measured from the outside of the cylinder wall to the end of the coupling under the cock of the pipe-indicator. The pipe and fittings were covered first with a wrapping of asbestos board, next with three-eighths of an inch of hair felt, and finally with an outside wrapping of cloth. It is to be noted that the bend in the pipe at *f* is easy, and that there is a continual rise in the pipe in its course from the cylinder to the indicator. Both indicators were always well warmed before cards were taken. A gauge between the throttle and the valve box was useful as an aid in securing constant pressure within the latter. In the tests herein described, however, the boiler pressure was kept constant as nearly as possible, and the throttle was generally "full open."

A pair of new Crosby indicators was set apart for this work, and while it will be shown that the value of the comparisons which were undertaken is not dependent upon a high degree of individual accuracy in the indicators, these instruments, when calibrated under steam, gave results which were nearly identical.

The results, which are presented in the form of diagrams (Figs. 85, 86, 87, etc.), were obtained in the following manner:

The engine having been run for a considerable period, and the desired conditions as to pressure, speed, and cut-off having been obtained, cards were taken simultaneously from the cylinder and the pipe-indicator. Two pairs of cards (*i.e.*, two from cylinder and two from pipe) were thus taken as rapidly as convenient, after which the position of the indicators was reversed, by the cylinder-indicator. As a result of this lagging in the action of the pipe-indicator, its card is in error in the location and curvature of the expansion and compression curves; also in the location of the events of the stroke, and in the area which it presents. The speed at which these errors are shown to occur is moderate (200 revolutions), and the length of pipe attached to the indicator is not greater than is often used.

The general effect of a ten-foot length of pipe (Fig. 86) is the same with that of the shorter length, but the lagging action due to the pipe is more pronounced, and all errors are proportionately greater. In this case, also, the admission and exhaust lines fail to agree, the total range of pressure recorded upon the cards being less than the range existing in the cylinder.

A still further addition to the length of the pipe brings changes (Fig. 87) into the form of the pipe-card diagram which, while entirely in harmony with those already discussed, are of such magnitude that the form of the card loses some of its characteristic features. The admission and expansion lines are lower, and the exhaust line is higher, than are the corresponding lines for the true card. Reference to Table I. will show that while cards from pipes of five and ten feet in length present an area greater than that of the true card, the card in question (Fig. 87) from a fifteen-foot length of pipe makes the area less.

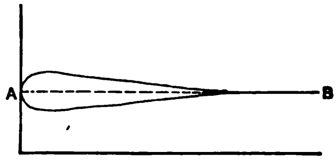

FIG. 88.

A comparison of the pipe-cards, Figs. 85, 86, 87, makes it evident that a pipe of suitable length would result in a diagram somewhat similar in form to that shown by Fig. 88; a pipe still longer would give a card which would be represented by a single line, as *AB*, Fig. 88.

Various numerical results from Figs. 85, 86, and 87 are exhibited in Table I.

It is true that the lengths of some of the pipes experimented with are excessive as compared with those commonly used for the connection of indicators, but this fact does not deprive the results of their significance. If pipes of fifteen, ten, and five and the work repeated. There were thus obtained four cylinder-cards and four pipe-cards, one-half of each set having been made by one of the indicators, and one-half by the other. Next, by the use of closely-drawn ordinates the four cylinder-cards were averaged and combined in the form of a single card, and the four pipe-cards were in the same way combined to form a single pipe-card. The two typical cards thus obtained, superimposed as in Fig. 85, constituted the record of the test. This process was repeated for each of the several conditions under which tests were made. It is proper to add that the accuracy of the indicators used, and the constancy of the conditions maintained, were such as to make each card almost, if not quite, the exact duplicate of the representative of its set.

The diagrams presented are full sized, the spring for all being sixty pounds.

III. Analysis of Results.

Different Lengths of Pipe.—The effects produced by the use of pipes between the indicator and the engine cylinder, of five, ten, and fifteen feet in length, are shown in Figs. 85, 86, and 87 respectively, the speed, steam pressure, and cut-off being constant. As noted upon the figures, the full outline represents the cylinder-card, and the dotted outline the pipe-card.

It would seem that, under the conditions stated, the form of cylinder-cards in the figures referred to should be nearly the same, whereas the figures show them to vary considerably. It will be well to omit, for the present, all discussion concerning the causes of these differences, and to accept the cylinder-card in each case as representing the true conditions within the cylinder.

By reference first to Fig. 85, it will be seen that the effect of a five-foot pipe is to make the indicator attached to it a little tardy in its action. Thus, during exhaust, when for a considerable interval of time the change of pressure to be recorded is slight, the lines from the two indicators agree ; but during the compression which follows, the loss of sensitiveness in the pipe-indicator is made evident by its giving a line which falls below the corresponding line traced by the cylinder-indicator. Similarly, during admission there is an approximate agreement, while during the expansion which follows, the lagging of the pipe-indicator results in a line which is higher than the expansion line given

Increased clearance would lower the pressure at the end of compression, and would change the curvature of the compression line; but it would not make the compression line as it appears in Fig. 87.

The larger exposed surface would increase the effect due to the interchange of heat between the steam and the walls inclosing it. If it be assumed that, during the early stages of compression, this interchange results in re-evaporation, and during the later stages in condensation, the sum total of the effect would be in line with that recorded. Such an assumption is reasonable, and such an action may in part account for the change under discussion, but it is not likely that the extent of this action is so great as the indicator has recorded.

By far the most active agent tending to reduce the curved compression line of Fig. 85 to the straight line of Fig. 87 is that of motion due to the flow of steam in and out of the mouth of the pipe. Thus, when compression begins in the cylinder, the pressure at the pipe-indicator is greater than that in the cylinder (see Fig. 87), and steam must flow from the pipe to the cylinder. This current of steam entering the cylinder just when the mixture of steam and water already there is undergoing the early stages of compression, helps to augment the cylinder pressure, and to carry the early part of the compression line higher than it would otherwise go. As the process of compression goes on, the current in the pipe is reversed, and the cylinder supplies steam to the pipe, thus causing the curve for this portion of the event to fall lower than it otherwise would. Increased curvature during the early stages and diminished curvature during the later stages result in a line which is approximately straight (Fig. 87).

Similar reasoning will account for the rapid drop in pressure after cut-off (cylinder-card Fig. 87). At the instant of cut-off the cylinder is supplying steam to the pipe. The flow is rapid, and the kinetic energy of the steam causes it to pile up in the pipe; and although as the stroke advances this pressure is constantly decreasing, the pipe continues throughout expansion to hold a higher pressure than that contained by the cylinder.

It is obvious that the pressure is not the same at the two ends of the pipe, except for points indicated by the crossing of the lines, as at a, b, and c (Fig. 87), and that the difference of pressure shown at other points is quite sufficient to account for the pronounced change in the cylinder-diagram when pipes of different lengths are used. The existence of these differences in the form of the cylinder-diagram does not in any way affect the results which this paper is designed to present. All cylinder-cards may be accepted as true, and the fact that they are not all alike does not diminish their value, but rather emphasizes the importance of this whole subject.

The Effect of the Pipe at Different Speeds.—The effects thus far discussed are those recorded for a constant speed of 200 revolutions per minute. In considering to what extent changes of speed will modify these results, reference should be made to Figs. 89, 90, and 91, which give a series of results for which all conditions were constant except that of speed. Numerical comparisons may be made from Table I. It will be seen that increase of speed produces modifications in the form of the pipe-diagrams which, in kind, are similar to those produced at constant speed by increasing the length of the pipe, but these changes are not great. For example, increasing the speed from 100 to 200 revolutions per minute (Figs. 89 and 90) produces less change than increasing the length of the pipe from five to ten feet (Figs. 85 and 86). The fact that an engine runs slowly, therefore, does not seem to justify the use of an indicator at the end of a considerable length of pipe. Slow running reduces the error; it cannot be depended upon to eliminate it entirely.

The Effect of the Pipe at Different Cut-offs.—The relative effect of the pipe at different cut-offs, other conditions being constant, is shown by Figs. 92, 93, and 94, and numerically by Table I. It will be seen that the differences of pressure recorded during expansion by the two indicators (pipe and cylinder) are approximately the same for all cut-offs; but the relative effect of these differences upon the area of the diagram is most pronounced upon the smallest, or shortest, cut-off card. The fact that in Fig. 94 the steam line on the pipe-card rises while that of the cylinder-card declines, constitutes a good illustration of the slowness with which the pressure in the pipe responds to that in the cylinder.

Comparisons have been made from tests run under still other conditions, and all conclusions thus reached have been consistent with those presented. This whole plan of work was outlined with the expectation of securing such data as would permit a complete analysis of the effects produced by a pipe. But the results show that these effects are modified by so many different conditions that their precise character cannot be safely predicted.

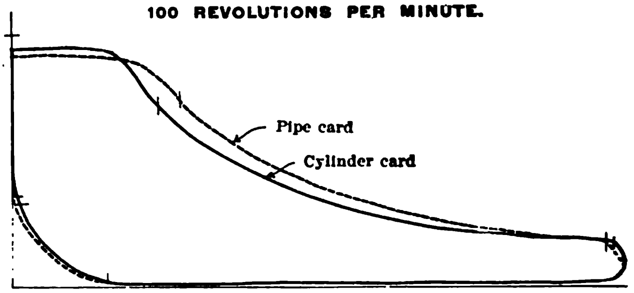

FIG. 89.

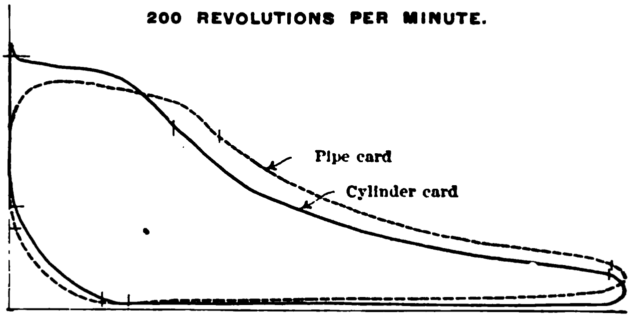

FIG. 90.

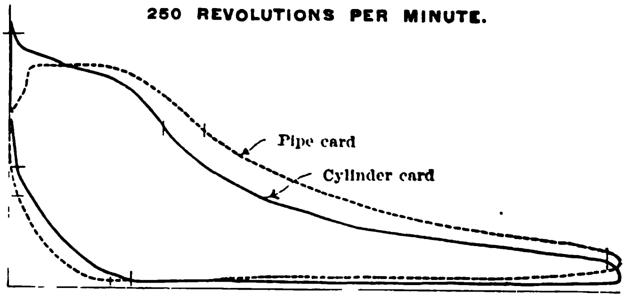

FIG. 91.

NOTE: -

The steam pressure (90 pounds), the length of pipe (10 feet) and the cut-off (approximately ¼ stroke), were constant for all diagrams on this page.

Even if it were possible to construct an expression for reducing a distorted pipe-diagram to a form which would correctly represent the relation of pressure and volume within the cylinder, the number of its terms would be so great, and its form so complicated, that the expression would have no practical value.

TABLE I.

Test Number.	No. of Figure Representing Diagram.	APPARENT CUT-OFF. EXCESS SHOWN BY PIPE DIAGRAM.		PRESSURES. EXCESS (+) OR DEFICIENCY (−) SHOWN BY PIPE DIAGRAM.								STEAM CONSUMPTION PER HORSE-POWER PER HOUR. EXCESS (+) OR DEFICIENCY (−) AS SHOWN BY PIPE DIAGRAM.	
				At Cut-off.		At Release.		At the Beginning of Compression.		M. E. P.			
		Per Cent. of Stroke.	Per Cent. of Cyl. Cut-off.	Pounds.	Per Cent.	Pounds.	Per Cent.	Pounds.	Per Cent.	Pounds.	Per Cent.	Pounds.	Per Cent.
1	2	3.0	11.5	−1.3	−2.2	0.0	0.0	−0.1	−5.6	+1.2	+3.7	−0.1	−0.5
2	3	6.8	24 3	−2.8	−4.8	+2.1	+18.0	+0.2	+9.2	+2.7	+8.5	−0.4	−1.7
3	4	10.0	38.4	−5.1	−9.8	+6.5	+57.7	+4.0	+200.0	−1.5	−5.0	+11.7	+45.9
4	6	4.0	16.6	+1.1	+2.0	−0.5	−3.7	+0.1	+6.0	+3.0	+8.8	−2.0	−7.2
5	7	7.5	27.7	−2.8	−4.8	+2.1	+18.0	+0.2	+9.2	+2.2	+6.6	−0.4	−1.7
6	8	6.8	26.7	−3.0	−5.7	+2.3	+24.3	−0.3	−9.0	+5.3	+18.7	−1.0	−4.2
7	9	3.3	25.4	+3.5	+6.7	0.0	0.0	0.0	0.0	+6.5	+35.3	+11.5	+47.9
8	10	7.0	25.9	−2.8	−4.8	+2.1	+18.0	+0.2	+9.2	+4.2	+12.8	−0.4	−1 7
9	11	2.3	6.5	+6.0	+10.3	+3.0	+18.2	+1.0	+50.0	+1.4	+3.4	−6.8	−23.6

All percentage values are based on results from cylinder-diagrams. For example, in test No. 4 the pressure at cut-off shown by pipe-card is 2 per cent. in excess of that shown by the cylinder or true card; the pressure at release by the pipe-card is 3.7 per cent. less than by the true card; the pressure at the beginning of compression by the pipe-card is 6 per cent. greater than by the true card; and the mean effective pressure by the pipe-card is 8.8 per cent. greater than by the true card.

IV. CONCLUSIONS.

The following conclusions constitute a summary of the data already presented:

1. If an indicator is to be relied upon to give a true record of the varying pressures and volumes within an engine cylinder, its connection therewith must be direct and very short.

2. Any pipe connection between an indicator and an engine cylinder is likely to affect the action of the indicator; under ordinary conditions of speed and pressure, a very short length of pipe may produce a measurable effect in the diagram, and a length of three feet or more may be sufficient to render the cards valueless except for rough or approximate work.

3. In general, the effect of the pipe is to retard the pencil action of the indicator attached to it.

4. Other conditions being equal, the effects produced by a

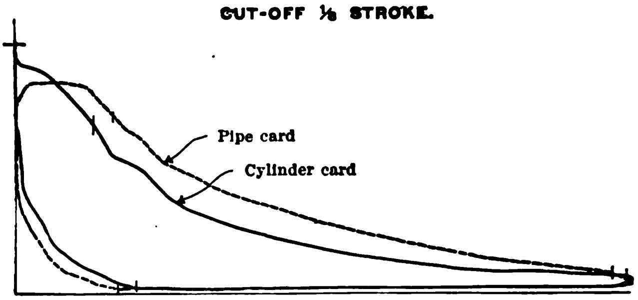

FIG. 92.

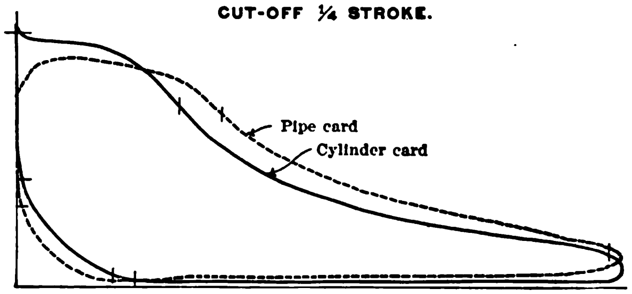

FIG. 93.

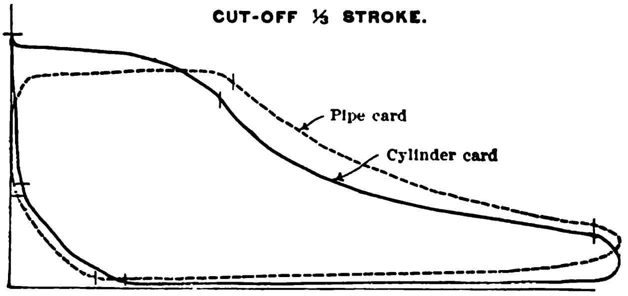

FIG. 94.

NOTE:—

The cut-off as given above is approximate. The steam pressure (80 pounds), the speed (200 revolutions per minute) and the length of pipe (10 feet), were constant for all diagrams on this page.

pipe between an indicator and an engine cylinder become more pronounced as the speed of the engine is increased.

5. Modifications in the form of the diagram resulting from the presence of a pipe, are proportionally greater for short cut-off cards than for those of longer cut-off, other things being equal.

6. Events of the stroke (cut-off, release, beginning of compression) are recorded, by an indicator attached to a pipe, later than the actual occurrence of the events in the cylinder.

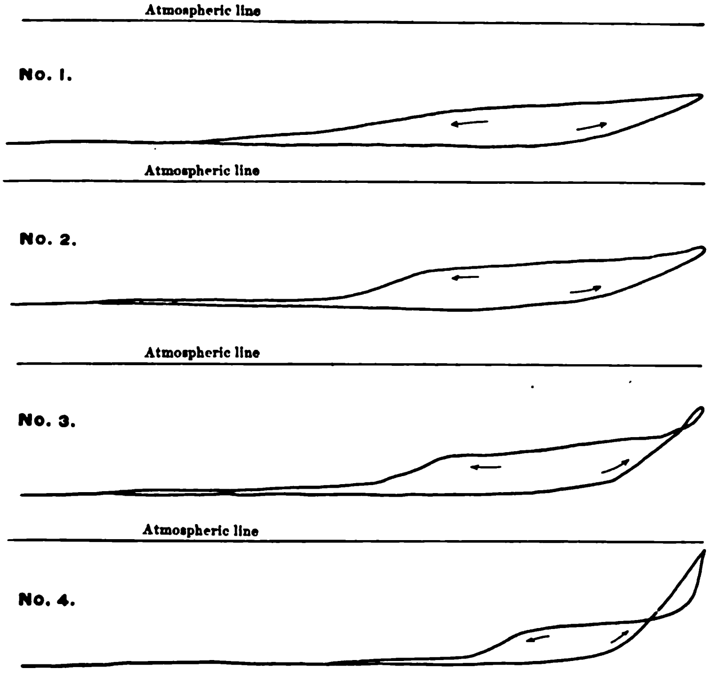

FIG. 95.

7. As recorded by an indicator attached to a pipe, pressures during the greater part of expansion are higher, and during compression are lower, than the actual pressures existing in the cylinder.

8. The area of diagrams made by an indicator attached to a pipe, may be greater or less than the area of the true card, depending upon the length of the pipe; for lengths such as are ordinarily used, the area of the pipe-cards will be greater than that of the true cards.

9. Within limits, the indicated power of the engine is increased by increasing the length of the indicator pipe.

10. Conclusions concerning the character of the expansion or compression curves, or concerning changes in the quality of the mixture in the cylinder during expansion or compression, are unreliable when based upon cards obtained from indicators attached to the cylinder through the medium of a pipe, even though the pipe is short.

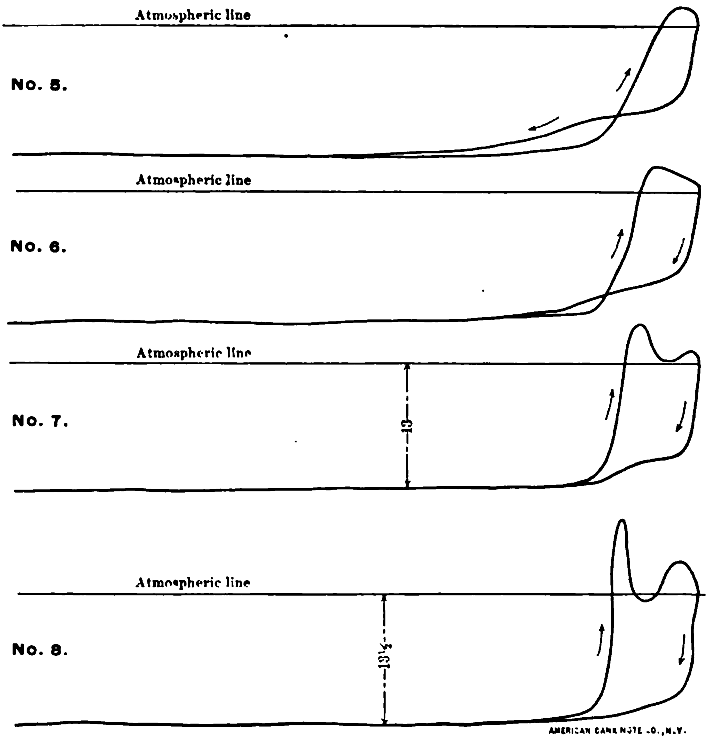

Fig. 96.

DISCUSSION.

Mr. Albert F. Hall.—The accompanying copies of indicator cards, Figs. 95 and 96, showing the effect of excessive throttling of the indicator cock, may be of some interest in connection with Mr. Goss's paper. They were taken from a single-acting vertical air pump, the greatest closing of the cock occurring in No. 1, Fig. 95. It is interesting to notice the reversal of the curves from this cause.

DCLXXXV.*

STRUCTURAL STEEL FLY-WHEELS.

BY THOMAS E. MURRAY, ALBANY, N. Y.
(Member of the Society.)

WITH the increasing use of large and fast-running engines in the generation of electric power, the problem of providing fly-wheels which shall not be liable to bursting is one of great and growing importance to the mechanical engineer. This is especially so because large power stations are usually and necessarily located in the central and crowded sections of cities, where any accident is liable to cause much loss of life and the destruction of much valuable property. That large iron castings are unreliable, when subjected to sudden and severe strains, is recognized by all. It is evident that cast-iron fly-wheels have reached the limit of development, and it is doubtful if much further improvement is to be expected in them. The frequent accidents to large wheels of this type show that there must be some radical change in construction in order to make wheels which shall be free from danger of bursting by centrifugal force.

With the cheaper production of steel, the latter metal, in nearly every branch of mechanical industry, has taken the place of cast iron, and the object of this paper is to describe a novel application of steel plates as a substitute for cast iron in fly-wheels.

The engine for which this new wheel was designed and made was one of a pair in the power house of the Albany Railway at Albany, N. Y.

The former cast-iron wheel which it replaced and which was twenty feet in diameter by fifty inches face, and weighing fifty thousand pounds, burst, causing considerable damage. It was connected to a twenty-inch by thirty-six-inch by forty-eight-inch tandem compound engine, and was belted to a forty-eight-inch pulley located on a 500 Kilowatt generator.

Running under normal conditions this engine made seventy-

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* Presented at the St. Louis meeting (May, 1896) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

two revolutions per minute. At the time of the accident, the speed of the engine (according to statements given at the time, and from computations made from the distances that portions of the wheel were thrown) was far beyond the conditions of every-day practice.

The author does not attempt to state here the cause of the accident, or the acceleration in speed, but his faith in *cast-iron fly-wheels* was considerably shaken, and to replace the broken wheel he naturally looked for something better and of different material, which would stand the very high rate of speed and have a greater factor of safety, and, at the same time, locate the weight in the wheel where the best results would be accomplished.

As some balance wheels had been constructed of structural steel with good results, the writer looked for a *belted wheel* of the same material, but was unable to locate any which had been built, and accordingly designed a wheel as per the accompanying drawing,

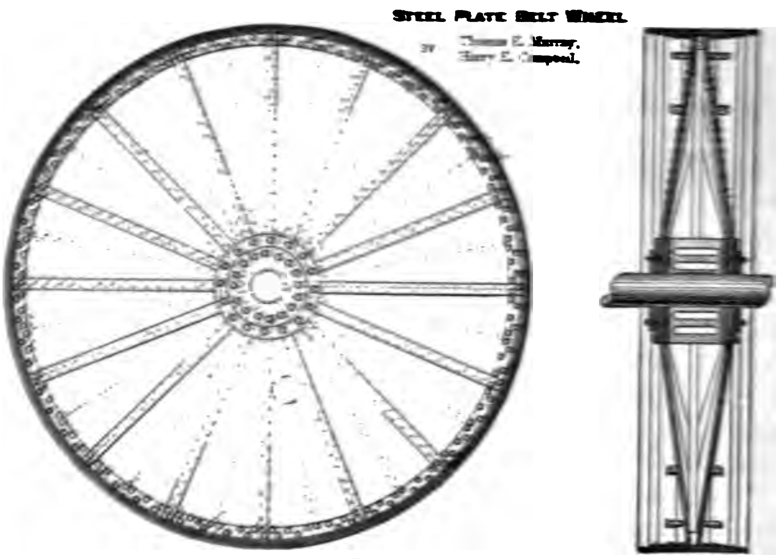

FIG. 97.

and an order was placed for two wheels with Harry E. Campbell, of the Albany Construction Works.

It may be well to say here that the wheel was not designed to run at seventy-two revolutions per minute, or at any stated factor of safety, but the construction was of the strongest possible at a moderate cost. I am well aware that certain parts

of the wheel are much stronger than others, as, for instance, the hub and disks which take the place of the arms or spokes.)

DESCRIPTION OF WHEEL.

The steel was of a grade known as "shell-steel," *open-hearth* process, and of 60,000 pounds tensile strength, and great care was used to have grain, in the direction in which the plates were rolled, placed in position so as to give the greatest strength. All rivets used were Burden's best, and were of two sizes; namely, one and one-quarter inches, and three-quarters of an inch in diameter.

HUB.

The hub is described as follows: Six ¾-inch disks were sheared 36 inches in diameter, and fourteen, 48 inches in diameter; and these plates, together with the cast-iron separator or spider, 23 inches long by 48 inches in diameter, composed the hub, and were assembled as follows: Two sets, composed of three 36-inch and three 48-inch disks each, were drilled for 32 countersunk rivets, and after being securely clamped to tight joints, were riveted together, making two hub sections for outer part of wheel hub, each 4½ inches thick, and these were bored to a "driving fit" to shaft; two sets of four disks each were secured together and bored in same manner for inside sections of hub, giving a steel bearing on shaft of 15 inches. The casting or spider, weighing 2,700 pounds, was bored to a close fit and placed on shaft. This casting was faced on ends and cored for thirty-two 1$\frac{5}{16}$-inch hub bolts and provision made for keys. The four steel hub sections were next clamped together and bored for the 32 steel bolts. The two sections, 48 inches by 3 inches, were driven on the shaft, one against each end of spider, and one of the 36-inch by 48-inch by 4½-inch started on each end of shaft and driven past bearings, after which the shaft was set in position in bearing. Each part of hub was faced to right angles with bore.

DISKS.

Two dished webs were formed, 19 feet 6¾ inches in diameter, each composed of two layers of ¼-inch plate, and each layer having 16 sections, making 64 plates in all. These plates were drilled so as to have all joints broken. Said rivet holes were 3 inches on centres, staggered, and four lines of holes running lengthways of plate. The small ends of plates were heated and bent on a form to right angle to shaft, and each drilled for two 1⅞ hub bolts. The rim ends of plates were drilled for two lines of rivets, and in such a manner as to properly secure segments of 6-inch by 6-inch by ½-inch angle irons. These plates were next connected between inside and outside hub steel plates, sections forming two complete dished disks which were 2 inches apart at rim, and 29 inches apart at hub. Thirty-two 5-inch by ¾-inch steel bars were fitted one over each outside joint of disk plates with hub end bent, and rim ends formed two right angles with centre of wheel, or parallel with shaft. This end was bent to secure rim in connection with angles, and were each drilled for two 1¼-inch rivets. Great care was used in making these bends, and sharp angles were avoided. All bars were drilled from a template. After the bars and plates were assembled in position, with temporary bolts, the hub was bolted together with bolts passing entirely through hub and disks and drawn close and firmly together, each bolt passing through 2 bars, 4 plates, and all parts of hub. Between the outer edges of disks a cast-iron filler ring was placed and all bolted temporarily together. As all parts were drilled to templates, the work proved true and in line. The riveting was done from the outside with one man inside holding on and taking the hot rivets through a man-hole left for that purpose.

RIM.

The manner of constructing rim was as follows: eight 32-inch by ½-inch plates were rolled to form a circle, and riveted to, and with joints over, the 5-inch by ¾-inch bars. Over these plates another layer of 40-inch by ¾-inch plates, in sixteen parts, was placed with joints broken over the first layer. The 6-inch by 6-inch by ½-inch angle irons were next formed, and securely riveted and bolted to disks, and also through both rim plates, with countersunk rivets. The ¾-inch and ½-inch plates were also riveted together, rivets 4-inch centres. Another layer of ⅝-inch plate, 50 inches wide, was next riveted on. This was also cold rolled, and the last or face sheet, 50-inch by ⅝-inch, was rolled hot and riveted on. The countersink of last sheet was almost its full thickness; sixty-four 1¼-inch rivets were driven through the 5-inch by ¾-inch bars and all rim plates, connecting all plates and disks. The wheel was then keyed to shaft with two cast-steel keys, one driven from each side of hub; and without turning or facing the wheel in any way, the belt was put on and the wheel put to work. The belt remained in centre of wheel, and has been running two months. There are three points in the diameter of wheel which buckles in plate, due to heating, raised $\frac{3}{16}$ of an inch out of true, but the balance of wheel is practically true and in line with shaft. The wheel will be turned later. The weight of wheel is 57,930 pounds, distributed as follows:

Rim	32,000 pounds.
Disks	16,400 "
Hub	9,530 "

In calculating the strength of this wheel we need not begin at the hub and figure out every part as in a cast-iron arm-wheel. It is enough to know its strength at the weakest point, which is undoubtedly the outer layer of rim plates, as those plates must leave the wheel before any other part could give way.

Each of these plates weighs 590 pounds, and the direct centrifugal force on each plate, tending to hurl it off the wheel, is, according to Haswell's formula:

$$F = W\frac{n^2 d}{5,217} = \frac{590 \times 72^2 \times 20}{5,217} = 11,725 \text{ pounds nearly.}$$

But these plates are held in position by rivets having a total area of 20.75 square inches, which at a strain of 15,000 pounds per square inch would carry 311,250 pounds.

$$\text{Then the factor of safety} = \frac{311,250}{11,725} = 26 \text{ nearly.}$$

I regard the device of making the disks or webs dished, on the same principle as a bicycle wheel, as the most important feature of this wheel, and I believe it could be applied with success to broad-faced wheels for mill work by using double pairs of disks, and also to balance wheels, such as are used with direct connected engines for the generation of electric light or power.

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Mr. William Kent.—I can scarcely agree with the way of calculating the factor of safety on page 417. A strain of 15,000 pounds per square inch is given for rivets. Surely the rivets would have a maximum strength of 45,000—three times as much —and the factor of safety would be three times what is given in the paper.

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The author states his care to use the material carefully "in the direction of the grain" in the case of open-hearth steel. It is one of the great advantages of steel that it has no grain in the sense which iron has, and it occurs to me that the makers of open-hearth steel would be not a little surprised to be told that their material should be used with regard to this peculiarity.

Mr. H. H. Suplee.—This wheel suggests to me some acquaintance which I had ten or twelve years ago with the subject of wrought-iron wheels for high-speed uses in large band-saw mills. These band-saw wheels were of 7, 8, or 9 feet in diameter, running at 250 to 300 revolutions a minute, and they would not stand if made of cast iron. They had fluctuating strains upon them, the centrifugal force due to the high speed, and the crushing force from very high tension on the band-saw blade. The saw had to be strained so taut that cast-iron wheels were crushed, while the high speed occasionally caused accidents from centrifugal force. To avoid those a wrought-iron wheel was designed. It was not greatly different from this in construction except that it was made with rods for arms. The great point there was to have the upper wheel as light as possible consistent with strength, to avoid the fly-wheel action, and to make the lower wheel heavy in order to secure this fly-wheel

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Mr. John B. Blood.—This matter of built-up fly-wheels first ame to my notice by the destruction of the cast-iron Amoseag wheel at Manchester, N. H. They constructed then the ooden built-up wheel which Mr. Manning has described efore the Society.* I think it is running there to-day. In ood, of course, they have to have a great deal more bulk; but nasmuch as that was a belt wheel, it did not make so much lifference, as they had the broad rim. I think the bicycle point omes in with reference to belted wheels, so that where the pull s slightly eccentric for any reason it will not get out of line. Three of these built-up wheels have been put in the East Boston tation of the West End Road, with 300-kilowatt electric enerators. They are built on the design for a fly-wheel to be sed without a belt, and the laminæ of the rim are placed erpendicular instead of parallel to the axis. The wheels, as uilt there, have a great many less rivets; and indeed I think hat a wheel can be built with a great many less rivets in than he one in hand.

Another point comes in here which I have had to take up: ith built-up laminated rings, if the sections are in numer odd, and the laminæ are equal to twice the number of ections, once around will pass by a half section, and it will give vice the number of broken joints with the given length of minæ.

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way—that is, with laminæ perpendicular instead of parallel to the axis—if they were dovetailed in the ends as well as riveted, that it would be an improvement in the design of the wheel.

*Mr. Thomas E. Murray.**—The $1\frac{1}{4}$-inch rivets which Mr. Henning criticises were 5 inches long; the steel through which they passed $3\frac{3}{8}$ inches; the countersink was $\frac{3}{4}$ inch deep; the angle of base 40 degrees; the hole $1\frac{5}{16}$ inches, and when driven they were finished flush with sheets. Now, if they only upset at the head, what became of the rest of the rivet? These rivets were driven with sledges, and being so large, they retained the heat long enough to give sufficient time to properly upset them. My experience leads me to believe $1\frac{1}{4}$-inch rivets can be just as well set up as those of smaller sizes, if properly heated. As experiences seem to differ in this case, might not the skill of the driver have something to do with the matter?

In regard to the grain in steel, all engineers understand that there is a vast difference between it and iron; but that steel has a difference in properties lengthwise and crosswise to the direction in which it is rolled, and which corresponds to a grain which is not visible to the eye, is undoubtedly the case, and can be found at all times in plates.

I will give as an authority on this question an extract from the specifications for steel plates for battle-ships 5 and 6, U. S. Navy, which reads:

"Test specimens must show a tensile strength between 65,000 and 73,000 pounds per square inch, with an elongation of at least 22 per cent. in eight inches in the case of transverse specimens, and at least 24 per cent. in eight inches in the case of longitudinal specimens," etc., etc.

Mr. Kent considers 45,000 pounds the maximum strength of rivets per square inch. This is undoubtedly the case ordinarily; but when the strain is directly on the head, and the tension due to shrinkage has occurred, I believe any engineer familiar with structural work will agree with me that 15,000 pounds is all that can be safely relied upon.

I regard the dished disks an important feature of the wheel, because a successful wheel must necessarily be rigid, and where an end pressure on the plates occurs, as in a belted wheel, a

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* Author's closure, under the Rules.

curved plate will certainly withstand many times the compression of a flat. Again, it has been proven in practice that it is very difficult to form and finish two parallel plates in a wheel and keep them true and without a wabble; while two dished disks, if accurately formed and drilled, will undoubtedly draw themselves to a perfect circle. Again, these plates are braced in such a manner as to make a very rigid structure with much less material than parallel plates would require, thereby throwing the additional weight in the rim, where the weight properly belongs.

No doubt the wheel can be built with less rivets, but a few hundred rivets is a very small additional expense, when the benefit derived is considered. I believe I covered Mr. Blood's suggestion by having the layer sections of different lengths—that is, the first plate to reach three of the joint bars, while the next layer of plates reached to but two.

two revolutions per minute. At the time of the accident, the speed of the engine (according to statements given at the time, and from computations made from the distances that portions of the wheel were thrown) was far beyond the conditions of every-day practice.

The author does not attempt to state here the cause of the accident, or the acceleration in speed, but his faith in *cast-iron fly-wheels* was considerably shaken, and to replace the broken wheel he naturally looked for something better and of different material, which would stand the very high rate of speed and have a greater factor of safety, and, at the same time, locate the weight in the wheel where the best results would be accomplished.

As some balance wheels had been constructed of structural steel with good results, the writer looked for a *belted wheel* of the same material, but was unable to locate any which had been built, and accordingly designed a wheel as per the accompanying drawing,

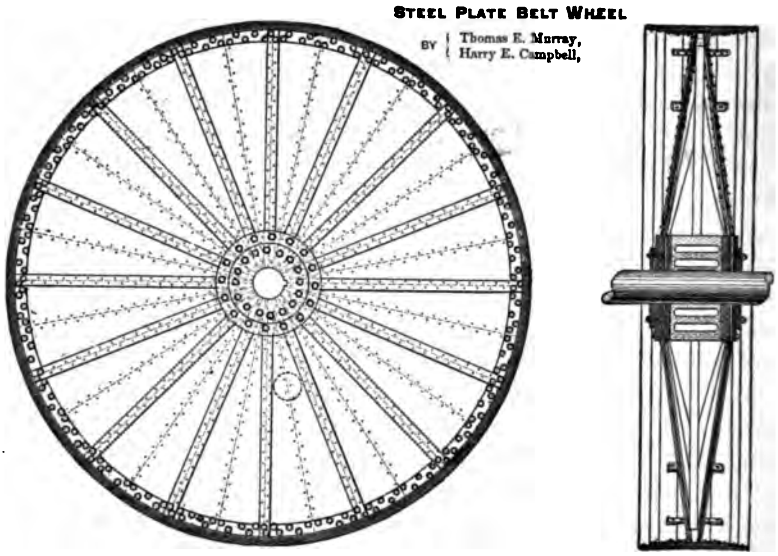

FIG. 97.

and an order was placed for two wheels with Harry E. Campbell, of the Albany Construction Works.

(It may be well to say here that the wheel was not designed to run at seventy-two revolutions per minute, or at any stated factor of safety, but the construction was of the strongest possible at a moderate cost. I am well aware that certain parts

of the wheel are much stronger than others, as, for instance, the hub and disks which take the place of the arms or spokes.)

Description of Wheel.

The steel was of a grade known as "shell-steel," *open-hearth* process, and of 60,000 pounds tensile strength, and great care was used to have grain, in the direction in which the plates were rolled, placed in position so as to give the greatest strength. All rivets used were Burden's best, and were of two sizes; namely, one and one-quarter inches, and three-quarters of an inch in diameter.

HUB.

The hub is described as follows : Six $\frac{3}{4}$-inch disks were sheared 36 inches in diameter, and fourteen, 48 inches in diameter; and these plates, together with the cast-iron separator or spider, 23 inches long by 48 inches in diameter, composed the hub, and were assembled as follows : Two sets, composed of three 36-inch and three 48-inch disks each, were drilled for 32 countersunk rivets, and after being securely clamped to tight joints, were riveted together, making two hub sections for outer part of wheel hub, each $4\frac{1}{2}$ inches thick, and these were bored to a "driving fit" to shaft; two sets of four disks each were secured together and bored in same manner for inside sections of hub, giving a steel bearing on shaft of 15 inches. The casting or spider, weighing 2,700 pounds, was bored to a close fit and placed on shaft. This casting was faced on ends and cored for thirty-two $1\frac{5}{16}$-inch hub bolts and provision made for keys. The four steel hub sections were next clamped together and bored for the 32 steel bolts. The two sections, 48 inches by 3 inches, were driven on the shaft, one against each end of spider, and one of the 36-inch by 48-inch by $4\frac{1}{2}$-inch started on each end of shaft and driven past bearings, after which the shaft was set in position in bearing. Each part of hub was faced to right angles with bore.

DISKS.

Two dished webs were formed, 19 feet $6\frac{3}{4}$ inches in diameter, each composed of two layers of $\frac{1}{4}$-inch plate, and each layer having 16 sections, making 64 plates in all. These plates were drilled so as to have all joints broken. Said rivet holes were 3 inches on centres, staggered, and four lines of holes running lengthways of plate. The small ends of plates were heated and bent on a form to right angle to shaft, and each drilled for two $1\frac{5}{16}$ hub bolts. The rim ends of plates were drilled for two lines of rivets, and in such a manner as to properly secure segments of 6-inch by 6-inch by ½-inch angle irons. These plates were next connected between inside and outside hub steel plates, sections forming two complete dished disks which were 2 inches apart at rim, and 29 inches apart at hub. Thirty-two 5-inch by ¾-inch steel bars were fitted one over each outside joint of disk plates with hub end bent, and rim ends formed two right angles with centre of wheel, or parallel with shaft. This end was bent to secure rim in connection with angles, and were each drilled for two 1¼-inch rivets. Great care was used in making these bends, and sharp angles were avoided. All bars were drilled from a template. After the bars and plates were assembled in position, with temporary bolts, the hub was bolted together with bolts passing entirely through hub and disks and drawn close and firmly together, each bolt passing through 2 bars, 4 plates, and all parts of hub. Between the outer edges of disks a cast-iron filler ring was placed and all bolted temporarily together. As all parts were drilled to templates, the work proved true and in line. The riveting was done from the outside with one man inside holding on and taking the hot rivets through a man-hole left for that purpose.

RIM.

The manner of constructing rim was as follows: eight 32-inch by ½-inch plates were rolled to form a circle, and riveted to, and with joints over, the 5-inch by ¾-inch bars. Over these plates another layer of 40-inch by ⅝-inch plates, in sixteen parts, was placed with joints broken over the first layer. The 6-inch by 6-inch by ½-inch angle irons were next formed, and securely riveted and bolted to disks, and also through both rim plates, with countersunk rivets. The ⅝-inch and ½-inch plates were also riveted together, rivets 4-inch centres. Another layer of ⅝-inch plate, 50 inches wide, was next riveted on. This was also cold rolled, and the last or face sheet, 50-inch by ⅞-inch, was rolled hot and riveted on. The countersink of last sheet was almost its full thickness; sixty-four 1¼-inch rivets were driven through the 5-inch by ¾-inch bars and all rim plates, connecting all plates and disks. The wheel was then keyed to shaft with two cast-steel keys, one driven from each side of hub; and without turning or facing the wheel in any way, the belt was put on and the wheel put to work. The belt remained in centre of wheel, and has been running two months. There are three points in the diameter of wheel which buckles in plate, due to heating, raised $\frac{3}{16}$ of an inch out of true, but the balance of wheel is practically true and in line with shaft. The wheel will be turned later. The weight of wheel is 57,930 pounds, distributed as follows:

Rim	32,000	pounds.
Disks	16,400	"
Hub	9,530	"

In calculating the strength of this wheel we need not begin at the hub and figure out every part as in a cast-iron arm-wheel. It is enough to know its strength at the weakest point, which is undoubtedly the outer layer of rim plates, as those plates must leave the wheel before any other part could give way.

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DCLXXXVI.*

A CLASSIFICATION AND CATALOGUE SYSTEM FOR AN ENGINEERING LIBRARY.

BY F. R. HUTTON, NEW YORK CITY.
(Member of the Society.)

It became necessary, in 1895, for the writer to decide upon the system which should be used in classifying and cataloguing the rapidly growing library of the American Society of Mechanical Engineers. Under the impression that the result of his thought and investigation upon this question might be of use, not only to the users of the library, but to other persons who might have the same or similar questions to meet and solve, it has seemed advisable to present a paper for record in the *Transactions* in which this matter should be set forth and discussed.

The subject of cataloguing libraries has become a special field in which experts have been trained and concerning which a growing literature and mass of precedents is accumulating. The first treatise on this subject, which seems to have served as a groundwork for much of its later development, is Mr. Melvil Dewey's *Decimal Classification and Relative Index*, published by the Library Bureau of Boston. For the present purpose no more successful presentation of the Dewey system can be made than one which I quote, with the author's permission, from an article presented in 1893 by Mr. W. L. Chase and published in volume xiv., page 780, of the *Transactions* of this Society.

"The Dewey system was developed chiefly in the interest of library economy, and in it the whole field of knowledge is arbitrarily divided into nine classes, represented by the Arabic numerals in hundreds place, namely:

"Philosophy, 100.; Religion 200.; Sociology, 300.; Philology, 400.; Natural Science, 500.; Useful Arts, 600.; Fine Arts,

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* Presented at the St. Louis meeting (May 6, 1896) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

of the wheel are much stronger than others, as, for instance, the hub and disks which take the place of the arms or spokes.)

DESCRIPTION OF WHEEL.

The steel was of a grade known as "shell-steel," *open-hearth* process, and of 60,000 pounds tensile strength, and great care was used to have grain, in the direction in which the plates were rolled, placed in position so as to give the greatest strength. All rivets used were Burden's best, and were of two sizes; namely, one and one-quarter inches, and three-quarters of an inch in diameter.

HUB.

The hub is described as follows: Six $\frac{3}{4}$-inch disks were sheared 36 inches in diameter, and fourteen, 48 inches in diameter; and these plates, together with the cast-iron separator or spider, 23 inches long by 48 inches in diameter, composed the hub, and were assembled as follows: Two sets, composed of three 36-inch and three 48-inch disks each, were drilled for 32 countersunk rivets, and after being securely clamped to tight joints, were riveted together, making two hub sections for outer part of wheel hub, each $4\frac{1}{2}$ inches thick, and these were bored to a "driving fit" to shaft; two sets of four disks each were secured together and bored in same manner for inside sections of hub, giving a steel bearing on shaft of 15 inches. The casting or spider, weighing 2,700 pounds, was bored to a close fit and placed on shaft. This casting was faced on ends and cored for thirty-two $1\frac{5}{16}$-inch hub bolts and provision made for keys. The four steel hub sections were next clamped together and bored for the 32 steel bolts. The two sections, 48 inches by 3 inches, were driven on the shaft, one against each end of spider, and one of the 36-inch by 48-inch by $4\frac{1}{2}$-inch started on each end of shaft and driven past bearings, after which the shaft was set in position in bearing. Each part of hub was faced to right angles with bore.

DISKS.

Two dished webs were formed, 19 feet $6\frac{3}{4}$ inches in diameter, each composed of two layers of $\frac{1}{4}$-inch plate, and each layer having 16 sections, making 64 plates in all. These plates were drilled so as to have all joints broken. Said rivet holes were 3 inches on centres, staggered, and four lines of holes running lengthways of plate. The small ends of plates were heated and bent on a form to right angle to shaft, and each drilled for two $1\frac{5}{16}$ hub bolts. The rim ends of plates were drilled for two lines of rivets, and in such a manner as to properly secure segments of 6-inch by 6-inch by ½-inch angle irons. These plates were next connected between inside and outside hub steel plates, sections forming two complete dished disks which were 2 inches apart at rim, and 29 inches apart at hub. Thirty-two 5-inch by ¾-inch steel bars were fitted one over each outside joint of disk plates with hub end bent, and rim ends formed two right angles with centre of wheel, or parallel with shaft. This end was bent to secure rim in connection with angles, and were each drilled for two 1¼-inch rivets. Great care was used in making these bends, and sharp angles were avoided. All bars were drilled from a template. After the bars and plates were assembled in position, with temporary bolts, the hub was bolted together with bolts passing entirely through hub and disks and drawn close and firmly together, each bolt passing through 2 bars, 4 plates, and all parts of hub. Between the outer edges of disks a cast-iron filler ring was placed and all bolted temporarily together. As all parts were drilled to templates, the work proved true and in line. The riveting was done from the outside with one man inside holding on and taking the hot rivets through a man-hole left for that purpose.

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The manner of constructing rim was as follows: eight 32-inch by ½-inch plates were rolled to form a circle, and riveted to, and with joints over, the 5-inch by ¾-inch bars. Over these plates another layer of 40-inch by ⅝-inch plates, in sixteen parts, was placed with joints broken over the first layer. The 6-inch by 6-inch by ½-inch angle irons were next formed, and securely riveted and bolted to disks, and also through both rim plates with countersunk rivets. The ⅝-inch and ½-inch plates were also riveted together, rivets 4-inch centres. Another layer of ⅝-inch plate, 50 inches wide, was next riveted on. This was also cold rolled, and the last or face sheet, 50-inch by ⅞-inch, was rolled hot and riveted on. The countersink of last sheet was almost the full thickness; sixty-four 1¼-inch rivets were driven through the 5-inch by ¾-inch bars and all rim plates, connecting all plates and disks. The wheel was then keyed to shaft with two cast steel keys, one driven from each side of hub; and without turn-g or facing the wheel in any way, the belt was put on and the heel put to work. The belt remained in centre of wheel, and as been running two months. There are three points in the iameter of wheel which buckles in plate, due to heating, raised of an inch out of true, but the balance of wheel is prac-ically true and in line with shaft. The wheel will be turned ater. The weight of wheel is 57,930 pounds, distributed as ollows:

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DISCUSSION.

r. *William Kent.*—I can scarcely agree with the way of cal-ting the factor of safety on page 417. A strain of 15,000 nds per square inch is given for rivets. Surely the rivets would have a maximum strength of 45,000—three times as much—and the factor of safety would be three times what is given in the paper.

Mr. Murray also regards the device of making the webs dished on the same principle as the spokes of a bicycle as one of the most important features of this wheel. I would like to know what effect the dishing has. I always understood that the dishing of a wheel in bicycles and other vehicles was to resist the transverse strain which would come sidewise on the rim when the wheel is run over stones and the like. But the strains on a fly-wheel from centrifugal force are entirely radial. Why would not this wheel be just as good if the side plates were parallel and radial?

Mr. Gus C. Henning.—I think that only those mechanics who would commend the use of 1¼ rivets would be likely to approve working strains of 15,000 pounds to the square inch. Such rivets cannot be driven properly, in my experience, but their heads are simply somewhat upset.

The author states his care to use the material carefully "in the direction of the grain" in the case of open-hearth steel. It is one of the great advantages of steel that it has no grain in the sense which iron has, and it occurs to me that the makers of open-hearth steel would be not a little surprised to be told that their material should be used with regard to this peculiarity.

Mr. H. H. Suplee.—This wheel suggests to me some acquaintance which I had ten or twelve years ago with the subject of wrought-iron wheels for high-speed uses in large band-saw mills. These band-saw wheels were of 7, 8, or 9 feet in diameter, running at 250 to 300 revolutions a minute, and they would not stand if made of cast iron. They had fluctuating strains upon them, the centrifugal force due to the high speed, and the crushing force from very high tension on the band-saw blade. The saw had to be strained so taut that cast-iron wheels were crushed, while the high speed occasionally caused accidents from centrifugal force. To avoid those a wrought-iron wheel was designed. It was not greatly different from this in construction except that it was made with rods for arms. The great point there was to have the upper wheel as light as possible consistent with strength, to avoid the fly-wheel action, and to make the lower wheel heavy in order to secure this fly-wheel

action, otherwise the saw is apt to be broken. The slightest tendency for the upper wheel to overrun will make a slight buckle and the saw will snap. But by making the wheels as above described, the lower one acted as a fly-wheel and prevented the check of speed below; while the upper wheel, being light, yielded to any such corrective action and the saws did not break. Those wheels were made with a cast-iron hub, long enough to allow the spokes to be staggered. The rim had wood and rubber put on the outside merely to make a bedding for the saw. I have frequently compared and tested wheels of that sort, 9 feet in diameter, running 300 revolutions a minute, and they were afterwards tried by the severe test of practical use in saw mills, and they never have been known to fail. I have often wondered why they have not been used for fly-wheels.

Mr. John B. Blood.—This matter of built-up fly-wheels first came to my notice by the destruction of the cast-iron Amoskeag wheel at Manchester, N. H. They constructed then the wooden built-up wheel which Mr. Manning has described before the Society.* I think it is running there to-day. In wood, of course, they have to have a great deal more bulk; but inasmuch as that was a belt wheel, it did not make so much difference, as they had the broad rim. I think the bicycle point comes in with reference to belted wheels, so that where the pull is slightly eccentric for any reason it will not get out of line. Three of these built-up wheels have been put in the East Boston station of the West End Road, with 300-kilowatt electric generators. They are built on the design for a fly-wheel to be used without a belt, and the laminæ of the rim are placed perpendicular instead of parallel to the axis. The wheels, as built there, have a great many less rivets; and indeed I think that a wheel can be built with a great many less rivets in than the one in hand.

Another point comes in here which I have had to take up: with built-up laminated rings, if the sections are in number odd, and the laminæ are equal to twice the number of sections, once around will pass by a half section, and it will give twice the number of broken joints with the given length of laminæ.

Another thing, I think if the wheel is built up in that

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* *Transactions* of the American Society of Mechanical Engineers, vol. xiii., p. 618, No. 497.

In cataloguing the books, the first step was to make the *Index Rerum* of subjects. This was done upon the buff cards with projecting edge used as "index guides" in ordinary card catalogues. This, of course, will be done to the best of some one's ability and experience; but it is not to be expected that his foresight will cover every possible topic for which the library will be consulted. Such a list will be a matter of growth from year to year, with progress in science and with experience in use. Every topic in every table of contents of every book in the library is to have its card, however, and behind it, the usual white book card or cards with reference to the book or books where this subject may be found, or else a cross-reference to some other title under which it has seemed more convenient to group such literature. The idea is that no matter from what point of view or of ignorance the stranger enters the library, the catalogue shall at once by direct pointing or by cross reference enable him to list upon a pad the books which he wishes, or else indicate the location of books upon that general subject, from among which in a small library he may select those particular volumes which seem best suited to his need.

The alphabetical list of authors which will run parallel to the subject list is, of course, most simple, and is based on accepted library precedents for such a dictionary catalogue.

It will take too much space to give the *Index Rerum* of subjects complete. It is, perhaps, also unnecessary. But in an appendix has been placed the list of classes and sub-classes for convenient reference and for criticism.

The object of the author will have been attained if his work can be of service to others with the same problem before them, and if to those accustomed to the Dewey system it shall serve to indicate how radically that needs extension in the fields of the engineer.

The writer wishes, in closing, to express his recognition of the help rendered by Prof. H. B. Gale, member of the Society, whose valuable suggestions both as to principle and detail, have been most heartily appreciated.

APPENDIX.

CLASS 1.—*General Works.*

a. Dictionaries.
b. Encyclopædias.
c. Atlases and Maps.

d. Indexes.
e. Directories and Registers.
f. Guide-books and Hand-books.
g. Pocket-books, Engineering Hand-books, Tables, etc.
h. Tables of Logarithms, Reckoners, etc.
i. Albums and Collections of Photographs.
j. Manuals of Railways.

Class 2.—*Periodicals and Magazines.*

(Not transactions of Societies.)

a. Electricity.
b. Steam Power, Machine Shop, Transmission of Power.
c. General Engineering.
d. Textile Mill and Factory.
e. Railways and Locomotives.
f. Metallurgy, Mining, and Gas.
g. Structural, Sanitary, Architectural, and Building.
h. Marine.
i. German, Scandinavian, and Russian.
j. French, Spanish, and Italian.
k. Miscellaneous.

Class 3.—*Transactions of Societies.*

a. American.
b. British.
c. Colonial, also Scotch and Irish.
d. Danish and Dutch.
e.
f. French.
g. German.
h. Hispanian and Helvetian.
i. Italian.
s. Scandinavian and Sclavic.

Class 4.—*Trade Catalogues.*

1. Agricultural Machinery.
2. Electrical Machinery and Supplies.
3. Electro-metallurgy and plating.
4. Fuel, Stokers, Combustion.
5. Gas and Oil Engines.
6. Hoisting and Conveying.
    a. Coal and Ore Handling.
    b. Contractors' Plant.
    c. Dredges and Steam Shovels.
    d. Cranes and Elevators.
    e. Grain Elevators.
7. Hydraulic Machinery.
    a. Motors.
    b. Pumps and Injectors.

CLASS 9.—*Drawing and Machine Design and Mechanism.*

a. Drawing in general.
b. Descriptive Geometry.
  b. 1. Shades and Shadows.
  b. 2. Perspective.
c. Stereotomy or Stone-cutting.
d. Machine Design.
e. Kinematics, Mechanism, Geometry of Motion.
f. Horology, Clock and Watch Making.
g. Dynamics.
h. Friction and Lost Work and Lubrication.

CLASS 10.—*Timber, Carpentry, Joinery, and Wood Working.*

a. House Carpentry, Stair Building.
b. Joinery and Cabinet Making.
c. Piano and Organ Building.
d. Wood Working, Machine Tools.
e. Pattern Making.
f. Preservation of Timber.

CLASS 11.—*Metals and Metal Working.*

a. Foundry Practice for Cast-iron ; Pattern Making.
b. Forging and Blacksmithing.
c. Sheet Metal Work.
d. Machine-shop Practice and Tools.
e. Abrading and Grinding Machinery.

CLASS 12.—*Mills, Manufactures, and Shops.*

a. Mill Construction and Factories.
b. Textile Mills.
c. Flour Mills.
d. Paper Mills.
e. Printing Machines.
f. Accidents in Factories.
g. Shop Management.
h. Shop Accounts.
i. Shop and Factory Buildings.

CLASS 13.—*Heat, Fuel, and Engines (not steam).*

a. General.
b. Theory of Thermodynamics.
c. Practical Treatises on Heat.
d. Fuels and Combustion.
e. Chimneys.
f. Gas, Oil, and Vapor Engines.
g. Hot-air or Caloric Engines.
h. Wind Mills.

i. Compressed Air Motors.
  See Air Compressors.
  See Ventilation.
j. Animate Motors.

CLASS 14.—*Steam Engineering (Stationary) and Motors for Mills and Shops and Power Plants.*

a. General.
b. Boilers.
c. Steam Engines in general, for Power.
d. Pumping Engines and Pumps.
  See Hydraulics.
  See Transmission.
e. Hoisting Engines and Elevators.
f. Air Compressors and Blowing Engines.
  See Compressed Air Motors.
  See Ventilation.
g. Ice Machines and Refrigeration.
h. Boiler Explosions.
i. Boiler Insurance and Inspection.
j. Boiler Tests for Efficiency.
k. Engine Tests for Efficiency.
  See Engineering Laboratory Appliances.
l. Engine Valve Gears.
m. Hydraulic Motors, Turbines, Water Wheels.

CLASS 15.—*Power Transmission.*

a. Gearing, Teeth of Wheels.
b. Belting.
c. Cable and Rope and Chain.
d. Conveying and Hoisting (not engines).
e. Compressed Air.
f. Hydraulic Machinery and Presses (not motors).

CLASS 16.—*Electrical Engineering.*

a. Generation of Electrical Energy, Dynamos, Batteries, Thermo-electricity.
b. Distribution of Electrical Energy.
c. Electric Power and Motors.
d. Electric Lighting.
e. Electro-metallurgy.
f. Electro-plating.
g. Telegraph and Telephone.
h. Magnetism.
i. Electric Accumulators and Storage.

CLASS 17.—*Railway Machinery and Equipment.*

a. Locomotives.
b. Cars.
c. Train Brakes.

d. Permanent Way, Switches and Signals.
e. Traction Engineering on Roads; Auto-mobile Carriages, Bicycles.
f. Street Railway Engineering.
g. Rapid Transit in Cities.
h. Manuals of Railways. (See 1. j.)

CLASS 18.—*Marine and Naval Engineering.*

a. Marine Architecture, Ship building and Hulls.
b. Dock Yards and Ship Yards.
c. Marine Engines.
d. Ship Propelling Apparatus.
e. Steering Machinery.
For Electric Navigation see Electricity.

CLASS 19.—*Aerial Transportation.*

a. Aeroplanes.
b. Flying Machines.
c. Balloons.
See Military Engineering.

CLASS 20.—*Military, Ordnance, Sea-coast Defence.*

a. Forts, Fortifications, Sea-coast Defence.
b. Guns and Carriages.
c. Projectiles and Armor-plate.
d. Explosives.
See Chemistry.
See Mining.
e. Tactics, Signalling, Manœuvres, etc.
f. Lighthouses.

CLASS 21.—*Hydraulic Engineering (not Motors).*

a. Water Power in general.
b. Irrigation.
c. Dams.
d. Canals and Locks.
e. River and Harbor Improvement.
Canalization of Rivers.
f. Hydrography, and Hydrographic Engineering.

CLASS 22.—*Sanitary and Municipal.*

a. Heating and Ventilation.
b. Drainage, Sewerage and Sewage and Garbage Disposal.
c. Crematories and Cremation.
d. Water-works Engineering.
See Pumping Engines, Irrigation.
e. Irrigation.
See Hydraulic and Canals.
f. Lighting of Cities.
See Electricity, Gas, etc.
For Lighthouses see Military.

g. Public Works of Cities.
h. Roads and Pavements.
i. Docks, Piers, and Bulkheads.
j. Health Boards and Public Health.

CLASS 23.—*Structural, also called Civil Engineering.*

a. Bridges, Roofs, and Viaducts.
b. Cellular or Skeleton Structures.
c. Retaining Walls and Masonry in general.
d. Foundations.
e. Arches.
f Cements and mortars.
g. Beams and Girders.
Tunnelling, see Mining.
Railways, see Transportation.
Canals, see Hydraulics.
Water-works, see Sanitary.
h. Slow-burning Constructions.
i. Fire-protection of Buildings.
j. Cements and Mortars.

CLASS 24.—*Fine Arts, Architecture.*

a. Architectural History.
b. Architectural Decoration.
c. Architectural Monuments.
d. Painting.
e. Sculpture.
f. Photography.
g. Art Processes for Engraving.
h. Engraving.
i. Music.
j. Arts of Design.

CLASS 25.—*Technical Miscellany.*

a. Exhibitions and Expositions: World's Fairs.
b. Amusements and Sports.

CLASS 26.—*Law Patents and Inventions.*

a. General and Common Law.
b. Contracts.
c. Laws of Business
d. Engineering Law.
e. Specifications.
f. Patent History.
g. Patent Decisions and Suits.
h. Patent Specifications and Claims (Gazette).
i. Patent Reports.
j. Patents (English).
k. Patents (Continental).

CLASS 27.—*Medicine and Surgery.*

a. Physiology.
b. Hygiene.
c. Nutrition and Foods.

CLASS 28.—*Philosophy, Mental Science, and Religion.*

a. Logic.
b. Metaphysics.
c. Insanity.
d. Ethics.
e. Theology.

CLASS 29.—*Social Science, Economics, Philanthropy, Ethnology, Anthropology.*

a. Political Economy.
b. Civil Government.
c. Labor Problems.
d. Education (general).
e. Education (technical).
f. Social Customs.
g. Statistics.
h. Census Reports on Population.
i. Industrial Evolution.
j. Reformatory Institutions.
k. Hospitals, Asylums, Sanatoriums.
l. Charity Organizations.

CLASS 30.—*Philology, Literature, Language.*

a. Philology.
b. Literature.
c. Language.
d. Grammar.
e. Rhetoric.

CLASS 31.—*History, etc.*

a. History.
b. Biography.
c. Memoirs.
d. Letters.
e. Travels and Voyages.

CLASS 32.—*Fiction, etc.*

a. Fiction.
b. Essays.
c. General (non-technical) Literature.
d. Wit and Humor.
e. Poetry.

CLASS 33.—*Library Methods and Cataloguing; Rarities.*

DISCUSSION.

Mr. John B. Blood.—This problem of the classification of engineering literature has come to me in several ways, principally that of cataloguing manufactured apparatus and cataloguing drawings and shop work and apparatus, together with the cataloguing of literature both in detail for my own personal engineering use and for a library. In taking this up for study I have taken it up both from the practical point as it has come to me in business connections, and from the theoretical side with reference to the correct method of taking it up in practice. From my standpoint and from my studies I will take up a few points in Mr. Hutton's paper as they come to me.

On page 423, paragraph 3, the Dewey principle is departed from on account of the modifications necessary. Now in this connection, as I have taken it up, the modifications necessary are simply additions. That is to say, Mr. Dewey has taken the thing up in a very general way, inasmuch as most libraries do not have a large space devoted to engineering, and therefore he has not had time and has not had occasion to take this matter up.

Referring to paragraph 4, I would say the best system is the system which is the simplest, and has the fewest references. I will take one case in the system proposed here. Supposing a man wants to look up data with reference to a mining air compressor: he has to look under Section II., division *f*, for periodicals on that subject; under Section III. for the transactions; under Section IV., 16*d*, for trade catalogues; under Section VII., *g*, for statistics; under Section XXVI. for patents; where, by any system which is reasonably adapted to this work, only one, or possibly two, references—that is, the function and the thing itself—would be needed. This gives the other side of it; that is, the very general references rather than the particular. The greater number of calls would not be for transactions as such, but some particular transactions and some particular thing. The system collects all books into one place, or possibly two; that is to say, if the subject has two main points—one particular thing itself and one particular function—it ought to be catalogued under those two points.

At page 423, paragraph 5, it says that the catalogue should take up the case in hand with regard to it solely; that is to say, the definite functions of the library in hand should be considered primarily. I think that the subject should be taken up in a general manner primarily, and its adaptation secondarily; that is, if the adaptation does not materially increase the difficulties.

Page 424, paragraph 3, refers to a standard which has not been made. The reason that it has not been made is because the engineers or the people in this country who would use this work have not taken it up, and I think it is this general standard that we want to establish rather than to get something that is simply adapted to one particular case.

Referring to page 424, paragraph 4, where the limitation of nine classes is spoken of, that is the point which has always been brought up by men looking into this system. I have had that thrown at me a great many times, as I have posed as a decimal classification man, for the last eighteen months especially, and I have had that question to answer a great many times. I do not think it is a limitation at all, because if you want to run from 9 to 99 class, you have simply to use two figures instead of one; and if you want one hundred divisions the lowest number of figures which you need to give is two; but if by mistake of the cataloguer, or by lack of foresight, some of the divisions are given more prominence than they should have, of course that makes the subdivision come wrong, and Mr. Dewey in his work has left the ninth class open, and sometimes more than the ninth—the seventh, eighth, and ninth—for a subdivision. He always, if practicable, gives this ninth class the title of Miscellaneous, and suggests that, where the foresight of the cataloguer has not been sufficient, this ninth class can be subdivided, and used in parallel with the other eight classes.

At page 424, paragraph 4, mention is made of the difficulty of separating pure science from applied science. In my branch of the business, electrical engineering, this seems to be the worst case, because from its nature electrical engineering is so technical. I know the point has come and we have found no trouble with it. I would say in this relation that we have worked the Dewey or decimal system in connection with our literature and tests and records for about eighteen months now, and we have had no occasion to find the limitations. Of course there have been some compromises and cross references, which must come on account of the non-infallibility of the original cataloguer. But pure science and applied science do not make the cataloguing difficult. The way I have taken this up is where science, apparently pure, was directly applied to the construction or design of apparatus, to put it under the applied science heading. Of course, if the subject is on the line between—that is to say, if it is very near pure and very near applied—a man looking it up would naturally look at both headings anyway. That is to say, he might not know whether what he wanted was pure or applied, and irrespective of where the book was catalogued he would look up the two headings, and therefore get the book whether it was in one or the other.

On page 424, paragraph 5, the question is asked: "What is the catalogue of a library of engineering for?" And the answer given is: "To enable a visitor to the library in search of its sources of information on a certain subject to find what the library contained for his purpose, and where it might be found." I think I would add to that answer—"with as few references and the least complication possible." As I mentioned before, in some cases there may be five or six references to find one subject, whereas if they were classified by subjects instead of by groups these would all be near together. Of course the general and specific, where there were a great number of specific cases in a group, would make the number of headings so large that they might not be side by side for one particular subject. For instance, periodicals on mining would be in the mining department, whereas an article on air compressors in a periodical on mining would not be absolutely side by side with books on air compressors.

Referring to page 425, paragraph 2, when the classes are based on other than subject lines the catalogue ceases to be a subject index, and simply becomes a systematic grouping. In referring to trade catalogues, periodicals, and patent office reports, it is not in general desired to refer to them as such, although if it is necessary they can be put together. For instance, trade catalogues are now coming to be pretty good dissertations on the branch to which they relate. In fact, in some cases the latest and best information can be found in the trade catalogues, and I would prefer a system where these trade catalogues and periodicals can, as nearly as possible, be put by their heads There is a publication entitled *Compressed Air*. If that was put under periodicals, of course it could not be found there; but practically, for the practical use of the subject, that periodical on fields of the engineer." I agree with all this, and it is with this object that I make these remarks. One of the British societies, I think it is the Royal Society, is to take up this subject with reference to their publications, and with reference to the cataloguing of the work in their society; and the Belgian and French engineers have been taking this up and pushing this classification for what they can. The members are business men in the different branches, and the law, medicine, and sociology sections have been taken up in detail through the aid of these different societies. The proceedings are properly catalogued current literature, with their numbers in order. The Belgians are strongly advocating the decimal system for a uniform system. I think it is specially timely that this subject should be taken up in this country, and it can be by this Society, as it is eminently the place from which it should come. We can work in conjunction with others, doing the same work at the same time, and benefit will accrue from the fact that more people are working on it who have cognizance of this subject. I would like to make a motion, or recommend that the Council of this Society appoint a committee to take up the matter of systematic classification of engineering literature in this way. Would that be a motion or recommendation?

The Secretary.—It might very properly come up as new business presently.

Mr. Paul M. Chamberlain.—I would like to say a word regarding Class 5, the trade catalogue. I presume that every one having had occasion to keep trade catalogues for reference has been much annoyed with the difficulty of shelving and indexing them in such manner as shall make them readily accessible. The lack of uniformity in size and difficulty of affixing a number to the back are the principal obstacles. Several years ago we used for this purpose in the mechanical department of the Michigan Agricultural College a series of drawers labelled with the general headings. This did fairly well so long as the catalogues did not get out of place, but if one did not find that which he had good reason to believe should be there, a search through many and perhaps all the drawers followed. We finally adopted a scheme which, though new, commended itself and has proven very satisfactory. The catalogues we wished to preserve were obtained in duplicate and the margins of the pages trimmed off with a hand paper trimmer. The consecu-

d. Indexes.
e. Directories and Registers.
f. Guide-books and Hand-books.
g. Pocket-books, Engineering Hand-books, Tables, etc.
h. Tables of Logarithms, Reckoners, etc.
i. Albums and Collections of Photographs.
j. Manuals of Railways.

CLASS 2.—*Periodicals and Magazines.*

(Not transactions of Societies.)

a. Electricity.
b. Steam Power, Machine Shop, Transmission of Power.
c. General Engineering.
d. Textile Mill and Factory.
e. Railways and Locomotives.
f. Metallurgy, Mining, and Gas.
g. Structural, Sanitary, Architectural, and Building.
h. Marine.
i. German, Scandinavian, and Russian.
j. French, Spanish, and Italian.
k. Miscellaneous.

CLASS 3.—*Transactions of Societies.*

a. American.
b. British.
c. Colonial, also Scotch and Irish.
d. Danish and Dutch.
e.
f. French.
g. German.
h. Hispanian and Helvetian.
i. Italian.
s. Scandinavian and Sclavic.

CLASS 4.—*Trade Catalogues.*

1. Agricultural Machinery.
2. Electrical Machinery and Supplies.
3. Electro-metallurgy and plating.
4. Fuel, Stokers, Combustion.
5. Gas and Oil Engines.
6. Hoisting and Conveying.
    a. Coal and Ore Handling.
    b. Contractors' Plant.
    c. Dredges and Steam Shovels.
    d. Cranes and Elevators.
    e. Grain Elevators.
7. Hydraulic Machinery.
    a. Motors.
    b. Pumps and Injectors.

ance enough in every shelf for books of all heights, and in practice it is found to work very well The little book is called *L'Art de Classer les Notes*, by M. Guyot-Daubes.

Mr. William Kent.—I do not see it definitely stated in the paper whether it is a classification of a card catalogue or a classification of the books. I would like to ask, if we want to find architecture, do we look under letter " A " or under Class 24?

Professor Hutton.—There is a heading in the card catalogue, Architecture, and all the books on the subject of architecture and all periodicals on the subject of architecture and all references to the subject are under that. There is no classification reference whatever on the cards. That is not a matter that concerns anybody whatever but the librarian.

Mr. Kent.—Then if I wanted to find architecture in the card catalogue I would go to letter " A " first?

Professor Hutton.—Yes.

Mr. Kent.—Then it seems to me that all this question of classification described in the paper is simply one, as the author says, of administration of the library and not for the convenience of users. It would not make any difference to the users whether the books were classified as shown here or classified chronologically or in any other way. That is, if you wanted to find some one's book on architecture you would go to the card catalogue and find under "A" the book you wanted and its number, shelf so-and-so, alcove so-and-so, and you go and get the book from its location. So the classification is only one of convenience to the administrators of the library, and this classification for that purpose is probably as good as any other. But this whole subject of classification I think should be treated a little more broadly—how we should classify our own libraries, our notes and our clippings, and all that sort of thing; and then this question comes up, Is this system of Professor Hutton's a good system? I, myself, don't think it is. For instance, we want to study something about the ventilation of mines. If I wanted to look up that subject in Professor Hutton's classification I would have to look under several classes, viz.: compressors, compressed air, mines, mine ventilation, fans and blowers, and blowing engines, and all these things in different classes; and if we wanted to use a wind-mill to make power, that is still under another class. If we want to consider the problem of digging a ditch to drain the mine and also to pump

CLASS 5.—*Pure or Natural Science.*

- *a.* Mathematics.
- *b.* Astronomy, Geodesy, and Surveying ; Topography and Geodetic Surveys.
- *c.* Physics.
- *d.* Chemistry.
- *e.* Geology and Paleontology ; Geological Surveys.
- *f.* Geography.
- *g.* Mineralogy, Lithology, and Crystallography.
- *h.* Biology, Bacteriology.
- *i.* Zoology.
- *j.* Fish and Fisheries.
- *k.* Botany.

CLASS 6.—*Industrial Arts.*

(Not Engineering, Metals and Metallurgy, nor Wood Working.)

- *a.* Agriculture and Forestry.
- *b.* Chemical Technology.
  - *b.* 1. Dyeing and Color Printing.
  - *b.* 2. Paper Making.
  - *b.* 3. Breweries.
  - *b.* 4. Sugar Making, Refining, and Machinery.
  - *b.* 5. Pottery and Glass.
  - *b.* 6. Printing and Inks.
  - *b.* 7. Brick Making.
- *c.* Gas Making and Gas Engineering.
- *d.* Trades and Handicrafts.

CLASS 7.—*Mining and Metallurgy.*

- *a.* Prospecting.
- *b.* Excavation, Tunnelling, Shaft-sinking, Boring, Well-sinking.
- *c.* Mine Transportation Underground.
- *d.* Mine Drainage.
- *e.* Mine Ventilation.
- *f.* Mine Accidents.
- *g.* Mining Statistics.
- *h.* Ore Dressing, Concentration and Separation.
- *i.* Alloys.
- *j.* Precious Metals.
- *k.* Blast Furnace.
- *l.* Steel Processes.

CLASS 8.—*Strength of Materials and Testing Machines.*

- *a.* Strength of Materials.
- *b.* Testing Machines.
- *c.* Results of Test and Research.
- *d.* Methods of Test, Standards, etc.
- *e.* Engineering Laboratory Appliances and Procedure.

CLASS 9.—*Drawing and Machine Design and Mechanism.*

a. Drawing in general.
b. Descriptive Geometry.
  b. 1. Shades and Shadows.
  b. 2. Perspective.
c. Stereotomy or Stone-cutting.
d. Machine Design.
e. Kinematics, Mechanism, Geometry of Motion.
f. Horology, Clock and Watch Making.
g. Dynamics.
h. Friction and Lost Work and Lubrication.

CLASS 10.—*Timber, Carpentry, Joinery, and Wood Working.*

a. House Carpentry, Stair Building.
b. Joinery and Cabinet Making.
c. Piano and Organ Building.
d. Wood Working, Machine Tools.
e. Pattern Making.
f. Preservation of Timber.

CLASS 11.—*Metals and Metal Working.*

a. Foundry Practice for Cast-iron ; Pattern Making.
b. Forging and Blacksmithing.
c. Sheet Metal Work.
d. Machine-shop Practice and Tools.
e. Abrading and Grinding Machinery.

CLASS 12.—*Mills, Manufactures, and Shops.*

a. Mill Construction and Factories.
b. Textile Mills.
c. Flour Mills.
d. Paper Mills.
e. Printing Machines.
f. Accidents in Factories.
g. Shop Management.
h. Shop Accounts.
i. Shop and Factory Buildings.

CLASS 13.—*Heat, Fuel, and Engines (not steam).*

a. General.
b. Theory of Thermodynamics.
c. Practical Treatises on Heat.
d. Fuels and Combustion.
e. Chimneys.
f. Gas, Oil, and Vapor Engines.
g. Hot-air or Caloric Engines.
h. Wind Mills.

i. Compressed Air Motors.
  See Air Compressors.
  See Ventilation.
j. Animate Motors.

CLASS 14.—*Steam Engineering (Stationary) and Motors for Mills and Shops and Power Plants.*

a. General.
b. Boilers.
c. Steam Engines in general, for Power.
d. Pumping Engines and Pumps.
  See Hydraulics.
  See Transmission.
e. Hoisting Engines and Elevators.
f. Air Compressors and Blowing Engines.
  See Compressed Air Motors.
  See Ventilation.
g. Ice Machines and Refrigeration.
h. Boiler Explosions.
i. Boiler Insurance and Inspection.
j. Boiler Tests for Efficiency.
k. Engine Tests for Efficiency.
  See Engineering Laboratory Appliances.
l. Engine Valve Gears.
m. Hydraulic Motors, Turbines, Water Wheels.

CLASS 15.—*Power Transmission.*

a. Gearing, Teeth of Wheels.
b. Belting.
c. Cable and Rope and Chain.
d. Conveying and Hoisting (not engines).
e. Compressed Air.
f. Hydraulic Machinery and Presses (not motors).

CLASS 16.—*Electrical Engineering.*

a. Generation of Electrical Energy, Dynamos, Batteries, Thermo-electricity.
b. Distribution of Electrical Energy.
c. Electric Power and Motors.
d. Electric Lighting.
e. Electro-metallurgy.
f. Electro-plating.
g. Telegraph and Telephone.
h. Magnetism.
i. Electric Accumulators and Storage.

CLASS 17.—*Railway Machinery and Equipment.*

a. Locomotives.
b. Cars.
c. Train Brakes.

d. Permanent Way, Switches and Signals.
e. Traction Engineering on Roads; Auto-mobile Carriages, Bicycles.
f. Street Railway Engineering.
g. Rapid Transit in Cities.
h. Manuals of Railways. (See 1. j.)

CLASS 18.—*Marine and Naval Engineering.*

a. Marine Architecture, Ship building and Hulls.
b. Dock Yards and Ship Yards.
c. Marine Engines.
d. Ship Propelling Apparatus.
e. Steering Machinery.
For Electric Navigation see Electricity.

CLASS 19.—*Aerial Transportation.*

a. Aeroplanes.
b. Flying Machines.
c. Balloons.
See Military Engineering.

CLASS 20.—*Military, Ordnance, Sea-coast Defence.*

a. Forts, Fortifications, Sea-coast Defence.
b. Guns and Carriages.
c. Projectiles and Armor-plate.
d. Explosives.
See Chemistry.
See Mining.
e. Tactics, Signalling, Manœuvres, etc.
f. Lighthouses.

CLASS 21.—*Hydraulic Engineering (not Motors).*

a. Water Power in general.
b. Irrigation.
c. Dams.
d. Canals and Locks.
e. River and Harbor Improvement.
Canalization of Rivers.
f. Hydrography, and Hydrographic Engineering.

CLASS 22.—*Sanitary and Municipal.*

a. Heating and Ventilation.
b. Drainage, Sewerage and Sewage and Garbage Disposal.
c. Crematories and Cremation.
d. Water-works Engineering.
See Pumping Engines, Irrigation.
e. Irrigation.
See Hydraulic and Canals.
f. Lighting of Cities.
See Electricity, Gas, etc.
For Lighthouses see Military.

g. Public Works of Cities.
h. Roads and Pavements.
i. Docks, Piers, and Bulkheads.
j. Health Boards and Public Health.

CLASS 23.—*Structural, also called Civil Engineering.*

a. Bridges, Roofs, and Viaducts.
b. Cellular or Skeleton Structures.
c. Retaining Walls and Masonry in general.
d. Foundations.
e. Arches.
f Cements and mortars.
g. Beams and Girders.
Tunnelling, see Mining.
Railways, see Transportation.
Canals, see Hydraulics.
Water-works, see Sanitary.
h. Slow-burning Constructions.
i. Fire-protection of Buildings.
j. Cements and Mortars.

CLASS 24.—*Fine Arts, Architecture.*

a. Architectural History.
b. Architectural Decoration.
c. Architectural Monuments.
d. Painting.
e. Sculpture.
f. Photography.
g. Art Processes for Engraving.
h. Engraving.
i. Music.
j. Arts of Design.

CLASS 25.—*Technical Miscellany.*

a. Exhibitions and Expositions: World's Fairs.
b. Amusements and Sports.

CLASS 26.—*Law Patents and Inventions.*

a. General and Common Law.
b. Contracts.
c. Laws of Business
d. Engineering Law.
e. Specifications.
f. Patent History.
g. Patent Decisions and Suits.
h. Patent Specifications and Claims (Gazette).
i. Patent Reports.
j. Patents (English).
k. Patents (Continental).

1. When the fires are pushed, as on capacity tests, the damper is open wider than on gentle tests, the draught is stronger, and fine particles of ash, etc., are carried from the furnace and lodged in the dead space behind the bridge wall, deposited in the tubes and front connection, and carried up the stack. Hence it is reasonable to expect a smaller percentage of ash as the fires are pushed.

2. On the other hand, it would be reasonable to expect more fuel to be wasted in the ash on a capacity than on a gentle test. But, as a matter of fact, about as much fuel dropped through the grate on the gentle as on the forced tests, and it formed a larger percentage of the total ash.

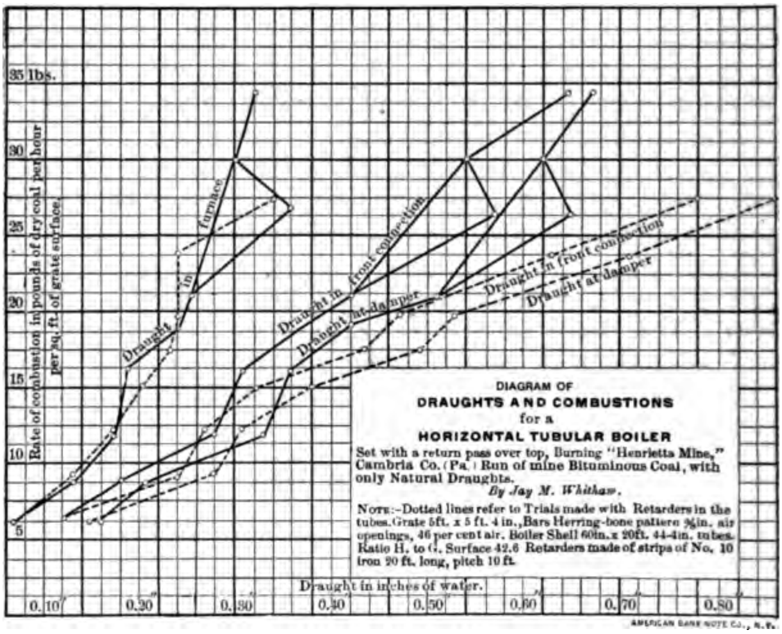

FIG. 98.

It is important to here observe that since coal rather than combustible is bought, and since the percentage of ash varies for the reasons just given, that *in all comparisons of work done by the same grade of fuel under varying conditions, reference should be had to what the coal, rather than the combustible, does.*

Draughts.—The draughts were measured in the furnace, in the

DISCUSSION.

Mr. John B. Blood.—This problem of the classification of engineering literature has come to me in several ways, principally that of cataloguing manufactured apparatus and cataloguing drawings and shop work and apparatus, together with the cataloguing of literature both in detail for my own personal engineering use and for a library. In taking this up for study I have taken it up both from the practical point as it has come to me in business connections, and from the theoretical side with reference to the correct method of taking it up in practice. From my standpoint and from my studies I will take up a few points in Mr. Hutton's paper as they come to me.

On page 423, paragraph 3, the Dewey principle is departed from on account of the modifications necessary. Now in this connection, as I have taken it up, the modifications necessary are simply additions. That is to say, Mr. Dewey has taken the thing up in a very general way, inasmuch as most libraries do not have a large space devoted to engineering, and therefore he has not had time and has not had occasion to take this matter up.

Referring to paragraph 4, I would say the best system is the system which is the simplest, and has the fewest references. I will take one case in the system proposed here. Supposing a man wants to look up data with reference to a mining air compressor: he has to look under Section II., division *f*, for periodicals on that subject; under Section III. for the transactions; under Section IV., 16*d*, for trade catalogues; under Section VII., *g*, for statistics; under Section XXVI. for patents; where, by any system which is reasonably adapted to this work, only one, or possibly two, references—that is, the function and the thing itself—would be needed. This gives the other side of it; that is, the very general references rather than the particular. The greater number of calls would not be for transactions as such, but some particular transactions and some particular thing. The system collects all books into one place, or possibly two; that is to say, if the subject has two main points—one particular thing itself and one particular function—it ought to be catalogued under those two points.

At page 423, paragraph 5, it says that the catalogue should take up the case in hand with regard to it solely; that is to say, the definite functions of the library in hand should be considered primarily. I think that the subject should be taken up in a general manner primarily, and its adaptation secondarily; that is, if the adaptation does not materially increase the difficulties.

Page 424, paragraph 3, refers to a standard which has not been made. The reason that it has not been made is because the engineers or the people in this country who would use this work have not taken it up, and I think it is this general standard that we want to establish rather than to get something that is simply adapted to one particular case.

Referring to page 424, paragraph 4, where the limitation of nine classes is spoken of, that is the point which has always been brought up by men looking into this system. I have had that thrown at me a great many times, as I have posed as a decimal classification man, for the last eighteen months especially, and I have had that question to answer a great many times. I do not think it is a limitation at all, because if you want to run from 9 to 99 class, you have simply to use two figures instead of one; and if you want one hundred divisions the lowest number of figures which you need to give is two; but if by mistake of the cataloguer, or by lack of foresight, some of the divisions are given more prominence than they should have, of course that makes the subdivision come wrong, and Mr. Dewey in his work has left the ninth class open, and sometimes more than the ninth—the seventh, eighth, and ninth—for a subdivision. He always, if practicable, gives this ninth class the title of Miscellaneoüs, and suggests that, where the foresight of the cataloguer has not been sufficient, this ninth class can be subdivided, and used in parallel with the other eight classes.

At page 424, paragraph 4, mention is made of the difficulty of separating pure science from applied science. In my branch of the business, electrical engineering, this seems to be the worst case, because from its nature electrical engineering is so technical. I know the point has come and we have found no trouble with it. I would say in this relation that we have worked the Dewey or decimal system in connection with our literature and tests and records for about eighteen months now, and we have had no occasion to find the limitations. Of course there have been some compromises and cross references, which must come on account of the non-infallibility of the original cataloguer. But pure science and applied science do not make the cataloguing difficult. The way I have taken this up is

where science, apparently pure, was directly applied to the co
struction or design of apparatus, to put it under the appli
science heading. Of course, if the subject is on the line b
tween—that is to say, if it is very near pure and very ne
applied—a man looking it up would naturally look at bo
headings anyway. That is to say, he might not know wheth
what he wanted was pure or applied, and irrespective of whe
the book was catalogued he would look up the two hea
ings, and therefore get the book whether it was in one or t
other.

On page 424, paragraph 5, the question is asked: "What
the catalogue of a library of engineering for?" And the answ
given is: "To enable a visitor to the library in search of i
sources of information on a certain subject to find what t
library contained for his purpose, and where it might be found
I think I would add to that answer—"with as few referenc
and the least complication possible." As I mentioned befor
in some cases there may be five or six references to find o
subject, whereas if they were classified by subjects instead
by groups these would all be near together. Of course the ge
eral and specific, where there were a great number of speci
cases in a group, would make the number of headings so lar
that they might not be side by side for one particular subje
For instance, periodicals on mining would be in the mini
department, whereas an article on air compressors in a period
cal on mining would not be absolutely side by side with boo
on air compressors.

Referring to page 425, paragraph 2, when the classes are bas
on other than subject lines the catalogue ceases to be a subje
index, and simply becomes a systematic grouping. In referri
to trade catalogues, periodicals, and patent office reports, it
not in general desired to refer to them as such, although if it
necessary they can be put together. For instance, trade cat
logues are now coming to be pretty good dissertations on t
branch to which they relate. In fact, in some cases the late
and best information can be found in the trade catalogues, a
I would prefer a system where these trade catalogues and pe
odicals can, as nearly as possible, be put by their heads The
is a publication entitled *Compressed Air*. If that was put und
periodicals, of course it could not be found there; but prac
cally, for the practical use of the subject, that periodical

compressed air would come beside the books on compressed air, and be easy of access when wanted.

Page 426, paragraph 3—the transactions. If it is necessary to keep them together, as I say, it can be done by using a special number. For instance, at the World's Fair the New York State Library sent a catalogue of books written by women, and this library has been designed to be kept separate. Therefore the numbers were given the same as they would be under an ordinary catalogue and a "W" prefixed, so that these books appear in the catalogue the same as ordinarily, with this "W" prefixed; and any one wanting those books—whether there is another one in another part of the library or not—that special collection is in the "W" alcove, and they are catalogued in the same way as they would be if they were in the same library. So I think if it is necessary to keep the transactions separate, all you have to do is to give a separate letter before the catalogue number, which would indicate that they are in a special alcove by themselves.

Cross references are always necessary, because authors have not got to the time yet where they will define the subject about which they are writing. A great many times two different phases, or two different subjects, are brought together under one cover. Of course a general treatise would naturally go further up in the same classification; but two special treatises in the same book must necessitate a cross reference.

With regard to the detail—Roman characters in cataloguing have been thrown out a long time ago, on account of the large number; in fact, one of the chief troubles in systematic classification is the large number of characters which you run across, and the Roman characters simply add to the complication. In this system you have five characters to start with. Then the subdivision will give you two more possibly, and the number of the book may give you another letter or two additional numbers, which will make the catalogue number of the book quite large. Of course, where you simply break it up and refer to the alcove as the 27th alcove, you have to remember that, and remember the number as well.

The subject of classes—I have taken up and proposed to Mr. Dewey a system whereby a large number of classes can be had; that is to say, I have separated letters and figures—for instance, 2 B 6 A. You can index each section and an innumerable tive pages were then pasted on sheets of stout paper 18 x 24 inches, and put under a press made with two drawing boards and simple clamps. These large sheets were then made into book form by punching four holes on one edge and fastening with shoestring. The whole was indexed by name and by subject. The books are too large to be moved but are very conveniently arranged for reference. It is seldom that a catalogue covers more than two or three of these large pages, so one can look over a vast number of catalogues in a very short time.

Mr. H. H. Suplee.—I think that probably the largest strictly technical mechanical library in the country which has been fairly classified is that of the Franklin Institute in Philadelphia, and the system in use there is very similar to the one which Professor Hutton has reported here. The contracted quarters for the library are such that they cannot get the classification on the shelves that they wish. The card catalogue is divided into a subject catalogue and an author's catalogue; and so far as being classified for the user's convenience, as the prime point, and the librarian's as the secondary one, it is certainly a success. The members use it successfully, and people go at once to the catalogue and, as a rule, find directly what they want. That library is particularly rich in the transactions of societies and also in patent reports. It is one of the few places in the country where entirely complete sets of the patent reports of nearly every foreign country can be found and where they are constantly being consulted I think an attempt to classify either those transactions or the reports so that they would be arranged strictly by subjects would interfere with their use. No attempt is made there to follow the decimal system, but the classification of the subjects by Roman numerals I think is followed.

I would like to call the attention of members to a point mentioned in a small French pamphlet on the classification of books, as to the arrangement of books on shelves in vertical rows instead of horizontal ones. Books on the same subject are of all sizes. If we attempt to place them horizontally we have a big book and two little ones and then an odd sized one; but if we place the shelves with the smaller spaces above, constantly increasing in depth, and place the class divisions vertically, then we can place the books of the same sizes on shelves side by side. We can get many more books in the same space, because by having this gradation we do not have to have allowance enough in every shelf for books of all heights, and in practice it is found to work very well The little book is called *L'Art de Classer les Notes,* by M. Guyot-Daubes.

Mr. William Kent.—I do not see it definitely stated in the paper whether it is a classification of a card catalogue or a classification of the books. I would like to ask, if we want to find architecture, do we look under letter "A" or under Class 24?

Professor Hutton.—There is a heading in the card catalogue, Architecture, and all the books on the subject of architecture and all periodicals on the subject of architecture and all references to the subject are under that. There is no classification reference whatever on the cards. That is not a matter that concerns anybody whatever but the librarian.

Mr. Kent.—Then if I wanted to find architecture in the card catalogue I would go to letter "A" first?

Professor Hutton.—Yes.

Mr. Kent.—Then it seems to me that all this question of classification described in the paper is simply one, as the author says, of administration of the library and not for the convenience of users. It would not make any difference to the users whether the books were classified as shown here or classified chronologically or in any other way. That is, if you wanted to find some one's book on architecture you would go to the card catalogue and find under "A" the book you wanted and its number, shelf so-and-so, alcove so-and-so, and you go and get the book from its location. So the classification is only one of convenience to the administrators of the library, and this classification for that purpose is probably as good as any other. But this whole subject of classification I think should be treated a little more broadly—how we should classify our own libraries, our notes and our clippings, and all that sort of thing; and then this question comes up, Is this system of Professor Hutton's a good system? I, myself, don't think it is. For instance, we want to study something about the ventilation of mines. If I wanted to look up that subject in Professor Hutton's classification I would have to look under several classes, viz.: compressors, compressed air, mines, mine ventilation, fans and blowers, and blowing engines, and all these things in different classes; and if we wanted to use a wind-mill to make power, that is still under another class. If we want to consider the problem of digging a ditch to drain the mine and also to pump water out of the mine, we would perhaps have to look under Mine Engineering, one class; Mine Drainage, another class; Pumping Engines, another class; Hydraulic Machinery, another class; Drainage and Irrigation, another class. This question of classification came up with myself—to make a personal reference—in getting all the mass of stuff that I had out of which I compiled my *Mechanical Engineer's Pocketbook*—how to classify it for a subject of study, and then how to classify it to put it in the book; and I adopted the system—taking air as an illustration—of putting everything relating to air under the general head Air. Under that would be wind-mills, air compressors, compressed air, ventilation—ventilation I put as a combination of heat and air, coming under both of them—fans and blowers and blowing engines, and anything relating to air, I put under that general head. Anything that had relation to water I put under water—irrigation, mine drainage, sewage, evaporation of water, the qualities of water, water meters and turbine wheels, pumps—everything that has relation to water. So also I gave a general class to steam. Under that class would be subdivisions for steam boilers, steam engines, steam pipes; while in Professor Hutton's classification I think he has steam in two or three places. In Professor Hutton's classification he has fuels, combustion, and chimneys together under Heat, Fuel, and Engines (not steam). Then he has boilers under another heading—under Steam Engineering. It seems to me that boilers and engines ought to go nearer together. The system I adopted I found very satisfactory indeed.

Mr. Blood.—I would like to say in connection with that shelf number, that that is one of the main instigations to Mr. Dewey to work out that system. That is, he worked out a system so that a number of a book would not put it in any one place. If you number your book and it is the correct number, that is the correct number wherever you put it; and if one section grows large and you want to put the next section in with it, you do not have to change the shelf numbers at all, because the shelves are not numbered. You simply move that section along; and that divorcing of the shelf number from the book number, or, in fact, having no such thing as a shelf number, and letting the book number be the entire reference, is the main object of the decimal system as applied to libraries. For instance, mention is made of the fact that that has nothing to do with the man who wants to see the books. In the State Library at Albany they have this system. It is not entirely a free library, so that certain privileges are given to those who have a chance to use it which they would not have in a large free library. I can go into that library and find the number that I want. If I want to look up engineering I can look at 621. If I want to look at a specialty, say dynamos in electrical engineering—621.311. I go to that part of the library and the books are there. I need to ask no attendant about it. The same with genealogy, 921—all you have to do is to get your key number and you know where all those books are. There is no such thing as the additional function of the shelf number and drawer number. The point in cataloguing, especially in trade cataloguing, is to get the single number to represent many functions. In the cataloguing of manufactures, we have the catalogue number of the article, the drawing number which it is made by, the patent number, and the factory number on which the thing is carried through the factory. And besides that, there are the requisition number of the man who wants the article, and the shipping number of the man who gets it. How can we combine those? In a library it is the same problem—how can we have one number do the function of recording the book and showing where it can be found, and have it so that it can be found with the like books?

*Prof. F. R. Hutton.**—I have been much interested in the discussion which this paper has elicited, and particularly because it reveals that much difference of opinion is possible, and yet most of the opinions be correct.

I am particularly interested in Mr. Suplee's reference to the method pursued in the library of Franklin Institute.

There is not so much difference between the view of the author and those members who have differed with him as to make a reconciliation impossible, if such should seem desirable. The real difference is, that I lay particular stress upon the *card catalogue of material* to be considered, and put the division of it into classes into an entirely subordinate relation. My critics consider the classification of prime significance, and would put everything into the pigeon-hole section, or alcove, where their principle of classification would compel it. By the dictionary, or alphabetical system, which is the basis or starting point of

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* Author's closure, under the Rules.

water out of the mine, we would perhaps have to look under Mine Engineering, one class; Mine Drainage, another class; Pumping Engines, another class; Hydraulic Machinery, another class; Drainage and Irrigation, another class. This question of classification came up with myself—to make a personal reference—in getting all the mass of stuff that I had out of which I compiled my *Mechanical Engineer's Pocketbook*—how to classify it for a subject of study, and then how to classify it to put it in the book; and I adopted the system—taking air as an illustration—of putting everything relating to air under the general head Air. Under that would be wind-mills, air compressors, compressed air, ventilation—ventilation I put as a combination of heat and air, coming under both of them—fans and blowers and blowing engines, and anything relating to air, I put under that general head. Anything that had relation to water I put under water—irrigation, mine drainage, sewage, evaporation of water, the qualities of water, water meters and turbine wheels, pumps—everything that has relation to water. So also I gave a general class to steam. Under that class would be subdivisions for steam boilers, steam engines, steam pipes; while in Professor Hutton's classification I think he has steam in two or three places. In Professor Hutton's classification he has fuels, combustion, and chimneys together under Heat, Fuel, and Engines (not steam). Then he has boilers under another heading—under Steam Engineering. It seems to me that boilers and engines ought to go nearer together. The system I adopted I found very satisfactory indeed.

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DCLXXXVII.*

THE EFFECT OF RETARDERS IN FIRE TUBES OF STEAM BOILERS.

BY JAY M. WHITHAM, PHILADELPHIA, PA.
(Member of the Society.)

THE trials were conducted on a 100 horse-power horizontal tubular boiler at the Sutherland Avenue Station of the Philadelphia Traction Company, Philadelphia. The purpose of the trials was to ascertain under what conditions, if any, retarders in the fire tubes would add to the efficiency of the boiler.

DIMENSIONS AND PROPORTIONS OF BOILER AND SETTING.

Boiler shell	60 in. × 20 ft.
Tubes (44)	4 in. × 20 ft.

Grates—stationary, herring-bone pattern, air openings ⅜-inch wide, or 46 per cent. of grate.

Grate	5 ft. 4 in. wide by 5 ft. long.
Grate surface	26.7 sq. ft.
Water-heating surface	1,137 sq. ft.
Boiler rated at	100 horse-power.
Ratio of heating surface to grate area	42.6 to 1.
Steam-drying surface in top of shell	150 sq. ft.
Liberating surface in boiler	83.3 sq. ft.
Distance from grate to under side of boiler shell	18 in.
Distance from top of bridge wall to under side of boiler shell	10 in.

Boiler set with a return pass over the top.

Ten of such boilers are connected to a brick stack 10 feet diameter by 175 feet high. During the tests from four to seven of these boilers were run in connection with the boiler tested. On certain tests, noted in Sheets Nos. 1A and 1B, retarders were used in the tubes. These were made of loosely fitting strips of No. 10 sheet-iron, running the whole length of the tubes, and

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* Presented at the St. Louis meeting (May, 1896) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

the paper, it is a matter of complete indifference in what alcove or section a book or filed material is to be found, since the card catalogue gives full information on this point.

As a matter of fact, although making the card catalogue the primary basis, the classification principle is followed in practice; the shelving is divided vertically, according to the most shrewd suggestion of Mr. Suplee, and each vertical section is headed by a class number. Nobody uses the class number, however, unless he prefers to reject the card catalogue. If he does, he goes to the section desired, designated by his class number, and there finds the books on that subject. The card-catalogue user, on the other hand, is directed to the book or books upon the subject which he has found by its alphabetical relation in the catalogue, by the shelf number, and not by the class number.

I do not sympathize with the criticism against the system proposed as to finding a subject in so many different places. The periodicals, the transactions, the catalogues, and the patent reports, in such a library as that in question, cannot be subdivided by subject, as the year or quarter of such issues will be bound together, making such absolute subject-subdivision as proposed an impracticability.

The criticism concerning Roman characters is a sound one, and is a detail which I shall be very glad to change.

With respect to combining the societies representing different branches of engineering for joint action upon a suggested classification scheme, it seems eminently desirable that engineering should stand on as creditable a footing as the other professions; and if a sufficient number of experienced and willing members in the various societies can be got together to agree upon a system, it would be a long step in a good direction.

I still feel, however, the comparative hopelessness of an enthusiastic agreement, when so many different objects are before the minds of the various capable and strong men who are engaged in coping with the problem, each in his own way and for his own purpose.

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Ten of such boilers are connected to a brick stack 10 feet diameter by 175 feet high. During the tests from four to seven of these boilers were run in connection with the boiler tested. On certain tests, noted in Sheets Nos. 1A and 1B, retarders were used in the tubes. These were made of loosely fitting strips of No. 10 sheet-iron, running the whole length of the tubes, and

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* Presented at the St. Louis meeting (May, 1896) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

front connection, and in front of the damper at the rear end of the return pass over the top of the boiler. The damper was manipulated so that the draughts would be just sufficient to burn coal for the power desired to be developed on each test.

These observations are given in lines 7, 8, and 9 of Sheet No. 1A, and are plotted in Fig. 98, for various rates of combustion per square foot of grate. From this sheet the following table and curves given in Fig. 99 were formed by drawing "fair" lines through the various points plotted. Fig. 99 shows that to burn, say, thirty pounds of dry coal an hour per square foot of grate, the following draughts are needed:

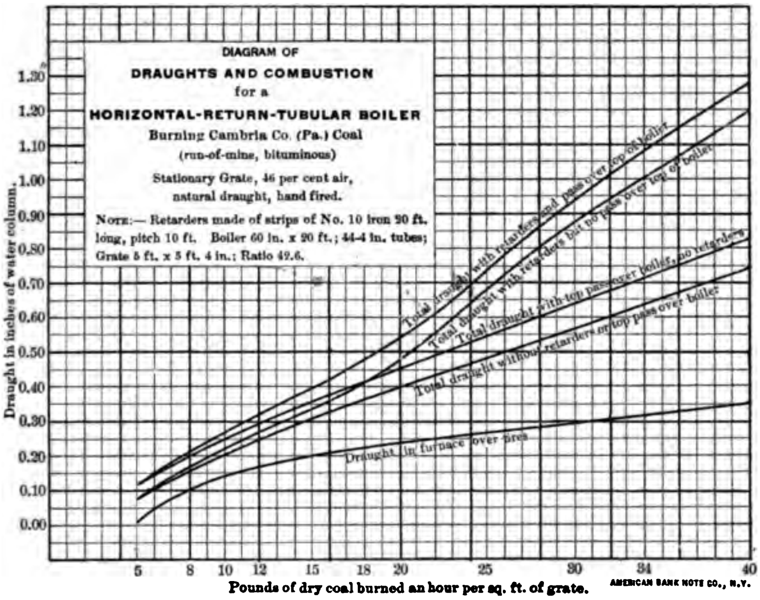


FIG. 99.

Furnace draught	.30	in. water column.
Resistance of pass under boiler and through tubes without retarders	.27	" "
Total draft of stack if no top pass is used	.57	" "
Resistance due to having retarders	.31	" "
Total draft if there is no return pass and retarders are used.	.88	" "
Increased resistance due to return pass over top of boilers	.07	" "

1. When the fires are pushed, as on capacity tests, the damper is open wider than on gentle tests, the draught is stronger, and fine particles of ash, etc., are carried from the furnace and lodged in the dead space behind the bridge wall, deposited in the tubes and front connection, and carried up the stack. Hence it is reasonable to expect a smaller percentage of ash as the fires are pushed.

2. On the other hand, it would be reasonable to expect more fuel to be wasted in the ash on a capacity than on a gentle test. But, as a matter of fact, about as much fuel dropped through the grate on the gentle as on the forced tests, and it formed a larger percentage of the total ash.

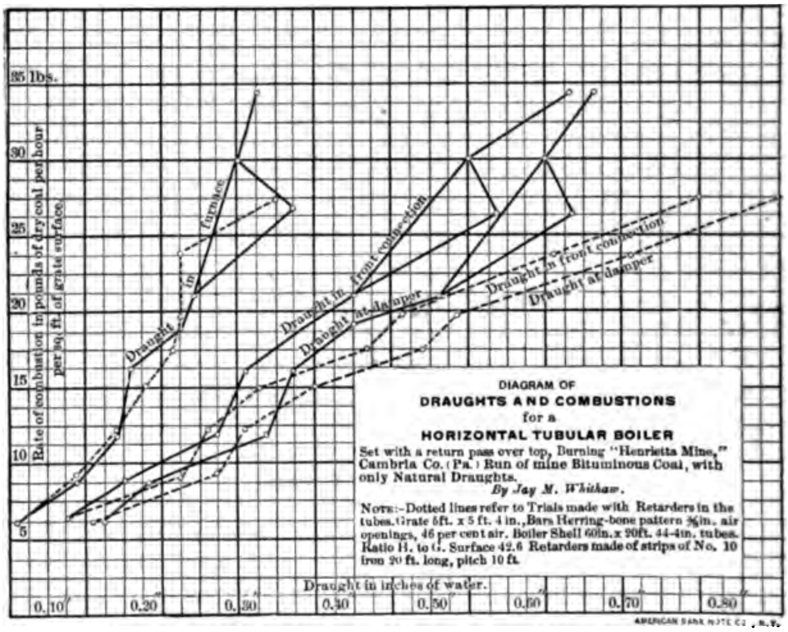


FIG. 98.

It is important to here observe that since coal rather than combustible is bought, and since the percentage of ash varies for the reasons just given, that *in all comparisons of work done by the same grade of fuel under varying conditions, reference should be had to what the coal, rather than the combustible, does.*

Draughts.—The draughts were measured in the furnace, in the atmospheric pressure—*i.e.*, "from and at 212 degrees Fahr.") was the same whether the retarders were used or not. This is not, however, true for all capacities, for the *advantage due to retarders* is as high as 18 per cent. when the boiler is greatly forced, as shown in columns 16 and 17 of Sheet No. 1A, lines 24 and 26.

The temperature of the waste gases is always less when retarders were used, as seen in line 13 of Sheet No. 1A. Herein lies the advantage of retarders. Their use renders more efficient the heating surface of the tubes, enabling the gases to be reduced in temperature, and the same capacity of boiler to be developed with a less expenditure of fuel.

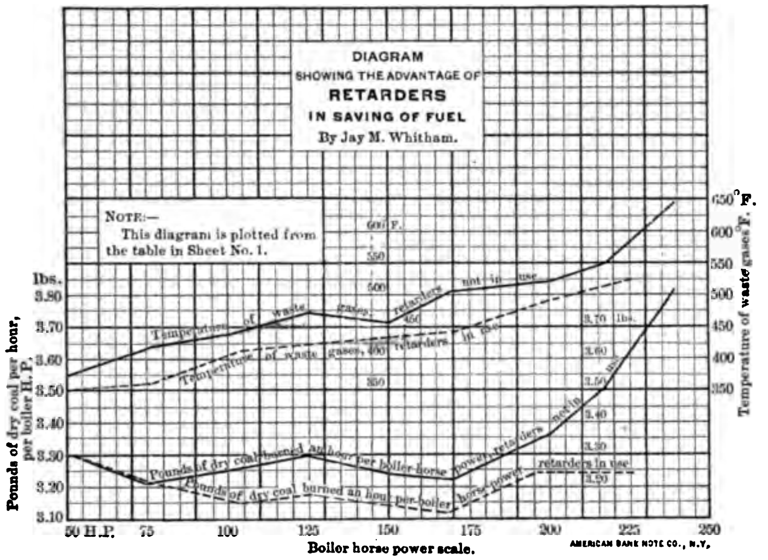


FIG. 100.

Line 32 of Sheet No. 1A states *the pounds of dry coal an hour burned to develop a boiler (evaporative) horse-power.* It is known as the "*commercial line.*" In Fig. 100, this line and also the temperatures of the waste gases are plotted for the various horsepowers developed by the boiler. The sheet shows at a glance the usefulness of retarders. A reduction in temperature of the waste gases shows at once a decrease in the coal consumption, as follows:

52	horse-power,	gases reduced	20	degrees Fahr.,	fuel saving	0.0	per cent.
75	“	“	58	“	“	0.0	“
100	“	“	32	“	“	8.2	“
125	“	“	46	“	“	4.0	“
150	“	“	19	“	“	3.3	“
170	“	“	59	“	“	3.6	“
200	“	“	36	“	“	4.1	“
225	“	“	26	“	“	8.6	“
239	“	“	123	“	“	18.4	“

Variation of Economy with Capacity.—By lines 24, 27, 29, 30, and 31 of Sheet No. 1A we see that the 100 horse-power boiler, rated on 11.37 square feet of water-heating surface to the horse-power, could easily develop over 200 horse-power. At its rated power 3.03 pounds of water, from and at 212 degrees Fahr., were evaporated per hour, yet on test 355 there was no difficulty in evaporating 7.26 pounds to one square foot, or in getting a horse-power on 4.76 square feet of heating surface.

The cost in fuel of a horse-power was as follows for the tests made *without the use of retarders:*

52.4	boiler	horse-power,	3.30	pounds	dry coal	hour	to one horse-power.
74.6	“	“	3.21	“	“	“	“
99.7	“	“	3.25	“	“	“	“
125.3	“	“	3.30	“	“	“	“
150.0	“	“	3.24	“	“	“	“
169.6	“	“	3.22	“	“	“	“
199.7	“	“	3.36	“	“	“	“
217.4	“	“	3.51	“	“	“	“
239.0	“	“	3.82	“	“	“	“

These results show that there is practically no change in the economic workings of the boiler when run at from 50 per cent. below to 70 per cent. above its rating; *i.e.*, when making a horse-power an hour on anywhere from 21.7 to 6.7 square feet of heating surface.

The cost of fuel per horse-power was as follows for the tests made *with retarders in the tubes:*

52.4	boiler	horse-power,	3.30	pounds	dry coal	hour	to one horse-power.
77.8	“	“	3.21	“	“	“	“
104.2	“	“	3.15	“	“	“	“
127.5	“	“	3.18	“	“	“	“
148.6	“	“	3.14	“	“	“	“
169.1	“	“	3.11	“	“	“	“
197.3	“	“	3.23	“	“	“	“
226.1	“	“	3.23	“	“	“	“

atmospheric pressure—*i.e.*, "from and at 212 degrees Fahr.") was the same whether the retarders were used or not. This is not, however, true for all capacities, for the *advantage due to retarders* is as high as 18 per cent. when the boiler is greatly forced, as shown in columns 16 and 17 of Sheet No. 1A, lines 24 and 26.

The temperature of the waste gases is always less when retarders were used, as seen in line 13 of Sheet No. 1A. Herein lies the advantage of retarders. Their use renders more efficient the heating surface of the tubes, enabling the gases to be reduced in temperature, and the same capacity of boiler to be developed with a less expenditure of fuel.

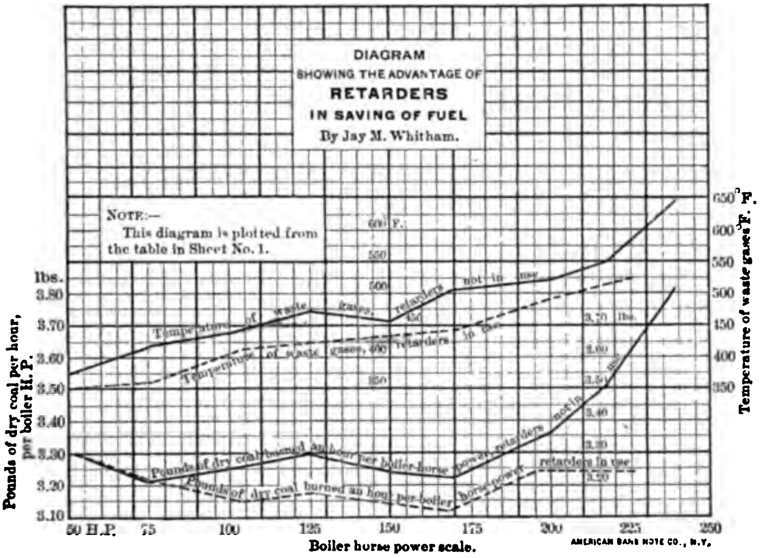


FIG. 100.

Line 32 of Sheet No. 1A states *the pounds of dry coal an hour burned to develop a boiler (evaporative) horse-power.* It is known as the "*commercial line.*" In Fig. 100, this line and also the temperatures of the waste gases are plotted for the various horse-powers developed by the boiler. The sheet shows at a glance the usefulness of retarders. A reduction in temperature of the waste gases shows at once a decrease in the coal consumption, as follows:

52	horse-power,	gases reduced	20	degrees Fahr.,	fuel saving	0.0	per cent.
75	"	"	58	"	"	0.0	"
100	"	"	32	"	"	3.2	"
125	"	"	46	"	"	4.0	"
150	"	"	19	"	"	3.3	"
170	"	"	59	"	"	3.6	"
200	"	"	36	"	"	4.1	"
225	"	"	26	"	"	8.6	"
239	"	"	123	"	"	18.4	"

Variation of Economy with Capacity.—By lines 24, 27, 29, 30, and 31 of Sheet No. 1A we see that the 100 horse-power boiler, rated on 11.37 square feet of water-heating surface to the horse-power, could easily develop over 200 horse-power. At its rated power 3.03 pounds of water, from and at 212 degrees Fahr., were evaporated per hour, yet on test 355 there was no difficulty in evaporating 7.26 pounds to one square foot, or in getting a horse-power on 4.76 square feet of heating surface.

The cost in fuel of a horse-power was as follows for the tests made *without the use of retarders:*

52.4	boiler	horse-power,	3.30	pounds dry	coal	hour	to one horse-power.
74.6	"	"	3.21	"	"	"	"
99.7	"	"	3.25	"	"	"	"
125.3	"	"	3.30	"	"	"	"
150.0	"	"	3.24	"	"	"	"
169.6	"	"	3.22	"	"	"	"
199.7	"	"	3.36	"	"	"	"
217.4	"	"	3.51	"	"	"	"
239.0	"	"	3.82	"	"	"	"

These results show that there is practically no change in the economic workings of the boiler when run at from 50 per cent. below to 70 per cent. above its rating; *i.e.*, when making a horse-power an hour on anywhere from 21.7 to 6.7 square feet of heating surface.

The cost of fuel per horse-power was as follows for the tests made *with retarders in the tubes:*

52.4	boiler	horse-power,	3.30	pounds dry	coal	hour	to one horse-power.
77.3	"	"	3.21	"	"	"	"
104.2	"	"	3.15	"	"	"	"
127.5	"	"	3.18	"	"	"	"
148.6	"	"	3.14	"	"	"	"
169.1	"	"	3.11	"	"	"	"
197.3	"	"	3.23	"	"	"	"
226.1	"	"	3.23	"	"	"	"

NO. 1A.

TUBULAR BOILER, RUN AT VARIOUS CAPACITIES, BURNING HENRIETTA MINE, VALUE OF RETARDERS IN THE TUBES. MADE BY JAY M. WHITHAM, CONSULT-PHILADELPHIA, PA. ; J. E. GIBSON, ASST. ENGINEER ; L. KENNEDY, FIREMAN.

7	8	9	10	11	12	13	14	15	16	17	
350	377	351	379	356	378	353	382	354	381	355	1
9/21/'95	1/17/'96	9/23/'95	1/21/'96	10/1/'95	1/20/'96	9/27/'95	1/24/'96	9/28/'95	1/23/'96	9/30/'95	2
9	9	9.1	9	9	9	9	9	9	9	9	3
Witho't	With.	Witho't	With.	Witho't	With.	Witho't	With.	Witho't	With.	Witho't	4
Temperatures observed on Tests.											
14.70	14.80	14.70	14.80	14.83	14.82	14.70	14.56	14.79	14.83	14.66	5
138.30	183.90	136.70	132.80	136.23	133.52	136.90	133.56	136.59	133.53	135.66	6
0.36	0.38	0.42	0.40	0.51	0.53	0.65	0.71	0.62	0.86	0.67	7
0.31	0.32	0.37	0.43	0.42	0.47	0.57	0.63	0.54	0.78	0.64	8
0.19	0.20	0.24	0.23	0.25	0.24	0.86	0.24	0.30	0.34	0.32	9
97	38	97	37	65	34	70	44	71	39	68	10
112	75	110	76	87	76	102	78	99	80	89	11
76.4	37.5	78	39.8	69.8	42	77.2	39.6	71.5	39.1	72	12
470	424	455	436	506	447	526	490	551	523	646	13
Pa., Run-of-mine Bituminous Coal.											
3,800	3,700	4,490	4,300	5,100	4,800	6,200	6,200	7,000	6,700	8,400	14
2	1.5	1.53	2.5	2	1.25	2.5	7.5	2	2	2	15
3.724	3,646	4,421	4,193	5,000	4,740	6.045	5,735	6,860	6.536	8,232	16
184	212	217	216	248	278	280	315	304	297	350	17
4.93	5.81	4.93	5.06	4.96	5.76	4.63	5.49	4.43	4.53	4.25	18
3,540	3,434	4,204	3,977	4,752	4,467	5,765	5,420	6,556	6,269	7,882	19
Total Water Evaporated.											
0.9990	0.9941	0.9981	0.9999	0.9980	0.9989	0.9967	0.9955	0.9976	1.0000	0.9938	20
32,849	32,517	39,820	37,764	45,051	43,084	52.568	50.870	56.955	57,440	61,987	21
32,816	82,325	39,745	37,760	44,961	43,037	52,395	50,143	56,878	57,440	61,913	22
38,887	39,598	47,098	46,14	53,573	52,505	62,036	61,275	67,514	70,192	74.236	23
in Fuel by use of Retarders.											
10.44	10.86	10.65	11.00	10.70	11.09	10.26	10.68	9.84	10.69	9.03	24
10.99	11.53	11.20	11.60	11.27	11.53	10.76	11.30	10.29	11.19	9.43	25
4.02		3.20		3.55		4.09		8.64	18.89		26
and Combustion.											
3.80	8.87	4.55	4.51	5.25	5.13	6.06	5.99	6.59	6.86	7.26	27
16.35	15.18	19.20	17.45	20.87	19.73	26.55	23.86	30.10	27.32	34.30	28
Developed.											
125.8	127.5	150.0	148.6	169.6	169.1	199.7	197.3	217.4	226.1	239.0	29
+25.8	+27.5	+50	+48.6	+69.6	+69.1	+99.7	+97.3	+117.4	+126.1	+139.0	30
9.09	8.92	7.58	7.65	6.70	6.72	5.68	5.76	5.23	5.03	4.76	31
3.30	3.18	3.24	3.14	3.22	3.11	3.36	3.23	3.51	3.23	3.82	32

a return pass over top of boiler. Water-heating surface, 1,137 square feet. Steam-drying surface, 5 feet 4 inches wide by 5 feet long ; surface, 26.7 square feet ; air openings, three-eighths inch wide, of grate from shell, 18 inches. Distance of bridge wall from shell, 8 inches. Boiler is one of ten 20 feet long, twisted in 10-foot pitch, or two convolutions per tube. Tests begun and ended with 15-minute intervals. Boiler cleaned at commencement of each test.

SHEET NO. 1B.

Condensed table showing principal results of a series of trials on a 100 horse-power horizontal tubular boiler, run at various capacities, burning "Henrietta Mine," Cambria Co., Penn., run-of-mine bituminous coal, to determine the value of retarders in the tubes. Made by Jay M. Whitham, Consulting Engineer, Philadelphia, at the Sutherland Av. Sta. of P. T. Co., Philadelphia. J. E. Gibson, assistant engineer. L. Kennedy, fireman. Boiler shell, 60 in. x 20 ft.; 44 4-in. tubes; 1,137 sq. ft. heating surface; grate, 5 ft. x 5 ft. 4 in.; ratio, 42.6; steam drying surface, 150 sq. ft.; liberating surface, 83.3 sq. ft.; air openings in grate, ½ in. wide, or 46%; distance from grate to boiler, 18 in.; grate to top of bridge wall, 10 in. Water and coal weighed on tests. Observations taken every 15 minutes; started and ended tests with bare grates. Retarders made of No. 10 iron strips, 20 ft. long, 10 ft. pitch. Boiler clean at start of each test. Ten such boilers on stack 10 ft. x 175 ft.

Trial No.	H. P. developed.	With or without retarders in tubes.	DRAUGHT IN INCHES AT			Temperature of waste gases °F.	Moisture in steam, part of one per cent.	POUNDS OF WATER EVAPORATED FROM AND AT 212° F. PER LB.		Per cent. of ash in dry coal.	Pounds of dry coal burned an hour per H. P. developed.	Pounds of water 212° F. per sq. ft. of heating surface.	Pounds of dry coal burned an hour per sq. ft. of grate.	Sq. ft. of heating surface to one H. P. developed.
			Furnace.	Front connection.	Boiler damper.			Of dry coal.	Of combustible.					
348	52.4	Without	0.07	0.12	0.16	371	0.34	10.43	11.38	8.33	3.30	1.59	6.49	21.70
375	52.4	With	0.07	0.12	0.15	351	0.21	10.44	11.43	8.72	3.30	1.59	6.49	21.70
Saving of fuel by use of retarders, 0.0 per cent.														
346	74.6	Without	0.13	0.18	0.21	414	0.45	10.70	11.38	6.04	3.21	2.25	8.89	15.24
374	77.3	With	0.13	0.24	0.28	361	0.12	10.72	11.57	7.42	3.21	2.34	9.38	14.71
Saving of fuel by use of retarders, 0.0 per cent.														
349	99.7	Without	0.17	0.28	0.33	444	0.00	10.58	11.29	6.15	3.25	3.03	12.13	11.37
376	104.2	With	0.17	0.27	0.31	412	0.95	10.92	11.56	5.55	3.15	3.16	12.30	10.91
Saving of fuel by use of retarders, 3.2 per cent.														
350	125.3	Without	0.19	0.31	0.36	470	0.10	10.44	10.99	4.93	3.30	3.80	16.35	9.09
377	127.5	With	0.20	0.32	0.38	424	0.59	10.86	11.53	5.81	3.18	3.87	15.18	8.92
Saving of fuel by use of retarders, 4.0 per cent.														
351	150.0	Without	0.24	0.37	0.42	455	0.19	10.65	11.20	4.93	3.24	4.55	19.20	7.58
379	148.6	With	0.23	0.43	0.49	436	0.01	11.00	11.60	5.06	3.14	4.51	17.45	7.65
Saving of fuel by use of retarders, 3.3 per cent.														
356	169.6	Without	0.25	0.42	0.51	506	0.20	10.71	11.27	4.96	3.22	5.25	20.87	6.70
378	160.1	With	0.24	0.47	0.53	447	0.11	11.09	11.53	5.76	3.11	5.13	19.73	6.72
Saving of fuel by use of retarders, 3.6 per cent.														
353	199.7	Without	0.26	0.57	0.65	526	0.33	10.26	10.76	4.63	3.36	6.06	26.55	5.68
382	197.3	With	0.24	0.63	0.71	490	0.45	10.68	11.30	5.49	3.23	5.90	23.86	5.76
Saving of fuel by use of retarders, 4.1 per cent.														
354	217.4	Without	0.30	0.54	0.62	551	0.24	9.84	10.29	4.43	3.51	6.50	30.10	5.23
381	226.1	With	0.34	0.78	0.86	523	0.00	10.69	11.19	4.53	3.23	6.86	27.32	5.03
Saving of fuel by use of retarders, 8.6 per cent.														
355	239	Without	0.32	0.64	0.67	646	0.12	9.03	9.43	4.25	3.82	7.26	34.30	4.76
Saving of fuel by use of retarders, comparing tests 355 and 381, 18.4 per cent.														

NO. 1A.

TUBULAR BOILER, RUN AT VARIOUS CAPACITIES, BURNING HENRIETTA MINE, VALUE OF RETARDERS IN THE TUBES. MADE BY JAY M. WHITHAM, CONSULT- PHILADELPHIA, PA.; J. E. GIBSON, ASST. ENGINEER; L. KENNEDY, FIREMAN.

7	8	9	10	11	12	13	14	15	16	17	
350	377	351	379	356	378	353	382	354	381	355	1
9/21/'95	1/17/'96	9/23/'95	1/21/'96	10/1/'95	1/20/'96	9/27/'95	1/24/'96	9/28/'95	1/23/'96	9/30/'95	2
9	9	9.1	9	9	9	9	9	9	9	9	3
Witho't	With.	Witho't	With.	Witho't	With.	Witho't	With.	Witho't	With.	Witho't	4
Temperatures observed on Tests.											
14.70	14.80	14.70	14.80	14.83	14.82	14.70	14.56	14.70	14.83	14.66	5
138.30	133.90	136.70	132.80	136.23	133.52	136.90	133.56	136.59	133.53	135.66	6
0.36	0.38	0.42	0.40	0.51	0.53	0.65	0.71	0.62	0.86	0.67	7
0.31	0.32	0.37	0.43	0.42	0.47	0.57	0.63	0.54	0.78	0.64	8
0.19	0.20	0.24	0.23	0.25	0.24	0.36	0.24	0.30	0.34	0.32	9
97	38	97	37	65	34	70	44	71	39	68	10
112	75	110	76	87	76	102	78	99	80	89	11
76.4	37.5	78	39.8	69.8	42	77.2	39.6	71.5	39.1	72	12
470	424	455	436	506	447	526	490	551	523	646	13
Pa., Run-of-mine Bituminous Coal.											
3,800	3,700	4,490	4,300	5,100	4,800	6,200	6,200	7,000	6,700	8,400	14
2	1.5	1.53	2.5	2	1.25	2.5	7.5	2	2	2	15
3.724	3,646	4,421	4,193	5,000	4,740	6.045	5,735	6,860	6,536	8,232	16
184	212	217	216	248	278	280	315	304	297	350	17
4.93	5.81	4.98	5.06	4.96	5.76	4.63	5.49	4.43	4.53	4.25	18
3,540	3,434	4,204	3,977	4,752	4,467	5,765	5,420	6,556	6,269	7,882	19
Total Water Evaporated.											
0.9990	0.9941	0.9981	0.9909	0.9980	0.9989	0.9967	0.9955	0.9976	1.0000	0.9938	20
32,849	32,517	39,820	37,764	45,051	43,084	52,568	50,870	56,955	57,440	61,987	21
32,816	32,325	39,745	37,760	44,961	43,037	52,395	50,143	56,878	57,440	61,913	22
38,887	39,598	47,099	46,14	53,573	52,505	62,036	61,275	67,514	70,192	74,206	23
in Fuel by use of Retarders.											
10.44	10.86	10.65	11.00	10.70	11.09	10.26	10.68	9.84	10.69	9.03	24
10.99	11.53	11.20	11.60	11.27	11.53	10.76	11.30	10.29	11.19	9.43	25
4.02		3.29		3.55		4.09		8.64	18.39		26
and Combustion.											
3.80	3.87	4.55	4.51	5.25	5.13	6.06	5.99	6.59	6.86	7.26	27
16.85	15.18	19.20	17.45	20.87	19.73	26.55	23.86	30.10	27.32	34.30	28
Developed.											
125.8	127.5	150.0	148.6	169.6	169.1	199.7	197.3	217.4	226.1	239.0	29
+25.8	+27.5	+50	+48.6	+69.6	+69.1	+99.7	+97.3	+117.4	+126.1	+139.0	30
9.09	8.92	7.58	7.65	6.70	6.72	5.68	5.76	5.23	5.03	4.76	31
3.30	3.18	3.24	3.14	3.22	3.11	3.36	3.23	3.51	3.23	3.82	32

a return pass over top of boiler. Water-heating surface, 1,137 square feet. Steam-drying surface,
5 feet 4 inches wide by 5 feet long; surface, 26.7 square feet; air openings, three-eighths inch wide,
of grate from shell, 18 inches. Distance of bridge wall from shell, 8 inches. Boiler is one of ten
20 feet long, twisted in 10-foot pitch, or two convolutions per tube. Tests began and ended with
15-minute intervals. Boiler cleaned at commencement of each test.

and stand in beads upon the fire side of the tube when a current of gas at a temperature of over 1,000 degrees Fahr. was passing through the tube.

The rate of absorption of heat by boiler heating surface, then, depends almost entirely on how much heat we can impart to this surface on the fire side. In the ordinary boiler tube, heat is imparted to the surface of the tube only by the contact of the hot gases. Now suppose we place in the tube any solid body, of any shape whatever. Manifestly, as it is surrounded and bathed on all sides by gases at a temperature of say 1,000 degrees, it will, if it loses no heat, soon become of the same temperature as the hot gases. Suppose the surface of the tube is of a temperature of 300 degrees Fahr.; then we shall have these two surfaces only an inch or two apart, and a difference of temperature between them seven times as great as exists between a very cold winter day and the maximum heat of summer. Under these circumstances, of course the hot body at the centre of the tube will energetically radiate heat to the walls of the tube, and will materially increase the amount of heat transmitted to the water.

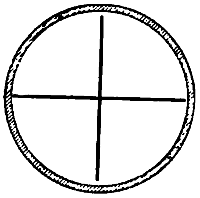


FIG. 101.—Section of boiler tube, with radiator in position.

The amount of radiation in any given tube depends on the area of radiating surface and on the difference in temperature between the radiating surface and the surface of the tube. A radiator of cross shape, like that shown in the accompanying cross-section of a tube, has a radiating surface nearly one and one third times as great as the inner surface of the tube, and experiments show it to radiate nearly twice as much heat in a given time as a flat strip of a width equal to the tube diameter.

I have made numerous experiments to test the efficiency of radiators with the apparatus shown in the accompanying sketch. It represents a section of a single tube of a vertical boiler. The water space surrounding it is well protected by non-conductors, so that the loss of heat is very small. Through the tube a current of hot gas is caused to flow from a lamp, gas jet, or other suitable source, and the amount of heat transmitted to the water in a given time is measured. The test is then repeated under identical conditions, except that a radiator of the form shown in Fig. 101 is placed in the tube. The increased amount

DISCUSSION.

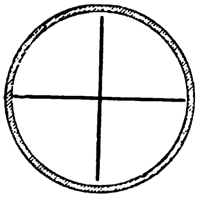
Mr. Charles Whiting Baker.—It is a rather curious fact that while "retarders," as they are called, have been used more or less for several years, and in some instances with very notable advantage, Mr. Whitham's paper is, so far as I am aware, the first extended account of their use and their advantages which has appeared in technical literature, although, of course, allusions to their use in connection with various steam plants have been made in various papers.

Another curious fact is that the action of "retarders" in the flue has been generally misunderstood, as is indicated by their name. The retarder does of course obstruct and "retard" the flow of gas through the flue, but this is by no means the purpose for which it is placed there. If it were desired simply to make the hot gases flow more slowly through the tubes, the simplest and best way is to check the draft by dampers in the chimney or at the ash-pit.

What the so-called retarder does which is beneficial is to increase the amount of heat transmitted to the tube surface from the hot gases, and it does it in two ways: first, by a mixing action upon the gas in the tube. The friction upon the surface of the retarder aids in stirring up the gas in its passage through the tube and in mixing the hot gas at the centre with the cold film next the surface of the tube. Also, in every horizontal tube there is a tendency for the gases to be cooler in the upper part of the tube and hotter in the lower, for the upper half of the tube extracts heat far more readily from the gases than the lower half. The twist of the retarder has the effect of repeatedly turning over the gas in the tube as it flows along.

In the second place, the retarder acts by direct radiation of heat to the tube surface. While this action may not be apparent at first sight, it is of such importance that it should be clearly understood. To this end the fact should first be realized that the temperature of the tube surface exposed to the fire in any steam boiler is practically the same as that of the water in contact with it, no matter what the temperature of the gas on the other side. (We of course suppose the tube surface to be clean.) The reason is that water absorbs heat many times as rapidly as gas. As experimental proof I may add that in a small boiler filled with cold water I have often seen dew collect and stand in beads upon the fire side of the tube when a current of gas at a temperature of over 1,000 degrees Fahr. was passing through the tube.

The rate of absorption of heat by boiler heating surface, then, depends almost entirely on how much heat we can impart to this surface on the fire side. In the ordinary boiler tube, heat is imparted to the surface of the tube only by the contact of the hot gases. Now suppose we place in the tube any solid body, of any shape whatever. Manifestly, as it is surrounded and bathed on all sides by gases at a temperature of say 1,000 degrees, it will, if it loses no heat, soon become of the same temperature as the hot gases. Suppose the surface of the tube is of a temperature of 300 degrees Fahr.; then we shall have these two surfaces only an inch or two apart, and a difference of temperature between them seven times as great as exists between a very cold winter day and the maximum heat of summer. Under these circumstances, of course the hot body at the centre of the tube will energetically radiate heat to the walls of the tube, and will materially increase the amount of heat transmitted to the water.



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Mr. Whitham.—With reference to the remarks of Mr. Barrus, I would state that on page 456 is a table explaining the diagram, Fig. 100, to which he refers. He will notice that when the boiler was run at 239 horse-power the gases were reduced 123 degrees. Of course on the capacity tests the volume of gas was great, and the reduction in temperature of the gases was greater by the use of the retarders than at any other time, which accounts for the large saving effected. With regard to economizers, it is well known that the saving by their use varies all the way from nothing to 10 or 12 per cent. If retarders in the fire tubes of a boiler will accomplish the same results, certainly they are to be preferred, if for no other reason than the question of cost. There is nothing to prevent both retarders and economizers being used provided the draft is adequate. In general a plant is not provided with a draft great enough to stand the checking action of both.

Mr. George H. Barrus.—It may or may not be true that economizers so-called save all the way from 0 to 10 or 12 per cent. (my experience is that the range is from *minus* 5 per cent. to 33⅓ per cent.), but it is hardly right to place them in the same category as retarders Economizers utilize *waste* heat, while retarders make the existing heating surfaces more efficient. The limit of temperature to which the former can reduce the flue gases is the initial temperature of the feed water, and this limit in some cases is the *freezing point.* Of course this can never be reached. In practice the temperature of the gases having an economizer often runs down to 200 degrees Fahr. On the other hand, the limiting temperature in the case of retarders is that of the water in the boiler, and this at 100 pounds pressure is 338 degrees. The actual temperature in Mr. Whitham's test with retarders, designated No. 16, was 523 degrees. With these figures before us, Mr. Whitham would surely not have us believe that no advantage would result from utilizing the heat of the gases corresponding to the difference between 523 degrees and 200 degrees! The probability is that a properly arranged heater placed in the flue of the very boiler which he used in these investigations would have saved far more than when care is not taken in this respect. It appears likely that either of these devices may be used with especial advantage, therefore, where a clean fuel like gas or oil is used. Another application of these devices which appears to have promise is to the tubes of vertical boilers of the Corliss or Manning type. An objection to these otherwise excellent types of boilers is the very high head-room that is required to get in tubes long enough to extract the heat from the gases with reasonable completeness. By the use of some device to increase the tube-heating surface efficiency a shorter tube should be permissible, with a consequent reduction in the height of the boiler.

The economic gain by the use of either radiators or retarders depends entirely upon the temperature at which the boiler is discharging its hot gases. In general it may be assumed that every 100 degrees reduction in the temperature of the waste gases represents from five to ten per cent. saving in fuel.

In general it will not usually be found worth while to introduce either retarders or radiators in the tubes of any boiler unless the thermometer shows its hot gases to be discharging at a temperature of over 550 degrees Fahr.

I notice among Mr. Whitham's conclusions the statement that "retarders can be used only with fire-tube boilers." This doubtless refers to the proposition to place retarders inside the water tubes, which is absurd on its face to any one correctly understanding the action of retarders. The use of radiating bodies of extended surface, however, in the gas passages between the tubes of a water-tube boiler, should in theory give at least the same advantage as in the case of fire tubes. Two me hods for effecting this radiating action, devised by the writer, may be found by reference to U. S. Patents Nos. 529,997 and 559,02 .

Mr. George H. Barrus.—I notice in the diagram on page 455, showing the temperature of the waste gases in these experiments, that when the retarders were in use the temperature was about an average of 30 degrees less than it was when the retarders were not in use, and Mr. Whitham says that the reduction in the temperature of the waste gases accounts for the advantage due to the retarders. Of course this is true. Now, he says that retarders may often prove to be as economical as economizers. I think he ought to explain a little more fully what he means by that. I would like to understand whether he intends to convey the idea that no further saving could be made by the use of an economizer. I do not think any one has any doubt as to what he means, but I think he ought to put it on record as showing a little more explicitly the explanation of that point.

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Mr. George H. Barrus.—It may or may not be true that economizers so-called save all the way from 0 to 10 or 12 per cent. (my experience is that the range is from *minus* 5 per cent. to 33⅓ per cent.), but it is hardly right to place them in the same category as retarders Economizers utilize *waste* heat, while retarders make the existing heating surfaces more efficient. The limit of temperature to which the former can reduce the flue gases is the initial temperature of the feed water, and this limit in some cases is the *freezing point.* Of course this can never be reached. In practice the temperature of the gases having an economizer often runs down to 200 degrees Fahr. On the other hand, the limiting temperature in the case of retarders is that of the water in the boiler, and this at 100 pounds pressure is 338 degrees. The actual temperature in Mr. Whitham's test with retarders, designated No. 16, was 523 degrees. With these figures before us, Mr. Whitham would surely not have us believe that no advantage would result from utilizing the heat of the gases corresponding to the difference between 523 degrees and 200 degrees! The probability is that a properly arranged heater placed in the flue of the very boiler which he used in these investigations would have saved far more than the 8.6 per cent. reported as the advantage due to the retarders on the test in question.

It may be that retarders will in *some cases* produce as many per cent. saving as economizers in *some cases*, but it is hardly fair to the latter to make it appear, as Mr. Whitham's statements seem to do, that retarders answer the same purpose as economizers.

Mr. William Kent.—I notice that in Mr. Whitham's paper he does not seem to give any theory of the action of the retarders. He gives merely the data which he has observed. Mr. Baker in his discussion does give a theory. I wish to call attention to another possible theory which may act in conjunction with the theory of Mr. Baker. In an ordinary tubular boiler as ordinarily set there is a great tendency for the gases to go through the upper rather than through the lower tubes, and if we put pyrometers in these tubes, we will find that the gases going out of the upper row of tubes are much hotter than those going out of the lower row. I have found this by using bolts of iron placed in the tubes of a vertical row for an hour or so, and taking them out and putting them in water. A regular gradation of temperature was found from the upper to the lower tube in the vertical row; also, by putting pieces of wood in these tubes it is found that wood in the lower tubes will be scarcely charred, while in the upper tubes it will be burned to ashes. If we put a pyrometer in the chimney flue of this boiler, we may find that we have a temperature of say 500 degrees, while the temperature of the gas escaping from the upper tubes may be 1,000 degrees, and that of the lower about 350 degrees, a little above the temperature of the water in the boiler. So that the 500 degrees is simply an average of the temperature of the waste gases coming from the different tubes. If, however, we can retard the flow through the upper row of tubes, or all the tubes, there will be a tendency for all the gases more equally to distribute themselves. So I submit that one of the actions of the retarder is possibly to force the gases to flow through all the tubes more equally.

I have suggested for the use of tubular boilers another kind of retarder, differing from those mentioned by Mr. Whitham or Mr. Baker—namely, a deflecting plate running across the discharge end of the boiler, which will slightly obstruct the flow of the gases through the upper tubes; this plate being pivoted improved by graduating them smaller and smaller as you go down, and not applying them of the same width over the entire surface.

Mr. Edwin M. Herr.—The use of a retarding plate or distributer is a common practice in locomotive work. Mr. Bryan has just outlined almost exactly the arrangement which is in use in locomotive practice, and has been for a long time. The deflector plate, it is called, is carried from above the upper tubes, inclined farther and farther from the tubes, and ending usually 16 or 18 inches from the bottom of the shell. This retards the gases passing through the upper tubes.

The matter of blowing out the tubes with compressed air is also practised to a considerable extent in railroad work. I have had experience with this method, and can testify that it is very efficient and satisfactory.

Mr. George H. Barrus.—I made a test on a 66-inch horizontal return tubular boiler for Mr. Weeks, of the Society, and I do not believe he would have any objection to my telling about it. There was an inclined baffling plate extending down and covering nearly the whole of the tube openings, set at the bottom about 6 inches from the tube sheet. The regulating damper consisted of another plate centred at the bottom of the baffling plate, and fitting against the cleaning door in front. Now the best result on any of the tests reported in the paper is 11.56 pounds; I got on this particular trial about 12 pounds.

Mr. Kent.—What kind of coal?

Mr. Barrus.—Cumberland.

Mr. Whitham.—I would like to add one point to make this paper plainer, and that is with regard to cleaning tubes. The idea seems to be that retarders interfere with the cleaning of the tubes. As a matter of fact, they are an aid. By catching hold of the end of the retarder and moving it back and forth, you disengage the deposit from the inside of the tube, when a suction blower will draw the soot out and drive it up the stack.

Prof. J. H. Kinealy.—I am very much interested in this, especially when I think of it in connection with the experiments of Isherwood. They bear also upon the theory advanced by Mr. Kent. Isherwood found that he got better results when he plugged up a number of the lower tubes than when he had them all open. It seems to me that retarders ought to give good results when the area through the tubes is large. I have depends very much on the nature or amount of draught used. The greater the draught, the greater the saving. In many instances the saving of coal amounts to 15 per cent., and even 20 per cent., where both Serve tubes and retarders were used and the draught was equal to 3 inches vacuum in the smoke-box. In our boilers, in Sheffield, we use 3¼ Serve tubes, fitted with retarders, with splendid results; and we believe the retarders give us an extra economy of 5 per cent. by throwing the heated gases more effectually between the ribs, as well as retarding the rate of flow; and with a vacuum of 3 inches of water the tubes keep quite clean for a week.

With regard to the remarks of one speaker about the difference of temperature in the upper and lower tubes, I found from personal experience that, in the case of a marine boiler which was short of steam, I got the best results by fitting the top half of the tubes only with retarders, thus causing the lower tubes to do more work; and the same result is accomplished by a firm in England who fit a diaphragm in the smoke-box in such a way as to retard the passage of the hot gases through the upper row of tubes, the result being very similar to that mentioned by another speaker, of checking the flow of gases through the upper tubes by means of small ferrules placed over the ends of the upper tubes.

Mr. Wm. H. Bryan.—It appears to me that the device is rather one for improving a badly designed boiler, as it would seem that better work could be done by plenty of heating surface, well located, in the first place. Isn't its effect very similar to that of extended radiating surfaces in steam heating? One objection which would practically rule the retarders out with our Western service is the low character of our fuels, and the very great amount of soot. Another is that it would certainly impair the draught, or rather the effect of the draught on the grate surface, where we want it to do its work. I find that, with our coals here, plenty of draught is essential; in fact, I have not found the limit. I do not believe we can get too much draught for the low-grade fuels we have here, always, of course, decreasing the grate surface, and burning at a higher rate. My great contention with steam users here is to give me enough chimney rather than reduce the draught we have. In regard to the statement made by Mr. Kent as to those dampers over the end of the tubes, their efficiency would, of course, be

DCLXXXVIII.*

A HYDRAULIC DYNAMOMETER.

BY JAMES D. HOFFMAN, LAFAYETTE, INDIANA.
(Junior Member of the Society.)

THE above machine was constructed at Purdue University in the winter of 1894–95, to make a series of tests on the application of cutting edges to iron. It has been in use since September, 1895, giving quite satisfactory results.

The original design was obtained from Prof. J. J. Flather, with permission to change such parts as seemed best to accomplish the work in hand. The main features of the machine are as follows: Two cylinders, *E E'* (Fig. 104), are fastened diametrically opposite each other to a double yoke, which in turn is fastened to a hollow shaft. Each cylinder is connected to the centre of the shaft by the hollow tubing and ground joint shown at *a'*. The cylinders are rotated; that is, the shaft is rotated by the pull of the driving belt on the loose pulley *A*, tending to force the brass pistons to the bottom of the cylinders. The shaft and cylinders are full of oil, and any fluctuations of power between *A*, the receiving, and *C*, the delivering, pulleys, are shown in pounds on the gauge to the right, and an indicator card on the left hand. The oil flows around the bearing *G*, giving good lubrication, and is kept from leakage by means of the stuffing-box shown in the section (Fig. 105).

By a number of interchangeable gears, the paper has different speeds, which is of much importance in taking cards where sudden changes of resistance appear, such as turning iron of an uneven texture, or the short, quick stroke of the shaper.

In working up the cards, the area and length are measured accurately, and the mean height (M. H.) obtained. This M. H. is converted into M. P. by calibrating the machine and finding the value of the resisting spring under the casting *b'* (Fig. 104).

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* Presented at the St. Louis meeting (May, 1896) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

looked through this paper and can find no statement as to the tube area—the tube area per pound of coal burned. It seems to me that is quite important. Isherwood found it so; and, if I remember rightly, he also got better results when he put ferrules in his tubes where the tube area was large, reducing the calorimetric area, as it is sometimes called. Unless we can show by later experiments that Isherwood was mistaken, we must believe that closing the bottom tubes will probably give better results than closing the top tubes.

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The recording device (see Fig. 106) is designed to give a straight line motion, at the end of the pencil arm. A bronze point and metallic-surfaced paper are used. No flexible material, such as cup leather, is used in the cylinders, and the pistons fit loosely enough to reduce the friction to a minimum. When the oil runs low by leakage, it is the work of but a few minutes to replenish, by means of the pump at the rear. The leakage does not exceed a half pint daily when doing ordinary duty.

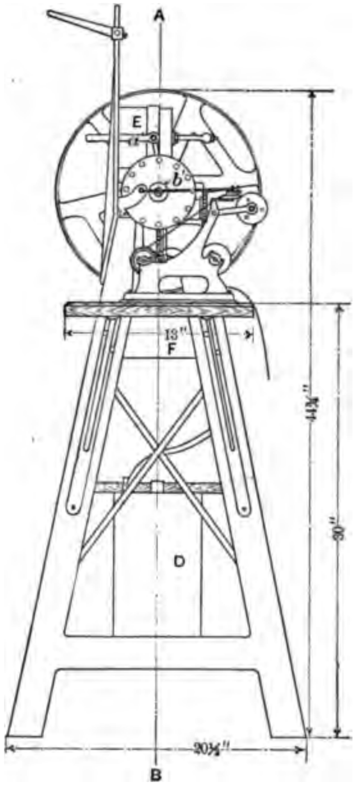

Fig. 103.

When in use, the cylinders are surrounded by a sheet-iron case to catch the oil. *D* and *F* are oil tanks.

Calibrating the Machine.—To do this, the method shown in Fig. 106 was adopted. Two thirty-pound gauges were selected and tested in the laboratory for this purpose. Readings were taken from each gauge and averaged for results. By a downward pressure on the lever shown (the pulley A, held stationary by wire to the floor), the gauge was brought to read exact pounds, and at these readings the paper was moved, giving lines

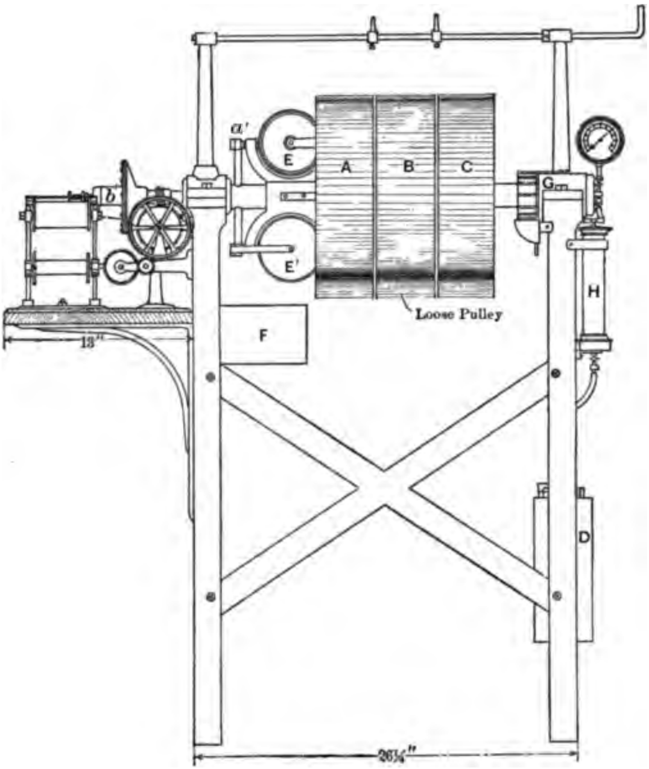

Fig. 104.

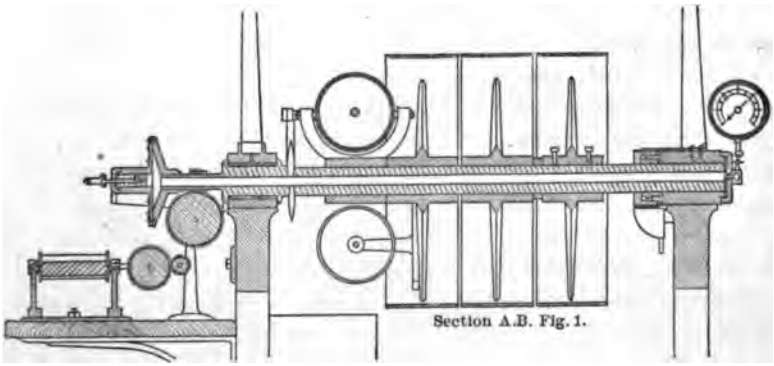

Fig. 105.

The friction of the machine and work was such a variable quantity, especially so considering the pressure on the tail centre, that it was found necessary to take friction cards at intervals during the series, as *E*, *F*, *G*, *H*.

Figs. 110 and 111 show the effect of sand holes in a casting.

TURNING CAST IRON, 1¾" TO 1⅝"

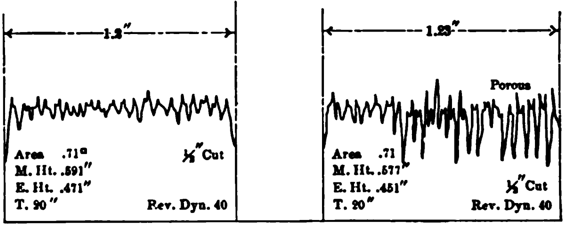

Fig. 110.

DRILLING CAST IRON, 1" HOLE.

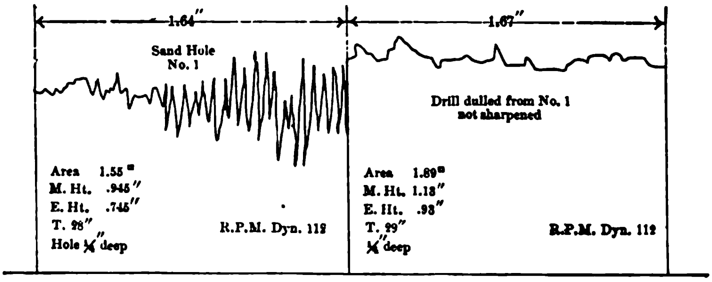

Fig. 111.

EFFECT OF TIGHT CENTER.

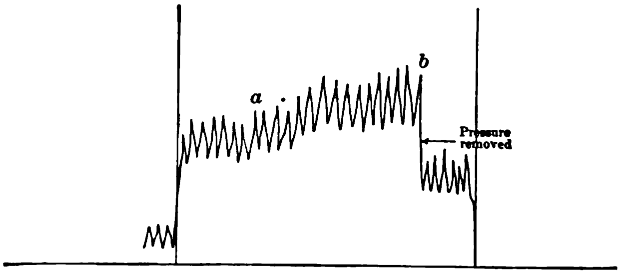

Fig. 112.

The cutting edge of the drill (Fig. 111) was dulled, as indicated by the increased height of the card after passing the sand hole.

Fig. 112 was taken while turning machine steel. The tail centre proved to be too tight, and from *a* to *b* shows an increase, due to the grooving of the centre. At *b* the pressure was removed.

PLATE 2.

WEIGHT AT END OF 4-FOOT LEVER ARM.

POUNDS.

	2	4	6	8	10	12	14
NO. OF TEST.	REGISTERED HEIGHT AT RECORDER IN INCHES.						
1.......	.20	.64	1.10	1.53	1.93	2.34	2.80
2.......	.20	.67	1.14	1.55	2 00	2.42	2.82
3.......	.23	.67	1.18	1.63	2.00	2.40	2.82
4.......	.23	.65	1.15	1.62	2.01	2.45	2.85
5.......	.25	.68	1.17	1.60	2.02	2.45	2.85
6.......	.25	.68	1.14	1.58	2.00	2.45	2.85
7.......	.23	.68	1.15	1.56	2.00	2.45	2.84
8.......	.25	.70	1.15	1.63	2.04	2.43	2.83
9.......	.21	.62	1.17	1.58	2.00	2.48	2.87
10.......	.25	.70	1.25	1.63	2.05	2.48	2.85
Aver.....	.230	.669	1.160	1.591	2.005	2.434	2.838

Difference....	.439	.491	.431	.414	.429	.404

Average difference, .434.

In its use the dynamometer has possibly been more accurate when operated by differences; that is, take a card of the machine (lathe or planer) in motion without cutting; then a card following, with the tool in operation. The differences in the

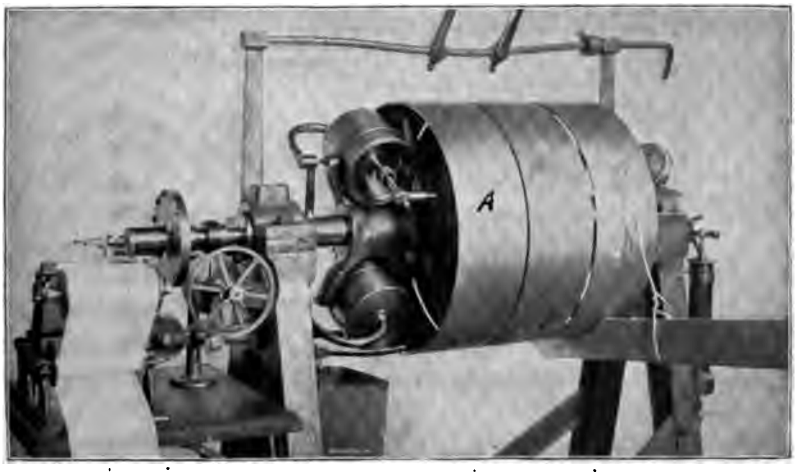

FIG. 106.

heights of the cards are evidently due to the action of the tool. If the friction of the machine and work (without cutting action) is not sufficient to move the pencil from the base line, under the compression of the spring used, a device shown in Fig. 108 is employed. With slight modifications this has been applied to every machine tested. If the object of the test were to register the *friction* of the machine, then the appliance shown in Fig. 108 would be omitted, and the compression on the spring reduced by unscrewing the cap on the casting *b*.

FIG. 107.

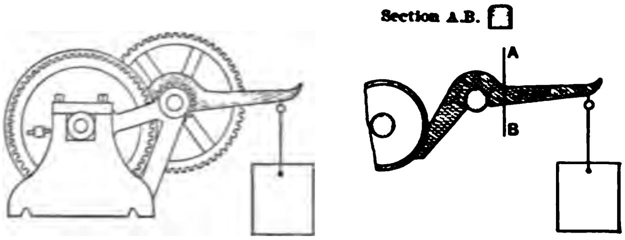

FIG. 108.

A few of the cards have been added to show how readily the recording device responds to any slight change in the power transmitted.

Fig. 109 is taken from a 12 x 18 tracing, and serves to show the gradual reduction in height of the card as the diameter of the

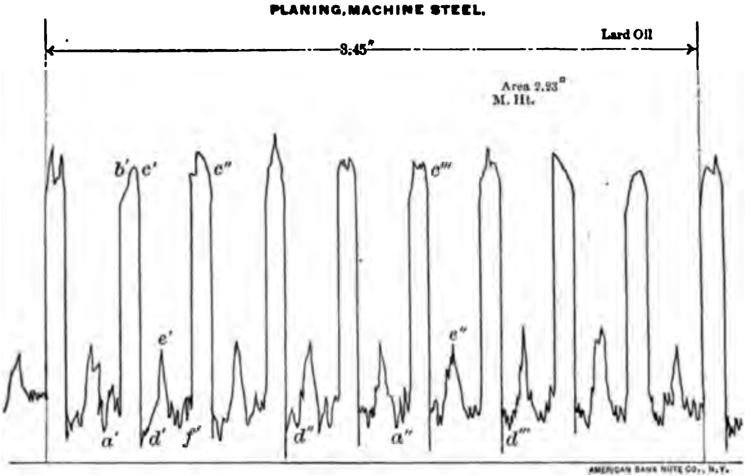

FIG. 115.

* The following (Plates 3 and 4) gives the data for one test taken on an 18-inch Reed lathe. The tool was sharpened before each cut, and the conditions surrounding the cutting edge of the tool were kept constant throughout the series. The cutting action only is recorded.

PLATE 3.

18-INCH LATHE. BACK GEAR OUT, SLOWEST SPEED. R. P. M. of dynamometer, 112. R. P. M. of lathe, 62. Diamond point tool. Constant, .324.

TURNING.	CAST IRON.			WROUGHT IRON.			MACHINE STEEL.		
	M.E.H.	AV. M.E.H.	M.E.P.	M.E.H.	AV. M.E.H.	M.E.P.	M.E.H.	AV. M.E.H.	M.E.P.
1⅞" – 1¾"	.317 .569 .455	.447	1.379	.710 .702 .702	.705	2.175	.786 .782 .812	.793	2.447
1¾" – 1⅝"	.324 .437 .460	.407	1.256	.633 .680 .634	.649	2.003	.762 .732 .748	.747	2.305
1⅝" – 1½"	.283 .408 .387	.359	1.108	.536 .570 .587	.564	1.740	.715 .650 .605	.657	2.027
1½" – 1⅜"	.282 .319 .291	.297	.916	.643 .561 .571	.592	1.826	.618 .672 .631	.640	1.975
1⅜" – 1¼"	.237 .298 .291	.275	.848	.556 .528 .550	.545	1.682	.592 .540 .519	.550	1.697
1¼" – 1⅛"	.208 .285 .241	.245	.756	.535 .503 .526	.521	1.609	.581 .565 .456	.534	1.648

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* The constant .324 was obtained in the manner previously described. The difference here shown is greater than usual, the dynamometer having been taken apart and readjusted, thus changing the conditions of the spring slightly.

The friction of the machine and work was such a variable quantity, especially so considering the pressure on the tail centre, that it was found necessary to take friction cards at intervals during the series, as *E*, *F*, *G*, *H*.

Figs. 110 and 111 show the effect of sand holes in a casting.

TURNING CAST IRON, 1¾″ TO 1⅝″

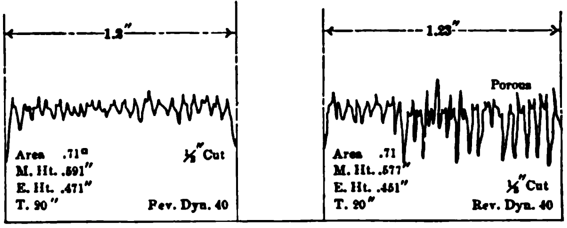

FIG. 110.

DRILLING CAST IRON, 1″ HOLE.

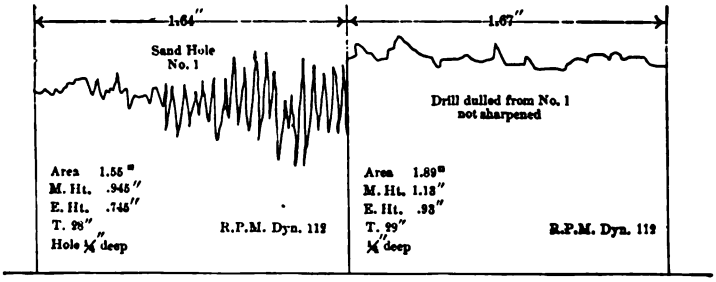

FIG. 111.

EFFECT OF TIGHT CENTER.

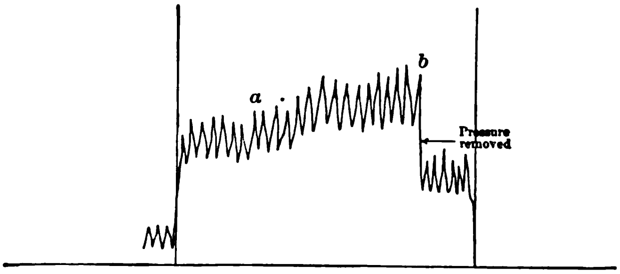

FIG. 112.

The cutting edge of the drill (Fig. 111) was dulled, as indicated by the increased height of the card after passing the sand hole.

Fig. 112 was taken while turning machine steel. The tail centre proved to be too tight, and from *a* to *b* shows an increase, due to the grooving of the centre. At *b* the pressure was removed.

Other important points might be developed here in connection with this test, but the above will show fully the general conditions surrounding the use of the dynamometer.

DISCUSSION.

Mr. Gustavus C. Henning.—I would like to say that I talked this design over with Mr. Nason, who has some ideas on the subject, and I will not encroach upon his field; but I would like to point out a few other points, although I agree with Mr. Nason in the remarks that he made to me. In regard to the possibility of error in the operation of the machine, I consider that the loss of oil, and the consequent relative changes of position of the piston and piston rod, or connecting rod, will introduce errors, because the centrifugal force will act differently on the cylinder, and might change some of the factors of resistance in the machine. The necessity of making these cylinders pendulate, so to say, I do not think is apparent or very great. I think if, instead of using pistons, proper flexible diaphragms were used, with sufficient motion to force the oil out just in right quantities to move the pencil over the length of the paper, all the leakage through the stuffing-box would be avoided, and the friction of those flexible diaphragms, if they are properly designed, is practically nothing, or at least it is constant, if it is not nothing. It is certainly negligible, judging from other apparatus which has been constructed on this principle. The ground joint can be made tight, so that there will be no leakage running 24 hours, if you please. That would simplify matters, and would eliminate some of the principal errors. The pressure should always be normal to the piston from the point of application, which is the pin which comes out from the loose pulley which forces the oil out into the cylinder driving the pencil over the paper. Now, if the piston changes its position very much, the angle of application of the force will change; while if a diaphragm was used, which is always sealed tight, no oil would be lost, and the diaphragm would at the same time allow the oil to come back again when the pressures are released. I think the additional supply of oil should be avoided by substituting, instead of a piston moving in a cylinder, thin, flexible diaphragms, eliminating friction as well, because the friction of the piston must be something, and although it can be determined, it may become variable. It is always one of the additional elements of error which must be taken care of.

Mr. Carleton W. Nason.—I have but little to add to what Mr. Henning has said, but in a talk with him last evening about this paper I suggested that as it was admitted that there was a definite, though small, amount of oil leakage past the pistons, such leakage must necessarily change their position in the cylinder.

This being the case, it is evident that as the pistons approach the ends of the cylinders the pressure transmitted to the indicator becomes greater, for the reason that, the cylinders being oscillating, and the distance between the piston-rod pins and cylinder trunnions variable, the angle enclosed by lines drawn through the rod centres and those radii of the pulley which pass through the trunnion centres diminishes, and hence the thrust is proportionately increased.

Mr. Henning is, I believe, quite right, however, in the statement that centrifugal force will lessen the pressures transmitted by the pistons as they approach the cylinder heads, and in estimating such reduction the weight of the oil in the cylinders should be added. If leakage is considerable, experimental work going on for several minutes would require perhaps two or more base lines to insure accurate results in comparing various parts of cards.

Whether the piston motion is sufficient to affect sensibly cards from the cause given is not stated, and information regarding this would be of interest.

Mr. H. H. Suplee.—This device resembles very closely an apparatus on which I did some work several years ago in Philadelphia, in making a load governor for a steam engine. It contained two cylinders much in the same shape as this dynamometer, acting in conjunction with centrifugal force, the idea being to obtain a load governor similar to that which is made by springs, as in the well-known Ball load governor, operating by hydraulic cylinders pressing on oil and delivering the pressure through a plunger on the end of the shaft. It worked all right, except that it was too sensitive, as Mr. Hoffman has said, and had to be abandoned for something which should not work quite so well. Possibly when he has found how to make this not too sensitive, his device may be available for such a governor.

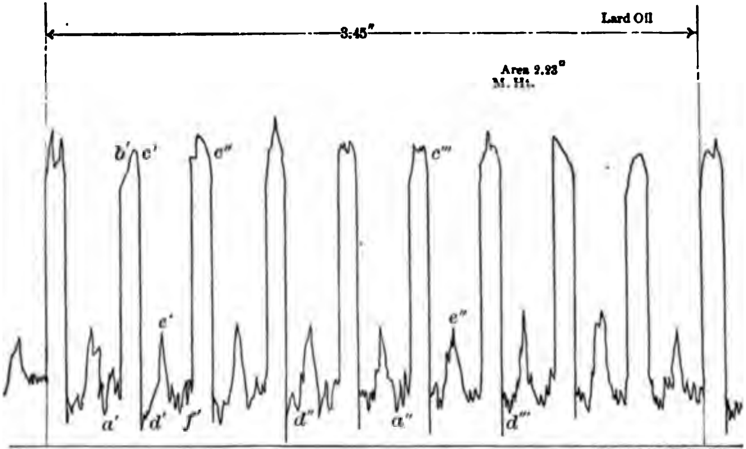

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PLATE 4.

Weight per Cubic Inch.....			Cast Iron. .26			Wrought Iron. .28			Steel. .284		
Feed: C. I.—1.48″ W. I.—1.45″ S.—1.4″	Cutting Speed.	Reduction in Area.	Volume per Minute.	Weight per Hour.	H. P.	Volume per Minute.	Weight per Hour.	H. P.	Volume per Minute.	Weight per Hour.	H. P.
$1\frac{7}{8}'' - 1\frac{3}{4}''$	29.4′	.356	.527	8.22	.187	.516	8.67	.295	.498	8.49	.332
$1\frac{3}{4}'' - 1\frac{5}{8}''$	27.4′	.331	.490	7.64	.171	.480	8.06	.272	.468	7.89	.313
$1\frac{5}{8}'' - 1\frac{1}{2}''$	25.4′	.307	.451	7.10	.150	.445	7.48	.236	.429	7.31	.275
$1\frac{1}{2}'' - 1\frac{3}{8}''$	23.4′	.282	.417	6.51	.124	.409	6.87	.248	.395	6.73	.268
$1\frac{3}{8}'' - 1\frac{1}{4}''$	21.3′	.258	.382	5.96	.115	.374	6.28	.228	.361	6.15	.230
$1\frac{1}{4}'' - 1\frac{1}{8}''$	19.3′	.233	.345	5.38	.103	.338	5.68	.218	.326	5.56	.224
Aver.....	....	....	....	6.80	.142	....	7.17	.249	....	7.02	.274

In finding the weight of metal removed per hour, the constants 26, .28, and .284 were used for the weight of one cubic inch of cast iron, wrought iron, and steel, respectively. The cutting speeds were taken from the mean diameters ($1\frac{13}{16}$, $1\frac{11}{16}$, and $1\frac{9}{16}$).

The feed was retarded slightly in the harder metals in the proportion of 1.48 for cast iron, 1.45 for wrought iron, 1.4 for steel; the travel per minute, in inches, of the tool. From the foregoing a relation can be established between the weight of chips removed per hour and the horse-power used, such that HP equals CW.

For steel, HP equals $.039\ W$.
Wrought iron, HP " $.0347\ W$.
Cast iron, HP " $.021\ W$.

* Comparing these results with those of Hartig and Smith, we have for "Constant C":

	Cast Iron.	Wrought Iron.	Steel.
	.021	.0347	.039
†Hartig..................	.030	.032	.047
†Smith....................	.023	.028	.042

The average pressure exerted at the point of the tool was found to be: cast iron, 192 pounds; wrought iron, 337 pounds; and steel, 371 pounds.

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* The steel and cast-iron test pieces were of the best quality, but the wrought iron was below the average.

† Taken from "Flather's Measurement of Power."

age were large enough to affect results sensibly, the pistons might be kept in a fixed position by running the pump at a speed which would deliver an amount of oil just equal to the leakage.

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Mr. Carleton W. Nason.—I have but little to add to what Mr. Henning has said, but in a talk with him last evening about this paper I suggested that as it was admitted that there was a definite, though small, amount of oil leakage past the pistons, such leakage must necessarily change their position in the cylinder.

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Prof. W. F. M. Goss.—My experience with transmitting dynamometers of several different forms convinces me that such machines have a difficult part to perform. It is for this reason that I have been interested in Mr. Hoffman's work. While his machine requires careful manipulation, there seems to be no real difficulty in locating the zero line; moreover, the form of the record permits the machine to be used with great facility where differences in power transmitted only are desired, and most problems involving the machine may be solved by differences. It has seemed to me that the results obtained from the machine justify its design.

Mr. A. F. Nagle.—It may interest the author to know that nearly twenty years ago I patented a hydraulic dynamometer,* with which Mr. C. J. H. Woodbury (member of the Society) did considerable experimenting. The inherent defect in my design was the same which has been pointed out in this discussion—that the effect of centrifugal force upon the fluid made a recalibration necessary for every change of speed.

Mr. James D. Hoffman.†—I am pleased to make a few remarks in closing, and will endeavor to be brief. Mr. Henning would substitute flexible diaphragms for the pistons, stating that "the leakage through the stuffing-box would be avoided, and the friction, if any, would be a constant quantity." If there were no leakage except the small amount around the cylinders this might be a good suggestion; but the stuffing-box spoken of in the paper is at the rear of the machine, having no connection with the cylinders, and it is at this point where most of the oil escapes. The substitution, then, as suggested, would unfortunately not cover the objection. If it were thought necessary to eliminate this small leakage which occurs at the stuffing-box, a different kind of bearing could be used at this end, in which case the cause of leakage would be avoided. The present arrangement merely affords an additional means of readily obtaining the pressures during the progress of a test, and has nothing whatever to do with the working of the dynamometer. My experience with diaphragms has shown that the results are not as accurate nor as reliable as those obtained by the use of pistons. They were tried in connection with this machine, with the result that the full pressure was recorded when the dia-

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* Patent No. 195,837, October 2, 1877.

† Author's closure, under the Rules.

engine and would actually complete the result sought to be attained by the engineer. The two sources of difficulty to be overcome are those attending the construction of a superheater incapable of injury in the process of superheating, and the introduction of the required and variable amount of superheat at the engine without injury to cylinder, piston, valves, or packing.

This problem is to-day the most important of all the visible and possible tasks confronting the designing engineer who seeks the further improvement of the steam engine as a thermodynamic machine. Its solution will go far toward the insurance of further steady advance, even beyond the limits now apparently set by those practical conditions which seem to have closed in upon the machine in later years more and more closely, and which have been thought by many to be likely to compel the abandonment of this type of heat engine and the adoption of the gas engine in its place.

Gain at the boiler is not precisely the subject of this study; but it should be distinctly recognized that, incidentally, the superheating apparatus as most commonly applied constitutes a very considerable addition to the heating surface and thus increases the efficiency of the boiler. The gain thus obtained at the engine is, as in the case of steam-jacketing, always accompanied by a larger gain at the boiler, and this occurs in two distinct ways. First, the reduced expenditure of steam at the engine makes the demand upon the boiler less than otherwise would be the case, and thus the quantity of steam made per unit of heating surface being reduced, the result must always be, in good practice, a gain of efficiency at the boiler. Secondly, the added heating surface of the superheater gives a still further gain (in general) the same sort of increase of efficiency, and, the two effects coöperating, a gain in steam utilization at the engine is found to have a corresponding gain at the boiler, in consumption of fuel, that may be very considerably greater, numerically. As with the steam jacket, or with compounding on the locomotive, a gain of twenty per cent. in steam consumption may be accompanied by gain in fuel expended, for a stated power and work, of twenty-five per cent., or even more; the latter excess of gain being the greater as the boiler is, initially, the less economical.

SUPERHEATED STEAM differs from steam in the familiar, "saturated," state in the fact that it has a temperature exceeding that of the water from which it is formed at the temperature due the pressure with saturated steam. The excess of temperature must be conferred upon it by isolating it from its liquid and exposing it to contact with substances themselves heated to a still higher temperature, or by mixing it with other steam, previously raised to a degree of "superheat" as much in excess of the desired superheat as the total mass of the mixture exceeds that of the superheating steam. The latter method is sometimes called, distinctively, "adheating." Steam and water, in contact, and in the process of vaporization of the latter, are always of similar temperature, and this temperature is always that due the pressure as stated in the steam tables. The steam formed being brought into contact with substances of higher temperature rises in temperature by absorption of heat by conduction, and, if thus superheated a moderate amount, loses the characteristic properties of vapor and takes on those of a gas. Gaseous steam, steam gas, has sometimes been called "stame" to distinguish it from steam "dry and saturated," as obtained by slow evaporation in the steam boiler, and as always existing when at rest in contact with the water from which it has been formed, and out of contact with more highly heated substance. The range of heating from the condition of dry and saturated to superheated steam is considerable—9 degrees C., 16 degrees Fahr., according to Hirn—and, within that range of temperature, the properties of the fluid are intermediate between those of a true vapor and those of a gas. With steam in the latter form, the thermodynamic formulas for the perfect gas become applicable, and we have, as shown by experiment, in British measures, $pv = R = 85.5$.

Plotting the curve exhibiting the relations of pressure and volume of steam gas, and comparing it with the similar curve for saturated steam, it will be observed that the former exhibits larger values of specific volumes for stated pressures and falls outside the former. Hence, the latter demands most heat during expansion and must partially condense, as it cannot supply the demand for heat to be converted into work from its store of sensible heat and still remain a vapor.

Volume for volume, saturated steam does more work than superheated; weight for weight, the contrary is the fact.

STEAM IN THE STEAM ENGINE, superheated or saturated, is worked in precisely the same manner, and ordinarily the indicator diagram gives little or no indication of the quality of the steam, except by its study in comparison with the coincident measures of feed-water supplied the boiler. Careful measurement, however, gives a means of ascertaining the quality of the working charge of steam at every point in the stroke of the piston within the limits of the "expansion line." The "saturation curve" being drawn for the weight of fluid traversing the engine per stroke of piston, the variation of its abscissas from those of the diagram itself measure, on the one hand, the quantity of steam condensed behind the piston, if wet, and on the other, the expansion due superheating if the charge is thus given increased volume. In the case of wet steam, further data are needed, as obtainable by the steam calorimeter, to determine to what extent the moisture present comes of original "priming" and what from later condensation in boiler, steam pipes, and steam cylinder.

Steam may be worked in the engine either in the saturated condition, as constantly wet, or as steam gas, or as, from time to time in the course of the piston stroke, a fluid changing from a higher to a lower state as respects its stored heat. It may even, under exceptional conditions, change in the jacketed cylinder from wet steam to dry and from dry to superheated steam. In the usual case, wet steam becomes wetter, and superheated steam becomes wet, as loss of heat from the working charge occurs by transformation of thermal into dynamic energy. This reduction in quality of the working steam also occurs through waste by absorption of heat by the walls of the cylinder, and the advantage of employing superheated steam is reduction of this waste. It is never used in the common forms of steam engine as a "working fluid" in the ordinary sense. Working steam is always wet.

It is usually considered impracticable to employ superheated steam as the working fluid of the steam engine, since to retain the gaseous condition throughout the stroke, and despite the transformation of heat into work during the period of adiabatic expansion, it is requisite to carry the superheating, initially, to a higher point than is, at present at least, safe and practicable. Its use in this form presumably involves the construction of a special form of engine that shall permit its safe employment, and at the same time evade those forms of waste which have, hitherto, reduced the superheat to zero immediately upon the dangers; and English and American engineers have, for now many years, rarely attempted its employment except on a very moderate scale and in a very conservative manner.

In continental Europe, however, where the scientific aspect of the subject attracts more attention, and secures a more tolerant, if not an actually respectful, attitude on the part of the practitioner, the desirability of finding ways of availing ourselves of the economy to be attained through a successful practice in this direction has been so fully recognized, that considerable numbers of steam engines are there constantly in use with moderately superheated steam, and occasionally some enthusiastic inventor or builder brings out a machine working with superheated steam of high temperature. The European, and especially the Continental, builders and users are thus to-day very much more familiar with the subject than are our own, and progress in this field is there continually, though still slowly, taking place.*

The purpose of the following paper is to give a *résumé* of the "state of the art" to date, so far as data at hand permit, with a brief and simple discussion of the theoretical side of the subject, and, finally, deductions relative to the direction of improvement, and the promise given by experience and scientific study, to date, in regard to the possibilities and probabilities of gain by the use of superheated steam, either in the ordinary working of the familiar forms of engine, or in real "superheated-steam engines."

Of the four principal and recognized methods of reduction of that form of waste in the steam engine which comes of initial, or cylinder, condensation—compression, jacketing, compounding, and superheating—the last named, could all mechanical difficulties of construction and operation be overcome, would be by far the best and most effective. It would involve no important change in the boiler; but little, if any, extension of its size and cost; no such complication of engine construction as the jacket compels, no change, in fact, in the design or construction of the

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* In seeking information on this subject, the writer consulted numerous friends and acquaintances on both sides the Atlantic, and nearly all noted builders and contemporary authorities. The outcome of this somewhat full and formal investigation was that substantially nothing is being done on this side the ocean, and our own people, as a rule, have no experience in the practical use of highly superheated steam. Such information as was obtainable from these classes of engineers, and from men of science expert in engineering, usually came from the other shore.

The first of these processes has not yet been made successful, and no satisfactory form of steam engine has been yet constructed in which the increase of thermodynamic efficiency to be thus gained has been attained by the working of steam as a gas throughout a cycle, or even in which any large increase of working range of temperature above the minimum limit—that of saturation at the temperature of the condenser—has been secured by superheating. The Siemens superheated steam engine illustrates an attempt in this direction.

The second of these methods of improvement of the steam engine has been frequently attempted, usually without permanent success, and it remains a promising but unsolved problem. It is this method which is, mainly, the subject of this memoir. Its value consists solely in its power of reduction of the internal wastes of the engine by the substitution of a comparatively gas-like fluid, with reduced heat-transferring power, for the easily condensed and highly conducting vapor, saturated steam, with consequent diminution, by a large proportion, of the waste known as initial or cylinder condensation. This it does with undoubted and great success; but the endeavor to utilize this well-recognized method of improvement of steam-engine efficiency is, in practice, found to be fraught with so many and such serious practical difficulties of construction and operation that it has, hitherto, been very little employed, and seldom, if ever, as yet, with complete success.

The third gain by the use of superheated steam is a minor but unquestionable improvement, to be anticipated as incidental to the use of superheat for the other purposes enumerated.

The same remark applies to the fourth item in the list.

The fifth effect of superheating, or rather of the introduction of superheating apparatus, comes simply of the extension of the ratio of the area of boiler heating surface to the weight of steam to be supplied in the unit of time. Equal or greater gain would be secured by similar extension of the heating surface of the boiler itself, since the difference of temperature between the gases delivering and the fluid receiving heat would be greater than with the superheaters in operation. Superheaters, therefore, are not desirable where a boiler is employed for heating purposes purely, except, possibly occasionally, where superheating, by reducing condensation, facilitates the transfer of steam from the boiler to some distant point at which it is to be employed.

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Volume for volume, saturated steam does more work than superheated; weight for weight, the contrary is the fact.

STEAM IN THE STEAM ENGINE, superheated or saturated, is worked in precisely the same manner, and ordinarily the indiheat stored by initial condensation is mainly rejected and wasted at each passage of the engine through its exhaust period; that stored and, later, wasted by the action of the engine, when jacketed, when employing superheated steam, or when worked with large compression, is not only less in proportion to the reduced temperature range, but, also, this temperature range is further restricted as the surfaces are held up, more and more completely and constantly, to or above the temperature of saturated steam, and as the heat-transferring power of the fluid is thus reduced.

Leloutre employs the same algebraic treatment, therefore, whether the heat stored in the cylinder wall, in reduction of initial condensation, comes of jacketing or of superheating. He studies the physical condition, the "quality" of the steam at the boiler, in the steam chest, in the cylinder at cut-off, at exhaust, and in the condenser. He computes an economy of 21 to 25 per cent., with moderate superheating similar in extent and in method to the cases reported by Walther-Meunier; while the gain by an efficient jacket, in the Logelbach experiments, is reported as 22.5 per cent. Superheated steam gives somewhat higher terminal pressure, on the expansion line, than with the same engine jacketed. The drop in pressure at entrance is one-third as great, in the Logelbach experiments, with the jacket in use as when employing saturated steam, and about one-fifth as great with superheated steam; the latter being purely consequent upon throttling at the ports, the former due to combined throttling and condensation. The moisture present at the end of admission is about sixty per cent. with the jacket, compared with saturated steam, and about sixteen per cent. with superheated steam; and at the end of expansion, three per cent. and zero respectively; notwithstanding the fact, the remarkable fact, that the superheat only transferred to the cylinder wall about one-half as much heat as did the jacket.

The purpose of the engineer in applying either method of economizing heat, whether by jacketing, by superheating, or by compression, is recognized as being the reduction of this waste at its very incipient stage, the *prevention* of initial condensation. Superheating possesses the advantage of penetrating every crevice and reaching every cooling surface of the interior of the cylinder wall; it does not supply heat continuously during expansion, as does the jacket; but it does not, on the other hand, necessarily waste heat during the period of exhaust and condenentrance of the fluid into the cylinder of the engine and thus converted the cycle of the machine into the familiar form, working saturated or wet steam. Assuming the practicability of thus employing superheated steam, however, the possibilities of further economical advance in the operation of the engine become very great. With such an engine, combining the advantages of large thermodynamic range of working, and consequent high thermodynamic efficiency, with comparatively high mean working pressures, in consequence of the comparative density of the substance, and thus securing high mechanical efficiency, the machine might be expected, if successfully constructed, to give a higher total and commercial efficiency than either the gas engine or the ordinary form of the steam engine.

The steam engine using superheated steam is, to-day, always an engine in which the working fluid is wet, but is dryer than when employing saturated steam, in the proportion to which the surcharge of heat in the superheated steam reduces the condensation ordinarily taking place at entrance of the working charge into the cylinder.

The Purposes of Superheating Steam, as practised in the past and as recognized at present, are the following:

(1) Raising the temperature which constitutes the upper limit in the operation of the heat engine in such manner as to increase the thermodynamic efficiency of the working fluid.

(2) To so surcharge the steam with heat that it may surrender as much as may be required to prevent initial condensation at entrance into the cylinder and still perform the work of expansion without condensation or serious cooling of the surrounding walls of the cylinder.

(3) To make the weight of steam entering the condenser, and its final heat-charge, a minimum, with a view to the reduction of the volume of condensing water and the magnitude and cost of the air-pump and condenser system to a minimum.

(4) To reduce the back pressure and thus to increase the power developed from a given charge of steam and the efficiency of the engine.

(5) To increase the efficiency of the boilers both by the reduction of the quantity of the steam demanded from the original heating surface and by increasing the area of surface employed to absorb the heat of the furnace and flue gases, and also by evading the waste consequent upon production of wet steam.

"That economy attends the use of superheated steam in engine cylinders has been shown at least since 1828, when Richard Trevithick reported on the engines at Binner Downs Mine in Cornwall. The engineer of the mine, Capt. Gregor, wishing to rival the record of a neighboring mine, where the cylinders had been cleaded in sawdust, built in his cylinders and steam pipes with brickwork, making a fire-grate underneath them, and flues around. The results were unexpected, and the duty of the engine was raised from forty-one to sixty-three million foot-pounds per bushel (eighty-four pounds) of coal. Trevithick tested the 70-inch cylinder engine, which, when five bushels of coal were burned in twenty-four hours under the cylinder, took sixty-seven bushels under the boiler; when no coal was burned under the cylinder, 108 bushels of coal was used under the boiler for the same work, showing a saving of one-third of the coal by superheating. The steam pressure was forty-five pounds per square inch, and the strokes eight per minute. With the cylinder fires on, thirteen gallons of injection condensing water was used per stroke, and heated from 70 degrees to 104 degrees; without the cylinder fires, fifteen and one-half gallons of condensing water was used per stroke, and heated from 70 degrees to 112 degrees. Trevithick followed this up by inventing, in 1832, a tubular boiler, combined with a superheater between the boiler and the engine cylinder; he also jacketed the cylinder with the waste gases from the furnace. An external series of vertical pipes connected top and bottom to a hollow ring, constitute the boiler; the superheating pipes inside it are formed like inverted siphons, so as to avoid jointing at the lower end next the fire." *

Progress in the introduction of superheating began in France, according to Raffard, about 1848, when, as he states, after the memorable work of Combes on steam-jacketing, it came to be understood that initial condensation might be suppressed by the substitution of that method of its reduction for the steam jacket.†

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The earliest patents were those of Becker, November 20, 1827, proposing a maximum temperature of 210 degrees C., using a tubular superheater, into which water was injected in minute quantities as required to produce superheated steam of the desired quality. Quillac, July 3, 1849, patented devices for producing the familiar method of superheating, claiming that every form of engine would gain by its use. Raffard's patents for the now common method of drying the steam in the manner previously indicated by him was issued January 30, 1851. Hirn patented, November 12, 1855, his "hyper thermo-generator," which was simply a cast-iron superheating apparatus, consisting of an assemblage of tubes placed in the flue, with an arrangement by means of which more or less of the current of flue gases could be taken through it to adjust the degree of superheating to the demands of the engine. By this date, superheating was recognized in all countries as a legitimate and promising method of securing economical use of steam in the steam engine, and inventors in all civilized lands were seeking to find practicable ways of availing themselves of its advantages without submitting to the disadvantages which common experience soon revealed as apparently universally arising.

By the middle of the century, Hirn and his followers were making a moderate success of it, thanks to the advances in mechanical construction, which by that time had reached such a point as permitted them to make use of joints which were fitted perfectly and remained tight, the abutting surfaces being held firmly into metallic contact by a system of heavy bolts. This mechanical advance was the essential prerequisite of the improvement sought. French writers ascribe to Becker (1827) the invention, and to Hirn (1855) the real introduction of this system of economical use of steam in the steam engine.

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Bourne states (1869) that "superheaters are sometimes formed of a congeries of cast-iron pipes set at the root of the chimney, and through which pipes steam is passed. Cast iron has this advantage over wrought iron: that from the protective influence of the carbon entering into its composition, it is less liable to corrosion; but such superheaters are heavier and more liable to accident than those made of wrought iron."

This authority prescribes an area of superheating surface of 0.3 square foot per cubic foot of water evaporated per hour.* This would correspond, in modern and fairly economical engines, to 0.1 square foot per indicated horse-power.

A locomotive supplied with superheated steam was experi-

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* *Ibidem*, p. 13.

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Based upon such computations, Rankine has given tables of the properties of steam gas.*

The volumes and densities of steam, tabulated by Rankine, are computed by a modified method. They agree well with the assumption of the following values of v_0 and p_0v_0, smaller than those deduced from chemical composition:

$$\left.\begin{aligned} v_0\text{(ideal, for 32 degrees and one atmosphere) } 19.699 \text{ cubic feet;} \\ D_0 = 0.05076 \text{ pounds;} \\ p_0v_0 = 41{,}690 \text{ foot-pounds.} \end{aligned}\right\} \quad (3)$$

If atmospheric steam were perfectly gaseous at 212 degrees, the following would be the results of the above formulæ:

$$\left.\begin{aligned} v_1 = 1.365\, v_0 = 26.89 \text{ cubic feet;} \\ D_1 = 0.03719 \text{ pounds;} \\ p_1v_1 = 1{,}365\, p_0v_0 = 56{,}907 \text{ foot-pounds.} \end{aligned}\right\} \ldots\ldots\ldots(4)$$

The actual density of steam exceeds that computed, and the excess is greater, the greater the pressure.

The tables give, for one atmosphere and 212 degrees:

$$\left.\begin{aligned} v_1 = 26.36 \text{ cubic feet per pound;} \\ D_1 = 0.03797\text{;} \\ p_1v_1 = 55{,}783 \text{ foot-pounds;} \end{aligned}\right\} \ldots\ldots\ldots\ldots(5)$$

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For steam under the pressure of one atmosphere, and at temperatures varying from 250 degrees to 380 degrees Fahr., Mr. Siemens's experiments give, as the mean coefficient of expansion,

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Computing the value of p_1v_1 by the process already illustrated, the measure of work performed is obtainable by multiplying this value by the proper factor indicated and deducting the work of back pressure. The magnitude of back pressure may be taken as less than that of the engine employing saturated steam in proportion to the decrease of density, and this, in turn, as proportional to the increase in absolute temperature.

Thus, take the case first discussed by the author quoted, assume the following data, units being pounds, feet, and absolute temperature Fahr. Pressures are therefore measured in pounds on the square foot, and volume in cubic feet per pound. Boiler pressure is 34 pounds on the square inch, 4,896 pounds on the square foot, and the temperature of saturation, 258 degrees Fahr., but the steam superheated, 428 degrees Fahr.

Data: $p_1 = 4{,}896$; $v_1 = 15.52$; $T_1 = 889.2$; $r = 5$; $p_3 = 493$; $v_2 = 77.6$; $p_1v_1 = 75{,}976$; $p_m \div p_1 = 0.456$; $rp_m \div p_1 = 2.28$.

Then, the work performed measures:

$$U = p_1v_1 \cdot \frac{rp_m}{p_1} - p_3v_1 = 134{,}986 \text{ foot-pounds.}$$

The mean effective pressure must be equal to the mean total, p_e, less the back pressure, p_3.

$$p_m - p_3 = \frac{U}{rv_1} = 1{,}740 \text{ pounds per square foot.}$$

The heat expended per pound of steam supplied is the difference between the total heat supplied, H_1, and the total heat of the feed water, h_4, taken into the system, per pound.

$$H_1 - h_4 = 989{,}788 - 55{,}612 = 934{,}176 \text{ ft. lbs.}$$

The efficiency of the thermodynamic operation is thus

$$E = \frac{U}{(H_1 - h_4)} = 134{,}968/934{,}176 = 0.145.$$

Had the steam been saturated, the same process of computation would have shown the efficiency to be 0.128, and the gain by increased temperature due to superheating is seen to be nearly twenty per cent. of that quantity, as measured at the engine. It must be remembered, however, that it is, in such case, assumed that the heat supplied as superheat is obtained by utilizing otherwise wasted heat at the boiler by taking it up from the flue gases. This increases the boiler efficiency also, and the total, some twenty-five to thirty per cent., as shown both by computation and by experiment with usual proportions of boilers, is to be credited to this process of improving efficiency.

Unfortunately, however, as already elsewhere stated, the superheated-steam engine is not yet found a practicable type of heat engine. The efficiency of such an engine would be found to increase rapidly with increasing temperature, as the excess of temperature is acquired without corresponding increase in total heat supplied the fluid. The total heat of gasification at the maximum temperature is constant, whatever the temperature and pressure of vaporization. The energy derivable increases very nearly as the absolute temperature, while the latent heat of expansion only increases correspondingly. Steam-gas may be worked in all the forms of cycle appropriate to the air and gas engines, and, thus operated, combines the high thermodynamic efficiency of that class of engines with the high machine efficiency of the steam engine.

In the case just discussed, were the steam, at the given pressures and temperatures, worked in a Carnot cycle, the thermodynamic efficiency would be found to be

$$Eff. = \frac{889 - 609}{889} = 0.315;$$

while, were the steam at the same pressure, but saturated, the efficiency would be only

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the temperature of the back-pressure steam being, absolute, 609 degrees Fahr., and that of saturation at boiler pressure 258 degrees. The efficiency would, in this case, be doubled by superheating to the extent here assumed. Mr. Siemens has actually constructed and operated an engine, with regenerators substituting isodiabatic lines for those of adiabatic expansion, supplying heat at constant temperature, and, even on the very small scale of his experiments, brought down the consumption of fuel to about 1.5 pounds per hour per indicated horse-power.

THE ECONOMICAL EFFECT OF SUPERHEATING is observed, when of small amount, in the securing of dry steam at the engine; if superheated more than five or ten degrees, with steam initially satisfactorily dry, it takes effect in the reduction of "cylinder condensation" by an amount proportional to the extent of superheating above the limit just indicated and until this initial condensation ceases. From this latter point, if superheating is still increased in amount, the condensation due the performance of work in adiabatic expansion becomes more and more reduced, and, finally, the working substance remains in a dry, and perhaps superheated, condition throughout the forward stroke of the piston. Further superheating transforms the engine into a "superheated-steam engine;" the working fluid is then a gas and the machine a gas engine. The latter result is rarely attained, even where it is sought, and is very seldom sought.

The quantity of superheating required to dry the steam is that which supplies the amount of heat in excess of that required for production of dry steam which would, so applied, evaporate the water carried out of the steam chamber of the boiler to the superheater with the mass. The quantity needed for this purpose is the "latent heat" of the steam; that supplied in superheating is 0.48 B. T. U. per pound and per degree of steam superheated. Where cylinder or initial condensation is to be extinguished, the amount of superheating required, as a maximum, will be, per unit weight,

$$Q = \frac{a\,l}{0.48};$$

where a is the fraction of the entering charge condensed by the cylinder walls, and l is the latent heat of the steam supplied. The amount of required superheat is, however, always less than this, and generally by a considerable proportion, in consequence of the fact that the steam becomes less and less subject to this method of waste as its quality is improved by superheating, until, worked as a gas, heat-transfer to and from the cylinder wall becomes a small fraction of the quantity originally thus lost. Saturated or wet steam condenses very freely; steam-gas transfers heat as reluctantly as other gases.

The effect of superheating, so far as employed in the steam engine, ordinarily, is the checking of heat waste by initial condensation; that effect being secured largely, probably mainly, by the change produced in the physical condition of the fluid, and by its transformation from the state of vapor to that of gas, with resultant diminution of its conductivity and heat-transfer-

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the temperature of the back-pressure steam being, absolute, 609 degrees Fahr., and that of saturation at boiler pressure 258 degrees. The efficiency would, in this case, be doubled by superheating to the extent here assumed. Mr. Siemens has actually constructed and operated an engine, with regenerators substituting isodiabatic lines for those of adiabatic expansion, supplying heat at constant temperature, and, even on the very small scale of his experiments, brought down the consumption of fuel to about 1.5 pounds per hour per indicated horse-power.

THE ECONOMICAL EFFECT OF SUPERHEATING is observed, when of small amount, in the securing of dry steam at the engine; if superheated more than five or ten degrees, with steam initially of wastes in the engine, and the saving effected, are difficult to find, and, in consequence of deficiency in reported data, usually impossible of analysis; but we have many figures for similar saving by means of heat supplied through jackets. We may thus easily obtain the minimum value of heat supplied the working steam in the shape of superheat. The following table gives the best figures that the writer has been able to find, and are presumably illustrative of the most effective employment of heat, by this method, in the prevention of the waste sought to be reduced by superheating.*

ECONOMIC VALUE OF SUPERHEAT (*Minimum*).

(1) SIMPLE NON-CONDENSING ENGINES.

No. Case.	p^1 lbs. per sq. in.	Rev. per Min.	Ratio of Expansion.	Per cent. Heat Expended.	Per cent. of Gain.	Ratio of Econ. Value.
2	115	203	....	3.2	23.0	7 to 1
8*b*	110	62	6.2	3.4	22.0	7.
8*c*	110	62	5.3	3.1	16.7	5.5
8*d*	110	63	4.4	2.0	16.7	8.
7	100	97	3.4	2.7	16.3	6.
7*f*	78	93	5.1	3.3	22.4	6.6
8*a*	32	47	7.1	2.5	19.7	8.

Average Value, 7.

(2) SIMPLE CONDENSING ENGINES.

23*a*	110	60	10.	2.9	23.0	8.
23*b*	110	60	6.4	3.2	20.0	6.3
23*c*	88	59	12.	3.0	16.7	5.6
23*d*	89	58	11.3	3.1	17.7	6.
23*g*	89	60	5.9	1.5	14.3	9.5
15	80	55	10.	3.8	23.7	6.
19*a*	67	50	5.7	3.5	21.5	6.
19*b*	68	50	12.4	4.8	30.3	6.3
20	58	53	4.7	3.4	15.5	4.7
22	42	20	4.3	4.9	16.6	3.6
16*a*	17	37	3.4	7.25	37.4	4.5
16*b*	16	37	3.4	7.25	31.3	4.3
18*a*	14	41	1.75	2.4	16.3	6.6

Average Value, 6.

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* "Theory of the Steam Jacket," *Transactions* A. S. M. E., vol. xv., June, 1894, p. 843.

ring power. It further gives a gain by improvement of the thermodynamic cycle, restricting, more completely than would be otherwise possible, departure from the Carnot or perfect-engine cycle, and making expansion more nearly adiabatic. The real limit of gain at the engine, in practice, is found where the gain by reduction of initial condensation reaches its economical maximum, and this has been found, as a rule, hitherto. with very moderate superheating. A more serious restriction of the process, in practice, has been often found to be the difficulty found in constructing superheating apparatus that shall be durable, safe, adjustable to the varying demands of the engine, and costing little for maintenance. At sea, also, further difficulty arises from the fact that superheaters are liable to become encrusted with salt and lime whenever it becomes necessary to employ sea-water in the boilers, even in small quantity.

It is evident that, were the effect of superheating simply the reduction of cylinder condensation by the substitution of superheat in the steam for the heat transferred to the cylinder wall, unit for unit, the known economical effect of the process would be entirely unaccounted for. A lower figure obtained for weight of steam demanded per horse-power and per hour would be compensated by the larger quantity of heat carried through the system by each unit weight of steam supplied. The quantity of steam demanded is steadily reduced, and the apparent, but misleading, percentage of gain as steadily increased, throughout the whole computed range ; but since each pound of steam carries with it into the cylinder an increased amount of heat from the boiler, the result is no gain, except where the added heat comes of utilization of a portion otherwise wasted at the chimney, and, in this case even, this economy could be better effected by extension of the boiler heating surface. The real fact is that the saving by superheating is always vastly greater than is assumed in such computations, and is produced mainly by the transformation of the working fluid at entrance into a form in which it yields little heat to the cylinder walls, and which has little effect, during expansion and exhaust, in chilling those walls. This fact is distinctly shown by the reported results of all the earlier as well as recent experiments on a large scale.

Superheating at the steam chest thus does not imply superheating in the engine, where small quantities of heat are added to saturated steam. M. Dwelshauvers-Dery has found that, with assumed above may give a return of not less than two units in net saving. The more economical the engine, the less the gain to be secured by these methods of reducing wastes. The final limit in saving is the magnitude of the waste to be reduced. Jacketing may save a large part of this waste; superheating may reduce it almost or quite entirely.

THE QUANTITY OF HEAT REQUIRED to retain initially dry steam in the vaporous state throughout the expansion period is readily computed by a process original with Rankine and applied by him to the case of a jacketed cylinder in which this result is effected by continuous drain of heat from the jacket. The same quantity being supplied as superheat in the entering steam, the same result follows. If the steam be supplied wet, the computed heat supply will suffice to cause it to leave the cylinder at the opening of the exhaust valve with its quality unchanged. It is, however, understood that initial condensation is, in these cases, entirely absent.

The computation is effected by adding to the total heat of vaporization, from feed-water temperature and at the terminal pressure of the expansion line, the thermal equivalent of the work performed, as measured on the indicator diagram, between initial and terminal pressures. Thus, if T_1 and T_2, and p_1 and p_2, are the initial and terminal absolute pressures and temperatures on the expansion line in these cases, and L_2 the latent heat of vaporization at the lower of these limits, in foot pounds or other dynamic units, the total heat expenditure per unit weight will be

$$H' = J(T_2 - T_4) + L_2 + \int_{p_2}^{p} v\,dp,$$

in which T_4 is the temperature of the feed water and the integral measures the work between the limits T_1 and T_2, or p_1 and p_2. This reduces to

$$H' = J(T_2 - T_4) + a\left(1 + \log_e \frac{T_1}{T_2}\right) - bT_1,$$

where $L = a - bT$, and with $J = 778$, the constants, following Regnault, are $a = 1{,}117{,}850$, and $b = 544.5$.

Under the conditions of operation of the best classes of high-pressure multiple-cylinder engines, the quantity of steam employed is from twelve to thirteen pounds per I. H. P. per hour, as a total, of which not far from ten per cent., usually, is applied to the jacket for the purpose here indicated. The best results thus far obtained are reported from engines in which the steam is finally exhausted from the low-pressure cylinder in a dry or slightly superheated condition. It may probably be fairly presumed that the same quantity of extraneous heat supply during expansion should be furnished, with superheated steam, by the prime steam entering the high-pressure cylinder and the successive "reheatings" between the cylinders—if the latter can be provided, as is always desirable—both on the score of minimum initial temperature of superheating and of uniformity of distribution of the superheat throughout the whole range of expansive working of the steam.*

Superheated steam possesses, further, valuable properties which would permit, if it could be used, not only a considerable increase of the efficiency of the steam engine, but also a certain advantage in construction through the reduced dimensions of the condenser and steam pipes, and, especially, in the suppression of that costly, cumbersome, and awkward element, the steam jacket. It would also reduce the necessary dimensions of the boilers.

M. Hirsch sends the writer a valuable list of references to French literature on this subject.† He agrees with the writer that the introduction of metallic packings and of mineral lubricants has radically altered the aspect of this question within the last few years.

Walther-Meunier, discussing the methods of superheating customary in Alsace-Lorraine, observes that the boiler, as commonly employed, is liable to sensible priming and furnishes wet

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* "Now, we have seen the gain by superheating in the case of the *Georgiana* to be three-eighths of the effect of saturated steam from her boiler; consequently we find that it is more economical to expend heat in superheating steam after it is generated than in generating its equivalent of saturated steam by (37.5 — 16.5) = 21 per cent. It is therefore advantageous, by this amount, to provide a separate superheating apparatus, and superheat the steam in it by the direct expenditure of fuel in those cases in which it is not allowable to place the superheater in the uptake on account of the height required—very objectionable in war steamers—taking care at the same time to employ a type and proportion of boiler that will give the maximum evaporation."—Isherwood. *Experimental Researches*, vol. ii.

† Correspondence, 1895.

steam, and that the use of superheaters is here more desirable than in other cases. He notes that superheating is especially advantageous where engines are either given large clearances or where large ratios of expansion are adopted in any one cylinder. Less weight of steam is required, in the former case, to fill the dead spaces, and a greater initial condensation occurs in the latter than in the average case. He might also add that it reaches and acts upon all parts of the inner wall of the cylinder which promote waste.

"THE LIMIT IN SUPERHEATING is, to-day, considered to be practically somewhere inside of the temperature 500 degrees Fahr. (260 degrees C.), or within a range of not much above 100 degrees Fahr. (56 degrees C.) above the now usual maximum temperature of saturation If this amount of adheating can be secured, steadily and with certainty, no serious difficulties are anticipated; but at higher points on the scale the burning-out of superheaters and the difficulties of cylinder lubrication are such as are likely to intimidate both engineer and owner.

"*The desirable limit* of superheating is determined, for the purposes now in view, by the amount of initial condensation to which the steam is liable if supplied in the saturated, or the wet, state. Assuming, for example, that each pound of wet steam entering the engine, bringing with it 1,200 thermal units from the fuel, is subject to loss of 20 per cent. of its latent heat by cylinder condensation, storing about 250 B. T. U. in the metal of the engine. Since the specific heat of gaseous steam is, according to Regnault, 0.4805, it is seen that the amount of superheating required in order that it may surrender this quantity of heat without condensation on admission must be approximately

$$\frac{250}{0.4805} = 521^\circ \text{ Fahr.},$$

which is far beyond the practically advisable limit as fixed by experience to date.

"Fortunately, however, this is not necessary, and very much less adheating is amply sufficient to accomplish the purpose in view, and a small addition by superheating, as by jacketing, suffices to greatly reduce or even suppress initial condensation. All that is necessary, in this case, is to supply an excess sufficient to meet the demand due to interior wastes of a fluid of the character of that actually at the moment to be worked in the engine cylinder. The drying and the superheating of the steam continually improve the working of the engine in two distinct ways: (1) giving a better working substance, and thus initially reducing interior wastes; (2) at the same time meeting more completely the demand for heat to bring up the temperature of the metal to that of the prime steam before the entrance of the latter into the cylinder; thus, each process conspiring with the other, the final effect is large economy with small expenditure.

"It is found that in engines of moderate size—as 250 to 500 I. H. P.—superheating 80 degrees Fahr. to 100 degrees Fahr. will sometimes check all sensible condensation. This indicates that superheated steam is in such cases productive of cylinder waste to the extent of not more than about

$$\frac{100 \times 0.4805}{1,000} = 0.048,$$

or less than 5 per cent., initial condensation being entirely prevented. Against this saving by the reduction of waste perhaps by about $25 - 5 = 20$ per cent., must be charged the cost of superheating. This, when the extra heat is obtained at the chimney flue, will be only the financial charge for first cost and maintenance of superheaters, and by simple extension of heating surface, and will be only its proportion of the cost of steam production, in other cases; or

$$\frac{1,000 + 48}{1,000} - 1 = 0.048,$$

to give a gross gain of about 25 per cent. in steam by the expenditure of 5 per cent. additional fuel, or a net gain of 20 per cent.; a not infrequently reported case."*

With sufficiently superheated steam, the jacket is not needed; it would add nothing to the efficiency of the engine; with wet steam it might be possible that the loss from the jacket during the terminal portion of the expansion period, and throughout the exhaust, might exceed the gain in the earlier part of the

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* *Manual.* In fact, it is probably usually the fact that the total of heating and superheating surface may be made substantially the same for engines using any grade of steam from wet to highly superheated; the gain by superheating reducing the required heating surface quite as much as superheating surface is added.

assumed above may give a return of not less than two units in net saving. The more economical the engine, the less the gain to be secured by these methods of reducing wastes. The final limit in saving is the magnitude of the waste to be reduced. Jacketing may save a large part of this waste; superheating may reduce it almost or quite entirely.

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The computation is effected by adding to the total heat of vaporization, from feed-water temperature and at the terminal pressure of the expansion line, the thermal equivalent of the work performed, as measured on the indicator diagram, between initial and terminal pressures. Thus, if T_1 and T_2, and p_1 and p_2, are the initial and terminal absolute pressures and temperatures on the expansion line in these cases, and L_2 the latent heat of vaporization at the lower of these limits, in foot pounds or other dynamic units, the total heat expenditure per unit weight will be

$$H' = J(T_2 - T_4) + L_2 + \int_{p_2}^{p} v\,dp,$$

in which T_4 is the temperature of the feed water and the integral measures the work between the limits T_1 and T_2, or p_1 and p_2. This reduces to

$$H' = J(T_2 - T_4) + a\left(1 + \log_e \frac{T_1}{T_2}\right) - bT_1,$$

where $L = a - bT$, and with $J = 778$, the constants, following Regnault, are $a = 1{,}117{,}850$, and $b = 544.5$.

Under the conditions of operation of the best classes of high-pressure multiple-cylinder engines, the quantity of steam embrought over from the boiler brings with it its proportion of foreign matter, in suspension or in solution, and, in either case, all this solid material must be left behind when the steam, dried and superheated, passes on into the engine. The deposition of incrustation and sediment upon the surfaces exposed, necessarily, to high temperatures, and unprotected by the cooling influence of water or of saturated steam, gives rise to rapid corrosion, to "burning," and to leaking joints, and often to early destruction of the superheater, with attendant risks to persons and property. Either such water must be absolutely avoided, or superheating must be given up, or the method of superheating must be that which transfers heat from steam and water of comparatively high temperature and pressure to the working steam at lower temperature and pressure.

It is possible that some form of superheater may be devised which will withstand, uninjured, the highest temperatures of the furnace gases; but this has not yet been done.

THE METHODS OF SUPERHEATING sought to be practised during the periods which have been distinguished by attempts in this direction are:

(1) Direct superheating, consisting in the exposure of the steam pipes through which the fluid is conducted to the engine to the direct action of the hot furnace gases.

(2) Indirect superheating, consisting in the expansion of steam from a higher pressure to that at which it is to be employed, and usually, at the same time, jacketing it with steam of boiler pressure to prevent loss of heat, thus securing drying and slight superheating, where practicable, by a kind of "wire-drawing."

(3) Superheating by mixture or adheating, where highly heated steam is introduced into the steam coming from the boiler in the saturated state, and *en route* to the engine, in such quantity as may be required to secure the desired amount of superheat in the latter.

In greater detail, the methods of superheating usually practised, and all of which have been known for many years and are still to a limited extent employed, are the following:

(1) SUPERHEATING BY "WIRE-DRAWING," the steam being allowed to pass through an orifice or a pipe of such small section as to compel a considerable fall in pressure with free

expansion. By this action all the heat of the steam of high pressure is retained in the mass at the lower pressure, and the surplus of the former over the latter at saturation takes effect in superheating $1/K_r = 1/0.48 = 2.08$, about two degrees to each thermal unit difference of total heats. With steam rendered by the use of separators or otherwise initially dry at the throttle, this may, at times, prove a very valuable method of securing a moderate amount of superheat. At atmospheric pressure a variation of a pound by throttling will produce two degrees superheat; at one hundred pounds pressure it requires two and one-half pounds to superheat one degree; throttling from one hundred and fifty pounds down to one hundred superheats steam about twenty degrees.

Where engines are governed or their power adjusted to their load by throttling, as with many stationary and all locomotive engines, the discrepancy of indicated work and steam and actual steam supply may be made comparatively small, and little superheating is needed to extinguish initial condensation. Large compression and restricted range of temperature along the expansion line, and even extensive drying, sometimes superheating, by the throttling action of the regulator at low powers, make the necessity of provision of large superheating surfaces unnecessary in such cases.* On the other hand, the irregularity of load on the locomotive makes the adjustment of the superheating to the requirements of the engine with varying expansion especially difficult.

(2) SUPERHEATERS IN THE FLUES constitute the most usual construction, and this has the double advantage of taking up heat otherwise lost at the chimney and of securing the desired effect upon the steam without alteration of boiler and setting. This method has been, as a rule, claimed to exhibit more advantages and fewer disadvantages than any other where any considerable amount of superheating is demanded.

(3) SUPERHEATING BY SENDING THE FURNACE GASES THROUGH FLUES SET ABOVE THE WATER LINE OF THE BOILER has frequently been practised, and with some success at times, but it involves a special construction of boiler, and liability to serious expense in repair and in maintenance, in most cases. With very mod-

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* *Vide* "Goss on Locomotive Tests, Conclusions," *Transactions* A. S. M. E., vol. xiv., August, 1893.

character of that actually at the moment to be worked in the engine cylinder. The drying and the superheating of the steam continually improve the working of the engine in two distinct ways: (1) giving a better working substance, and thus initially reducing interior wastes; (2) at the same time meeting more completely the demand for heat to bring up the temperature of the metal to that of the prime steam before the entrance of the latter into the cylinder; thus, each process conspiring with the other, the final effect is large economy with small expenditure.

"It is found that in engines of moderate size—as 250 to 500 I. H. P.—superheating 80 degrees Fahr. to 100 degrees Fahr. will sometimes check all sensible condensation. This indicates that superheated steam is in such cases productive of cylinder waste to the extent of not more than about

$$\frac{100 \times 0.4805}{1,000} = 0.048,$$

or less than 5 per cent., initial condensation being entirely prevented. Against this saving by the reduction of waste perhaps by about $25 - 5 = 20$ per cent., must be charged the cost of superheating. This, when the extra heat is obtained at the chimney flue, will be only the financial charge for first cost and maintenance of superheaters, and by simple extension of heating surface, and will be only its proportion of the cost of steam production, in other cases; or

$$\frac{1,000 + 48}{1,000} - 1 = 0.048,$$

to give a gross gain of about 25 per cent. in steam by the expenditure of 5 per cent. additional fuel, or a net gain of 20 per cent.; a not infrequently reported case."*

With sufficiently superheated steam, the jacket is not needed; it would add nothing to the efficiency of the engine; with wet steam it might be possible that the loss from the jacket during the terminal portion of the expansion period, and throughout the exhaust, might exceed the gain in the earlier part of the

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* *Manual.* In fact, it is probably usually the fact that the total of heating and superheating surface may be made substantially the same for engines using any grade of steam from wet to highly superheated; the gain by superheating reducing the required heating surface quite as much as superheating surface is added.

the tube box, and the nozzles of the connections projected through openings in the side of the boiler. To the nozzle nearest the front of the boiler a pipe bringing the saturated steam to the superheater was bolted, and to the other nozzle another pipe was bolted carrying the superheated steam to the main steam pipe. These pipes were all controlled by stop valves, so that the superheater could be shut off when the fire was hauled from the furnace, and the engine could be supplied with saturated steam, or superheated steam, or a mixture of saturated and superheated steam.

"Each of the two boilers contained five furnaces, and the two boilers contained in the aggregate 200 square feet of grate surface, 4,536 square feet of water-heating surface, and 1,058 square feet of superheating surface.

"Using natural draught and burning 11.67 pounds of anthracite coal per square foot of grate per hour, the temperature of the steam was raised from 270.2 degrees Fahr. when saturated to 365.0 degrees Fahr. when superheated.

"Using a fan blower, and burning twenty-seven pounds of anthracite coal per square foot of grate per hour, the temperature of the steam was raised from 295.0 degrees Fahr. when saturated to 380.0 degrees Fahr. when superheated."*

The superheater of the United States steamship *Plymouth* consists of a box extending along the front of the boiler and traversed by numerous vertical brass tubes, through which the products of combustion pass from the front connections to the uptake. At one end of the box the saturated steam is admitted from the boiler through suitable pipes and stop valves, and at the other end the superheated steam is carried off to the main steam pipe.

The vertical tubular boiler, as illustrated in the work of Corliss and Manning, affords excellent facilities for drying and even for moderately superheating steam when it is desired so to do, either in supplying it to the steam engine or in conveying it long distances. Mr. Manning has carried steam thus several thousand feet and delivered it at the engine dry.†

Bourne describes various forms of superheater:

"But in most cases the steam is sent through a fagot of small tubes set in the smoke at the root of the chimney.

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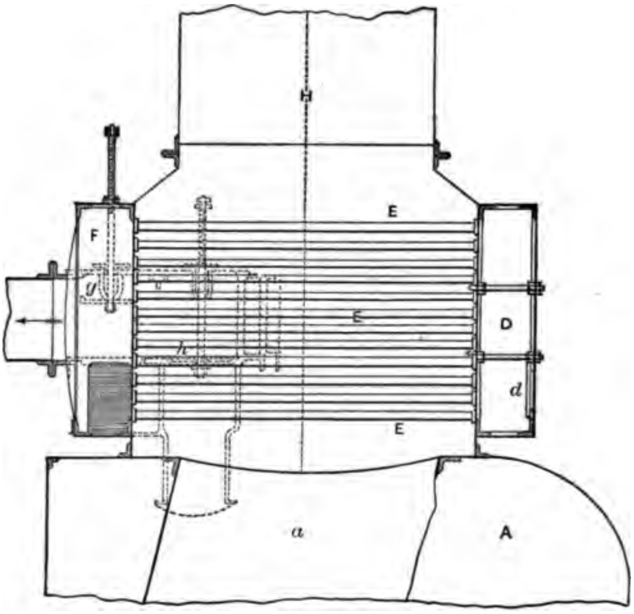
* *Steam Boilers*, Shock.

† Correspondence, 1895.

"An example of this arrangement is given in Fig. 116, which is a representation of the superheater introduced by Messrs. R. Napier & Sons into the steamer *Oleg*, belonging to the Russian Steam Navigation Company. *A* is the boiler, and *a* the uptake of the boiler; *d*, position of inlet valve connecting boiler with superheater; *D* and *F*, inlet and outlet chambers of superheater; *E*, tubes through which the steam passes; *g*, double outlet stop-valve chest, in which *g* connects superheater to steam pipe, and *h* connects boiler to steam pipe direct. *H* is the chimney. The smoke in ascending the chimney impinges on the tubes transmitting the steam, whereby the steam is heated to the required extent.



LONGITUDINAL SECTION.
SUPERHEATING APPARATUS OF S. S. OLEG, BY R. NAPIER & SONS, 1860.

FIG. 116.

"In Lamb and Summers's superheating arrangement, a narrow rectangular pipe or chamber—which winds in a zigzag manner like the flue of a flue boiler—conducts the steam backwards and forwards amongst the smoke at the root of the chimney, until finally the steam debouches in the steam pipe.

"This superheater is shown in Fig. 117, where *A* is the winding rectangular chamber; *B* the stop valve for admitting steam into

"When the available range, t', of superheating is given, the condensation may be, on the above assumptions, reduced by the quantity

$$m' = t' \div l.$$

"Thus, when $t' = 100°$ Fahr. and $m = 0.25$,

$$m' = t' \div l = 100 \div 890 = 0.11,$$

and the cylinder-condensation may be reduced to something like

$$m - m' = 0.25 - 0.11 = 0.14;$$

or, in the case of the larger engine, completely with a surplus to extend the period of pre-condensation in the forward stroke, in the first case, and to $0.15 - 0.11 = 0.04$ in the second. It is to be remembered, however, that even with complete suppression of condensation by superheating the steam, heat-waste still goes on, to some slight extent at least, by storage and transfer, as before." *

The fact that decided improvement may be effected in the economical performance of the steam engine with a very moderate accession of heat, drying the steam and slightly superheating it, has been familiar to constructing engineers for many years, and the high steam chimneys of the steamboats of Robert L. Stevens and his successors on the rivers and sounds of the United States, the later general use with stationary engines of vertical boilers in which the upper portion of the tubes, passing through the steam space, effect this drying and often a moderate superheating, the use of "re-heaters" with compound engines, and the jacketing of the heads of various classes of engines, are all illustrations of the influence of this experience upon the practice of successful builders. Such minor provisions for supplying dry steam and for reducing initial condensation account for much of the special efficiency of steam pumping engines like those at Louisville and at Milwaukee, of marine engines like those of the *Hudson*, and of mill engines, giving similar efficiencies, throughout the country.

"Priming," with impure water, is always liable to make trouble at the superheater, as does, also, the introduction of salt into the marine superheater in a similar manner. All the water

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* *Manual Steam Engine*, vol. i., p. 677.

brought over from the boiler brings with it its proportion of foreign matter, in suspension or in solution, and, in either case, all this solid material must be left behind when the steam, dried and superheated, passes on into the engine. The deposition of incrustation and sediment upon the surfaces exposed, necessarily, to high temperatures, and unprotected by the cooling influence of water or of saturated steam, gives rise to rapid corrosion, to "burning," and to leaking joints, and often to early destruction of the superheater, with attendant risks to persons and property. Either such water must be absolutely avoided, or superheating must be given up, or the method of superheating must be that which transfers heat from steam and water of comparatively high temperature and pressure to the working steam at lower temperature and pressure.

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(3) Superheating by mixture or adheating, where highly heated steam is introduced into the steam coming from the boiler in the saturated state, and *en route* to the engine, in such quantity as may be required to secure the desired amount of superheat in the latter.

In greater detail, the methods of superheating usually practised, and all of which have been known for many years and are still to a limited extent employed, are the following:

(1) SUPERHEATING BY "WIRE-DRAWING," the steam being allowed to pass through an orifice or a pipe of such small section as to compel a considerable fall in pressure with free

"*Third.* The most economical measure of expansion with which to use the steam of the most economical initial cylinder pressure. Also, the weight of steam required, under these premises, to be expended per hour for the production of one total and net indicated horse-power.

"*Fourth.* The highest degree of superheating which can be given to the steam of the most economical initial cylinder pressure and measure of expansion, and the best method of accomplishing it, whether by waste heat in the chimney, or by heat specially expended for the purpose in a separate apparatus. Also, the weight of steam required, under these premises, to be expended per hour for the production of one total indicated and net horse-power.

"*Fifth.* The most economical back pressure against the piston, under the above premises. As the temperature of the feed water, the condensation in the cylinder, and the power expended in removing the back pressure, are dependent on the quantity of that pressure, its effect upon the economy of the fuel is evident.

"*Sixth.* The most economical area of cylinder port, in proportion to capacity of cylinder and speed of piston, taken in connection with cushioning, steam lead, and exhaust lead.

"*Seventh.* The most economical speed of piston.

"*Eighth.* The economy produced by steam-jacketing the cylinder—top, bottom, and sides—both with saturated and superheated steam."*

That the gain obtained is not thermodynamic but purely that due the checking effectively of a serious internal thermal waste, is well shown by computing the gains for a series of cases and comparing the computed with the actual gains as reported in practice.

Mr. Isherwood reports for the case of superheating in a small engine, 5¼-inch cylinder, 10-inch stroke, at 60 revolutions a minute, the effect of "adheating" by the Wethered system and of its conjoint action with the steam jacket.† This engine is evidently too small to afford definite knowledge of the action of superheated steam on a large scale. The machine is enormously wasteful at best. The following are the results reported as above:

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* *Experimental Researches in Steam Engineering*, Chief Engineer B. F. Isherwood, United States Navy, Philadelphia, 1865.

† Isherwood's *Researches*.

	CUT-OFF 0.19.		CUT-OFF 0.83.	
	Pounds per hour per I. H. P.	Proportional.	Pounds per hour per I. H. P.	Proportional.
Saturated steam, air in jacket	67.15658	1.000	79.42902	1.000
Adheated steam, air in jacket	66.50316	0.990	....	....
Saturated steam, steam in jacket	44.35160	0.664	....	....
Steam adheated in coil	37.15161	0.553	42.66123	0.537
Steam adheated in tubular adheater	40.86778	0.608	46.79664	0.589
Steam adheated in steam pipe	39.97301	0.595	47.14389	0.594
The last three had steam in the jacket.				

Experiments on the United States steamship *Eutaw*, upon a paddle engine of 58-inch cylinder and $8\frac{3}{4}$ feet stroke of piston, superheating steam to about 90 degrees Fahr. above the normal. The following are the results:*

ECONOMY DUE MODERATE SUPERHEATING.

	SATURATED STEAM.				SUPERHEATED STEAM.			
Cut-off	0.24	0.32	0.50	0.58	0.29	0.32	0.50	0.58
Number of expansions	3.339	2.679	1.855	1.632	2.894	2.679	1.855	1.632
Consumption per horse-power per hour:								
Total	36.429	29.166	31.635	30.540	28.574	26.636	25.019	26.033
Indicated	39.205	31.039	33.236	32.008	30.586	28.346	26.285	27.764
Net	42.284	33.068	34.924	33.549	32.791	30.199	27.620	29.101
Comparative size of cylinders for equal net horse-power	1.632	1.358	1.055	1.000	1.498	1.358	1.065	1.000

The effect of using different ratios of expansion appears to be substantially the same for superheated as for saturated steam.

The Schwoerer System of Superheating, as applied in the establishment of Mess. Koechlin & Cie., at Massevaux, was reported upon March 16. 1892, by M. Ludwig, engineer of the Alsatian Association.† Three boilers were used with the superheaters, and four without; the fourth being found to be needed to keep up steam. Steam pressure was carried at about five atmospheres. The feed water was raised from just above the freezing point to 105 degrees or 110 degrees C. (220 degrees to 230 degrees Fahr.) by a Green economizer. A full day was given to each trial. The engine was a 300 horse-power Corliss machine, making sixty revolutions per minute. The degree of super-

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* Isherwood's *Researches*. † *Transactions*, 1892.

the tube box, and the nozzles of the connections projected through openings in the side of the boiler. To the nozzle nearest the front of the boiler a pipe bringing the saturated steam to the superheater was bolted, and to the other nozzle another pipe was bolted carrying the superheated steam to the main steam pipe. These pipes were all controlled by stop valves, so that the superheater could be shut off when the fire was hauled from the furnace, and the engine could be supplied with saturated steam, or superheated steam, or a mixture of saturated and superheated steam.

"Each of the two boilers contained five furnaces, and the two boilers contained in the aggregate 200 square feet of grate surface, 4,536 square feet of water-heating surface, and 1,058 square feet of superheating surface.

"Using natural draught and burning 11.67 pounds of anthracite coal per square foot of grate per hour, the temperature of the steam was raised from 270.2 degrees Fahr. when saturated to 365.0 degrees Fahr. when superheated.

"Using a fan blower, and burning twenty-seven pounds of anthracite coal per square foot of grate per hour, the temperature of the steam was raised from 295.0 degrees Fahr. when saturated to 380.0 degrees Fahr. when superheated."*

The superheater of the United States steamship *Plymouth* consists of a box extending along the front of the boiler and traversed by numerous vertical brass tubes, through which the products of combustion pass from the front connections to the uptake. At one end of the box the saturated steam is admitted from the boiler through suitable pipes and stop valves, and at the other end the superheated steam is carried off to the main steam pipe.

The vertical tubular boiler, as illustrated in the work of Corliss and Manning, affords excellent facilities for drying and even for moderately superheating steam when it is desired so to do, either in supplying it to the steam engine or in conveying it long distances. Mr. Manning has carried steam thus several thousand feet and delivered it at the engine dry.†

Bourne describes various forms of superheater:

"But in most cases the steam is sent through a fagot of small tubes set in the smoke at the root of the chimney.

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* *Steam Boilers*, Shock. † Correspondence, 1895.

not many engines working with less than 2.7 pounds of coal per effective horse-power hour. Hence the consumption, allowing a little for lighting-up, etc., must amount to 400 tons annually for an engine working at 100 effective horse-power for 3,000 hours in the year. A saving of one-fifth of this, or 80 tons of coal annually, represents a considerable saving in money. With inferior engines or unjacketed engines it may be expected that that economy will be greater than with very good engines. Where the engine is at a distance from the boilers, in the case, for instance, of boilers above ground supplying steam to steam pumping engines in underground workings, the saving may be much greater than in the cases described above."

GENERAL SUMMARY OF UNWIN'S TRIALS.

	TRIAL II.	TRIAL I.	TRIAL III.	TRIAL III.
	Without superheating. Six hours.	With superheating. Five hours.	With superheating. Six hours.	With superheating. Five hours.
Total indicated H. P......	475.0	491.0	501.4	502.8
Boiler pressure, lbs. per sq. inch................	95.72	99.05	93.74	94.0
Amount of superheating..	None.	118.3°	119.2°	126.9°
Lbs. of steam per lb. of coal..................	6.276	6.024	6.655	6.21
Lbs. of steam per indicated H. P. hour.......	19.75	15.63	17.06	15.61
Lbs. of coal per indicated H. P. hour.............	3.147	2.593	2.564	2.513
Perc't of economy of steam due to superheating....	....	20.9	13.6	20.9
Percent of economy of coal due to superheating.....	....	17.6	18.5	20.1

"According to my results, therefore, there is a mean economy of 18½ per cent. of steam, and of 18¾ per cent. of coal, when steam is superheated at the moment of entering the valve chest about 120 degrees above the saturation temperature."*

Prof. J. A. Ewing experimentally determined the efficiency of a Laval steam turbine, employing steam superheated about 60 degrees Fahr., and 100 pounds per square inch pressure, by gauge, with good results. The power developed was reported as 137 horse-power, and the steam consumed per effective horse-

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* Unwin's Report, May 4, 1893.

power 21.2 pounds per hour. Still better results have been reported by the builders as obtained in Sweden by other able experimenters. It may be safely stated that, in all instances of the application of superheated steam in the operation of any and of all types of modern steam engine, increased economical effect has been obtained and usually a very considerable gain in reduction of internal wastes, and, consequently, in costs of power in heat, steam, and fuel employed.

The economical advantages of superheated steam *in small motors* have been exhibited by tests of a Serpollet motor conducted by M. Seguin. The motor had a single horizontal cylinder, 5.1 inches in diameter by 5.1 inches stroke. The cut-off was fixed at 66 per cent.; the admission pressure was 58 pounds per square inch, and the revolutions 284 per minute. The brake horse-power on a four hours' trial averaged 4.57 horse-power, and the steam consumption was but 29.87 pounds per brake horse-power per hour. At the Plymouth trials of the Royal Agricultural Society the best engine, a compound, required 35.75 pounds, while the best of the single-cylinder engines demanded 57.75 pounds of steam per indicated horse-power. The advantage shown by the Serpollet motor must be credited to a boiler which supplies superheated steam. It consists of a stout coiled tube flattened so as to reduce the passage to a narrow slit. This tube has one end connected with a feed pump, and the other with the engine to be driven. The boiler had a heating surface of 26.8 square feet, and a grate area of 2.9 square feet. The steam had a temperature of 1,009 degrees Fahr. on issuing from the coil, and of 572 degrees Fahr. at the steam chest. The temperature of saturated steam at 58 pounds pressure is about 306 degrees Fahr.; as used, the steam was superheated by some 266 degrees Fahr. The output of steam was 4.9 pounds per square foot of heating surface per hour. The fuel was briquettes having a heating value, as tested in a calorimeter, of 8.28 pounds of water evaporated from and at 212 degrees Fahr. per pound of fuel. The boiler efficiency was 67.3 per cent.

The apparatus of M. Satre consists simply of a set of superheating tubes placed back of the furnace, or constituting a bridge wall, through which the steam, *en route* to the engine, passes. In the latter case, it is made in the form of a cast-iron chamber set on the top of the brick wall, and is given sufficient area to secure the desired amount of superheat without, at the same time, involving risk of excessively high temperature. The apparatus is as simple as possible and very inexpensive. The use of cast iron, however, would probably not be recommended with high steam pressures. The following are the data and the results of trial of such a system, as reported by M. Hirsch for a small stationary "plant."*

DIMENSIONS.

Area of grate surface	1.12 m. (12.05 sq. ft.)
Heating surface	72.00 m. (774.72 sq. ft.)
Diameter of small cylinder	3.4 m. (13.4 in.)
Large cylinder	6 m. (23.6 in.)
Length of stroke of piston	6 m. (23.6 in.)

RESULTS OF TRIALS.

	With Superheater.	Without.
Length of trial	3 hours.	3 hours.
Steam pressure	6 k. (90 lbs.)	6 k. (90 lbs.)
Temperature of saturated steam	164 ° C. ( )	164° C. ( )
Temperature in the steam chest of engine	233 ° C. ( )	164° C. ( )
Loss of pressure between boiler and engine	0.1 k. (1.5 lbs.)	0.5 k. (7 lbs.)
Cut-off in small cylinder	0.13	0.11
Mean pressure in small cylinder		
Mean pressure in large cylinder	1.65 k. ( )	1.406 k. ( )
Mean pressure referred to large cylinder	0.792 k. ( )	
Indicated horse-power, small cylinder	32.7 ( )	29.2 ( )
Indicated horse-power, large cylinder	15.6 ( )	18.2 ( )
Total indicated horse-power	48.3 ( )	47.4 ( )
Total weight of feed water	990 k. ( )	1200 k. ( )
Feed water per I.H.P. per hour	6.83 k. ( )	8.44 k. ( )

Gain by use of superheater 0.19

Lubrication was effected by the introduction of a good mineral oil into the steam chest of the small cylinder only, and was perfectly satisfactory. The gain of 19 per cent. net is most satisfactory also, and the reduction of the loss of pressure between boiler and engine, due to the lesser density of the superheated steam, is one element of advantage not to be overlooked in those cases in which the sizes of steam pipe are insufficient.

In another instance reported in the same document by M.

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* *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, February, 1894.

"*Third.* The most economical measure of expansion with which to use the steam of the most economical initial cylinder pressure. Also, the weight of steam required, under these premises, to be expended per hour for the production of one total and net indicated horse-power.

"*Fourth.* The highest degree of superheating which can be given to the steam of the most economical initial cylinder pressure and measure of expansion, and the best method of accomplishing it, whether by waste heat in the chimney, or by heat specially expended for the purpose in a separate apparatus. Also, the weight of steam required, under these premises, to be expended per hour for the production of one total indicated and net horse-power.

"*Fifth.* The most economical back pressure against the piston, under the above premises. As the temperature of the feed water, the condensation in the cyclinder, and the power expended in removing the back pressure, are dependent on the quantity of that pressure, its effect upon the economy of the fuel is evident.

"*Sixth.* The most economical area of cylinder port, in proportion to capacity of cylinder and speed of piston, taken in connection with cushioning, steam lead, and exhaust lead.

"*Seventh.* The most economical speed of piston.

"*Eighth.* The economy produced by steam-jacketing the cylinder—top, bottom, and sides—both with saturated and superheated steam."*

That the gain obtained is not thermodynamic but purely that due the checking effectively of a serious internal thermal waste, is well shown by computing the gains for a series of cases and comparing the computed with the actual gains as reported in practice.

Mr. Isherwood reports for the case of superheating in a small engine, 5¼-inch cylinder, 10-inch stroke, at 60 revolutions a minute, the effect of "adheating" by the Wethered system and of its conjoint action with the steam jacket.† This engine is evidently too small to afford definite knowledge of the action of superheated steam on a large scale. The machine is enormously wasteful at best. The following are the results reported as above:

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* *Experimental Researches in Steam Engineering,* Chief Engineer B. F. Isherwood, United States Navy, Philadelphia, 1865.

† Isherwood's *Researches.*

ing surface of a boiler is well exhibited in the following set of balance sheets reported by Mr. Crossland, Chief Engineer of the Manchester Boiler Insurance and Steam Power Co. in 1893. The whole added area was in this case required to secure dry steam, and the superheating effect was too slight to have much value as such at the engine. The illustration has value in this connection merely as showing the manner and the extent to which boiler efficiency may be improved by such extension of heating surface.

PARTICULARS OF BOILER AND SUPERHEATER.

Type of Boiler:

Lancashire, 7 feet 6 inches diameter by 28 feet long, two internal flues, each 3 feet diameter, five Galloway tubes in each flue. Worked in conjunction with a superheater.

Flues:

Gases pass along internal flues and envelop superheating pipes and boxes at back of boiler, afterwards passing along bottom flue, thence along side flues to chimney.

Heating Surface:

Heating surface of boiler	896 sq. ft.
Heating surface of superheater	464 sq. ft.
Total heating surface	1,360 sq. ft.

Fire-Grates:

Dimensions of fire-grates	5 ft. long by 3 ft. wide.
Total fire-grate area	30 sq. ft.
Number of bars in each fire grate	20
Area of opening below grates	3.84 sq. ft.
Ratio of heating surface to grate surface (boiler only)	29.86 to 1
Ratio of heating surface to grate surface (boiler and superheater)	45.33 to 1

Method of Firing:

Mechanical stoker with coking pit at end of fire bars.

BALANCE SHEET OF BOILER AND SUPERHEATER. HEAT PER POUND OF DRY COAL, AND ITS APPROPRIATION. TEMPERATURES FROM 32 DEGREES FAHR.

DR.	January 15, 1894. B. T. U.
To calorific value of one pound of dry coal	12,688
" heat contained in steam, coal, air, and vapor when entering furnaces, per pound of coal	35
	12,723

CR.	B. T. U.	Percentage.
By heat absorbed by water in boiler and superheater........	9,704	76.27
" heat carried away in products of combustion............	1,319	10.36
" heat carried away in surplus air........................	709	5.57
" heat carried away in vapor in air.......................	16	.13
" heat carried away in steam supplied to stoker bars	48	.38
" heat carried away in steam from water in coal	65	.51
" heat lost by imperfect combustion	6	.05
" heat lost by unburnt carbon in ashes....................	532	4.18
" heat lost in ashes drawn from furnaces..................	54	.43
" residue, including loss by radiation and convection and heat unaccounted for...............................	270	2.12
	12,723	100.00

BALANCE SHEET OF BOILER WITHOUT SUPERHEATER.

DR.	August 2 and 3, 1898. B. T. U.
To calorific value of one pound of dry coal..................	12,669
" heat contained in steam, coal, air, and vapor when entering furnace, per pound of coal	206
	12,875

CR.

	August 2.		August 3.	
	B. T. U.	Percentage.	B. T. U.	Percentage.
By heat absorbed by water in boiler..........	7,043	54.70	7,276	56.51
" heat lost by unburnt carbon in ashes......	876	6.80	621	4.82
" heat lost in ashes drawn from furnaces....	59	0.46	51	0.40
" heat carried away in products of combustion, surplus air, vapor in air, steam from water in coal, and heat lost by radiation and convection	4,897	38.04	4,927	38.27
	12,875	100.00	12,875	100.00

In this case the addition of about 50 per cent. to the total heating surface of boiler by the introduction of the so-called superheater produced steam of a temperature exceeding that of saturation by four or five degrees, raised the boiler efficiency from 56.5 to 76.3, or 30 per cent., and insured dry steam at the engine, where previously the steam supplied had been wet and very wastefully produced. The evaporation, "from and at 212 degrees," was raised from 8.67 to 11.29 pounds of water per pound of combustible.

Tests of this superheater, made by the chief engineer of the Messrs. Fox & Co. woolen mills, Wellington, G. B., are reported to have given results as follows, which measure, simply, the gain by the addition of heating surface, in this form, to a boiler previously working uneconomically:

is doubtless the chief reason for the important economy obtained.

The experience of the Westinghouse Co., according to Mr. Rites,* indicates that with engines of the class and sizes usual in their business, decided gain is secured by moderate superheating. The gain is proportionally greatest up to the point at which the steam can be made to enter the engine perfectly dry or slightly above the temperature of saturation; while with increasing excess of temperature, gain becomes greater in a rapidly decreasing proportion. Thus, a sixty-five horse-power compound engine, having cylinders ten and eighteen by ten inches, worked at 320 revolutions, under 100 pounds steam pressure, both condensing and non-condensing, gave the following figures on test:

TESTS OF COMPOUND SINGLE-ACTING ENGINE.

Temperature	390	898	Sat.	Sat.
Pressure..........	100	100	100	100
Arrangement	Non-Con.	Con.	Con.	Non-Con.
I. H. P...........	56.1	55.5	55.1	54.7
Feed per I. H. P...	21.95	17.47	20.6	25.7

Thus a superheat of fifty to sixty degrees gave a gain of about fifteen per cent.

Experiments on superheating, made by Messrs. Ludwig and Weber, reported to the Société Industrielle de Mulhouse, are recorded in the bulletin of that association of date of 1894. They occupied six weeks, and were very carefully conducted. Unfortunately, they were not good illustrations of the best work obtainable by the use of superheaters, and have therefore comparatively little value for present purposes. The superheating was from 40 to 50 degrees C. (72 to 90 degrees Fahr.). It was observed, as one interesting incident, that the cooling off of engines and boilers, each Sunday, so affected their action that it was only after many hours of steady operation that a permanent *régime* was attained. In fact, the observations were not resumed by the investigators until Tuesday noon.

In this case, the boilers were less efficient by about three per cent., when the superheaters were in use, than when supplying

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* Correspondence, 1895.

mm. (63 inches). The speed of revolution was 60 per minute, and the speed of piston 3 m. (9.75 feet) per second (585 feet per minute). Steam was carried at six atmospheres (88 pounds) pressure, though intended by the designer to be carried up to eleven atmospheres (160 pounds). The valve gear was similar to the well-known Sulzer gear, consisting of four poppet valves on each cylinder, the cut-off being effected by a "French cam" arrangement controlled by a loaded centrifugal governor acting on the gear of the high-pressure cylinder, the others being adjusted by hand. The steam cylinders were jacketed with prime steam and covered by a good lagging. The engine weighs 220,000 kilograms (210 tons), or 147 kilograms (323 pounds) per horse-power.

The power actually developed during the trials varied between 1,000 and 1,200 horse-power. The temperature of the steam at entrance into the engine ranged from 164 degrees C. (327 degrees Fahr.), when saturated, to 212 and 216 degrees C. (414 degrees to 421 degrees Fahr.) superheated; the superheat thus amounting to from 48 degrees to 52 degrees C. (86 degrees to 93 degrees Fahr.). The temperature of the feed water ranged between 6.36 degrees and 6.91 degrees C. (43 degrees to 44 degrees Fahr.); that of the hot well from 21 degrees to 22 degrees C. (69 degrees to 72 degrees Fahr.). The steam jackets absorbed from 5 to 7 per cent. of the total steam supply when working with superheated steam, and from 9.2 to 12.4 per cent. when using saturated steam. The consumption of feed water and steam per indicated horse-power per hour amounted to 5.5 kilograms (12.1 pounds) with superheated, and to 6.1 (13.4 pounds) with saturated steam. The boiler supplied steam at the rate of 14 to 24 kilograms per square meter per hour. The net gain was thus, practically, ten per cent. of the quantity of saturated steam required by the engine in normal working.

The steam consumption per delivered, or brake, horse-power was 7.25 kilograms (16 pounds) with saturated, and 6.6 kilograms (14.5 pounds) with superheated steam. It is presumed that, could a full load be obtained for this engine, and full boiler pressure thus utilized, with best adjustment of the ratio of expansion, these figures might be improved eight or ten per cent.* The engine was much underloaded and the steam pressure was

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* *Z. des Ver. Deutscher Ingenieure,* March 7, 1896.

not many engines working with less than 2.7 pounds of coal per effective horse-power hour. Hence the consumption, allowing a little for lighting-up, etc., must amount to 400 tons annually for an engine working at 100 effective horse-power for 3,000 hours in the year. A saving of one-fifth of this, or 80 tons of coal annually, represents a considerable saving in money. With inferior engines or unjacketed engines it may be expected that that economy will be greater than with very good engines. Where the engine is at a distance from the boilers, in the case, for instance, of boilers above ground supplying steam to steam pumping engines in underground workings, the saving may be much greater than in the cases described above."

GENERAL SUMMARY OF UNWIN'S TRIALS.

	TRIAL II.	TRIAL I.	TRIAL III.	TRIAL III.
	Without superheating. Six hours.	With superheating. Five hours.	With superheating. Six hours.	With superheating. Five hours.
Total indicated H. P.	475.0	491.0	501.4	502.3
Boiler pressure, lbs. per sq. inch	95.72	99.05	93.74	94.0
Amount of superheating	None.	118.3°	119.2°	126.9°
Lbs. of steam per lb. of coal	6.276	6.024	6.655	6.21
Lbs. of steam per indicated H. P. hour	19.75	15.63	17.06	15.61
Lbs. of coal per indicated H. P. hour	3.147	2.593	2.564	2.513
Perc't of economy of steam due to superheating	....	20.9	13.6	20.9
Percent of economy of coal due to superheating	....	17.6	18.5	20.1

"According to my results, therefore, there is a mean economy of 18½ per cent. of steam, and of 18¾ per cent. of coal, when steam is superheated at the moment of entering the valve chest about 120 degrees above the saturation temperature."*

Prof. J. A. Ewing experimentally determined the efficiency of a Laval steam turbine, employing steam superheated about 60 degrees Fahr., and 100 pounds per square inch pressure, by gauge, with good results. The power developed was reported as 137 horse-power, and the steam consumed per effective horse-

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* Unwin's Report, May 4, 1893.

TABLE I.—BOILER.

NUMBER OF TEST	1		2	
Duration of test.......................hours	8		8.1	
Coal consumption, total................pounds	597.5		705.5	
" " per hour............ "	74.69		87.08	
Calorific value of coal................B. T. U.	14,589		14,589	
Feed water evaporated, total...........pounds	5,436.5		5,466	
" " " per hour....... "	679.55		675.8	
Feed-water temperature before entering heater .... degrees Fahr.	59		61	
Feed-water temperature before entering boiler........... .... degrees Fahr.	194		194	
Steam, mean pressure..... .. ..pounds	128.29		127.25	
Evaporation of water per pound of coal. "	9.1		7.76	
Equivalent evaporation, calculated for feed water of 82 degrees Fahr. and steam of 212 degrees Fahr......................pounds	8.16		6.94	
Mean temperature of steam for mean pressure.........................degrees Fahr.	354		352.4	
Mean temperature before entering main heater...... ....degrees Fahr.	422.5		442.4	
Mean temperature before entering engine.........................degrees Fahr.	687.2		694	
Temperature of fuel gases entering the chimney.........................degrees Fahr.	703.5		692	
	B. T. U.	Per cent.	B. T. U.	Per cent.
Heat utilized for generating steam	9,356.4	64.14	7,972	54.65
" " " superheating steam..........	1,440	9.87	1,260	8.64
Total heat utilized for steam	10,796 4	74.01	9,232	63.29

TABLE II.—MOTOR.

NUMBER OF TEST	1	2
Duration of test..... ....hours	8	8.1
Work done.—Indicator tests:		
Temperature of superheated steam.......degrees Fahr.	687.2	694
Mean pressure, from diagrams.................pounds	(39.96)	(41.10)
Revolutions per minute...........................	161.5	162.8
Mean work .... horse-power	(39.45)	(40.92)
Work done.—Brake tests:		
Weight carried...............................pounds	138.9	141.78
Length of lever..................................feet	8.798	8.83
Revolutions per minute.......	161.5	162.8
Mean work..................................horse-power	37.96	39 20
Efficiency....................................per cent.	(96.22)	(95.85)
Consumption of steam, total.......................pounds	5,496.5	5,466
" " per indicated H. P. per hour. "	(17.22)	(16.5)
" " per brake H. P. per hour... "	17.90	17.22
" of coal, total................... "	597.5	705.5
" " per indicated H. P. per hour. "	(1.89)	(2.14)
" " per brake H P. per hour.... "	1.967	2.222
Heat utilized by exhaust steam. ....B. T. U.	135	183
Resulting in a saving of coal of...............per cent.	8.42	7.09

An engine and boiler of this class, constructed by Mr. J. E. Christoph, of Niesky, in Silesia, of somewhat larger dimensions, were subjected to a series of trials by Professor Lewicki, of Dresden, in order to determine the following points: (1) Steam consumption of the engine when fully loaded. (2) Frictional resistance of the unloaded engine. (3) Useful effect under different conditions of work. The engine has two cylinders of 250 mm. diameter and 400 mm. stroke. The heating surface of the boiler was 5.8 square metres. The principal results are tabulated as follows:

Duration of trial	5 hr. 10 min.
Steam pressure in boiler, effective	8.81 atm.
Temperature of feed water	17 deg. C.
Temperature of feed water from feed-water heater	84.1 "
Pyrometer reading, bottom of fore superheater	596.1 "
Pyrometer reading, bottom of after superheater	412.9 "
Steam temperature in after evaporator, below	296.2 "
Steam temperature in after evaporator, above	287.8 "
Steam temperature, engine admission	345.7 "
Steam temperature, engine exhaust	143.3 "
Steam temperature, feed-water heater	101.1 "
Air temperature in engine-room	27.3 "
Feed water per hour	331.19 kilogs.
Revolutions of engine per minute	157.93
Indicated horse-power	48.48
Effective horse-power	41.47
Steam consumption per I. H. P. per hour	6.83
Steam consumption per effective H. P. per hour	7.98
Coal	1.10 kilogs.

The friction of the unloaded engine, when running at 159.46 revolutions per minute, represented 2.12 horse-power, and the difference in speed between the engine when light and when fully loaded was only 0.96 per cent.

The effective power under different conditions of steam admission and speed varied as follows:

STAGE.	Revolutions per minute.	Indicated horse-power.	Effective horse-power.	Efficiency, per cent.
1	160.55	15.35	11.09	72.2
2	158.55	26.95	21.99	81.3
3	157.55	38.65	32.66	84.5
4	157.93	48.48	41.47	85.5

Hirsch, in which a semi-portable engine was employed, the power developed was greater by about 50 per cent. with superheat than without, and the gain in economy of fuel amounted to 36.5 per cent.; the superheating being about 70 degrees C. (126 degrees Fahr.). The reported consumption of fuel was 12.67 kilos, as against 20 kilos (27.9 pounds and 44 pounds) before the superheater was introduced, and that of fuel 1.95 kilos (4 pounds) in place of 3.05 kilos (6.6 pounds).

M. Hirsch concludes from these experiments that, with superheating, both power and economy may be improved, and to a very important extent; that sizes of steam pipes and of steam ports may be reduced, and that the condenser and air pump may also be lessened in size and cost.

M. Hirsch reports to the Société d'Encouragement, in behalf of the Committee on the Mechanic Arts, on the trials of a superheater devised by MM. Dusert and Epêche, which were conducted by M. Roche, Ingénieur des Constructions Navales.*

In this apparatus, the superheater consists of an extension of the steam pipe into and through the furnace of the boiler, discharging its steam into the steam-engine cylinder at a temperature exceeding that of the saturated steam about 70 degrees C. (126 degrees Fahr.). With an increased power from 16.04 to 25.24 D. H. P., the consumption of steam was reduced from 20.00 to 12.67 kilos per horse-power per hour, and the fuel from 3.05 to 1.95 kilos; the gain being 36.8 and 36.5 per cent. for the two cases, respectively. Boiler pressure was carried at six atmospheres. M. Hirsch concludes that steam jackets may be dispensed with when superheating is thus employed, and that the dimensions of steam pipes, of valves and ports, and of the whole condensing and air pump system, may be reduced considerably. In this case, mineral oils were used, and no trouble was experienced in lubrication.†

The effect of the superheater as a simple addition to the heat-

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* *Bulletin de la Société*, February, 1894.

† "The use of well-designed superheaters is attended with saving in all cases, and may be adopted in the fullest confidence that the troubles of twenty or thirty years ago will be easily avoided. The greatest percentage of saving is, however, usually secured in cases where the engine or its appointments are most defective, where the weight of steam consumed is greatest, and especially where a high rate of expansion is adopted without adequate provision against cylinder condensation."—*Sutcliffe.*

"By a well-conditioned engine is meant one with the joints, piston, and valves tight. When the engines were worked with a wide throttle, the cylinder initial pressure averaged about two and one-half pounds per square inch less than the boiler pressure, and the steam admission line of the diagram was horizontal until near the point of cutting off, when it rounded down by a nearly quadrantal curve two and one-half pounds per square inch, at which the cut-off valve closed and the expansion curve commenced. When saturated steam is used, the pressure at the end of the stroke of the piston is a very little greater than is due to the Mariotte law, and when superheated steam is used it is a very little less.

"7. One of the most remarkable results of the experiments on superheated steam, when used with different measures of expansion, is the fact that the economy due to these different measures of expansion is not affected by the superheating; that is to say, if, when using saturated steam without expansion, and with a certain measure of expansion, the difference in the cost of the total indicated horse-power is found to be a certain per centum of the former, then, when using superheated steam similarly, without expansion, and with the same measure of expansion, the difference in the cost of the total indicated horse-power will be the same per centum of the former as in the case with the saturated steam. In other words, the difference in the cost of the total indicated horse-power with superheated steam used with different measures of expansion is, relatively, one with another, the same as in the case of saturated steam. This is, perhaps, the most difficult fact of all to explain. In rests on the purely experimental evidence, but may be depended on as true, whether a satisfactory reason can be found for it or not. The fact remains incontestable that superheating steam to a certain temperature increases its economic effect the same quantity over that of saturated steam, in the same category, whether it be used without expansion or with any measure of expansion whatever.

"8. With the highest practicable amount of superheating, that is to say, an amount which does not injure the metals of the superheating apparatus or cylinder, and under which the piston, valves, and packings will work conveniently, the number of pounds of steam required per hour for the production of the total indicated horse-power will be reduced one-third, leaving

CR.	B. T. U.	Percentage.
By heat absorbed by water in boiler and superheater	9,704	76.27
" heat carried away in products of combustion	1,319	10.36
" heat carried away in surplus air	709	5.57
" heat carried away in vapor in air	16	.13
" heat carried away in steam supplied to stoker bars	48	.38
" heat carried away in steam from water in coal	65	.51
" heat lost by imperfect combustion	6	.05
" heat lost by unburnt carbon in ashes	532	4.18
" heat lost in ashes drawn from furnaces	54	.43
" residue, including loss by radiation and convection and heat unaccounted for	270	2.12
	12,723	100.00

BALANCE SHEET OF BOILER WITHOUT SUPERHEATER.

DR.	August 2 and 3, 1898. B. T. U.
To calorific value of one pound of dry coal	12,669
" heat contained in steam, coal, air, and vapor when entering furnace, per pound of coal	206
	12,875

CR.

	August 2.		August 3.	
	B. T. U.	Percentage.	B. T. U.	Percentage.
By heat absorbed by water in boiler	7,043	54.70	7,276	56.51
" heat lost by unburnt carbon in ashes	876	6.80	621	4.82
" heat lost in ashes drawn from furnaces	59	0.46	51	0.40
" heat carried away in products of combustion, surplus air, vapor in air, steam from water in coal, and heat lost by radiation and convection	4,897	38.04	4,927	38.27
	12,875	100.00	12,875	100.00

In this case the addition of about 50 per cent. to the total heating surface of boiler by the introduction of the so-called superheater produced steam of a temperature exceeding that of saturation by four or five degrees, raised the boiler efficiency from 56.5 to 76.3, or 30 per cent., and insured dry steam at the engine, where previously the steam supplied had been wet and very wastefully produced. The evaporation, "from and at 212 degrees," was raised from 8.67 to 11.29 pounds of water per pound of combustible.

Tests of this superheater, made by the chief engineer of the Messrs. Fox & Co. woolen mills, Wellington, G. B., are reported to have given results as follows, which measure, simply, the gain by the addition of heating surface, in this form, to a boiler previously working uneconomically:

Monsieur J. Hirsch, professor at the Conservatoire, and the Ingénieur en Chef des Ponts et Chaussées, in Paris, the distinguished counsel of the French Government in such matters, informs the writer that, as the outcome of his own observations and experiments, he concludes that superheating is the main line of desirable advance with the steam engine. As he says:

"In my view, the steam engine has attained, in our time, a degree of perfection that, in its present form, has given the utmost possible utilization of heat. To secure a better performance, it is necessary to enter upon new paths. Among the numerous methods available, presenting some chance of success, one of the most simple and attractive is superheating. This process promises, in theory, positive gain in efficiency; in practice, it introduces only the difficulties of securing tight joints and especially of effective lubrication. But, notwithstanding the progress effected in late years in the preparation, the selection, and the use of lubricants, these difficulties remain serious, and this remains an obstacle, not only where it is proposed to superheat steam, but also wherever any working fluid is employed at high temperatures. The difficulty of securing good lubrication opposes every effort to obtain amelioration of the performance of thermic motors. This obstacle has not been surmounted, but rather has been evaded, and in a very incomplete way, in the explosive engines. On success in overcoming this impediment depends the success of the heat engine of the future. Could this difficulty be overcome, the employment of superheating would come to be general."

M. Hirsch asserts the problem thus sought to be solved "un des plus important de ceux que soulève le fonctionnement des appareils à vapeur." He considers the fact undoubted that, by means of this device, could it be made thoroughly practicable, the advantages now only obtainable by increase of steam pressure, and which have their origin, in fact, in the simultane-

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the difference is very great, and many superheaters have been removed after a few months', or even, in some cases, a few weeks' service. It is thought by many engineers, however, that it is not impossible to so construct and work them that they may last for many years. The writer has examined many certificates of satisfactory operation of superheaters for considerable periods of time, with no apparent injury or perceivable wear. The Yorkshire Boiler Insurance Company of Great Britain has issued many such on superheaters employed by its customers." —*Reports of the Yorkshire Boiler Insurance and Steam Users' Co., Ltd.*, 1893, 1894.

mm. (63 inches). The speed of revolution was 60 per minute, and the speed of piston 3 m. (9.75 feet) per second (585 feet per minute). Steam was carried at six atmospheres (88 pounds) pressure, though intended by the designer to be carried up to eleven atmospheres (160 pounds). The valve gear was similar to the well-known Sulzer gear, consisting of four poppet valves on each cylinder, the cut-off being effected by a " French cam " arrangement controlled by a loaded centrifugal governor acting on the gear of the high-pressure cylinder, the others being adjusted by hand. The steam cylinders were jacketed with prime steam and covered by a good lagging. The engine weighs 220,000 kilograms (210 tons), or 147 kilograms (323 pounds) per horse power.

The power actually developed during the trials varied between 1,000 and 1,200 horse-power. The temperature of the steam at entrance into the engine ranged from 164 degrees C. (327 degrees Fahr.), when saturated, to 212 and 216 degrees C. (414 degrees to 421 degrees Fahr.) superheated; the superheat thus amounting to from 48 degrees to 52 degrees C. (86 degrees to 93 degrees Fahr.). The temperature of the feed water ranged between 6.36 degrees and 6.91 degrees C. (43 degrees to 44 degrees Fahr.); that of the hot well from 21 degrees to 22 degrees C. (69 degrees to 72 degrees Fahr.). The steam jackets absorbed from 5 to 7 per cent. of the total steam supply when working with superheated steam, and from 9.2 to 12.4 per cent. when using saturated steam. The consumption of feed water and steam per indicated horse-power per hour amounted to 5.5 kilograms (12.1 pounds) with superheated, and to 6.1 (13.4 pounds) with saturated steam. The boiler supplied steam at the rate of 14 to 24 kilograms per square meter per hour. The net gain was thus, practically, ten per cent. of the quantity of saturated steam required by the engine in normal working.

The steam consumption per delivered, or brake, horse-power was 7.25 kilograms (16 pounds) with saturated, and 6.6 kilograms (14.5 pounds) with superheated steam. It is presumed that, could a full load be obtained for this engine, and full boiler pressure thus utilized, with best adjustment of the ratio of expansion, these figures might be improved eight or ten per cent.* The engine was much underloaded and the steam pressure was

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* *Z. des Ver. Deutscher Ingenieure*, March 7, 1896.

steam, and Mr. Louis Seymour has adopted the plan of boring cylinders under steam pressure to secure a better and more symmetrical distribution of stresses and final shape.

Professor Ewing remarks, in his admirable treatise on the steam engine in the *Encyclopædia Britannica*: "In former years superheating steam was a common feature of marine practice; but serious practical difficulties caused engineers to abandon its use and to seek economy rather by increasing initial pressure, and by using compound expansion. In those days, however, the theoretical advantage of superheating was less understood than now. The economy of fuel which its employment would probably secure is so great as to warrant a fresh and energetic attempt to overcome the mechanical difficulties of construction and lubrication which have hitherto stood in the way." *

Mr. Donkin states: "It is probably only a question of another ten or fifteen years before engineers generally will again be using slightly superheated or dry steam not only in land engines, but at sea and with locomotives. Modern ideas favor the change, and the economy which will be obtained by preventing the large amount of condensation now going on in steam cylinders.

"In Germany, France, and other countries, experiments are being made with superheated steam, with various kinds of engines and different apparatus. The writer has lately seen many different types of superheaters at work. These are sometimes placed in boiler flues, but in other factories they are fired separately. A number of engines of considerable power are now regularly working with steam superheated from 50 degrees Fahr. to 100 degrees Fahr. above the temperature due to the working pressure.

"In the writer's opinion, the time has arrived to re-open this question of superheating. With modern conditions of lubrication and better materials, further experiments should be under-

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* "Superheating has been adopted during recent years much more extensively on the Continent than in England, and very successful results have been achieved. The consumption of steam in an ordinary unjacketed compound engine of high class may generally be reduced by about 15 per cent. upon the adoption of superheating, and the coal consumption a little more or less, according to the conditions and to the type of superheater adopted. A saving twice as great is sometimes secured in the treatment of an engine which, from its small size or other reasons, consumes an exceptionally large amount of steam for the work done."—*Sutcliffe.*

taken. At present we are not even following in this matter, when we should be taking the lead." *

Mr. Shocks concludes: "Superheaters, with their steam-pipe connections and stop valves, add largely to the weight and cost of boilers; and unless they are easily accessible for sweeping (which is frequently not the case), the efficiency of their heating surface is soon impaired, and the draught of the boiler is often seriously affected by the accumulation of soot. The most serious troubles, however (which have brought superheaters somewhat into disrepute), are due to the rapid corrosion of the iron of which superheaters are constructed, and to the leakage of their tubes. The rapid corrosion of superheating surfaces has been observed for a long time, even in the case where the degree of superheating was relatively small, as in steam drums traversed by flues, but its causes have not been definitely determined.

"Practically considered, the value of superheaters depends, as far as the boilers are concerned, not only on the economic and potential evaporative efficiency of the latter, but on the additional bulk, weight, and cost of the superheating apparatus, on the labor and expense of keeping it in working order, and on its liability to derangement." †

"I have no doubt myself that superheating will be largely used again. The practical difficulties exist, but they are not insuperable.

"No possible improvement of the steam-engine, of which we have any knowledge at this moment, offers anything like so great a chance of important economy as the reintroduction of superheating, and especially of superheating to at least 100 degrees or more above the saturation temperature of the steam.

"Lately Professor Schröter, of Munich, has been experimenting with a small special compound condensing engine of only 60 indicated horse-power, running at the moderate piston speed of 380 feet per minute, and with the not excessive boiler pressure of 165 pounds per square inch. The high-pressure cylinder is not jacketed. The low pressure is jacketed with receiver steam. In this case, in a tube superheater of a rather special construction in the uptake of the boiler, the steam is superheated to 670 degrees Fahr., or nearly 300 degrees above the saturation

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* Donkin on Superheating.

† *Steam Boilers*, Shock.

temperature corresponding to the pressure. In two trials of six or eight hours' duration, periods quite long enough for accurate determination of results with so accomplished an observer as Professor Schröter, the consumption of steam was only 10.2 pounds per indicated horse-power hour, and the consumption of German coal of moderate quality only 1¼ pounds per indicated horse-power hour. The steam consumption is the lowest on record for any engine of any type or size, and it is very remarkable for so small an engine.

"It is often argued that, as very little heat is required to superheat steam, it cannot produce much effect. The answer is that a small amount of heat rightly applied in preventing initial condensation produces a disproportionately large effect. That is consistent with the strictest principles of thermodynamics. In the Schmidt engine only eight per cent. of the heat was used in superheating the steam, and to this eight per cent. the remarkable economy is due. In a steam jacket acting well, about twelve per cent. of the steam used is condensed, and to this twelve per cent. the advantage of the jacket, which often reduces the amount of steam used in the cylinder by twenty or thirty per cent., is due. But the heat from a jacket is much less efficiently applied than the heat taken direct to the interior of the cylinder by superheated steam and used primarily in maintaining the temperature of the admission surface. Further, the quantity of superheat brought into the cylinder in a given time increases with the speed of the engine, while jacket heat diminishes in effect as the speed is greater. The action of the superheated steam is shown clearly enough on the indicator diagrams. In my own trials in Alsace the wetness of the steam at cut-off in the high-pressure cylinder with jacket, but without superheating, was thirty-five per cent. ; with steam superheated 100 degrees it was only fifteen per cent. In the trial with the Schmidt engine there was no moisture at cut-off in the high-pressure cylinder, and the steam remained dry nearly to the end of the stroke." *

SUMMARY.—Opinion seems substantially unanimous, and all testimony confirms the conclusion that superheat may effect large net economies. Collating the results of about fifty authen-

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* Unwin on Experimental Study, *Transactions* B. I. C. E., session 1894–95, page 25.

An ordinary non-condensing steam engine would probably require for the same work 16.38 kilograms of steam and 2.10 kilograms of coal per horse-power hour effective, so that the saving by high superheating is 351.76 kilograms of water and 41.47 kilograms of coal on the power developed, or about 52 per cent.*

General Opinion, based on experiments on the expansion of steam and on superheating, may be discovered in the following summary. According to Isherwood,

"1. The cost of the total indicated horse-power does not appear to be affected by speed of piston, *per se*, other things being equal.

"2. The cost of the total indicated horse-power appears to be less with larger than with smaller cylinders, other things equal, but not in any important degree after cylinders of medium size are reached.

"3. The cost of the total indicated horse-power appears to be less by the use of a greater average pressure upon the piston, other things being equal.

"4. The cost of the total indicated horse-power does not appear to be affected by type of valve gear, other things equal.

"5. The cost of the total indicated horse-power appears to be less with higher back pressure against the piston, other things equal.

"6. An analysis of a vast number of indicator diagrams from well-conditioned steam engines of many types and proportions, using steam with widely varying measures of expansion, and fitted with great diversity of valve gear, shows the mean total pressure to be almost exactly that which is due to the Mariotte law, namely, the presſures are inversely as the spaces, including in the latter the contents of the clearance and steam passage. And this agreement is not affected by the steam being in the saturated or in the superheated condition and with any degree of superheating. In the case of saturated steam the expansion curve falls at first a little too rapidly, and at the last not quite rapidly enough, while the reverse is the case with superheated steam. This, of course, is purely a coincidence, but it is a useful fact to know, and can be confidently depended on in computation.

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* *The Engineer*, January 31, 1896.

or one dollar, expended in reduction of this internal waste, returns three; and a profit of three hundred per cent. pays, in turn, the excess of cost of maintenance of superheating apparatus and incidental costs and repairs at engine and at boiler.

Where the gain by use of superheating is less, the proportion of profit to expenditure is, as a rule, greater, since the effect of the first few degrees of elevation of temperature and of superheat is by far the most effective introduction of initial condensation; precisely as the first instant of that condensation is vastly more effective in production of waste than the later period.

CONCLUSIONS OF PRACTICAL IMPORTANCE, relative to the theoretical and actual value and promise of superheating, may be, in the opinion of the writer, definitely stated as deductions from the preceding compilation of facts and experimental data, from the opinions expressed by unquestionable authorities, regarding the physics and the engineering side, and from the scientific discussion of the thermodynamics of the ideal case and of the action of the fluid in the heat engine. The conclusions of the writer are the following:

1. Superheated steam, as hitherto employed in the steam engine, has absolutely no thermodynamic value. It neither raises the upper limit of temperature nor depresses the lower; it gives no increased range of temperature of the cycle; the value of the maximum measure of ideal efficiency, $(T_1 - T_2)/T_1$, is in no manner altered by its introduction into the system.

On the other hand, it is evident, from a study of the physics and thermodynamics of the case, that, could any way be found of practically working superheated steam, safely and with economy in its production, it would permit a thermodynamic gain only limited by the extent to which the range $T_1 - T_2$ could be thus expanded. It would further permit the combination of maximum pressures with maximum temperatures, and the adjustment of the one to the other, in such manner as to enable the engineer to secure the best possible combination of thermal and dynamic efficiencies, and the highest possible net total efficiency of fluid and of machine consistent with the employment of such materials in construction as the arts of the time may provide.

2. Superheating has for its sole purpose and result, in the steam engine to-day, the extinction or reduction of the internal

thermal wastes of the engine, consequent upon the phenomenon known as initial or "cylinder condensation." Here it is extraordinarily effective, and a small quantity of heat expended in superheating the entering steam effects a comparatively large reduction in the expenditure of steam in the engine, each thermal unit thus employed saving several thermal units otherwise wasted. The process is one, mainly, at least, of prevention rather than of cure of that fault. and prevention is, as usual, here found to be vastly more effective than attempted cure.

3. Superheating is superior to any other known means of reduction of internal waste. Jacketing ordinarily suppresses but a fraction of that waste, and the multiple-cylinder engine has also its limitations; while superheating may not only extinguish it but may also check wastes due the resistance to flow of the denser, wet steam through steam and exhaust ports, and may sensibly improve the vacuum attainable in the condenser, with corresponding reduction of back pressure, of the quantity of condensing water demanded, and of the load on the air pump.

Superheating even a few degrees improves considerably the performance of the engine, and, in the average case, superheating one hundred degrees Fahrenheit will entirely extinguish that waste.

4. The hitherto unconquered obstructions to the use of superheated steam in the engine have been those resulting from destruction of packing and decomposition of lubricants, with consequent friction and "cutting" of the rubbing surfaces. The introduction of metallic packings and of high-test lubricants has now enormously reduced the difficulties of application of superheating. No trouble need now be found at the engine with sufficient superheating, under usual conditions of operation, to annihilate cylinder condensation. It seems not at all improbable that even this limit may be, ere long, safely, and perhaps even largely, overpassed, with resulting improvement of thermodynamic efficiency.

5. The obstruction at the boiler has been, and still remains, difficulty of construction of a superheater, or of a superheating system, which will be at once effective, safe, and durable.

The comparatively low temperatures at which modern boilers discharge their gases into the uptake, while reducing these difficulties largely, introduces the complementary one of increased

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the difference is very great, and many superheaters have been removed after a few months', or even, in some cases, a few weeks' service. It is thought by many engineers, however, that it is not impossible to so construct and work them that they may last for many years. The writer has examined many certificates of satisfactory operation of superheaters for considerable periods of time, with no apparent injury or perceivable wear. The Yorkshire Boiler Insurance Company of Great Britain has issued many such on superheaters employed by its customers." —*Reports of the Yorkshire Boiler Insurance and Steam Users' Co., Ltd.*, 1893, 1894.

ous increase of temperature, could be readily and fully attained. But, as asserted by Hirn and by Tresca, at an earlier date, he finds it "a long way from the theory to the practice in this matter." Hirn had concluded that the limit in superheating is practically attained when cylinder condensation is substantially, but not absolutely, suppressed by it. At this point, as he states, large gains may be secured, without injury by destruction of lubricants, of packing, or of the engine cylinder, both in reducing costs of fuel and costs of construction, suppressing the steam jacket as a needless encumbrance. The later introduction of high-test mineral oils and of metallic packing has removed many of the objections formerly existing to the employment of superheating, and the subject is again attracting attention among engineers, and M. Hirsch anticipates its successful reintroduction.

M. A. Mallet concludes, after a careful study of the results of experiment and general experience in marine engineering, that, during a period of a decade or more, superheating was applied at sea to several hundred thousands of horse-power of marine engines, and was, in fact, in common if not general use for that period of time, and then went almost completely out of use, in consequence of rapid deterioration of the apparatus and liability to serious accidents when carelessly or ignorantly handled, and when worn out and neglected.* These difficulties became too serious for successful use of the system as soon as, about 1860, steam pressures began to rise rapidly and to become such as to demand considerable strength of boiler and of superheater. With improved constructions, and especially with the introduction of lubricants capable of sustaining uninjured the temperatures of high-pressure steam and superheating, a new period of experimentation has been entered upon, and success of moderate amount has been attained, and especially in reheating between the cylinders of the multiple-cylinder engine. At the date of this report, Raffard was still working on the problem and endeavoring to secure satisfactory methods of employment of the system which, in 1827, Becker found himself unable to employ because of the rudeness of the methods of mechanical construction of his time.

In some cases, it is supposed that distortion of the steam cylinder has been a consequence of the use of superheated

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* *Bulletin de la Société des Ingénieurs Civils*, May, 1892.

DCXC.*

EXPERIMENTS WITH AUTOMATIC MECHANICAL STOKERS.

BY J. M. WHITHAM, PHILADELPHIA, PA.

(Member of the Society.)

Stokers in General.—The recognized *advantages* of mechanical stoking are:

1. Adaptability to the burning of the cheapest grades of fuel.
2. A 40 per cent. labor saving in plants of 500 or more horse-power when provided with coal-handling machinery.
3. Economy in combustion, even under forced firing, with proper management.
4. Constancy and uniformity of furnace conditions, the fires being clean at all times, and responding to sudden demands made for power. This should result in prolonged life of boilers.
5. Smokelessness.

The *disadvantages* are:

1. High first cost, varying from $25 to $40 per square foot of grate area.
2. High cost of repairs per annum, which, with some stokers, is as much as $5 per square foot.
3. The dependence of the power plant upon the stoker engine's workings.
4. Steam cost of running the stoker engine, which is from $\frac{1}{5}$ to $\frac{2}{5}$ of 1 per cent. of the steam generated. This is about $50 a year on a 10-hour basis for 1,000 horse-power when fuel is $2 a ton.
5. Cost of steam used for a steam blast, or for driving a fan blast, whenever either is used. This, for a steam blast, is from 5 to 11 per cent. of the steam generated by the boilers, and from 3 to 5 per cent. for a fan blast. This amounts to about

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* Presented at the St. Louis meeting (May, 1896) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

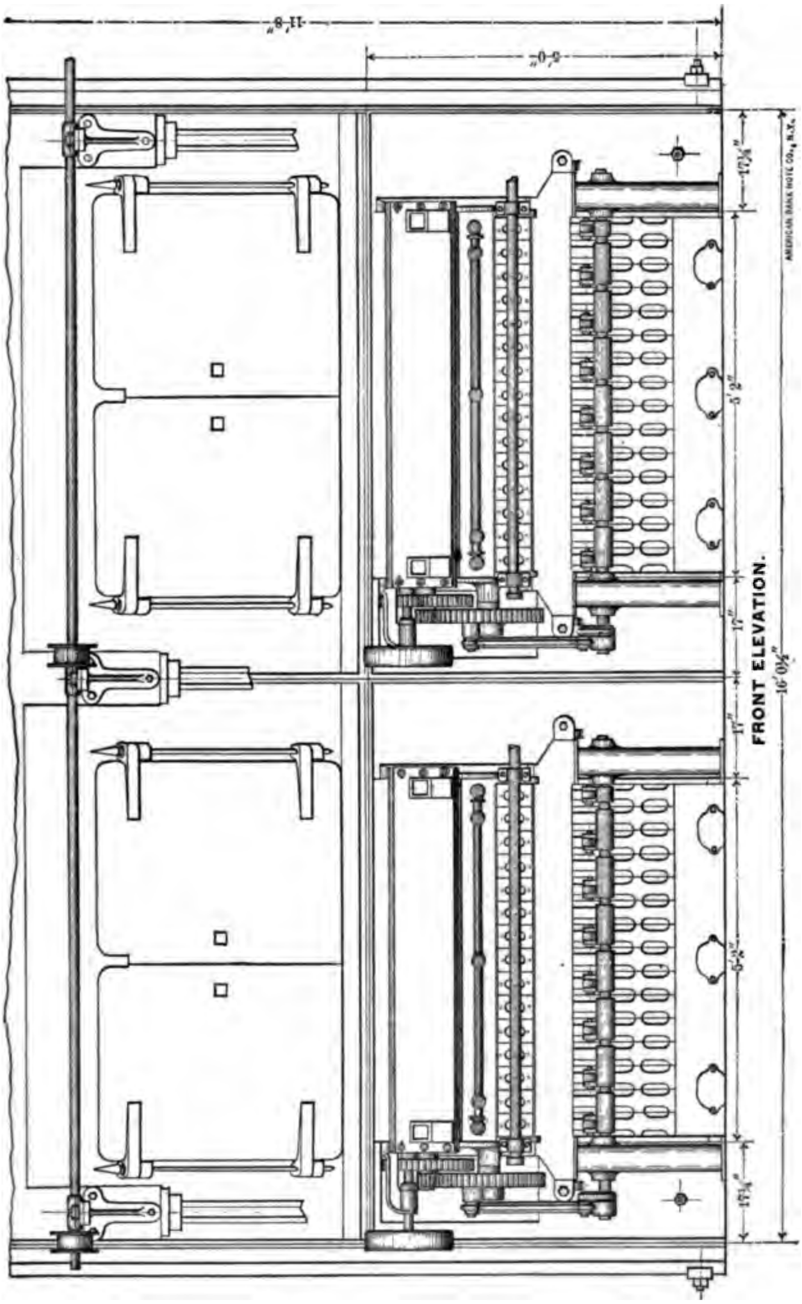


FIG. 119.—WILKINSON MECHANICAL STOKER.

$1,000 a year for a steam blast, and $500 a year in fuel for a fan blast, for a 1,000 horse-power plant on a 10-hour basis, when fuel is $2 a ton.

6. Skill required in operating the stoker. Careless management causes either loss of fuel in the ash, or loss due to poor combustion when the coal is too soon burned out on the grate, thus permitting cold air to freely pass through the ash.

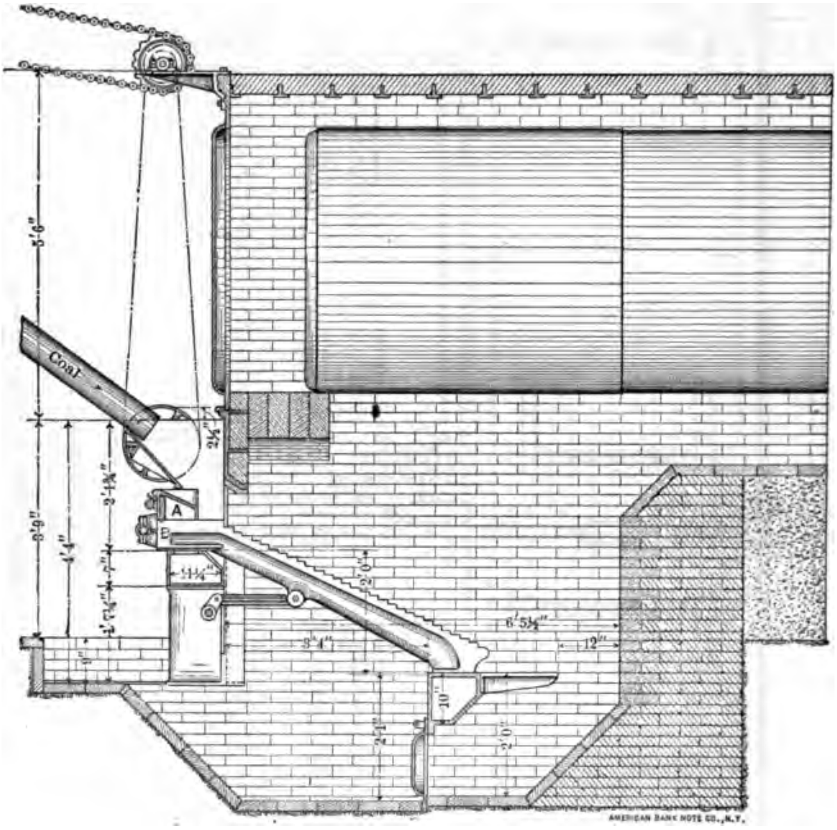


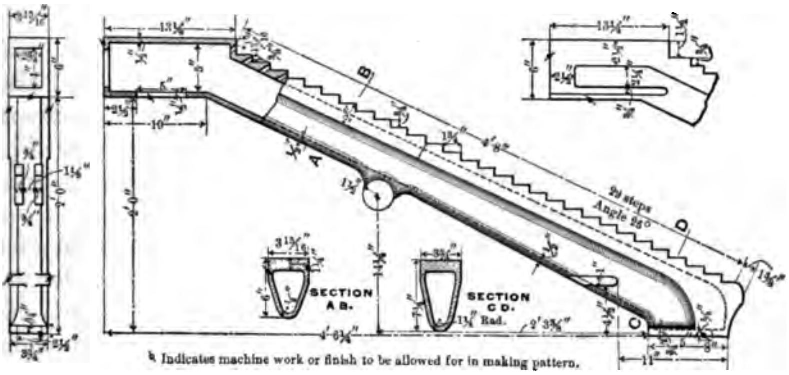
FIG. 120.—WILKINSON STOKER FOR A RETURN TUBULAR BOILER.

7. The stoker is a machine subject to a severe service, and, like any other machine, wears out and requires constant attention.

This paper is intended to show the performances of the Wilkinson stoker, and the use of steam in combustion; the operation of the Coxe stoker using a graduated fan blast, and of the Babcock & Wilcox stoker under a strong natural draught. The Coxe is designed for use with buckwheat and rice grades of anthracite coal, the Wilkinson stoker is adapted to both anthracite and bituminous coal, while the Babcock & Wilcox stoker is used only with bituminous coal.

THE WILKINSON STOKER.

General Description.—This stoker is shown in front elevation in Fig. 119, in longitudinal section in Fig. 120, while Fig. 121 is a cut of its grate bar. The stoker consists of hollow bars, set at an angle of about 25 degrees with the horizontal, with open ends. The top of the bars is stepped, and tuyere-shaped openings, about $\frac{1}{4} \times 3$ inches, are provided in each riser.



f Indicates machine work or finish to be allowed for in making pattern.

FIG. 121.—BAR OF THE WILKINSON STOKER.

The bars are carried, at their ends, on hollow boxes. The lower box, or bearing bar, has finger grates, about 15 inches long, secured to its rear face. The bars are 4 inch centres, so that, practically, the air openings are restricted to the risers, already noted. Adjacent bars move in opposite directions by a system of toggles controlled by a compound spur gearing, which is driven by the stoker engine.

The feeding is accomplished by the motion of the grates, no feed roll or pusher being required. The wedge-shaped gate, shown at *A* in Fig. 120, is removable, thus affording access to the grate when desired. A small observation door is provided near or one dollar, expended in reduction of this internal waste, returns three; and a profit of three hundred per cent. pays, in turn, the excess of cost of maintenance of superheating apparatus and incidental costs and repairs at engine and at boiler.

Where the gain by use of superheating is less, the proportion of profit to expenditure is, as a rule, greater, since the effect of the first few degrees of elevation of temperature and of superheat is by far the most effective introduction of initial condensation; precisely as the first instant of that condensation is vastly more effective in production of waste than the later period.

CONCLUSIONS OF PRACTICAL IMPORTANCE, relative to the theoretical and actual value and promise of superheating, may be, in the opinion of the writer, definitely stated as deductions from the preceding compilation of facts and experimental data, from the opinions expressed by unquestionable authorities, regarding the physics and the engineering side, and from the scientific discussion of the thermodynamics of the ideal case and of the action of the fluid in the heat engine. The conclusions of the writer are the following:

1. Superheated steam, as hitherto employed in the steam engine, has absolutely no thermodynamic value. It neither raises the upper limit of temperature nor depresses the lower; it gives no increased range of temperature of the cycle; the value of the maximum measure of ideal efficiency, $(T_1 - T_2)/T_1$, is in no manner altered by its introduction into the system.

On the other hand, it is evident, from a study of the physics and thermodynamics of the case, that, could any way be found of practically working superheated steam, safely and with economy in its production, it would permit a thermodynamic gain only limited by the extent to which the range $T_1 - T_2$ could be thus expanded. It would further permit the combination of maximum pressures with maximum temperatures, and the adjustment of the one to the other, in such manner as to enable the engineer to secure the best possible combination of thermal and dynamic efficiencies, and the highest possible net total efficiency of fluid and of machine consistent with the employment of such materials in construction as the arts of the time may provide.

2. Superheating has for its sole purpose and result, in the steam engine to-day, the extinction or reduction of the internal

Line 56.	Evaporative horse-power developed by boilers		691
	Boiler horse-power used by stoker engine	1.42	
	Boiler horse-power used by stoker jets	73.21	—74.63
Line 56, corrected.	Available boiler horse-power		616.37
	Per cent. of power developed used to operate stoker engine		0.21
	Per cent. of power developed used to operate stoker jets		10.59
	Per cent. of power developed used to operate the stoker		10.80
Line 49, corrected.	Evaporation, 212° F., per pound of dry coal		8.21 lbs.
" 50, "	Evaporation, 212° F., per pound of combustible		9.34 "
" 59, "	Dry coal burned per hour per available boiler horse-power developed		4.21 "

In trial 254 air was supplied by a fan driven by a small slide-valve engine. The air was led to the hollow posts carrying the front bearing bar or box, from whence it entered the hollow grate bars and passed into the fire. The open ends of the grate bars were closed, the steam jets being removed. Clinker formation was prevented by turning the fan engine's exhaust into the air conduit, and also by bleeding so much live steam into the bars as was necessary to protect them. Burning Lykens Valley rice coal, we found:

Line 56.	Boiler horse-power developed		410.5
	Boiler horse-power used by fan engine	13.15	
	Boiler horse-power as live steam bled into grates to prevent injury to them	23.1	
	Boiler horse-power used to drive stoker engine	1.03	—37.28
Line 56, corrected.	Available boiler horse-power remaining		373.22
	Per cent. of power developed used to operate fan engine		3.21
	Per cent. of power developed used for protecting the grate bars		5.62
	Per cent. of power developed used to drive stoker engine		0.25
	Per cent. of power developed used to drive fan, stoker, etc.		9.08
	Engine horse-power developed by the fan engine		5.92
	Steam consumption of fan engine, in pounds of water, 212° F., per engine horse-power developed		76.6 lbs.
Line 49, corrected.	Evaporation, 212° F., per pound of dry coal		9.09 "
" 50, "	Evaporation, 212° F., per pound of combustible		10.88 "

Comparing these two tests, we see that about the same percentage of the steam generated was required when running with the fan as when using the steam blast, while this stoker can be pushed harder with the steam blast.

necessary area of superheating surface, and consequent volume, weight, and cost of the superheaters. The real difficulty is to-day found at this point, and the production of a superheater which will safely withstand the effects of high temperature of flue gases, will effectively transfer heat from gas to steam, and will have a satisfactorily long life, still challenges the engineer as one of his most serious, yet attractive and important problems. The gain in economy of fuel exceeds the gain in steam consumption. It is the gain at the furnace and in cost of fuel, not that at the engine in steam consumption, which measures its importance.

6. The more wasteful the engine, the larger the promise of gain by superheating, and small engines will profit by it more than large, slow engines more than fast, and simple engines more than the multiple-cylinder systems, which latter require such auxiliaries less as their cascade action is the greater and its steps more numerous.

7. The larger the waste to be checked in the engine, the further should the superheating be carried. That degree which would serve every purpose in the simple, slow, small mill engine would be entirely too high for safe use, and quite inexpedient in the high-speed compound of large size, while that which would be ample for the latter would be entirely insufficient for the former.

8. The extent of superheating should be adjustable—not only to the particular size and type of engine in view, but also in the same engine—to the extent to which expansion is carried.

That degree found best for a low ratio of expansion would prove entirely unequal to the required task in case of small load and short cut-off, although the total heat taken up from the superheater would be in any one engine fairly constant.

A perfectly satisfactory system of superheating should be adjustable in this respect with the load on the engine, and still free from danger of burning out at light loads, while giving suitable action at heavy loads. In the one case it must supply a small amount of highly superheated steam ,to the engine, in the other a larger quantity with less superheat.

This presents the engineer with a problem not yet really attacked.

9. The average simple engine may be said, under such conditions as we are most familiar with, to demand a quantity of fuel

annually about equal in value to its own first cost. In such cases it is obvious that under these conditions, and with the above return of five dollars in saving to each dollar paid to thus reduce waste, it will pay to annually expend the full equivalent of the interest on the price of the engine in maintaining a good superheating system. When, however, as has usually hitherto happened, this account includes such large interest and wear-and-tear accounts as cause the total annual expense to exceed this financial limit, the engineer will wisely decline to thus invest capital.

The Finance of the Case may be summaried as follows:

Studying the results of experiments to date determining the magnitude of the internal wastes which superheating is expected to reduce, we shall find that the following may be taken as, roughly, the measure of those wastes, the relative quantities of heat gained by complete extinction and expended in the work, and the extent of the necessary superheat:

Gain by Superheating.

Engine.	Steam pressure, pounds per square inch.	Percentage steam condensed, without superheating.	Relative heat lost by condensation and expended by superheating.	Degrees Fahr. superheat.
Simple	50 to 100	50 to 30	5 to 1	100
Compound	75 to 125	30 to 20	3 to 1	75
Triple	125 to 180	20 to 10	2 to 1	50

The gain secured actually ranges from ten to fifty per cent., averaging about twenty-five per cent.

10. Given a safe and durable and efficient superheater, and the engineer will have the power to adjust his temperatures and pressures of working fluid to any limit that may be set by the character of his materials in boiler and engine, and to secure the best adjustment of the thermal to the dynamic limit.

In other words, he may produce a working fluid having at once the high temperature and wide range of adiabatic expansion requisite for maximum thermodynamic efficiency, and the high initial and mean effective pressures needed to insure maximum dynamic efficiency or efficiency of the mechanism of the engine; the two combined thus giving the maximum total efficiency obtainable by any means whatever. The high thermodynamic efficiency of the gas engine and the peculiarly high "efficiency of machine" characteristic of the steam engine would be both secured, and the steam engine once more placed beyond rivalry among all the heat engines.

11. This is, to-day, the greatest of all the problems presented the designing and constructing engineer, with the possible exception of that of finding a system of effectually rendering the interior of the working cylinder non-conducting, in such manner as to entirely prevent the occurrence of initial condensation, thus conforming the "ideal case" to the real, and making the steam engine a purely thermodynamic machine.*

DISCUSSION.

Mr. George I. Rockwood.—I agree with the author that superheating is a very important subject for discussion, as it presents the only unexplored field of experiment and investigation left in connection with the steam engine.

I feel quite confident that a successful direct superheating apparatus never will be obtained. By direct, I mean an apparatus which brings high-pressure steam into contact with one side of metal highly heated by waste gases on its other side. It will always be dangerous to use such an apparatus, and moreover, it is not necessarily economy to use this class of heater. The waste gases may be less dangerously employed in heating either the air for combustion or the feed water. It is quite possible to superheat the steam in the usual way of heating the feed water; that is, by carrying steam of a higher temperature and pressure inside the tubes of a tubular heater and causing the live steam to pass around these tubes on its way to the engine. By placing such a heater above the boiler, gravity will return the drips without the aid of traps This method of superheating has been extensively applied in compound engines to the steam exhausted from the high-pressure cylinder on its way to the low-pressure cylinder. I have obtained a superheat of forty degrees above the temperature normal to the pressure in the receiver with one-half of a square foot of brass tubing to

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* "The Final Improvement of the Steam Engine;" R. H. Thurston; *Transactions United States Naval Institute*, 1891; *Sibley Journal of Engineering*, 1892.

horse-power, and I understand Mr. E. D. Leavitt has tained a superheat of one hundred degrees by using, if I ollect rightly, nearly two square feet of surface to the horse-wer.

Prof. R. H. Thurston.—I think Mr. Rockwood entirely right. is particular method is referred to in the text under the head eheating."

TABLE OF DATA OF TESTS.

Name of steam blower	McCLAVE. 18 $\frac{1}{32}$-in. Jet Holes, 1.2-in. Centres.							
Steam pressure at jets, lbs	15	30	45	60	75	90	105	115
Ash-pit pressure, in. of water	0	+ 08	+ .10	+ .25	+ .33	+ .40	+ .42	+ .45
Vacuum in furnace, in. of water	.06	.06	.08	.08	.08	.10	.08	.05
Total furnace draught, in. of water	.06	.14	.18	.33	.41	.50	.50	.50
Temperature of air fed to fires, deg. Fahr	56	56	56	56	56	56	56	56
Cu. ft. air injected per hour	187,700	128,100	157,200	178,560	202,020	228,000	264,120	276,968
Boiler H. P. used to operate blower	....	9.42	10.66	11.00	12.38	15.32	....	....
Cu. ft. of air injected per hour per boiler H. P. expended to operate blower jets	....	13,600	14,747	16,233	16,318	14,882	....	....

TABLE OF DATA OF TESTS.—*Continued.*

Name of steam blower	YOUNG. 20 $\frac{1}{32}$-in. Holes, 1$\frac{1}{8}$-in Centres.						EYNON-KORTING. No. 5 Size, $\frac{1}{8}$-in. Orifice.							
Steam pressure at jets, lbs	9.3	17.8	40	59.4	67.1	70.3	5	10	15	20	30	47½	60	75
Ash-pit pressure, in. of water	− .10	0	+ .08	+ .15	+ .20	+ .25	− .06	+ .01	+ .04	+ .09	+ .18	+ .45	+ .48	+ .76
Vacuum in furnace, in. of water	.35	.35	.33	.30	.30	.30	.23	.18	.19	.14	.14	.05	.06	.06
Total furnace draught, in. of water	.25	.35	.41	.45	.50	.55	.17	.19	.23	.23	.32	.50	.54	.82
Temperature of air fed to fires, deg. Fahr	56	56	56	56	56	56	60	60	60	60	60	60	60	60
Cu. ft. air injected per hour	104,400	123,000	163,320	187,560	202,080	206,880	58,420	78,347	98,476	111,476	138,780	185,875	214,953	239,550
Boiler H. P. used to operate blower	6.31	9.44	12.91	16.87	20.06	....	3.50	4.78	5.45	6.40	8.10	10.90	13.30	15.90
Cu. ft. of air injected per hour per boiler H. P. expended to operate blower jets	16,545	13,029	12,651	11,119	10,074	....	16,691	16,390	18,069	17,418	17,133	17,053	16,162	15,060

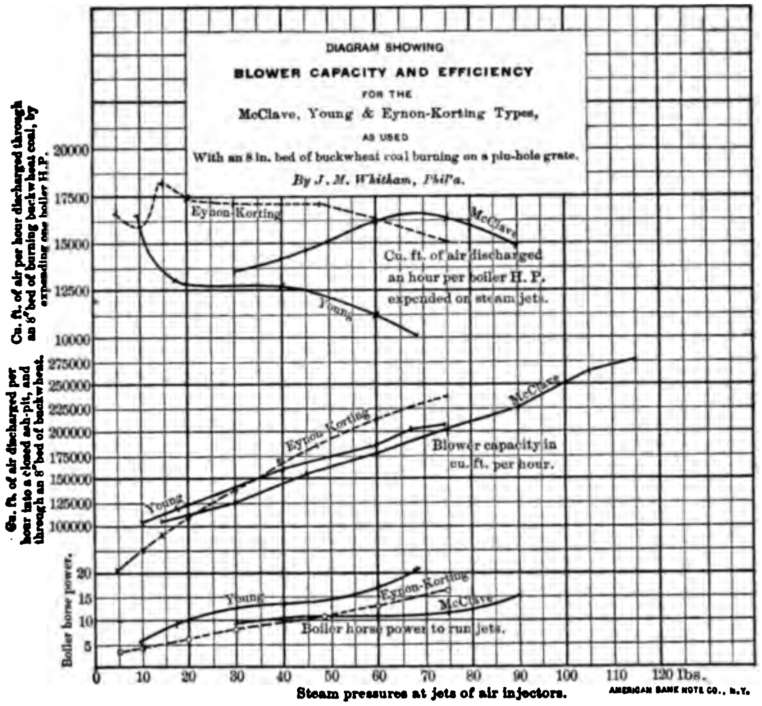


FIG. 128.

SUMMARY OF STEAM USED TO OPERATE THE McCLAVE AND YOUNG STEAM BLOWERS.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Boiler test number.	Kind of coal (all from one mine).	Kind of boiler test.	Rated H. P. of boilers.	H. P. developed by boilers.	Name of blower used.	No. of blowers used.	Boiler H. P. required to operate the blowers.	Per cent. of boiler H.P. required to operate blower jets.	Pounds of dry coal burned an hr. per sq. ft. of grate.	Per cent. of ash and refuse in dry coal.	Per cent. of air openings in grate bars.	Gauge steam pressure at the blower jets.	DRAUGHT IN IN. OF WATER. Pressure in ash-pit.	Vacuum in furnace.	Vacuum in stack flue.	Total draught.
301	Rice.	Capacity	250	378.2	Young.	2	42.0	11.1	25.8	28.4	11	70.3	0.59	0	0.30	0.89
302	"	Economy	250	270.0	"	2	18.9	7.0	17.9	26.4	11	17.8	0.24	0.10	0.30	0.54
303	B'kw't.	Capacity	250	374.2	"	2	40.1	10.8	27.3	29.1	11	67.1	0.61	0.08	0.33	0.94
304	"	Economy	250	272.2	"	2	12.6	4.6	16.7	28.7	11	9.3	0.16	0.18	0.31	0.49
305	"	Capacity	250	380.1	"	2	33.7	8.9	31.4	29.5	26	59.4	0.67	0.04	0.33	1.00
306	"	Economy	150	150.9	McClave.	1	10.2	6.7	16.4	25.6	11	37.4	0.32	0.11	0.22	0.54
307	"	Capacity	150	209.4	"	1	19.4	9.3	26.1	27.1	11	103.4	0.73	0.08	0.23	0.96

Combining the main features of this table with similar results obtained for the Wilkinson steam jets, we have the following table :

CONSUMPTION OF STEAM BLASTS COMPARED.

Boiler test number.	Coal.	Name of blower.	Per cent. of air openings in grate.	Pounds of dry coal burned an hour per sq. ft. of grate.	Per cent. of total steam generated in the boilers that is required to operate the steam blasts.
301	Rice.	Young.	11	25.8	11.1
302	"	"	11	17.9	7.0
253	"	Wilkinson.	7	27.0	10.8
303	Buckwheat.	Young.	11	27.8	10.8
304	"	"	11	16.7	4.6
305	"	"	26	31.4	8.9
306	"	McClave.	11	16.4	6.7
307	"	"	11	26.1	9.3
290	"	Wilkinson.	7	32.5	7.8
291	"	"	7	45.4	10.2

This table shows that the Wilkinson stoker requires for operating its steam blast about the same quantity of steam as the other blowers. It should, however, be noted, in justice to the other blowers (as is seen by comparing tests 303 and 305 in this table), that the 10.8 per cent. steam consumption, with 11 per cent. air openings in grate, dropped to 8.9 per cent. when the grate bars were changed so that the air area was 26 per cent. This indicates that the steam consumption decreases as the percentage of air openings in the grate increases.

Summary Regarding the Wilkinson Stoker.—1. Small grades of anthracite coal pack closely upon the grate, and offer much resistance to the introduction of the air supply. They require a strong blast.

2. With the same draught, natural or otherwise, the rates of combustion and costs of small grades of anthracite coal are about as follows :

RELATIVE RATES OF COMBUSTION AND COSTS OF SMALL SIZES OF ANTHRACITE COALS.

Grade.	Size of coal (round holes, punched plates).	Relative rates of combustion for same draught.	RELATIVE COSTS.	
			At mine.	On cars, Philadelphia.
Pea	Through $\frac{7}{8}$ inch and over $\frac{9}{16}$ inch	100	100	100
Buckwheat..	" $\frac{9}{16}$ " " $\frac{3}{8}$ "	85	57	72
Rice........	" $\frac{3}{8}$ " " $\frac{3}{16}$ "	70	37	61

3. A steam blast, in general, will use from 5 to 11 per cent. of the steam generated in the boiler. The Wilkinson stoker blast is no exception.

4. The efficiency of the Wilkinson steam blast is less than that of the other forms of steam blowers noticed in this paper; yet, for a given combustion rate, no more steam is used, because this stoker has a more perfect diffusion of the air through the fire than is possible with flat grates, and can secure a good evaporation with less air for dilution than can any other system of burning coal known to the writer.

5. Most anthracite coals of inferior sizes clinker badly if the fire is forced. Such clinkers freeze to the sides of the furnace and to the grates. This is specially true for fan blasts. But the effect of a steam blast is to chill the grates and non-combustible material against them, so that a clinker cannot form. The result is a prolonged life of bars and furnace linings.

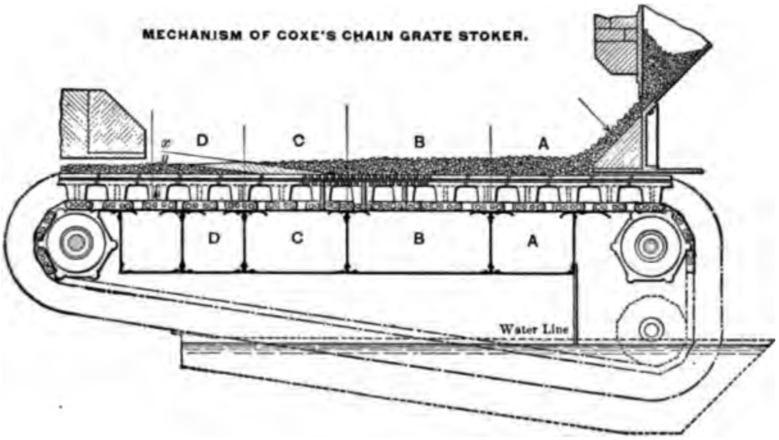


Fig. 124.

6. In plants subject to extreme fluctuations in power demands, the bars of this stoker are subject to a severe service. When an intensely active combustion has been required for a time and the demand ceases, the steam jets are shut off and the fire is, as it were, banked until the demand is resumed. In this case no air or steam, practically speaking, is given to protect the bars, and the white-hot coal against them may cause damage.

each end of the hopper, through which a slice bar may be passed to cut away any side-wall deposit.

Steam jets at the open upper end of each bar force into the fire the air needed for combustion. There is one jet to each bar, having an opening of about $\frac{3}{32}$ inch (see *B*, Fig. 120).

This stoker is specially well adapted to the burning of small sizes of anthracite coal, and is also used with bituminous coal.

Stoker Trials.—Thirteen trials of this stoker, with various anthracite coals and various boilers, have their results summarized in Sheet No. 1 The trials were conducted in accordance with the methods advised by this Society.

Trials 252, 253, 254, and 239 were made with rice coal, while the remaining ones were with buckwheat.

The *commercial results* are given in line 59, while lines 55 and 55½ show the manner in which the boilers were forced. The results are all good, and indicate that this stoker is nearly as economical when working with forced as with gentle fires. The range of the rate of combustion varied from 14.8 to 45 4 pounds of dry coal an hour per square foot of grate.

Effects of Steam on Combustion.—Steam in passing through a bed of burning coal must extinguish the fire or become decomposed. The steam, in practice, acts upon the coal as in a gas producer, and the combustion chamber is filled with burning gases. With natural draught and anthracite coal the flame is seldom longer than from 8 inches to 36 inches, yet a steam blast will make a flame 40 feet long if permitted to do so. The effect of the steam, then, is to gasify the coal. This results in a more uniform distribution of the effective heating surface of the boiler, reduces local injury, gives a more uniform expansion to the parts of the boiler, but is apt, if not properly controlled, to cause a loss of heat in the stack.

Steam prevents the formation of clinkers, thus prolonging the life of the bars and furnace linings.

Steam Used by the Wilkinson Stokers.—While conducting trials 253, 254, 290 and 291, separate trials were made on an auxiliary boiler supplying the steam jets and the stoker engine. The exhaust from the stoker engine was condensed, so that the amount strictly chargeable to the jets would be known.

Thus in trial 253 we have, when burning Lykens Valley rice coal:

Ash Analyses:	Boiler Test 332.	Boiler Test 333.
Moisture in sample	0.02 p. c.	0.02 p. c.
Volatile combustible matter	0.65 p. c.	0.13 p. c.
Fixed carbon	18.13 p. c.	12.00 p. c.
Ash	81.20 p. c.	87.85 p. c.
Slate Test of Coal:		
Pure coal	87.53 p. c.	84.36 p. c.
Slate and bone	12.46 p. c.	15.63 p. c.
Sizing Tests (round holes, punched plates):		
Chestnut size, through $1\frac{1}{2}$ inches and over $\frac{7}{8}$ inch	0.82 p. c.	.....
Pea size, through $\frac{7}{8}$ inch and over $\frac{9}{16}$ inch	19.86 p. c.	10.04 p. c.
Buckwheat size, through $\frac{9}{16}$ inch and over $\frac{3}{8}$ inch	61.09 p. c.	73.36 p. c.
Rice size, through $\frac{3}{8}$ inch and over $\frac{3}{16}$ inch	16.98 p. c.	15.26 p. c.
Barley size, through $\frac{3}{16}$ inch and over $\frac{3}{32}$ inch	0.68 p. c.	0.80 p. c.
Culm size, through $\frac{3}{32}$ inch	0.54 p. c.	0.53 p. c.

Analyses of the flue gases were not made for these tests, but the results were probably similar to the tests made two days earlier, when the same coal was burned with the stoker driven about as in tests 332 and 333. These analyses were also made by Mr. Wagner, and were:

Gas Analyses, Boiler Trial 328:

	Carbonic Acid Gas.	Free Oxygen.
	13.4 p. c.	6.2 p. c.
	12.7 p. c.	5.9 p. c.
	17.5 p. c.	1.5 p. c.
	17.4 p. c.	1.9 p. c.
	15.8 p. c.	4.3 p. c.
	12.2 p. c.	7.4 p. c.
	16.4 p. c.	3.1 p. c.
	15.5 p. c.	4.1 p. c.
Average,	15.1 p. c.	4.3 p. c.
	Sum, 19.4 p. c.	

Gas Analyses, Boiler Trial 329:

	Carbonic Acid Gas.	Free Oxygen.
	12.8 p. c.	7.1 p. c.
	13.2 p. c.	6.7 p. c.
	13.0 p. c.	6.8 p. c.
	13.1 p. c.	6.8 p. c.
	13.7 p. c.	6.3 p. c.
	12.7 p. c.	7.2 p. c.
	12.9 p. c.	7.1 p. c.
	12.7 p. c.	7.0 p. c.
	12.2 p. c.	7.1 p. c.
	13.3 p. c.	6.3 p. c.
	12.7 p. c.	7.1 p. c.
Average,	12.9 p. c.	6.9 p. c.
	Sum, 19.8 p. c.	

The operations of the stoker were as follows:

Trial No.	Speed of grate per hour.	Thickness of fire on grate in front.
332	54 in.	10 in.
333	100 in.	10 in.
334	80 in.	10 in.

The blast pressures and draught conditions were as follows, in inches of water:

DRAUGHT CONDITIONS OF THE COXE STOKER TRIALS.

ITEMS.	Buckwheat coal, Test 332.	Buckwheat coal, Test 333.	Rice coal, Test 334.
Pressure in igniting compartment *A* (Fig. 124)...	0.14 in.	0.25 in.	0.44 in.
" " burning " *B* "	0.31 in.	0.56 in.	0.89 in.
" " burning-down compart'nt *C* (Fig. 124)	0.24 in.	0.49 in.	0.73 in.
" " burning-out " *D* "	0.17 in.	0.42 in.	0.67 in.
" of blast of air, average	0.24 in.	0.43 in.	0.68 in.
Vacuum in furnace	0.10 in.	0.15 in.	0.24 in.
Total furnace draught	0.34 in.	0.58 in.	0.92 in.
Vacuum in stack flue.......................	0.13 in.	0.40 in.	0.58 in.
Total draught..................................	0.37 in.	0.83 in.	1.26 in.
Pounds of dry coal an hour per sq. ft. of grate...	19.8	32.9	28.0

The engine horse-power used to run the stoker and its fan blast varied with the manner of operating the stokers, but averaged about 10.8 horse-power. This, for a Westinghouse engine 7½ x 7 inches, must have called for about 20 boiler horse-power. In this event, the boiler developing about 500 horse-power, four per cent. of the steam generated would be charged to the Coxe stoker. This is an expression of the writer's best judgment, rather than a statement of facts, as the stoker engine was not indicated until after the tests.

Trial Sheet No. 4 shows excellent results with this stoker. Each test covers a double column, the first part referring to the boiler only, and the other to the boiler and water-back combined. Assuming the four per cent. charge for operation to hold, we must deduct it from the apparent results to get the net results. The results previously found with the Wilkinson stoker, trial No. 290, Sheet No. 1, will now be compared with the Coxe stoker, trial No. 332, sheet No. 4, both referring to a 375 horse-power Babcock & Wilcox boiler, using P. & R. C. & I. Co.'s buckwheat coal, the boilers being run in each instance to secure best economy, *i.e.*, to develop near their rated power. This comparison is made in the following table:

COMPARISON OF NET RESULTS OF ECONOMY TRIALS MADE WITH THE COXE AND WILKINSON STOKERS.

ITEMS.	COXE STOKER, TRIAL 332.		WILKINSON STOKER, TRIAL 290.
	Water-back neglected.	Water-back included.	
Per cent. of ash in coal.........	17.2	....	19.5
Moisture in coal, per cent.......	0.7	....	4.5
Pounds dry coal burned per hr. per sq. ft. of grate..........	19.8	....	32.5
Total furnace dra'ght, in. of water	0.34	...	0.90
Total draught, in. of water......	0.37	. ..	1.08
Boiler H. P. develop'd, per boiler	370.4	378.0	420.2
Boiler H. P. available, per boiler	355.6	362.9	387.3
Corrected evaporation, from and at 212° F., per lb. of dry coal, pounds....................	8.87	9.17	9.12
Corrected evaporation, from and at 212° F., per lb. of combustible, pounds.............	10.72	11.07	11.32
Pounds of dry coal an hour per available boiler H. P. developed.........	3.84	3.76	3.78
Pounds of combustible per hour per available boiler H. P. developed.................	3.18	3.11	3.05
Ratio of heating to grate surface	61.3	....	93.9

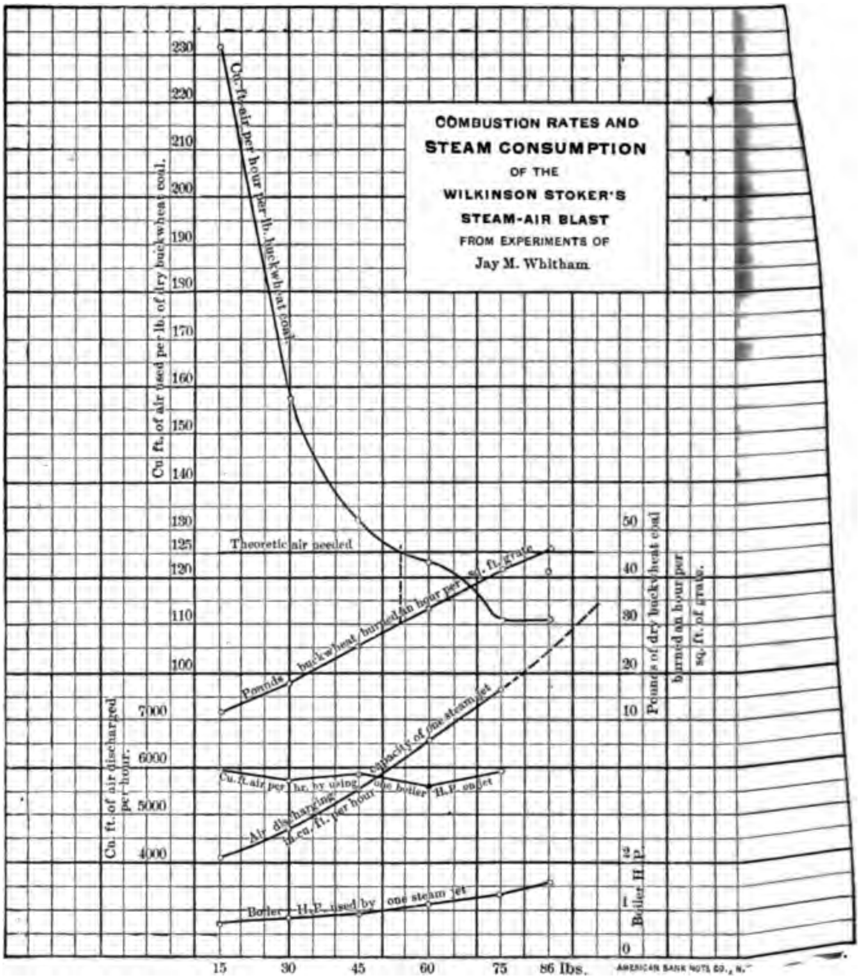
This table shows that there is no practical difference between the net economic results obtained with either form of stoker, when operated so as to develop about the rated power of the boiler. The Coxe developed the greatest capacity, as seen by comparing trial 333, Sheet No. 4, with trial 291, Sheet No. 1, because it had much advantage in the extent of grate area.

Summary Regarding the Coxe Stoker.—1. The stoker engine and fan blast use about four per cent. of the steam generated in the boilers.

2. There was no clinker formed during the trial, as the coal was what is known as "white ash." It is probable that the clinkering would not be serious with even Lykens Valley coal.

3. The fires resembled a puddling furnace. The furnace temperatures must have been nearly 2,800 degrees Fahr. over the two central blast compartments. Analyses of the flue gases proved that the combustion was good.

4. A most annoying and peculiar deposit of ash, etc., rapidly



Steam pressures at the jets of the Wilkinson Stoker.

FIG. 122

a range of combustion up to 45 pounds of dry coal an hour per square foot of grate.

It is common knowledge that ordinary furnaces, run with natural draught, use about 100 per cent. excess air for dilution, and that blasts in general use 50 per cent. excess. The following table shows that a 10 per cent. deficiency of air supply gives a boiler nearly the same theoretic absorbing efficiency as a 1[illegible]0 per cent. excess supply. The table is based upon the burning of one pound of pure carbon. It shows the approximate flame connection with an open feed-water heater, like the Webster, Hoppes, etc. Too much water for boiler-feed purposes was circulated on the test. If a water box is a necessity (the writer thinks it is not), it should be made strong enough to stand the boiler pressure, and to receive the feed water just before it enters the boiler. In this event pipes should be provided for an induced circulation when not feeding the boiler.

6. The stoker will quickly respond to sudden fluctuations in power demands.

7. The economic results obtained on the trials were good.

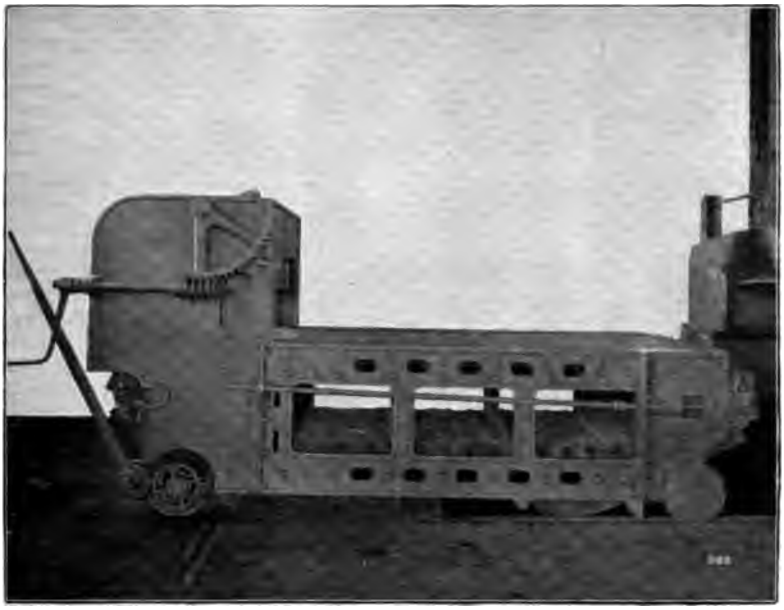


FIG. 126.—SIDE VIEW OF BABCOCK & WILCOX STOKER.

8. Crowding the fires produces but little reduction in the economy.

9. About three-fourths as much capacity can be developed with rice as with buckwheat coal, under like conditions, with this stoker.

10. More than ordinary care and skill are required in operating this stoker, on account of the graduated air blast used. This is specially true for a plant receiving mixed coal, *i.e.*, buckwheat coal from different mines, or from different levels from one

mine. Any inattention may result in too much or too little air being supplied over the last two, *i.e.*, the burning-down and burning-out compartments, or *C* and *D* of Fig. 124.

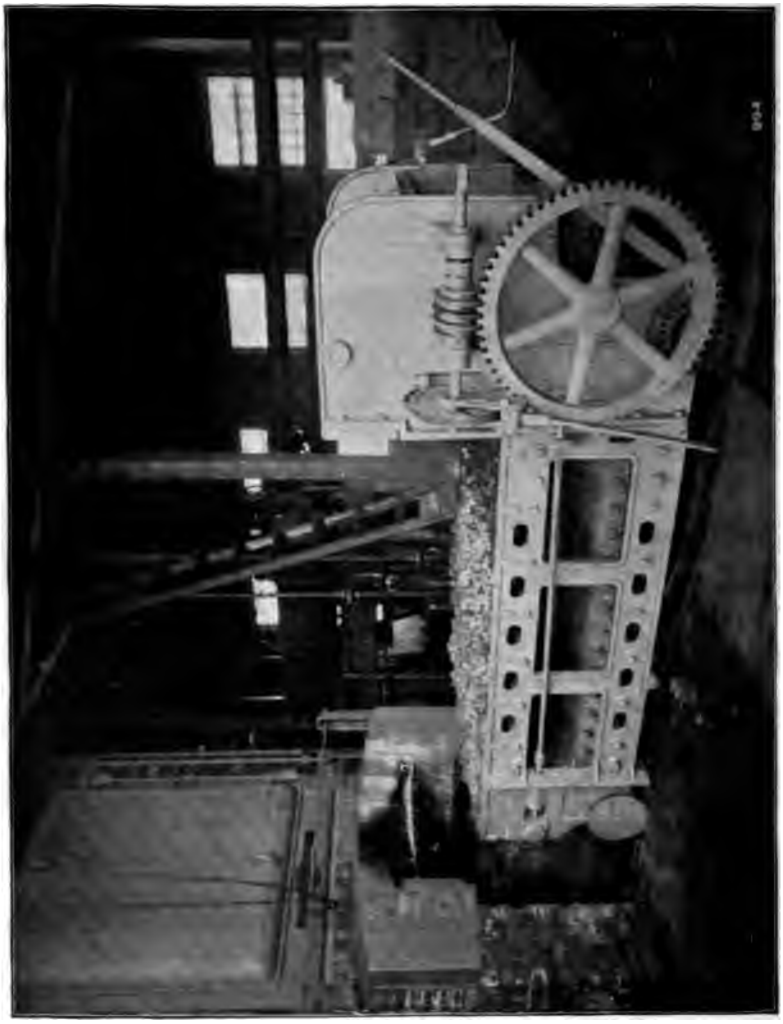


FIG. 127.—BABCOCK & WILCOX STOKER REMOVED FROM FURNACE.

THE BABCOCK & WILCOX STOKER.

General Description.—Like the Coxe, this stoker is of the chain-grate type. It is useful only for burning bituminous coal. It differs from the Coxe in many constructive features (see Figs. 125 to 128).

As used on the tests noted in Sheet No. 5, the Babcock & Wilcox stoker had an active grate 78 inches wide by 84 inches long, with 21 per cent. air openings for the boilers described in the sheet. The ratio of heating to grate surface was 60.6 for trials 330 and 331, and 61.3 for trial 278. The fires were carried 5½ inches thick in front. The speed of the grate varied from 2⅝

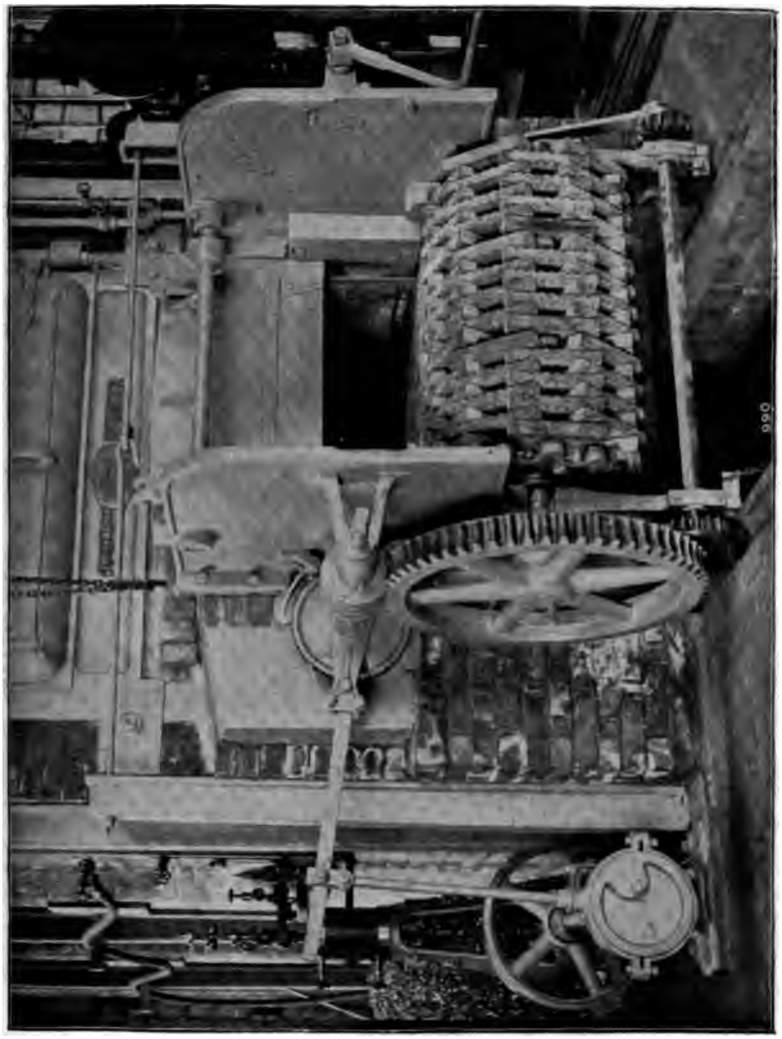


FIG. 128.—DRIVING MECHANISM OF THE BABCOCK & WILCOX STOKER.

inches to 2⅞ inches per minute. Only natural draught was employed, and that was indifferent on trials 330 and 331.

Stoker Trials.—Sheet No. 5 contains the results of three trials made on this stoker, in accordance with the methods advised by this Society. Trial 278 was made jointly by Mr. Daniel Ashworth, of Pittsburg, and the writer. The economic results are ideal.

FIG. 129.—FURNACE FITTED TO RECEIVE BABCOCK & WILCOX STOKER.

The general items of interest were as follows:

Items.	Test 330.	Test 331.	Test 278.
Furnace draught, in inches of water	0.26	0.34	0.61
Stack flue draught, in rear of boiler, inches of water	0.41	0.51	1.16
Kind of bituminous coal burned	"Columbian" from W. Va.	"Columbian" from W. Va.	Connellsville, Pa., slack.
Pounds of dry coal burned an hour per square foot of grate	18.4	23.9	33.2
Per cent. of ash and refuse in coal.	9.24	9.70	10.16
Temperature of gases in flue in rear of boiler, degrees Fahr.	365	389	538
Square foot of heating surface to one developed horse-power	10.61	7.95	5.94
Commercial result, or pounds of dry coal burned an hour per boiler horse-power developed	3.23	3.13	3.22

Summary Regarding the Babcock & Wilcox Stoker.—1. This stoker is smokeless when run as in the tests. It did not form a clinker, nor require the use of a firing tool.

2. It readily responds to fluctuating boiler demands, where the stack draught is good.

3. It, like the other stokers named in this paper, requires a strong draught, either natural, induced, or forced. The air openings in the grate are but about one-half of the extent usually found with stationary grates, hence a stronger draught is required than with hand firing.

4. A remarkable feature of the tests is that the boiler develops almost ideal economy when forced to develop an evaporative horse-power on six square feet of heating surface. This is never realized with hand firing. The writer's experience is that when a boiler, rated on 10 to 12 square feet to the horse-power, is forced to develop a horse-power on less than 8.5 square feet of heating surface, the economy rapidly drops.

5. No charge can be made against this stoker for steam used, other than from one-fifth to two-fifths of one per cent for driving the stoker engine.

GENERAL SUMMARY.

1. Each stoker seems well adapted to the conditions for which it was designed.

2. Each stoker gives ideal economic results when properly handled.

SHEET No. 1.

WILKINSON'S AUTOMATIC MECHANICAL STOKER TRIALS, MADE WITH VARIOUS BOILERS AND VARIOUS ANTHRACITE COALS.

BY JAY M. WHITHAM, CONSULTING ENGINEER, PHILADELPHIA.

TRIALS MADE FOR		ATLANTIC OIL REFINERY, PHILADELPHIA.			LANG'S PAPER MILL, PHILADELPHIA.			MARSHALL BROS.' ROLLING MILLS, PHILADELPHIA.		NIXON'S PAPER MILLS, PHILADELPHIA.		GIRARD COLLEGE, PHILADELPHIA.	PHILADELPHIA TRACTION CO., PHILADELPHIA.	
No. of boiler trial		Test 252	Test 254	Test 253	Test 249	Test 370	Test 371	Test 296	Test 337	Test 288	Test 289	Test 287	Test 290	Test 291
	Units.													
Date of trial		7/20/'94	7/24/'94	7/21/'94	7/7/94	12/23/95	12/24/95	8/26/'95	8/1/'95	5/17/'94	5/18/'94	6/5/'94	8/18/'95	8/19/'95
Duration of trial	Hrs.	10	10	10	9	9½	14½	8	9	10	10	8	11	10
Dimensions and Proportions.														
1. Type of boiler		Double Deck Hor. Tubular.			Hor. Tubular boiler.			National.		Babcock & Wilcox.		Babcock & Wilcox.	Double Deck Babc'k & Wilcox	
2. Number in use		4			1	7		1	2	1		2	2	1
3. Diameter of boiler	Ins.	60″ and 50″ shells.			72	....		3-36	3-36	1 36		36	3 36	
4. Length of boiler	Ft.	15			18	....		20	20	16.5		....	22.5	
5. Width of grate per boiler	Ins.	52			60	....		124	124	48		....	108	
6. Length of grate per boiler	"	66½			60	....		72	72	60		....	60	
7. Number of tubes per boiler		60			48	....		180	180	64		108	108	
8. Diameter of tubes	Ins.	4			4½	....		4	4	4		4	4	
9. Length of tubes	Ft.	15			18	....		18	18	16		16.3	18	
10. Steam-heating surface per boiler	Sq. ft.	141			....	....		....	....	....		....	....	
12. Total water-heating surface per boiler	"	1,286			1,215	Total, 7,594		3,850	3,850	1,353		2,180	4,225	
13. Grate surface per boiler	"	24			25	Total, 165		62	62	20		28	45	
14. Air space in grate, per cent.		7			7	7		7	7	7		7	7	
16. Total tube cross section per boiler	Sq. ft.	4.60			5.3	....		....	....	....		....	....	
19. Ratio of water heating surface to grate surface		53.6			48.6	45.6		62.1	62.1	63.6		78	93.0	
20. Ratio of tube cross section to grate surface		1 to 5.2			1 to 4.7	....		....	....	....		....	....	
21. Area of stack	Sq. ft.	28.3			....	....		9.62	10.42	....		....	....	
22. Height of stack above dead plate	Ft.	88			116	....		115	115	....		....	Mechanic'l Dra't	

	Boiler Test 332.	Boiler Test 333.
Ash Analyses:		
Moisture in sample	0.02 p. c.	0.02 p. c.
Volatile combustible matter	0.65 p. c.	0.13 p. c.
Fixed carbon	18.13 p. c.	12.00 p. c.
Ash	81.20 p. c.	87.85 p. c.
Slate Test of Coal:		
Pure coal	87.53 p. c.	84.36 p. c.
Slate and bone	12.46 p. c.	15.63 p. c.
Sizing Tests (round holes, punched plates):		
Chestnut size, through 1½ inches and over ⅞ inch	0.82 p. c.	.....
Pea size, through ⅞ inch and over 9/16 inch	19.86 p. c.	10.04 p. c.
Buckwheat size, through 9/16 inch and over ⅜ inch	61.09 p. c.	73.36 p. c.
Rice size, through ⅜ inch and over 3/16 inch	16.98 p. c.	15.26 p. c.
Barley size, through 3/16 inch and over 3/32 inch	0.68 p. c.	0.80 p. c.
Culm size, through 3/32 inch	0.54 p. c.	0.53 p. c.

Analyses of the flue gases were not made for these tests, but the results were probably similar to the tests made two days earlier, when the same coal was burned with the stoker driven about as in tests 332 and 333. These analyses were also made by Mr. Wagner, and were:

Gas Analyses, Boiler Trial 328:

	Carbonic Acid Gas.	Free Oxygen.
	13.4 p. c.	6.2 p. c.
	12.7 p. c.	5.9 p. c.
	17.5 p. c.	1.5 p. c.
	17.4 p. c.	1.9 p. c.
	15.8 p. c.	4.3 p. c.
	12.2 p. c.	7.4 p. c.
	16.4 p. c.	3.1 p. c.
	15.5 p. c.	4.1 p. c.
Average,	15.1 p. c.	4.3 p. c.
	Sum, 19.4 p. c.	

Gas Analyses, Boiler Trial 329:

	Carbonic Acid Gas.	Free Oxygen.
	12.8 p. c.	7.1 p. c.
	13.2 p. c.	6.7 p. c.
	13.0 p. c.	6.8 p. c.
	13.1 p. c.	6.8 p. c.
	13.7 p. c.	6.3 p. c.
	12.7 p. c.	7.2 p. c.
	12.9 p. c.	7.1 p. c.
	12.7 p. c.	7.0 p. c.
	12.2 p. c.	7.1 p. c.
	13.3 p. c.	6.3 p. c.
	12.7 p. c.	7.1 p. c.
Average,	12.9 p. c.	6.9 p. c.
	Sum, 19.8 p. c.	

The operations of the stoker were as follows:

Trial No.	Speed of grate per hour.	Thickness of fire on grate in front.
332	54 in.	10 in.
333	100 in.	10 in.
334	80 in.	10 in.

The blast pressures and draught conditions were as follows, in inches of water:

Draught Conditions of the Coxe Stoker Trials.

Items.	Buckwheat coal, Test 332.	Buckwheat coal, Test 333.	Rice coal, Test 334.
Pressure in igniting compartment *A* (Fig. 124)...	0.14 in.	0.25 in.	0.44 in.
" " burning " *B* "	0.31 in.	0.56 in.	0.89 in.
" " burning-down compart'nt *C* (Fig. 124)	0.24 in.	0.49 in.	0.73 in.
" " burning-out " *D* "	0.17 in.	0.42 in.	0.67 in.
" of blast of air, average	0.24 in.	0.43 in.	0.68 in.
Vacuum in furnace	0.10 in.	0.15 in.	0.24 in.
Total furnace draught	0.34 in.	0.58 in.	0.92 in.
Vacuum in stack flue.......................	0.13 in.	0.40 in.	0.58 in.
Total draught..................................	0.37 in.	0.83 in.	1.26 in.
Pounds of dry coal an hour per sq. ft. of grate...	19.8	32.9	28.0

The engine horse-power used to run the stoker and its fan blast varied with the manner of operating the stokers, but averaged about 10.8 horse-power. This, for a Westinghouse engine 7½ x 7 inches, must have called for about 20 boiler horse-power. In this event, the boiler developing about 500 horse-power, four per cent. of the steam generated would be charged to the Coxe stoker. This is an expression of the writer's best judgment, rather than a statement of facts, as the stoker engine was not indicated until after the tests.

Trial Sheet No. 4 shows excellent results with this stoker. Each test covers a double column, the first part referring to the boiler only, and the other to the boiler and water-back combined. Assuming the four per cent. charge for operation to hold, we must deduct it from the apparent results to get the net results. The results previously found with the Wilkinson stoker, trial No. 290, Sheet No. 1, will now be compared with the Coxe stoker, trial No. 332, sheet No. 4, both referring to a 375 horse-power Babcock & Wilcox boiler, using P. & R. C. & I. Co.'s buckwheat coal, the boilers being run in each instance to secure best economy, *i.e.*, to develop near their rated power. This comparison is made in the following table:

COMPARISON OF NET RESULTS OF ECONOMY TRIALS MADE WITH THE COXE AND WILKINSON STOKERS.

ITEMS.	COXE STOKER, TRIAL 332.		WILKINSON STOKER, TRIAL 290.
	Water-back neglected.	Water-back included.	
Per cent. of ash in coal	17.2	....	19.5
Moisture in coal, per cent	0.7	....	4.5
Pounds dry coal burned per hr. per sq. ft. of grate	19.8	....	32.5
Total furnace dra'ght, in. of water	0.34	...	0.90
Total draught, in. of water	0.37	...	1.08
Boiler H. P. develop'd, per boiler	370.4	378.0	420.2
Boiler H. P. available, per boiler	355.6	362.9	387.3
Corrected evaporation, from and at 212° F., per lb. of dry coal, pounds	8.87	9.17	9.12
Corrected evaporation, from and at 212° F., per lb. of combustible, pounds	10.72	11.07	11.32
Pounds of dry coal an hour per available boiler H. P. developed	3.84	3.76	3.78
Pounds of combustible per hour per available boiler H. P. developed	3.18	3.11	3.05
Ratio of heating to grate surface	61.3	....	93.9

This table shows that there is no practical difference between the net economic results obtained with either form of stoker, when operated so as to develop about the rated power of the boiler. The Coxe developed the greatest capacity, as seen by comparing trial 333, Sheet No. 4, with trial 291, Sheet No. 1, because it had much advantage in the extent of grate area.

Summary Regarding the Coxe Stoker.—1. The stoker engine and fan blast use about four per cent. of the steam generated in the boilers.

2. There was no clinker formed during the trial, as the coal was what is known as "white ash." It is probable that the clinkering would not be serious with even Lykens Valley coal.

3. The fires resembled a puddling furnace. The furnace temperatures must have been nearly 2,800 degrees Fahr. over the two central blast compartments. Analyses of the flue gases proved that the combustion was good.

4. A most annoying and peculiar deposit of ash, etc., rapidly

collected against the water tubes, due to the intensity of the blast in the two central compartments of Fig. 124. This deposit is not readily removed by a steam blast but comes off with ease when scraped. The particles clinging to the tubes appear to have been fused. They much resemble the formations observed on boilers burning blast-furnace gases.

FIG. 125.—FRONT OF CHAIN-GRATE STOKER, BABCOCK & WILCOX PATTERN.

5. The water-box furnace lining is an advantage when used in

connection with an open feed-water heater, like the Webster, Hoppes, etc. Too much water for boiler-feed purposes was circulated on the test. If a water box is a necessity (the writer thinks it is not), it should be made strong enough to stand the boiler pressure, and to receive the feed water just before it enters the boiler. In this event pipes should be provided for an induced circulation when not feeding the boiler.

6. The stoker will quickly respond to sudden fluctuations in power demands.

7. The economic results obtained on the trials were good.

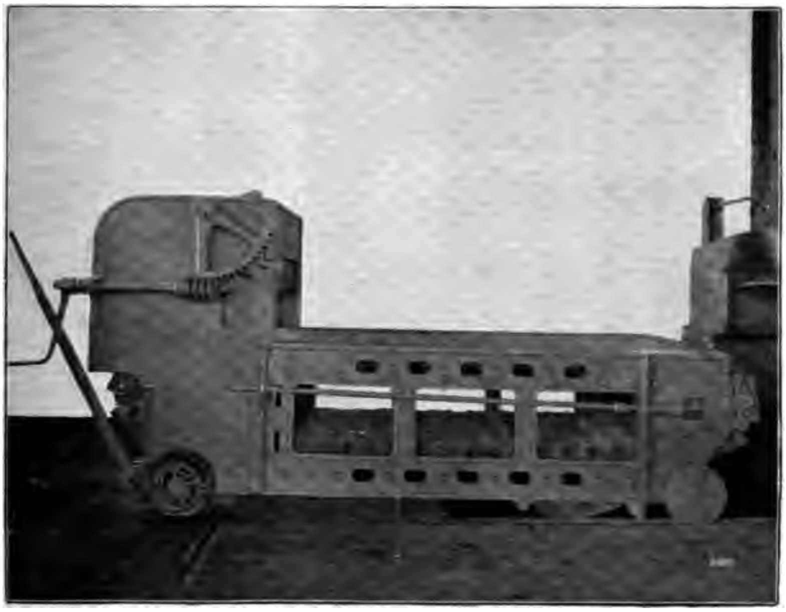


FIG. 126.—SIDE VIEW OF BABCOCK & WILCOX STOKER.

8. Crowding the fires produces but little reduction in the economy.

9. About three-fourths as much capacity can be developed with rice as with buckwheat coal, under like conditions, with this stoker.

10. More than ordinary care and skill are required in operating this stoker, on account of the graduated air blast used. This is specially true for a plant receiving mixed coal, *i.e.*, buckwheat coal from different mines, or from different levels from one

mine. Any inattention may result in too much or too little air being supplied over the last two, *i.e.*, the burning-down and burning-out compartments, or *C* and *D* of Fig. 124.

FIG. 127.—BABCOCK & WILCOX STOKER REMOVED FROM FURNACE.

THE BABCOCK & WILCOX STOKER.

General Description.—Like the Coxe, this stoker is of the chain-grate type. It is useful only for burning bituminous coal. It differs from the Coxe in many constructive features (see Figs. 125 to 128).

As used on the tests noted in Sheet No. 5, the Babcock & Wilcox stoker had an active grate 78 inches wide by 84 inches

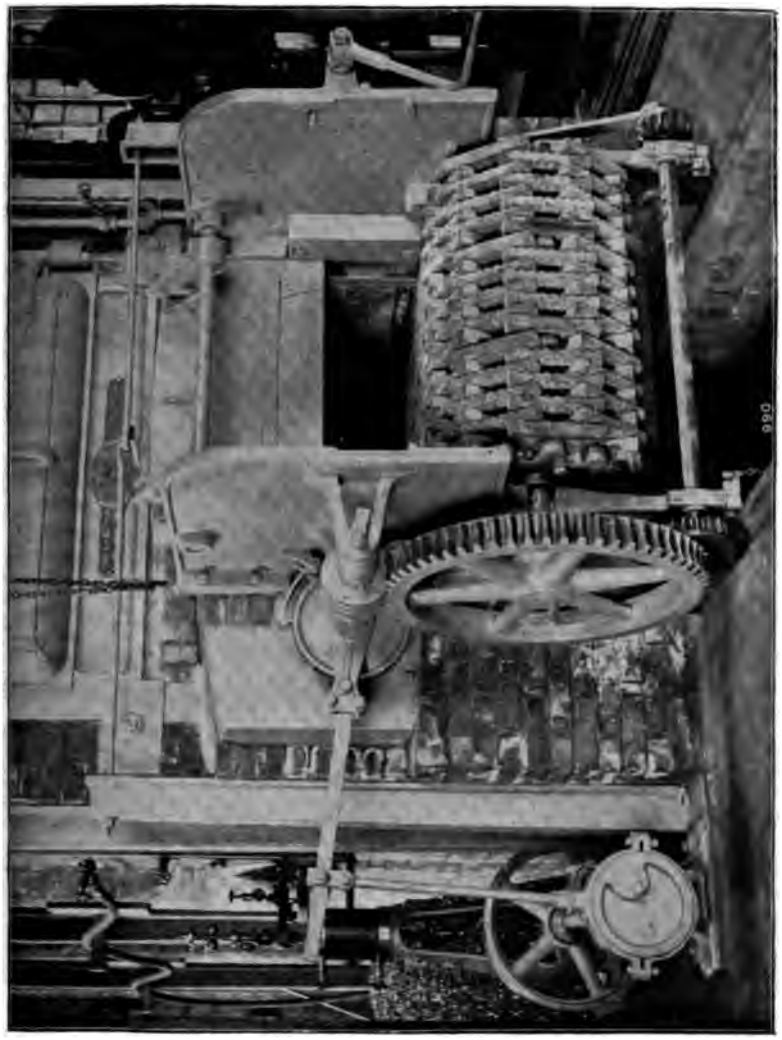


FIG. 128.—DRIVING MECHANISM OF THE BABCOCK & WILCOX STOKER.

long, with 21 per cent. air openings for the boilers described in the sheet. The ratio of heating to grate surface was 60.6 for trials 330 and 331, and 61.3 for trial 278. The fires were carried 5½ inches thick in front. The speed of the grate varied from 2⅜

3. Stoker engines use from one-fifth to two-fifths of one per cent of the steam generated.

4. Fan blasts use from three to five per cent. of the steam generated.

5. Steam blasts use from five to eleven per cent. of the steam generated.

6. A defect, common to each of the stokers named in this paper, is a too scanty air space in the grate.

7. Neither stoker will develop as much capacity as will hand firing with stationary grates, having the same draught and coal conditions. Stokers, however, are not only more constant in the power developed, than is a hand-fired grate, but are more responsive to fluctuations in the power demands. The stoker is always in the condition that a hand-worked fire is in just after its cleaning—*i.e.*, always clean and "ready for a pull."

DISCUSSION.

Mr. William H. Bryan.—This paper is an able and valuable contribution to the literature of boiler appliances.

I violate no confidence in stating that mechanical stokers have, as a rule, failed utterly when using the low-grade coals common in this part of the country (St. Louis). Hundreds of the most expensive types have been applied in this city, and less than a dozen remain in use to-day. Stokers of national reputation, and of established merit with good fuels, have proved themselves unfit for use with our common coals, and I believe it would be a matter of some difficulty to give away a stoker of even the best makes in this city to-day. The greatest difficulties have come from the large percentages of ash, clinker, and sulphur in the coal, which form incombustible matter very difficult to handle. Furthermore, they have not responded readily to sudden and extreme changes of load, and do not seem capable of being overworked to any great extent. Not only the first cost, but the cost of maintenance and repairs, has in most cases been enormous. Furthermore, the claimed improvements in fuel efficiency, and reduction of the smoke, have not always been realized. Good hand firing has nearly always shown better results. Perhaps when the Western steam user gets out of the idea that it is good engineering to work a boiler 100 per cent. above its rating regularly and without notice, the mechanical stoker may have a better show.

s from the Coxe in many constructive features (see Figs.
o 128).

used on the tests noted in Sheet No. 5, the Babcock &
ox stoker had an active grate 78 inches wide by 84 inches

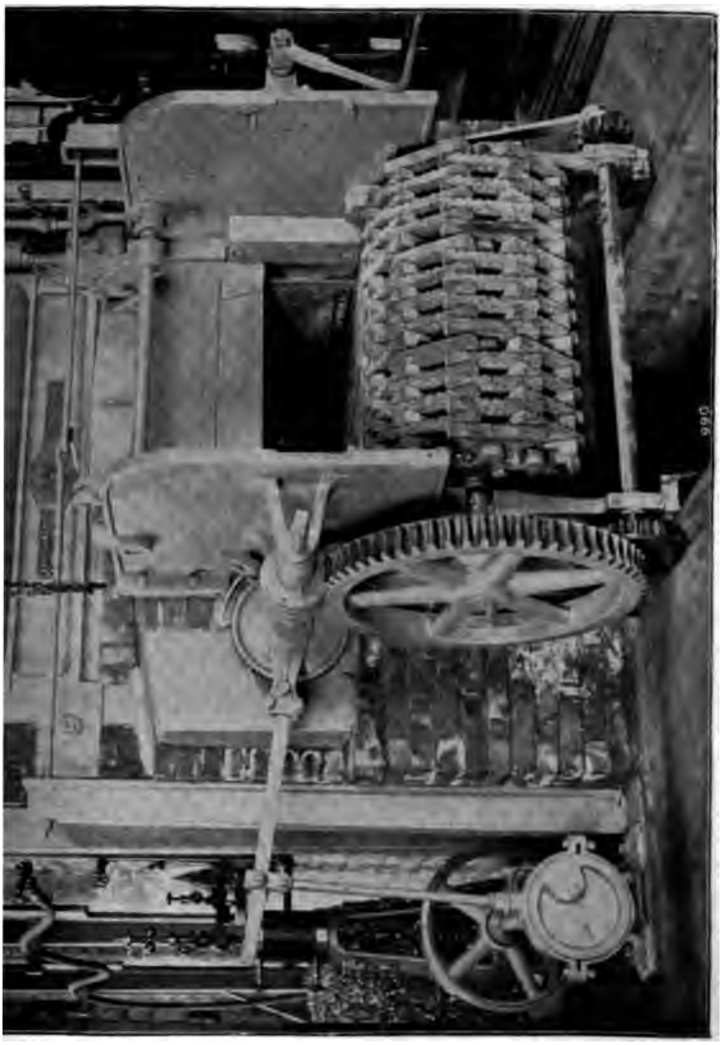


FIG. 128.—DRIVING MECHANISM OF THE BABCOCK & WILCOX STOKER.

with 21 per cent. air openings for the boilers described in
heet. The ratio of heating to grate surface was 60.6 for
330 and 331, and 61.3 for trial 278. The fires were carried
ches thick in front. The speed of the grate varied from 2¼

and are heated and burned, and the speed of feeding is so regulated that when any fuel particle reaches the top surface it has been completely consumed and only clinker and ash remain. The feeding is done from the middle, so that the fresh coal is continually causing the clinker to roll down from the burning mound to the sides, and doors at convenient places permit this clinker and ash to be removed. There has been some trouble with some of these stokers in handling the clinker, but with a little care in selection, or, better still, in mixing a fusing or a badly clinkering coal with some other, good results can be generally obtained. Variable loads can be well cared for in the American stoker, since the screw which feeds the coal to the stoker can have its speed so varied that it will feed from 25 up to 1,000 pounds per hour. This variation in feed can be made automatic by the damper-regulating principle so as to vary the speed as the pressure varies, which will meet the objection against the action of stokers when the load varies.

Mr. George I. Rockwood.—I have had a little experience with stokers of the class referred to by Mr. Cary. In my experience it would not work unless all the conditions were ideal and the manager was willing to pay to see it work. It would burn out rapidly; the coal would not run down on the sides, and the beautiful picture of combustion with an underfed stoker was not realized. I do not doubt that with Eastern coals and under perfect conditions, and in the hands of an artist who knows how to use it, it can be made a continuous success. In New England we have become pretty well satisfied that there is no money to be saved in the direction of economy as such from using stokers. After many years of expensive experience we have found that an Irishman with a wheelbarrow and a scoop make the best combination stoker.

Before I close, however, I wish to compliment the paper. Its form and its impartiality are rare and splendid and make it admirable. I have no doubt that there are some stokers in use which are valuable adjuncts in large plants with poor grades of coal—perhaps, however, not so poor as the ordinary grades in this part of the country.

The general items of interest were as follows:

Items.	Test 330.	Test 331.	Test 278.
Furnace draught, in inches of water	0.26	0.34	0.61
Stack flue draught, in rear of boiler, inches of water...............	0.41	0.51	1.16
Kind of bituminous coal burned....	"Columbian" from W. Va.	"Columbian" from W. Va.	Connellsville, Pa., slack.
Pounds of dry coal burned an hour per square foot of grate.......	18.4	23.9	33.2
Per cent. of ash and refuse in coal.	9.24	9.70	10.16
Temperature of gases in flue in rear of boiler, degrees Fahr........	365	389	538
Square foot of heating surface to one developed horse-power....	10.61	7.95	5.94
Commercial result, or pounds of dry coal burned an hour per boiler horse-power developed..... ..	3.23	3.13	3.22

Summary Regarding the Babcock & Wilcox Stoker.—1. This stoker is smokeless when run as in the tests. It did not form a clinker, nor require the use of a firing tool.

2. It readily responds to fluctuating boiler demands, where the stack draught is good.

3. It, like the other stokers named in this paper, requires a strong draught, either natural, induced, or forced. The air openings in the grate are but about one-half of the extent usually found with stationary grates, hence a stronger draught is required than with hand firing.

4. A remarkable feature of the tests is that the boiler develops almost ideal economy when forced to develop an evaporative horse-power on six square feet of heating surface. This is never realized with hand firing. The writer's experience is that when a boiler, rated on 10 to 12 square feet to the horse-power, is forced to develop a horse-power on less than 8.5 square feet of heating surface, the economy rapidly drops.

5. No charge can be made against this stoker for steam used, other than from one-fifth to two-fifths of one per cent for driving the stoker engine.

GENERAL SUMMARY.

1. Each stoker seems well adapted to the conditions for which it was designed.

2. Each stoker gives ideal economic results when properly handled.

of Chemistry, 1868, dries one to two grammes, after pulverizing, one hour at 115 degrees C.

Fischer also quotes Regnault (*Ann. de Min.*, iii., 12, 161), who asserts that moisture determinations at 100 degrees are inexact if the coal contains any clay, since the latter gives up its water at a red heat only.

(7) Richters (*Dingl.*, 1870, 195, 320), quoted by Fischer, puts fine pulverized coal first under a bell near a cup with water, lets it stand at 15 degrees, and then dries it at 100 degrees.

Fischer gives some experiments showing these methods to be inexact. Also others showing that in three hours coal heated to between 100 and 110 degrees lost 0.125 per cent. CO_2 and 0.07 per cent. CH_4.

(8) Fischer then gives as his rule: "Heat two to four grammes between two watch glasses, or in a receptacle with well-fitting cover, two hours at 100 to 110 degrees C. in an air bath."

(9) F. W. Dean and Dexter Bracket, "Test of Louisville Pumping Engine": "Samples of the coal were taken daily and the amount of moisture determined by drying on top of the boiler flue." The results were:

Pocahontas coal, three samples, 2.25 per cent., 2.8 per cent., and 2.74 per cent. Chemist's report, 1. 8 per cent.

Pittsburg coal, 0.6 per cent., 0.7 per cent., and 0.8 per cent. Chemist's report, 0.73 per cent. Mr. Dean recommends six hours only. (*Trans.* A. S. M. E., xvi., p. 963.)

(10) R. C. Carpenter, *Experimental Engineering*, p. 458: "Put 100 pounds of coal in a box and dry in a hot place twenty-four hours."

(11) Private letter from an engineer of reputation: "Dry 100 pounds of coal in galvanized iron pan, in warm, dry room, with air circulation, a sufficient length of time to ensure its being perfectly dry."

(12) From another engineer: "Dry at 80 degrees a time, according to size and moisture in sample."

(13) From another engineer: "Dry 25 to 100 pounds eight to ten hours at 200 degrees to 250 degrees Fahr., time also according to moisture."

(14) From another engineer: "Dry in a current of hot air at 150 degrees Fahr. for six hours." Is also satisfied with drying twelve hours at 110 degrees Fahr. over a boiler.

The following also include the proximate analysis of coal. Mr.

Kent has shown that the heating power follows the proximate analysis very closely. The different methods here given as authoritative suggest that perhaps the three per cent. difference found by Mr. Kent may be due to incorrect methods of analysis and not to failure to follow his law. Hinrichs's paper on the proximate analysis, published in 1868, should be referred to by any one who wishes to follow up the subject. One of his results may be quoted, that "if coal be dried and then proximately analyzed, the sum of the moisture and volatile matter is some two or three per cent. less than if they are both driven off at once." He found that if the same method was always used, results could be repeated to one-tenth per cent., but that different methods differed fifteen per cent. on the same sample. The temperature, time, amount of sample, etc., etc., are all important in getting the same results from similar samples.

(15) Blair, *Chemical Analyses of Iron*, 1891, p. 274: *Moisture.*—Dry one to two grammes one hour at from 105 to 110 degrees C. *Volatile Matter.*—Weigh one to two grammes undried powdered coal into platinum crucible; heat, with cover on, three and one-half minutes with Bunsen burner, then, without cooling, three and one-half minutes with blast lamp. Loss is sum of moisture and volatile matter. *Fixed Carbon.*—Completely burn above; difference is fixed carbon and residue is ash (earthy matter).

(16) Arnold, *Steel Works Analyses*, 1895, p. 295: *Moisture.*—Dry two grammes about one hour at a temperature slightly over 100 degrees C. *Coke.*—Put twenty-five grammes powdered coal in clay crucible; heat in muffle until no gas appears from beneath cover of crucible. *Ash.*—Two grammes in platinum crucible are completely incinerated.

(17) M. Troilius, *Notes on Chemistry of Iron*, 1886: *Moisture.*—Two grammes of powdered coal are dried one hour at 120 degrees C. *Volatile Matter.*—Heat this same coal over Bunsen burner till no flames are given off. *Ash.*—Completely incinerate residue of above.

(18) N. W. Lord, *Notes on Metallurgical Analyses*, 1893: *Moisture.*—Dry one gramme one hour at 105 degrees C. in platinum crucible. *Volatile Matter.*—Same as Blair, except that the dried coal is used.

(19) F. A. Cairns, *Quantitative Analysis*, 1880: *Moisture.*—Dry two grammes pulverized at 115 degrees for thirty minutes;

SHEET No. 4.

TRIALS OF THE COXE CHAIN-GRATE STOKER AND BABCOCK & WILCOX DOUBLE-DECK BOILERS.

BY JAY M. WHITHAM, PHILADELPHIA.

Trials made for Philadelphia Traction Co., Philadelphia.

	Units.			
Number of Trial		332	333	334
Date of Trial		7/17/'95.	7/18/'95.	7/26/'95.
Type of Boiler		Double-deck Babcock & Wilcox.		
1. Number of boilers tested	....	1	1	1
2. Duration of trial	Hrs.	9	10	10
Dimensions and Proportions.				
(*For description of boiler see remarks.*)				
3. Total water-heating surface per boiler	Sq. ft.	....	4,225	....
4. Width of grate	Ft.	....	7.25	....
5. Length of grate	"	....	9.50	....
6. Area of grate	Sq. ft.	....	68.9	....
7. Ratio of water-heating to grate surface		....	61.3	....
8. Kind of grate		....	....	....
9. Percentage of air-space in grate.	%	....	18.8	....
10. Height of stack above dead plate	Ft.	Mechanical draught with fan blast under fire.		
11. Area of stack	Sq. ft.			
12. Ratio of stack area to grate surface				
Average Pressures.				
13. Atmospheric pressure, per barometer	Lbs.	14.69	14.70	14.69
14. Steam pressure in boiler by gauge	"	131.5	132.6	130.1
15. Force of draught in stack, in inches of water	Ins.	−0.13	−0.40	−0.56
16. Force of draught in inches of water { Furnace	"	−0.10	−0.15	−0.24
{ Ash-pit		+0.24	+0.43	+0.68
Average Temperatures.				
17. Of external air	°F.	84	88	85
18. Of fire room	"	90	94	90
19. Of feed water	"	107.1	119.7	115.9
20. Of escaping gases	"	439	547	533
Fuel: P. & R. C. & I. Co.'s Anthracite.		Buckwheat.	Buckwheat.	Rice.
21. Total amount of coal consumed	Lbs.	12,380	23,720	19,800
22. Moisture in coal	%	0.7	4.3	2.5
23. Dry coal consumed	Lbs.	12,293	22,690	19,305
24. Total refuse in coal	"	2,121	4,292	4,172
25. Percentage of refuse in coal	%	17.2	18.8	21.6
26. Total combustible (dry weight of coal, less refuse)	Lbs.	10,172	18,398	15.133
Results of Calorimetric Tests.				
27. Quality of steam, dry steam being taken as unity	....	0.998	0.998	0.998

SHEET No. 4.—*Continued.*

Number of Trial		332		333		334	
Date of Trial		7/17/'95.		7/18/'95.		7/26/'95.	
Type of Boiler		Double-deck Babcock & Wilcox.					
Water.	Units.		Including water back.		Including water back.		Including water back.
28. Total weight of water pumped into boiler and apparently evaporated	Lbs.	99,787		177,680		183,548	
29. Water actually evaporated, corrected for quality of steam, etc.	"	99,587		177,452		133,281	
30. Equivalent water evaporated into dry steam from and at 212° Fahrenheit	"	115,023	117,384	202,451	205,782	152,607	155,529
31. Equivalent water evaporated into dry steam from and at 212° Fahrenheit per hour	"	12,780	13,043	20,245	20,578	15,261	15,553
32. Total heat derived from fuel per lb. of coal	B. T. U.	......	......	......	......	......	......
33. British thermal units by analysis per lb. of coal	"	......	......	......	......	......	......
34. Efficiency of boiler	%	......	......	......	......	......	......
Economic Evaporation.							
35. Water actually evaporated per lb. of dry coal from actual pressures and temperatures	Lbs.	......	......	......	......	......	......
36. Equivalent water evaporated per lb. of dry coal from and at 212° Fahrenheit	"	9.36	9.55	8.92	9.07	7.91	8.06
37. Equivalent water evaporated per lb. combustible from and at 212° Fahrenheit	"	11.31	11.53	11.00	11.18	10.08	10.28
Rate of Evaporation.							
38. Water evaporated, from and at 212° Fahrenheit, per hour, per sq. ft. of Heating surface	Lbs.	3.03	......	4.77	......	3.61	......
39. Water evaporated, from and at 212° Fahrenheit, per hour, per sq. ft. of Grate surface	"	185.5	......	293.6	......	221.5	......
Rate of Combustion.							
40. Dry coal burned per sq. ft. grate surface per hour	Lbs.	19.8	......	32.9	......	28.0	......
41. Lbs. of coal per horse-power developed	"	3.68	......	3.98	......	4.36	......
Horse-Power.							
42. On a basis of 30 lbs. of water evaporated per hour from temperature of 100° Fahr. into dry steam at 70 lbs. gauge	H. P.	370.4	378.0	581.0	596.5	442.3	450.8
43. Horse-power, builders' rating at sq. ft. per horse-power	"	375.0	375.0	375	375	375	375
44. Per cent. developed above or below rating	%	—1.3	......	+55.0	......	+16.6	......
45. Sq. ft. of heating surface per horse-power developed	Sq. ft.	11.4	......	7.27	......	9.55	......

SHEET No. 5.

BABCOCK AND WILCOX CHAIN-GRATE STOKER TRIALS MADE WITH BITUMINOUS COALS.

BY JAY M. WHITHAM, CONSULTING ENGINEER.

TRIALS MADE AT		WARREN'S PAPER MILLS, CUMBERLAND MILLS, ME.		DUQUESNE STEEL WORKS, DUQUESNE, PA.	
Number of boiler test		Test 330.	Test 331.	Test.	Test 278.
	Units.				
Date of trial	....	7/9/'95	7/10/'95		1/25/'95
Duration of trial	....	10	10		8
Dimensions and Proportions.					
1. Type of boiler	....	Babcock & Wilcox.	Babcock & Wilcox.		Babcock & Wilcox.
2. Number in use	....	1	1		1
3. Diameter of boiler drum	Ins.	....	....		2-36
4. Length of boiler drum	Ft.	....	....		23.25
5. Width of grate	Ins.	78	78		78
6. Length of grate	"	84	84		84
7. Number of tubes in boiler	....	....	....		126
8. Diameter of tubes	Ins.	....	....		4
9. Length of tubes	Ft.	....	....		18
10. Diameter of dome	Ins.				
11. Height of dome	"				
12. Total water-heating surface per boiler	Sq. ft.	2,758	2,758		2,789
13. Grate surface per boiler	"	45.5	45.5		45.5
14. Air space in grate, per cent	Ins.	21	21		21
15. Width of metal in bars	"				
16. Distance of grate (dead plate) to shell	"				
17. Distance of flat bridge wall to shell	"				
18. Total tube cross section	Sq. ft.				
19. Ratio of water-heating surface to grate surface	....	60.6	60.6		61.2
20. Ratio of tube cross section to grate surface					
21. Area of stack	Sq. ft.				
22. Height of stack above dead plate	Ft.	133	133		192
23. Ratio of stack area to grate surface					
24. Ratio of stack area to tube area					
Average Pressures.					
25. Atmospheric pressure per barometer (mercury column)	Ins.	29.70	29.90		29.38
26. Steam pressure in boiler by gauge	Lbs.	87	85		98
27. Absolute steam pressure	"				
28. Force of chimney draught, in inches of water	Ins.	0.41	0.51		1.16
28½ Force of furnace draught, in inches of water	"	0.26	0.34		0.61
Average Temperature.					
29. Of external air	° F.	76	69		32
30. Of fire room	"	84	79		36
31. Of steam	"				
32. Of feed water	"	154.7	152.8		38
33. Of escaping gases	"	365	388		538
Fuel.					
34. Total amount of coal consumed	Lbs.	8,700	11,285		12,600
35. Moisture in coal	Per cent.	3.63	3.38		4.00
36. Dry coal consumed	Lbs.	8,385	10,905		12,096
37. Total ash and refuse	"	775	1,058		1,229
38. Percentage of ash and refuse in dry coal.	Per cent.	9.24	9.70		10.16
39. Total combustible (dry weight of coal less refuse)	Lbs.	7,610	9,847		10,867
Results of Calorimetric Tests.					
40. Percentage of moisture in steam, fraction of one per cent	Per cent.	0.167	0.172		0.550

SHEET No. 4.—*Continued.*

Number of Trial Date of Trial		332 7/17/'95.		333 7/18/'95.		334 7/26/'95.	
Type of Boiler		Double-deck Babcock & Wilcox.					
Water.	Units.		Including water back.		Including water back.		Including water back.
28. Total weight of water pumped into boiler and apparently evaporated	Lbs.	99,787		177,630		133,548	
29. Water actually evaporated, corrected for quality of steam, etc.	"	99,587		177,452		133,281	
30. Equivalent water evaporated into dry steam from and at 212° Fahrenheit	"	115,023	117,384	202,451	205,782	152,607	155,529
31. Equivalent water evaporated into dry steam from and at 212° Fahrenheit per hour	"	12,780	13,043	20,245	20,578	15,261	15,553
32. Total heat derived from fuel per lb. of coal	B. T. U.	......	......	......	......	......	......
33. British thermal units by analysis per lb. of coal	"	......	......	......	......	......	......
34. Efficiency of boiler	%	......	......	......	......	......	......
Economic Evaporation.							
35. Water actually evaporated per lb. of dry coal from actual pressures and temperatures	Lbs.	......	......	......	......	......	......
36. Equivalent water evaporated per lb. of dry coal from and at 212° Fahrenheit	"	9.36	9.55	8.92	9.07	7.91	8.06
37. Equivalent water evaporated per lb. combustible from and at 212° Fahrenheit	"	11.31	11.53	11.00	11.18	10.08	10.28
Rate of Evaporation.							
38. Water evaporated, from and at 212° Fahrenheit, per hour, per sq. ft. of Heating surface	Lbs.	3.03	......	4.77	......	3.61	......
39. Water evaporated, from and at 212° Fahrenheit, per hour, per sq. ft. of Grate surface	"	185.5	......	293.6	......	221.5	......
Rate of Combustion.							
40. Dry coal burned per sq. ft. grate surface per hour	Lbs.	19.8	......	32.9	......	28.0	......
41. Lbs. of coal per horse-power developed	"	3.68	......	3.98	......	4.36	......
Horse-Power.							
42. On a basis of 30 lbs. of water evaporated per hour from temperature of 100° Fahr. into dry steam at 70 lbs. gauge	H. P.	370.4	378.0	581.0	596.5	442.3	450.8
43. Horse-power, builders' rating at sq. ft. per horse-power	"	375.0	375.0	375	375	375	375
44. Per cent. developed above or below rating	%	—1.3	......	+55.0	......	+16.6	......
45. Sq. ft. of heating surface per horse-power developed	Sq. ft.	11.4	......	7.27	......	9.55	......

3. Stoker engines use from one-fifth to two-fifths of one per cent of the steam generated.

4. Fan blasts use from three to five per cent. of the steam generated.

5. Steam blasts use from five to eleven per cent. of the steam generated.

6. A defect, common to each of the stokers named in this paper, is a too scanty air space in the grate.

7. Neither stoker will develop as much capacity as will hand firing with stationary grates, having the same draught and coal conditions. Stokers, however, are not only more constant in the power developed, than is a hand-fired grate, but are more responsive to fluctuations in the power demands. The stoker is always in the condition that a hand-worked fire is in just after its cleaning—*i.e.*, always clean and "ready for a pull."

DISCUSSION.

Mr. William H. Bryan.—This paper is an able and valuable contribution to the literature of boiler appliances.

I violate no confidence in stating that mechanical stokers have, as a rule, failed utterly when using the low-grade coals common in this part of the country (St. Louis). Hundreds of the most expensive types have been applied in this city, and less than a dozen remain in use to-day. Stokers of national reputation, and of established merit with good fuels, have proved themselves unfit for use with our common coals, and I believe it would be a matter of some difficulty to give away a stoker of even the best makes in this city to-day. The greatest difficulties have come from the large percentages of ash, clinker, and sulphur in the coal, which form incombustible matter very difficult to handle. Furthermore, they have not responded readily to sudden and extreme changes of load, and do not seem capable of being overworked to any great extent. Not only the first cost, but the cost of maintenance and repairs, has in most cases been enormous. Furthermore, the claimed improvements in fuel efficiency, and reduction of the smoke, have not always been realized. Good hand firing has nearly always shown better results. Perhaps when the Western steam user gets out of the idea that it is good engineering to work a boiler 100 per cent. above its rating regularly and without notice, the mechanical stoker may have a better show.

SHEET No. 5.—*Continued.*

TRIALS MADE AT		WARREN'S PAPER MILLS, CUMBERLAND MILLS, ME.		DUQUESNE STEEL WORKS, DUQUESNE, PA.	
Number of boiler test		Test 330.	Test 331.	Test.	Test 278.
	Units.				
Date of trial		7/9/95	7/10/95		1/25/95
Duration of trial		10	10		8
Water.					
41. Total weight of water pumped into boiler and apparently evaporated	Lbs.	81,750	109,490		106,188
42. Water actually evaporated, corrected for quality of steam, etc	"	81,614	109,202		
43. Equivalent water evaporated into dry steam from and at 212° F	"	89,530	120,122		129,488
44. Equivalent water evaporated into dry steam from and at 212° F. per hour	"	8,953	12,012		16,186
45. Total heat perived from heat in British thermal units per pound of coal	B. T. U.				
46. British thermal units by analysis per pound of coal	"				
47. Efficiency of boiler	Per cent.				
Economic Evaporation.					
48. Water actually evaporated per pound of dry coal from actual pressures and temperatures	Lbs.				
49. Equivalent water evaporated per pound of dry coal from and at 212° F	"	10.67	11.01		10.70
50. Equivalent water evaporated per pound of combustible from and at 212° F	"	11.76	12.19		11.90
Rate of Combustion.					
51. Dry coal actually burned per square foot of grate surface per hour	"	18.4	23.9		33.2
52. Combustible burned per hour per square foot of grate surface	"				
53. Combustible burned per hour per square foot of water-heating surface	"				
Rate of Evaporation.					
54. Water evaporated from and at 212° F. per hour per square foot of grate surface	"	196.8	264.0		355.7
55. Water evaporated from and at 212° F. per hour per sq. ft. of water-heating surface	"	3.25	4.36		5.80
Commercial Horse-power.					
56. On the basis of 30 lbs. of water per hour evaporated from temperature of 100° F. into steam at 70 lbs. gauge pressure	H. P.	259.5	348.2		468.8
57. Horse-power, builders' rating, square feet per horse-power	"	240	240		250
58. Per cent. developed above rating	Per cent.	8.1	45.1		87
59. Dry coal burned per hour per boiler horse-power developed	Lbs.	3.23	3.13		3.22
GENERAL REMARKS.					
Kind of coal used. Slack from		"Columbian," W. Va.		Connellsville, Pa.	
Appearance of coal					
Percentage of lumps					
Percentage of small coal					
Percentage of slack	Per cent.	90	90		100
Condition of weather		Overcast, rain.	Fair.		
Direction of wind		S. by W.	N. by W.		E.
Force of wind		Light airs.	Light Breeze		Light Breeze.
Thickness of fires in front	Ins.	5¼	5¼		5¼
Speed of grate in feet per hour	Ft.	11.87	13.75		14.38

NOTE.—Trial 278 was run jointly by Mr. Daniel Ashworth, Pittsburg, and J. M. Whitham.

3. Stoker engines use from one-fifth to two-fifths of one per cent of the steam generated.

4. Fan blasts use from three to five per cent. of the steam generated.

5. Steam blasts use from five to eleven per cent. of the steam generated.

6. A defect, common to each of the stokers named in this paper, is a too scanty air space in the grate.

7. Neither stoker will develop as much capacity as will hand firing with stationary grates, having the same draught and coal conditions. Stokers, however, are not only more constant in the power developed, than is a hand-fired grate, but are more responsive to fluctuations in the power demands. The stoker is always in the condition that a hand-worked fire is in just after its cleaning—*i.e.*, always clean and "ready for a pull."

DISCUSSION.

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I violate no confidence in stating that mechanical stokers have, as a rule, failed utterly when using the low-grade coals common in this part of the country (St. Louis). Hundreds of the most expensive types have been applied in this city, and less than a dozen remain in use to-day. Stokers of national reputation, and of established merit with good fuels, have proved themselves unfit for use with our common coals, and I believe it would be a matter of some difficulty to give away a stoker of even the best makes in this city to-day. The greatest difficulties have come from the large percentages of ash, clinker, and sulphur in the coal, which form incombustible matter very difficult to handle. Furthermore, they have not responded readily to sudden and extreme changes of load, and do not seem capable of being overworked to any great extent. Not only the first cost, but the cost of maintenance and repairs, has in most cases been enormous. Furthermore, the claimed improvements in fuel efficiency, and reduction of the smoke, have not always been realized. Good hand firing has nearly always shown better results. Perhaps when the Western steam user gets out of the idea that it is good engineering to work a boiler 100 per cent. above its rating regularly and without notice, the mechanical stoker may have a better show.

Personally, I had great hopes of securing excellent results from stokers, and made numerous experiments with them myself, but have been sadly disappointed. I trust, however, that engineers working in that field will not lose hope, but will continue their efforts. I for one would hail with rejoicing the advent of a mechanical stoker which would meet the difficult conditions surrounding boiler practice in this part of the country.

Mr. William Kent.—I would like to ask Mr. Bryan if the conditions are much worse here than in Chicago.

Mr. Bryan.—I think our coals run lower. We have very few of the high grades coming here at all.

Mr. Kent.—They are using stokers in Chicago.

Mr. A. A. Cary.—I notice the author calls his paper "Experiments with Automatic Mechanical Stokers." Those who are acquainted with stokers of these types can judge whether the term "automatic" is justified or not. The real automatic stoker, in my opinion, would be one similar to the type which I had the chance to erect this spring in New York city at the Electrical Exposition. I placed two Root boilers aggregating 500 horsepower in capacity, and under them the Wilkinson stoker with the coal fed from overhead hoppers by means of a Hunt conveyor from the bins. To make the combined plant still more automatic, the speed of the engine driving the mechanism of the stoker was controlled by a damper regulator attachment so that when the pressure in the boiler fell the engine would run faster and feed more coal. The steam jets of the stoker were similarly controlled so that with falling steam pressure the jets opened wider, thus hastening the fire The ordinary damper regulator attachment operated the usual flue damper.

There is another stoker which the author does not mention which ought to overcome some of the objections raised against stokers in this part of the country. I described it at the last meeting of the Society in New York in discussion of Mr. Emery's paper, and there is another operating upon somewhat similar principles which is built in Chicago. The principle of the American and the Jones stokers—which are both underfed stokers —is somewhat that of a gas producer. The fresh coal from the hopper is forced by the feeding mechanism upwards from below underneath the layer of incandescent coke which forms the top. The gases distilled off rise through the incandescent coke

of Chemistry, 1868, dries one to two grammes, after pulverizing, one hour at 115 degrees C.

Fischer also quotes Regnault (*Ann. de Min.*, iii., 12, 161), who asserts that moisture determinations at 100 degrees are inexact if the coal contains any clay, since the latter gives up its water at a red heat only.

(7) Richters (*Dingl.*, 1870, 195, 320), quoted by Fischer, puts fine pulverized coal first under a bell near a cup with water, lets it stand at 15 degrees, and then dries it at 100 degrees.

Fischer gives some experiments showing these methods to be inexact. Also others showing that in three hours coal heated to between 100 and 110 degrees lost 0.125 per cent. CO_2 and 0.07 per cent. CH_4.

(8) Fischer then gives as his rule: "Heat two to four grammes between two watch glasses, or in a receptacle with well-fitting cover, two hours at 100 to 110 degrees C. in an air bath."

(9) F. W. Dean and Dexter Bracket, "Test of Louisville Pumping Engine": "Samples of the coal were taken daily and the amount of moisture determined by drying on top of the boiler flue." The results were:

Pocahontas coal, three samples, 2.25 per cent., 2.8 per cent., and 2.74 per cent. Chemist's report, 1. 8 per cent.

Pittsburg coal, 0.6 per cent., 0.7 per cent., and 0.8 per cent. Chemist's report, 0.73 per cent. Mr. Dean recommends six hours only. (*Trans.* A. S. M. E., xvi., p. 963.)

(10) R. C. Carpenter, *Experimental Engineering*, p. 458: "Put 100 pounds of coal in a box and dry in a hot place twenty-four hours."

(11) Private letter from an engineer of reputation: "Dry 100 pounds of coal in galvanized iron pan, in warm, dry room, with air circulation, a sufficient length of time to ensure its being perfectly dry."

(12) From another engineer: "Dry at 80 degrees a time, according to size and moisture in sample."

(13) From another engineer: "Dry 25 to 100 pounds eight to ten hours at 200 degrees to 250 degrees Fahr., time also according to moisture."

(14) From another engineer: "Dry in a current of hot air at 150 degrees Fahr. for six hours." Is also satisfied with drying twelve hours at 110 degrees Fahr. over a boiler.

The following also include the proximate analysis of coal. Mr.

DCXCI.*

DETERMINING MOISTURE IN COAL.

BY R. S. HALE, BOSTON, MASSACHUSETTS.

(Junior Member of the Society.)

THE work of the following paper was done for the Steam Users' Association of Boston, organized by Mr. Edward Atkinson, of which Mr. Geo. Atkinson is secretary, and Prof. Peter Schwamb director. From its nature its only use will be in aiding the standardizing of boiler tests by all engineers, and I therefore, after consultation with one of the Society's Committee on Boiler Tests, and with the permission of the above gentlemen, take pleasure in offering it to the Society.

In a partial review of the literature of the subject, the following statements of methods have been found:

(1) 1886 Boiler Test Committee, American Society Mechanical Engineers: "The coal must be dry; or if wet, a sample must be dried carefully and a determination of the amount of moisture in the coal made, and the calculation of the results of the test corrected accordingly."

(2) G. H. Barrus, *Boiler Tests*, p. 14: "When the coal is moist a sample is selected and dried 24 hours, and the quantity of moisture determined by a comparison of the wet and dry weights."

(3) F. Fischer, *Chem. Tech. v. d. Brennstoffe*, p. 107, gives as a common rule, "one to five grammes are dried at 100 to 110 degrees C. until two successive weighings give the same result." This is also quoted from Kerl, *Probirbuch*, p. 131, and Stein, *Untersuchung der Steinkohle Sachsens*, p. 14.

(4) (5) Fischer also quotes Schondorf, who dries at 90 degrees C., and Richardson, who dries at 100 degrees C.

(6) Hinrichs, quoted by Fischer, and also in *American Journal*

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* Presented at the St. Louis meeting (May, 1896) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

of Chemistry, 1868, dries one to two grammes, after pulverizing, one hour at 115 degrees C.

Fischer also quotes Regnault (*Ann. de Min.*, iii., 12, 161), who asserts that moisture determinations at 100 degrees are inexact if the coal contains any clay, since the latter gives up its water at a red heat only.

(7) Richters (*Dingl.*, 1870, 195, 320), quoted by Fischer, puts fine pulverized coal first under a bell near a cup with water, lets it stand at 15 degrees, and then dries it at 100 degrees.

Fischer gives some experiments showing these methods to be inexact. Also others showing that in three hours coal heated to between 100 and 110 degrees lost 0.125 per cent. CO_2 and 0.07 per cent. CH_4.

(8) Fischer then gives as his rule: "Heat two to four grammes between two watch glasses, or in a receptacle with well-fitting cover, two hours at 100 to 110 degrees C. in an air bath."

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Pocahontas coal, three samples, 2.25 per cent., 2.8 per cent., and 2.74 per cent. Chemist's report, 1. 8 per cent.

Pittsburg coal, 0.6 per cent., 0.7 per cent., and 0.8 per cent. Chemist's report, 0.73 per cent. Mr. Dean recommends six hours only. (*Trans.* A. S. M. E., xvi., p. 963.)

(10) R. C. Carpenter, *Experimental Engineering*, p. 458: "Put 100 pounds of coal in a box and dry in a hot place twenty-four hours."

(11) Private letter from an engineer of reputation: "Dry 100 pounds of coal in galvanized iron pan, in warm, dry room, with air circulation, a sufficient length of time to ensure its being perfectly dry."

(12) From another engineer: "Dry at 80 degrees a time, according to size and moisture in sample."

(13) From another engineer: "Dry 25 to 100 pounds eight to ten hours at 200 degrees to 250 degrees Fahr., time also according to moisture."

(14) From another engineer: "Dry in a current of hot air at 150 degrees Fahr. for six hours." Is also satisfied with drying twelve hours at 110 degrees Fahr. over a boiler.

The following also include the proximate analysis of coal. Mr.

Kent has shown that the heating power follows the proximate analysis very closely. The different methods here given as authoritative suggest that perhaps the three per cent. difference found by Mr. Kent may be due to incorrect methods of analysis and not to failure to follow his law. Hinrichs's paper on the proximate analysis, published in 1868, should be referred to by any one who wishes to follow up the subject. One of his results may be quoted, that "if coal be dried and then proximately analyzed, the sum of the moisture and volatile matter is some two or three per cent. less than if they are both driven off at once." He found that if the same method was always used, results could be repeated to one-tenth per cent., but that different methods differed fifteen per cent. on the same sample. The temperature, time, amount of sample, etc., etc., are all important in getting the same results from similar samples.

(15) Blair, *Chemical Analyses of Iron*, 1891, p. 274: *Moisture.*—Dry one to two grammes one hour at from 105 to 110 degrees C. *Volatile Matter.*—Weigh one to two grammes undried powdered coal into platinum crucible; heat, with cover on, three and one-half minutes with Bunsen burner, then, without cooling, three and one-half minutes with blast lamp. Loss is sum of moisture and volatile matter. *Fixed Carbon.*—Completely burn above; difference is fixed carbon and residue is ash (earthy matter).

(16) Arnold, *Steel Works Analyses*, 1895, p. 295: *Moisture.*—Dry two grammes about one hour at a temperature slightly over 100 degrees C. *Coke.*—Put twenty-five grammes powdered coal in clay crucible; heat in muffle until no gas appears from beneath cover of crucible. *Ash.*—Two grammes in platinum crucible are completely incinerated.

(17) M. Troilius, *Notes on Chemistry of Iron*, 1886: *Moisture.*—Two grammes of powdered coal are dried one hour at 120 degrees C. *Volatile Matter.*—Heat this same coal over Bunsen burner till no flames are given off. *Ash.*—Completely incinerate residue of above.

(18) N. W. Lord, *Notes on Metallurgical Analyses*, 1893: *Moisture.*—Dry one gramme one hour at 105 degrees C. in platinum crucible. *Volatile Matter.*—Same as Blair, except that the dried coal is used.

(19) F. A. Cairns, *Quantitative Analysis*, 1880: *Moisture.*—Dry two grammes pulverized at 115 degrees for thirty minutes;

They were then left in the laboratory until the next morning, when:

TIME. H. M.	Weight in Grammes.
8 53	18.1246
10 —	18 1235

Here the coal, though starting in a moderately dry condition (less than two per cent.) lost seven-tenths of one per cent. The joint between the two glasses was not perfect, as could be seen on inspection.

Instead of having some glasses ground, it was found more convenient to use weighing bottles with ground-glass stoppers.

Bottle.

TIME. H. M.	Weight in Grammes.
9	Tare, 185.8566
9 05	With coal, 191.8000
	Net coal, 5.9434
9 32	191.2995
9 54	191.2995
Next morning 8 50	191.2961

This shows that even with ground glass there is danger of some leak, but that it was quite slight, less than one-tenth of one per cent. in twelve hours.

Two experiments were then made with the oven at about 220 degrees C.

Four samples of the same coal, put in the oven together and taken out at various intervals, showed the following result (between one and two grammes of coal were used in each):

18′	sample lost	1.50	per cent.	All of original weight in whole time heated.
46′	" "	.86	"	
68′	" "	.71	"	
143′	" "	2.23	"	

This shows, if the samples were the same (and the coal had been so thoroughly mixed that there was but little chance that they were not), first a loss, then a gain, then a loss.

This was tried again, the only difference in the coal being that the second lot had been kept in a separate and not so tightly covered receptacle for about a week, and was then heated to 230 degrees C. in the oven:

Glass No. 1.

TIME. H.	M.	Weight in Grammes.	
		Tare, 4.1053	
		With coal, 5.0869	
1	17		Placed in oven at about 100 degrees C.
1	50		Taken from oven and placed in desiccator above calcic chloride.
2	07	5.0743	And replaced in desiccator.
2	33	5.0745	And replaced in desiccator.
3	07	5.0750	Left to stand in balance box with door closed, and two beakers of sulphuric acid in box.
3	09	5.0755	
3	16	5.0761	
3	23	5.0765	
3	39	5.0769	

The net weight of the coal was 0.9816 grammes, and the gain between two hours thirty-three minutes, and three hours thirty-nine minutes, was over one-fourth of one per cent., although in certainly a moderately dry atmosphere. It was then placed in the oven again until four hours twenty minutes.

Glass No. 1—*Continued.*

TIME. H.	M.	Weight in Grammes.	
3	39		Placed in oven at about 100 degrees C.
4	20		Taken out and placed in desiccator.
4	40	5.0745	Replaced in desiccator and left until the next morning.
9	37	5.0750	

This shows that the gain was probably due to exposure to the air while transferring from the desiccator to the balance, and that the balance box was probably not air tight.

If another watch glass had been ground to fit the first and make an air-tight joint, the gain of weight could probably have been avoided. Without a ground joint the protection was not sufficient, as the following shows :

Glasses 11, 15. *and Clip holding them together.*

TIME. H.	M.	Weight in Grammes.
4	04 P. M.	Tare, 17.2408
4	24 "	With coal, 18.1297
		Net coal, 0.8889
4	48 "	18.1283

The temperature over the boilers, as shown by a thermometer suspended directly adjoining the coals, was 43 degrees to 45 degrees C.

The pail from which the above were taken, containing about 733 grammes, and some ten to twelve centimeters deep, was dried over the boiler for twenty-three and one-half hours. Result, loss five and three-tenths per cent.

The apparent gain of weight in the thin sample after seven and one-half hours indicates the strong probability that oxidation takes place even at such temperature as is found over boilers. The deep samples show that this temperature is not enough to dry coal in eight or even twenty-four hours unless good chance is given for air to reach all parts of the coal. In my own practice I once kept a sample less than four inches deep over a boiler a full week before it ceased to lose weight.

To see whether one hour was sufficient to dry a very wet coal in a very small sample, a lump of soft coal was broken up and partly screened. Three samples were taken, one consisting of one lump, the second of fine coal to which, after weighing, a portion of water was added; the third was also fine. These were all dried for one hour at about 100 degrees C., with the following result:

Lump coal, initial weight	3.7716
Lost	.0071
Percentage of loss	.019
Fine coal, not wetted, initial weight	1.7243
Lost	.0051
Percentage of loss	.30
Fine coal, initial weight	1.6840
Water added	.3109
Percentage of water added	12.5
Lost below original weight	.0043
Percentage of loss	.26

Here, although twelve and one-half per cent. more of water had to be evaporated, the difference was only four hundredths of one per cent. in the final result of the two fine coals, while the lump only lost about two-thirds as much as the fine.

Another lump of coal was taken from a wet lot of soft coal and broken into smaller lumps. One of these smaller lumps was broken in two; one half was ground in a mortar, and the other left as a lump, making two samples. Two more samples

34′	sample	lost .07	per cent.	All of original weight in whole time heated.
98′	"	gained .65	"	
242′	"	" .84	"	
328′	"	lost .73	"	

The difference in time may be due to the coal or to the temperature being not quite the same. The alternate gain and loss is easily explainable as follows: First, moisture (H_2O) is driven off. Then the hydrogen and carbon oxidize to H_2O and CO_2, and the weight increases. Then the combined H_2O and CO_2 thus formed are driven off, and the weight decreases. Probably both actions are going on simultaneously.

These experiments are at 220 degrees C., but Fischer's experiments, quoted above, show that the action may probably occur at 100 degrees, though perhaps not quite so rapidly. It would probably, like rot in wood, be promoted most by alternations of heat and cold, of moist air and dry air.

Another lot of soft coal, quite moist, was then taken, the larger lumps were removed, and the remainder was thoroughly mixed. Six bottles were filled as follows: Two with about ten grammes each, say two centimeters deep; two with about twenty-four grammes, say four centimeters deep; two with about forty-five grammes, say eight centimeters deep. The bottles were about nine centimeters tall and two to three centimeters in diameter.

One bottle of each depth was placed on top of a battery of two boilers at about 5.30 P.M., after weighing The other three were allowed to stand in the laboratory over night and placed over the boilers at 9 A.M. the next morning. At 4.30 P.M. all six were removed for weighing. While on the boilers they were protected from dust particles. The results were:

Thin coal in seven and one-half hours lost	6.41	per cent.
" " twenty-three hours lost	5.78	"
Medium-depth coal in seven and one-half hours lost	5.9	"
" " " twenty-three hours lost	5.71	"
Full depth coal in seven and one-half hours lost	4.88	"
" " " twenty-three hours lost	6.25	"

The two full-depth samples were then dried an hour at about 100 degrees C. in the oven, with the result:

Seven and one-half hours sample, total loss	5.8	per cent.
Twenty-three hours sample, total loss	6.4	"

Of the latter probably some are true chemical combinations, the others are combinations of various hydro-carbons with a certain number of molecules of water, in the same way that water of crystallization enters into various salts. These water molecules, in combination with the hydro-carbons, may pass off in dry air at a low temperature, or at 100 degrees C., or they may refuse to pass off at 200 degrees, or even 400 degrees C., just as the water in clay will not all pass off except at a red heat. These combinations are also probably very unstable, so that a reaction which does not take place at once may begin a little latter and then proceed or stop. Thus, when coal is heated, first the true H_2O and some of the combined H_2O may pass off, and at the same time some of the hydro-carbons take up O from the air and change into other combinations with combined H_2O as a part. Then this combined H_2O passes off, while more hydro-carbons are taking up more O_2 from the air. The exact gain or loss of weight in a given time would depend on which of these three sets of reactions had gone on farthest.

Some action certainly occurs even at ordinary temperatures, as is shown by the spontaneous combustion of coal. It is probable that for each temperature and degree of humidity of the air each coal tends towards some definite percentage of moisture, but that this percentage is continuously varying according to the previous history and treatment of the coal. A sample once heated to 100 degrees C. will never afterwards act just the same as a sample not so heated. I hope, before long, to make some investigations on coal dried in a nitrogen atmosphere.

DISCUSSION.

Mr. William H. Bryan.—I am sure that we all feel indebted to Mr. Hale for the investigation which he has made of this subject. I have more than once expressed my disapproval of the common method of drying a sample of the coal on top of the boiler flue, and thus determining its percentage of moisture, and making a corresponding reduction in the coal actually burned. It seems to me that we want to base all results on the coal as it actually comes from the mines. Such moisture as then exists in it is *characteristic* of the coal, and should be charged against it. Moisture which may have been added by rain, snow, or by wetting-down during unloading, should, so far as possible, be eliminated entirely. Wherever possible, I have the entire lot of coal to be burned were prepared in a similar way. A fifth sample was of fine coal from the original lot, which had been kept with the lumps in a corked bottle for about two weeks. On account of the closing of the laboratory, it was found necessary to dry these in two times of one-half hour each.

No. of Bottle.	Coal.	Weight of coal.	Lost first half hour.	Lost second half hour.	Total loss.
			Per cent.	Per cent.	Per cent.
4	Fine	2.3800	3.93	.30	4.23
5	Corresponding lump	3.2381	2.90	.80	3.70
7	Fine	2.4607	3.52	.23	3.75
6	Corresponding lumps	4.9686	1.55	.30	1.85
3	Original fine	2.1971	5.71	.43	6.14

Here we see that lump coal takes on and gives up weight far more slowly than the fine coal, and very irregularly. The lumps of 6 had as good a chance to take on and give up moisture as either 4, 5, or 7.

Some of the conclusions that may be drawn from the above are as follows:

First. That if we use a large sample we must dry it a long time to dry the interior, and before the interior is dried the exterior will begin to oxidize.

Second. If we allow lumps to remain in the sample, the lumps will not have lost their moisture when the fine coal has begun to oxidize.

Third. If we pulverize the coal, this will of itself cause a certain loss. It has not been thought necessary to experiment on this.

Fourth. If moisture corrections are to be allowed, a standard method should be adopted, giving the method of selecting the sample, the method of crushing the lumps in it, the size screen it must finally pass through, the precautions to be taken if any time elapses between its selection and the moisture determination, the size of the sample on which the determination is finally made, the method, temperature and time of drying.

A theory which might account for the action of the coal is as follows: Coal, exclusive of the ash, consists chiefly of C H, and O, with a little N and S. Some of the C exists as C. The rest of the coal consists of various combinations of C with H, of H with O (this as H_2O). and of combinations of C, H, and O.

that its moisture will evaporate? The advantage is, we can take this out and weigh it every half hour or so. I think in testing a series of coals this will give us relative results; and if it has a constant error we may determine that later by the chemist's work, and be able to correct our results accordingly. I would like to know if any one has seen the use of such an apparatus, and if they have any opinion of how it would work.

Mr. Gustavus C. Henning.—I have an opinion on that. We have just heard that these Western coals have a good deal of volatile gas. If the steam heats the coal to 212 degrees, we might lose the volatile part of that coal. If I were to make an amendment to that apparatus I would simply do this—use it practically as it is and have a little chamber with some calcium in it; pass air over it and through the coal at ordinary temperatures—the freezing point, if you like. Passing the air over calcium will absorb the moisture, and thereby the coal will not be heated, and there will be much less chance of oxidation, which, as some say, does occur in passing warm air through bituminous coals. Most hard coals would not be affected. But I think heating by steam is not the best thing to do fôr great quantities of coals used, especially those mined in the Alleghanies and west of them. Inasmuch as the drying power of dry air is much greater than that of air heated by steam without removing moisture, better and quicker results will be obtained. I do not see why this method should not be used. It is very simple. We can in almost all cases get a little air pressure or suction, to drive or draw air through the sample of coal, and calcium is readily obtainable and inexpensive; this will readily absorb the slight moisture which is in the air, and can be used over and over again.

Mr. H. H. Suplee.—Mr. Henning has brought up one point which I think bears at once on the open-air method of drying spoken of. I have had no experience in drying coal, but I have had experience in drying other materials, and I have found it is necessary to consider the humidity of the atmosphere; under some circumstances the material will scarcely dry at all, and under others very readily. The time element depends on the humidity of the atmosphere, and also the method in which it is exposed. I think in the apparatus which Mr. Kent proposes, that even with a central tube there would be such a difference in temperature that the drying would be unequal, and the outer portions would begin to gain before the inner portions began to lose. I dried in the open air for at least twenty-four hours before the test, which usually eliminates all the accidental or mechanical water. I then burn the coal in this condition without any correction whatever for moisture, as I see no reason why the boiler is entitled to any allowance on this score.

If only a small sample is dried, how can we be sure it is a characteristic sample? And how shall we make the correction properly? Shall we only deduct its weight from the coal charged? Shall we also deduct the heat required to evaporate it? Even then, have we measured its harmful effect fully?

Prof. J. H. Kinealy.—It seems to me that if we are to determine the moisture of the coal it ought to be done in the laboratory. It ought not be done in the boiler-room at all. It is a chemical question. We should determine all the impurities of the coal in the laboratory, not in the boiler-room; and the man who does the work should be a man skilled in that kind of work, and it is better to have a chemist to do it.

Mr. William Kent.—I did the very thing that Professor Kinealy recommends. I sent it to a laboratory and got two different results from two different laboratories from the identical sample of coal.

In regard to what Mr. Bryan said about drying the coal, I think it would be very good if we could always do that. I once had to make a test, lasting a whole week, in a cellar, and running three or four hundred horse-power night and day, and the coal was received mixed with water and snow and ice, and it was impracticable to dry it at all. It was dripping coal, and we had to dry samples of it on the flue and got about 7 per cent. of moisture. Mr. Hale's paper certainly shows that all determinations of moisture are liable to error. I have thought of a plan for determining moisture in coal that I would like to submit to the Society and ask if any one knows about such a method. Get a galvanized ash or garbage can which will hold about 50 pounds. Put a flange on the outside. Set it inside of another ash can a trifle larger, and connect a steam pipe to one side and put a little drip pipe at the bottom. Felt the whole apparatus so as to keep it hot. Put in the middle, say, a tin pipe 4 or 5 inches in diameter, with a lot of holes dented in it, so that the moisture coming from any part of the coal has only to go into this pipe to get out; and with this layer of coal only 4 or 5 inches thick. The problem is, how long will it take for that coal to get heated up to 212 degrees, so that its moisture will evaporate? The advantage is, we can take this out and weigh it every half hour or so. I think in testing a series of coals this will give us relative results; and if it has a constant error we may determine that later by the chemist's work, and be able to correct our results accordingly. I would like to know if any one has seen the use of such an apparatus, and if they have any opinion of how it would work.

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Mr. A. A. Cary.—I am inclined to agree with Professor Kinealy, that it is not the simplest thing to expel the moisture from coal. I learned recently that the method pursued at Sibley College, under Professor Carpenter's direction, for drying coal, is to put their sample in a vessel or flask with a neck or opening. The drying in this vessel is continued until a slight showing of ignition appears where the gas given off from the coal, escaping at the neck, meets a small flame whose direction is across the mouth of the flask. This indicates that the beginning of distillation has been reached and volatile matter is escaping. The sample of coal is then weighed and the loss is called the moisture. If coal is heated to 212 degrees, it will not be long before the volatile gases begin to be driven off.

Mr. Carleton W. Nason.—Although I believe that the testing of coals should almost invariably be referred to the chemist and laboratory, there are times when the determination of water alone is desirable, and this can, in my opinion, be done in the boiler-room with considerable accuracy and with a comparatively simple and inexpensive apparatus.

In a conversation with Mr. Kent yesterday, I suggested to him that instead of taking the difference between the weights of coal before and after drying as a means of hygrometric analysis, by the method with iron cylinder and central vent tube just shown by him, it would be better to collect the water driven off by heat and weigh it.

For this purpose I propose to use a steam-jacketed cylinder containing, in order to obtain a fair average of the coal pile, not less than 50 pounds of fuel. Its top is to be closed with a bolted cover, into which is to be connected a half-inch pipe through which all vapors and steam will pass into a worm, the latter being surrounded by iced water in a pail. Steam at any desired pressure from the boiler is to be admitted to the jacketed cylinder, by which the temperature of the whole mass is to be raised to a point considerably above 212 degrees. After vapor ceases to be discharged, the water is to be weighed and its weight compared with that of the coal, both before and after it has been dried.

While it is evident that much volatile hydrocarbon vapor will pass over with the steam, its escape in no way interferes with the water determination, for all steam will necessarily be condensed; it is, on the contrary, an advantage, for the difference in weight of coal after drying and that of the water collected will give an approximate weight of free hydrocarbon vapor contained in the coal sample.

Such an apparatus would have a distinct advantage over the cruder boiler-room methods hitherto used, where coal has been dried in the open air and only differences in its weight before and after drying taken, for the reason that a wide range in time and temperature is probably permissible without affecting the weight of water collected; while by long exposure to heat and high temperature the coal under examination would doubtless continue to lose weight, only the water given out would be condensed, and I believe by this method water analysis of duplicate samples can be repeated with but little variation in results.

Mr. Kent.—I neglected to state that an addition to that apparatus was a hood over the top and the pipe carrying the moisture into a cooling chamber, as Mr. Nason has suggested. My idea was to put it in a flask surrounded by water. The worm is a still better idea, of course.

*Mr. R. S. Hale.**—Mr. Bryan's method is, I take it, to get rid, as far as possible, of any abnormal amount of moisture before weighing the coal for the test. Of course, he recognizes that air-dried coal is not in exactly the same condition as when it came from the mine, but when testing two coals his method seems better than drying at a higher temperature and making a correction. When the object is to test the boiler, it is proper to correct for that part of the volatile constituents of the coal that we call "moisture" which has no heat value, just as it is proper to correct for a brick that some boy may have thrown into the coal cart or for the pieces of slate the miner has omitted to pick out when he mined the coal. But even in a boiler test as distinguished from a coal test it would seem advisable to air-dry the coal as Mr. Bryan suggests before making the other corrections.

Mr. Kent's and Mr. Cary's suggestions do not meet the difficulty that some of the water driven off at even ordinary tempera-

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* Author's closure, under the Rules.

tures, 80 degrees or 100 degrees Fahr., was very likely in chemical combination with the coal. In coal we always find some oxygen and some hydrogen even in the dryest coal, and if we heat the coal to a certain point we get some of this driven off as water, and if we heat it hotter still more comes off. It seems to the writer that Mr. Henning has struck the right idea, if we are going to make an absolute determination of the moisture, in keeping the coal at its normal temperature throughout. But the absolute determination is, perhaps, not necessary for technical work. We may not know the absolute strength of a piece of iron ;. we only know that if we test it in a government test piece we get a figure of so many pounds per square inch, and quite a different figure in a standard test piece. Will not one of these methods of drying at 100 degrees C. or 212 degrees Fahr. give us results that will be of more practical value in boiler and coal testing than even the absolute determination? The essential point seems to the writer that we should all use the same method; then, even if the results are not the absolute moisture, they will at least be comparative. Hinrichs found when proximately analyzing coal that he could repeat results for the volatile matter to $\frac{1}{10}$ per cent. if he used the same method, but got a variation of 15 per cent. with different methods, and the same thing holds true of the moisture determinations. Possibly two alternate methods might be recommended. One a method which could be employed by any engineer with a set of ordinary scales. For the other we should consult the chemists or even leave the method entirely to them, but we should feel sure that even the chemists used a standard method for our determinations instead of making their individual choice out of all the methods which have ever been proposed.

This correction is, however, a very small amount and of no practical importance, as it would seldom affect the results by even one one-hundredth of one per cent. The percentage of moisture in the steam is found by dividing the weight of water, as shown on the inner reading of the gauge, by the sum of this quantity and that shown on the attached gauge; the quality or percentage of dry steam by dividing the difference of the readings by the sum.

In the use of the instrument, the outer vessel and connected pipe through which the sample is obtained should be carefully clothed to prevent unnecessary loss of heat by radiation.

The total size of the instrument is about 10 x 2½ inches, and its weight about six pounds, so that it is in portable and convenient form.

The accuracy of the instrument depends first on the accuracy of the scales, both of which can be readily verified by experiment; second, upon the complete separation of the water from the steam by the separator. This was tested by a large number of experiments, by discharging the steam from the outer vessel through a throttling calorimeter. Nearly one hundred observations were made, the average results of which as given in the following table show the exhaust steam in the conditions tested to have a quality of 99.998 per cent. As it is certain that some loss of heat occurred between the two instruments, it is believed that we can consider with confidence the steam as passing from the inner into the outer vessel perfectly dry and saturated.

Table giving results of examination of quality of steam discharged from inner to outer vessel:

of the outside chamber. It is discharged from the outside chamber through an orifice 8 of known area in the bottom part, which is much smaller than any section of the passages through the calorimeter, so that the steam in the outer chamber suffers no sensible reduction in pressure by passing through the calorimeter. The pressure in the outer chamber, being the same as in the interior, has the same temperature, and consequently no loss by radiation can take place from the interior chamber except that which takes place from the exposed surface of the gauge glass. The pressure in the outer chamber, and also the flow of steam in a given time, is shown by suitably engraved scales on the attached gauge. The scale for showing the flow of steam is the outer one on the gauge and is graduated by trial, and gives the weight which is discharged in ten minutes of time.

By what is commonly known as Napier's law, the flow of steam through an orifice from a higher to a lower pressure is proportional to the absolute steam pressure, until the pressure against which the flow takes place equals or exceeds .6 of that in the vessel under pressure. The accuracy of this law has been discussed in a paper by Professor Peabody, vol. xi., p. 187, *Transactions*, and it has also been tested by experiments in Sibley College. The experiments in both cases indicate its substantial accuracy. The reading of the pressure gauge is proportional to pressures above the atmosphere, and hence the calibration curve will not give results proportional to gauge readings, and, furthermore, there will be a slight correction due to change in barometer reading. This latter correction is, however, exceedingly small, and will never make any sensible error in results. Thus a change in barometer of one inch would increase or diminish results by only one 230th part when the steam pressure is 100 pounds. This would seldom exceed one one-hundredth of one per cent. The values of the calibrations on the gauge can readily be verified by condensing the discharge steam for a given period of time.

The graduations of the scale 12 attached to the inner vessel show, when the index is set properly, the weight of water in pounds and hundredths which has been separated from the steam. This scale is graduated by actual calibration with water at a temperature of 100 degrees, and corrected for a coefficient of expansion so as to be as nearly as possible correct for water at a temperature corresponding to a steam pressure of 100 pounds.

This correction is, however, a very small amount and of no practical importance, as it would seldom affect the results by even one one-hundredth of one per cent. The percentage of moisture in the steam is found by dividing the weight of water, as shown on the inner reading of the gauge, by the sum of this quantity and that shown on the attached gauge; the quality or percentage of dry steam by dividing the difference of the readings by the sum.

In the use of the instrument, the outer vessel and connected pipe through which the sample is obtained should be carefully clothed to prevent unnecessary loss of heat by radiation.

The total size of the instrument is about 10 x 2½ inches, and its weight about six pounds, so that it is in portable and convenient form.

The accuracy of the instrument depends first on the accuracy of the scales, both of which can be readily verified by experiment; second, upon the complete separation of the water from the steam by the separator. This was tested by a large number of experiments, by discharging the steam from the outer vessel through a throttling calorimeter. Nearly one hundred observations were made, the average results of which as given in the following table show the exhaust steam in the conditions tested to have a quality of 99.998 per cent. As it is certain that some loss of heat occurred between the two instruments, it is believed that we can consider with confidence the steam as passing from the inner into the outer vessel perfectly dry and saturated.

Table giving results of examination of quality of steam discharged from inner to outer vessel:

SEPARATING CALORIMETER.

DETERMINATION OF QUALITY WITH SEPARATING CALORIMETER.					DETERMINATION OF QUALITY OF STEAM DISCHARGED BY SEPARATING CALORIMETER WITH THROTTLING CALORIMETER.		
Duration run, minutes.	Gauge pressure, pounds.	Pounds separated water in run.	Pounds condensed steam in run.	Quality steam, per cent.	Temperature in calorimeter.	Quality steam in exhaust from separating calorimeter.	No. of observations.
25	81.5	1.15	4.45	79.46	281	99.95	6
25	78.2	0.15	5.20	97.2	281.8	100.00	6
25	80.8	0.525	4.25	89.005	286.5	100.00	6
25	79.5	0.150	4.75	96.94	281.8	99.95	6
25	78.5	0.300	5.000	94.84	282.8	100.00	6
25	77.6	0.150	5.45	97.32	282.8	100.00	6
24	79.5	1.8	4.55	71.65	280.1	99.94	6
24	78.5	1.4	4.90	77.77	279.5	99.9	6
20	83.5	1.15	4.1	77.67	286.5	100.00	5
20	81.6	1.70	4.75	73.64	282.7	99.98	5
20	74.8	0.65	3.95	85.87	283.7	100.05	5
20	82.0	0.85	3.95	82.29	286.8	100.05	5
20	82.6	0.35	4.15	92.22	285.6	100.0	5
20	81.5	0.20	3.95	95.15	285.2	100.05	5
20	81.4	2.20	4.325	66.28	283.1	100.0	5
20	80.3	0.30	4.55	93.81	282.8	100.0	5
20	82.0	0.20	4.65	95.8	282.8	99.98	5
20	81.1	0.20	4.40	95.7	284.0	100.0	5

Average of 18 trials, involving 98 observations, 99.998.

It is also true that a considerable error in the weight of steam discharged will affect the results but very little, since in every practical case the moisture is a small percentage of the total. Thus, supposing that the results of our examination show five per cent. moisture, but that an error in the weight of the steam discharged of five per cent. has been made. In that case the correction to our result should be but .05 or one-twentieth of the results obtained, in this case amounting to one-fourth of one per cent. The above is an extreme case, and is several times greater than any that is likely to occur, as shown by the results of various tests quoted.

Third, the loss by radiation in the exposed portions of the water glass and fittings. This surface is a very small portion of he whole surface, and the loss by radiation is always an exedingly small amount. We have made a number of experients in Sibley College to determine this amount, and have conlered that in every case it affects the results less than errors of observation. We have tested this quantity by comparing the instrument with a throttling calorimeter taking steam of essentially the same quality, and the difference has always been a very small fraction of one per cent. Professor W. C. Unwin, in a paper before the Institution of Civil Engineers on the determination of the dryness of steam, also gives tests of this instrument as compared with a throttling instrument, and considers that

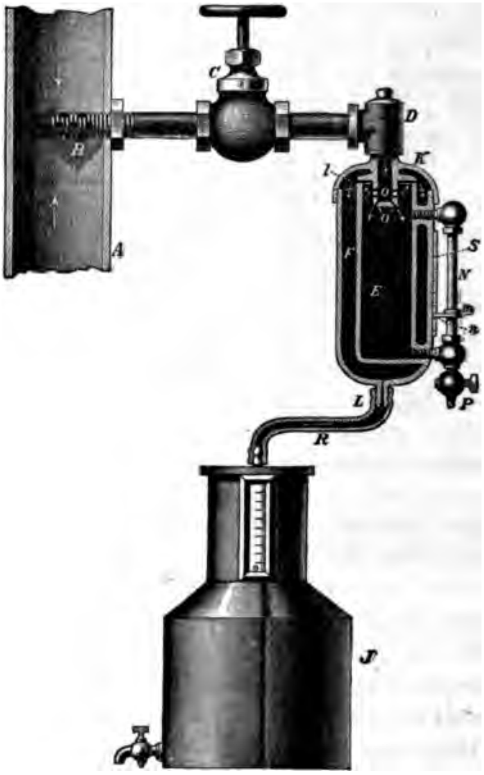

FIG. 131.

the results in every case practically confirm each other. It could if essential be tested by passing dry steam through the instrument.

An instrument somewhat like that described above has been in use some years in connection with a graduated condensing can, as shown in Fig. 131, for receiving the steam discharged from the outer chamber. This has proved a very serviceable instrument, but not as portable nor as convenient to use as the form described in this paper.

Still earlier forms of separating calorimeters were described by the writer in vol. xii., page 825, *Transactions*.

The question has recently been raised regarding the value of calorimetric determinations from the fact that great difficulty is experienced in obtaining a sample of steam which fairly represents the average in the steam pipe. This great variation of samples of steam was pointed out in a paper, "Notes Regarding Calorimeters," vol. xii., page 827, *Transactions*, and numerous experiments were cited showing great variation. Valuable information has also been laid before the Society by papers at the Detroit meeting by Professor Jacobus, and at the last meeting in New York by Professor Denton. The writer believes from occasional expressions seen in the technical press that there is a tendency to extend the application of the conclusions drawn from the experiments to a greater field than the experiments would warrant or the authors desire. The laboratories of Sibley College have also been engaged in the further investigation of this subject, and while these investigations are not concluded the writer feels that the following conclusions are justified and may in a certain measure serve to guide calorimetry practice.

They may be briefly stated as follows: First, the steam ordinarily discharged from a boiler of proper proportion and in good working condition carries an exceedingly small percentage of water. Second, a certain amount of water will be carried along by the steam in the form of vapor or small drops; that this amount varies somewhat with the velocity, but probably does not exceed two or three per cent. by weight, and furthermore, a fair sample of such steam is usually obtained by any of the ordinary methods in use. Third, water is sometimes thrown from the boiler in large amounts, and in such a case it will usually remain distinct from the steam and will pass along the bottom of horizontal pipes in a stream of greater or less depth, and will flow if moving downward in a vertical pipe in irregular positions depending upon its velocity and various other considerations. Steam carrying water in this way when ascending in a vertical pipe will probably be irregularly charged, and samples drawn from time to time are likely to vary greatly. This condition can usually be considered an abnormal one and probably cannot be fairly sampled by any method. In case large amounts

Any change of a machine which enables one thing to do the work formerly done by two things is an improvement, and the instrument described may be classed in the category of such improvements, but I have looked in vain through the paper for any feature which entitles the changed instrument to be called a *new form of calorimeter.*

It would avoid some confusion if the title of this paper were changed, for in one of the earlier volumes of the *Transactions* there is a paper on almost identically the same subject, though treating of a radically different instrument. I refer to the paper submitted by myself and describing the so-called "superheating" calorimeter.

There are some points in the paper to be criticised.

The professor states that "no loss by radiation can take place from the inner chamber except that which takes place from the exposed surface of the gauge glass." I am sorry to differ with the author on this point, for in this I believe he is wrong. There is a solid metal connection between the inner and outer chamber at the two points where the gauge-glass fittings are applied, and a solid screwed connection between the two at the entrance of the steam supply. If these connections were insulated so that no conduction of heat could take place from one to the other, the professor's statement would be warranted, but with the conditions as they exist, there is one unbroken continuity of metal from the inner chamber to the outer one, and any loss due to radiation from the exterior surface will be felt all the way through.

The paper gives the results of a test showing the apparent perfection with which the instrument separates the water from the steam. The calorimeter does this so perfectly that, according to the figures reported, only $\frac{2}{1000}$ of one per cent. of moisture remains in the steam. Such reputed perfection appears to me impossible, and I believe the figures given are in some way erroneous. The professor himself seems to question their reliability in saying "it is certain that some loss of heat occurred between the two instruments" (that is, between the outlet of the separating calorimeter and the inlet of the throttling instrument which was used for the comparison). Upon this point is it not true that there was even more loss than simply that occurring between the instruments? How about radiation from the outside of the apparatus? Assuming the steam to be dry on leaving the separating chamber, it certainly took on moisture in passing out through the surrounding jacket space before it reached the orifice of the outer chamber. Moisture would be formed on account of the radiation loss. The exterior may have been covered, but even with the best protection some loss occurred, and whatever it amounted to should have appeared in the indications of the throttling calorimeter beyond. The area of the exterior surface, according to dimensions given, was about one-half a square foot, and this would condense at least one-eighth of a pound of steam per hour. The quantity passing through in an hour, judging from the table given, is some 12 pounds. The radiation between the two instruments, then, is sufficient to condense at least one-ninety-sixth of the steam, or say one per cent. This is very different from the quantity actually indicated, according to the report, viz., $\frac{2}{1000}$ of one per cent.; and to my mind it throws serious doubt upon the accuracy of the test.

A remark in the paper, upon the subject of radiation from the water glass, is worthy of note. The statement is as follows: "This surface is a very small portion of the whole surface, and the loss by radiation is always an exceedingly small amount. We have made a number of experiments in Sibley College to determine this amount, and have considered that in every case it affects the results less than errors of observation. We have tested this quantity by comparing the instrument with a throttling calorimeter taking steam of essentially the same quality, and the difference has always been a very small fraction of one per cent."

If the comparisons referred to possess the same indications of unreliability as those given in the paper already noted, it seems to me that they are valueless. I don't know what others may think of the statement last quoted, but I, for one, consider it an indication of exceedingly rough experimental work, and hardly worthy of record in such a matter as this.

Now a word as to the instrument itself, which in reality does not possess the highest degree of utility.

A separating calorimeter for general testing work is not very useful. A throttling or wire-drawing calorimeter is all which is needed in nine cases out of ten, and no one would think of using the separating instrument universally, when for most cases the other is so much more convenient and accurate. Still, there are times when both are needed.

A gauge glass, which forms a necessity in this instrument, is an objectionable feature. It is always troublesome, and especially so at extremely high pressures.

The panacea for the objections noted is the Universal calorimeter, "1895 pattern," which has been associated with my name. I call it the "1895 pattern" to distinguish it from those which have preceded it. There is enough novelty and utility in it to make it of general interest to engineers, and I do not feel like apologizing for bringing it up at this time, although I will say that I had long ago promised myself that I would not again inflict upon the Society any further reference to the calorimeter subject —already worn threadbare, as it seems to me.

The 1895 pattern calorimeter is a wire-drawing instrument and separator combined, but the latter is attached to the outlet and is subjected simply to steam at atmospheric pressure. No guage glass is required, and the whole apparatus is simplicity itself. If the moisture is too great for the range of the wire-drawing part, the separator catches the balance, without manipulation of any kind, and the resulting water is collected and weighed.

The apparatus is protected from radiation, finished in nickelplate and japan, and the whole equipment, including two thermometers, is contained in a case no larger than an indicator box. The calorimeter itself weighs less than seven pounds.

Its chief features are shown in the accompanying cut, Fig. 132.

Mr. William H. Bryan.—It has occurred to me that the Society might be interested in the results of some experiments which I recently made on different forms of calorimeter nipples. The test was made on the main delivery pipe from a 250 horse-power Pierpoint boiler at the Stifel brewery in this city (St. Louis). The pipe was 8 inches diameter, vertical, the steam ascending, these being the conditions under which it is generally assumed that the fairest samples can be secured. The three nipples were located as close together as possible. The calorimeters used were all of the same type—the Carpenter separating, with condensing vessels. Nipple *A* is the one usually sent out with this instrument. It extends about four inches into the pipe and is open at the inner end, and has two holes through the sides. Nipple *B* was of the type recommended some years ago by Professor Thurston, extending clear across the pipe, with its inner end closed and the sides perforated with a large number of small holes, except within an inch of each end. Nipple *C* extended clear across the pipe, with a $\frac{1}{16}$-inch slot extending its entire length, the opening pointing towards the direction from which the steam came, being downward in this case. **Results** of six simultaneous observations are given in the table below.

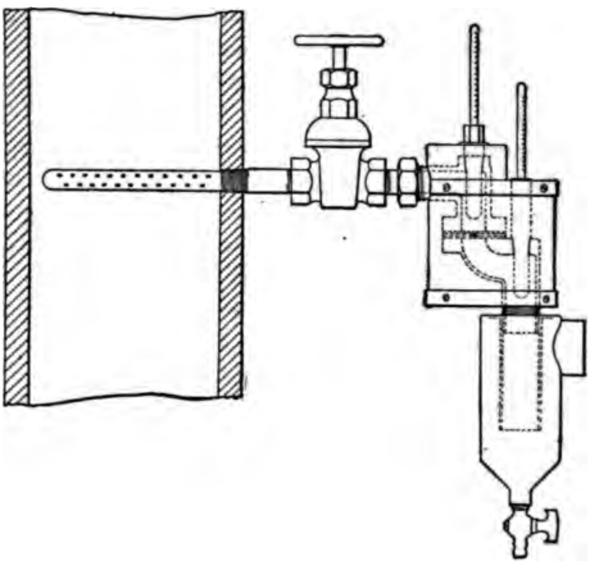

Fig. 182.

Comparison of Calorimeter Nipples.

Pressure.	A		B		C	
	Per cent.	Intervals.	Per cent.	Intervals.	Per cent.	Intervals.
100.....	.670	14	1.910	8½	1.112	10½
93.....	.547	16	1.405	11	1.161	15
87.....	1.063	14½	1.259	10½	1.283	12½
104.....	.990	13½	1.792	9	1.622	10
102.....	1.137	14½	1.477	9	2.319	10
101.....	.769	14½	.941	9	1.235	12½
Mean.	.863	14.50	1.464	9.50	1.455	11.75

It was thought that the sample secured by nipple *A* would not be a fair one, being taken from the centre of the pipe. It was thought also that nipple *B* would give a sample showing more moisture than really existed, as all moisture striking the nipple would be drawn into the holes without the corresponding percentage of steam. This it was thought would be avoided by nipple *C*. The experiments confirmed the supposition in regard to nipple *A*, but did not enable a choice to be made between nipples *B* and *C*, as the results averaged about the same.

Mr. E. D. Meier.—I do not agree with Professor Carpenter that the location of the pipe for sampling the steam in a vertical pipe is the best one. If the steam flowed through the main pipe at a uniform velocity of 50 feet per second or over, this might be a good plan, but when an engine is drawing steam from the pipe there are constant pulsations. Suppose it cuts off at quarter stroke, then for every second of high velocity we have three seconds of almost no velocity. All the water carried up during the high-velocity period and all that is condensed on the inner surface of the pipe will run down that surface during the periods of no velocity, and reaching the sampling pipe it will run in drops along the bottom of that pipe and be drawn into the calorimeter, thus showing a much larger result than the real average percentage of moisture. I have seen a large reduction made in calorimeter readings taken in this manner by simply covering the vertical pipe and the elbow at the top with good non-conductors, they having been before exposed.

Suppose the vertical portion of the pipe and the elbow had 10 square feet of exposed surface, we could easily and fairly figure, with steam at 100 pounds, and the air at 57 degrees, a loss by condensation of 4.5 pounds per hour, and this might be greatly increased if open windows or doors made a draught in the boiler-room. By covering the pipe, we could reduce this to 1.5 pounds. The difference of three pounds, which would amount to .05 pound per minute, would make a very grave error in the calorimeter if the sampling pipe were placed as indicated. I believe the safest plan is to put the sampling pipe in a horizontal pipe at middle height, and make it a plain open pipe extending at least one-third the diameter of the main pipe into the same.

Prof. R. C. Carpenter. *—Regarding the remarks by the first speaker, the writer would say that the gentleman has seemed to misunderstand many of the statements in the paper, although it was not expected that much commendation would be expressed. His principal discussion seems to have reference to the table which appears on page 611, and which he states gives results which are

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* Author's closure, under the Rules.

This correction is, however, a very small amount and of no practical importance, as it would seldom affect the results by even one one-hundredth of one per cent. The percentage of moisture in the steam is found by dividing the weight of water, as shown on the inner reading of the gauge, by the sum of this quantity and that shown on the attached gauge; the quality or percentage of dry steam by dividing the difference of the readings by the sum.

In the use of the instrument, the outer vessel and connected pipe through which the sample is obtained should be carefully clothed to prevent unnecessary loss of heat by radiation.

The total size of the instrument is about 10 x 2½ inches, and its weight about six pounds, so that it is in portable and convenient form.

The accuracy of the instrument depends first on the accuracy of the scales, both of which can be readily verified by experiment; second, upon the complete separation of the water from the steam by the separator. This was tested by a large number of experiments, by discharging the steam from the outer vessel through a throttling calorimeter. Nearly one hundred observations were made, the average results of which as given in the following table show the exhaust steam in the conditions tested to have a quality of 99.998 per cent. As it is certain that some loss of heat occurred between the two instruments, it is believed that we can consider with confidence the steam as passing from the inner into the outer vessel perfectly dry and saturated.

Table giving results of examination of quality of steam discharged from inner to outer vessel:

SEPARATING CALORIMETER.

DETERMINATION OF QUALITY WITH SEPARATING CALORIMETER.					DETERMINATION OF QUALITY OF STEAM DISCHARGED BY SEPARATING CALORIMETER WITH THROTTLING CALORIMETER.		
Duration run, minutes.	Gauge pressure, pounds.	Pounds separated water in run.	Pounds condensed steam in run.	Quality steam, per cent.	Temperature in calorimeter.	Quality steam in exhaust from separating calorimeter.	No. of observations.
25	81.5	1.15	4.45	79.46	281	99.95	6
25	78.2	0.15	5.20	97.2	281.8	100.00	6
25	80.8	0.525	4.25	89.005	286 5	100.00	6
25	79.5	0.150	4.75	96.94	281 8	99.95	6
25	78.5	0.300	5.000	94.84	282.8	100.00	6
25	77.6	0.150	5.45	97.32	282.3	100.00	6
24	79.5	1.8	4.55	71.65	280.1	99.94	6
24	78.5	1.4	4.90	77 77	279.5	99.9	6
20	83.5	1.15	4.1	77.67	286.5	100.00	5
20	81.6	1.70	4.75	73.64	282.7	99.98	5
20	74.8	0.65	3.95	85.87	283.7	100.05	5
20	82.0	0.85	3.95	82.29	286.8	100.05	5
20	82 6	0.35	4.15	92.22	285.6	100.0	5
20	81.5	0.20	3.95	95.15	285.2	100.05	5
20	81.4	2.20	4.325	66.28	283.1	100.0	5
20	80.3	0.30	4.55	93.81	282.8	100.0	5
20	82.0	0.20	4.65	95.8	282.8	99.98	5
20	81.1	0.20	4.40	95 7	284.0	100.0	5

Average of 18 trials, involving 98 observations, 99.998.

It is also true that a considerable error in the weight of steam discharged will affect the results but very little, since in every practical case the moisture is a small percentage of the total. Thus, supposing that the results of our examination show five per cent. moisture, but that an error in the weight of the steam discharged of five per cent. has been made. In that case the correction to our result should be but .05 or one-twentieth of the results obtained, in this case amounting to one-fourth of one per cent. The above is an extreme case, and is several times greater than any that is likely to occur, as shown by the results of various tests quoted.

Third, the loss by radiation in the exposed portions of the water glass and fittings. This surface is a very small portion of the whole surface, and the loss by radiation is always an exceedingly small amount. We have made a number of experiments in Sibley College to determine this amount, and have considered that in every case it affects the results less than errors culations, neither of which is reliable without large corrections for radiation, for error in reading of thermometers, etc.

The writer feels confident that the errors which exist in the separating calorimeter as described will in every case be less than those induced in collecting the sample of steam.

Regarding the best location for the supply pipe to the calorimeter, there is reason for a great difference of opinion, and the remarks by Mr. Meier are certainly worthy of attention. He does not seem, however, to be able to adduce any figures whatever in support of his proposition. His conclusion is directly opposed to the results of experiments in Sibley College, and also to those by Professor Jacobus.* His remarks regarding the effect of condensation are certainly opportune, and it is very evident indeed that if the sampling pipe is so arranged as to receive the drip from the side of the pipe, that the results will be as indicated in his remarks.

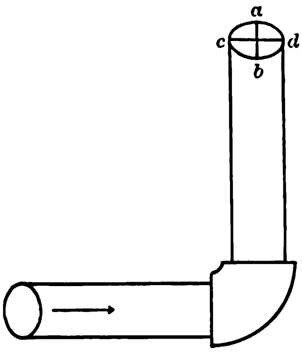

Fig. 133.

We made an extended series of experiments this last year as to the quality of samples drawn from different portions of a vertical pipe in which there was an ascending current of steam moving at rates varying from 50 to 100 feet per second.

The steam first passed through a horizontal pipe; a set of samples were drawn in the plane of the horizontal pipe, and also in one at right angles. I will not take the time here to describe the experiment in full, but will merely state that the variation obtained was very great, and that it varied in all sorts of ways from the mean. Samples drawn at a distance of 25 per cent. of the diameter from the edge of the pipe, at right angles to the plane through the centre of the pipe, were in nearly every case reliable, differing only a small fraction of one per cent. from the mean. Those drawn from near the centre of the pipe were in every case very much too dry, differing in various positions one to two per cent. from the mean. Those near the edges much too wet. The quality of the mean was determined by converting the whole system into an enormous throttling calorimeter, after having

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* See *Transactions* A. S. M. E., vol. xv.

removed a certain amount of the water by the separator. I submit a sketch showing the variation in quality from the mean. Fig. 133 shows the arrangement of the positions, and Fig. 134 the result in one plane, and Fig. 135 in the plane at right angles.

I am rather inclined to believe from these experiments that fair samples may be obtained by drawing the steam from a point

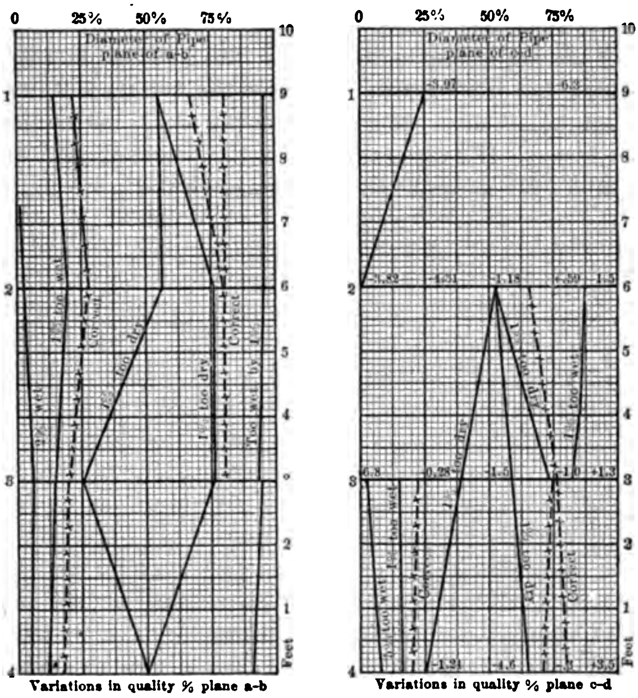

FIG. 134.

FIG. 135.

Diagrams showing simultaneous determinations of quality and variation from mean quality in a vertical pipe. The current ascends. Mean quality, 95 per cent. Plane *c-d* is plane of bend, and variation is irregular. Fair samples are found in plane *a-b* at distances from surface equal to 25 per cent. of diameter. Experiments, June, 1896.

well within a pipe, provided the current is ascending; I do not believe that a fair sample should differ more than one per cent. from the mean. With horizontal pipes the water will flow in a stream along the bottom, and will fall in a descending current in a vertical pipe irregularly in different portions of the pipe. The experiments made by Mr. Bryan are of interest as showing that the form of collecting nipple is itself of importance. The form marked *B* is the one that should have been sent by the makers if they had carried out my directions, since I have advised the collection of steam from all portions of the pipe. Our recent experiments would seem to indicate that a sample drawn from the open end of a pipe about half way to the centre agrees well with the average, but we are not certain that it agrees more closely than that drawn from all portions of the pipe. Mr. Bryan did not in his experiments determine the average quality of the whole steam, but his experiments show the quality obtained with nipple *A* to be about six-tenths of one per cent. better than with the other forms. His observations on the whole show a uniformity of results fully as great as could be expected.

Any change of a machine which enables one thing to do the work formerly done by two things is an improvement, and the instrument described may be classed in the category of such improvements, but I have looked in vain through the paper for any feature which entitles the changed instrument to be called a *new form of calorimeter.*

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There are some points in the paper to be criticised.

The professor states that "no loss by radiation can take place from the inner chamber except that which takes place from the exposed surface of the gauge glass." I am sorry to differ with the author on this point, for in this I believe he is wrong. There is a solid metal connection between the inner and outer chamber at the two points where the gauge-glass fittings are applied, and a solid screwed connection between the two at the entrance of the steam supply. If these connections were insulated so that no conduction of heat could take place from one to the other, the professor's statement would be warranted, but with the conditions as they exist, there is one unbroken continuity of metal from the inner chamber to the outer one, and any loss due to radiation from the exterior surface will be felt all the way through.

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The apparatus is protected from radiation, finished in nickel-plate and japan, and the whole equipment, including two thermometers, is contained in a case no larger than an indicator box. The calorimeter itself weighs less than seven pounds.

Its chief features are shown in the accompanying cut, Fig. 132.

Mr. William H. Bryan.—It has occurred to me that the Society might be interested in the results of some experiments which I recently made on different forms of calorimeter nipples. The test was made on the main delivery pipe from a 250 horse-power Pierpoint boiler at the Stifel brewery in this city (St. Louis). The pipe was 8 inches diameter, vertical, the steam ascending, these being the conditions under which it is generally assumed that the fairest samples can be secured. The three nipples were located as close together as possible. The calorimeters used were all of the same type—the Carpenter separating, with condensing vessels. Nipple *A* is the one usually sent out with this instrument. It extends about four inches into the pipe and is open at the inner end, and has two holes through the sides. Nipple *B* was of the type recommended some years ago by Professor Thurston, extending clear across the pipe, with its inner end closed and the sides perforated with a large number of small holes, except within an inch of each end. Nipple *C* extended clear across the pipe, with a $\frac{1}{16}$-inch slot extending its entire length, the opening pointing towards the direction from which the steam came, being downward in this case. Results of six simultaneous observations are given in the table below.

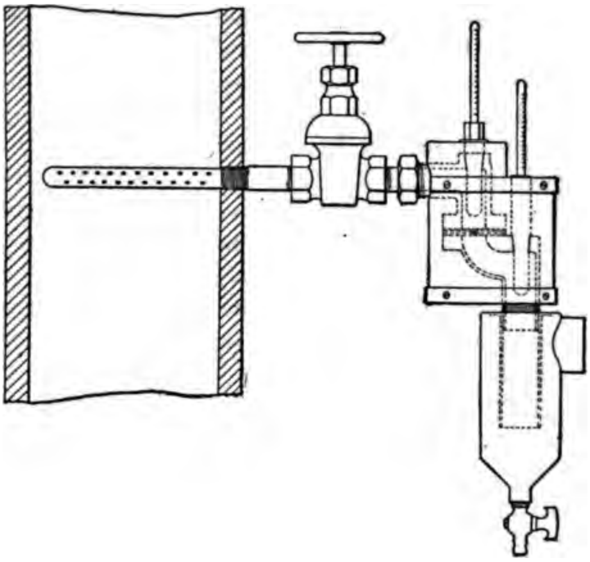

FIG. 182.

COMPARISON OF CALORIMETER NIPPLES.

	A		B		C	
PRESSURE.	Per cent.	Intervals.	Per cent.	Intervals.	Per cent.	Intervals.
100.....	.670	14	1.910	8½	1.112	10½
93.....	.547	16	1.405	11	1.161	15
87.....	1.063	14½	1.259	10½	1.283	12½
104.....	.990	13½	1.792	9	1.622	10
102.....	1.137	14½	1.477	9	2.319	10
101.....	.769	14½	.941	9	1.235	12½
Mean.	.863	14.50	1.464	9.50	1.455	11.75

It was thought that the sample secured by nipple *A* would not be a fair one, being taken from the centre of the pipe. It was thought also that nipple *B* would give a sample showing more moisture than really existed, as all moisture striking the nipple would be drawn into the holes without the corresponding percentage of steam. This it was thought would be avoided by nipple *C*. The experiments confirmed the supposition in regard to nipple *A*, but did not enable a choice to be made between nipples *B* and *C*, as the results averaged about the same.

Mr. E. D. Meier.—I do not agree with Professor Carpenter that the location of the pipe for sampling the steam in a vertical pipe is the best one. If the steam flowed through the main pipe at a uniform velocity of 50 feet per second or over, this might be a good plan, but when an engine is drawing steam from the pipe there are constant pulsations. Suppose it cuts off at quarter stroke, then for every second of high velocity we have three seconds of almost no velocity. All the water carried up during the high-velocity period and all that is condensed on the inner surface of the pipe will run down that surface during the periods of no velocity, and reaching the sampling pipe it will run in drops along the bottom of that pipe and be drawn into the calorimeter, thus showing a much larger result than the real average percentage of moisture. I have seen a large reduction made in calorimeter readings taken in this manner by simply covering the vertical pipe and the elbow at the top with good non-conductors, they having been before exposed.

Suppose the vertical portion of the pipe and the elbow had 10 square feet of exposed surface, we could easily and fairly figure, with steam at 100 pounds, and the air at 57 degrees, a loss by condensation of 4.5 pounds per hour, and this might be greatly increased if open windows or doors made a draught in the boiler-room. By covering the pipe, we could reduce this to 1.5 pounds. The difference of three pounds, which would amount to .05 pound per minute, would make a very grave error in the calorimeter if the sampling pipe were placed as indicated. I believe the safest plan is to put the sampling pipe in a horizontal pipe at middle height, and make it a plain open pipe extending at least one-third the diameter of the main pipe into the same.

*Prof. R. C. Carpenter.**—Regarding the remarks by the first speaker, the writer would say that the gentleman has seemed to misunderstand many of the statements in the paper, although it was not expected that much commendation would be expressed. His principal discussion seems to have reference to the table which appears on page 611, and which he states gives results which are

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* Author's closure, under the Rules.

absurd because "the radiation from the instruments must have been more than $\frac{2}{1000}$ of one per cent."

If such a statement had been made in the paper, the critic would no doubt be warranted in his strictures. By referring to page 610, however, and to the statements which immediately precede the table, it will be seen that this table gives the result of an investigation to determine whether or not it is possible by mechanical separation to remove all water from steam, and that in this connection the instrument was so arranged as to eliminate all other losses. It is distinctly stated that this table was for this purpose, although it may be added, to what has already been stated by inference, that the instrument was arranged for this test so that no radiation was possible. It is, I think, clearly stated in the paper that the radiation losses of the instrument are not included in that table, and that they are discussed under two later heads. The statement in regard to the radiation of the instrument is found on page 612, and the claim is made that it is a small fraction of one per cent.

Let us consider the matter from a theoretical standpoint. The coefficient of heat transmission from steam to air through a naked pipe under similar conditions of exposure is thoroughly well known, and varies from 1.5 to 2 B. T. U. per square foot of exposed surface per hour per degree difference of temperature between the steam and the air. This difference of temperature, with ordinary temperature of room, with steam at 100 pounds pressure, would be about 250 degrees, and the amount of heat transmitted per square foot per hour would be 500 B. T. U. When instruments are well covered as directed in connection with this instrument, the radiation loss is less than one-fifth the above, or not over 100 B. T. U. per square foot per hour.

In the instrument as now constructed and of the latest form we have nine square inches of exposed water-glass fittings (Mr. Barrus makes a fine distinction when he calls attention to the fact that in specifying the glass the fittings are omitted), and six square inches of glass surface. The radiation from the metallic surface should not exceed under usual conditions 28 or 30 B. T. U. per hour, or from $\frac{1}{30}$ to $\frac{1}{40}$ of a pound of steam when unclothed, and from $\frac{1}{150}$ to $\frac{1}{200}$ of a pound when properly protected. That from the glass should not exceed 18 to 24 B. T. U. per hour, or from $\frac{1}{45}$ to $\frac{1}{60}$ of a pound of steam, so that the total loss should not reach by condensation $\frac{1}{30}$ of a pound of steam per hour. In the experiments quoted on page 611, a smaller instrument was employed than is now used, although the radiating surface was also smaller. With the instrument of the smaller size, the percentage of radiation loss, provided the radiation surface remained as in our larger instrument, would have been nearly one-fifth of one per cent. In the instrument as now built, steam is discharged at the rate of about 50 pounds per hour at 100 pounds pressure, and the radiation loss is reduced to less than one-tenth of one per cent.

This is the total loss regarding which such erroneous statements have been made, and I think I will be warranted in saying that it is many times less than the errors which cannot possibly be avoided in collecting a sample of steam.

The small amount of the loss by radiation is shown incidentally in the figures submitted in the discussion by Mr. W. H. Bryan.

It is somewhat strange that the opinions formed by examining the same subject from different standpoints should differ so materially; thus, for instance, Mr. Barrus can see little which is new or novel in the calorimeter described in the paper, although he does not claim to have thought of the same instrument himself, and he does admit certain novel features. He does, however, describe an instrument which appears to him as new, but which to me appears to be not only not new, but to possess no novel features. He has, it appears to me, simply taken the throttling calorimeter of Peabody,* and the early form of the separating calorimeter as described by myself,† and arranged them in tandem so that the exhaust of the throttling calorimeter should feed the separator. That is, his invention consists in making a compound calorimeter which must be as difficult to use as it is complicated in shape. More than this, I do not believe the instrument in that form is accurate or reliable unless the steam is sufficiently dry as to be within the limits of the throttling instrument, in which case the separating attachment can be of no possible use. Supposing that the steam contains five or six per cent. of moisture, which is more than can be evaporated by the process of superheating due to throttling, in its passage through the throttling instrument a certain portion of this moisture is evaporated, and the remainder must be caught in the separator. The amount of moisture must then be determined from two complicated cal-

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* See *Transactions* A. S. M. E., vol. x., p. 827.

† See *Transactions* A. S. M. E., vol. xii., p. 825.

culations, neither of which is reliable without large corrections for radiation, for error in reading of thermometers, etc.

The writer feels confident that the errors which exist in the separating calorimeter as described will in every case be less than those induced in collecting the sample of steam.

Regarding the best location for the supply pipe to the calorimeter, there is reason for a great difference of opinion, and the remarks by Mr. Meier are certainly worthy of attention. He does not seem, however, to be able to adduce any figures whatever in support of his proposition. His conclusion is directly opposed to the results of experiments in Sibley College, and also to those by Professor Jacobus.* His remarks regarding the effect of condensation are certainly opportune, and it is very evident indeed that if the sampling pipe is so arranged as to receive the drip from the side of the pipe, that the results will be as indicated in his remarks.

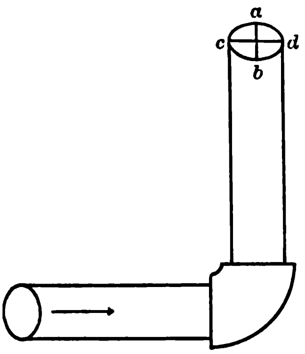

FIG. 133.

We made an extended series of experiments this last year as to the quality of samples drawn from different portions of a vertical pipe in which there was an ascending current of steam moving at rates varying from 50 to 100 feet per second.

The steam first passed through a horizontal pipe; a set of samples were drawn in the plane of the horizontal pipe, and also in one at right angles. I will not take the time here to describe the experiment in full, but will merely state that the variation obtained was very great, and that it varied in all sorts of ways from the mean. Samples drawn at a distance of 25 per cent. of the diameter from the edge of the pipe, at right angles to the plane through the centre of the pipe, were in nearly every case reliable, differing only a small fraction of one per cent. from the mean. Those drawn from near the centre of the pipe were in every case very much too dry, differing in various positions one to two per cent. from the mean. Those near the edges much too wet. The quality of the mean was determined by converting the whole system into an enormous throttling calorimeter, after having

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* See *Transactions* A. S. M. E., vol. xv.

removed a certain amount of the water by the separator. I submit a sketch showing the variation in quality from the mean. Fig. 133 shows the arrangement of the positions, and Fig. 134 the result in one plane, and Fig. 135 in the plane at right angles.

I am rather inclined to believe from these experiments that fair samples may be obtained by drawing the steam from a point well within a pipe, provided the current is ascending; I do not believe that a fair sample should differ more than one per cent. from the mean. With horizontal pipes the water will flow in a stream along the bottom, and will fall in a descending current in a vertical pipe irregularly in different portions of the pipe. The experiments made by Mr. Bryan are of interest as showing that

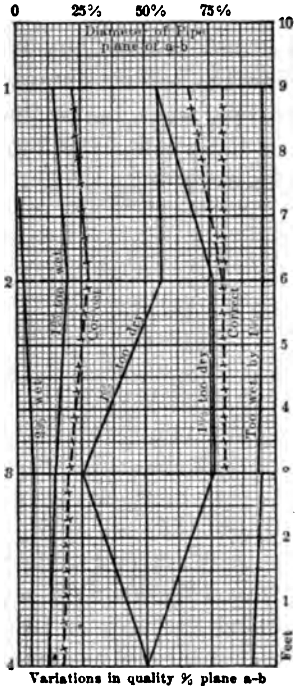

FIG. 134.

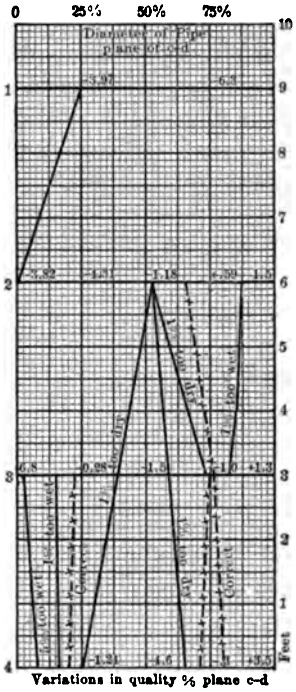

FIG. 135.

Diagrams showing simultaneous determinations of quality and variation from mean quality in a vertical pipe. The current ascends. Mean quality, 95 per cent. Plane *c-d* is plane of bend, and variation is irregular. Fair samples are found in plane *a-b* at distances from surface equal to 25 per cent. of diameter. Experiments, June, 1896.

the form of collecting nipple is itself of importance. The form marked *B* is the one that should have been sent by the makers if they had carried out my directions, since I have advised the collection of steam from all portions of the pipe. Our recent experiments would seem to indicate that a sample drawn from the open end of a pipe about half way to the centre agrees well with the average, but we are not certain that it agrees more closely than that drawn from all portions of the pipe. Mr. Bryan did not in his experiments determine the average quality of the whole steam, but his experiments show the quality obtained with nipple *A* to be about six-tenths of one per cent. better than with the other forms. His observations on the whole show a uniformity of results fully as great as could be expected.

DCXCIII.*

A SELF-COOLING CONDENSER.

BY LOUIS R. ALBERGER, NEW YORK CITY.

(Member of the Society.)

It is the object of this paper to present to the attention of the Society a practical condensing apparatus for use with steam engines, and one which, while operating without a natural water supply, gives results which compare most favorably with those obtained in the ordinary manner. Because the circulating water employed to produce the condensation of the steam is cooled by the apparatus for re-use in itself, it is called a self-cooling condenser. It depends, however, for its effectiveness upon the capacity of atmospheric air to carry off heat and moisture when brought into intimate contact with heated water.

Broadly considered, the air becomes the condensing medium in the place of cold water as ordinarily employed, and, on account of its general distribution, the process can be performed at any place which may be desired. The adoption of this machine gives to all users of steam power a means of economy heretofore commercially unavailable, except to those whose engines are in close proximity to an abundant natural water supply. Non-condensing engines, in any locality, can be run condensing, with all the benefits which accrue, by the use of a vacuum. In the installation of new steam-power plants, the highest types and most modern practice of compound and triple-expansion condensing engines can be used, without reference to the quantity of water available, except to provide a sufficient amount for boiler-feeding purposes.

The idea of cooling the discharge water from the air pumps and re-using it in the condenser is an old one, and, in fact, steam plants are in operation in which the heated discharge water is

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* Presented at the St. Louis meeting (May, 1896) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

delivered into a pond and allowed to cool to as low a temperature as possible before being used again. Open pans placed in the yard adjoining the engine house, or on the roof of a building, have been found fairly serviceable in a few instances where the structures were of sufficient expanse and were strong enough to support the weight. Both of these methods of cooling water are slow, and, as only the surface exposed to the air is active to any great extent, very large areas are required; and, furthermore, they are uncertain, as they rely upon the favorable conditions of the wind and atmosphere for anything like satisfactory results.

In Europe the heated water is sometimes pumped upon a pile of brush or fagots, and in that way caused to expose a large surface to the air. Modified and somewhat improved forms of this plan have been used for a long time on the island of Cuba, in connection with vacuum pans, in the manufacture of sugar, at places where water is scarce, the prevalence of trade winds adding much to the reliability and effectiveness of these contrivances.

Rilleaux, who is credited as being the inventor of multiple effect evaporating apparatus, many years ago suggested the use of gunny bags, suspended by one edge and arranged in a series, with a space for the circulation of the air, and a device for supplying the heated water along the upper edge of the bags. He found, however, that the cloth, subjected to the combined action of heat, moisture, and air, decayed very rapidly, and its use was soon abandoned. In Hungary and Germany expensive constructions quite like Rilleaux's are in use, wooden plates or partitions being substituted for the gunny bags. The plates are hung in a parallel series a few inches apart. It is very desirable, and at the same time difficult, to maintain an even distribution of the heated water along the edges of the plates, so that each plate will present a thoroughly wetted surface to the action of the air, and elaborate means are adopted to secure that result. The heated water is taken from the air-pump discharge and elevated by means of an additional pump to the top of the structure.

As distinguished from the above methods, in which the exhaust steam is brought in contact with the water, numerous forms of so-called air or evaporative condensers have been devised and used with varying success. They consist of a series of tubes or hollow plates exposed to the atmosphere, into which the steam from the engine is exhausted, the steam being condensed, and the water resulting from the condensation, after being freed of the lubricating oil from the engine, is fed to the boiler. This system was experimented with for a long time on the London underground railroad, where its success would have been very desirable. The surface required merely to condense the steam without producing even a moderate degree of vacuum was very large, and the machine, to be of full effect, was bulky and expensive. The efficiency of this type of condenser can be increased by continually wetting the surface of the tubes exposed to the air. Aside from the cost, which prevents its commercial use, it possesses a very great practical disadvantage in that the whole structure, including the tubes, with their fastening devices arranged to accommodate expansion and contraction, requires to be air tight against atmospheric pressure.

It is obvious that such methods and constructions, while interesting, and in a limited way operative, would be inapplicable to the large majority of the steam plants of considerable capacity with which we are familiar, and which have become so necessary for modern mill, electric light, and railway purposes during the last few years.

An apparatus for this purpose, and one which can be safely employed as a reliable portion of a steam-power plant, must be simple and compact in construction, thoroughly durable, and so completely under control as to be practically independent of changes of wind and weather. These features are to be found in the self-cooling condenser as illustrated in section in Fig. 136. It consists of two parts: the condenser, in which the exhaust steam of the main engine or engines is condensed, and the tower, in which the heated discharge from the condenser is cooled to a proper temperature to be used again for the further condensation of exhaust steam. The tower consists of a cylindrical steel shell open at the top, supported upon a suitable foundation, and having fitted at one side a fan, the function of which is to circulate a current of air through the tower and its filling. This filling consists of layers of cylindrical tubular tiling, which rest upon a grating supported by a brick wall extending around the circumference of the tower. The heated discharge water from the condenser enters the tower at the side, passes up the central pipe, is delivered on the upper layer of tiling and over the whole cross section of the tower by a distributing device consisting of four pipes, which are

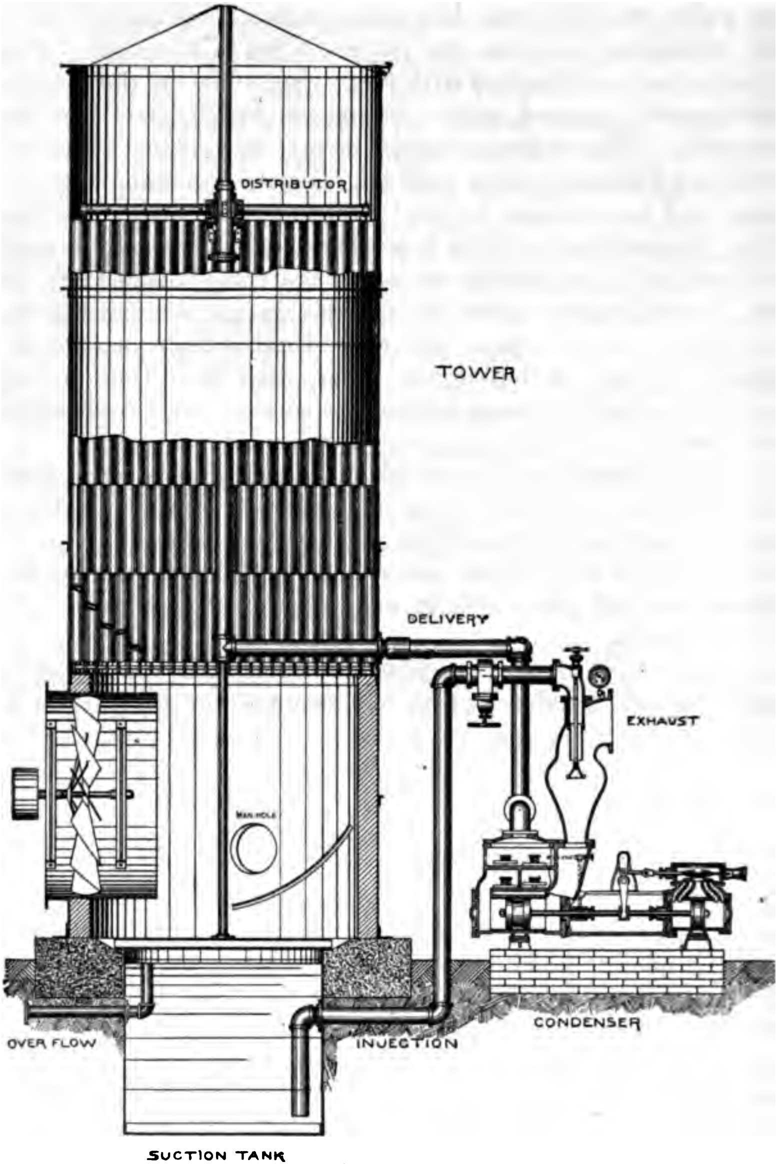

FIG. 136.

caused to rotate about the central water pipe by the simple reaction of the jets of heated water issuing from one side of each pipe after the manner of a Barker's mill. The water thus delivered spreads over the outside and inside surfaces of the walls of the tiling, and forms a continuous sheet, which is presented to the action of the air. The tiling, which are preferably six inches in diameter and twenty-four inches long, are placed on end in horizontal layers, one upon the other, and packed as closely as possible, the walls of each individual tile of each successive layer being disposed so as to come opposite the air spaces of the next lower layer, breaking joints, as it were.

Fig. 137 shows the arrangement of a portion of the tiling, the object being in this disposition to break up both the currents of air and water so that the most thorough and extended contact will take place. If there are ten layers of tiling in a tower, then there are nine places, in addition to the original spreading at the top, at which there is a complete redistribution of the water. It will be seen that each tile must rest on at least two, and possibly three, in the next lower layer. Assuming, however, that each tile rests on only two others, a given quantity of water, placed on any one tile in the top layer, will be divided over at least two tiles in the second layer, three in the third, four in the fourth, and so on, until it becomes spread over fifty-four in the lowest layer on the grating. The practical importance of this extremely effective distribution of the water, due to the mere arrangement of the filling, has been demonstrated in a tower where the distributer was purposely stopped, when the efficiency of the apparatus was found to be so slightly impaired that the difference was not noticeable in the engine room. The air is distributed in an equally good manner,

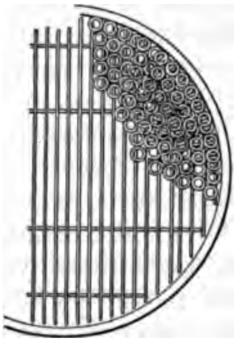

FIG. 187.

and there is a large free area with equal facility for its passage upward over the entire cross section of the tower. The heated water falling through the tower is cooled by three processes: first, radiation from the sides of the tower; second, the contact of cool air; and third, evaporation. This latter is by far the most important, as the evaporation of a pound of water in this way carries off about 1,000 units of heat, and enables a pound of steam to be condensed in the condenser. As quite a proportion of the cooling is done by the first two processes, the evaporation of water in the tower must be less than the water formed by steam condensed in the condenser. Consequently, the supply of circulating water is constantly augmented and requires no replenishing. The cooled water falls from the grating to the subsiding tank at the bottom, and is from there drawn by the condenser to perform condensation again.

The condenser forming a part of this apparatus has certain special and novel features which render it particularly well adapted to the service. The condensing chamber in which the exhaust steam is brought into contact with the water is shaped so as to conserve the velocity of the incoming water, increased by the impact of the exhaust steam at the point of condensation. The injection water and the water resulting from the condensation of the steam pass unobstructedly to the pump, and by their momenta assist the pump very materially. The air and uncondensable vapors are thoroughly intermixed with the water, and are not at any time allowed to separate from it. The pump has a duplex valve motion and gives a regular and constant flow of the mixture, which is more nearly aerated water, and is widely distinguished from the air and water in comparatively large and separated volumes as they are found in ordinary air pumps and condensers. The effect of this intimate and complete mixture is twofold; the pump is largely assisted in its work, as shown by the fact that there is a less degree of vacuum in the pump cylinders than obtains in the condensing chamber, and the action of the pump is steady, as it moves in a constant stream a fluid of practically uniform density. For this latter reason the pump is capable of elevating the water to the top of the tower with ease and regularity. A single pump thus performs the double function of maintaining the vacuum and of supplying the heated water to the tower, reducing the apparatus to its simplest form.

The operation of the system may be summarized as follows: The cool water drawn into the condenser from the suction tank is mingled with the exhaust steam from the main engines, and being heated and increased in quantity by the condensation of the latter, is delivered by the pump to the tower, where it is cooled by the air and falls into the subsiding or suction tank, from which it again passes to the condenser. There is constantly coming into the system water from the city mains or other source to feed the boilers. There is constantly going out of the system the water evaporated in the tower—an amount which is less than that which comes from the steam condensed—and the slight overflow from the suction tank which will carry off the oil and grease which come from the engine with the exhaust steam, and which would tend to accumulate in the suction tank.

In situations where the water to be had for boiler feeding is so impure as to form objectionable scale in the boilers, a modification of the apparatus may be used to great advantage. This modification consists in the substitution of a surface condenser with air and circulating pumps for the jet condenser and pump. Fig 138 shows a system so arranged. The circulating pump draws the cool water from the suction tank, passes it through the tubes of the surface condenser and the tower and back again in a continuous circuit to the suction tank. The exhaust steam from the main engine brought in contact with the outside of the tubes is condensed. The pure water thus formed, together with the air and uncondensable vapor, is removed by the air pump and delivered to the hot well, from whence the water is fed to the boilers. The loss to the circulating water by evaporation in the tower must needs be made up from the source of water supply.

The floor space occupied by the cooling tower of this self-cooling condenser is not excessive, as will be appreciated when it is understood that an apparatus suitable for 1,000 horse-power is only 17 feet in diameter and 30 feet high. The suction tank, which is placed directly under the tower and in the foundation, is 8 feet in diameter and 7 feet deep, and contains about 2,000 gallons of circulating water, this being a sufficient quantity to fill the condenser pump, pipes, and tower on starting up, and to carry on continuously the transfer of heat from the exhaust steam to the atmospheric air. The location of the tower may be on the engine-room floor, on the top of the building, or in the yard, the latter place being well adapted. It may be at any reasonable distance from the engine and the condenser, and connected to the latter by one pipe for the heated and one for the cooled circulating water. The distance is only limited by the friction of the water, which depends, of course, upon the size and directness of the pipes. A machine which the writer has in mind is 150 feet away from the engine room, and as the fan is driven by an extension of the line shafting, the fan is set in operation at the first movement of the main engine, the condenser in the mean time having been started and a vacuum obtained.

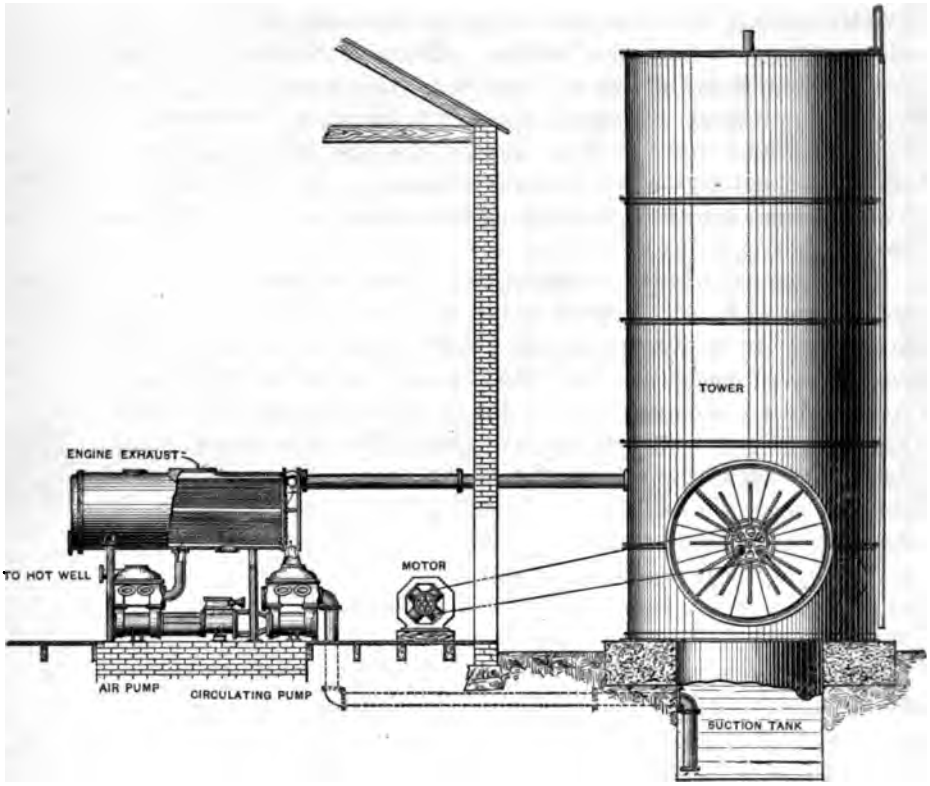

FIG. 138.

The fan for the circulation of the air requires but very little power for its operation, and careful tests have shown it to be less than 2 per cent. of the power of the main engine during the maximum requirements of summer, while the average for the year in this climate will not exceed 1¼ per cent. The fan may be driven by an electric motor, belting from the main shafting, or by a small steam engine, as the conditions of the situation may render most desirable. The latter method is usually preferable, as the speed can be more easily regulated to suit the requirements.

It may be interesting to state some of the average temperatures of cooled water observed under different ranges of temperatures of air in an apparatus performing regular service in connection with a steam engine.

Temperature of Air.	Average Temperature of Cooled Water.	Difference between Air and Cooled Water.
20 degrees Fahr.	45 degrees Fahr.	25 degrees.
30 "	50 "	20 "
40 "	56 "	16 "
50 "	62 "	12 "
60 "	70 "	10 "
70 "	78 "	8 "
80 "	87 "	7 "
90 "	96 "	6 "
95 "	100 "	5 "

It will be noticed that, as the temperature of the air increases, the temperature of the cooled water becomes nearer that of the former. With the atmosphere at 20 degrees Fahr. there is a difference of 25 degrees, and at 95 degrees Fahr. the difference is only 5 degrees, when circulating practically the same volume of air and carrying off the same amount of heat, the circulation of the water having been reduced as the temperature lowered. This shows plainly the activeness of the evaporation at the higher temperatures, when the air has a largely increased capacity for moisture. Advantage is taken of this action in another form of this apparatus which is being used to cool water which has passed over the ammonia condensers of ice and refrigerating machinery so that it may be used again, thus avoiding the cost of city water, or dependence upon salt or corrosive waters for this purpose. In this design of cooling tower the quantity of air circulated and the exposed surface of water bear a larger ratio to the amount of heat carried off than when the tower forms a part of a steam-engine condensing system. This is necessary because ammonia condensers are operated to the best advantage at lower ranges of temperature. It is possible to obtain under favorable conditions a reduction of temperature some 15 or 20 degrees below the temperature of the atmosphere. By carrying this method too far—that is, by circulating too great an amount of air—the warming-up effect of contact of the air with the water will overcome the cooling effect produced by the evaporation, and the desired result of further reduction will not be attained. Just at what point this occurs the writer has not had an opportunity of determining, but experiments are under way at the present time to locate definitely the point of maximum efficiency.

The relative amount of moisture in the air, of course, affects its cooling value, especially in summer, when the evaporation in the tower is the process principally relied upon to carry off the heat. When the humidity is high—that is, when the vapor of water in the air approaches in amount that which it is possible for the air to contain before becoming saturated—the effect in the tower can be maintained by the circulation of a larger quantity of air, and experience readily determines to what extent this can be economically carried in any given case. The practical results produced by this system are not affected as greatly as might be supposed by extreme and unfavorable conditions of the atmosphere, such as coincident high temperature and humidity. This will be understood upon consideration of the following facts. The temperature of steam under a vacuum of 26 inches is 126 degrees Fahr., and the discharge water from a condenser producing that degree of vacuum is usually about 110 degrees Fahr., so that it is quite possible to maintain 26 inches of vacuum in a system when the injection water is, say, 100 degrees Fahr., simply by employing a condenser pump of very large size, and causing a circulation of three times the quantity of water which would be necessary if the injection was 80 degrees Fahr., or a difference of 30 degrees, instead of 10 degrees, as in the supposed case. Such a procedure is not advisable, because the times during the year when the atmospheric conditions are so severe as to prevent cooling below a point of 100 degrees Fahr. are very few and last but a few hours. It is found to be better practice to carry a lower degree of vacuum for the time being. An injection of 100 degrees Fahr. and a discharge of 130 degrees, requiring a circulation of only the normal amount of water, will give a vacuum of from 22 to 23 inches. A self-cooling condenser of 200 horse-power capacity, corresponding to the description just given, was built by Henry R. Worthington and put in operation June, 1894. It has been in constant service since that time, maintaining during the hottest weather of July and August of two seasons a vacuum never below 22 inches, and very often as high as 26 inches. During the other months the vacuum has seldom been below 25 inches. Some ten installations, varying in size from 400 to 5,000 horse-power each, have been built by the same company and put into successful operation during the last year.

Fig. 139 is from a photograph of an apparatus of this construction, at the Second District Station of the Edison Electric Illuminating Company of Brooklyn. This tower is placed in the yard at the rear of the station, and at a distance of about 60 feet from the condenser. It has run continuously since March, 1895, in connection with three Ball cross-compound engines of 250 horse-power each. Through the heated term of last summer 24 to 25 inches of vacuum was readily maintained. The appearance and operation of the condenser in the engine room are exactly as if a large natural water supply was being employed for the condensation. The circulating fan in the tower is operated by an electric motor, and after it is started requires no further attention from the engineer in charge.

In the application of this system to a plant in which the engines are run non-condensing, no change is made in the method of feed-water supply as there employed. The feed pump and the ordinary main exhaust heater are left in position, and the exhaust steam from the main engine is passed through the latter on the way to the condenser. The steam exhausted by the condenser pump, boiler-feed pump, and the small engine which runs the fan (if a separate engine be used), is conveyed to a separate heater of moderate size. This supplementary heater receives the feed water, which already has been heated nearly to the temperature of the exhaust steam, say to 110 degrees Fahr., with a vacuum of 26 inches, by the main heater between the engine and the condenser. The exhaust from the auxiliaries being entirely condensed in the supplementary heater, its heat is transferred to the feed water and by this means returned to the boiler. The temperature of the feed water will approximate that obtained when the same plant is run non-condensing, and varies, according to the conditions, from 170 degrees to 200 degrees Fahr. It is evident that as that portion of the heat in the steam supplied to the auxiliaries, and not converted into useful work nor lost by radiation, is completely returned to the boilers, the efficiency of these machines is very high. They approach, in fact, what may be called

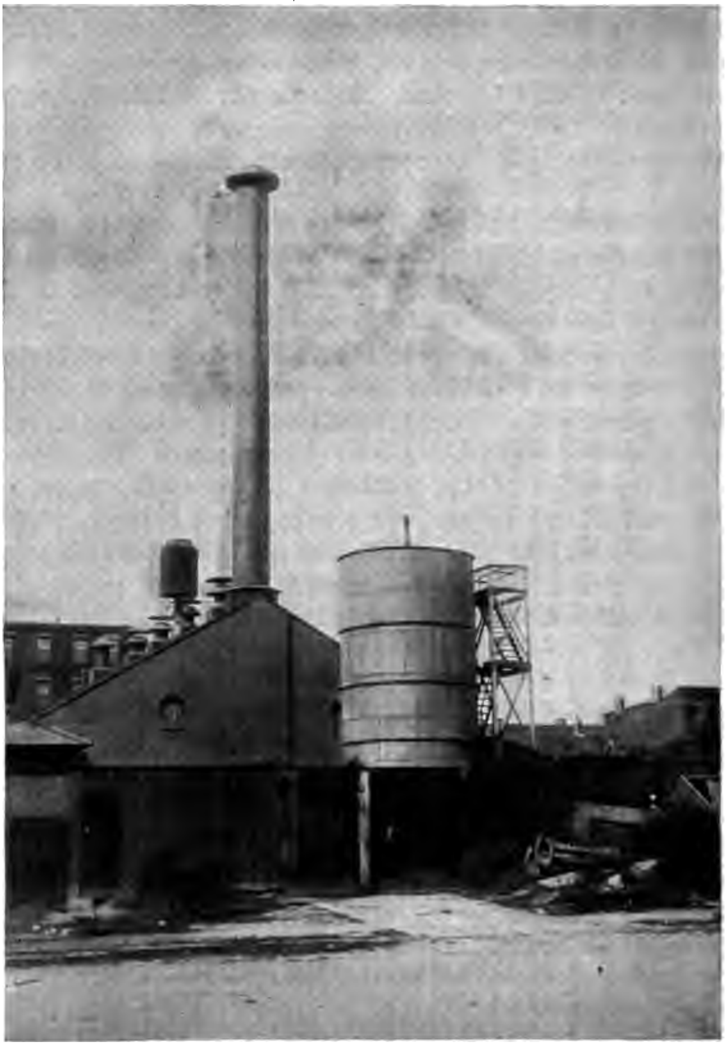

FIG. 139.

perfect steam engines, for an engine which returns to the boiler the heat which is not converted into useful work may certainly be said to be a perfect one. For a careful exposition of the economy to be reached in the operation of the auxiliaries by utilizing the heat of the exhaust steam, reference is made to a paper by Otto H. Mueller, C.E., read before the Hungarian Architects' and Engineers' Society of Budapest, and published in *Engineering*, November 10, 1893.

Fig. 140 shows a complete self-cooling condenser system as applied to a Corliss engine, and indicates the positions of the main and supplementary heaters with the pipes and connections. The condenser is shown in the basement, but it can just as well be on the level of the engine-room floor, if the proper arrangement of exhaust piping is made to prevent accumulation of drip water in the horizontal length. Referring again to the matter of heating the boiler-feed water, it is obvious that if the feed water be taken from the discharge of the condenser at a temperature which quite closely approximates that obtained in the main heater, if one be used, and passed through the supplementary heater to the boilers, that the main heater may be omitted without appreciable loss of economy. The amount of water thus taken from the system must be replaced by an equal quantity of cold water admitted to the suction tank from the source of supply. This method is not ordinarily advisable on account of the oil which may in this way get into the boilers, although with some feed waters the presence of a small amount of oil is not objectionable.

Regarding the total cost of producing vacuum by this system it can be said that, while the cost varies according to the size of the plant and different operating conditions, it may safely be taken as within an average of five per cent. of the power of the main engines when the latter develop a horse-power with twenty or less pounds of water per hour. The relative economy of condensing over non-condensing engines of the various types of simple, compound, and triple expansion is so generally well known, and has received such practical and comprehensive treatment by Charles E. Emery, Ph.D., in a paper entitled "The Cost of Steam Power Produced with Engines of Different Types under Practical Conditions" (*Transactions* American Institute Electrical Engineers, March, 1893), that it is unnecessary to make any more than a brief reference to that paper. The

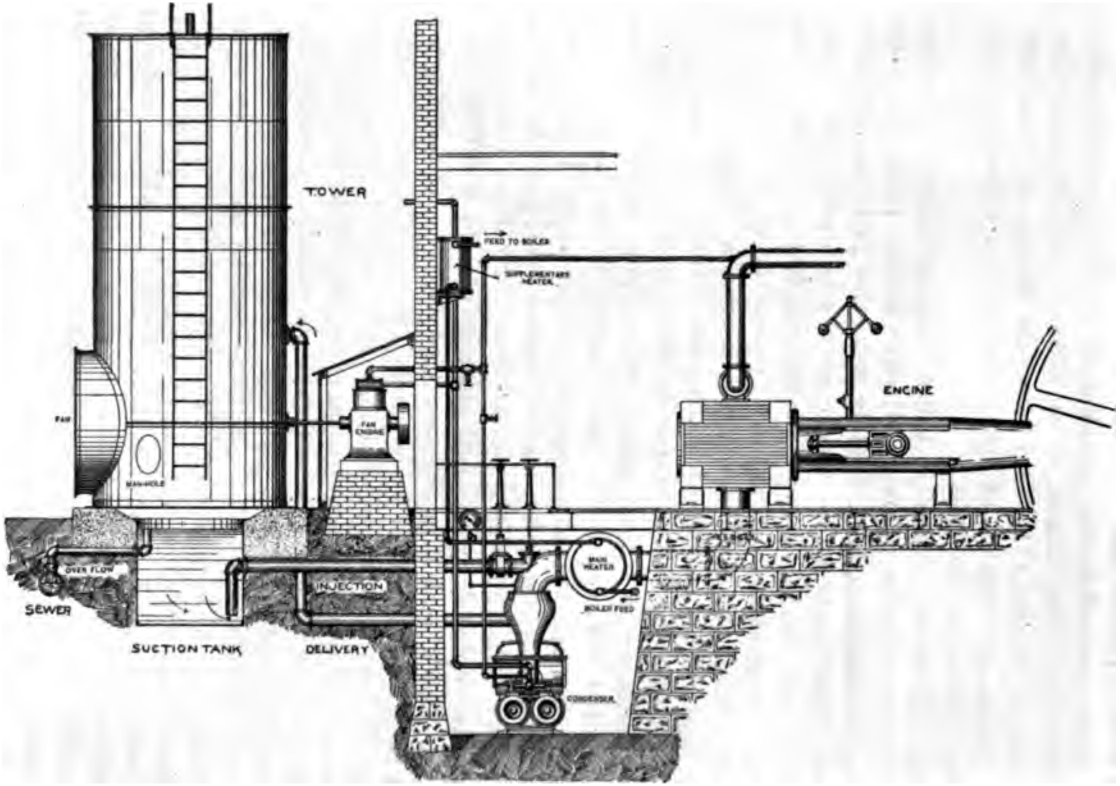
TOWER
FEED TO BOILER
SUPPLEMENTARY HEATER
ENGINE
FAN
MAN-HOLE
FAN ENGINE
OVER FLOW
SEWER
SUCTION TANK
INJECTION
DELIVERY
MAIN HEATER
BOILER FEED
CONDENSER

FIG. 140.

following condensed table is selected from a very elaborate one contained therein:

b	e	f	e	f	
TYPE OF ENGINE.	FEED WATER PER INDICATED HORSE-POWER PER HOUR.				PER CENT. GAINED BY CONDENSING.
	Non-Condensing.		Condensing.		
Name.	Probable Limits.	Assumed for Comparison.	Probable Limits.	Assumed for Comparison.	
	Lbs.	Lbs.	Lbs.	Lbs.	
Simple High Speed...	35 to 26	38	25 to 19	22	33
Simple Low Speed.....	32 to 24	29	24 to 18	20	31
Compound High Speed.	30 to 22	26	24 to 16	20	23
Compound Low Speed..	....	*	20 to 12½	18	25
Triple High Speed.....	27 to 21	24	23 to 14	17	29
Triple Low Speed......	....	....	18 to 12½	16	....

* The paper does not give a water rate for the compound low-speed non-condensing engine, but it may be fairly assumed to be about the same as for the triple high-speed non-condensing engine, namely, 24 pounds. This will make the gain by condensation just twenty-five per cent.

The terms "high speed" and "low speed," it is believed, refer to the number of revolutions per minute, and not to the piston travel. Low-speed engines are Corliss engines and the like, with releasing cut-offs, and have a rotative speed usually less than 120 revolutions per minute.

Dr. Emery says: "The figures in this column [referring to the water rates assumed for comparison, as given in column *f*] are not intended to be averages of those given in column *e*, but those which can be safely depended upon under conditions of practice with the load varying between considerable limits, thereby affecting somewhat the economy. It is believed, however, from a careful consideration of all the evidence available on the subject, that the figures given are all that can be depended upon under average conditions of practice. Engines operating cotton mills, or large numbers of machines of any kind under conditions securing a substantially uniform load, necessarily give nearer the maximum results shown in column *e*; but engines generating electric current for electric railways, or subject to variable loads of any kind, will rarely show economies as low as have been assumed for comparison in column *f*." And again: "The comparison shows the non-condensing engine inferior at every point to the condensing engine, even if better results [than those given in the table] be obtained for the former in certain cases; still, as has been referred to before, the principal difference will be found by causing the quantities in column *f* to approximate more nearly the minimum quantities in column *e*. Some forms of engines undoubtedly accomplish this, but it is believed that the quantities stated are nearly correct for average good practice with variable loads. Non-condensing engines are wasteful of fuel when heavily loaded on account of low expansion, and at light loads the back pressure forms a large proportion of the total resistance, whereas condensing engines will maintain their economy through a wider range on account of reduction of back pressure."

It may be well to mention a feature of superiority of the self-cooling condenser over a condenser dependent upon a natural water supply such as is usually to be had, especially when used in connection with steam engines subject to great variations of load, as are found in electric-railway, rolling-mill, and similar irregular work. It is substantially correct to say that not less than half of the condensing apparatus in use in connection with stationary engines is located so as to be compelled to lift the injection water at least 16 feet, and a number as high as 20 to 22 feet. This is caused by the fact that the stations or mills, if they are alongside of a river, are usually placed upon moderately high and firm ground. The result of this arrangement is that, in case of a sudden overload of the engine by which steam may be carried three-fourths of the stroke instead of one-fourth of the stroke as normally, the condenser is not capable of maintaining the full degree of vacuum, and when the vacuum falls, as it must necessarily, unless a very large and extravagant amount of water is being passed through the condenser, to a point below that due to the suction lift plus the friction in the pipe, say to twenty inches, then the water is lost entirely, and the engine must either be run non-condensing or the condenser cooled off and started by means of a forced injection from some outside source. This is a very undesirable occurrence in an electric railway station, as can readily be understood. With the self-cooling condenser, however, having the suction lift reduced to a few feet, and a supply of water on hand entirely free from débris or foreign material such as would cause the stoppage of the injection supply, an overload may come to the condenser and the vacuum temporarily fall to a point as low as ten inches without becoming entirely lost. Just as soon as the cut-off again takes place at an earlier point, the vacuum will return to the normal degree without the extreme annoyance of shutting down or of cooling and priming the condenser.

Many of the plants erected during the early history of electric lighting were located without the advice of qualified steam engineers, or the benefit of advanced practice. The question of the economical production of power was lost sight of in the strife to be the first in the field with the electric light. Furthermore, it was expected by some that electricity would be so cheap as to render it unnecessary that the cost of its production be taken into consideration. This, however, has now assumed quite a different aspect, and the power plant is conceded to be the main feature in the success or failure of an electric lighting or power venture.

Those companies with generating plants away from a natural water supply, such as a river or a canal, are severely handicapped in the matter of cost of power by competitors who have been more fortunate in the locations selected, and who, by means of condensation, are able to produce power at very much less expense. On the other hand, it may be said that sites along water fronts in large cities are expensive, and are often at a long distance from the centre of distribution of the electric current, making necessary the use of lengthy and costly conductors to transmit the current. By the use of the self-cooling condenser, the advantages of condensation can be added to those of central and already determined locations, and the plant placed nearly, if not fully, on a par with the best and most recent practice of condensing engines with natural water privileges.

DISCUSSION.

Dr. Chas. E. Emery.—Mr. Alberger is entitled to the thanks of the Society for the presentation of the details of construction and of actual results obtained with modified air condensers on a large scale, or, more strictly, with apparatus for cooling water of condensation with air. The evaporation and consequent waste of a portion of water have a very important, though not governing influence on the result. Condensers of this kind have heretofore generally been made with shallow pans over which the water flowed and between which air was circulated. The method shown appears to be quite effective, and should tend to promote the introduction of this very desirable and important type of condenser. Little can be said in discussion of the paper, for it is very complete in itself. It will be interesting in a scientific sense to have experiments made directly with and without the condenser. My paper before the Institute of Electrical Engineers on "The Cost of Steam Power," quoted from, was of course written without having any such comparisons in view; but I cannot criticise the additional application, and think that the results shown will be sustained in practice, with the exception, perhaps, of some modifications due to the efficiency of the heaters employed. All the heat imparted to the feed water by exhaust steam is saved, whereas the heat in the exhaust steam from the auxiliaries is neither lost nor gained if steam be entirely condensed. The power is, however, under such circumstances obtained without cost and the exhaust simply returns to the boiler nearly all the heat taken from it for the particular purposes.

Mr. William Kent.—Those of us who had the good fortune to visit Paris in 1889, and accepted the invitation of M. Popp to visit his system of compressed air, may remember the enormous cooling tower he had for cooling the condensing water. It is described by Mr. Alberger's paper as a tower of brush and faggots —a great wooden structure filled with brush from trees, tied together, and the water distributed over that immense structure. There is no doubt that the cooling tower described by Mr. Alberger will do the same work with a great saving of real estate and probably of expensive construction. I would like to ask Mr. Alberger if that tank in Fig. 139 is made of wood. It appears to be, in the figure.

Mr. Alberger.—No; it is made of steel.

Mr. Kent.—I suppose in some cases it could be, as there is no pressure.

Mr. Alberger.—It is not required to stand pressure.

Mr. Kent.—So that this structure could be made of boards?

Mr. Alberger.—Yes.

Mr. Kent.—He states in another place that these tiles are preferably six inches in diameter. I would like to ask, why preferably six inches? Why not four inches or three inches? It seems the smaller the tube the greater the surface for a given weight.

Mr. Alberger.—That is correct. The smaller the tube the greater the surface which can be put in the tower, but not exactly for a given weight, because tiles have considerable thickness. A point which has to be considered, in addition to the question of surface, is free area for the air. It is very desirable, of course, to keep the power down which is to drive the fan and circulate the air, and the larger the free area through the tower for the air the less power will be required to circulate it. The whole scheme is to circulate air under very low pressure, simply to cause it to travel over the surface, and six-inch tiling has been found to keep the machine within a reasonable size and operate effectively. It is the regular size of tiling, easy to handle, and does not put too much clay in the structure.

Col. E. D. Meier.—I think it is especially fortunate that this paper should have been read at the St. Louis meeting. We require something of the kind here, perhaps, more than anywhere else. As you must have noticed, the river water here is very muddy, and, consequently, it is a pretty difficult thing to get along with surface condensers there. Otherwise, if it had not been for that difficulty, we should probably have had more large plants located right on the river front for the purpose of using that water. I have in mind at least six large plants—electric light and electric power plants—in this city, which could, I think, be induced to use such a cooling tower and condenser, and which would get great advantage from it. There is one advantage in a plant of that kind, outside of the economy, which Mr. Alberger did not notice, and that is, that some of those plants have been placed right in the residence district, on account of mistaken advice by electrical experts in the early times—that is, early times of electricity, about five or six years ago—that it was necessary to put those plants right in the middle of the length of the electric lines; and as the electric lines are now extended, instead of being in the middle, they are one-quarter inside and three-quarters outside. The exhaust steam becomes a positive nuisance to the neighborhood. Now, they would do away with that nuisance, and save a lot of money at the same time. I think Mr. Alberger had better stay here and see if he cannot put in about six of them before he returns to New York.

Mr. Kent.—They need them in New York more than they do here.

Mr. W. H. Bryan.—I would just like to ask Mr. Alberger, in the case of surface condensers, where the water of condensation and the circulating water are kept separate, how much of the circulating water would have to be added.

Mr. Alberger.—The evaporation in the tower is, on an average, about eight-tenths, we may say, of the steam condensed—it varies, you can readily understand, according to the condition of the atmosphere. But we have saved water, and have had a little to spare, just enough to spare to cause a slight overflow to take place in the tank and carry off the oil and dirt and scum which come from the lubrication of the engine.

Mr. Bryan.—You actually use less water than before?

Mr. Alberger.—Yes; we not only save water by increasing economy in the engine, that is, by giving it the benefit of the vacuum—20 to 30 per cent. economy—but we also save some water in the tower, making the total cost of water to be purchased from the city from six-tenths to seven-tenths of the previous amount, depending, of course, upon conditions.

Prof. W. F. M. Goss.—I would like to ask whether any trouble is experienced from the presence of the oil in the exhaust steam. Do these condensers foul, and, if so, is it necessary to clean them? and how much of a job is it to clean them?—if it is necessary.

Mr. Alberger.—Do you refer to surface condensers or jet condensers? I have used both systems.

Professor Goss.—I thought that in either the water for condensation passed through these tiles or over the tiles.

Mr. Alberger.—It does, yes. With surface condensers, of course, the oil does not get on the tiles. It goes, as in ordinary surface condensers, to the hot well, and then to filters or settling devices, where the oil is removed. But with the jet condenser, where the water of condensation, together with the water from the condensation of the steam, is discharged continuously over the filling of the tower, the oil accumulates in the suction tank. The tiling soon becomes covered with a thin coating of hardened grease, and the inside of the shell is entirely covered with this same material. I have had these machines running two years, and they are well greased and in a thorough state of preservation. They will stand indefinitely before they would become stopped up.

Mr. Kent.—Is there any good oil filter?

Mr. Alberger.—That is for you to discuss.

DCXCIV.*

THE EFFICIENCY OF A STEAM BOILER—WHAT IS IT?

BY WILLIAM KENT, NEW YORK CITY.
(Member of the Society.)

THE following paper is offered as a contribution to the discussion of the subject of the efficiency of steam boilers, which was begun by Mr. F. W. Dean's paper, presented at the Detroit meeting in June of last year, and continued by Dr. Chas. E. Emery's paper, presented at the New York meeting in November. (*Transactions*, vol. xvi., p. 962; xvii., p. 237.)

Within the past few years there has been developed on the part of some engineers a tendency to discredit the "pound of combustible." Mr. E. D. Meier, in the discussion of Mr. Dean's paper (p. 980), says: "I cannot agree with him [Mr. Dean] in regard to retaining that indefinite quantity, the pound of combustible, at all." Mr. W. H. Bryan (p. 988) says: "It seems to me, also, that we should discontinue the use of the term 'combustible,' which is now worse than misleading." Mr. Robert W. Hunt (p. 994) says: "The theoretical 'combustible' as obtained from the analysis [Note by W. K: It is not usually obtained from the analysis, but from the boiler test] is of no value to him [the owner of the boiler] when his grates will allow twenty per cent of the fuel to pass through. This would give a high evaporation per pound of combustible, but the cost of making steam would not be lowered. Combustible is an extremely elastic term, and a dangerous one." Prof. W. B. Potter (p. 999) says: "It is curious to see what a prejudice remains in the minds of engineers in favor of that ancient fraud, the pound of combustible. . . . It is greatly to be hoped that revision of the code will result in the final and effectual removal of the pound of combustible."

Mr. Dean, in his paper read at the Detroit meeting, proposed

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* Presented at the St. Louis meeting, May, 1896, of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

to include in the report of a boiler trial the efficiency, defined thus:

$$(a)\ \frac{\text{Heat units imparted to the boiler per pound of dry coal.}}{\text{Number of heat units in a pound of dry coal by analysis.}}$$

$$(b)\ \frac{\text{Heat units imparted to boiler per pound of combustible.}}{\text{Number of heat units in a pound of combustible by analysis.}}$$

In Mr. Dean's paper as printed in the *Transactions*, vol. xvi., p. 966, the definition is revised as follows:

$$\text{Efficiency} = \frac{\text{Heat usefully absorbed from 1 lb. of combustible.}}{\text{Heat value of 1 lb. of combustible.}}$$

Mr. G. H. Barrus (p. 971) objects to the words "by analysis" and would substitute "by oxygen calorimeter."

Mr. Bryan (p. 988) would discard the "combustible" altogether, and use the efficiency obtained from coal, as in Mr. Dean's first definition.

What the owner of the boiler wants to know concerning the economy of the boiler is, "How many pounds of water will it evaporate per pound of coal?" The economy of an engine is usually expressed in "pounds of water per hour per horse-power," and in "pounds of coal per hour per horse-power." Knowing the pounds of water per hour required by the engine, the pounds of water evaporated by the boiler per pound of coal, and the price of the coal, the engine owner can then figure the cost of fuel per hour per horse-power. Hence arises the necessity for the report of a boiler test stating the result in "pounds of water evaporated per pound of coal under actual conditions" (1).

For comparing different tests, however, the conditions of feed-water temperature and steam pressure must be reduced to a uniform standard; hence it is customary to reduce the result (1) to the "equivalent pounds of water from and at 212 degrees per pound of coal" (2).

But coals from any given district vary in percentages of moisture and ash (largely in moisture if transported during rainy weather); hence for a further reduction to a standard of comparison we divide the result (2) by the percentage remaining after deducting the percentage of moisture (determined by drying a large sample, say 100 pounds, at the time of the boiler test), and the percentage of "ash and refuse" (determined by weighing all the ash and refuse withdrawn from the furnace during the test). This gives us the "pounds of water evaporated from and at 212 degrees per pound of combustible" (3).

These three results have been included almost universally in the reports of all boiler tests that have been published both in this country and in Europe during the past fifty years or more.

Let us now consider two ideal boiler tests in which, after obtaining the ordinary results, pounds of water evaporated from and at 212 degrees per pound of coal and per pound of combustible, we attempt to obtain the "efficiency." The coals are, say, Pocahontas, Coal A, and Indiana Block, Coal B. The tests are made with the same boiler, and under the same conditions as far as possible. The steam is assumed to be dry saturated, and the temperature of the flue gases 500 degrees Fahr. The engineer, with no other apparatus than platform scales, tanks, thermometers, and a steam gauge, obtains the results:

	A	B	
Pounds of water from and at 212 degrees per pound coal ...	11.04	7.65	(1)

The sum of the "ash and refuse" obtained in the test, and the moisture obtained by drying a sample of the coal, is, A, 8 per cent.; B, 15 per cent.; making what the engineer calls combustible, A, 92 per cent.; B, 85 per cent.; and from this we obtain:

	A	B	
Pounds of water from and at 212 degrees per pound combustible	12.00	9.00	(2)

From results (2) the engineer, knowing what results are usually obtained with Pocahontas and with Indiana coals, can form a fair opinion as to whether the boiler is doing what it ought to do, and what changes in rate of driving, setting of furnace, method of firing, etc., may make it do a little better. Until the term "efficiency" had been introduced into guarantees it would also determine whether or not the boiler had filled its guarantee. The results (2) could also be compared with the published results of all the tests that have been made during the last fifty years, and conclusions could be drawn from the comparison.

From results (1) the boiler owner, knowing the price of the two coals, could determine which one was most economical for him to buy, and the fuel cost per horse-power per day. Thus far, all the work has been done by the engineer with ordinary apparatus, and neither the chemist nor the fuel calorimeter expert, necessarily involving additional expense, has been called in. But the "efficiency" of the boiler is desired. How shall we obtain it?

The first thing required is a correct average sample of the coal used during the test. The use of a sampling machine, such as would be used in sampling silver ores, in which the whole of the ore is passed through the machine, is impracticable, so the engineer takes a shovelful of coal from the pile at frequent intervals during the test, and thus gradually accumulates a barrelful. The barrel is dumped on the floor, and by repeated quartering a sample of from five to fifty pounds is obtained, which he sends to the chemist and to the calorimeter man. Who knows whether this sample is a correct average of the coal used in the test, or how much it is air-dried during the process of accumulating the barrelful, during the quartering, or during the subsequent transportation, mixing, quartering, etc., to which it is subjected before the chemical or the calorimeter test is made? The error of the sample may be two or three per cent. or more.

The chemist reports his analysis as follows:

	A, Pocahontas.	B, Indiana Block.
Carbon	86.51	72.94
Hydrogen	4.44	4.50
Oxygen	4.95	11.77
Nitrogen	0.66	1.79
Sulphur	0.61	.....
Ash	1.54	4.50
Moisture	1.29	4.50
	100.00	100.00

Calculated by Dulong's formula,

$$\text{B. T. U.} = 14{,}500\left[C + 4.28\left(H - \frac{O}{8}\right)\right],$$

the heating power of the coals is, A, 14,915; B, 12,457 (3).

Subtracting the ash and moisture, 2.83 per cent. in A, and 9 per cent. in B, we obtain:

	A	B	
Heating power of the "combustible"	15,349	13,689	(4)

Let us suppose that the fuel calorimeter man, by accident, also finds that his samples contain respectively 2.83 and 9 per cent. of ash and moisture, and he reports the heating value as follows:

	A	B	
Per pound of coal	14,818	11,211	(5)
Per pound of combustible	14,735	12,320	(6)

The heating power of A is 4 per cent. less, and that of B 10 per cent. less, than that calculated from the analysis. These differences between results calculated from analysis and those found by the calorimeter have actually been obtained by a chemist to whom Mr. F. W. Dean sent samples of coal of the same class, viz., Pocahontas, as shown below. Scheerer-Kestner, however (see table in Dr. Emery's paper read at the last meeting, November, 1895), found the heating power of one coal (coking coal from Anzin) 18.8 per cent. *greater* by calorimeter test than that calculated from analysis; and in nineteen coals tested by him found the calorimeter result greater in every case except one, which was 4.6 per cent. less. These variations in calorimeter tests certainly throw doubt on all calorimeter work until a sufficient number of tests shall have been made by different experimenters and with different calorimeters upon similar samples, and until tests so made show a reasonable degree of uniformity.

In the present state of our knowledge upon the subject, who is to decide which of the results (3), (4), (5), and (6) is to be accepted as accurate?

The engineer, having obtained these results, is now ready to make his calculations of the "efficiency" of the boiler. His own results he is sure of, within the ordinary limits of error of a boiler test. They are:

	A	B	
Pounds of water from and at 212 degrees per pound of coal......	11.04	7.65	(1)
Pounds of water from and at 212 degrees per pound of combustible	12.00	9.00	(2)

Multiplying these figures by 965.7 he obtains the heat units absorbed by the boiler, as follows:

	A	B	
Heat units absorbed per pound of coal	10,661	7,388	(7)
Heat units absorbed per pound of combustible................	11,588	8,691	(8)

Figuring first from coal, dividing (7) by (3), he obtains:

	A	B	
Efficiency (7) ÷ (3)..	71.48%	59.31%	(9)
" (7) ÷ (5)..	74.46%	65.90%	(10)

Figuring now from combustible, he obtains:

	A	B	
Efficiency (8) ÷ (4)....	75.50%	63.49%	(11)
" (8) ÷ (6)................................	78.64%	70.54%	(12)

The results (9) and (10) express the ratio of the heat absorbed by the boiler to the heat units in the coal (including its moisture and ash) *fed* into the furnace. The results (11) and (12) express the ratio of the heat absorbed by the boiler to the heat units in the combustible portion of the coal that was *burned* in the furnace—that is, the coal fed minus the deduction for moisture and the refuse coal and ashes withdrawn from the furnace. The latter express the efficiency of the combination of the boiler as an absorber of heat, and of the furnace as it more or less completely burns the combustible gases; the former the efficiency of the combination of the boiler, the furnace, the spaces between the grates which allow unburned coal to fall through them, and the method of stopping the test, by which a greater or less quantity of coal is withdrawn with the ashes. Can any one of them properly be called *the efficiency of the boiler*, and if so, which one?

After the boiler owner has received the report of the results (9), (10), (11), and (12), how much wiser is he than he was when he received the report of results (1) and (2) only, with the comparison of these results with those observed from other boilers using the same kinds of coal? Can he with these later results figure any closer than before the cost of fuel per horse-power, or does he know any more about the relative values of different boilers, or different kinds of fuel? If these results have any value, is it sufficient to warrant the engineer asking the boiler owner to go to the expense of having chemical and calorimeter tests made?

Enough has been said to show the uncertainty, in the present state of our knowledge, of the accuracy of tests by the fuel calorimeter. Are we any more certain of the results of ultimate chemical analysis?

Mr. Dean has furnished me the following results, which he obtained from a chemist, of the analyses of twelve samples of semi-bituminous coal. The first five are Cumberland coal:

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
Moisture	Dry	Dry	0.58	0.49	0.60	Dried at 212°
C	81.03	84.16	79.40	84.55	80.15	82.55
H	4.57	4.86	5.11	4.88	4.94	5.20
O	5.20	4.03	3.80	3.86	5.76	3.84
N	1.50	2.00	1.25	1.00	1.00	1.00
Ash	7.21	4.54	9.24	4.61	6.68	6.86
S	0.99	0.83	0.62	0.61	0.87	0.55
	100.00	100.00	100.00	100.00	100.00	100.00
Heat units, calculated	14,182	14,909	14,389	14,990	14,240	14,898
Heat units, by calorimeter	....	....	13,452	14,092	13,463	13,680
Difference	....	....	937	898	777	12.18
Per cent	....	....	6.51	5.99	5.46	8.18
Heat units per lb. combustible, calculated	15,284	15,723	15,956	15,796	15,358	15,995
Heat units per lb. combustible, by calorimeter	....	....	14,917	14,849	14,520	14,687

Nos. 6 to 10, inclusive, are Pocahontas. No. 11 is called Clinch Valley. No. 12 is from New River, W. Va.

	No. 7.	No. 8.	No. 9.	No. 10.	No. 11.	No. 12.
Moisture	0.55	0.60	0.69	Dry	Dry	Dry
C	87.86	80.23	82 27	87.70	79.23	83.42
H	5.17	4.75	4.53	5.20	5.22	5.50
O	3.77	7.76	6.15	2.68	5.09	5.08
N	1.00	1.00	1.00	1.25	1.27	1.26
Ash	1.65	5.13	4.88	2.49	8.60	4.07
S	....	0.53	0.48	0.68	0.59	0.67
	100.00	100.00	100.00	100.00	100.00	100.00
Heat units, calculated	15,657	13,978	14,265	15,729	14,350	15,115
Heat units, by calorimeter	14,092	13,450	13,604	14,654	13,401	14,026
Difference	1,565	528	661	1,075	949	1,089
Per cent	10.0	3.78	4.64	6.83	6.61	7.25
Heat units per lb. combustible, calculated	16,009	14,828	15,106	16,131	15,700	15,756
Heat units per lb. combustible, by calorimeter	14,409	14,267	14,406	15,028	14,662	14,621

In these analyses we notice, (1) that they all add up to exactly 100 per cent., showing that some one of the elements must have been obtained "by difference"; (2) that the nitrogen in six out of the twelve analyses is exactly 1 per cent., in two others 1.25, in another 1.50, and in another just 2 per cent., which raises a suspicion that the nitrogen was "estimated" and not exactly determined; (3) that coal No. 7, which shows the greatest difference between the heat units as determined by calorimeter and as calculated from the analysis, also shows by analysis the highest heating value with one exception; (4) that the coal which has the lowest heating value, as calculated from the analysis, also shows the smallest difference between that value and the value found by calorimeter. These facts do not demonstrate that any of the analyses are in error, but they do throw suspicion on them. Comparative accuracy in iron and steel analysis has only been attained after years of experiment and comparison of results obtained by different chemists. I have yet to learn of any duplicate samples of coal having been analyzed by two or more different chemists for the purpose of checking results. Until this is done, and until more definite information in regard to the accuracy of analyses of coal is obtained than we now have. any analysis must be open to more or less suspicion of inaccuracy.

Another objection which may be made to the use of "efficiency" as a standard in commercial boiler tests is the following: In boiler tests made to compare two competing boilers, or to determine the fulfilment of a guarantee, when there is a premium or a forfeit at stake there are usually two parties to the test, whose interests are antagonistic, the competing boiler makers or the boilermaker and the purchaser. In the ordinary test in which the evaporation per pound of combustible is the standard the boilermaker has the privilege of using the best coal he can obtain of the kind named in the contract, and both parties are represented at the test by experts who check the accuracy of every recorded observation. There is no difficulty in their obtaining identical results, for the platform scales, tanks and other instruments are standardized, and the weights and measurements are easily verified. But when "efficiency" is adopted as a standard, who is to verify the work of the chemist, or who shall determine the accuracy of the fuel calorimeter? When ores are purchased on certified chemical analyses, the chemist himself or his representative, as a disinterested party, does the sampling, but in a boiler test the chemist or the calorimeter expert merely certifies that the particular sample which has been sent to him, "as received" has such a chemical analysis or such a heating value. There is no check upon his work, and each party to the test takes the risk of his inaccuracy, which may be serious.

I am informed that in a recent boiler test at St. Louis, a boilermaker was subjected to a forfeiture of several thousand dollars as a result of his failing to show a certain guaranteed "efficiency." I think it more than probable that if the coal used in that test had been differently sampled, and if its heating value had been determined by a different chemist or by a different calorimeter, the amount of the forfeiture would have been greatly diminished.

The agitation in favor of the use of the "efficiency" of boilers as a standard of comparison has already extended so far that some engineers who frame specifications for contracts are including "efficiency" as among the things to be guaranteed. Two examples of this have recently come under my notice. The first specifies that "the contractors are to state the efficiency they will guarantee from coal having a calorific value of 12,000 B. T. U.; if fuel with different calorific value is used in making the test, correction will be made." The second worded the specification to the effect that contractors will be required to state the efficiency they will guarantee from the coal now being used in the works, Illinois screenings; the efficiency to be computed from coal and not from combustible; and the coal will have a calorific value of not less than 10,500 B. T. U.

In neither case was any definite information given concerning the nature of the coal to be used in the test, nor was it stated whether the calorific value was to be determined by analysis or by calorimeter, or by whose calorimeter. The boilermaker who bids on such a specification is taking a gambling risk. He not only has to fix his price on the usual basis of cost plus profit, modified possibly by his anxiety to get the job and by his opinion as to what competition he is to meet, but he has to guess at what kind of guarantee his competitors will give, knowing that the competitor who knows the least about actual boiler tests with Western coals will be apt to give the highest guarantee. In one of these cases, I was asked by a boilermaker, who proposed to bid, what guarantee I would advise him to make. I have made a great number of tests with Western coals, with different boilers, and am well acquainted with what can be done by this maker's boiler with anthracite and with semi-bituminous coals, but I could not give any advice concerning this guarantee. I would like if those who may discuss this paper would give their opinions of what kind of guarantee should be given on these specifications, assuming that the boiler was either a horizontal tubular or a Heine water-tube, amply proportioned in every respect, and set with an ordinary grate for hand firing. My own opinion is that not enough is yet known concerning the calorific power of Western coals, concerning the method of determining their calorific power, nor concerning the "efficiency" of boilers, to warrant efficiency being considered as an accurate standard of comparison, nor of its being specified in guarantees. I would especially condemn the particular method of specifying it which is used in the two examples given above. If an engineer believes that "efficiency" is a proper standard for bidders to be governed by and to guarantee, then he should state in his specifications what kind of coal will be used in the test, what percentage of efficiency is required, and how the efficiency is to be determined; if by analysis, by what chemist; and if by calorimeter, by whose calorimeter.

I have no objection whatever to the use of the term "efficiency" in reports of boiler tests, whenever the heating value of the coal can be determined, whether by analysis or by calorimeter. A knowledge of the efficiency may be of great value for scientific study of comparative boiler tests by the boiler maker and by the engineer, and the efficiency may be conveniently recorded in the result of a test as an addition to the time-honored evaporation per pound of coal and per pound of combustible, but I would by no means substitute it for these results, and especially I would not advise its adoption as a commercial standard to be specified in contracts or in guarantees.

Postscript.—Since the above was put in type, I have received the results of calorimetric tests, by two different calorimeters, of two coals which I recently used in testing a boiler. One coal (C) was from Jackson Co., Ohio, and the other (D) was from New River, W. Va. The results obtained in the boiler test were as follows:

	C.	D.	
Water evaporated per lb. coal, actual conditions........ lbs.	6.793	9.649	(1)
" " from and at 212 degrees.. "	8.188	11.618	(2)
" " combustible " .. "	8.577	12.252	(3)
Ash and refuse, per cent....................................	4.527	5.158	(4)
Heat absorbed by the boiler, per lb. coal...........B. T. U.	7,907	11,220	(5)
" " " combustible.... "	8,283	11,853	(6)

The moisture in the coals was not determined during the boiler test, but they both appeared to be quite dry. The moisture found in the calorimeter samples of coal C, 3.83 and 3.94 per cent., gives rise to a suspicion that either the crushed coal is very hygroscopic, or that what was determined as "moisture" may in part have been volatile matter. The results (3) of evaporation per pound of combustible have been calculated from (2) by deducting the ash and refuse only, no account being taken of the moisture.

The first calorimeter test was made by Prof. R. C. Carpenter on his calorimeter, described in vol. xvi. of the *Transactions*, p. 1,040. He reported the proximate analysis of the coal as follows:

	Coal C.		Coal D.	
	Moist Coal.	Combustible.	Moist Coal.	Combustible.
Moisture....................	3.83	—	1.18	—
Volatile matter..............	32.07	35.76	20.92	22.24
Fixed carbon................	57.60	64.24	72.90	77.76
Ash.........................	6.50	—	5.00	—
	100.00	100.00	100.00	100.00

The ash found by this analysis in coal C is greater than that found in the boiler test. This is probably accounted for by the fact that the coal was fed by the American underfeed stoker, and was so thoroughly burned that no unburned coal whatever appeared in the ash, while the ashes were exceedingly light, and to some extent were blown by the forced blast as dust into the flue leading to the chimney. Coal C was dry-burning, or non-coking, which facilitated this blowing of the ash dust, while coal D was a coking coal, and the coking prevented the blowing of the dust.

Duplicate samples of the coal, which had been crushed and thoroughly mixed by Prof. Carpenter, were sent to a chemist in Boston, who used the Lewis Thompson calorimeter.

The results of the calorimeter tests are as follows:

	C.	D.	
Heat units per lb. coal, Carpenter cal. B. T. U......	13,170	15,200	(7)
Heat units per lb. coal, Thompson cal. B. T. U......	11,913	13,066	(8)
Heat units per lb. combustible, Carpenter cal. B. T. U.	14,620	16,210	(9)
Heat units per lb. combustible, Thompson cal. B. T. U.	13,302	13,799	(10)
Difference between results (9) and (10), B. T. U.. ...	1,318	2,411	
Difference, per cent. of greater...............per cent.	9.02	14.87.	

The heating value per pound of combustible was not reported by the Boston chemist, but he reported the moisture in coal C to be 3.94 per cent. and in coal D 0.31 per cent. Taking these figures for moisture and Prof. Carpenter's figures for ash—viz.: C 6.50 per cent., D 5.00 per cent.—the results (10) have been calculated from the results (8). The "efficiency" of the boiler, as calculated from the above data, is as follows:

	C.	D.
Figuring from coal:		
Results (5) ÷ (7), Carpenter calorimeter, per cent.	60.04	73.82.
Results (5) ÷ (8), Thompson calorimeter, per cent.	66.37	85.83.
Figuring from combustible:		
Results (6) ÷ (9), Carpenter calorimeter, per cent.	56.66	73.12.
Results (6) ÷ (10), Thompson calorimeter, per cent.	62.27	85.17.

The efficiencies figured from combustible for coal C might be raised to about 60 and 65 per cent. respectively, if the moisture in the coal had been taken account of in figuring the results (3) of the boiler test. As the above record stands the "efficiency" of the boiler may be anywhere from 56.66 to 85.83 per cent., according to how the results are calculated and what calorimeter is used. The high figures, 85.17 and 85.83 per cent., might be useful for advertising purposes—and they suggest that the way to get a high "efficiency" for a steam boiler is to use the Lewis

Thompson calorimeter to determine the heating value of the fuel—but they are utterly untrustworthy. This may be shown by the following calculation:

Heat absorbed by the boiler per lb. combustible, B. T. U.	11,853
Loss of heat in the chimney gases: temperature, 480°; temperature of air in boiler room, 90°; estimated air used per lb. of combustible, 24 lbs., or double the theoretical amounts; 24 lbs. × 0.24 specific heat × 390° =	2,346
Estimated loss by radiation, 4% of 11,853	474
Total	14,673
Reported heating value of coal, per lb. combustible	13,799
Excess	874

or 6.3 per cent of the reported heating value of the coal, no allowance being made for loss due to imperfect combustion.

These calculations, I submit, demonstrate the total unreliability of the "efficiency," as at present determined, for a commercial standard for boiler tests.

DISCUSSION.

Mr. Geo. H. Barrus.—It seems to me to be premature and unwise to present this subject before a general meeting of the Society when, as the author intimated, it has been made a matter to be considered by a specially constituted committee, before which it must come for action and recommendation.

This paper is not in any sense an action of the committee, but must be viewed as an individual matter on its author's own responsibility.

Col. E. D. Meier.—Mr. Kent objects to the comparison of the performance of different boilers in terms of efficiency, and holds that the old method of comparing the work by the amount of evaporation per pound of combustible is better and safer alike for the engineer and for the owner of the plant. I do not believe that any one of those who object to the use of the pound of combustible in work of this kind intended any unfavorable criticism of the work of the former committee of this Society which formulated the code for boiler tests. We all acknowledge that those gentlemen did good and conscientious work, and this is shown by the very general acquiescence in their methods. But we all of us base our judgment on our experience, and when we consider any abstract question, our reasoning is always affected by our experience. It is very fortunate that it is so. Now the gentlemen who composed that committee probably had at that time more experience in boiler testing than an equal number of engineers any where in the Union. But I believe I am well within the mark when I estimate that there are ten boiler tests made to-day to one made in the period when that report was framed, and the vast majority of the tests then made were run on such coals as are regularly used for the making of steam in the section of the country lying east of the Alleghany Mountains. This limited the experience of the members of this committee practically to anthracite and Cumberland (semi-bituminous) coals. Now anthracite is a coal which, like Jeff. Davis and his friends, simply requires to be "let alone." Cumberland also requires little manipulation after it has once been properly distributed on the grates. I have known tests run on Cumberland coal—and for that matter on anthracite coal—where, during a ten-hour test, no general cleaning of the fires was resorted to. Contrast with this the coals in general use in the vast and growing industrial region west of the Alleghanies and in the Mississippi Valley. With most of the coals in general use here, it is necessary to clean fires once in three or four hours, and much depends on the skill of the fireman in taking out the clinker in as short a time as possible, to reduce the loss due to the open fire door. Here is a radically different set of conditions. The pound combustible as defined by Mr. Kent as what remains after deducting the moisture and the ash and refuse, is something quite different in the case of Cumberland or anthracite coal from what it is in the case of Belleville coal or Streator coal. Mr. McMynn, of Chicago, whose experience has lain largely with coal of this latter quality, and who is almost constantly engaged in boiler tests, says: "The main objection to calculating efficiency from the evaporation per pound of combustible is that no two firemen will ever make just the same amount of ash, and it also gives a chance for error because it puts a premium on dropping good coal or half-burned fuel through the grates, for of course the greater the amount of ash the higher the evaporation per pound of combustible." His extensive experience shows him what is apt to happen when coal of from 40 to 45 per cent. fixed carbon and from 30 to 40 per cent. volatile matter is being fired. The experience of the older committee was with coals running from 75 to 80 per cent. fixed carbon, and perhaps 7 to 15 per cent. volatile matter. Even supposing the fireman to be perfectly honest and intelligent, it is practically impossible for him to prevent large quantities of coke being mixed with the cinders and slag he draws from the furnace when cleaning fires. Not only does a vast quantity of cold air rush in during the operation, but a large amount of heat is withdrawn from the furnace in the clinker. That both these causes are much more effective in reducing the apparent economy of the plant when we are dealing with coal which has from 10 to 20 per cent. of ash than when using such as hold from three to six per cent. is readily seen. In deducting the moisture obtained by drying a large sample over the boiler flue, there is a chance for a large error, because much of the volatile matter leaves the combination at a low temperature if long enough exposed. It is certainly much easier to get educated engineers to agree on the kind of calorimeter and the methods of making tests of the heat value of the coal than to get all the firemen of a given district to work with equal skill and equal conscientiousness in cleaning fires. There is a much greater error in thus drying a large sample of coal on the flue than that due to possible air drying during the process of accumulating the barrelful for the calorimeter test. Those of us who favor stating the efficiency in percentage of the heat value of the coal do not imagine that we will get something absolutely correct. But it must be remembered that we look to the establishing of certain coals as standards for the various great coal districts. People will soon learn that the percentage of efficiency which can be obtained in the best practice will be less for Iowa or Illinois coals than for Youghiogheny, Cumberland, or New River. Each great district will soon have its own record, and these records will be nearer the exact truth than could ever be hoped for in comparing the record per pound combustible in two tests, one made on Northern Colorado lignite and the other on Pocahontas coal.

In regard to the question about Western coal which Mr. Kent's boilermaker asks, the answer is simple. The boilermaker will do best to ask each expert for an opinion on such coals with which he is thoroughly familiar; for in the others he is no expert. And it is just as easy for the New York boilermaker to ask a St. Louis or Chicago expert in regard to Illinois coal, as it is for us Western men to ask the Philadelphia or New York expert when we are called upon to make guarantees on anthracite coal. I believe it is a fortunate thing for engineers that this is so. These differences, which must be studied with patience and under a great variety of conditions, enable each engineer to grow up with his own country, and go to prevent a sort of Standard Oil monopoly in expert work.

I heartily agree with Mr. Kent that when an engineer makes efficiency the standard for bidders he should state distinctly what kind of coal will be used in the test. For the possible maximum efficiency varies greatly in coals from the same districts having similar calorific value. He should also state by what calorimeter the heat value is to be determined, and expert engineers will as readily use a coal calorimeter as they now do the steam calorimeter. The percentage of efficiency then becomes the equivalent of the "time-honored evaporation per pound of coal." But neither time nor anything else can put any honor into that hoary myth "the pound combustible."

If the evaporation per pound of combustible is to be honestly and accurately given, why not give the pound of combustible actually doing evaporative work in the boiler its honest due? Why saddle it with the work of heating up noncombustible ash and clinkers to furnace temperature, or of heating up the noncombustible volatile matter to stack temperature? Why ignore the fact that the reduction of the initial furnace temperature due to the presence of inert nitrogen, water vapor, etc., reduces the difference in degrees of heat between the gases of the furnace and the water in the boiler on which the activity of the transfer depends? If the pound combustible is worth any paternal love, it is worth more than it gets from its progenitors.

The example given by Mr. Kent of coals (C and D) illustrates the point exactly: That Jackson Co. coal has no doubt a great deal of noncombustible volatile matter which had to be heated by the actual combustible, so that this poor time-honored misnomer was robbed on both sides. First by the thief appropriating a quantity of heat, and then passing himself off as a part and parcel of his victim.

In this case Mr. Kent himself made both tests, and it was the same boiler and same setting. Suppose they had been two different boilers, one in Ohio and one in New York, would Mr. Kent undertake the task of satisfying the average manufacturer or steam user that the one boiler was as good as the other?

In conclusion I would remind Mr. Kent that if he applies the deduction made from the difference in the results of the Carpenter and the Thompson calorimeter, to the forfeiture made in the boiler test at St. Louis to which he refers, the forfeiture would be very much increased, for this forfeiture is based on a Thompson calorimeter, and the Carpenter calorimeter seems to give much higher results.

Mr. William H. Bryan.—The contention of those engineers who have faith in the determination of steam-boiler efficiency is not necessarily that the "pound combustible" be discarded altogether, but that results so stated be given less weight among engineers than heretofore. The objections to the use of the "pound combustible" have been stated frequently, and are well known. We may, however, continue the use of the term in our reports, until the steam-using public has been educated up to appreciate a better form of expression. In my reports I give both the "efficiency" and the evaporation per "pound combustible," and you can take your choice. The owner of the boiler not only wants to know how many pounds of water it will evaporate per pound of coal, but also what percentage of the heat existing in the coal he gets out of it in useful work. The engineer, furthermore, wants all tests reduced to a common basis for purposes of comparison.

I do not believe in drying 100 pounds of fuel at the time of the test for the purpose of correction. The entire amount of fuel to be used should, if possible, be air-dried for at least twenty-four hours, in thin layers.

As to sampling the coal: My own practice is to have the fireman take a shovelful out of every 500-pound lot, and instead of throwing it into the furnace, dump it into the sample barrel. The whole sample is carefully preserved and sent to the chemist entire. I believe this method insures a very accurate sample of the coal.

My definition of the term "efficiency" is as stated in (*a*) of Mr. Kent's paper, using the pound of coal and not the "pound combustible." I believe that equation 10, page 649, of Mr. Kent's paper is a fairly correct definition of the efficiency under the conditions named.

The expense of a calorific determination is small, and cuts but little figure in the total expense of a boiler investigation. Most of the calorific determinations used by engineers in this part of the country have been made by the St. Louis Sampling and Testing Works, under the direction of Prof. W. B. Potter, manager. The Thompson calorimeter is used, and the chemists in charge have attained great skill in the use of the instrument, under the immediate personal direction of Prof. Potter. They have made many hundreds of such determinations, both from the same and from different mines, and they have shown a degree of consistency which is ample to inspire confidence in the methods. The question is largely one of chemistry. It would appear reasonable to expect here the same careful results which we secure from trained observers with good apparatus in any field of engineering observation. I have frequently known samples of the same coal to be checked by different observers and to agree within reasonable limits of personal error.

Mr. Kent speaks of a recent boiler test in St. Louis where there was a forfeiture of several thousand dollars. He thinks that if a different chemist or calorimeter had made the determination, the forfeiture would have been greatly diminished. I believe that, on the contrary, it would have been increased, as the efficiency then secured has never been reached since, although repeated trials have been made. The case referred to has been discussed so generally, and the results have reached so wide a circulation, that there is little probability of boiler builders again making mistakes with Western fuels.

Answering Mr. Kent's request for an opinion as to the guarantee which might safely be given with Western coals such as are common in this vicinity, on both horizontal tubular or Heine water-tube boilers, set with ordinary grate for hand firing, properly designed, I will say that an efficiency of 60 should be secured with the tubular and 70 with the water tube, perhaps slightly more.

I cannot agree with Mr. Kent in his conclusions, believing, as I do, that—even admitting, for the sake of argument, some possible uncertainty as to the exact accuracy of the results of calorimeter determinations—the efficiency computed from the coal by calorimeter determination is a better measure of a boiler's merit to-day, than the equivalent evaporation "per pound combustible."

It should not be forgotten that the efficiency of any given boiler is not constant. It varies in the same boiler with the kind of coal, the rate of firing, and the skill of manipulation. The best boiler and furnace is certainly that one which realizes, in useful work, the greatest percentage of the heat which exists in the fuel. There can be no argument on this point, and that is why we want to measure a boiler's merit in efficiency and devote our attention to perfecting the means of getting at this result with accuracy.

I do not agree with Mr. Kent that it is only necessary to use the Thompson calorimeter to get a high efficiency. The low results secured on the St. Louis boiler trial to which he refers, were given by an instrument of this character, and I have every confidence in the accuracy of such determinations, within reasonable limits of personal error

Mr. George I. Rockwood.—The agitation of this question regarding the wisdom of changing the rules of the Society for conducting tests of boilers has been productive of much good, although thus far it appears to me that the good has been of a negative sort. On the one hand, Mr. Kent's arguments against the propriety of using "efficiency" as a standard in *commercial* boiler tests, as recommended by Mr. Dean and by many Western engineers, are unanswerable, and should serve, for the present at least, as a check upon the proposition to establish the custom by giving it the virtual sanction of the Society; on the other hand, the discussion has brought out into the open light the fact that the relative economies of boilers cannot be known with scientific accuracy if simple reliance is placed on the figures giving the evaporation per pound of combustible.

Mr. Kent is of the opinion that "not enough is yet known concerning the calorific power of Western coals, concerning the method of determining their calorific power, nor concerning the 'efficiency' of boilers, to warrant efficiency being considered as an accurate standard of comparison, nor of its being specified in guarantees." My own belief is that in all commercial or competitive trials, guarantees should be based on "the evaporative effect of a pound of that particular kind of fuel which the purchaser has got to use, for the use of which the furnace is designed, and which the seller has the right and the duty to examine before a contract is drawn."

Mr. Albert A. Cary.—Mr. Kent certainly could not have presented any paper to this Society which would be of greater moment to those interested in steam-boiler work than the one which he has just read, and I hope that it will receive the proper amount of appreciation and the consideration which it deserves.

My business places me in constant contact with steam users, and scarcely a day passes without bringing to me one or more specifications in which I find guarantee clauses.

Those clauses relating to the evaporation of the boiler vary considerably in their method of expression, and probably nothing has ever been introduced into these expressions which serves to make them more meaningless than that calling for a guarantee of efficiency of the boiler.

At one time I was quite pleased with this method of summing up a boiler test, and to-day I would be quite as enthusiastic over the expression of a boiler's efficiency if my faith in the ability of those handling coal calorimeters as well as in the chemists making coal analyses had not been shaken severely, and I would add that this experience has forced me to endorse all that Mr. Kent has said.

Two years ago, at the Montreal meeting of this Society, I stated, in a discussion, that engineers drawing boiler specifications were beginning to call for guarantees of the efficiency of boilers from those bidding on their work.

This call for efficiency guarantees was comparatively limited then, but since the Detroit meeting of this Society, last year, when Mr. Dean presented the paper which Mr. Kent has mentioned, calls for efficiency guarantees in boiler specifications have been very frequent, and nowhere has this form of guarantee been demanded so frequently as in Chicago, Detroit, Milwaukee, and other places in that neighborhood.

The increasing demand for this form of guarantee finally led me to look into the matter more carefully and systematically to find the true calorific value of the different coals, and then the trouble began.

I found that the different published results of the calorific value of the same coal varied considerably when it was tested by different people, and also, in many cases, when the same coal was tested by one man at different times. So much did these results vary that I was tempted to send a sample of the same coal to different coal calorimeter men, and that proved to me so conclusively that the results obtainable were so unreliable that I finally decided to refuse to make any further boiler efficiency guarantees.

My experience has taught me where I could send samples of coal and obtain, over a good signature, a low calorific value for any coal; and further, I learned just who should be avoided, if I wished to make my boiler show a very high efficiency.

These facts show plainly how unscrupulous people could easily deceive the purchaser of their boiler, and with such a chance for fraud, should we not denounce this steam-boiler efficiency guaranteeing, at least until the (coal) doctors cease to disagree?

In looking over some recent specifications containing this efficiency clause, I find the two following requirements, which are good examples of the boiler efficiency guarantees required:

The first makes no mention of the coal to be used, and reads as follows:

> "Guarantees :
>
> "The contractors are to state the efficiency they will guarantee from coal having a calorific value of 12,000 B.T.U.; if fuel with different calorific value is used in making the test correction will be made.
>
> "The contractors further guarantee that when working under the conditions under which this efficiency is obtained the moisture in the steam shall not exceed *1.5 per cent.*; that these boilers will work satisfactorily and without injury, and without materially impairing the economy, at 25 per cent. above rating for an indefinite period, and with an entrainment not to exceed *1.75 per cent.* of moisture; an average sample of steam to be obtained in all calorimeter tests.
>
> "Also, that these boilers can be forced to 50 per cent. above rating without injury to any of the parts."

The second guarantee demanded is certainly quite extended, reading as follows:

> "Required :
>
> "Per cent. of the theoretical calorific value of various nut coals as found in Chicago market, that will be practically obtained?..........Per cent. of each?"
>
> Big Muddy, Jackson County?.......................
> Bureau County?..................................
> Coldchester slack?................................
> Duquoin Jupiter?..................................
> Grape Creek?......................................
> Streator?...
> Vulcan nut?.......................................
> Indiana block?....................................
> Hocking Valley?...................................

Regarding the use of "evaporation per pound of combustible," I am afraid that I cannot make up my mind to eliminate it from my reports of boiler tests, notwithstanding that it is called "an ancient fraud."

At one time I ran a series of boiler tests in West Virginia, using coal from one mine in the neighborhood.

All ash drawn from the pit was carefully inspected, and any good coal which had fallen through the grates was picked out and returned to the furnace.

One day I had 14 per cent. ash, while another day I had but 8 per cent. ash from a new lot of coal, which I know positively came from the same shaft.

The results of these two tests per pound of combustible agreed very closely, whereas the results per pound of coal varied considerably, as can readily be understood.

At another time I was running a test where a new cargo of anthracite coal had just been received. A little while later I had occasion to repeat this test, and in the meantime the greater part of this cargo of coal had been used. Of course the dirt, etc., had fallen to the bottom of the pile, and in consequence I had more ash and clinker.

My results in these two cases compared very closely per pound of combustible, but they differed materially per pound of coal.

Furthermore, Col. Meier has suggested that we select some particular type of calorimeter. I do not know what one he would select, nor that all would agree upon such selection. There are a good many instruments in the market, and more than one may be right. I would only ask if there is one which is right, and if everyone could agree to specify its use to determine the calorific value of a fuel. Until such an agreement is reached I do not see how we can make progress as to guarantees of boiler efficiency.

Further, in his remarks Col. Meier speaks of getting the opinion of experts in different parts of the country where the fuel differs from that of your own neighborhood. I have done this, and shall continue to do it, and have been finding out how much there is to know. In some places nothing is so important as a good fireman. He is very essential for anything like a fair test for the fuel in question, as he will get more out of it than any stranger. While, of course, there is a good deal of jockeying and chicanery possible in boiler work, I do not think that the burning of fuel in a way which skill and experience shows to be proper is to be classed under that head. I think also many thinkers have too confused an idea of the relation between the boiler and the furnace. They take them together as a whole, and get results which are confusing and wrong. I believe there is a furnace efficiency which should be considered by itself, and the boiler efficiency is to be considered after the heat is delivered from the furnace to the boiler. The furnace should be adapted to the coal, even if it should run itself into a gas producer. Some of these Western coals can only be properly burned in an enclosed brick chamber. By trying to burn all kinds of coal in one kind of furnace the results can never be very good for comparison.

Mr. Bryan said that in drying coal he would have it air-dried for twenty-four hours. I have found a good deal of moisture in coal dried much longer than that. I do not think that plan will remove the moisture sufficiently to determine the real weight of good fuel and of water.

Prof. J. H. Kinealy.—It seems to me that we ought to state the efficiency not only per pound of coal but also per pound of combustible. I do not think that we are yet in such a position that we can drop the efficiency per pound of combustible. The trouble however in determining the efficiency is to determine the actual heating power of the coal. If it is determined by one calorimeter we get one result; if it is determined by another, we get a very different result. Those results may check or they may not check, depending entirely upon the circumstances under which the calorimeters are used. There are two calorimeters mentioned in this paper; one is the Carpenter calorimeter and the other is the Thompson. The Carpenter calorimeter is an oxygen-flow calorimeter. If the oxygen in that calorimeter flows too fast we get one result; if it flows too slow we get an entirely different result. The Thompson calorimeter I have used. In the Thompson calorimeter we get our oxygen from a mixture of chlorate and nitrate. If we have too much chlorate, we have one result; if we have too much nitrate we get a very different result from the same coal. An anthracite coal or a coke—any coal that is very high in carbon or very low in combustible gases—will need a large proportion of chlorate and a small proportion of nitrate. Put, however, that same mixture of nitrate and chlorate in a fast-burning coal and we blow a part of the charge out of the furnace. I have made these experiments in the open air and have made them under water and have there found the particles of coal floating on the water. It is probable that the reason the two Thompson calorimeters gave about the same results with one of the coals, as shown in column 1 on the blackboard,* is that the calorimeters had probably been used for eleven or twelve thousand heat unit coals right along, and the proportions of chlorate and nitrate were about

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* The figures referred to as being placed on the blackboard were as follows:

	Jackson, O., Coal. 1	New River, W. Va., Coal. 2
Carpenter calorimeter	13,170	15,200
Thompson calorimeter, Boston chemist	11,918	13,066
" " Professor Potter	11,894	13,527

right for that coal; and the results given for the second coal, as shown in column 2 on the blackboard, differ because it is probable that the proportions of chlorate and nitrate were not right for that coal. The results for the second coal differ by about four per cent. If we are letting a contract and expect to enforce a forfeit or give a bonus there ought always to be some space that should be called "no man's land." If the probable error of the calorimeter is, say, two per cent., in an average of, say, five or six experiments, then if the error is two per cent. too large, the efficiency will be about two per cent. too small. If the error of the calorimeter is two per cent. too small, then the efficiency will be about two per cent. too large. So that we ought not to begin to enforce the forfeiture unless the efficiency goes two per cent. below the guarantee; and we ought not give a bonus unless it goes about two per cent. above, depending entirely on the probable error of the calorimeter. It seems to me that we ought to use either the closed oxygen calorimeter of Berthelot or Mahler or Hempel—either one—or we ought to use the analysis in determining the heat of combustion of a coal. The chemists check better than the various calorimeters. Chemists can check. The objection, of course, is that they use a very small sample of coal. Well, the Thompson calorimeter, which I believe uses a larger sample than any of the others, uses only 30 grains. Now, 30 grains—7,000 grains to the pound—and we will burn three or four or five or six or eight tons a day, and the base from which we make all our measurements is 30 grains! We have got to sample the entire pile of coal down to that amount, and there will be a great difference in our sampling. If we take lumps, we will get one thing; if we take the fine coal we will get something different. If the coal is a clean coal without any dirt and we are taking the fine particles we will get the richest kind of a coal and we will get the highest result from the calorimeter. I think we ought to adopt a bomb calorimeter, a calorimeter that is completely sealed, and pure oxygen put into that calorimeter and the coal burned in the presence of pure oxygen. The instrument, however, is a very expensive one. The Berthelot is very costly, as it is lined with gold or platinum. The Mahler instrument is somewhat more reasonable, as it has an enamel lining. Professor Hempel, of Germany, however, has got very good results with an unlined calorimeter. He heats the steel bomb to a very high temperature and then exposes it to steam and oxygen and oxidizes the inside of the calorimeter. A friend of mine who is a personal friend of Professor Hempel wrote to him last year to ask him how the calorimeter that he used was doing—what sort of result it was giving, and he said that he had used it on quite a large number of tests, I think about 200, and there was no effect of oxidation on the inside of the calorimeter. Even with the bomb calorimeter you must make corrections for nitric acid if you want absolutely correct results. Now I object very much to results being stated as they are stated on that board—11,913. No one knows anything about the figure 9 much less the 1 and the 3. The result is not correct within one per cent., and therefore only three significant figures ought to be given.

Mr. J. W. Blood.—Mr. Kent's argument seems to be that evidence shows the calorimeters are not correct within themselves, and he therefore does not wish to change the standard to something which he knows is not accurate. Now it seems to me it lies with the people who are backing up the calorimeter guarantee to say that a calorimeter experiment can be depended on within a certain amount, and again to show that the test specimens taken throughout a test do not vary within wide limits. It seems to me that it is a problem to be taken up by the Committee on Boilers to show how much calorimeters can be depended upon, and what variation may be expected in the same calorimeter on distinct tests. I have had guarantees of a similar nature to make, and we have had to come down to the more practical points until the scientific points are more definitely stated. But in this work it seems that there are two sides; that is to say, now we have something definite in a commercial way, and we are asked to change from that guarantee to a scientific one of which we do not know the definiteness. It seems the problem is to find out how much variation can be expected in calorimeters. Of course, the efficiency—and that is what the engineers are interested in, the real measure of a boiler—is to be determined by an analysis of the coal, and that gives the measure of the ability and design of different boilers. But from actual work and from actual evidence which we have now, it seems that the best guarantee is the most definite guarantee on practical work; that is to say, a boiler-maker must guarantee under certain conditions to give certain results, and those conditions are actual conditions; that is to say, I would recommend guaranteeing that with a certain grade of coal we get a certain output. This is the figure the purchaser wants. He wants to take that guarantee of the boilermaker and put the price on his coal, and see which kind of coal will be best for him. I think that is the case now, and it is to be demonstrated how accurately the new guarantee can be handled.

Col. Meier.—Mr. Cary instances that remarkable case in Chicago where boilermakers were expected to guarantee on every coal which came into the Chicago market. It was just that which we want to avoid by establishing standard coals for each great coal district. When that is once done, then you avoid all that difficulty.

Now in regard to the choice of a calorimeter, it is just as easy to choose beforehand the calorimeter which is to be used, and if you wished to refer it to a chemist as an umpire, the chemist and the calorimeter can be agreed on in advance, as well as the coal.

The remark made by the gentleman now just reminded me that several times during the discussion gentlemen have referred to making guarantees under actual conditions I do not believe they mean what that implies; because when a boiler is sold—contracted for—we do not know what the actual conditions of test are going to be, and it would be perfectly absurd to ask for a guarantee under actual conditions when we do not know whether we are going to get the feed water at 80 degrees or 200.

*Mr. Wm. Kent.**—Mr. Barrus thinks it is inadvisable to have any discussion on this subject pending the deliberations of the Boiler Test Committee. I do not think you agree with him; I think most of you have enjoyed this discussion. In Detroit last year one side of this discussion was presented. That side of the discussion was continued by the revised notes of the members who took part in it, and in the *Transactions* to-day appears a long catalogue of opinions on that one side, with none that I know of against it. The discussion has been continued in the technical press, and I believe Mr. Barrus himself has taken part in that discussion. One of the writers on the subject in the *Engineering Record*—I may mention his name, Mr. Bryan, who is here present—said in his article in that paper that the opinion in Detroit appeared to be unanimous in favor of this efficiency standard, and brought that out as a strong argument in favor of the efficiency standard. I thought then that it was high time that it should appear that I, at least, was not one of the unanimous mem-

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* Author's closure, under the Rules.

bers. Therefore I wrote this paper, and I did not mean any disrespect to my colleagues on the Boiler Test Committee. I think we should all contribute all the light that we can to the subject. Mr. Meier, in opening the discussion, says that I object to the comparison of the performance of different boilers in terms of efficiency. I made no such objection, but, on the contrary, on page 653 of my paper I say: "I have no objection whatever to the use of the term 'efficiency' in reports of boiler tests whenever the heating value of the coal can be determined, whether by analysis or by calorimeter." His statement to the effect that the experience of the members of the former Boiler Test Committee was limited practically to anthracite and Cumberland (semi-bituminous) coals should also not be allowed to go unanswered. I served on that committee in 1884, and previous to that time I had considerable experience with coals mined west of the Alleghany Mountains, some of which experience is related in my paper on "The Heating Value of Bituminous Coals," read at the Cleveland meeting in 1883. (*Transactions*, vol. iv., p. 249.)

Mr. Meier quotes Mr. McMynn as saying that calculating the efficiency from the evaporation per pound of combustible puts a premium on dropping good coal or half-burned fuel through the grates, "for of course the greater amount of ash the higher the evaporation per pound of combustible." The fact is that the premium is apt to work the other way in the coals mined west of Pittsburg, in which coals the volatile matter is, pound for pound, a less valuable fuel than the carbon. In such coals, if unburned carbon is allowed to fall through the grates, the evaporation per pound of combustible as well as per pound of coal will be less than if all the carbon is burned. Mr. McMynn's statement, quoted above, that "the greater the amount of ash the higher the evaporation per pound of combustible" is, of course, true if we are comparing two tests in which the evaporation per pound of coal is the same; but it is not true if we are comparing two tests of the same boiler with the same coal, in one of which tests more half-burned coal is allowed to fall through the grates than in the other, provided the coal is one in which the volatile matter, pound for pound, is less valuable than the carbon.

Mr. Meier states that in deducting the moisture obtained by drying a large sample over the boiler flue there is a chance for a large error, because much of the volatile matter leaves the combination at a low temperature if long enough exposed. I have as little confidence as Mr. Meier in this method of determining moisture, but for a different reason. I have never found any loss in volatile matter in coal even after heating for several hours to from 220 degrees to over 300 degrees Fahr.; but, on the contrary, have found an increase in weight after such heating. My objection to the method is the difficulty of getting the coal thoroughly dry by this method, especially in the case of Western coals. I mentioned this method in my paper because it is the one ordinarily used, not because I believe it to be the best one. What the best one is will probably be determined before long, as the result of investigations suggested by the paper of Mr. Hale, read at this meeting.

Col. Meier answers my question as to the kind of guarantee that an Eastern boilermaker should give on a Western contract. He says that the proper thing for the Eastern boilermaker to do was to call in a Western expert to tell him what kind of a guarantee to give. The boilermaker I referred to did that very thing. He called in a Western expert. The Western expert presented a very admirable report of what results could be got from that kind of coal. The question was then raised: "What duty shall I guarantee? Shall I guarantee eight pounds with this particular kind of coal? That is, shall I guess I am going to reach eight pounds, or shall I go a little higher?" I answered: "If you go higher than eight pounds you may just possibly reach it, and fill your contract and be all right. The margin is very close. But if you guarantee seven and three-quarter pounds you may lose the contract, for some other maker will guess eight pounds." I hold that if guarantees are to be used at all, the particular guarantee should be stated, and the boilermaker should not be asked to guess what another boilermaker is going to guarantee. If you want 70 per cent. efficiency, let the engineer who draws the specification state that 70 per cent. will be demanded.

Mr. Meier asks the question, in regard to the two coals I tested in Ohio under the same boiler: "Suppose they had been two different boilers, one in Ohio and the other in New York, would Mr. Kent undertake the task of satisfying the average manufacturer or steam user that the one boiler was as good as the other?" I answer: Certainly not. Two boilers cannot properly be compared when tested with different coals, nor two coals when tested under different boilers. But how much better is the comparison on the basis of "efficiency"? The efficiency, based on coal, by the Thompson calorimeter, was, for the Jackson coal, 66.37; for the New River coal, 85.83. If the test had been made on different boilers no one could say, with truth, from these figures that one boiler was better than the other.

My statement in regard to the recent boiler test in St. Louis, that if the heating value of the coal had been determined by a different calorimeter the amount of the forfeiture might have been diminished, is replied to by Mr. Meier. He states that the forfeiture would have been increased if the Carpenter calorimeter had been used instead of the Thompson. I admit this, but my statement is still true, for if the coal had been tested with the Thompson calorimeter used by the chemist in Boston, to whom I have referred in my paper, it is quite probable that a lower heating value would have been obtained, which would have reduced the forfeiture. On page 655 of my paper I give the heat units obtained from the sample of New River coal by the Boston chemist using the Thompson calorimeter as 13,066. A duplicate of this sample was sent to Professor Potter, at St. Louis, who also uses the Thompson calorimeter, and he reports its heating value as 13,527, a difference of nearly 4 per cent. So not only is there a difference between the Carpenter and the Thompson calorimeter, but there is also a difference between two Thompson calorimeters, one in St. Louis and one in Boston.

Referring to Mr. Bryan's remarks, I am glad to know that he has not yet discarded the "pound of combustible" and still includes it in his reports. I hope he will continue this good practice notwithstanding the denunciation of this term by some of his St. Louis colleagues as an "ancient fraud" and a "hoary myth." He recommends that, "if possible," the entire amount of fuel used in a test should be air-dried for at least twenty-four hours. He will rarely find it possible to air-dry the coal in this manner, and if he made the attempt with Illinois coal he would find that it would not become even approximately dry inside of the lumps in a week. I have air-dried a lump of such coal for ten days, weighing it every day, found it lost weight every day, and at the end of the time still contained a large amount of moisture which could be driven off by heating to 212 degrees Fahr.

I regret that Mr. Bryan still has such unbounded confidence in the accuracy of the Thompson calorimeter. It is quite possible that the results obtained by this instrument in the hands of Professor Potter should be consistent with each other, and yet the instrument itself have a large but approximately constant error. No amount of skill in handling an erroneous instrument will make its results reliable. In my paper I have shown that the test I made with New River coal gave 73.82 per cent. efficiency when the coal was tested by the Carpenter calorimeter, and 85.83 per cent. when tested by the Thompson calorimeter in Boston. The heating value as obtained by Professor Potter's Thompson calorimeter makes the efficiency 82.95 per cent. I think the figure 73.82 per cent. is all that can reasonably be expected under the circumstances of the boiler test, which were by no means perfect, and I have no confidence whatever in the figures 82.95 per cent. and 85.83 per cent.

I have to thank Mr. Cary and Professor Kinealy for their important contributions to this discussion. I think they have done much to place the subject of efficiency in its proper light.

Professor Kinealy recommends the use of the Berthelot, the Mahler, or the Hempel calorimeter. I heartily agree with him. As far as I have looked up the subject, these three calorimeters are the standard calorimeters, but even they are subject to correction for the combined nitrogen and oxygen. They have to be manipulated with the utmost care, and by skilful chemists, also. But if we are going to use calorimeters at all, let us come to one of these three or to a new one made upon the same principle.

DCXCV.*

STRENGTH OF CAST IRON.

BY W. J. KEEP, DETROIT, MICH.

(Member of the Society.)

THIS paper contains all of the results of tests of various sizes of test bars made in 1894, from different mixtures of cast iron, for Committee on Methods of Testing of the American Society of Mechanical Engineers. The individual logs are on file in the Society's library in New York.

The object of these experiments is to find a method of testing which shall reveal the physical properties of cast iron.

Before this could be done it was necessary to determine the physical properties of this material.

Cast iron is not a simple metal, nor is it an alloy, but it is an aggregation of compounds combined chemically and mechanically.

Any change in the proportion of the compounds and of the elements of which it is composed, in the conditions attending its production in the blast furnace, in remelting, or in its solidification, changes its character so much that it becomes a material of different qualities.

Cast iron is a comprehensive term covering any iron with carbon too high to be classed as steel, and in the different furnace yards it is separated into more than 20 grades, on account of differences in the appearance of its exterior surface or of its fracture, and when sold by its chemical composition each run of iron may be different from any other on account of unequal diffusion of the elements.

Silicon is, however, the primary element which needs to be taken into account for ordinary foundry work, provided the others do not exist in excess.

Increasing silicon changes white iron to gray, causes combined carbon to become graphitic, makes hard iron soft, and removes

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* Presented at the St. Louis meeting (May, 1896) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

brittleness, and by doing this increases strength, thus increasing the strength of small castings by preventing brittleness, and it decreases the strength of large castings by increasing the size of the grain.

In the tables the records from bars of the same dimensions and the same composition are the only ones that can be averaged or compared directly with each other. Test bars 2″ x 1″ of the same series, whether tested flat or on edge, can be compared with each other, but cannot be compared with the bars 2″ □ of the same series, because the latter cooled more slowly and have a looser grain and are therefore proportionately weaker.

There were three tons each of "Iroquois" and "Hinkle" pig iron. Drillings for analysis were taken from 25 pigs of each kind, and of the silicon iron used with them. Seven hundred pounds were weighed out for each series so as to bring the silicon to the intended per cent., and one-quarter of one per cent. more to allow for loss in. re-melting. The mixture was made with great care, based on actual chemical analysis.

NOTE.—A full chemical analysis of each pair of test bars has been made by Mr. R. N. Dickman (71 Atwater Building, Cleveland, Ohio), assisted by Mr. John Douglas and by Mr. E. Klootz, and by Messrs. Dickman and MacKenzie, 1224 Rookery Building, Chicago.

All test bars 1″ □ and 1″ x 2″ were tested by Professors R. C. Carpenter and C. E. Houghton at Sibley College, Cornell University.

All bars 2″ □, 3″ □, and 4″ □ have been tested by Professor C. H. Benjamin, assisted by Messrs. Lyman Marshall and L. G. Robbins at Case School of Applied Sciences, Cleveland, Ohio. The 3″ □ and 4″ □ bars of Series 17 were tested on the 800,000 pound testing machine of the Otis Steel Company of Cleveland.

The round bars, both transverse and tension, were tested by Professor Ira H. Woolson, of Columbia College.

Series 1 to 12 were made at the Detroit Stove Works, under the supervision of L. Crowley.

Series 13, 14, and 15 were made at the works of the Michigan Stove Company, from their regular iron mixture.

Series 16 was made by Messrs. C. G. Bretting & Co., of Ashland, Wis., makers of machinery castings; Series 17 by the Michigan Malleable Iron Company, of Detroit; Series 18 was made by Messrs. Bement, Miles & Co., makers of heavy machinery, Philadelphia; and Series 19 by Messrs. A. Whitney & Sons, makers of car wheels in Philadelphia.

The "Iroquois" pig iron, for the first six series of bars, was furnished by the Iroquois Furnace Company, of Chicago, and the "Hinkle" pig iron, for the second six series, was furnished by the Ashland Iron and Steel Company, of Ashland, Wis.

In the preparation of the tables, checking results, and calculations I am greatly

indebted to Professor Carpenter, Mr. Houghton, and their assistants, and to Mr. E. D. Estrada, for checking tables with original logs, and to Mr. Gus. C. Henning, Reporter of the Committee.

SLIGHT VARIATIONS IN THE SIZE OF TEST BARS.

In any one size of bar of any one series, whatever the section, the variation in strength does not follow the variation in size.

A measure of size of a cast bar is only an approximate measure of section, for more or less of scale will remain on large bars. In any case the surface is uneven, being a series of elevations and depressions corresponding to the shape of the grains of sand which composed the mould, and the caliper measures across the highest points.

A depression or a,cold shut, so small that it is difficult to detect either after fracture, may act as notches and often hasten fracture, and bars with the corners round, on account of the corners not running full, even if the round corners are placed down, will as often show great strength as other bars poured full from the same ladle. Such round corners are perfectly smooth, never having touched the sand mould, and there are therefore no depressions to start a fracture.

Larger test bars cool more slowly, and the size of the grain is thereby increased, which in turn decreases the strength of the bars.

The largest bars cast off the same pattern are often found to be weakest.

Figures 142 and 143 show the average records of actual loads to be slightly more uniform than when reduced to equivalent loads for bars of the nominal size.

The differences in crystallization on account of varying conditions, cause a variation in the records much greater than the variation due to slight differences in size. The variation in cast iron on account of peculiar conditions is so great that only general tendencies in records should be considered.

Autographic Diagrams.—The diagrams in Fig. 141 are from test bars one-half inch square by twelve inches long (Tables I., II., and III.), made by Keep's Dead Load Autographic Testing Machine.

After the base line *ab* was drawn, the load was increased until it reached 300 pounds. Then the load was removed, and the pencil stood at *d* instead of *a*. Then the load was applied again

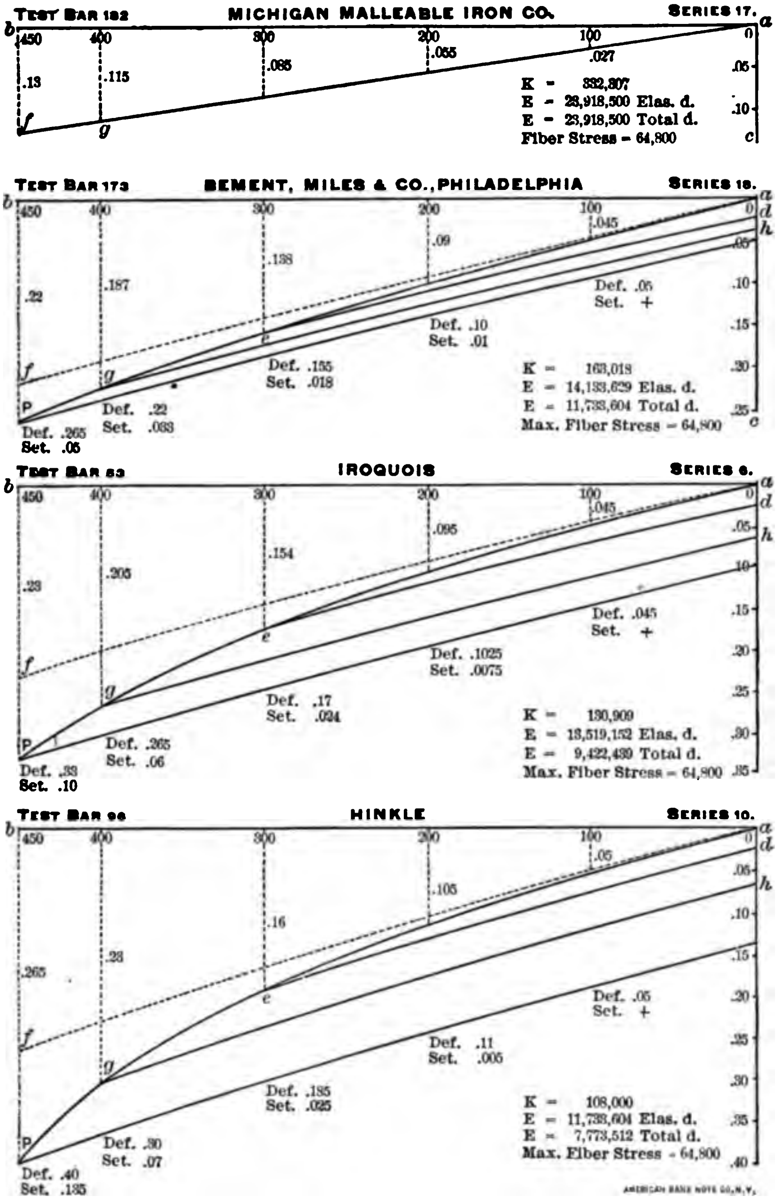

TEST BAR 182
MICHIGAN MALLEABLE IRON CO.
SERIES 17.
a
b
c
f
g
450
400
300
200
100
0
.13
.115
.085
.055
.027
.05
.10
K = 332,807
E = 28,918,500 Elas. d.
E = 23,918,500 Total d.
Fiber Stress = 64,800
TEST BAR 173
BEMENT, MILES & CO., PHILADELPHIA
SERIES 18.
a
d
h
b
c
e
f
g
P
450
400
300
200
100
0
.22
.187
.138
.09
.045
.05
.10
.15
.20
.25
Def. .05
Set. +
Def. .10
Set. .01
Def. .155
Set. .018
Def. .22
Set. .033
Def. .265
Set. .05
K = 163,018
E = 14,133,629 Elas. d.
E = 11,733,604 Total d.
Max. Fiber Stress = 64,800
TEST BAR 53
IROQUOIS
SERIES 6.
a
d
h
b
e
f
g
P
450
400
300
200
100
0
.23
.205
.154
.095
.045
.05
.10
.15
.20
.25
.30
.35
Def. .045
Set. +
Def. .1025
Set. .0075
Def. .17
Set. .024
Def. .265
Set. .06
Def. .33
Set. .10
K = 130,909
E = 13,519,152 Elas. d.
E = 9,422,439 Total d.
Max. Fiber Stress = 64,800
TEST BAR 96
HINKLE
SERIES 10.
a
d
h
b
e
f
g
P
450
400
300
200
100
0
.265
.23
.16
.105
.05
.05
.10
.15
.20
.25
.30
.35
.40
Def. .05
Set. +
Def. .11
Set. .005
Def. .185
Set. .025
Def. .30
Set. .07
Def. .40
Set. .135
K = 108,000
E = 11,738,604 Elas. d.
E = 7,773,512 Total d.
Max. Fiber Stress = 64,800
AMERICAN BANK NOTE CO., N.Y.

FIG. 141.

and the elastic line *de* was drawn. After passing *e* the original diagram was resumed. When the 400 pound mark was reached the load was removed and the pencil rested at *h*; the load applied again made the new line *hg* parallel to *de*.

All elastic lines from the same bar are parallel.

The elastic line from a tempered steel bar or a bar of white cast iron like bar 182 will be nearly straight, but those from gray cast iron which takes set are slightly curved lines.

A template may be made from the longest elastic line, and if placed parallel to the elastic line, tangent with the first diagram, a new elastic line *af* can be drawn. This divides all deflections into elastic deflection and set deflection, and all perpendicular distances between *af* and *ag* are permanent sets.

The letters employed in formulæ are as follows:

W,	Measured maximum load in pounds.
W_1,	Maximum load of a test bar of any other size.
b,	Measured breadth of test bar in inches.
h,	Measured height of test bar in inches.
b_1,	Breadth of any other size of test bar in inches.
h_1,	Any other height of test bar in inches.
l,	Measured distance between centers of supports of test bar in inches.
l_1,	Any other distance between supports in inches.
d,	Total deflection in inches.
I,	Moment of inertia
p,	Maximum fibre strain per square inch.
E,	Modulus of elasticity.

$$\text{Moment of inertia, } I = \frac{bh_3}{12} \quad \ldots\ldots\ldots\ldots \quad (1)$$

To reduce the measured maximum load of a test bar to that for any other size of bar:

$$W_1 = \frac{Wb_1h_1^2l}{bh^2l_1} \quad \ldots\ldots\ldots \quad (2)$$

The maximum stress per square inch on outer fibre:

$$p = \frac{3Wl}{2bh^2} \quad \ldots\ldots\ldots \quad (3)$$

p is the stress per square inch on the extreme fibres of the free side of test bars broken transversely.

The Modulus of Elasticity is a number obtained by dividing a number indicating unit stress by a number indicating unit strain within the elastic limit, and in case of transverse loads is:

$$E=\frac{Wl^3}{4bhd} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

This formula is true only for a perfectly elastic body, in which case d = elastic deflection. No kinds of cast iron are perfectly elastic.

In taking d as representing only elastic deflection, we take into account only the part of the diagram a, b, f (Fig. 141), while the whole diagram, a, b, p, represents the behavior of the material. The portion of a, f, p which has been ignored is a very important part, for it shows how much the beam will remain bent after a stress has been applied.

Resilience.—This is the work which a body will do on being relieved from a state of strain, or the amount of work which has been done on the body. Some even multiply one-half stress by the total deflection in cases where set has been taken.

$$\text{Resilience} = \frac{W}{2}\,d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

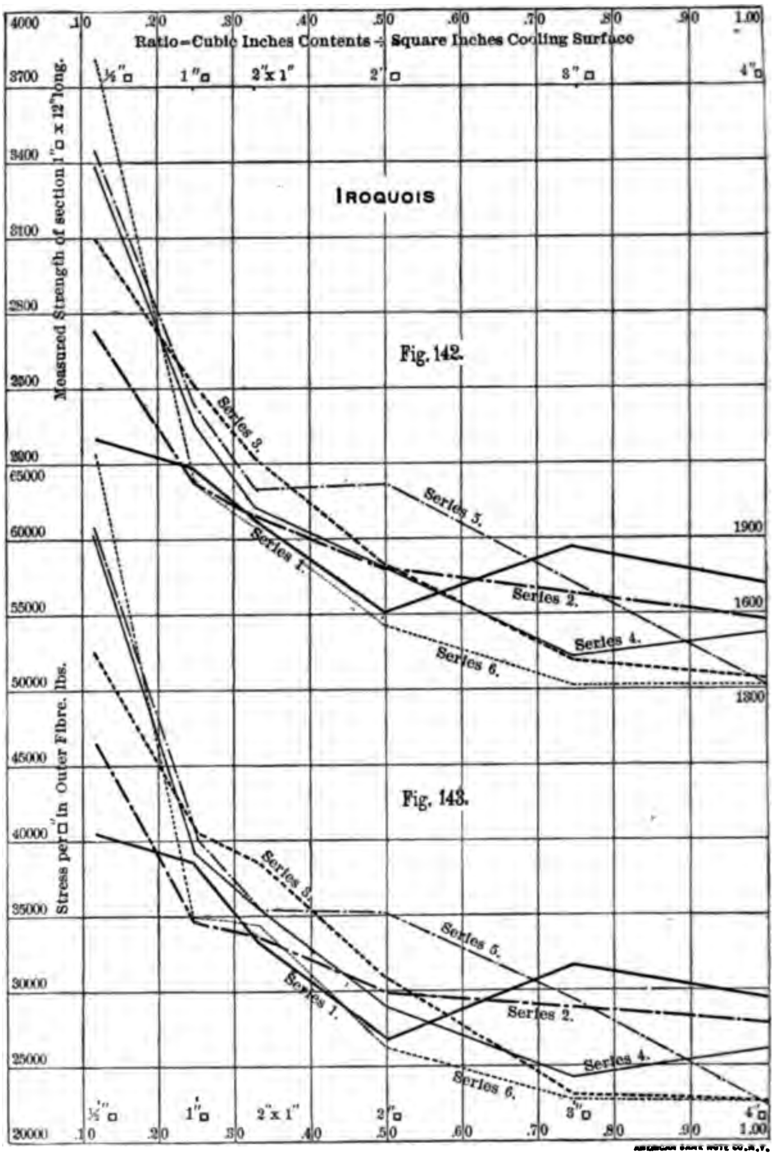
A cast-iron beam is not generally required to raise a load through the greatest possible distance, but it is required to sustain the greatest possible load with the least deflection.

$$\text{The shearing stress} = \frac{W}{2bh} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

In Tables XIV. to XVIII. vertical columns show variations due to changes in composition, and horizontal rows of figures show variations due to change in the rate of cooling (size), and the figures at the right-hand lower corner of any group show variations from the combination of both these causes.

In previous monographs regarding these tests I have been obliged to use incomplete results, which, with some errors and transpositions, cause trifling variations in the tables and charts therein presented, but they did not in any way affect conclusions.

The diagrams in Fig. 142 are from the measured maximum loads of Series 1 to 6; and the diagrams in Fig. 143 are from same results, reduced to the nominal sizes of bars.



The diagrams in Fig. 143 represent either the loads reduced to a one-half-inch square section, a one-inch square section, or to fibre stress, because a simple division or multiplication by a constant number reduces one to the other. The curves are the same, the only change being in the marginal numbers.

DIMENSIONS FOR TEST BARS.

The tables show the records for all the sizes and forms of test bars in general use.

One-half-inch Square by Twelve-inch Test Bars.—This is as small as it is practicable to make. It cools so quickly that the variations in the test record more nearly agree with variations in silicon than those of any other size. The measure of shrinkage of such a test bar is a mechanical analysis for silicon.

One-inch Square Test Bars.—The tests recorded in this paper show that a one-inch square bar gives records more nearly alike for cast iron of different compositions than any other size, for the following reason:

Figs. 142 and 143 and Fig. 145 show that the curves representing records of various sizes and compositions of cast iron cross each other near the record of the one-inch bar, which explains the similarity of one-inch records for all compositions.

Two-inch by One-inch Test Bars.—When these are broken with the narrow side down, the strength reduced to a section one inch square is greater than the strength of the same bar broken with the wide side down reduced to the same section. The bars of Table XIX. were all cast from the same ladle of iron.

A bar two inches by one inch is more clumsy to handle and to make than a one-inch square bar, and requires a larger testing machine.

Two-inch Square, Three-inch Square, and Four-inch Square Test Bars are seldom used on account of the difficulty in breaking them.

In casting four-inch bars with gates near the ends, there is nearly always a depression, and often a very deep cavity, in the top of the bar, near the gates, caused by contraction before the bar is solid all the way through. If the mould for the top of the bar is made partially metallic, by pressing small nails in the cope, so as to present enough iron surface to cause the metal to set over the whole surface of the mould, the outside of the bar would be perfect, and the shrinkage would show itself in an open, spongy grain near the centre of the bar, towards the ends near the gates. Such a bar would show the external shrinkage, the strength, and the grain, and would also show the tendency of the iron to form spongy spots.

Deflection of Cast Iron.—Referring to Fig. 141, and from an examination of the fractures of the test bars, it is evident that increased deflection for the same load shows increased softness. If the castings are thus shown to be softer than is required, a larger quantity of scrap can be added to the mixture.

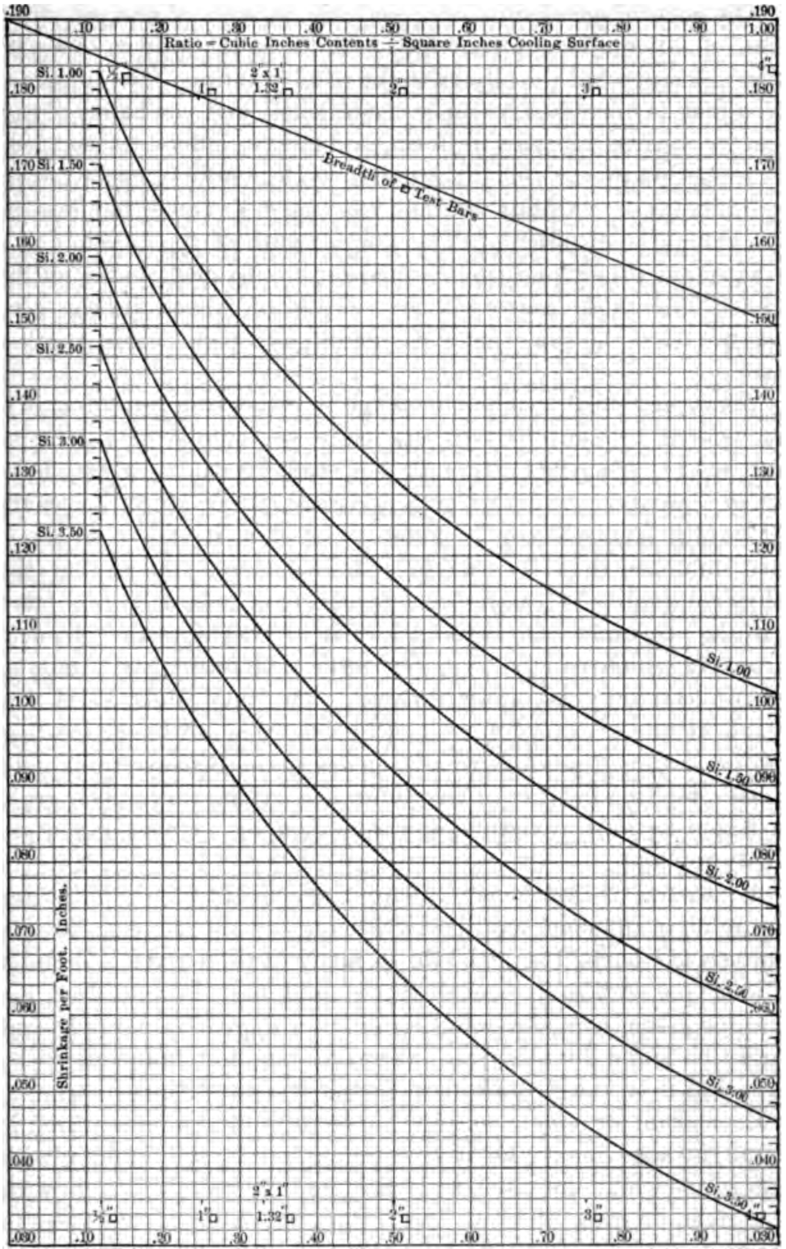
Shrinkage of Cast Iron.—Table XX. gives the average shrinkage of the test bars of the nineteen series.

When these shrinkages are compared with the records of strength given in Tables XIV. to XVIII., and with the grain of these bars, it becomes evident that the increase of silicon, which increased the size of grain, decreased shrinkage, and that the slow cooling which increased the size of grain, also decreased shrinkage. The casting containing most silicon, and of the greatest size, decreases in bulk less than smaller castings, or those containing less silicon. The records give the shrinkage per linear foot.

The figures on each side of chart Fig. 144 denote the shrinkage in inches per foot. The numbers at the top and bottom of the chart show the ratio of cooling. Each curved line shows the variation in shrinkage of iron containing a given percentage of silicon, in varying sizes of castings. The percentage of silicon in this iron is marked at each end of the curve. With this chart, if a founder knows the shrinkage of any one size of test bar, he can at a glance tell the amount that any other size will shrink; or if he knows the size of casting that he wishes to make, and the shrinkage that is desirable, he can find from the chart the percentage of silicon that the casting must contain. All these relations are approximate.

To find the approximate percentage of silicon in any iron mixture locate on the one-half-inch square line (12) the shrinkage of a one-half-inch square test bar from that mixture, and this will give the approximate percentage of silicon that should produce this shrinkage.

It is a fact of the utmost importance that, owing to the irregular composition of cast iron, even that poured from one ladle, every physical and chemical record, however obtained, is only an approximation to what would be obtained by another test. A considerable margin of approximation must be allowed in all calculations relating to cast iron.



AMERICAN BANK NOTE CO.N.Y.

KEEP'S IDEAL SHRINKAGE CHART.

Approximate relation of shrinkage to size and percentage of Silicon.

FIG. 144.

The percentage of silicon by analysis, because of unequal diffusion of silicon, is approximate. Drillings taken from one part may not represent the silicon in the whole casting. The influence of silicon is uncertain, because the quantity and condition of carbon in pig iron is never uniform, and silicon influences cast iron by its action on carbon; if carbon is too low, silicon cannot exert its influence. Sulphur in the coke used in remelting lessens the influence of silicon. The temperature of the cupola and a great many other conditions influence the physical quality of the iron. For these reasons 1.50 per cent. of silicon in one case may produce the same physical results as 2 per cent. in another case.

When we find the same shrinkage in other iron mixtures, it is convenient to ascribe it to the same percentage of silicon as indicated by Chart 144, though from various causes it may have taken a greater or a less actual percentage to produce the result. Generally, when silicon is below 1 per cent. it exerts so much less influence than the varying conditions referred to that the physical quality of castings from such iron cannot be predicted with any certainty (see Series 1 and 19). Therefore the physical property which can be expected from a definite percentage of silicon can only be approximated. On the other hand the physical property, as determined by a test bar, will vary in other castings, even if poured from the same ladle, because the conditions attending cooling of the different castings vary. The grain is liable to local variation, and spongy spots or blow-holes are likely to exist.

A measure of shrinkage with any one size of test bar measures the relative influence exerted by silicon; and for convenience, in the use of Charts 144 and 145, in many of the curves a definite silicon percentage is ascribed to each shrinkage. For the reasons given, this percentage is only an approximation of what might be found by analysis, but represents the influence to be expected from the definite percentage of silicon named.

Each founder must establish a standard shrinkage which is found to accompany the best castings in his own foundry with the irons which he uses, and then he can use the charts with any given mixture of iron; and if the composition is uniform an increase of silicon will decrease shrinkage, and *vice versa*.

The founder does not need to know the actual percentage of silicon present, for it is impossible to know the conditions which will influence the physical quantity. All he needs to know is whether in this particular case more or less silicon is needed.

Charts Figs. 144 and 145 are constructed from definite physical tests and from actual chemical analyses. The results obtained by the use of these charts are approximations of what similar duplicate tests and analyses of the same irons would show.

Every founder who has endeavored to regulate a foundry mixture by chemical analysis has found that a definite percentage of silicon cannot be depended upon to exert the same influence under all conditions.

The approximation found by these charts is nearer the truth than can be obtained by any existing method, but from the nature of the case there can be nothing absolutely definite about cast-iron castings.

Strength of Cast Iron.—The chart Fig. 145 is constructed from the records of tests reported in this paper, and will give a near approximation to the strength of castings of different sizes containing different percentages of silicon.

Iron mixtures should be divided at least into three classes:

1. Those made from very soft pig iron, or with an addition of very soft scrap, which will produce a one-half inch test bar with an open grain and of a dark color, with great deflection, as bars 53 and 96 of Fig. 141. In such mixtures a very small percentage of silicon will open the grain so as to greatly decrease the strength of large castings. These are used when softness is more desirable than strength, and should never be used for heavy castings. All of the series from 1 to 12, and Series 16, are from such mixtures.

2. A mixture made from close-grained pig iron and close-grained scrap, or a mixture which has had its grain closed by some process, and which will make a one-half-inch test bar of compact, close grain, and not very dark in color, and with a moderate deflection, as bar 173 in Fig. 141. Such a mixture will make strong, large castings, and will be soft enough for small machinery work. Series 18 is from such a mixture.

3. Mixtures which produce a white one-half-inch test bar, with small deflection, as in bar 182 of Fig. 141. Such a mixture should only be used for heavy castings thicker than one inch. Series 19 is an example of such a mixture.

To find the strength of a section one-half inch square by twelve inches long of a large test bar from chart Fig. 145: Locate on the one-half-inch line of the chart the average strength of three one-half-inch square test bars. With the shrinkage of a one-half-inch square test bar, find from the shrinkage chart the approximate percentage of silicon. With a template,* find on the graduated four-inch section the mark indicating the silicon. If the casting is of the first class described, place this mark on the point on the four-inch line of the chart which represents the silicon percentage; swing the template around until its edge touches the located one-half-inch strength, and draw the curve. *Example:* Series 2—Locate strength 339 on the one-half-inch perpendicular. Shrinkage .172 indicates silicon 1.50 per cent. Place the 1.50 four-inch point of the template on the 1.50 point of the four-inch perpendicular, and bring the edge of template to the 339 strength, and draw the curve. All curves for this class will indicate a trifle too great a strength for large castings. It makes the four-inch bar 10 per cent. too strong for Series 16.

If the mixture is of the second class, find the excess of the located one-half-inch strength over that due to the percentage of silicon. After finding the four-inch point on the template, and on the chart, raise the latter one-third of the excess just found, and place the mark of the template on this and draw the curve. *Example*: Series 18—The shrinkage is .161, indicating silicon 1.95 per cent. The strength is 446, or 89 excess over 357. The strength on the four-inch line for 1.95 per cent. silicon is 197; adding 30 equals 227, the new point on the four-inch line. Place the four-inch 2.00 per cent. point of template on this new point and draw the curve. This curve corresponds with all the measured strengths of Series 18 except the one-inch bar, which it makes 7 per cent. too weak.

If the mixture is of the third class, raise the four-inch point one-half of the excess. *Example:* Series 19—Shrinkage is .238. (When the shrinkage is above .200 the test bar is white, and the

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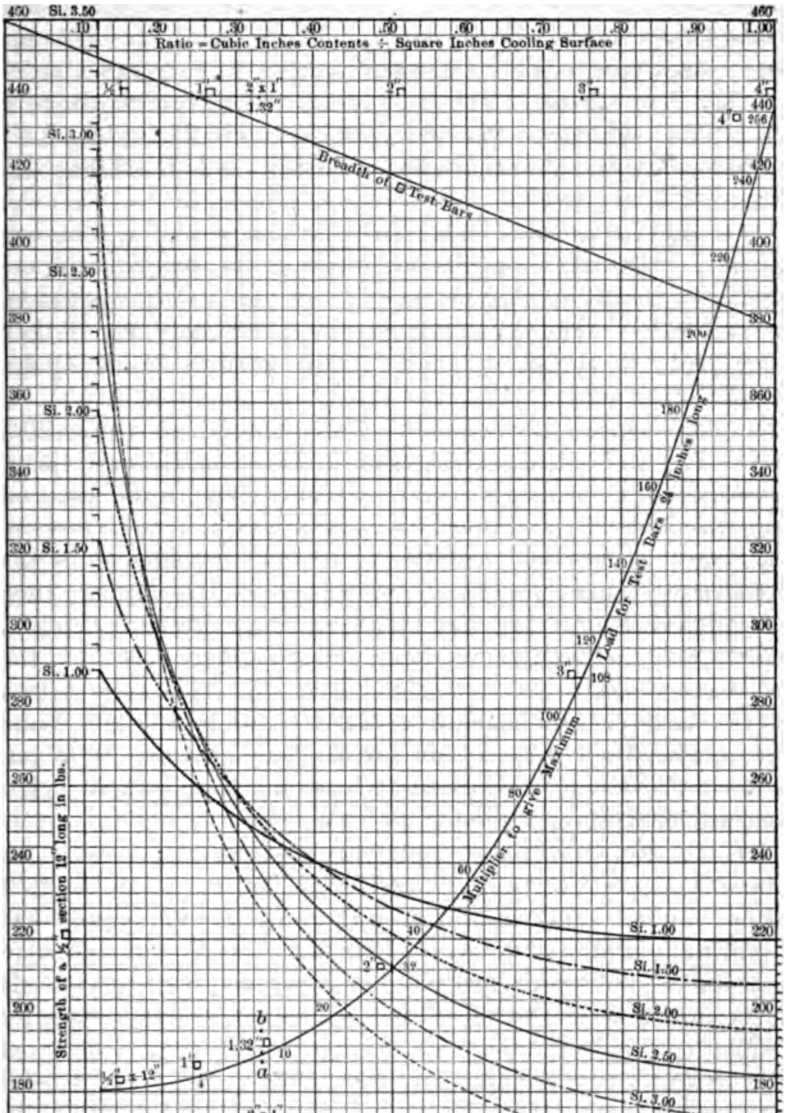
* All curves of the strength chart are made from one template of a graduated hyperbola. Make a template of the 3.50 per cent. curve, and extend it one inch beyond the four-inch line, and mark on it the ends of this curve. From the one-half-inch end measure down the curve five and seven-eighth inches, and place this point on the 1.00 per cent. point of the one-half-inch line, and mark both ends of the 1.00 per cent. curve on the template; then divide the distance between the 1.00 and 3.50 per cent. points on the one-half-inch end into five equal spaces. Place each division successively on the corresponding percentage points on the one-half-inch line, and mark the four-inch end of each curve on the template.



KEEP'S IDEAL STRENGTH CHART.

Approximate relation of strength to size and percentage of Silicon.

(Strength of a ½" ◻ x 12" section of each size of Test Bar.)

FIG. 145.

silicon is sure to be less than 1 per cent. It is safest, in such cases, to use the 1 per cent. curve.) The strength was 377, and the excess over 290 is 87. The strength on the four-inch line for 1.00 per cent. silicon is 220, and one-half of 87 brings it to 264. From this point draw the curve, which makes the strength for all bars somewhat less than the actual test made them, but this is safe.

If a machine can be constructed, that can be sold at a moderate price, that can break transversely a test bar four inches square by twenty-four inches long, the actual strength could be located on the four-inch square lines and the curve would then show actual strengths of one-half-inch sections of all square bars of other sizes.

To find from this chart, Fig. 145, *the strength of any casting,* find the cooling ratio of the casting and draw a strength curve corresponding to the strength of a one-half-inch square test bar cast from the same iron. Follow down the line which indicates the ratio, and its crossing with the upper diagonal line gives the breadth of a square test bar which represents the casting; then continue down until the perpendicular cuts the strength diagram, which gives the strength of a one-half inch square section of the test bar which actually represents the casting. The intersection of the same perpendicular with the curve of multipliers gives the number by which to multiply the strength already found, to give the actual strength of the test bar twenty-four inches long which represents the casting.

The curves of this chart apply only to square test bars. For example, a test bar two inches by one inch equals a bar 1.32 inches square, which is located on the ratio .33, Fig. 5, and has a multiplier 10 for a bar twenty-four inches long; but the same material in the shape two inches by one inch tested flat needs a multiplier 8 (*a*), but if tested on edge needs a multiplier 16 (*b*).

A Standard Test for Cast Iron should show for every size of casting, the shrinkage per foot, the strength, tendency to chill, hardness, grain, tendency to form spongy spots, and the amount of silicon necessary to produce the desired quality. Such a test should be rapid and inexpensive, and one that any founder can use.

The following test is suggested:

Make three or four test bars one-half-inch square by twelve inches long, and find the average shrinkage, strength, deflection, and depth of chill. By the shrinkage and strength charts, find the shrinkage, the approximate percentage of silicon, and strength for all sizes of test bars.

At the same time make two four-inch square by twenty-four inch test bars with uniform surface, and measure shrinkage and examine fracture for spongy spots. When practicable, get the average strength of the four-inch square bars, otherwise get four-inch square records from the strength chart. On a sheet of cross-section paper, like that used for the chart, mark the one-half-inch and four-inch strengths, and draw the curve which gives the actual strength and shrinkage for all intermediate sizes of test bars.

The relative deflection indicates relative hardness. In regular foundry work, so long as the shrinkage does not vary, the quality of the casting will not vary. An increase of shrinkage shows the need of more silicon, and *vice versa.*

Round or Square Test Bars.—These round bars were cast at the same time as the square bars in each series, and were tested by Professors Carpenter and Houghton, at Cornell University, and by Professor Woolson at Columbia University. The results are shown in Tables XXI. to XXIV., and averages of these round bars and of square bars are given in Table XXVI. for comparison. It has been claimed that the round bar would be strongest, but in every case the reverse is true, and the variation between the record of the two round bars cast together is fully as great as between square bars cast together.

Round Bars cast on end or cast flat. (*See Tables XXV. and XXVI.*)

In Series 19, bars 93 and 98 were so defective that the records were thrown out.

The average of the others in both Series 19 and 18 shows the bars cast on end to be considerably weaker than those cast flat.

In 1894 the Western Foundry Association appointed a committee to determine whether a round test bar cast on end was better than a square bar cast flat. The report was made November 21, 1894.* In one group of tests all square bars cast flat were perfect, while 43 per cent. of the round bars on end were defective. In another group of tests 18 per cent. of the square bars cast flat were defective, and 54 per cent. of the round bars on

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* The *Iron Trade Review*, Nov. 29, 1894.

end were defective. The committee reported that they could not endorse the round bar cast on end as against the square bar cast flat. During 1894 many other groups of tests were made by other members of the Association, and each exhibited similar results.*

"The cause of the large amount of defective round bars cast flat and on end is due to practical difficulties in getting iron into the mould."

Tensile Tests of Cast Iron.—It has generally been conceded that, owing to the peculiar grain of cast iron and to the irregular pull of machines for testing, this test did not give reliable results. But bars cast at the same time with the other bars, and tested by Professors Carpenter and Houghton, the results of which are given in Tables XXVII. to XXIX., give as regular results as the transverse tests, but no more so.

These records are extremely interesting, as they show by another system of testing that increase of silicon strengthens small castings but weakens large castings, and that large castings are proportionately weaker than small castings; that is, slower cooling of large castings causes them to be weaker than more rapidly cooled small castings.

The tensile tests of Table XXX. show nothing of value except that the extensions are less with each addition of silicon. The bars were 15 inches long and too short to hold well in the grips, and each bar broke in the fillet; the results, therefore, do not indicate the strength of the iron. The bars of Table XXXII. were turned very accurately by Mr. Henry B. Binsse, of Newark, N. J., and were 20 inches long with 8 inches at centre, 1.065 diameter, and they, with those of Table XXX., were pulled by Professor Woolson in the Emery testing machine at Columbia University. The readings of extension in both Tables were for each 2,000 pounds of load, and were in thousands of a millimetre in a length of 200 millimetres.

Bars 71 and 81 were held in the grips, the same as the other bars, and subjected to compression, for data to use in calculating the position of the neutral axis in a transverse bar. It is seen that the average of the bars 72 and 73 cast flat is 25,250, and of the two sound bars cast on end is 20,791, showing the bars cast flat to be stronger. All the bars of Tables XXIX. and XXXI. are from Series 18, except 103 and 104, which are

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* The *Iron Trade Review*, Nov. 1, 1894.

from Series 19. The main object of this accurate tensile test was to learn if the irregularity of other tensile tests of cast iron was due to uneven pull of the machine or whether the granular structure was so uneven as to give irregular strengths to test bars poured from the same ladle of iron. The latter seems to be the cause. Table XXXI. shows the strength per square inch of eight bars cut from a casting six inches thick, and was pulled on the Olsen machine.

These bars were made in the foundry of I. P. Morris & Co., and the records were given me by the superintendent, Mr. D. J. Matlack, of Philadelphia.

In explanation of the variation in strength of these bars, Mr. C. L. Prince, Camden, N. J., has sent me the following memorandum: "Cylinder of big press was cast from No. 2 X Swede and No. 2 X Pulaski, with 15 per cent. of steel scrap. From this iron a bar 6" x 6" by about 18" long was cast on end. This block was cut longitudinally by planer into nine test bars. The bars from the centre side, and corner were turned 1½" round, and at the middle for 4" to 1" diameter. The length was 12", taken from the lower end of the casting. Three of the bars were pulled by Messrs. Riehle Bros., with the following results :

Position in the casting.	Diameter in inches.	Area in sq. inches.	Broke at, in pounds.	Equivalent load, lbs. per sq. inch.
Centre........	1.00	.7854	10,800	13,750
Side..........	1.00	.7854	12,100	15,406
Corner........	1.00	.7854	12,920	16,450

"The grain of test bars in turning was very open and rotten, but the casting was close and good.

"The variation in strength was due to slower cooling of the sides and centre."

Chemical Analysis.—For complete analysis of all test bars and for a discussion of the influence of the various chemical elements in cast iron, reference is made to "Transverse Strength of Cast Iron," pages 1100 to 1107, *Transactions*, vol. xiv.; also "Physical Tests and Chemistry of Cast Iron," read at convention of American Foundrymen's Association, the *Iron Trade Review*, May 14, 1896.

DISCUSSION.

Prof. C. H. Benjamin.—As I had the pleasure of conducting the tests on the 2″ □, 3″ □, and 4″ □ bars for Mr. Keep, I would like to contribute to this discussion.

I will confine my remarks to Table XIV. of the Appendix, showing the average maximum loads for different sizes of beams.

The generally accepted formula for loaded beams assumes that the strength of a beam varies inversely as the length and directly as the breadth and the square of the height, or, in the ordinary notation:

$$W = k\frac{bh^2}{l},$$

where k is some constant depending on nature of material.

That this statement is not true is shown in the paper under discussion, and a method is indicated for finding the strength ratio in different cases.

I have prepared a supplementary table from Table XIV., showing the actual ratios of load or strength as compared with the theoretical ratio.

To save time, I have used the nominal sizes instead of the measured sizes, but the error is a slight one.

1. *Effect of Length.*—Comparing 1″ □ bars, 12″, 24″, 48″, and 54″ long: The longer bars are in nearly every case relatively weaker than the short bars. The few exceptions to this are mainly among the bars high in silicon—Nos. 11 and 12.

2. *Effect of Breadth.*—Comparing 1″ □ bars with 2″ x 1″: Theoretically, doubling the breadth of a beam doubles its strength. In the case of the 2″ x 1″ x 12″ the average ratio is 1.76. In the case of the bars 2″ x 1″ x 24″ the average ratio was 1.8.

There are only two exceptions in the whole list, and those are high in silicon.

3. *Effect of Height.*—Comparing 1″ □, 2″ □, 3″ □, and 4″ □: Theoretically, the strength of a square bar will vary as the cube of its side. The table shows that the bars are weaker relatively as they increase in size.

The theoretical ratios being

8, 27, and 64,

the actual ratios are only

6.53, 20, and 43.8.

4. *Exponents.*—The exponents of the length, l, which will give the actual strength ratios, are 1.061, 1.06, and 1.053, or an average of 1.058.

Similar exponents for the breadth, b, are 0.815 and 0.848, or an average of 0.83. The exponents for the side of the square bar are 2.7, 2.74, and 2.73—a very close coincidence.

The average exponent is 2.72. Subtracting from this the average exponent for breadth, we have $2.72 - 0.83 = 1.89$ as an average exponent for the height, h. Using these exponents in our original formula, we have—

$$W = k\frac{b^{0.83}h^{1.89}}{l^{1.058}}$$

as an empirical formula for the strength of any cast-iron bar, where k can be determined by breaking a bar 1″ □ by 12″ long.

Stresses and Moduli.—In looking over the Tables I. to XIII. one can hardly fail to be impressed with the fact that the terms "Stress on Outer Fibre," "Modulus of Elasticity," and "Resilience" are meaningless for cast iron, as the values are ordinarily computed.

The quantity in the tables is not the stress on the outer fibre, and no one seems to know what it is. If we wish to know the tensile strength of cast iron, we test it in tension. If we wish to know the load it will carry as a beam, we should test it as a beam, and then determine the effect of increase of any of the dimensions, and not resort to a term, "modulus of rupture," as some prefer to call it, which is of doubtful meaning anywhere, and especially so with cast iron.

Modulus of elasticity as computed in these tables is likewise meaningless, is not a constant, and not a measure of the stiffness of the material. Resilience does not mean anything unless it includes the whole area under the elastic curve.

Lastly, the elastic curve itself becomes meaningless when plotted from values of this so-called "fibre stress." The elastic curve should be plotted from the actual loads and deflections, or, what is better, drawn with an autographic attachment.

The maximum load, the maximum deflection, the area under the elastic curve, and its general character will thus tell us all we need to know.

The influence of the size of bar upon the deflection may be studied directly from experiments, and an empirical formula constructed, which will give the relative stiffness of all bars.

It seems to me that we have too long been in bondage to so-called rational formulas.

ALL BARS COMPARED WITH 1″ □ × 12″ OR 24″.

	Effect of Length.			Effect of Breadth.		Effect of Breadth and Height.		
SIZE OF BAR.	1″ □ × 24″	1″ □ × 48″	1″ □ × 54″	2″ × 1″ × 12″	2″ × 1″ × 24″	2″ □ × 24″	3″ □ × 24″	4″ □ × 24″
Theoretical Ratio $\frac{W}{W_1}$	$\frac{12}{24} = 0.5$	$\frac{12}{48} = .25$	$\frac{12}{54} = .222$	2	2	$2^3 = 8$	$3^3 = 27$	$4^3 = 64$
No. 1....	.392	.198	.181	1.62	1.83	6.32	24.9	53.8
" 2....	.480	.257*	.220	1.89	1.91	6.89	22.3	49.3
" 3....	.477	....	.198	1.64	1.84	5.73	15.4	34.2
" 4....	.423	.212	.197	1.65	1.66	6.35	17.4	44.1
" 5....	....	....	...	....	1.68	6.82	18.8	34.5
" 6....	....	.252*	.192	1.89	....	....	....	....
" 7....	.492	.214	.206	1.85	1.59	6.20	20.6	40.4
" 8....	.449	.215	.189	1.74	1.75	6.40	20.1	48.6
" 9...	.463	.224	.208	....	1.61	6.30	17.3	42.6
" 10...	.478	....	.210	1.73	....	6.37	19.7	49.4
" 11....	.513*	.254*	.230*	1.80	1.85	5.84	18.4	37.9
" 12....	.628*	.238	.232*	1.74	2.13*	5.91	21.1	34.4
" 14....	.464	.256	.198	1.84	1.64	6.90	21.0	43.7
" 13...	....	....	....	....	1.88	7.21	20.5	47.0
" 15....	....	....	....	....	....	7.76	20.3	50.5
" 19....	....	....	...	....	2.09*	7.43	24.4	53.0
" 16....	....	....	....	....	1.88	6.56	20.0	40.3
" 18....	....	....	....	....	1.68	5.86	18.1	41.9
" 17....	....	....	....	....	1.87	9.45*	29.4*	64.6*
Averages..	.478	.230	.205	1.76	1.80	6.53	20.0	43.8

NOTE.—No. 17 was omitted in making averages.
* Excessive values.

Mr. William Kent.—In connection with what Professor Benjamin has said, I would like to sketch on the board something which was shown in the discussion of papers on cast iron at the Pittsburg meeting of the Mining Engineers. It came in the form of a communication from Professor Carpenter, member of this Society, concerning the modulus of elasticity and the elastic limit of cast iron. If we test a bar of cast iron and plot the results, we get a curve something like that here shown (Fig. 146), which has no well-defined elastic limit at any point and in which the calculated modulus of elasticity varies at every point of the test. If we draw a tangent line from the initial point of the curve, that will not give the modulus of elasticity of the iron, because it is only the modulus at the beginning of the test. Now, if at any point we stop the test, take off the load, and plot the set of the bar, taking the elongations downwards as we go down, we will have a straight line. Then, starting the test over again, the diagram will be a straight line up to the same point; then, on continuing the test, the curve will follow the trend of the original curve. If we stop at any other point and bring the load down to zero, you will have another straight line. We then have a well-defined elastic limit of the bar, depending on how far we have previously strained the bar. If we strain the bar up to a certain point and take the load off, that point will be the elastic limit for the succeeding test, and these straight inclined lines will express the moduli of elasticity, these lines being practically parallel.

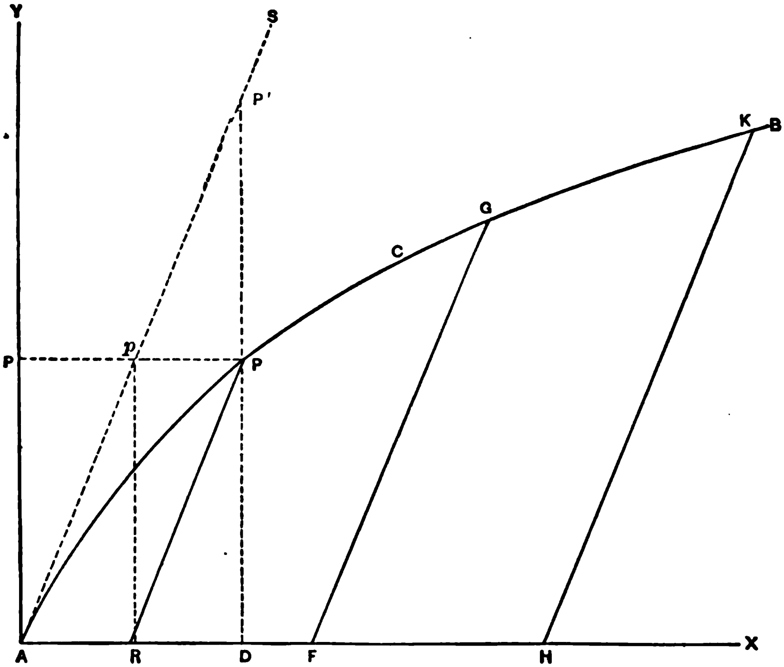

FIG. 146.

Mr. Gus. C. Henning.—I wish to discuss this very point too on the basis of results in autographic diagrams which are pretty well known and have been published for a couple of years. The diagram showing curve *abcd*, with lines *bi* and *cl*, is not strictly correct. If we obtain a proper curve, automatically drawn, of cast iron, we do not get the curve *ad*, but a curve like *ax* (Fig. 147). We will have a line which is very nearly straight for a very small distance, *ay* ; then there will be a slight kink, or distinct change of curve, at *y*. Then, instead of getting a curve like *abd*, we get a curve something like *ayx*. Bauschinger & Tetmajer plotted these curves several years ago very carefully and found a distinct kink at *y*, which is the only point from which to determine the modulus of elasticity. When we talk about modulus of elasticity, however, we must not forget that

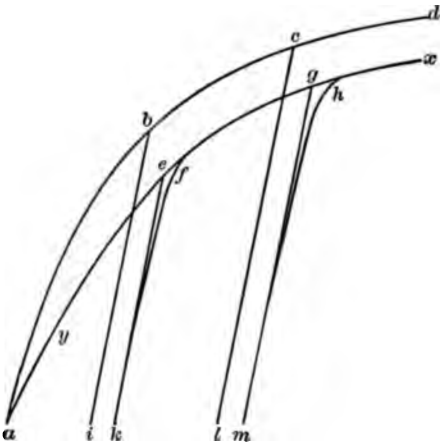

FIG. 147.

that applies to materials which are entirely uniform in their structure. It does not apply to minerals ; it does not apply to crystals ; it does not apply to cast iron, which is a conglomeration of cemented particles. Our theory sometimes misleads us. We speak of modulus of elasticity of bodies which are perfectly elastic. The modulus applies to that part of the curve of a material, when drawn automatically, within which the changes of shape are absolutely proportional to the loads applied. As soon as that point is passed, where the extensions or compressions—I mean to say, changes of shape—vary with the relations of the change of load, we no longer can apply our theory of the modulus ; there is no such thing constant for cast iron. In the first place, cast iron is not uniform. It has no point on its curve where change of shape is proportional to a change of loads. Therefore, our general definition of modulus, or our general method of determining modulus of elasticity of cast iron, does not hold good in this case, so we might as well drop them altogether.

The next point is about lines *bi* and *cl*. If we stop loading at the point *e* and then take off all the load, we will not get a straight line, as shown by *bi* and *cl* upon reloading. This is well known, and the latest illustration of it is shown by curves obtained by Olsen's autographic recording apparatus, which has been designed on my suggestion making the apparatus multiply at least five hundred times; that is, a hundredth of an inch actual elongation will appear half an inch in length on the diagram. He actually gets that and obtains most beautiful results. Now, when the stress is removed and the pencil drops to zero, it does not describe a straight line on reloading, as shown at *bi*; it rises in a curve, as at *kf*, which, however, is more nearly a straight line than in some alloys. In some materials this "elastic line" is almost straight. But in cast iron it is distinctly not. The variation from a straight line is only shown when a proper apparatus or method for observing the same is used. But when we talk of tenths of thousandths of inches in determining moduli of elasticity, we must take them into account. We cannot take a diagram only two or three inches high, where the thickness of a lead-pencil line more than covers all the variation in any kind of material; we cannot say those lines are straight lines, because we have nothing to observe them with. The variations are considerably less than the thickness of any pencil line which can be drawn on paper. When you take Olsen's apparatus, which multiplies five hundred times, then the thickness of his pencil line can be neglected, because the slightest variation immediately exceeds the width of that line. In that case we always find these lines *ek* and *gm*, and *fk* and *hm* parallel, as was stated; but they are not in any case straight lines, nor do the ascending and descending lines run back over themselves, but always vary very slightly from them. These nearly straight lines, *bi* and *cl*, and the large hump at *b*, are characteristic of our more uniform and symmetrical metals, such as some of the higher bronzes and the steels; when testing a high steel, almost a smooth curve like *ad* is obtained. But cast iron is like *ax*. All the difference in materials lies within that change in shape. Therefore it is not fair to show such a curve and to show these lines, where these lines cover all the vagaries and all the differences that may exist in the materials; that is, in the properties which are indicated by these curves. All the curves which have been drawn heretofore have shown us practically nothing. Olsen is the first one who, by his new autographic apparatus, has shown us the actual differences existing. I regret we have not yet in the Society a record of those diagrams, although he spoke of that apparatus at our meeting in New York two years ago.

These curves and these facts stated by the preceding speaker are not new. Attention was called to them by Bauschinger, as I said, several years ago—at least six or seven. Tetmajer, as long as ten years ago, in his investigations of cast iron, speaks of them and plots them very distinctly. It is very much to be regretted that Professor Tetmajer's work has never been published in the English language. I think he has done better work on cast iron of such grade as he has investigated than anybody else. But he never realized, not being a practical founder, that cast iron was as variable as apples or potatoes. That is, one man in his foundry will use one grade of iron and know all about it, but as soon as he tries another grade he does not know the first thing about it. He will have to learn all about how to treat the new brand, all about how to treat it when he tries to pour it into the moulds.

Mr. Keep on his autographic diagrams has also shown this. In the paper some diagrams are given; but, unfortunately, Mr. Keep's apparatus only gives you a very small diagram, and therefore they are not very distinct. Mr. Keep found that a long time ago, and has always emphasized it.

I wished to call attention to these differences, because so many erroneous opinions obtain at the present time about cast iron, and we cannot emphasize too strongly where the differences are.

APPENDIX.

TABLES OF PAPER NO. DCXCV.

In the following tables the records of dimensions of test bar, maximum load, deflection, shrinkage, etc., are correct, having been compared with the original logs in possession of the Society, and also with the original notes made at the time of making tests. The calculations given in other columns were made by various persons connected with several engineering schools, and while the formulæ used by each can be reduced to the form given in this paper, the results vary slightly from what would have resulted from the use of the formulæ as given.

The columns "Max. Fibre Distance" and "Moment of Inertia" were inserted in the tables because they were used in some of the formula employed.

The Modulus of Elasticity in Tables XI., XII., and XIII. was calculated from slightly different data from that used in the other tables, which accounts for the difference in the results.

Tables XV. and XVIII. were made by dividing the fiber stresses in Table XIV. by constants, which gave the required strength. The results in these tables are therefore influenced by the variations in the results in Table XIV.

So long as the data are correct the calculations are not important, and the variations are not sufficient to change the conclusions stated in the paper.

It was intended to have all calculations repeated, and to use the formulæ as given in this paper, but no one could be found who could give the necessary time to the work before going to press with the volume of *Transactions*. The columns which are not filled are vacant because those having these calculations in charge did not have time to make them.

The excuse for presenting these calculations with the incompleteness mentioned is, first, that the corrections were expected before the final printing; and, finally, because it is doubtful if any of the calculated results are of enough value to make it worth while to recalculate them.

KEY TO TABLES.

nd of Iron......	"Iroquois" (coke).						"Hinkle" (charcoal).						Southern.			Foundries.			White
mber of Series.	1	2	3	4	5	6	7	8	9	10	11	12	14	13	15	19	16	18	17
tended Si.......	1.00	1.50	2.00	2.50	3.00	3.50	1.00	1.50	2.00	2.50	3.00	3.50							
. Si. by Analysis	.81	1.20	1.88	2.01	3.19	3.04	.93	1.17	1.67	2.23	2.71	3.05	2.81	3.18	3.51	.76	1.76	2.05	.92

TABLE I.

No. of Series.	No. Test Bar.	"Iroquois" Test Bars, ½″ □ × 12″.						
		Breadth.	Height.	Max. Fibre Distance.	Max. Load in Lbs.	Deflection in Inches.	Equiv'lent Load on Test Bar ½″□ × 12″.	Stress per □″ in Outer Fibre.
1....	1	.501	.503	.251	260	.105	256	36,860
	2	.500	.496	.248	275	.11	279	40.230
	3	.510	.502	.251	285	.15	277	39,920
	4	.515	.504	.252	287	.12	274	39.470
	5	.505	.502	.251	287	.125	282	40,600
	6	.508	.502	.251	295	.14	288	41,500
	7	.502	.505	.252	298	.12	291	41,920
	8	.512	.508	.254	300	.125	284	40.850
	9	.505	.503	.251	312	.13	305	43,900
2 ...	11	.500	.505	.252	325	.20	318	45,800
	12	.511	.509	.254	330	.20	311	44,800
	13	.512	.503	.251	330	.215	318	45,800
	14	.504	.502	.251	340	.20	334	48,200
	15	.515	.505	.252	344	.23	327	47.100
	16	.514	.510	.255	348	.23	325	46,800
	17	503	.500	.250	352	.21	349	50,300
3....	21	.505	.504	.252	372	.245	362	52,100
	22	.502	.506	.253	377	.24	366	52,700
	23	.504	.509	.254	381	.25	364	52,450
	24	.511	.507	.253	391	.255	372	53.600
	25	.512	.505	.252	395	.285	378	54,500
	26	.517	.502	.251	405	.295	388	55,800
	27	.520	.510	.255	406	.30	326	46,950
4....	31	.498	.500	.250	405	.27	406	58,500
	32	.507	.498	.249	416	.315	418	59,550
	33	.505	.504	.252	420	.31	409	59,000
	34	.495	.502	.251	428	.29	428	61,700
	35	.500	.499	.249	430	.33	431	62.050
	36	.506	.500	.250	438	.32	432	62.200
	37	.509	.503	.251	450	.35	436	62,800
5....	41	.509	.502	.251	410	.275	399	57,500
	42	.508	.506	.253	415	.285	399	57.500
	43	.503	.500	.250	420	.27	417	60.000
	44	.505	.504	.252	430	.305	418	60,250
	45	.498	.500	.250	432	.285	433	62,400
	46	.504	.499	.249	440	.315	438	63,100
	47	.504	.503	.251	465	.355	455	65,600
6....	51	.525	.514	.257	450	.29	405	58,300
	52	.495	.497	.248	450	.33	460	66,300
	53	.505	.501	.250	450	.33	443	63.800
	54	.522	.513	.256	480	.355	486	62.800
	55	.504	.499	.249	495	.40	498	71,000
	56	.510	.501	.250	500	.40	488	70,500

Fibre stress = 144 × Load.

TABLE II.

No. of Series.	No. Test Bar.	"HINKLE" TEST BARS, ½" □ × 12".						
		Breadth.	Height.	Max. Fibre Distance.	Max. Load in Lbs.	Deflection in Inches.	Equiv'lent Load on Test Bar ½"□ × 12".	Stress per □" in Outer Fibre.
7....	61	.506	.503	.251	320	.155	313	45,100
	62	.499	.506	.253	327	.16	317	45,600
	63	.506	.504	.252	330	.15	320	46,100
	64	.510	.507	.253	335	.165	319	45,900
	65	.502	.500	.250	340	.165	348	50,100
	66	.519	.506	.253	347	.17	286	41,200
	67	.515	.510	.255	370	.20	345	49,600
	......	......	......	......	......	......	......	......
	......	......	......	......	......	......	......	......
8....	71	.501	.503	.251	380	.255	374	53,800
	72	.501	.503	.251	380	.265	374	53,800
	73	.501	.500	.250	385	.25	384	55,300
	74	.504	.503	.251	392	.285	384	55,300
	75	.501	.509	.254	405	.285	390	56,200
	76	.509	.505	.252	405	.32	390	56,200
	77	.512	.502	.251	418	.335	405	58,300
9....	81	.510	.507	.253	320	.20	305	43,900
	82	.504	.498	.249	322	.195	322	46,300
	83	.506	.512	.256	322	.195	308	44,300
	84	.512	.507	.253	322	.215	305	43,920
	85	.505	.504	.252	333	.22	324	46,700
	86	.517	.508	.254	335	.21	313	45,100
	87	.503	.504	.252	345	.19	337	48,500
10....	91	.507	.503	.251	412	.30	401	57,700
	92	.509	.495	.247	420	.31	431	62,100
	93	.497	.503	.251	440	.33	434	62,500
	94	.507	.500	.250	445	.365	432	62,200
	95	.508	.504	.252	448	.32	434	62,500
	96	.505	.505	.252	450	.40	437	63,000
	97	.499	.500	.250	455	.38	455	65,500
11....	101	.522	.513	.256	400	.28	364	52,400
	102	.497	.499	.249	400	.26	404	58,200
	103	.503	.504	.252	428	.29	418	60,200
	104	.510	.500	.250	460	.305	450	64,800
	105	.503	.502	.251	470	.36	463	66,700
	106	.521	.520	.260	500	.34	443	63,800
	107	....	......	......	......	......	......	......
12 ...	111	.510	.508	.254	383	.26	363	52,300
	112	.508	.506	.253	420	.28	403	58,100
	113	.506	.502	.251	448	.33	439	63,300
	114	.507	.500	.250	455	.36	448	64,600
	115	.507	.506	.253	461	.335	443	63,800
	116	.507	.500	.250	468	.37	461	66,300

Fibre stress = 144 × Load.

TABLE III.

No. of Series.	No. Test Bar.	Record of Test Bars ½″ □ × 12″.						
		Breadth.	Height.	Max. Fibre Distance.	Max. Load in Lbs.	Deflection in Inches.	Equiv'lent Load on Test Bar ½″ □ × 12″.	Stress per □″ in Outer Fibre.
14 ...	121	.520	.510	.255	370	.205	342	49,300
	122	.501	.501	.250	380	.205	374	53,800
	123	.511	.510	.255	385	.205	362	52,100
13....	131	.505	.505	.252	370	.215	359	51,700
	132	.506	.530	.265	380	.19	334	48,100
	133	.512	.505	.252	380	.225	363	52,300
	134	.505	.504	.252	390	.22	380	54,700
	135	.495	.497	.248	390	.225	397	57,200
	136	.492	.515	.257	455	.255	440	63,400
15....	141	.500	.500	.250	390	.21	390	56,200
	142	.509	.504	.252	400	.235	386	55,600
	143	.506	.503	.251	410	.225	400	57,600
	144	.508	.509	.254	423	.345	401	57,700
	145	.493	.519	.259	440	.22	414	59,600
	146	.491	.510	.255	450	.235	440	63,400
	147	.504	.502	.251	450	.255	442	63,600
	148	.497	.500	.250	450	.26	454	65,400
19....	151	.507	.520	.260	350	.095	319	45.900
	152	.522	.502	.251	370	.10	351	50,600
	153	.491	.506	.253	375	.10	372	53,600
	154	502	506	.253	380	.11	369	53,200
	155	.510	.505	.252	390	.12	374	53.800
	156	.517	.512	.256	395	.11	364	52,400
16 ...	161	.522	.495	.247	350	.22	342	49.300
	162	.501	.509	.254	355	.22	341	49.100
	163	.504	.504	.252	380	.25	371	53,400
	164	.522	.498	.249	390	.25	376	54,200
	165	.526	.510	.255	395	.265	360	51,800
	166	.515	·495	.247	395	.27	391	56,300
18....	171	.503	.498	.249	425	.24	425	61.300
	172	.507	.497	.248	443	.26	442	63,700
	173	.510	.495	.247	450	.265	450	64,900
	174	.510	.501	.250	453	.27	442	63,700
	175	.512	.503	.251	461	.26	444	64,000
17....	181	.502	.487	.243	418	.13	435	62,600
	182	.494	.498	.249	455	.13	481	69,300
	183	.495	.506	.253	487	.137	480	69,100

TABLE IV.

No. of Series.	No. of Test Bar.	BARS ½″□ × 12″.			
		Deflection.		Set.	
		At 300 lbs.	At 400 lbs.	At 300 lbs.	At 400 lbs.
1	....	.....	.....	....	....
2	14	.17	.....	.032	....
3	22	.165	.....	.032	....
	26	.....	.29	....	.076
4	34	.165	.265	.028	.066
5	45	.16	.25	.022	.056
6	52	.17	.265	.024	.06
7	62	.145	.....	.026	....
8	72	.18	.....	.036	....
	76	.....	.315	....	.084
9	87	.155	.....	.028	....
10	93	.17	.28	.028	.072
11	102	.175	.....	.032	....
	104	.....	.245	....	.054
12	113	.165	.265	.026	.066
14	**122**	.155	.....	.018	....
13	**135**	.16	.....	.018	....
	136	.....	.215	....	.036
15	**141**	.15	.....	.016	....
	145	.....	.195	....	.03
	146	.....	.20	....	.03
	148	.....	.21	....	.032
19	**156**	.085	.....	.006	....
16	**161**	.175	.....	.028	....
	162	.18	.....	.03	....
	164	.18	.....	.028	....
	166	.18	.....	.03	....
18	**171**	.16	.22	.016	.032
	172	.165	.23	.018	.034
	173	.15	.22	.018	.033
	174	.16	.225	.018	.034
	175	.15	.21	.014	.032
17	**181**	.0925	.1225	0	0
	182	.0925	.1225	0	0
	183	.0985	.1285	0	0

TABLE V.

Kind of Iron.	No. of Series.	No. Test Bar.	Size of Test Bar, 1″□ × 12″.									
			Breadth.	Height.	Max. Fibre Distance.	Moment of Inertia.	Max. Load in Lbs.	Deflection in Inches.	Stress per □″ Outer Fibre.	Shearing Stress Lbs. per □″.	Modulus of Elasticity.	Resilience.
"Iroquois" (coke).	1	2	1.06	1.04	.52	.099	2537.6	.117	40,000	1174	11,410,000	148.4
		1	1.04	1.04	.52	.097	2641.8	.123	42,500	1223	11,180,000	162.4
	2	23	1.06	1.04	.52	.099	1990	.096	31,368	904	8,620,000	94.
		24	1.04	1.04	.52	.097	2290	.117	36,840	1060	13,260,000	133.9
	3	45	1.04	1.04	....	.0975	2499	....	39,800	....	11,600,000	.....
		46	1.04	1.03	.515	.094	2737.8	.142	45,000	1279	10,510,000	194.3
	4	67	1.04	1.04	.52	.097	2580	.148	41,505	1194	14,510,000	190.9
		68	1.05	1.04	.52	.098	2660	.157	42,356	1220	12,620,000	208.8
	5	...	....	....	....	.....	......	....	......	....	....	.....
		...	....	....	....	.....	......	....	......	....	....	.....
	6	111	1.04	1.04	....	.097	2175	.171	35,000	....	10,100,000	.....
		112	1.04	1.04	.52	.097	2254	.104	36,354	1043	15,300,000	117.2
"Hinkle" (charcoal).	7	133	1.03	1.03	.515	.093	2092	.104	34,773	986	9,450,000	108.7
		134	1.03	1.03	.515	.093	2280	.115	37,899	1075	13,670,000	131.1
	8	156	1.04	1.03	.515	.094	2416	.142	39,710	1310	10,510,000	171.5
		155	....	....	.52	.....	2498	....	37,532	....	....	.....
	9	177	1.04	1.04	.52	.097	2331	.122	37,500	1079	10,300,000	142.1
		178	1.04	1.03	.515	.094	2380	.126	39,700	1112	11,500,000	149.9
	10	200	1.03	1.02	.51	.091	2100	.115	35,300	1000	10,850,000	120.7
		199	1.04	1.04	.52	.097	2270	.137	36,518	1050	10,200,000	155.4
	11	222	1.04	1.04	.52	.097	2150	.106	34,588	995	11,540,000	113.9
		221	1.04	1.04	.52	.097	2430	.150	39,092	1125	9,760,000	182.2
	12	244	1.03	1.03	.515	.093	2105.6	.105	35,000	993	9,620,000	110.4
		...	....	....	....	.....	......	....	......	....	....	.....
Southern......	14	277	1.04	1.03	.515	.094	2420	.089	39,776	1130	10,720,000	107.6
		278	1.01	1.02	.51	.089	2762	.100	47,500	1341	16,150,000	138.1

TABLE VI.

KIND OF IRON.	No. of Series.	No. Test Bar.	SIZE OF TEST BAR, 1″□ × 24″.									
			Breadth.	Height.	Max. Fibre Distance.	Moment of Inertia.	Max. Load in Lbs.	Deflection in Inches.	Stress per □″ in Outer Fibre.	Shearing Stress Lbs. per □″.	Modulus of Elasticity.	Resilience.
"Iroquois" (coke).	1	3	1.04	1.04	.52	.097	980	.310	31,571	453	11,390,000	151.9
		4	1.03	1.03	.515	.093	1,045	....	34,700	....	....	.....
	2	26	1.04	1.04	.52	.097	1,010	.385	32,500	467	12,380,000	194.4
		25	1.04	1.04	.52	.097	1,036	.385	33,333	479	11,300,000	199.43
	3	49	1.05	1.02	.51	.093	1,175	.49	38,650	549	12,340,000	287.8
		48	1.02	1.02	.51	.090	1,290	.5925	43,817	620	12,090,000	382.16
		47	1.04	1.04	.52	.097	1,250	.4825	40,218	578	13,100,000	301.56
		50	1.04	1.02	.51	.092	1,275	.61	42,500	601	11,520,000	388.87
	4	70	1.06	1.05	.53	.102	1,210	.595	37,750	560	10,500,000	360
		69	1.05	1.04	.52	.098	1,200	.57	38,216	550	11,699,000	342
	5	91	1.04	1.04	.52	.097	1,220	.46	39,253	564	11,610,900	280.60
		92	1.04	1.03	.515	.094	1,244	.52	40,921	581	10,940,000	323.44
	6	....	....	....	...	....	....	....	......	....	....	......
		....	....	....	....	....	....	....	......	....	....	......
"Hinkle" (charcoal).	7	135	1.03	1.03	....	.093	1,066	.340	35,400	....	12,900,000	......
		136	1.04	1.04	.52	.097	1,080	.365	34,749	500	10,740,000	197.10
	8	157	1.04	1.04	.52	.097	1,050	.3675	33,785	486	12,290,000	192.93
		158	1.04	1.03	.515	.094	1,150	.495	37,800	537	13,820,000	290.8
	9	180	1.04	1.04	....	.097	1,015	....	32,600	....	11,700,000	......
		179	1.03	1.03	.515	.093	1,160	.37	38,410	547	12,500,000	214.6
	10	202	1.04	1.04	.52	.097	1,085	.399	33,300	477	12,300,000	......
		201	1.04	1.03	.515	.094	1,050	.371	34,500	490.7	12,900,000	194.77
	11	224	1.05	1.05	.53	.101	1,145	.510	36,100	524	11,400,000	292
		223	1.04	1.03	.515	.094	1,200	.475	39,473	560	13,340,000	285
	12	246	1.04	1.04	.52	.097	1,240	.432	39,897	574	12,480,000	267.8
		245	1.03	1.03	.515	.093	1,400	.545	46,500	660	12,290,000	381.5
Southern ..	14	279	1.00	1.00	.50	.083	1,190	.365	43,053	....	15,210,000	217.1
		280	1.02	1.02	.51	.090	1,210	.385	41,955	581	14,950,000	232.9
	13	266	1.03	1.01	.50	.088	1,125	.380	40,600	....	12,900,000	......
		265	1.04	1.04	.52	.097	1,220	.395	39,300	564	11,740,000	276.5
	15	297	....	....	....	....	....	....	......	....	....	......
		298	1.04	1.03	....	.094	1,117	....	37,000	....	11,600,000	......
Foundries .	19	373	1.02	1.03	.515	.092	1,240	.24	41,168	591	19,100,000	148.8
		374	1.04	1.05	.525	.100	1,345	.26	42,300	622	17,100,000	175
	16	310	1.02	1.02	.51	.090	1,026	.397	34,900	497	14,000,000	203
		309	1.05	1.02	.51	.093	1,182	.425	38,828	552	13,700,000	246
	18	333	1.03	1.03	.515	.093	1,390	.350	45,800	655	15,898,000	242
		334	1.00	1.04	.52	.093	1,410	.350	46,900	675	15,600,000	......
Malleable.....	17	322	1.02	1.04	.52	.095	1,424	.19	46,700	677	22,000,000	356
		....	....	....	....	....	....	....	......	....	....	......

TABLE VII.

Kind of Iron.	No. of Series.	No. Test Bar.	SIZE OF TEST BAR, 1″ □ × 48″.									
			Breadth.	Height.	Max. Fibre Distance.	Moment of Inertia.	Max. Load in Lbs.	Deflection in Inches.	Stress per □″ in Outer Fibre.	Shearing Stress Lbs. per □″.	Modulus of Elasticity.	Resilience.
“Iroquois” (Coke).	1	7	1.05	1.08	.515	.095	501	1.510	32,600	232	13,245,897	378.25
		8	1.04	1.02	.51	.092	524	1.520	34,933	247	13,814,656	398.24
	2	30	1.04	1.03	.515	.094	538	1.945	35,450	251	12,300,000	503
		29	1.02	1.01	.505	.087	562	1.750	39,150	272	13,600,000	391.75
	3	...	....	.....	....	....	...	......	....	...	....	......
		...	....	....	....	....	...	......	....	...	....	....
	4	74	1.04	1.02	.51	.092	534	1.750	35,600	251	12,600,000	467.25
		73	1.03	1.02	.51	.091	578	2.240	38,948	272	12,500,000	647.36
	5	95	1.03	1.01	.505	.088	580	1.760	40,400	278	13,400,000	510.04
		96	1.04	1.01	.505	.089	590	1.940	40,200	280	13,600,000	572.30
	6	118	1.04	1.02	.51	.092	539	1.860	35,935	254	12,895,027	501.27
		117	1.04	1.04	.52	.097	574	1.960	36,950	265	11,200,000	562.52
“Hinkle” (Charcoal).	7	140	1.05	1.03	.515	.095	456	1.300	29.533	211	14,100,000	296.40
		139	1.02	1.02	.51	.090	480	1.450	32,608	230	13,100,000	348.00
	8	162	1.04	1.03	.515	.094	482	1.530	31,544	225	12,600,000	368.73
		161	1.06	1.04	.52	.099	574	1.900	36,200	261	13,300,000	545.30
	9	184	1.04	1.02	.51	.092	525	1.510	35,000	247	13,800,000	396.37
		183	1.05	1.04	.52	.098	528	1.440	33,308	242	13,150,000	379.16
	10	...	....	....	....	....	...	......	....	...	....	......
		...	....	....	....	....	...	......	....	...	....	......
	11	228	1.04	1.03	.515	.094	578	2,020	37,827	270	12,500,000	583.78
		227	1.06	1.02	.515	.096	583	1.890	37,467	267	12,500,000	550.93
	12	250	1.04	1.03	.515	.094	482	1.730	38,000	225	11,500,000	416.93
		249	1.06	1.04	.52	.099	520	1.740	32,745	236	11,400,000	452.00
Southern.	14	282	1.02	1.00	.50	.085	603	1.580	42,600	295	15,000,000	476.37
		281	1.01	0.99	.495	.081	622	1.560	45,735	311	15,900,000	485.16

TABLE VIII.

Kind of Iron.	No. of Series.	No. of Test Bar.	Size of Test Bar, 1″ □ × 54″.									
			Breadth.	Height.	Max. Fibre Distance.	Moment of Inertia.	Max. Load in Lbs.	Deflection in Inches.	Stress per □″ in Outer Fibre.	Shearing Stress Lbs. per □″.	Modulus of Elasticity.	Resilience.
"Iroquois" (Coke).	1	9	1.02	1.02	.51	.090	457.8	1.73	35,000	219	14,297,000	395.99
		10	1.03	1.02	.51	.091	478	1.92	36,212	227	14,955,000	458.88
	2	32	1.04	1.03	.515	.094	468	2.15	34,615	218	12,597,000	503.10
		31	1.04	1.03	.515	.094	473.2	2.18	35,000	221	12,644,000	615.78
	3	53	1.04	1.03	.515	.094	512	2.41	37,869	239	12,817,000	616.96
		54	1.03	1.03	.515	.093	523.2	2.36	39,200	246	13,447,000	617.37
	4	75	1.02	1.02	.51	.090	500	2.37	38,226	240	14,333,927	592.50
		76	1.04	1.02	.51	.092	532.8	2.59	40,000	251	13,240,000	689.97
	5	97	1.03	1.03	.515	.0936	540	2.66	40,178	254	12,250,000	718.20
		98	1.02	1.02	.51	.0902	540	2.44	41,281	259	12,600,000	658.80
	6	120	1.03	1.02	.51	.091	420	1.97	31,818	200	11,933,000	413.70
		119	1.02	1.02	.51	.0902	430	2.04	32,874	206	11,746,000	438.60
"Hinkle" (Charcoal).	7	141	1.04	1.03	.515	.0940	439.4	1.76	32,500	205	14,360,000	386.67
		142	1.04	1.02	.51	.0919	460	1.80	34,534	217	14,800,000	414.00
	8	164	1.04	1.02	.51	.0919	445	1.90	33,408	209	13,900,000	422.75
		163	1.02	1.02	.51	.0902	480	2.36	36,600	230	14,000,000	566.40
	9	185	1.03	1.02	.51	.0910	490	2.39	37,121	233	13,600,000	585.55
		186	1.02	1.02	.51	.0902	490.5	2.28	37,500	235	13,800,000	559.17
	10	207	1.03	1.02	.51	.0909	454	2.33	34,393	216	12,250,000	528.91
		208	1.03	1.02	.51	.0909	462	2.46	35,000	220	12,600,000	568.26
	11	229	1.04	1.02	.51	.0919	486	2.20	36,486	229	12,300,000	534.60
		230	1.03	1.02	.51	.0909	520	2.62	39,393	247	13,100,000	681.20
	12	....	......	......	......	......	......	......	....	......	....	......
		252	1.00	1.00	.50	.0830	478	1.98	38,850	239	13,900,000	473.22
Southern	14	284	1.02	1.00	.50	.0850	494	1.48	39,331	242	15,300,000	365.56
		283	1.01	1.00	.50	.0840	530	1.87	42,604	264	15,000,000	495.55.

TABLE IX.

Kind of Iron.	No. of Series.	No. Test Bar.	Size of Test Bar, 2″ × 1″ × 12″									
			Breadth.	Height.	Max. Fibre Distance.	Moment of Inertia.	Max Load in Lbs.	Deflection in Inches.	Stress per □″ in Outer Fibre	Shearing Stress Lbs. per □″	Modulus of Elasticity.	Resilience.
"Iroquois" (Coke).	1	12	2.00	1.00	.50	.1666	4110	.1067	.36990	1027.5	12,700,000	257
		11	2.05	1.04	.52	.192	4252	.117	.34557	998	11,180,000	248
	2	83	2.04	1.03	.515	.186	4000	.135	.33250	952	11,490,000	270
		84	2.04	1.03	.515	.186	4100	.142	.34100	976	10,340,000	291
	3	55	2.02	1.00	.50	.168	4100	.142	.38100	1019	12,240,000	291
		56	2.03	1.02	.51	.179	4500	.147	.38474	1086	12,390,000	330
	4	78	2.03	1.01	.505	.174	4250	.133	.37000	1037	12,000,000	282
		77	2.03	1.00	.50	.169	4420	.147	.39240	1088	11,440,000	324
	5	......	......	......	......	......	......	......	......	......	......	......
			......	......	......	......	......	......	......	......	......	......
	6	121	......	......	......	......	......	......	......	......	......	......
		122	2.02	1.00	.50	.168	4180	.104	.37321	1034	10,190,000	342
"Hinkle" (Charcoal).	7	143	......	......	......	......	......	......	......	......	......	......
		144	2.03	1.03	.515	.184	4030	.137	.33466	964	10,900,000	276
	8	166	2.04	1.02	.51	.180	4260	.136	.36400	1027	11,290,000	289
		165	2.04	1.04	.52	.191	4284	.093	.35000	1010	10,120,000	199
	9	......	......	......	......	......	......	......	......	......	......	......
			......	......	......	......	......	......	......	......	......	......
	10	209	2.06	1.04	.52	.193	3711	.147	.30000	......	9,000,000	......
		210	2.05	1.02	.51	.181	3840	.129	.32465	918	9,800,000	247
	11	232	2.03	1.00	.50	.169	4100	.137	.36339	1009	10,990,000	280
		231	2.02	1.00	.50	.168	4120	.128	.36800	1019.6	11,600,000	270
	12	253	2.05	1.00	.50	.1708	3670	.1154	.32330	919	10,800,000	220
		254	2.00	1.00	.50	.1666	3675	.118	.33075	918	10,000,000	231
Southern.	14	286	2.04	1.04	.52	.191	4700	.105	.38398	1108	12,450,000	246
		285	2.04	1.02	.51	.180	4880	.133	.40800	1161	11,290,000	321

TABLE X.

Kind of Iron.	No. of Series.	No. Test Bar.	Size of Test Bar, 2″ × 1″ × 24″.									
			Breadth.	Height.	Max. Fibre Distance.	Moment of Inertia.	Max. Load in Lbs.	Deflection in Inches.	Stress per □″ in Outer Fibre	Shearing Stress Lbs. per □″.	Modulus of Elasticity.	Resilience.
"Iroquois" (Coke).	1	13	2.06	1.04	.52	.193	1,822	.3725	29,450	425	10.550,000	339.34
		14	2.04	1.03	.515	.186	1,892	.....	31,471	......	10,900,000	....
	2	36	2.02	1.00	.50	.168	1,840	.489	32,500	910	10,106,864	....
		35	2.05	1.02	.51	.181	2,076	.4975	35,000	496	11,240,000	516.45
	3	58	2.04	1.00	.50	.170	2,230	.425	39,350	557.5	14,400,000	496
		57	2.05	1.03	.515	.186	2,350	.41	39,050	556	13,178,000	481.75
	4	80	2.02	1.00	.50	.168	1,824	.594	32,600	908	9,433,000	... ...
		79	2.00	1.00	.50	.1666	1,840	.50	32,750	459.5	12,200,000	492
	5	102	2.00	1.00	.50	.1666	1,985	.494	35,910	498.75	11,500,000	549
		101	2.06	1.04	.52	.193	2,160	.52	34,900	504	11,470,000	561.60
	6	...	....	....	....	.....	.....	.....	......	......	....	....
		...	....	....	....	.....	.....	.....	......	......	....	....
"Hinkle" (Charcoal).	7	146	2.08	1.04	.52	.195	1,700	.325	27,248	785	10,989,000	....
		145	2.00	1.00	.50	.1666	1,715	.3901	30,870	428.75	11,300,000	369
	8	167	2.00	1.00	.50	.1666	1,925	.4174	34,650	481.25	12,300,000	498
		168	....	....	....	.....	.....	.....	......	......	....	....
	9	190	2.00	1.00	.50	.1666	1,665	.3214	30,000	416	18,000,000	333
		189	2.08	1.03	.515	.189	1,840	.505	29,750	429	11,860,000	864.60
	10	...	....	....	....	.....	.....	.....	......	......	....	....
		...	....	....	....	.....	.....	.....	......	......	....	....
	11	233	2.04	1.02	.51	.180	2,122	.455	36,100	510	11,650,000	482.75
		234	2.00	1.00	.50	.1666	2,210	.483	33,780	552.5	12,600,000	657
	12	255	2.07	1.02	.51	.1831	1,940	.450	32,481	......	10,900,000	....
		256	2.03	1.01	.50	.174	2,010	.400	34,050	.. ..	....	....
Southern.	14	288	2.03	1.04	.52	.1903	1,880	.....	39,820	......	11,200,000	....
		287	2.00	1.00	.50	.1666	2,045	.3266	36,810	511.25	18,600,000	390
	13	267	2.00	1.00	.50	.1666	2,155	.404	38,790	536.5	12,900,000	500
		268	2.04	1.02	.51	.1800	2,245	.4316	38,165	539.6	13.400,000	483.997
	15	299	....	....	....	.....	.....	.....	......	......	....	....
		300	....	....	....	.....	.....	.....	......	......	....	....
Foundries.	19	375	2.03	1.01	.505	.1742	2,650	.315	46.100	646	17,000,000	417
		376	2.02	1.01	.505	.1734	2,756	.366	48,200	675	16,900,000	505
	16	312	2.01	.99	.495	.1625	1,914	.375	34,982	598	12,800,000	359
		31	2.03	1.01	.505	.1743	2,244	.467	38,650	596	12,600,000	525
	18	336	1.96	.99	.495	.158	2,224	.329	41.800	574	14,300,000	....
		335	2.04	1.03	.515	.186	2,480	.396	41,200	597	13,900,000	490
Malleable.	17	323	2.04	1.02	.51	.180	2,660	.193	45,200	663	14,900,000	257
		324	2.02	.98	.49	.159	2.661	.282	49,200	671	21,000,000	374

TABLE XI.

No. of Series.	No. Test Bar.	Size of Test Bar, 2″ □ × 24″.									
		Breadth.	Height.	Max. Fibre Distance.	Moment of Inertia.	Max. Load in Lbs.	Deflection in Inches.	Stress per □″ in Outer Fibre.	Shearing Stress Lbs. per □″.	Modulous of Elasticity.	Resilience.
1	16	2.05	2.05	1.025	1.4723	6,300	.158	26,315	749.4	11,430,000	497.7
	15	2.05	2.05	1.025	1.4723	6,500	.170	27,150	773.3		522.5
2	38	2.04	2.03	1.015	1.422	6,900	.230	29,759	833.2	9,800,000	793.5
	37	2.05	2.04	1.020	1.450	7,200	.201	30,390	860.8		723.6
3	59	2.05	2.02	1.010	1.409	7,000	.260	30,114	845.1		910.2
	60	2.04	2.02	1.010	1.402	7,300	.255	31,450	885.8	10,820,000	930.7
4	81	2.08	2.04	1.020	1.4714	6,700	.200	27,872.	789.6		670
	82	2.10	2.05	1.025	1.508	7,350	.251	29,980	853.7	9,657,000	922.6
5	103	2.06	2.05	1.025	1.478	8,400	.270	34,919	994.6		1134
	104	2.06	2.03	1.015	1.436	8,400	.270	36,100	1004.4	10,610,000	1134
6	125	2.06	2.04	1.020	1.456	5,950	.240	24,996	708		714
	126	2.05	2.04	1.020	1.450	6,500	.281	27,437	777.2	7,991,000	913.3
7	148	2.05	2.02	1.010	1.408	6,600	.215	28,393	796.8	10,700,000	709.4
	147	2.07	2.03	1.015	1.443	6,700	.210	28,281	797.3		703.6
8	170	2.05	2.07	1.035	1.516	6,800	.291	27,860	801.2	9,002,000	989.5
	169	2.07	2.06	1.030	1.508	7,300	.320	30,150	855.9		1168
9	191	2.06	2.03	1.015	1.436	6,800	.249	28,650	813.1		846.7
	192	2.07	2.03	1.015	1.443	6,900	.273	29.125	821	9,762,000	941.9
10	214	2.06	2.03	1.015	1.436	6,480	.230	27,280	774.9	9,601,000	745.3
	213	2.05	2.03	1.015	1.429	6,800	.246	28,650	817		836.4
11	235	2.10	2.07	1.035	1.552	6,800	.250	27,200	782.2		850
	236	2 10	2.07	1.035	1.552	6,900	.240	27,600	793.6	9,277,000	828
12	257	2.05	2.04	1.020	1.450	7,000	.200	29,547	837		700
	258	2.06	2.04	1.020	1.457	8,600	.293	36,124	1023.5	9,564,000	1260
14	290	2 03	2.03	1.015	1.415	8,250	210	34,800	1001.2	10,560,000	866.4
	289	2.03	2.03	1.015	1.415	8,300	.210	35,723	1007.2		871.6
13	269	2.07	2.04	1.020	1.465	8,400	199	35.112	994.8		836
	270	2.05	2.04	1.020	1.450	8,500	.218	35,878	1016.2	10,306,000	926.7
15	301	2.04	2.02	1.010	1.4015	8,400	.203	36,200	1019.1		852.8
	302	2.04	2.03	1.015	1.422	8,900	.232	38,300	1075	10,610,000	1032.5
19	377	2.07	2.06	1.03	1.508	9,500	.185	38,929			
	378	2 05	2.03	1.015	1.429	9,700	.215	41,750			
16	314	2.02	2.03	1.015	1.408	7,100	.209	30.757			
	313	2.10	2.04	1.02	1.486	7,400	.210	30,450			
18	338	2.02	2.01	1.005	1.368	8,000	.195	35,289			
	337	2.08	2.03	1.015	1.415	8,400	.210	36,350			
17	326	2.03	2.03	1.015	1.415	13,400	.182	57.900			
	325	2.03	2.05	1.025	1.456	13,500	.180	56,965			

TABLE XII.

No. of Series.	No. Test Bar.	SIZE OF TEST BAR, 3"□ × 24".									
		Breadth.	Height.	Max. Fibre Distance.	Moment of Inertia.	Max. Load in Lbs.	Deflection in Inches.	Stress per □" in Outer Fibre.	Shearing Stress Lbs. per □".	Modulus of Elasticity.	Resilience.
1	17	3.05	3.03	1.515	7.068	24,800	.200	31,900	1,342		2,480
	18	3.06	3.05	1.525	7.285	25,600	.195	32,884	1,371.5	7,706,000	2,496
2	40	3.06	3.06	1.53	7.305	22,500	.196	28,283	1,202	7,667,000	2,205.5
	39	3.07	3.04	1.52	7 188	23,100	.220	29,300	1,236		2,541
3	61	3.15	3.09	1.545	7.740	19,200	.161	22,982	986.3		1,546
	62	3.15	3.06	1.53	7.520	19,300	.170	23,565	1,001.4	7,536,000	1,641
4	83	3.11	3.04	1.52	7.275	18,700	.160	23,412	988.8		1,496
	84	3.11	3.06	1.53	7.425	19,900	.167	24,616	1,046	7,536,000	1,662
5	105	3.09	3.02	1.51	7.093	21,950	.169	28,052	1,176		1,855
	106	3.09	3.03	1.515	7.162	24,400	.182	30,963	1,303	7,609,000	2,221
6	127	3.04	3.02	1.51	6.978	16,000	.100	20,784	871.4		800
	128	3.05	3.03	1.515	7.068	19,500	.114	25,077	1,055	7,837,000	1,111.5
7	150	3.13	3.04	1.52	7.329	21,500	.202	26,768	1,130	7,642,000	2,171.5
	149	3.12	3.03	1.515	7.231	22,800	.225	28,660	1,206		2,565
8	171	3.09	3.04	1.52	7.236	21,600	.260	27,216	1,150		2,808.5
	172	3.10	3.04	1.52	7.255	22,750	.240	28,574	1,207	7,506,000	2,730
9	193	3.08	3.04	1.52	7.213	18,400	.190	23,276	982.5		1,748.2
	194	3.10	3.04	1.52	7.255	19,300	.200	24,241	1,024	7,630,000	1,930
10	216	3.10	3.04	1.52	7.255	20,500	.210	25,748	1,088	7,935,000	2,153
	215	3.10	3.04	1.52	7.255	20,600	.210	25,874	1,093		2,163
11	238	3.09	3.05	1.525	7.207	21,400	.218	26,804	1,185	6,898,000	2,279 5
	237	3.07	3.04	1.52	7.188	21,750	.230	27,601	1,165.5		2,501.5
12	260	3.05	3.04	1.52	7.138	27,100	.209	34,607	1,461.5	8,157,000	2,832
	259	3.05	3.04	1.52	7.138	28,700	.230	36,650	1,548		3,301
14	292	3.06	3.03	1.515	7.091	24,900	.160	31,922	1,343	8,664,000	1,992
	201	3.05	3.02	1.51	7.000	25,600	.170	33,152	1,390		2,175 5
13	271	3.09	3.07	1.535	7.449	23,700	.146	29,305	1,249		1,730
	272	3.10	3.10	1.55	7 695	24,400	.150	29,475	1,269.3	8,183,000	1,830
15	304	3.06	3.05	1 525	7.235	20,800	.132	26,312	1,114.5	8,272,000	1,373
	303	3.07	3.03	1.515	7.114	24,600	.165	31,439	1,322.5		2,029.5
19	379	3.09	3.03	1.515	7.158	31,600	.190	40,090			
	380	3.04	3.04	1.52	7.118	31,600	.196	39,200			
16	316	3.12	3.04	1.52	7.299	21,700	.165	27,087			
	315	3.12	3.02	1.51	7.160	22,600	.195	28,585			
18	340	3.01	3.04	1.52	7.040	25,300	.165	33,150			
	339	3.09	3.01		7.022	25,400	.190	32,652			
17	327	3.04	2.95		6.501	41,200	.180	56,049			
	328	3.03	2.99		6.745	42,400	.198	55,839			

TABLE XIII.

No. of Series.	No. Test Bar.	SIZE OF TEST BAR, 4″ □ × 24″.									
		Breadth.	Height.	Max. Fibre Distance.	Moment of Inertia.	Max. Load in Lbs.	Deflection in Inches.	Stress per □″ in Outer Fibre.	Shearing Stress Lbs. per □″.	Modulus of Elasticity.	Resilience.
1	20	4.03	4.04	2.02	22.145	53,000	.165	29,100	1,628	6,586,000	4,373
	19	4.07	4.06	2.03	22.695	56,000	.190	30,061	1,695		5,321
2	42	4.04	4.02	2.01	21.87	48,900	.163	26,973	1,506	5,580,000	3,986
	41	4.07	4.03	2.015	22.195	52,000	.220	28,330	1,585.5		5,720
3	64	4.06	4.08	2.04	22.98	41.400	.150	22,050	1,250	5,161,000	3,105
	63	4.07	4.06	2.03	22.695	44,000	.170	23,619	1,332		3.740
4	85	4.14	4.04	2.02	22.75	48,500	.170	25.846	1.450		4,122
	86	4.05	4.04	2.02	22.26	49,000	.170	26,685	1.497	5,751.000	4,165
5	108	4.11	4.07	2.035	23.09	41,300	.130	21,844	1.235	5,298,000	2,685
	107	4.10	4.06	2.03	22.86	43,900	.136	23,394	1,319		2,985.5
6	130	4.05	4.05	2.025	22.48	39,100	.154	21,184	1,192	4,860,000	3,011
	129	4.09	4.05	2.025	22.645	45,200	.189	24,250	1,364		4,272
7	152	4.08	4.06	2.03	22.78	43,000	.179	22,950	1,298	5,213,000	3,849.5
	151	4.10	4.00	2.00	21.875	43,700	.190	24,000	1,332		4.152
8	173	4.08	4.06	2.03	22.78	52,700	.185	28,150	1,591		4,875
	174	4.09	4.00	2.00	21.815	54,200	.191	29,810	1,656.5	6,033,000	5.176
9	195	4.07	4.07	2.035	22.865	45,600	.175	24.355	1,377		3.990
	196	4.07	4.06	2.03	22.695	47,000	.200	25,320	1,422	5,385,000	4,700
10	218	4.06	4.05	2.025	22.48	50,300	.170	27,187	1,530	6,319,000	4,276
	217	4.07	4.05	2.025	22.535	52,700	.164	28,416	1,598.5		4,321
11	240	4.09	4.06	2.03	22.854	42,600	.170	22,757	1,283	4,913,000	3,621
	239	4.08	4.07	2.035	22.925	46,200	.180	24,611	1,391		4.158
12	261	4.13	4.06	2.03	22.52	44,400	.170	24,000	1,324		3,774
	262	4.06	4.07	2.035	22.81	46,400	.180	24,843	1,404	4,867.000	4.176
14	294	4.06	4.04	2.02	22.31	51,500	.136	27,985	1,570	6,036,000	3,502
	293	4.07	4.04	2.02	22.367	53,400	.166	28.943	1,624		4,432
13	273	4.14	4.11	2.055	23.945	54,400	.140	28.016	1,599		3,808
	274	4.08	4.12	2.06	23.78	55,700	.135	28,958	1,657	6,320.000	3,760
15	305	4.10	4.07	2.035	23.084	56,000	.170	29.691	1,678		4,760
	306	4.07	4.07	2.035	22.865	56,700	.162	30,283	1,711.5	5,813,000	4.593
19	382	4.06	4.06	2.03	22.65	67,000	.111	36,000			
	381	4.13	4 05	2.025	22.88	70.000	.120	37,157			
16	318	4.06	4.02	2.01	21.95	43,400	.167	23,800			
	317	4.04	4.05	2.025	22.39	45.600	.160	24,754			
18	341	4.06	4.07	2.035	22.81	58,400	.175	31,238			
	342	4.01	4.08	2.04	22.72	59,000	.170	31,800			
17	329	4.04	3.90	1.950	19.96	92.000	.146	53,852			
	330	4.03	3.95	1.975	20.68	92,000	.110	52,626			

TABLE XIV.

AVERAGE MEASURED MAXIMUM LOAD (TRANSVERSE).

No Series.	½″ □ × 12″	1″ □ × 12″	1″ □ × 24″	1″ □ × 48″	1″ □ × 54″	2″ × 1″ × 12″	2″ × 1″ × 24″	2″ □ × 24″	3″ □ × 24″	4″ □ × 24″
1	289	2,589	1,013	513	468	4,181	1.857	6,400	25.200	54,500
2	339	2,140	1,023	550	471	4,050	1.958	7,050	22,800	50,450
3	389	2.619	1.248	...	518	4,300	2,290	7,150	19,250	42,700
4	427	2,620	1,107	556	517	4,335	1,832	7,025	19,800	48,750
5	430	.....	1,232	585	540	.....	2,077	8,400	23,175	42,600
6	471	2,214	.....	557	425	4.180	.....	6,225	17,750	42,150
7	338	2,186	1,073	468	450	4,030	1,708	6.650	22,150	43,350
8	395	2,457	1,100	528	463	4,272	1,925	7,050	22.175	53.450
9	329	2,356	1,088	527	490	.....	1,753	6.850	18,850	46,300
10	439	2,185	1,042	...	458	3,775	.....	6.640	20.550	51,500
11	443	2.290	1,172	581	503	4.110	3,166	6,850	21.575	44,400
12	456	2,105	1,320	501	478	3,670	2,807	7,800	27,900	45,400
14	378	2,591	1,200	612	512	4,765	1,962	8,275	25,250	52,450
13	394	.....	1,173	...	...	.....	2,200	8,450	24,050	55,050
15	427	.....	1,117	...	...	.....	.....	8,650	22.700	56,350
19	377	.....	1,292	...	...	.....	2,703	9,600	31,600	68,500
16	378	.....	1,104	...	...	. ..	2,079	7,250	22,150	44.500
18	446	.....	1,400	...	...	....	2,352	8.200	25,350	58,700
17	471	.....	1,424	...	...	.....	2,661	13.450	41,800	92,000

TABLE XV.

Average Maximum Load for Nominal Size Bar (Transverse).

Iron.	No. Series.	½″ □ × 12″	1″ □ × 12″	1″ □ × 24″	1″ □ × 48″	1″ □ × 54″	2″ × 1″ × 12″	2″ × 1″ × 24″	2″ □ × 24″	3″ □ × 24″	4″ □ × 24″
"Iroquois" (Coke)	1	282	2,292	918	468	489	3,975	1,687	5,962	24,112	52,555
	2	326	1,894	914	520	430	3,759	1,883	6,661	21,556	49,201
	3	365	2,369	1,141	...	481	4,171	2,173	6,853	17,459	40.632
	4	422	2,329	1,046	518	483	4,216	1,823	6,427	18,015	46.744
	5	423	. ...	1,113	555	503	.....	1,962	7,838	22,136	40,247
	6	454	1,982	.....	504	400	4,147	....	5,826	17,202	40,422
"Hinkle" (Charcoal)	7	321	2,018	972	431	414	3,793	1,614	6.299	20.791	40,964
	8	386	2,146	1.046	469	436	3,956	1,925	6,419	20.929	51,628
	9	316	2,158	985	474	461	.....	1,665	6,440	17.823	44.114
	0	432	1,981	936	..	428	3,563	. ...	6,274	19,363	49.468
	11	424	2,047	1,036	523	468	4,066	2,104	6,091	20,406	42,142
	2	426	1,944	1.198	446	490	3,634	2,012	7,299	26.728	42,994
Southern...	4	359	2,424	1,181	611	506	3,858	1,877	7,936	24,409	50,649
	3	379	.....	1.080	...	...	.....	2,137	7,910	22,048	50,904
	15	416	.....	1,015	...	...	.....	.....	8,272	21,661	53,357
Foundries..	19	358	.....	1,183	...	...	.....	2,703	8,941	30,221	65,094
	16	363	.....	1,024	...	...	.....	2,066	6,789	20,882	44,217
	18	441	.....	1,287	...	...	.....	2,342	7,919	24,526	56,079
Malleable....	17	...	. ...	1,297	...	...	.....	2,651	12,736	41,968	94,731

TABLE XVI.

AVERAGE STRESS PER □ INCH ON OUTER FIBRE.

Iron.	No. Series.	½"□ × 12"	1"□ × 12"	1"□ × 24"	1"□ × 48"	1"□ × 54"	2" × 1" × 12"	2" × 1" × 24"	2"□ × 24"	3"□ × 24"	4"□ × 24"
"Iroquois" (Coke.)	1	40,584	41,250	33,052	33,690	35,606	35,773	30,372	26,732	32,142	29,536
	2	46,944	34,104	32,916	37,438	34,807	33,828	33,893	29,974	28,735	27,651
	3	52,581	42,640	41,085	......	38,934	37,540	39,115	30,839	23,273	22,834
	4	60,664	41,930	37,658	37,274	39,113	37,947	32,810	28,926	24,014	26,265
	5	60,995	......	40,087	39,958	40,729	.....	35,307	35,271	29,507	22,619
	6	65,400	35,677	......	36,270	32,346	37,321	......	26,216	22,930	22,717
"Hinkle" (Charcoal.)	7	46,243	36,336	34,989	31,070	33,517	33,866	29,056	28,337	27,714	23,022
	8	55,563	38,621	37,665	33,799	35,279	35,606	34,650	28,884	27,895	29,013
	9	45,545	38,852	35,455	34,154	37,310	......	29,973	28,982	23,758	24,792
	10	62,222	35,666	33,700	.....	34,696	32,069	......	28,232	25,811	27,801
	11	60,713	36,840	37,286	37,647	37,939	36,595	37,873	27,400	27,202	28,684
	12	61,201	35,000	43,127	32,144	39,700	32,702	36,217	32,835	35,628	24,163
Southern.	14	51,777	43,638	42,504	44,018	40,967	34,727	33,815	35,615	32,537	28,464
	13	54,552	......	38,888	......	......	......	38,477	35,495	29,390	28,487
	15	59,852	......	36,561	......	......	......	......	37,225	28,875	29,987
Foundries.	19	51,526	......	42,584	......	......	.....	48,650	39,741	40,286	36,083
	16	53,011	.....	36,856	......	......	......	37,101	30,550	27,836	24,850
	18	63,446	......	46,350	......	......	......	42,150	35,637	32,692	31,526
Malleable.	17	67,008	......	46,700	......	......	......	47,710	57,314	55,944	53,239

TABLE XVII.

AVERAGE MEASURED MAXIMUM LOAD IN TERMS OF SECTION OF TEST BAR ½"□ × 12" AND 1"□ × 12".

Iron.	No. Series.	½"□ × 12"	1"□ × 12"	1"□ × 24"	1"□ × 48"	1"□ × 54"	2" × 1" × 12"	2" × 1" × 24"	2"□ × 24"	3"□ × 24"	4"□ × 24"
"Iroquois" (coke).	1	289	324	253	257	263	261	232	200	233	213
		2,312	2,590	2,025	2,050	2,105	2,090	1,857	1,600	1,866	1,703
	2	339	267	256	275	265	253	245	220	211	197
		2,712	2,140	2,046	2,200	2,117	2,025	1,958	1,762	1,688	1,576
	3	389	327	312	......	291	269	286	223	178	167
		3,112	2,619	2,540	......	2,329	2,150	2,290	1,787	1,425	1,334
	4	427	328	301	278	290	271	229	220	179	190
		3,416	2,620	2,410	2,224	2,323	2,167	1,832	1,756	1,429	1,523
	5	430	......	308	292	303	......	260	262	214	166
		3,440	......	2,464	2,340	2,430	......	2,077	2,100	1,717	1,331
	6	471	277	......	279	339	261	......	195	164	164
		3,768	2,214	......	2,226	1,913	2,090	......	1,556	1,314	1,317
"Hinkle" (charcoal).	7	338	273	268	234	253	252	214	208	205	169
		2,704	2,186	2,146	1,872	2,023	2,015	1,707	1,662	1,640	1,355
	8	395	307	275	264	260	267	241	220	205	209
		3,160	2,457	2,200	2,112	2,081	2,136	1,925	1,762	1,642	1,669
	9	329	295	272	263	275	......	219	214	174	181
		2,632	2,355	2,175	2,106	2,206	......	1,752	1,712	1,396	1,447
	10	439	273	261	......	267	236	......	208	190	201
		3,512	2,185	2,085	......	2,061	1,887	......	1,660	1,522	1,608
	11	443	286	293	290	283	257	271	214	200	173
		3,544	2,290	2,345	2,322	2,263	2,055	2,166	1,712	1,598	1,389
	12	456	263	330	250	269	229	251	244	258	177
		3,648	2,106	2,640	2,004	2,151	1,836	2,005	1,950	2,067	1,419
Southern.	14	378	324	300	306	288	298	245	259	234	205
		3,024	2,591	2,400	2,450	2,304	2,382	1,962	2,069	1,781	1,639
	13	394	......	293	......	......	......	275	264	223	215
		3,152	......	2,345	......	......	......	2,200	2,112	1,870	1,719
	15	427	......	279	......	......	......	......	270	210	220
		3,416	......	2,234	......	......	......	......	2,162	1,681	1,761
Foundries.	19	377	......	323	......	......	......	338	300	292	167
		3,016	......	2,585	......	......	......	2,703	2,400	2,341	2,140
	16	378	......	276	......	......	......	260	227	205	174
		3,024	......	2,208	......	......	......	2,079	1,812	1,641	1,390
	18	446	......	350	......	......	......	294	256	235	229
		3,568	......	2,800	......	......	......	2,352	2,050	1,877	1,825
Malleable	17	471	......	356	......	......	......	333	420	387	353
		3,768	......	2,848	......	......	......	2,660	3,362	3,096	2,875

TABLE XVIII.

AVERAGE MAXIMUM LOAD FOR NOMINAL SIZE BAR IN TERMS OF SECTION OF TEST BAR ½" □ × 12" AND 1" □ × 12".

Iron.	No. Series.	½" □ × 12"	1" □ × 12"	1" □ × 24"	1" □ × 48"	1" □ × 54"	2" × 1" × 12"	2" × 1" × 24"	2" □ × 24"	3" □ × 24"	4" □ × 24"
"Iroquois" (coke).	1	282	286	229	234	247	248	211	186	223	205
		2,256	2,292	1,836	1,872	1,972	1,987	1.687	1,490	1,785	1,642
	2	326	237	228	260	242	235	235	208	200	192
		2,608	1,898	1,828	2,080	1,932	1,880	1,883	1,665	1,596	1,537
	3	365	296	285	......	270	261	272	214	162	159
		2,920	2,369	2,281	......	2,161	2,088	2,173	1,713	1,292	1,269
	4	422	291	262	259	271	264	228	201	169	183
		3,376	2,329	2,092	2,072	2,170	2,108	1,823	1,608	1,334	1,460
	5	423	......	278	277	283	......	245	245	205	157
		3,384	......	2,225	2,220	2,260	......	1,962	1,959	1,639	1,257
	6	454	248	......	252	225	259	......	182	159	158
		3,632	1,981	......	2,016	1,797	2,073	......	1,456	1,274	1,263
"Hinkle" (charcoal).	7	321	252	243	216	233	235	202	197	192	160
		2,569	2,018	1,944	1,726	1,862	1,881	1,614	1,572	1,539	1,279
	8	386	268	262	235	246	247	241	201	194	201
		3,087	2,146	2,092	1,878	1,969	1,978	1,925	1 605	1,549	1,612
	9	316	270	246	237	259	......	208	201	165	172
		2,530	2,158	1,969	1,897	2,078	......	1,665	1,610	1,319	1,377
	10	432	248	234	......	241	223	......	196	179	193
		3,457	1,981	1,872	......	1,928	1,782	......	1,568	1,434	1,544
	11	424	256	259	261	263	229	263	190	189	165
		3,373	2,047	2,071	2,091	2,108	2,033	2,104	1,522	1,511	1,316
	12	426	243	299	223	278	237	251	228	247	168
		3,400	1,944	2,396	1,786	2,205	1,817	2,012	1,824	1,970	1,342
Southern.	14	359	303	295	305	284	241	235	248	226	198
		2,872	2,424	2,361	2,440	2,273	1,928	1,876	1,984	1,808	1,582
	13	379	......	270	......	......	......	267	247	204	199
		3,032	......	2,160	......	......	......	2,136	1,977	1,632	1,590
	15	416	......	254	......	......	......	......	258	201	208
		3,328	......	2,029	......	......	......	......	2,068	1,604	1,667
Foundries.	19	358	......	296	......	......	......	338	276	280	250
		2,862	......	2,366	......	......	......	2,703	2,208	2,238	2,004
	16	364	......	256	......	......	......	258	212	193	173
		2,945	......	2,047	......	......	......	2,066	1,697	1,547	1,381
	18	441	......	322	......	......	......	293	247	227	219
		3,525	.....	2,575	......	......	......	2,342	1,980	1,816	1,751
Malleable.	17	465	......	324	......	......	......	331	398	388	370
		3,722	......	2,594	......	......	......	2,651	3,184	3,108	2,958

TABLE XIX.

Kind of iron.	No. test bar.	Size of Test Bar, 2″ × 1″ × 36″.						Modulus of Elasticity.	Resilience.
		Breadth.	Height.	Max. load in lbs.	Deflection in inches.	Stress per □″ in outer fibre.	Shearing stress per □″.		
Series 18. Bement, Miles & Co., Philadelphia, Pa.				TESTED NARROW SIDE DOWN.					
	359	1.02	2.00	2,800	.295	37,057	686	15,000,000	418
	366	1.01	1 98	3,000	.355	40,915	750	14,900,000	533
	367	1.01	1.98	3,020	.350	41,173	754	14,900,000	431
	358	1.00	1.99	3,028	.386	41,300	767	16,500,000	637
	364	.99	1.96	3,054	.416	43,000	786	16,000,000	635
	361	1.00	2.00	3,056	.433	41,254	764	14,900,000	662
	369	1.00	1.99	3,100	....	42,300	...	....	...
	372	1.04	2.00	3,950	.380	51,400	968	17,304,000	750
	Av....	....	....	3,251	.377	42,299	782	15,643,428	580
				TESTED WIDE SIDE DOWN.					
	363	1.97	.99	1,842	.628	37,600	345	16,000,000	418
	357	1.98	1.01	1,404	.604	38,400	352	15,200,000	422
	368	2.00	1.00	1,488	.555	38,842	359	14,100,000	399
	365	1.98	1.02	1,480	.750	38,800	282	14,500,000	560
	370	1.99	1.01	1,541	.655	41,100	380	14,000,000	500
	371	2.00	1.00	1,570	.470	42,300	392	17,900,000	370
	362	1.97	1.03	1,578	.750	40,800	287	11,700,000	592
	360	2.00	1.01	1,620	.720	42,800	401	14,900,000	583
	Av....	....	....	1,497	.556	40,042	349	14,780,000	480

TABLE XX.

SHRINKAGE PER FOOT.

No. Series.	½″ □.	1″ ⊏.	2″ × 1″	2″ □.	3″ □.	4″ ⊏.	Average Silicon.
1	.183	.160	.148	.131	.116	.102	0.80
2	.172	.150	.138	.125	.110	.106	1.21
3	.166	.145	.130	.109	.069	.039	1.88
4	.162	.143	.123	.099	.066	.128	2.01
5	.157	.105	.094	.075	.067	.057	3.19
6	.161	.130	.086	.077	.085	.033	3.04
7	.176	.149	.144	.139	.115	.072	0.98
8	.160	.145	.126	.122	.098	.092	1.17
9	.156	.141	.134	.128	.083	.036	1.67
10	.154	.124	.092	.094	.075	.067	2.23
11	.157	.102	.090	.062	.053	.028	2.71
12	.144	.098	.092	.068	.043	.023	3.50
14	.148	.098	.083	.072	.063	.035	2.82
13	.130	.095	.091	.079	.072	.052	3.18
15	.123	.094	.096	.091	.078	.032	3.50
16	.171	.151	.143	.129	.100	.069	1.76
17	.248	.247	.221	.201	.157	.144	0.89
18	.161	.139	.120	.091	.067	.042	2.06
19	.238	.153	.142	.144	.126	.115	0.77

TABLE XXI.

No. of Series.	No. Test Bar.	Test Bars, $\frac{9}{16}$ ○ × 12″ = .562″ Diameter.						
		Breadth.	Height.	Max. Fibre Distance.	Max. Load in Pounds.	Deflection in Inches.	Equiv. Load on Test Bar, size equal to .500″ □ × 12″	Stress per □″ on Outer Fibre.
1	1	.542	.555	.277	232	.135	230	39,900
	2	.563	.555	.277	235	.12	233	40,400
	3	.554	.549	.274	280	.13	277	48,200
	4	.556	.543	.271	340*	.12	337	58,400
2	5	.572	.563	.281	330	.26	327	56,700
	6	.583	.564	.282	330	.28	327	56,700
	7	.580	.567	.283	340	.28	337	58,400
	8	.580	.583	.291	345	.285	342	59,300
3	9	.561	.583	.291	345	.25	342	59,300
	10	.568	.578	.289	372	.28	368	63,900
	11	.568	.563	.281	378	.33	375	65,000
	12	.575	.576	.288	382	.29	378	65,700
4	13	.589	.578	.289	320	.27	317	55,000
	14	.577	.573	.286	330	.27	327	56,700
	15	.558	.569	.284	340	.30	337	58,400
	16	.573	.565	.282	355	.28	352	61,000
5	17	.560	.557	.278	330†	.26	327	56,700
6	18	.564	.551	.275	340	.265	337	58,400
	19	.568	.564	.282	368	.29	365	63,200
	20	.565	.570	285	370	.285	367	63,600
	21	.577	.578	.289	373	.325	370	64,100
7	22	.580	.567	.288	305	.20	302	52,400
	23	.566	.565	282	315	.20	312	54,200
	24	.577	.568	.289	345	.25	342	59,300
8	25	.571	.565	.282	325	.21	322	55,800
	26	.588	.576	.288	333	.24	330	57,200
	27	.570	.578	.289	338	.24	335	58,100
	28	.577	.580	.290	345	.26	342	59,300
9	29	.570	.570	.285	322‡	.20	319	55,300
	30	.573	.556	.278	325	.205	322	55,800
	31	.574	.557	.278	328	.21	325	56,400
	32	.570	.569	.284	350	.22	347	60,200
10	33	.565	.551	.275	378	.22	375	65,000
	34	.570	.560	.280	385	.25	382	66,200
	35	.558	.559	.279	406	.25	402	69,800
	36	.570	.563	.281	432	.285	427	74,100
11	37	.565	.560	.280	395§	.295	391	67,900
	38	.560	.559	.279	425	.32	421	73,100
12	39	.560	.546	.273	365	.27	362	62,700
	40	.575	.561	.280	390	.30	387	67,100
	41	.570	.560	.280	395	.29	391	67,800
	42	.559	.560	.280	420	.32	416	72,200

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* This is record of series 1. The other bars were defective at the centre and the results were not used. † The upper half of test bar was full of blow holes. ‡ All bars of this series have a small white line running the entire length of the bar. ⊙ at the centre. § There were some blow holes and shot iron in the upper quarter.

TABLE XXII.

No. of Series.	No. Test Bar.	Test Bars, $\frac{9}{16}''$ ○ × 12″ = .562″ Diameter.						
		Breadth.	Height.	Max. Fibre Distance.	Max. Load in Pounds.	Deflection in Inches.	Equiv. Load on a Test Bar, size equal .500″ □ × 12″	Stress per □″ in Outer Fibre.
14....	43	.568	.563	.281	348	.205	345	
	44	.563	.552	.276	350	.21	347	
	45	.568	.548	.274	350	.215	347	
	46	.559	.553	.276	350	.22	347	
13....	47	....	....	....	350	.20	347	
	48	....	....	....	350	.20	347	
	49	....	....	....	350	.21	347	
15....	50	.575	.561	.280	329	.215	326	
	51	.578	.565	.282	330	.215	327	
	52	.587	.572	.286	345	.21	342	
19....	53	.581	.569	.284	300	.085	297	
	54	.562	.572	.286	300	.09	297	
	55	.562	.568	.284	350	.11	347	
	56	.560	.584	.292	365	.105	362	
16....	57	.569	.562	.281	335	.24	332	
	58	.576	.504	.252	350	.25	347	
	59	.565	.550	.275	358	.255	355	
18....	60	.576	.583	.291	408	.195	404	
	61	.578	.568	.284	410	.21	406	
	62	.568	.582	.291	450	.23	446	
17 ...	63	.555	.448	.224	430	.125	426	
	64	.553	.556	.278	510	.145	505	

TABLE XXIII.

No. Series.	No. Test Bar.	Test Bar, $\frac{3}{16}$" ○ × 12".			
		Deflection.		Set.	
		At 300 lbs.	At 400 lbs.	At 300 lbs.	At 400 lbs.
1..........	4	.105	....	.015	....
2..........	6	.24	....	.06	....
3..........	11	.22	....	.045	....
4..........	14	.23	....	.05	....
5..........	17	.22	....	.045	....
6...	19	.21	....	.041	....
7..........	22	.20	....	.045	....
8..........	28	.205	...	.045	....
9	30	.18	....	.034	....
10...	33	.165	....	.019	....
	36	....	.26	....	.045
11..........	38	.185	.295	.031	.075
12........	39	.20	....	.039	...
	42	...	.30	....	.085
14........	44	.165	....	.019	....
	45	.17	....	.019	....
13..........	47	.165	....	.02	....
15..........	52	.175	....	.019	....
19........	53	.085	....	.0	....
	54	.09	....	.0	....
	56	.09	...	.0	....
16..........	59	.19	....	.03	....
18..........	62	.135	.195	.013	.03
17..........	64	.085	.11	.0	.0

TABLE XXIV.

Kind of Iron.	No. of Series.	No. Test Bar.	Size of Test Bar, 1⅛″ × 12″.									
			Breadth.	Height.	Max. Fibre Distance.	Moment of Inertia.	Max. Load in Lbs.	Deflection in Inches.	Stress per □″ in Outer Fibre.	Shearing Stress Lbs. per □″.	Modulus of Elasticity.	Resilience.
"Iroquois" (coke).	1	21	.....	1.12	.56	.077	1374	.069	30,000	701	12,700,000	47
		22	.....	1.14	.57	.083	1557.4	.063	32,500	763	11,800,000	49
	2	44	.....	1.14	.57	.083	1936	.153	40,000	950	11,533,000	189
		43	.....	1.14	.57	.083	2000	.1465	41,736	980	11,800,000	146
	3	65	.....	1.12	.56	.077	2100	.179	45,857	1071	12,300,000	....
		66	.....	1.12	.56	.077	2100	.149	45,851	1071	13,400,000	147
		87	.....	1.12	.56	.077	1800	.1445	39,301	927	11,200,000	130
		88	.....	1.14	.57	.083	1840	.1446	37,700	901	....	142
	5	109	.....	1.12	.56	.077	1620	.082	35,348.4	822.7	14,300,000	70.92
		110	.....	1.10	.55	.0719	2076	.174	47,658	1092	12,900,000	180
		132	.....	1.12	.56	.077	1750	.143	38,209	902	10,410,000	125
		131	.....	1.10	.55	.0719	1960.2	.143	45,000	1031	11,500,000	140
"Hinkle" (charcoal).		153	.....	1.14	.57	.083	1900	.136	39,649	931	11,800,000	129
		154	.....	1.12	.56	.077	1034	.158	42,230	997	11,300,000	152
	8	175	.....	1.12	.56	.077	2000	.146	43,668	1021	11,990,000	146
		176	.....	1.12	.56	077	2061	.151	45,000	1051	14,300,000	155
	9	197	.....	1.12	.56	.077	1700	.070	37,117	868	12,700,000	59
		198	.....	1.14	.57	.083	1862	.108	38,856	922	13,300,000	100
	10	220	.....	1.10	.55	.0719	2395.8	.125	55,000	1288	12,900,000	149
		219	.....	1.10	.55	.0719	2480	.139	56,932	1305	13,600,000	172
		240	.....	1.12	.56	.077	2380	.170	51,965	1226	11,300,000	202
		241	.....	1.12	.56	.077	2570	.170	56,113	1324	11,300,000	218
	12	264	.....	1.14	.57	.083	2000	.121	41,736	990	11,490,000	121
		263	.....	1.12	.56	.077	2120	.139	46,288	1062	12,900,000	147
Southern...	14	295	.....	1.12	.56	.077	2015	.107	43,848	1020	12,600,000	......
		296	.....	1.12	.56	.077	2175.5	.117	47,500	1109	13,400,000	127
	13	276	.....	1.14	.57	.083	2075	.1022	33,614	1016	8,510,000	106
		275	.....	1.12	.56	.077	2350	.125	51,310	1097	12,600,000	146
	15	308	.....	1.12	.56	.077	2225	.1226	49,200	1133	11,750,000	141.5
		307	.....	1.14	.57	.083	2250	.135	46,953	1113	10,300,000	151
Foundries..	19	384	1.131	1.135	.56	.077	3030	.086	62,200	......	....	......
		383	1.135	1.117	.56	.077	3210*	.089	68,700	......	....	......
	16	319	1.121	1.121	.56	.077	2290	.119	49,550	......	....	......
		320	1.120	1.120	.56	.077	2300	.122	49,500	......	....	......
	18	...	.....	.....	...	....	....	.....	....	......	....	......
		...	.....	.....	...	....	....	.....	....	......	....	......
Malleable...	17	332	1.110	1.115	.55	.072	2000	.037	44.450	.....	....	.....
		331	1.097	1.115	.55	.072	2300*	.065	52,000	.....	....	.....

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* No. 331 had a blow hole ¼″ diameter and 6″ long, and weighed 6 ounces less than 332, which was 8 lbs. 10 oz.

TABLE XXV.

Kind of Iron.	No. Test Bar.	SIZE ROUND TEST BAR, 1¼″ ○ × 12″.				
		Breadth.	Height.	Max. Load in Lbs.	Deflection in Inches.	Stress per □″ on Outer Fibre.
				CAST FLAT.		
Series 19. A. Whitney & Sons.	92	1.115	1.096	(2,750)*	(.079)	(62,150)
	91	1.125	1.096	2,980	.083	66,550
	384	1.131	1.135	3,080	.086	63,200
	383	1.135	1.117	3,210	.089	68,700
	89	1.128	1.120	3,360	.103	72,300
	90	1.139	1.133	3,380	.107	71,100
	Average …	………	………	3,192	.094	68,370
				CAST ON END.		
	98	1.080	1.123	(1,500)†	(.047)	(34,325)
	96	1.105	1.109	2,350‡	.058	53,100
	97	1.097	1.150	2,590	.069	56,750
	95	1.143	1.140	2,730*	.077	56,075
	Average …	………	………	2,557	.068	55,308
				CAST FLAT.		
Series 18. Bement, Miles & Co.	347	1.125	1.127	2,570	.087	55,000
	343	1.105	1.100	2,580	.091	59,000
	344	1.116	1.106	2,580	.084	57,650
	350	1.115	1.105	2,740	.106	61,200
	348	1.120	1.119	2,990	.121	65,000
	345	1.100	1.110	3,080	.116	70,000
	346	1.113	1.116	3,100	.110	68,500
	349	1.110	1.115	3,120	.116	69,400
	Average …	………	………	2,845	.104	63,219
				CAST ON END.		
	351	1.100	1.108	2,590	.091	58,200
	355	1.096	1.104	2,620	.104	60,200
	352	1.100	1.120	2,630	.110	58,800
	356	1.103	1.123	2,690	.102	59,800
	354	1.116	1.115	2,730	.095	60,100
	353	1.100	1.126	3,000	.121	67,400
	Average …	………	………	2,710	.104	60,750

( ) Nos. 92 and 98 thrown out before averaging ; 98 probably had a cold shut or flaw.

* Blow hole at fracture.

† Cracked from bottom upward and held.

‡ Large hole at fracture.

TABLE XXVI.

COMPARISON OF AVERAGES.

IRON.	No Series.	1″ □ x 12″.	Loads on 1″ □ x 24″ reduced to 1″ □ x 12″.	1¼′ O x 12″.	1¼″ O x 12″.	¼″ □ x 12″.	$\frac{5}{16}$″ O x 12″.
				Cast Flat.	On End.		
"Iroquois" (coke.)	1	2,590	2,025	1.465	.....	289	340
	2	2,140	2,046	1,968	.... .	339	336
	3	2,619	2,540	2.100	.....	389	369
	4	2,620	2,410	1,820	.....	427	336
	5	.....	2,464	1,848	.....	430	330
	6	2,214	.....	1,855	.....	471	363
"Hinkle" (charcoal.)	7	2,186	2.146	1,917	.....	338	322
	8	2,457	2,200	2,030	.....	395	335
	9	2,355	2,175	1,781	....	329	331
	10	2,185	2,085	2,438	.....	439	400
	11	2,290	2,345	2,475	.....	443	410
	12	2,106	2,640	2,060	.....	456	393
Southern.	14	2,591	2,400	'2,095	.....	378	350
	13	.....	2,345	2,212	.....	394	350
	15	.....	2,234	2,237	.....	427	335
Foundries.	19	.....	2,585	3,192	2,557	377	329
	16	.....	2,208	2,295	.....	378	348
	18	.....	2,800	2,845	2,710	446	423
Malleable.	17	....	2,848	2,150	.....	471	470

TABLE XXVII.

Kind of Iron.	No. of Series.	No. Test Bar.	TENSION TEST O BARS (.375).			
			Diameter.	Area.	Actual Load in Lbs.	Equivalent Load in Lbs. per ☐ in.
"Iroquois" (coke).	1 ..	..	....	....	.....	......
	..	4	.710	.396	7,930	20,000
	2 ..	8	.715	.402	7,680	19,100
	..	7	.690	.374	8,250	22,060
	3 ..	11	.710	.396	9,780	24.800
	..	12	.690	.374	9,460	25,300
	4 ..	16	.710	.396	8,630	21.800
	..	15	.700	.385	8,410	21.900
	5 ..	20	.700	.385	7,440	19,350
	..	19	.695	.379	9,740	25.500
	6 ..	24	.660	.342	8,750	25,500
	..	23	.695	.379	9,720	25,600
"Hinkle" (charcoal).	7 ..	28	.700	.385	7.000	18,200
	..	27	.690	.374	7,350	19,700
	8 ..	32	.735	.426	6.920	16,300
	..	31	.700	.385	7,350	19,100
	9 ..	..	....	....	.....	......
	..	..	....	....	.....	......
	10 ..	..	....	....	.....	......
	..	..	....	....	.....	......
	11 ..	..	....	....	.....	......
	..	..	....	....	.....	......
	12 ..	48	.710	.396	6.200	15.700
	..	47	.700	.385	7,570	19,700
Southern.	14 ..	56	.700	.385	2,200	5,700
	..	55	.680	.363	5,080	14.000
	13 ..	51	.690	.314	8,590	22,950
	..	52	.710	.396	9,550	24,100
	15 ..	..	....	....	.....	......
	..	59	.690	.374	9,100	24,400

TABLE XXVIII.

Kind of Iron.	No. of Series.	No. of Test Bar	Tension Tests O Bars (1.12).			
			Diameter.	Area.	Actual Load in Lbs.	Equivalent Load in Lbs. per □ in.
"Iroquois" (coke).	1	2	1.21	1.15	18,200	15,700
		2	....	....	......	.....
	2	5	1.18	1.09	23,700	21,700
		6	1.19	1.11	25,850	23,300
	3	10	1.19	1.11	21,900	19,800
		9	1 19	1 11	23,400	21,100
	4	13	1.19	1.11	20,900	18.900
		14	1.18	1.09	21,550	19,800
	5	18	1.20	1.13	20,300	18,000
		17	1.18	1.09	23,150	21,500
	6	21	1.19	1.11	18,300	16,600
		22	1.19	1.11	19.850	17.800
"Hinkle" (charcoal).	7	..	....	....	......	... ..
		26	1.15	1.04	18,410	17,700
	8	29	1.19	1.11	16,500	14,900
		30	1.19	1.11	17,600	15,800
	9	..	....	....	......	......
		33	1.20	1.13	16.700	14 800
	10	..	....	....	......	.. ..
		..	....	....	.....	......
	11	42	1.20	1.13	18,000	16,000
		41	1.21	1.15	15.700	18,000
	12	..	....	...	......	... ..
		46	1.20	1.18	19,800	17.500
Southern.	14	53	1.20	1.18	21,550	19.100
		54	1.21	1.15	20,400	23,500
	13	..	....	....	......	......
		49	1.21	1.15	23.600	20,500
	15	58	1.20	1.13	22.750	20,200
		57	1.20	1.13	28.900	20,400

TABLE XXIX.

AVERAGES OF TENSION TESTS ○ BARS.

No. of Series.	AREA, .375 □ IN.		AREA, 1.125 □ IN.	
	Actual Load in Lbs. .375 □ ″ Area.	Equivalent Load in Lbs. per □ ″ .375 Area.	Actual Load in Lbs. 1.12 □ ″ Area.	Equivalent Load in Lbs. per □ ″ 1.12 □″ Area.
1	7,930	20,000	18,200	15,700
2	7,965	20,580	24,775	22,500
3	9,620	25,050	22,650	20,450
4	8,520	21,850	22,225	19,350
5	8,590	22,425	21,725	19,750
6	9,235	25,550	19,075	17,200
7	7,175	18,950	18,410	17,700
8	7,135	17,700	17,050	15,350
9	.....	......	16,700	14,800
10	.....	.... .	......	......
11	.....	......	16,850	17,000
12	6,885	17,700	19,800	17,500
14	5,080	14,000	20,975	21,300
13	8,075	23,525	23,600	20,500
15	9,100	24,400	23,325	20,300

TABLE XXX.

No. Series.	No. Test Bar.	Bar 1.127′ Diameter Broke at	EXTENSION BETWEEN LOADS.			
			2,000	4,000	6,000	8,000
1	1	10,000	59	53	65	102
	2	11,000	49	48	61	91
2	3	11,600	45	39	55	69
	4	11,800	29	39	51	70
3	5	14,000	31	35	36	51
	6	14,500	43	39	36	54
4	7	10,000	39	40	31	102
6	11	9,900	39	41	52	72
7	14	11,000	32	31	45	68
10	19	11,700	43	41	50	70

All bars broke in fillet.

TABLE XXXI.

Eight bars 1.128, cut from a block 8″ thick, pulled on an Olsen machine. Lbs. per □ ″.	Analysis.
15,730	T.C, 2.84; Cd. C,2.24; G.C. .60; P, 0.335; Si, 1.10; S, .090; Mn. .49.
19,700	
19,850	
20,200	
24,600	
25,000	
25,400	
25,400	

TABLE XXXII.

How Cast.	No. Test Bar.	Test Bar 1.065″ Diameter Broke at	Extensions Between Loads.							Remarks. All bars 71 to 86 were poured from one ladle. All bars except 83, 86 and 103 had a large number of small blow holes in turned surface of test bar.
			2,000	4,000	6,000	8,000	10,000	12,000	14,000	
Flat	73	25,000	22	25	28	37	51	44	50	Small spongy spot.
	72	25,500	23	26	43	24	40	45	53	Small spongy spot.
Cast on End.	80	14,600	31	25	36	39	43	52	....	Bad spongy spot.
	82	16,300	29	32	32	34	44	54	....	Bad blow hole.
	79	17,400	24	26	32	38	56	44	57	Blow hole half through.
	77	20,200	28	28	30	36	42	53	75	Small blow hole.
	85	21,300	24	23	17	25	....	....	....	Small shot in fracture.
	76	22,400	30	21	38	35	48	45	53	Solid.
	75	22,500	29	26	24	43	42	44	55	Slight spongy spot.
	86	23,100	23	23	29	36	45	42	....	Solid (no holes in surface).
	78	23,400	24	27	29	36	44	47	51	Slight spongy spot.
	84	23,500	28	24	31	36	46	40	49	Solid.
	83	24,000	29	22	40	39	42	43	50	Solid (no holes in surface).
End	104	26,200	19	25	11	22	26	32	26	**Large bl. h. in fracture.**
	103	30,000	21	20	22	23	29	25	31	**Solid (no bl. hs. in surface).**
Flat	71	....	24	20	29	31	29	27	33	**Compression. Solid.**
End	81	....	24	23	28	31	28	34	33	Compression. Solid.

DCXCVI.*

TOPICAL DISCUSSIONS AND NOTES OF EXPERIENCE.

No. 696—129.

Clamp-fits.

Mr. William Sangster.—It was desired to use a clamping device to secure the follower of a small hydraulic press, and in looking up the authorities the coefficient of friction for dry cast-iron surfaces was given as 15 per cent. This called for such a heavy arrangement that the figure was questioned, and it was thought worth while to test it.

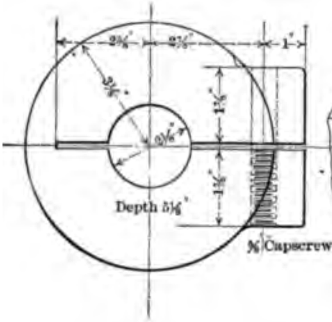

FIG. 148.

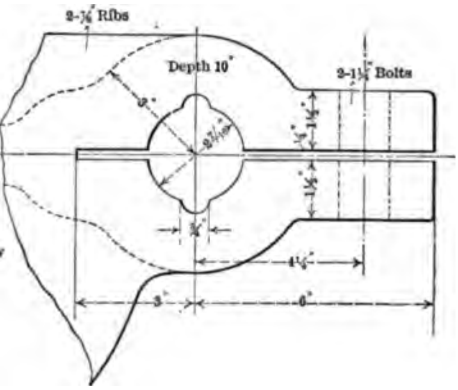

FIG. 149.

A split boss was found, shown in Fig. 148, into which a cast-iron plug was fitted, the hole being reamed and the plug finished in the lathe by float file and emery cloth to a snug sliding fit. The plug was more or less greasy from handling, and for that reason under ordinary shop conditions. A 30-ton hydraulic jack furnished the pressure, which was measured by an ordinary platform scale. The lengths of lever arms were 31 inches on the scale side and 8 inches on that of the jack. Three trials were

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* Presented at the St. Louis meeting (May, 1896) of the American Society of Mechanical Engineers, and forming part of Volume XVII. of the *Transactions*.

made, and after deducting the weight of levers, etc., the average pressure upon the scales was 1,300 pounds. This, multiplied by the ratios of arms, will give

$$\frac{31}{8} \times 1{,}300 = 5{,}038 \text{ pounds},$$

as the pressure exerted upon the plug before it slipped. The pull on the 12-inch wrench used in tightening the ⅝-inch clamping screw could not have exceeded 100 pounds. Assuming the friction of screw as 50 per cent., which is probably taken low, we have, as the pressure exerted by the screw,

$$100 \times 12 \times 2 \times \pi \times 11 \times .50 = 4{,}147 \text{ pounds}.$$

In the figure it will be seen that the distance from centre of screw to centre of fit is 2⅞ inches, and from centre of fit to bottom of cut 2⅜ inches. Calling the bottom of the cut the fulcrum, we have

$$\frac{2\frac{3}{8} + 2\frac{7}{8}}{2\frac{3}{8}} \times 4{,}147 = 9{,}167 \text{ pounds}.$$

This would give as the coefficient of friction,

$$\frac{5{,}038}{9{,}167} = 55 \text{ per cent.}$$

The method of testing and results given are crude, but yet they were sufficiently accurate to use in designing the press. The follower of this press slides upon and is clamped to two rods by the device shown in Fig. 148, and has successfully withstood a pressure of forty tons without slipping. It might be well to say here that when the press is working up to its full capacity a four-foot wrench is used upon the bolts.

The writer's excuse for presenting such approximate data lies in the fact that he could find nothing upon the subject, and hoped, by presenting these results, crude though they be, to get opinions and bits of experience from others which would prove of value. He therefore presents this query:

Has any member of the Society had experience as to the holding power of clamp-fits?

No. 696—130.

Power to drive disk fans.

Mr. William Sangster.—In "Centrifugal Ventilating Machinery," by Daniel Murgue, and translated by A. L. Steavenson, we have the efficiency of this class of fans given at from 20 to 30 per cent. From some data on disk wheels, which also agree with these values, the writer has worked up a formula which will probably be accurate enough for most purposes.

Attention is called to the low efficiency of these fans when exhausting from, or blowing into, closed spaces with no opening for the passage of air other than the wheel itself. This is due to the pressure of air varying as the square of the velocity, and therefore as the square of the distance of the blades from the centre of rotation. A disk fan blowing into a closed space with no other opening will cause a much greater pressure at the outer portion of the wheel, which is neutralized to a certain extent by the counter current of air near the centre, where the pressure is less. The horse-power required to drive a disk fan, instead of varying directly as the size of openings into a room, will vary as the resultant of the areas of the opening, and part of the area of the wheel itself. That is, the curve of horse-powers, instead of lowering rapidly with the decreased area of opening, as at *ab* (Fig. 150), would tend to remain more nearly a constant, as at *ac*.

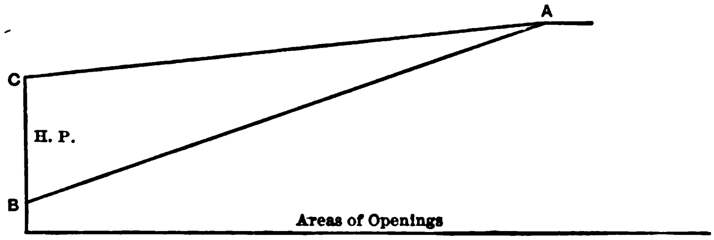

FIG. 150.

Since, as shown above, the central portion of a disk fan is of little use, we will assume that this central portion, up to one-third of the outside diameter of a fan, does not discharge any air. This theory is confirmed by Murgue, who states that the efficiency of the fan is increased by enlarging the relative diameter of the central plate, and it also receives practical consideration by the makers who put a central disk into their fans.

The work in moving air may be represented as

$$Pva,$$

in which P is the pressure and v the velocity of the air, and a is the area of discharge.

Since the air is moved in the direction of the axis of rotation by means of blades having an angular position relative to the direction of rotation, we theoretically should have the velocity of the air, relative to the velocity of the blades, varying as the tangent of the angle which the latter make with the direction of rotation. In practice 80 per cent. of this amount is much nearer the actual velocity. The angles of the blades are generally between 30 degrees and 45 degrees, making the tangents between 0.577 and 1. For convenience we may take the average as 0.75. Then the average velocity, in terms of the diameter of the wheel, and number of revolutions with a central plate equal to one-third of the outer diameter, is

$$v = \left(\frac{D^2 + \left(\frac{D}{3}\right)^2}{2}\right)^{\frac{1}{2}} \times \pi \times 0.75 \times 0.80 \times N = 1.405\,DN \quad . \; . \; . \; (1)$$

where D = diameter of the wheel in feet,
N = number of revolutions per minute.

Calling the velocity of air, at a pressure of one pound per square foot above the atmosphere at 70 degrees Fahr., 1,758 feet per minute, we have, as the pressure due to any velocity v,

$$P = \left(\frac{v}{1{,}758}\right)^2.$$

Substituting the value of v as found in equation 1, we have

$$P = \left(\frac{1.405\ DN}{1{,}758}\right)^2 \quad . \; . \; . \; . \; . \; . \; . \; . \; (2)$$

The area of discharge a, in terms of the diameter of the wheel in feet, allowing 0.65 as the coefficient of *vena contracta*, would be

$$a = 0.65\,\frac{\pi}{4}\left(D^2 - \left(\frac{D}{3}\right)^2\right) = 0.4538D^2 \quad . \; . \; . \; (3)$$

Combining these different equations, and allowing an efficiency of 20 per cent., we have, as the horse-power required by a disk fan at 70 degrees Fahr.,

$$HP = \frac{\left(\frac{1.405\ DN}{1758}\right)^2 \times 1.405DN \times 0.4538D^2}{33{,}000 \times 0.20}$$

Reducing, we have

$$HP = .000000000062\ D^5N^3 \quad . \quad . \quad . \quad . \quad . \quad (4)$$

This rule will usually be accurate enough for temperatures between 50 degrees Fahr. and 90 degrees Fahr. For a correction due to a change of temperature we may multiply equation (4) by $\frac{531}{T}$, in which T is the absolute temperature of the air handled.

The theoretical deductions in the above are believed to be correct. The constants of the angle of the fan blades, actual velocity, *vena contracta*, and efficiency are taken within the limits of present practice, but for any particular case they may be varied according to the judgment of the engineer. The writer therefore propounds the following query:

"Has any member data to give concerning the horse-power necessary to drive disk fans for exhausting or ventilating?"

Mr. William Kent.—There was a paper presented to the Society some years ago by Henry I. Snell, giving data on this subject, and there is also discussion by Past President Babcock on the same subject. There is quite a good deal of information and discussion of this subject in the *Transactions*.

Prof. J. H. Kinealy.—A year or two ago some very elaborate experiments on disk fans were made in Germany by Prof. Georg Wellner, of Brunn, Austria, to determine the efficiency of air propellers. The results were published in the *Transactions* of the Austrian Society of Engineers and Architects. An abstract of the paper was published in the *American Engineer and Railroad Journal*, May, 1895. It appears that the power depends on the shape of the blade, as well as the angle of inclination, and the distance of the centre of area of the blade from the centre of the fan; and, if I remember rightly, there was very little difference in the power required to drive the fan or in the pressure exerted by the fan, whether you had two blades or three or four or six. The experiments were very carefully made.

No. 696—131.

Effect of fire on machinery.

Mr. W. F. M. Goss.—Not long ago I had occasion to examine a considerable amount of machinery which had passed through fire, some of which was quite heavy.

The building containing the machinery was of brick, with a heavy mill floor, and a ceiled wooden roof with monitor. The heat developed was probably of average intensity for such a building, the fire burning until all of the woodwork had been consumed. But little water was used, and the machinery did not suffer from this cause. Damage to the machinery appeared to have arisen from three causes; namely, the falling of the machinery, the falling of the roof timbers and walls upon the machinery, and the action of the heat itself.

Machines which were on good foundation did not suffer from the first-named cause; but when there was no foundation, even heavy tools were either broken by the fall or distorted by the combined action of the heat and of strains resulting from imperfect support after the fall. The results justify the conclusion that in case of fire an indestructible foundation is an excellent life-preserver for a machine.

Falling *débris* carried away all lighter attachments such as lubricators, gauges, small piping, light shafts, rods, levers, hand-wheels, projecting brackets—everything, in fact, which offered an abutting surface to the falling masses and which was not strong enough to withstand their impact. There were a few cases where heavier parts also suffered from this cause. Of two six-inch shafts extending seven feet between bearings, one carrying an eight-foot fly-wheel was perfectly straight; the other, having no wheel, was sprung, evidently as the result of a blow.

To heat alone is, of course, to be attributed the destruction of woodwork about the machines, and the loss of babbitt from brasses and boxes. From this cause, also, bolts which served to connect different parts of heavy frames were often found loose. Steam-joints of every kind required refitting. Brass bushings which originally had been forced into turned holes to form bearings for shafts or pins were all loose in the castings and tight on the shaft. Castings having very large flat surfaces, either plain or ribbed, were in several cases found to contain fire cracks, but with a few exceptions heavy castings of good design were not injured by heat alone.

What experience have other members had as to the injury done to machinery when the building has burned in which it stood?

Mr. H. H. Suplee.—I have had no very extensive experience in this line, but I remember one case in which a large wrought-iron jib crane was returned to the factory to be rebuilt after having been through a fire. The owners thought that it would not cost as much as a new one, because it looked pretty fair. It was discolored and looked as if it had been through a good deal of heat, but yet it was intact, and it did not look very much the worse for the circumstance. But at the time it was ready to be sent back again it was found it had cost just about as much as a new crane would. The wrought-iron work was all warped, and had to be taken apart and straightened and put together again in order that the fitted parts could have neat action. The actual labor in making it a good working machine again played such a large figure in the work that the material was scarcely worth considering. This was mostly wrought-iron work with some cast-iron connections and cast-iron gearing. I believe only one gear wheel was broken by receiving a blow. But it did not pay.

Mr. Warner.—I presume this question comes up often, and I hope most often, to members of this Society who are called upon to adjust losses of others rather than those in their own individual experience. I have several times been called upon to adjust such losses, and in a few instances have undertaken to put in good condition machines which have been through a fire. My observations have taught me that if a machine has been through a fire which has been severe enough to melt the babbitt, I should call it of no value, and do my best to secure for the owner the full value of the machine rather than call it a partial loss. It is a nuisance to undertake to put in good order a machine which has passed through a fire, for after it has been repaired, even though it may look as good as new, it never can be true, it never can be of the value which it possessed before the fire, and I believe it is our duty in such calls as are liable to be made upon us, to be very careful in placing the value and not get it too high, for whoever buys a machine which has been through a fire will be very liable to be deceived.

No. 696—132.

How to locate a steam-engine condenser.

Mr. John H. Cooper.—The Newcomen engine which had the condenser *very close* to the cylinder—that, is within it—has been proven to be a very bad type of condensing engine ; on the other hand, a modern, first-class, high-speed engine which had an exhaust pipe to the condenser 50 per cent. longer than the engine bed, showed, on test, next to no vacuum in the cylinder when it was good enough in the condenser ; this proved to be a very bad type of condensing engine also, although the engine itself, as a non-condensing one, was quite perfect.

These two cases present the extremes of practice.

Two important conditions present themselves forcibly in this inquiry. The condenser must be far enough away from the steam cylinder to avoid cooling the latter, and it must be near enough to permit the free flow of steam away from the cylinder.

For slow-speed engines, it is a good plan to have a long pipe between cylinder and condenser because in this case there is time for the escape of steam while the cooling effect is least, but for high-speed engines the difficulty is to get the steam away into vacuum fast enough ; the exhaust ways become crowded with and heated by steam.

What is the opinion of the members as to the relative advantages of long or short pipe connections between cylinder and condenser of a steam engine ?

Mr. George I. Rockwood.—I doubt if mere length of exhaust pipe can produce a measurable difference between the degree of vacuum obtained in the condenser and that realized in the exhaust pipe where it attaches to the cylinder. It appears as if the case mentioned by Mr. Cooper must be explained differently, as I have had condensers located in another part of the building from the engine room, which give almost exactly the same indication on the vacuum gauge at the condenser and on the indicator diagram. In other words, while a large volume contained in the exhaust pipe and condenser may reduce the vacuum if the air pump is not large enough to cope with it, yet, if the exhaust pipe is large enough in diameter, I should think it impossible to maintain a greater vacuum in one part of the pipe than is in any other part of it.

DCXCVII.

MEMORIAL NOTICES OF MEMBERS DECEASED DURING THE YEAR.

JAMES G. DAGRON.

Mr. Dagron graduated in 1881 as Mechanical Engineer from the École Centrale des Arts et Manufactures of Paris. He served his school as tutor and preparator of the chemical lectures and in charge of the first-year laboratory for one year. Returning to America in 1883–84 he entered the engineering office of G. Bouscaren, at that time acting as Consulting Engineer of the Cincinnati Southern Railway. He was selected by Mr. Bouscaren to represent him as inspector of the bridges in process of erection at Pittsburg, in which relation he had the title of Asst. Engineer C. N. O. & T. P. R. R. He resigned in 1885 to become Inspector of Bridges for the Baltimore & Ohio R. R., and later rose to be Bridge Engineer. For a short interval he was Superintendent at Pencoyd, Pa. After leaving railway service he remained in Baltimore as Assistant City Engineer. He served the A. S. C. E. as secretary of its committee to report upon uniform systems of physical tests of materials. He was but thirty-four years old at the time of his death, May 25, 1895, and had become a member at the spring meeting of 1885.

WILLIAM C. MACKINNEY.

Mr. Mackinney was born September 27, 1848, in Brooklyn, N. Y. After leaving the public school, he entered the machine shop of the firm of Neafie & Levy, of Philadelphia; and after passing through into the drawing room, his ability in the line of marine engineering attracted the interest of Mr. J. S. Wilson, the superintendent of the works. He remained with them, advancing rapidly, until 1875, when he became head draughtsman and later superintendent for Baird & Houston, a new firm in the line of shipbuilding on the Delaware River. The depression in shipbuilding following those years compelled him to abandon the line of his choice, so that he became, first, a draughtsman for the I. P. Morris Co., and later for the H. W. Butterworth & Sons Co., with whom he remained until the time of his death. Their specialty of textile machinery was a new one to him, but he quickly mastered its minute details, and many of the ingenious devices upon the machines of this company are his invention. His friends speak of him as a man of much perseverance and energy, practical and thorough, and that as leader and associate he commanded both respect and love. He joined the Society in 1883, and passed away June 3, 1895, after a lingering illness caused by Bright's disease.

GEORGE DAVIDSON.

Mr. Davidson was of English birth, and began his practical training as apprentice and draughtsman with Greenwood & Batley of Leeds, England, in 1882. After serving for three years he came to America, and served with various firms as draughtsman from 1885 to 1887. From 1889 to 1891, at which time he joined the Society, he had been draughtsman and engineer for the Consolidated Refrigerating Company of New York, during which time he had been the designer and superintendent of the construction of large refrigerating and ice-making plants in several of the principal cities. Until 1893 he was manager of the Washington Cold Storage Company of New York City. He died July 11, 1895.

EZRA J. WHITAKER.

Mr. Whitaker was born April 12, 1839, at North Adams, Mass. It was intended that he should become a lawyer after leaving college, and was fitted by preparatory training at Williston Academy for his college course. He passed the necessary examinations for entry into the navy in 1860, and his first sea experience was in the *Minnesota*. He was a participant in the historic struggle between the *Merrimac* and *Monitor*, and was also in engagements with his ship at Hatteras Inlet, Fort Fisher, Mobile, James River, etc. After the close of the war he had various assignments in the North and South Atlantic, South Pacific, and Asiatic stations. His last sea service was on the cruiser *Philadelphia*, where the exactions and burdens of his position compelled him to be relieved, May 8, 1895, from disability arising in the line of duty. He returned to his home at Sacketts Harbor, N. Y., but never recovered, and passed away August 20, 1895, from valvular lesion of the heart. He was buried at his old home in North Adams.

Mr. Whitaker was zealous in the discharge of his professional work. Though reserved by nature, he was an amiable companion and of unquestioned personal integrity.

HERMAN WINTER.

Mr. Winter was born in Prussia, 1829, but came as a mere child to New York City. On leaving school he entered the Morgan Iron Works of that city, which had been established in 1836 by Mr. Charles Morgan, the owner at that time of a considerable sailing fleet, who operated the first steamship between New York and Charleston, and who subsequently founded the Morgan Line of Steamships. Mr. Winter was one of his trusted advisers, and was strongly influential in urging the change from side wheel to propeller for the coast trade in the Gulf of Mexico. When but twenty-two years of age, Mr. Winter was sent by his employer to the River Danube to install some engines built for that service, and he remained as superintendent of the Danube Navigation Company for several years. Returning to America a few years before the war of 1861, he was busily engaged in his specialty of marine architecture, and felt the immense stimulus which came to such concerns upon the demand for cruisers and transports during the years of that war. He was instrumental in directing the equipment of several shipbuilding yards created in response to the emergency of the times. Besides the American designs by Mr. Winter for the Norfolk and Richmond Line, now the Old Dominion, and the freight vessels for the Metropolitan Steamship Company, operating the outside route to Boston, one of the early Italian iron-clads was from his design, and the first twin-screw vessel launched in the United States was his Aransas, planned for shoal-water work in the Gulf of Mexico. The steamboats of Boston and Gloucester Line and many other smaller craft were Mr. Winter's work, and he served several important companies as chief or consulting engineer. He was one of the board appointed in 1885 to report upon the *Dolphin* and other United States Navy contracts. He was also inspector for Lloyds in New York City. He took out several patents, such as a rotary cut-off for beam engines, and a form of wharf drop for steamship gang planks, but had also presented to the public a great many of his designs in very general use without patent protection. He had been compelled by ill health to withdraw from active competitive business, and passed away September 4, 1895. He became a member of the Society in 1886.

WILLIAM A. PIKE.

Mr. William Abbot Pike was born July 3, 1851, in Dorchester, Mass. He graduated in 1871 from the Massachusetts Institute of Technology, and on graduation went into the engineering office of J. B. Henck for a short time, but was called that autumn to become Professor of Civil Engineering in the Maine State College. He was instrumental in starting shop training as a feature of his work in building up his department. In 1880 he was called to a larger field to become Dean of the College of Mechanic Arts of the University of Minnesota, with the title of Professor of Engineering. He served here for twelve years, and resigned in 1892 to enter consulting practice, although serving as lecturer in the University for one year. At the time of his death he was consulting engineer for important commissions in his city. He died October 13, 1895, from pneumonia. Among his best known professional engagements were the design of the coal docks for the Northern Pacific R. R. at Superior, Wis., and the water-works system at St. Cloud, Minn. He became connected with the Society at its meeting in 1890.

PHILIP R. VOORHEES.

Philip Randall Voorhees was born in Annapolis, Md., in 1835, and came from patriotic Revolutionary stock on both sides of his family. His father was Commodore Philip F. Voorhees, a native of New Jersey, who entered the navy in 1809, and died in 1862. He was a distinguished officer, and received a medal from Congress for gallant service in the war of 1812, under Decatur and Warrington, in the capture of the frigate *Macedonian* and sloop-of-war *Epervier*. Commodore Voorhees commanded some of the finest ships in the American navy, his last command being the East India squadron. His mother was Anne Randall, daughter of John and Deborah Randall, of Annapolis. His grandfather Randall was born in Virginia, served in the Revolution, and was afterward made Collector of the Port of Annapolis—at that time of greater importance than the Port of Baltimore. His daughter Anne—afterward Mrs. Voorhees—was a woman of remarkable grace and beauty, and their home was most attractive and hospitable. Commodore Voorhees had two children, the son Philip, and a daughter, afterward Mrs. Hollins McKim, of Baltimore. Mr. Voorhees was graduated from St. John's College, at Annapolis, in 1855. receiving the degree of A.B. and subsequently the degree of Master of Arts. Among the names of many distinguished alumni, St. John's numbers that of Francis Scott Key, the author of the "Star Spangled Banner."

Mr. Voorhees first studied law, but his inherited love for the sea and his mechanical taste led him, after devoting some time to law, to take up a practical course in mechanical engineering at the Vulcan Iron Works, in Baltimore, and in February, 1861, entered the navy as an engineer officer. During the late war of 1861–65, he was present at the battles of Hatteras Inlet, Port Royal, and in the two bombardments of Fort Fisher. He was also in the engagement at Cape Fear River, preceding the fall of Wilmington, and in one of the ships of the James River fleet at the fall of Richmond. While in the South Atlantic squadron at Port Royal, he acted as chief engineer of the *Wabash*, and received special mention and high praise for the skill and efficiency displayed in keeping the vessel in active service (when greatly needed) long after she had been condemned by the Board of Survey as unfit for further service. After a cruise in the South Pacific seas, he was detailed for duty as Instructor in the Naval Academy, from which station he resigned to resume his law studies. He was intrusted with a prominent position in the Centennial Exposition at Philadelphia, which he filled with great credit and entire satisfaction to the directors. After some service in the Examining Department of the United States Patent Office, he began the practice of law, devoting his attention particularly to the patent branch of the profession, settling in New York for the purpose.

Mr. Voorhees joined the American Society of Mechanical Engineers in 1889, and was also a member of the Engineers' Club, of the University and Lawyers' Clubs, New York Geographical Society, the New York Genealogical and Biographical Society, the American Society of Naval Engineers, and the Society of Naval Architects and Marine Engineers.

In character, Mr. Voorhees was a high-toned Christian gentleman, genial and affable; a man of fine education and mind, singularly modest and sincere, most loyal to his friends, and with a warm, generous nature which greatly endeared him to all who knew him. He died at Lakewood, New Jersey, December 12, 1895.

RUSSELL W. HILDRETH.

Mr. Hildreth was born in New York City. He graduated from the School of Engineering of Columbia University in 1885, and served for five years as assistant to Mr. George S. Morison, representing him in work upon the Omaha, Nebraska City, Sioux City, Willamette at Portland, the Cairo and other bridges, and in much subordinate achievement. The firm of R. W. Hildreth & Co. was formed in 1890 for the inspection of structural material, and much of interesting and important work was committed to the firm in this capacity, and as consulting engineer a considerable number of bridges in different parts of the country were designed and some structural work in the way of office buildings. Mr. Hildreth was just entering with some success the field of expert contracting as an additional department, when his career was cut short by his untimely death from pneumonia, December 23, 1895.

DAVID KINNEAR CLARK.

With the death, January 22, 1896, of Mr. D. K. Clark, at the age of seventy-four years, there has been removed another of the noted names which have made eminent the profession of mechanical engineering in the preceding generation, and whose work has been of very great repute and standing, particularly in the field of compilation.

Mr. Clark served his apprenticeship at the Phœnix Iron Works of Glasgow, and afterward became the mechanical engineering draughtsman in the civil engineering office of Mr. John Miller at Edinburgh. He devoted here his literary energies to the *Practical Mechanic and Engineer's Magazine*, acting as its assistant editor for two years. He was then engineer in chief of the Deep Sea Fisheries Association in London, but returned in 1853 to Scotland to become the locomotive superintendent of the Great North of Scotland Railroad, with headquarters at Inverness. During the six years from 1849–55 Mr. Clark had been at work by investigation and study upon his first great work, entitled *Railway*

Machinery: A Treatise on the Mechanical Engineering of Railways, Embracing the Principles and Construction of Rolling and Fixed Plant. It was dedicated to Robert Stevenson and was published in Glasgow in 1855. It was at once recognized as a classic and is still a standard, in spite, of course, of the many developments which each succeeding year has brought to the subject of which it treats. When Zera Colburn came to London from the United States the two men began immediate collaboration, and in 1860 the supplementary volume, entitled *Recent Practice in Locomotive Engines,* was issued. Mr. Clark became a recognized authority in railway and mechanical matters, and was about this time employed in valuing the rolling stock of the Irish railways and in similar work in Egypt. He also made a preliminary survey for ship railway at the first cataract of the Nile. He was entrusted with the machinery department of the great exhibition of 1862, and about 1864 he issued his first edition of that which in its later forms has become so well known to American engineers, his *Manual of Rules, Tables and Data for Mechanical Engineers.*

His relation to steam engineering early made him an authority on combustion and smoke prevention, and but shortly after the experiments of Dr. C. E. Emery in America, he produced his first observations and conclusions upon condensation in the engine cylinder. A smoke prevention device of his dates from 1857; he applied his system to the locomotives of several companies; he wrote a book, *Fuel: Its Combustion and Economy* (1879), and served as testing engineer for one of the smoke abatement committees. In this relation a most elaborate series of tests of fuels was made under his direction and are embodied in one of the British Blue Books of 1882. His two best known recent works were his *Tramways: Their Construction and Working* (1894) and his *Steam Engine* (1893). In this latter has been brought together an immense quantity of information for the steam-engine engineer concerning combustion, chimneys, boiler design, the working of steam and the mechanism of typical engines.

Mr. Clark had the distinction of being one of the first engineers elected to honorary membership in the American Society of Mechanical Engineers, an honor conferred upon him by action of the Society in November, 1882. He never contributed to its *Transactions,* but was a generous and valued author in the British societies.

NAT W. PRATT.

Mr. Nat W. Pratt was born in Baltimore, Md., January 31, 1852. His father, William Pratt, and his mother, Anne Elizabeth Eddy, were both descended from the Pilgrim stock which settled in Plymouth County, Mass., in 1630, and both survive their son. In 1860 they removed to Providence, R. I., where they remained until they removed to New York in 1864. When they left New York in 1871 for Middleboro, Mass., their present home, the son remained behind and became a member of the household of Mr. Stephen Wilcox, with whom he lived in Brooklyn until 1880, when he married Miss Carrie Virginia Deudney, of Kingston, N. Y., and established his own home. He continued to reside in Brooklyn until his death.

His early education was obtained from private schools in Baltimore, public schools in Providence and a private school of technology. Much of his training in mechanics and drawing he received from his father, from whom also he inherited a strong inventive faculty, which found full scope in his chosen career. During the civil war his father was superintendent of the Burnside Armory works at Providence, which were then engaged in making breech-loading guns for the government. Young Nat was about the works a good deal, and even at twelve years of age made creditable models for firearms.

During the past twenty-five years Mr. Pratt was engaged in the business of manufacturing steam boilers. From 1871 to 1881 he was connected with the firm of Babcock & Wilcox, composed of George H. Babcock and Stephen Wilcox, both of whom came from Westerly, R. I. When the firm was changed into a corporation in 1881, Mr. Pratt became its treasurer and manager, retaining the position until, at the death of Mr. Babcock, in 1893, he was elected president of the company. His best monument is the merited success and fame of the business enterprise to which he gave his time, his talents and his ceaseless energy. He combined engineering skill and inventive genius with extraordinary business capacity. In the particular department of steam, it is doubtful whether any man living had a better practical knowledge than Mr. Pratt, and his theoretical knowledge of the subject enabled him to devise many improvements on mechanical appliances. In 1884 he became consulting engineer to the Dynamite Gun Company. Under his designs and patents the first successful dynamite gun was built. It was with this gun, eight inch calibre and sixty feet long, that the experiments in throwing aerial torpedoes were conducted at Fort Lafayette, New York.

It is not often that the faculty for invention is united with an aptitude for business, but Mr. Pratt was known throughout the business world for sagacity and sound judgment. As the business of the Babcock & Wilcox Company grew in magnitude, he was equal to the increased demand. He had the rare good fortune to possess a quick and comprehensive mind, with a fondness for details, and the industry and energy to work things out to their end. He not only knew the advantages of system, but he loved to practise it. It may be truly said that he had a place for everything and everything in its place, and, what is more, he never forgot the place.

In business dealings Mr. Pratt was prompt, aggressive and persistent. He scorned meanness. Even his business opponents admired his sagacity and energy, and recognized his fairness.

Mr. Pratt was not given to clubs or general society. He was elected a member of the American Society of Mechanical Engineers early in its history, and belonged also to the American Institute of Mining Engineers, the American Naval Institute, and the Engineers' Club of New York City. When he could be prevailed on to visit friends he was always a welcome guest. He was the best of entertainers. He was preëminently attached to his own home and family, and was always devising ways of making his home more beautiful. He dearly loved children, and his affection for them was always reciprocated. He was passionately fond of rare flowers, and cultivated many in his fine conservatory, where he spent many happy hours.

Mr. Pratt died in Brooklyn, N. Y., March 10, 1896, at the age of forty-four.

FRANK CAWLEY.

Mr. Cawley was born near Woodstown, N. J., October 3, 1868. As a mere lad on the farm he showed a great fondness for machinery and was entrusted at ten years of age with the care of an agricultural engine. He graduated from Swarthmore College in 1888, and was instructor of manual training for two years, after which time he received his professional degree. From 1890 to 1892 he was mechanical engineer of the St. Bernard Coal Company at Earlington, and then was selected for a position in the

Ingersoll Rock Drill Company at their branch office in Montreal, Canada. Failing health compelled him to forgego certain assignments as draughtsman, and culminated in an enforced withdrawal from professional work in 1894, although he fought bravely for a year against the inroads of disease. He finally returned to his home in the United States in October, 1895, and passed away April 6, 1896. He became a member of the Society in 1892.

ALFRED HENRY SMITH.

Mr. Smith was born in June, 1867, and graduated from the University of Pennsylvania in 1887. His studies at the University were particularly directed to steam engineering and marine architecture, and to perfect himself in his chosen specialty he entered the shop and yard of James and George Thompson, of Clydebank, Scotland, 1888–90. He served also as cadet engineer on the steamships *Indiana. Ohio, Spartan, City of New York.* His first engagement in 1890 as draughtsman with The Pusey and Jones Company was with the understanding that he was to follow his chosen line, but circumstances directed him into the paper machine department, in which he became thoroughly competent. He was commissioned as representative of the firm to Scandinavia recently with marked success. His vigor of body, however, was not equal to the brilliancy of his mental attainments, so that by the advice of physicians he went to the South; but the experiment was not a success, and he died in Texas, April 24, 1896. He joined the Society in 1892.

DCXCVIII.

APPENDIX TO VOLUME XVII.

PROCEEDINGS OF THE FIFTH INTERNATIONAL CONFERENCE FOR THE UNIFICATION OF METHODS OF TESTING BUILDING AND STRUCTURAL MATERIALS, HELD AT ZURICH, SEPTEMBER 9, 10, AND 11, 1895.*

MINUTES OF THE FIRST DAY.

ON Monday, September 9th, Prof. L. von Tetmajer called the Fifth International Congress for the Unification of Methods of Testing Building and Structural Materials to order, and thereupon welcomed the participants, thanking the Fourth Standing Committee and the various chairmen of sub-committees, and also the Federal Government, the President of the Swiss School Board, the City Council of Zurich, the management of the Northeastern Railway of Switzerland, the editor of the *Swiss Building News*, and the engineers of Zurich for their assistance. He also announced that this Conference was entirely public and entirely unfettered, with the object of mutual exchange of opinions and experience; that the resolutions were not of a binding character, and only serve to express what the majority of those present consider to be the truth. After a few business notices the speaker referred to the order of business and to the fact that at the Zurich Conference a first attempt was made to define, in a series of comprehensive addresses, the present state of the art of testing various special classes of materials. He also pointed out that a number of the twenty problems remitted to the Fourth Standing Committee had remained unsolved, because the legacy left by the late Professor Bauschinger consisted mainly of difficult problems.

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* This Appendix has been prepared by Mr. Gus. C. Henning, Secretary and Reporter of the Committee of the American Society of Mechanical Engineers upon Standard Methods of Test and Testing Materials. Mr. Henning was commissioned to attend this conference as accredited delegate of the Society, and reported informally the results at the New York meeting of the Society in 1895. Persons interested in the previous work of these conferences and the Society's relation to them will find earlier appendices numbered as papers Nos. 378, 479, 480, 550, 551 of the *Transactions* of the Society.—*Secretary.*

The speaker called attention to the multilingual character of the proceedings, and stated that all announcements, propositions, etc., through the praiseworthy assistance of various professors and engineers, members of a special interpretation committee, would be translated from one language into the other.

Prof. L. von Tetmajer thereupon called attention to the printed papers added to the archives of the Conference, and made special reference to the four volumes issued by the French National Commission, edited by Professor Debray, and published by E. Rothschild in Paris, relating to unification of methods of testing, and requested examination of the same.

After reading obituary notices of members deceased since the Vienna Conference, and making several announcements, the floor was given to the representative of the Swiss Government, Major H. Bleuler, President of the Board of Education.

President Bleuler expressed thanks for the honor shown by the Conference to the country, the city, and the Swiss Polytechnic School by accepting their invitation, brought greetings of the Swiss authorities and the country, and wished success in the work and efforts of the Conference which had caused so many eminent men of science and practical professions to gather.

On motion of Prof. L. von Tetmajer, representing the Chairmen of the Fourth Standing Committee, the following officers were elected for the three days of the Conference:

FIRST DAY.

Honorary Presidents:

Chief Building Councillor BERGER, Building Director of Vienna.

Professor Dr. LEDEBUR, Royal Saxon Mining Councillor, Freiberg.

Chairman:

Major H. BLEULER, President Swiss Board of Education.

Secretaries:

P. DEBRAY, Chief Engineer P. and C., Professor at the National School of Bridges and Roads, Paris.

Prof. A. MARTENS, Engineer, Director Royal Prussian Testing Laboratories, Berlin.

SECOND DAY.

Honorary Presidents:

Prof. J. BENETTI, Director School of Application for Engineers, University, Bologna.

E. POLONCEAU, Chief Engineer Paris-Orleans Railway, ex-President French Society Civil Engineers.

Chairman:

Court Councillor Dr. **Exner**, Director Imperial Royal Technical Trades Museum, Vienna.

Secretaries:

G. **Alpherts**, Director Holland Technical Bureau Colonial Ministry, Government Representative.

A. **Sailler**, Chief Engineer of Mines, Vienna.

THIRD DAY.

Honorary Presidents:

His Excellency Professor **Belelubski**, Director Testing Laboratory of the Institute of Roads, Delegate of the Russian Society of Engineers, St. Petersburg.

Gus. C. **Henning**, Engineer, Delegate American Society Mechanical Engineers, New York.

Chairman:

Prof. C. **Zschokke**, Engineer, Professor of Engineering, Swiss Polytechnic Institute, Aarau.

Secretaries:

Engineer **Greil**, Director City Testing Laboratory, Vienna.

Engineer **Roussel**, Chief of Testing Laboratory, Malines Arsenal, Belgium.

Upon request of the Chairman, the officers elected took their respective seats, after provision for interpretation of the proceedings had been made, on motion of Engineer Luiggi, Livorno (Leghorn), and of the Baron Quinette de Rochemont de Paris, when Government Councillor Dr. Kick, Professor at the Technical High School at Vienna, took the floor to deliver an obituary address on the late Prof. J. Bauschinger of Munich.

In place of Dr. Delbrueck, who was detained by sickness, Mr. Dyckerhoff of Amoeneburg read the obituary on the late Dr. Boehme, the founder of the Royal Prussian Testing Laboratory at Berlin.

The President thanked the speakers for their remarks, on behalf of the Conference, which arose in honor of the late Professor Bauschinger, and moved to send a telegram of good cheer to Dr. Delbrueck.

Having carried out the programme of the day, the meeting dispersed at 12 o'clock.

P. Debray.
A. Martens.

Zurich, *September* 9, 1895.

MINUTES OF THE SECOND DAY.

Called to order at 9.15 A.M.

Prof. L. von Tetmajer, before the meeting proceeds to business, expresses sincere regret about the accident which occurred yesterday afternoon on the occasion of the descent of the Uetli Mountain Railway, the victim of which, Professor Hanisch of Vienna, had received a fracture of the ankle. The speaker stated that an investigation of the accident had been commenced, and requests those present not to consider the accident too seriously. Hereupon the officers elected for the second day are requested to take their seats. As *Honorary Presidents:* Prof. J. Benetti, Director School of Application for Engineers, University of Bologna; E. Polonceau, Chief Engineer of the Paris-Orleans Railway, ex-President of the French Society of Civil Engineers. As *Chairman:* Court Councillor Exner, Director Imperial Royal Technical Trades Museum, Vienna. As *Secretaries:* G. Alpherts, Director of the Technical Bureau of the Holland Colonial Ministry, The Hague; A. Sailler, Chief Engineer of Mines, Vienna.

After a few words of welcome to those present, by the Chairman, Chief Engineer Polonceau took the floor, expressing the thanks of his French colleagues for the great distinction shown his country and its engineers, and stated that he and his colleagues take part with pleasure in the labors of the Conference, and promised, in conjunction with them, to assist in reaching the objects sought.

The Chairman then gave the floor to Councillor of Mines Professor Dr. Wedding, who read his paper: "On the results of previous attempts at unification of analytical chemical analyses of iron." The speaker pointed out the reasons which necessitate attention to the chemical composition of iron, and methods of analyses which serve to check manufacture and those which serve to identify the finished product. Next the sources of errors were discussed; and the oft-observed variations in analytical results were shown to depend upon:

1. Uncertainty of samples.
2. Uncertainty of reagents.
3. Greater or lesser care of chemists.
4. Difference in reliability of methods used.

Messrs. E. Polonceau, G. C. Henning, E. Schroedter, and Toldt took part in the discussion.

After close of the discussion, which pointed out the importance of the subject and the desirability of regulating methods of analytical chemical analyses, the Chairman thanked the speaker for his clear and interesting discourse.

The next paper, by Baron H. von Jueptner, which is closely allied to the foregoing, was "On the necessity of unification of methods of iron analyses." The speaker, referring to a mass of evidence, pointed out the unreliability or inconsistency of the present condition of analytical chemical analyses of iron, treated of the sources of error, and emphasized particularly the desirability of standardizing the atomic weights to be used and the methods by which samples are to be obtained. Among the methods, distinction should be made between those used for scientific and those for industrial purposes, and the relative accuracy of various methods should be determined.

The paper was discussed by Dr. W. Sonne, Dr. Wedding, and E. Polonceau.

At the close of the session the President announced that the Wedding-Jueptner motion, read by Profesor Brunner-Lausanne, proposing the formation of an international commission for the purpose of establishing a standard method of iron analyses, had been adopted. The members of this commission are divided into sections, with instructions to report upon and make recommendations for the method of obtaining samples and of analyses of the various elements found in iron.

Hereupon the third subject on the programme was taken up, a paper by Prof. Dr. Fr. Steiner, "On the results of investigations of influence of low temperatures on the behavior of 'Flusseisen' (low steels)," being supplementary to the report on the subject presented in printed form by the author in conjunction with H. Gollner and C. Ludwik. The paper, and the question whether the study of this subject is to be continued, were discussed by Messrs. Polonceau, E. Schroedter, A. Martens, Toldt, the author, M. Barba, and R. Krohn.

Finally the motion formulated by the President, "The Commission is to be continued to pursue further studies," was adopted.

Hereupon a recess of one hour was taken.

Meeting reconvened at 12.45.

The chair was taken temporarily by Mr. Banovits, Royal Honorary Counsellor and Railway Director, Budapest, who gave the floor to Court Councillor Exner, to present his paper, which had been set down for the third day, "On the present status of methods of testing paper, textile fabrics, and other allied materials."

This paper, received by the members with the deepest interest, was fully discussed by Profs. A. Rejtõ, N. Belelubski, A. Haussner, and A. Martens.

Upon conclusion of the discussion, the author resumed the chair, and Chief Engineer G. Eckermann, Chairman of Sub-committee 19, took the floor, to move that in view of the fact of the ample report presented and the unanimity of opinions on the cardinal points treated by it, the work of the sub-committee be considered as terminated.

After a lively discussion by Messrs. Barba, B. Banovits, E. Polonceau, L. Baclé, F. Steiner, L. von Tetmajer, A. Pourcel, v. Leber, and Exner, the following very comprehensive resolution was offered by the Chair:

"The Conference decides, fully appreciating the meritorious work of Sub-committe 19, that it seems desirable to continue further study of 'Flusseisen' (low steels)."

The next paper is presented by Prof. B. Kirsch, Chairman of Sub-committee 13, "On the execution of comparative tests and determination of the most practicable and simple methods of measurement and expressions for flexibility of metallic bars." After a short discussion of the paper by Messrs. E. Polonceau, N. Belelubski, v. Leber, v. Stoltz, and Martens, the resolution of the Committee is adopted.

Prof. N. Belelubski is invited by the Chairman to communicate to the members his announcements, shortened because of lack of time, in an exhaustive manner. His studies relate to new method for the determination of toughness of wrought iron by bending tests, using same as a substitute for measures of extension in tension tests.

On account of lack of time three other reports were postponed to the following day, and the meeting then adjourned.

G. ALPHERTS.
ALB. SAILLER.

ZURICH, *September* 10, 1895.

MINUTES OF THE THIRD DAY.

Called to order at 9.15 A.M.

Prof. L. von Tetmajer made several business announcements before proceeding with the regular programme, and stated that the following new books had been donated to the archives of the Conference:

Professor *Le Chatelier*, Paris: Bulletin of the Society for the Encouragement of National Industry, Nos. 113 and 114. Vol. X., Fourth Series. Nos. 113 and 114, Annual for 1895.

Chief Councillor of Mines *Berger*, on behalf of the Austrian Engineers' and Architects' Association: Report of the Committee on Vaults.

Professor *Debray*, Paris: Bibliographic notes on the question of tests and testing laboratories for materials of construction (VII., 1895).

Mr. v. Leber announced, amid general gratification, that the member injured during the railroad excursion, Professor Dr. Hanisch, was progressing favorably under trying circumstances, and there were good reasons for hoping that the invalid would at no distant day be entirely cured.

Hereupon Prof. L. von Tetmajer invited the gentlemen selected to officiate during the day to take their seats. The *Honorary Chairmen* were his Excellency Prof. N. Belelubski of St. Petersburg, Engineer Gus. C. Henning of New York. *Presiding Chairman* was Engineer C. Zschokke, Professor of Engineering Science at Zurich. *Secretaries:* Engineer A. Greil, Vienna: Engineer E. Roussel, Malines, Belgium.

Messrs. Belelubski and Henning thank the meeting for the honor conferred upon their countries by their selection as honorary chairmen.

Upon inquiry by the Chairman it was decided to submit the minutes of the two previous sessions to a commission of three, to verify the same, consisting of Messrs. Prof. L. von Tetmajer, Chief Engineer R. Moser, Professor Dr. Amsler-Laffon.

Mr. Henning at once was given the floor to deliver a short address on "Methods of testing cast iron and other materials from a new point of view."

The investigation, which is still incomplete, has already shown that cast iron behaves in a peculiar manner when cooling from the molten state, or from a white heat, which is dependent upon the composition of the bars, similar results being regularly obtained with similar material. The accuracy thus obtained is not less than that observed in chemical analysis.

The tests are to be continued.

After Engineer Osmond of Paris discussed the subject, the unfinished business of the previous day is resumed, viz.:

Report 14. Professor Councillor of Mines A. Ledebour, Freiberg: "Appreciation of fragility due to acids; determination of this property in wire."

After a communication by Engineer Henning, New York, relative to a roller apparatus in use in the United States for at least twenty years to determine this property, in which the wire is not only strained in tension, but also by repeated bending, and a few remarks by Engineer Pourcel of Paris, the meeting adopted the resolutions offered by the author.

Report 15. Prof. A. Martens, Berlin, reported on "Appreciation of methods of examination of the micro-structure of metals; discussion of the possibility of establishing a standard method of examination; propositions." The reporter arrived at the conclusion that micrography of metals has not yet reached that stage so as to be on the same plane as the tension test or chemical analysis, to permit formulating methods of examination. In the report and the discussion the belief was expressed that further development can be entrusted to the laboratories and investigators. The Conference should, however, approach the various governments, in order to promote investigations, and to favor an advance of moneys for the purpose of publishing the work of review of this subject, which had been entrusted to Prof. H. M. Howe of Boston; and that a model collection of typical sections be established, by which a basis for comparison of methods may be secured.

Hereupon the report of Prof. Fr. Kick, Vienna, on "Appreciation of the impact test, and formulation of rules for its execution," was presented. Chief Engineer Polonceau called attention to the fact that the publication presented by the French Commission contains a report by Mr. Durand on a method for this test.

After a protracted discussion by Professor Nagy, Budapest; Professor Kirsch, Vienna; Professor Martens, Berlin; Mr. Henning, New York; and the author in closure, the recommendations of the sub-committee are adopted.

Next, Professor Dr. Kast of Carlsruhe presented his paper "On the present status of oil tests." The speaker emphasized that there still exist uncertainties about properties of lubricants, which are of importance in tests and opinions; these are still further magnified by the varying composition of mineral lubricating oils, which are now mainly used. After discussing these conditions, and describing the methods and apparatus now generally used, the speaker proposed the formation of a sub-committee to study and prepare standard methods of tests; this was adopted after a few remarks by Chief Engineer Polonceau.

A recess of one hour was now taken.

At 1 o'clock the meeting reassembled, and Director Dellwick, Liljeholmen, briefly describes the new Wyborg Thermophones for the measurement of high temperatures. According to statements by the speaker, these thermophones consist of clay cylinders, in the centre of which there are fulminates, noting the time required to cause explosion; high temperatures, it is stated, have been determined to within about twenty degrees of accuracy.

The Chairman then gave the floor to Mr. R. Dyckerhoff, Amoeneburg, who read his paper "On the results of investigations to determine the effect of sea water on hydraulic cements." A very spirited discussion was had on this paper by the Baron Quinette de Rochemont, Paris; Dr. Michaelis, Berlin; His Excellency Major-General Schulatschenko, St. Petersburg, His Excellency Professor Belelubski, St. Petersburg, and Professor Debray of Paris. The Conference decided that a sub-committee be appointed to study the subject.

Hereupon the Chairman put the question as to whether the prepared programme was to be carried out, or the written petition of several members was to be granted to proceed, on account of lack of time, to the discussion of the formation of the future organization of the Conference.

The majority deciding in favor of the latter, Prof. C. Bach of Stuttgart took the floor to present his report on the proposed constitution, which had been distributed in printed form.

After a thorough exposition of the French efforts to establish standard methods for testing all materials of construction, and a criticism of the proposed constitution, by the Baron Quinette de Rochemont, and a lively discussion of it by Director Peters, Chief Engineer Polonceau, Professor Debray, and Engineer Henning, the meeting decides to adopt it as formulated, and then to revise it, as may be required from time to time, by amendments.

Prof. L. von Tetmajer then presented his report on the question of issuing an official gazette, and recommended that the final arrangements looking to this end be intrusted to the council, which while protecting the interests of the Conference, were to make definite arrangements with Professor Giessler of Stuttgart.

This recommendation was adopted after having been further discussed by Professor Debray and Chief Engineer Polonceau, who heartily concurred in the proposition. The Chair then proceeded to the election of the proposed Council.

Those elected are:

Chairman: Prof. L. von Tetmajer, Zurich; *Councillors:* Professor Belelubski, St. Petersburg; Chief Building Commissioner Berger, Vienna; Prof. A. Martens, Berlin; the Baron Quinette de Rochemont, Paris.

The election of the Vice-Chairman is left to the Council.

The Chair then took up the discussion of time and place of the next meeting.

It was decided to convene the Sixth Conference in Stockholm, in 1897; and the Seventh Conference in Paris, in 1900.

Upon motion the meeting decided to intrust all unfinished business to the Standing Committee of the Fifth Conference.

Professor Kick, Vienna, finally requested the floor, to move votes of thanks to the authorities, to Prof. L. von Tetmajer, as well as to the respective chairmen, and suggested a rising vote, which is taken.

Hereupon the Baron Quinette de Rochemont took the floor, to express thanks and admiration, on behalf of the French representatives, to Major Bleuler, Hofrath Exner, and Professor Zschokke, for the successful management of the Conference.

The Conference was adjourned at 4 P.M.

A. GREIL, } *Secretaries.*
E. ROUSSEL, }

ZURICH, *September* 11, 1895.

Read and compared with the stenographer's reports, and found correct.

ZURICH, *October* 19, 1895.	PROF. L. VON TETMAJER, M.P.
ZURICH, *October* 21, 1895.	ROB. MOSER, M.P.
SCHAFFHAUSEN, *October* 22, 1895.	DR. J. AMSLER-LAFFON, M.P.

GENERAL INDEX TO VOLUME XVII.

[NOTE.—Names of Authors and Debaters are printed in SMALL CAPS.; Titles of Papers are printed in *italic type*.]

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