No. 827.*

REPORT OF THE COMMITTEE ON THE REVISION OF THE SOCIETY CODE OF 1885, RELATIVE TO A STANDARD METHOD OF CONDUCTING STEAM-BOILER TRIALS.

To the American Society of Mechanical Engineers.

Gentlemen: The undersigned Committee, to which was submitted the revision of the Society Code of 1885, relative to a standard method of conducting steam-boiler trials, reports as follows:

The Committee of 1885 presented a full statement of the principles which governed it in the preparation of the Code of Rules at that time recommended. These principles covered the ground in an admirable manner, so far as the practice of boiler testing had been perfected, and we are in unanimous accord with the sentiments which the report of that Committee expressed. During the interval of thirteen years which has passed, methods and instruments have in some measure changed. Improvements have been made in the instruments for determining the moisture in steam. The throttling and separating forms of calorimeters have displaced the barrel and other types of steam calorimeters referred to in the previous report. Attention has been devoted to the determination of the calorific value of coal, and a number of coal calorimeters have been brought out and successfully used for this purpose. It has come to be a practice with many experts to include in the table of results of boiler tests the percentage of "efficiency," or proportion of the calorific value of the coal which is utilized by the boiler. Specifications and contracts are in some cases drawn up, provid-

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ing for certain percentages of efficiency instead of a specified evaporation. The analysis of flue gases is receiving more attention than formerly, not only in our educational institutions, but also in the regular practice of engineers who make a specialty of boiler testing.

Your Committee submits a revised Code, termed the Code of 1899. The changes are mainly in the line of amendments such as the experience of the last thirteen years has shown to be desirable. The amendments relate to the use of improved steam calorimeters, to sampling coal and determining its moisture, to calorific tests and analysis of coal, to analysis of flue gases, to smoke observations, to determinations of efficiency, and to methods of working out the "heat balance."

The tabular form of presenting the results of the test is somewhat changed and enlarged, and alterations in the text of the Code are made wherever needed. At the same time a second or "short form" of report is added, for use in commercial tests or in cases where it is necessary to give only the principal data and results.

It is beyond the province of the Committee to recommend instruments of particular makers for obtaining the quality of the steam, the calorific value of the fuel, or any other data relating to the trial; but following the practice of the former Committee, individual members have submitted their views (with the approval of the full membership) in an "Appendix to the 1899 Code," signed by their initials. In this appendix are included some of the articles from the appendix to the former Code, which are thought to be of especial value.

In the matter of instruments for determining the calorific value of fuel, it seems desirable that the Committee should make a recommendation which is as specific as present knowledge and circumstances will warrant. It is agreed that some form of calorimeter in which the coal is burned in an atmosphere of oxygen gas is to be preferred, and it is generally held that the most perfect apparatus thus far brought out is the Bomb Calorimeter, originally designed by Berthelot and modified by Mahler and Hempel. Several of these instruments are in use in this country, principally in the laboratories of engineering schools; but the apparatus is complicated and expensive, and it is not probable that many engineers will have the instrument as a part of their equipment for testing boilers. It is recommended, therefore, that samples of the coal used in testing boilers be sent for determinations of their heating value to a testing laboratory provided with one of these instruments, or with some instrument which shall be proven to be equally good. (Article XVII., Code.)

The Committee approves the conclusions of the 1885 Code to the effect that the standard "unit of evaporation" should be one pound of water at 212 degrees Fahr. evaporated into dry steam of the same temperature. This unit is equivalent to 965.7 British thermal units.

The Committee recommends that, as far as possible, the capacity of a boiler be expressed in terms of the "number of pounds of water evaporated per hour from and at 212 degrees." It does not seem expedient, however, to abandon the widely recognized measure of capacity of stationary or land boilers expressed in terms of "boiler horse-power."

The unit of commercial boiler horse-power adopted by the Committee of 1885 was the same as that used in the reports of the boiler tests made at the Centennial Exhibition in 1876. The Committee of 1885 reported in favor of this standard in language of which the following is an extract:

"Your Committee, after due consideration, has determined to accept the Centennial standard, and to recommend that in all standard trials the commercial horse-power be taken as an evaporation of 30 pounds of water per hour from a feed-water temperature of 100 degrees Fahr. into steam at 70 pounds gauge pressure, which shall be considered to be equal to 34½ units of evaporation; that is, to 34½ pounds of water evaporated from a feed-water temperature of 212 degrees Fahr. into steam at the same temperature. This standard is equal to 33,305 thermal units per hour."

The present Committee accepts the same standard, but reverses the order of two clauses in the statement, and slightly modifies them to read as follows:

The unit of commercial horse-power developed by a boiler shall be taken as 34½ units of evaporation per hour; that is, 34½ pounds of water evaporated per hour from a feed-water temperature of 212 degrees Fahr. into dry steam of the same temperature. This standard is equivalent to 33,317 British thermal units per hour. It is also practically equivalent to an evaporation of 30 pounds of water from a feed-water temperature of 100 degrees Fahr. into steam at 70 pounds gauge pressure.*

The Committee also indorses the statement of the Committee of 1885 concerning the commercial rating of boilers, changing somewhat its wording, so as to read as follows:

A boiler rated at any stated capacity should develop that capacity when using the best coal ordinarily sold in the market where the boiler is located, when fired by an ordinary fireman, without forcing the fires, while exhibiting good economy; and, further, the boiler should develop at least one-third more than the stated capacity when using the same fuel and operated by the same fireman, the full draft being employed and the fires being crowded; the available draft in the flue just beyond the boiler, unless otherwise understood, being not less than ½ inch water column.

Respectfully submitted,

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Committee.

* According to the tables in Porter's Treatise on the Richards Steam-Engine Indicator, an evaporation of 30 pounds of water from 100 degrees Fahr. into steam at 70 pounds pressure is equal to an evaporation of 34.488 pounds from and at 212 degrees; and an evaporation of 34½ pounds from and at 212 degrees Fahr. is equal to 30.010 pounds from 100 degrees Fahr. into steam at 70 pounds pressure.

The "unit of evaporation" being equivalent to 965.7 thermal units, the commercial horse-power = $34.5 \times 965.7 = 33,317$ thermal units.

† The motion for the appointment of this Committee was made by Mr. Barrus in connection with the discussion of Mr. Dean's paper, No. DCL., on "The Efficiency of Boilers," etc. The President of the Society designated Mr. Kent, the chairman of the Committee of 1884, to call the first meeting of the new Committee. At that meeting, on motion of Mr. Kent, Dr. Emery was selected as chairman, and he conducted the preliminary correspondence. The draft of report in the form originally printed and presented for criticism at the Annual Meeting in December, 1897, was prepared by a sub-committee consisting of Messrs. Emery, Porter, Barrus, and Kent. Much of the work of revision of this preliminary draft was done by Dr. Emery a few weeks before his death in June, 1898, and the final revision, bringing the report to its present form, was done by Messrs. Barrus and Kent.

RULES FOR CONDUCTING BOILER TRIALS.

CODE OF 1899.

I. *Determine at the outset* the specific object of the proposed trial, whether it be to ascertain the capacity of the boiler, its efficiency as a steam generator, its efficiency and its defects under usual working conditions, the economy of some particular kind of fuel, or the effect of changes of design, proportion, or operation; and prepare for the trial accordingly. (Appendix II.)

II. *Examine the boiler*, both outside and inside; ascertain the dimensions of grates, heating surfaces, and all important parts; and make a full record, describing the same, and illustrating special features by sketches. The area of heating surface is to be computed from the surfaces of shells, tubes, furnaces, and fire-boxes in contact with the fire or hot gases. The outside diameter of water-tubes and the inside diameter of fire-tubes are to be used in the computation. All surfaces below the mean water level which have water on one side and products of combustion on the other are to be considered as water-heating surface, and all surfaces above the mean water level which have steam on one side and products of combustion on the other are to be considered as superheating surface.

III. *Notice the general condition* of the boiler and its equipment, and record such facts in relation thereto as bear upon the objects in view.

If the object of the trial is to ascertain the maximum economy or capacity of the boiler as a steam generator, the boiler and all its appurtenances should be put in first-class condition. Clean the heating surface inside and outside, remove clinkers from the grates and from the sides of the furnace. Remove all dust, soot, and ashes from the chambers, smoke connections, and flues. Close air leaks in the masonry and poorly fitted cleaning doors. See that the damper will open wide and close tight. Test for air leaks by firing a few shovels of smoky fuel and immediately closing the damper, observing the escape of smoke through the crevices, or by passing the flame of a candle over cracks in the brickwork.

IV. *Determine the character of the coal* to be used. For tests of the efficiency or capacity of the boiler for comparison with other boilers the coal should, if possible, be of some kind which is commercially regarded as a standard. For New England

and that portion of the country east of the Allegheny Mountains, good anthracite egg coal, containing not over 10 per cent. of ash, and semi-bituminous Clearfield (Pa.), Cumberland (Md.), and Pocahontas (Va.) coals are thus regarded. West of the Allegheny Mountains, Pocahontas (Va.) and New River (W. Va.) semi-bituminous, and Youghiogheny or Pittsburg bituminous coals are recognized as standards.* There is no special grade of coal mined in the Western States which is widely recognized as of superior quality or considered as a standard coal for boiler testing. Big Muddy lump, an Illinois coal mined in Jackson County, Ill., is suggested as being of sufficiently high grade to answer these requirements in districts where it is more conveniently obtainable than the other coals mentioned above.

For tests made to determine the performance of a boiler with a particular kind of coal, such as may be specified in a contract for the sale of a boiler, the coal used should not be higher in ash and in moisture than that specified, since increase in ash and moisture above a stated amount is apt to cause a falling off of both capacity and economy in greater proportion than the proportion of such increase.

V. *Establish the correctness of all apparatus* used in the test for weighing and measuring. These are:

1. Scales for weighing coal, ashes, and water.
2. Tanks, or water meters for measuring water. Water meters, as a rule, should only be used as a check on other measurements. For accurate work, the water should be weighed or measured in a tank. (Appendices I., IV., VII., VIII.)
3. Thermometers and pyrometers for taking temperatures of air, steam, feed-water, waste gases, etc. (Appendix XXVII.)
4. Pressure gauges, draught gauges, etc. (Appendices XXVIII. to XXX.)

The kind and location of the various pieces of testing apparatus must be left to the judgment of the person conducting the test; always keeping in mind the main object, *i.e.*, to obtain authentic data.

VI. *See that the boiler is thoroughly heated* before the trial to its usual working temperature. If the boiler is new and of a

* These coals are selected because they are about the only coals which possess the essentials of excellence of quality, adaptability to various kinds of furnaces, grates, boilers, and methods of firing, and wide distribution and general accessibility in the markets.

form provided with a brick setting, it should be in regular use at least a week before the trial, so as to dry and heat the walls. If it has been laid off and become cold, it should be worked before the trial until the walls are well heated.

VII. *The boiler and connections* should be proved to be free from leaks before beginning a test, and all water connections, including blow and extra feed pipes, should be disconnected, stopped with blank flanges, or bled through special openings beyond the valves, except the particular pipe through which water is to be fed to the boiler during the trial. During the test the blow-off and feed pipes should remain exposed to view.

If an injector is used, it should receive steam directly through a felted pipe from the boiler being tested.*

If the water is metered after it passes the injector, its temperature should be taken at the point where it leaves the injector. If the quantity is determined before it goes to the injector the temperature should be determined on the suction side of the injector, and if no change of temperature occurs other than that due to the injector, the temperature thus determined is properly that of the feed-water. When the temperature changes between the injector and the boiler, as by the use of a heater or by radiation, the temperature at which the water enters and leaves the injector and that at which it enters the boiler should all be taken. In that case the weight to be used is that of the water leaving the injector, computed from the heat units if not directly measured, and the temperature, that of the water entering the boiler.

Let w = weight of water entering the injector.
x = " " steam " " "
h_1 = heat units per pound of water entering injector.
h_2 = " " " " " steam " "
h_3 = " " " " " water leaving "

Then, $w + x$ = weight of water leaving injector.

$$x = w\frac{h_3 - h_1}{h_2 - h_3}.$$

* In feeding a boiler undergoing test with an injector taking steam from another boiler, or from the main steam pipe from several boilers, the evaporative results may be modified by a difference in the quality of the steam from such source compared with that supplied by the boiler being tested, and in some cases the connection to the injector may act as a drip for the main steam pipe. If it is known that the steam from the main pipe is of the same pressure and quality as that furnished by the boiler undergoing the test, the steam may be taken from such main pipe.

See that the steam main is so arranged that water of condensation cannot run back into the boiler.

VIII. *Duration of the Test.*—For tests made to ascertain either the maximum economy or the maximum capacity of a boiler, irrespective of the particular class of service for which it is regularly used, the duration should be at least 10 hours of continuous running. If the rate of combustion exceeds 25 pounds of coal per square foot of grate surface per hour, it may be stopped when a total of 250 pounds of coal has been burned per square foot of grate.

In cases where the service requires continuous running for the whole 24 hours of the day, with shifts of firemen a number of times during that period, it is well to continue the test for at least 24 hours.

When it is desired to ascertain the performance under the working conditions of practical running, whether the boiler be regularly in use 24 hours a day or only a certain number of hours out of each 24, the fires being banked the balance of the time, the duration should not be less than 24 hours.

IX. *Starting and Stopping a Test.*—The conditions of the boiler and furnace in all respects should be, as nearly as possible, the same at the end as at the beginning of the test. The steam pressure should be the same; the water level the same; the fire upon the grates should be the same in quantity and condition; and the walls, flues, etc., should be of the same temperature. Two methods of obtaining the desired equality of conditions of the fire may be used, viz.: those which were called in the Code of 1885 "the standard method" and "the alternate method," the latter being employed where it is inconvenient to make use of the standard method.*

X. *Standard Method of Starting and Stopping a Test.*—Steam being raised to the working pressure, remove rapidly all the fire from the grate, close the damper, clean the ash pit, and as quickly as possible start a new fire with weighed wood and coal, noting the time and the water level† while

* The Committee concludes that it is best to retain the designations "standard" and "alternate," since they have become widely known and established in the minds of engineers and in the reprints of the Code of 1885. Many engineers prefer the "alternate" to the "standard" method on account of its being less liable to error due to cooling of the boiler at the beginning and end of a test.

† The gauge-glass should not be blown out within an hour before the water level is taken at the beginning and end of a test, otherwise an error in the reading of the water level may be caused by a change in the temperature and density of the water in the pipe leading from the bottom of the glass into the boiler.

the water is in a quiescent state, just before lighting the fire.

At the end of the test remove the whole fire, which has been burned low, clean the grates and ash pit, and note the water level when the water is in a quiescent state, and record the time of hauling the fire. The water level should be as nearly as possible the same as at the beginning of the test. If it is not the same, a correction should be made by computation, and not by operating the pump after the test is completed.

XI. *Alternate Method of Starting and Stopping a Test.*—The boiler being thoroughly heated by a preliminary run, the fires are to be burned low and well cleaned. Note the amount of coal left on the grate as nearly as it can be estimated; note the pressure of steam and the water level. Note the time, and record it as the starting time. Fresh coal which has been weighed should now be fired. The ash pits should be thoroughly cleaned at once after starting. Before the end of the test the fires should be burned low, just as before the start, and the fires cleaned in such a manner as to leave a bed of coal on the grates of the same depth, and in the same condition, as at the start. When this stage is reached, note the time and record it as the stopping time. The water level and steam pressures should previously be brought as nearly as possible to the same point as at the start. If the water level is not the same as at the start, a correction should be made by computation, and not by operating the pump after the test is completed.

XII. *Uniformity of Conditions.*—In all trials made to ascertain maximum economy or capacity, the conditions should be maintained uniformly constant. Arrangements should be made to dispose of the steam so that the rate of evaporation may be kept the same from beginning to end. This may be accomplished in a single boiler by carrying the steam through a waste steam pipe, the discharge from which can be regulated as desired. In a battery of boilers, in which only one is tested, the draft may be regulated on the remaining boilers, leaving the test boiler to work under a constant rate of production.

Uniformity of conditions should prevail as to the pressure of steam, the height of water, the rate of evaporation, the thickness of fire, the times of firing and quantity of coal fired at one time, and as to the intervals between the times of cleaning the fires.

The method of firing to be carried on in such tests should be dictated by the expert or person in responsible charge of the test, and the method adopted should be adhered to by the fireman throughout the test.

XIII. *Keeping the Records.*—Take note of every event connected with the progress of the trial, however unimportant it may appear. Record the time of every occurrence and the time of taking every weight and every observation. (Appendices I., IV., V., VI., VII., VIII.)

The coal should be weighed and delivered to the fireman in equal proportions, each sufficient for not more than one hour's run, and a fresh portion should not be delivered until the previous one has all been fired. The time required to consume each portion should be noted, the time being recorded at the instant of firing the last of each portion. It is desirable that at the same time the amount of water fed into the boiler should be accurately noted and recorded, including the height of the water in the boiler, and the average pressure of steam and temperature of feed during the time. By thus recording the amount of water evaporated by successive portions of coal, the test may be divided into several periods if desired, and the degree of uniformity of combustion, evaporation, and economy analyzed for each period. In addition to these records of the coal and the feed water, half hourly observations should be made of the temperature of the feed water, of the flue gases, of the external air in the boiler-room, of the temperature of the furnace when a furnace pyrometer is used, also of the pressure of steam, and of the readings of the instruments for determining the moisture in the steam. A log should be kept on properly prepared blanks containing columns for record of the various observations. (Appendix XXII.)

When the "standard method" of starting and stopping the test is used, the hourly rate of combustion and of evaporation and the horse-power should be computed from the records taken during the time when the fires are in active condition. This time is somewhat less than the actual time which elapses between the beginning and end of the run. The loss of time due to kindling the fire at the beginning and burning it out at the end makes this course necessary.

XIV. *Quality of Steam.*—The percentage of moisture in the steam should be determined by the use of either a throttling or a separating steam calorimeter. The sampling nozzle should be placed in the vertical steam pipe rising from the boiler. It should be made of $\frac{1}{2}$-inch pipe, and should extend across the diameter of the steam pipe to within half an inch of the opposite side, being closed at the end and perforated with not less than twenty $\frac{1}{8}$-inch holes equally distributed along and around its cylindrical surface, but none of these holes should be nearer than $\frac{1}{2}$ inch to the inner side of the steam pipe. The calorimeter and the pipe leading to it should be well covered with felting. Whenever the indications of the throttling or separating calorimeter show that the percentage of moisture is irregular, or occasionally in excess of three per cent., the results should be checked by a steam separator placed in the steam pipe as close to the boiler as convenient, with a calorimeter in the steam pipe just beyond the outlet from the separator. The drip from the separator should be caught and weighed, and the percentage of moisture computed therefrom added to that shown by the calorimeter. (See Appendices XV. to XVII.)

Superheating should be determined by means of a thermometer placed in a mercury well inserted in the steam pipe. The degree of superheating should be taken as the difference between the reading of the thermometer for superheated steam and the readings of the same thermometer for saturated steam at the same pressure as determined by a special experiment, and not by reference to steam tables.

For calculations relating to quality of steam and corrections for quality of steam, see Appendices XVIII. and XIX.

XV. *Sampling the Coal and Determining its Moisture.*—As each barrow load or fresh portion of coal is taken from the coal pile, a representative shovelful is selected from it and placed in a barrel or box in a cool place and kept until the end of the trial. The samples are then mixed and broken into pieces not exceeding one inch in diameter, and reduced by the process of repeated quartering and crushing until a final sample weighing about five pounds is obtained, and the size of the larger pieces is such that they will pass through a sieve with $\frac{1}{4}$-inch meshes. From this sample two one-quart, air-tight glass preserving jars, or other air-tight vessels which will prevent the escape of moisture from the sample, are to be promptly filled, and these samples are to be kept for subsequent determinations of moisture and of heating value and for chemical analyses. During the process of quartering, when the sample has been reduced to about 100 pounds, a quarter to a half of it may be taken for an approximate determination of moisture. This may be made by placing it in a shallow iron pan, not over three inches deep, carefully weighing it, and setting the pan in the hottest place that can be found on the brickwork of the boiler setting or flues, keeping it there for at least 12 hours, and then weighing it. The determination of moisture thus made is believed to be approximately accurate for anthracite and semi-bituminous coals, and also for Pittsburg or Youghiogheny coal; but it cannot be relied upon for coals mined west of Pittsburg, or for other coals containing inherent moisture. For these latter coals it is important that a more accurate method be adopted. The method recommended by the Committee for all accurate tests, whatever the character of the coal, is described as follows:

Take one of the samples contained in the glass jars, and subject it to a thorough air-drying, by spreading it in a thin layer and exposing it for several hours to the atmosphere of a warm room, weighing it before and after, thereby determining the quantity of surface moisture it contains. Then crush the whole of it by running it through an ordinary coffee mill adjusted so as to produce somewhat coarse grains (less than $\frac{1}{16}$-inch), thoroughly mix the crushed sample, select from it a portion of from 10 to 50 grams, weigh it in a balance which will easily show a variation as small as 1 part in 1,000, and dry it in an air or sand bath at a temperature between 240 and 280 degrees Fahr. for one hour. Weigh it and record the loss, then heat and weigh it again repeatedly, at intervals of an hour or less, until the minimum weight has been reached and the weight begins to increase by oxidation of a portion of the coal. The difference between the original and the minimum weight is taken as the moisture in the air-dried coal. This moisture test should preferably be made on duplicate samples, and the results should agree within 0.3 to 0.4 of one per cent., the mean of the two determinations being taken as the correct result. The sum of the percentage of moisture thus found and the percentage of surface moisture previously determined is the total moisture. (Appendix XI.)

XVI. *Treatment of Ashes and Refuse.*—The ashes and refuse are to be weighed in a dry state. If it is found desirable to show the principal characteristics of the ash, a sample should be subjected to a proximate analysis and the actual amount of incombustible material determined. For elaborate trials a complete analysis of the ash and refuse should be made.

XVII. *Calorific Tests and Analysis of Coal.*—The quality of the fuel should be determined either by heat test or by analysis, or by both.

The rational method of determining the total heat of combustion is to burn the sample of coal in an atmosphere of oxygen gas, the coal to be sampled as directed in Article XV. of this code. (See Appendices XIII. and XIV.)

The chemical analysis of the coal should be made only by an expert chemist. The total heat of combustion computed from the results of the ultimate analysis may be obtained by the use of Dulong's formula (with constants modified by recent determinations), viz.: $14{,}600\ C + 62{,}000\left(H - \frac{O}{8}\right) + 4{,}000\ S$, in which C, H, O, and S refer to the proportions of carbon, hydrogen, oxygen, and sulphur respectively, as determined by the ultimate analysis.*

It is desirable that a proximate analysis should be made, thereby determining the relative proportions of volatile matter and fixed carbon. These proportions furnish an indication of the leading characteristics of the fuel, and serve to fix the class to which it belongs. (Appendix XII.) As an additional indication of the characteristics of the fuel, the specific gravity should be determined.

XVIII. *Analysis of Flue Gases.*—The analysis of the flue gases is an especially valuable method of determining the relative value of different methods of firing, or of different kinds of furnaces. In making these analyses great care should be taken to procure average samples—since the composition is apt to vary at different points of the flue (Appendix XXXI.). The composition is also apt to vary from minute to minute, and for this reason the drawings of gas should last a considerable period of time. Where complete determinations are desired, the analyses should be intrusted to an expert chemist. For approximate determinations the Orsat † or the Hempel ‡ apparatus may be used by the engineer. (See Appendix XXXIII.)

* Favre and Silberman give 14,544 B.T.U. per pound carbon; Berthelot 14,647 B.T.U. Favre and Silberman give 62,032 B.T.U. per pound hydrogen; Thomsen 61,816 B.T.U.

† See R. S. Hale's paper on "Flue Gas Analysis," *Transactions*, vol. xviii., p. 901.

‡ See Hempel's "Methods of Gas Analysis" (Macmillan & Co.).

For the continuous indication of the amount of carbonic acid present in the flue gases, an instrument may be employed which shows the weight of the sample of gas passing through it. (Appendix XXXIX.)

XIX. *Smoke Observations.*—It is desirable to have a uniform system of determining and recording the quantity of smoke produced where bituminous coal is used. The system commonly employed is to express the degree of smokiness by means of percentages dependent upon the judgment of the observer. The Committee does not place much value upon a percentage method, because it depends so largely upon the personal element, but if this method is used, it is desirable that, so far as possible, a definition be given in explicit terms as to the basis and method employed in arriving at the percentage. The actual measurement of a sample of soot and smoke by some form of meter is to be preferred. (See Appendices XXXIV. and XXXV.)

XX. *Miscellaneous.*—In tests for purposes of scientific research, in which the determination of all the variables entering into the test is desired, certain observations should be made which are in general unnecessary for ordinary tests. These are the measurement of the air supply, the determination of its contained moisture, the determination of the amount of heat lost by radiation, of the amount of infiltration of air through the setting, and (by condensation of all the steam made by the boiler) of the total heat imparted to the water.

As these determinations are rarely undertaken, it is not deemed advisable to give directions for making them.

XXI. *Calculations of Efficiency.*—Two methods of defining and calculating the efficiency of a boiler are recommended. They are :

1. $\text{Efficiency of the boiler} = \frac{\text{Heat absorbed per lb. combustible}}{\text{Calorific value of 1 lb. combustible}}$

2. $\text{Efficiency of the boiler and grate} = \frac{\text{Heat absorbed per lb. coal}}{\text{Calorific value of 1 lb. coal}}$

The first of these is sometimes called the efficiency based on combustible, and the second the efficiency based on coal. The first is recommended as a standard of comparison for all tests, and this is the one which is understood to be referred to when the word "efficiency" alone is used without qualification. The second, however, should be included in a report of a test, together with the first, whenever the object of the test is to determine the efficiency of the boiler and furnace together with the grate (or mechanical stoker), or to compare different furnaces, grates, fuels, or methods of firing.

The heat absorbed per pound of combustible (or per pound coal) is to be calculated by multiplying the equivalent evaporation from and at 212 degrees per pound combustible (or coal) by 965.7. (Appendix XX.)

XXII. *The Heat Balance.*—An approximate "heat balance," or statement of the distribution of the heating value of the coal among the several items of heat utilized and heat lost may be included in the report of a test when analyses of the fuel and of the chimney gases have been made. It should be reported in the following form:

HEAT BALANCE, OR DISTRIBUTION OF THE HEATING VALUE OF THE COMBUSTIBLE.

Total Heat Value of 1 lb. of Combustible....................B. T. U.

		B. T. U.	Per Cent.
1.	Heat absorbed by the boiler = evaporation from and at 212 degrees per pound of combustible × 965.7.		
2.	Loss due to moisture in coal = per cent. of moisture referred to combustible ÷ 100 × [$(212 - t) + 966 + 0.48\,(T - 212)$] (t = temperature of air in the boiler-room, T = that of the flue gases)		
3.	Loss due to moisture formed by the burning of hydrogen = per cent. of hydrogen to combustible ÷ 100 × 9 × [$(212 - t) + 966 + 0.48\,(T - 212)$].		
4.*	Loss due to heat carried away in the dry chimney gases = weight of gas per pound of combustible × 0.24 × $(T - t)$.		
5.†	Loss due to incomplete combustion of carbon = $\frac{CO}{CO_2 + CO} \times \frac{\text{per cent. C in combustible}}{100} \times 10{,}150$.		
6.	Loss due to unconsumed hydrogen and hydrocarbons, to heating the moisture in the air, to radiation, and unaccounted for. (Some of these losses may be separately itemized if data are obtained from which they may be calculated.)		
	Totals......................................		100.00

*The weight of gas per pound of carbon burned may be calculated from the gas analyses as follows:

Dry gas per pound carbon $= \frac{11\,CO_2 + 8\,O + 7\,(CO + N)}{3\,(CO_2 + CO)}$, in which CO_2, CO, O, and N are the percentages by volume of the several gases. As the sampling and analyses of the gases in the present state of the art are liable to considerable errors, the result of this calculation is usually only an approximate one. The heat balance itself is also only approximate for this reason, as well as for the fact that it is not possible to determine accurately the percentage of unburned hydrogen or hydrocarbons in the flue gases. (See Appendix XXXII.)

The weight of dry gas per pound of combustible is found by multiplying the dry gas per pound of carbon by the percentage of carbon in the combustible, and dividing by 100.

† CO_2 and CO are respectively the percentage by volume of carbonic acid and carbonic oxide in the flue gases. The quantity 10,150 = Number of heat units generated by burning to carbonic acid one pound of carbon contained in carbonic oxide.

XXIII. *Report of the Trial.*—The data and results should be reported in the manner given in either one of the two following tables, omitting lines where the tests have not been made as elaborately as provided for in such tables. Additional lines may be added for data relating to the specific object of the test. The extra lines should be classified under the headings provided in the tables, and numbered as per preceding line, with sub letters *a*, *b*, etc. The Short Form of Report, Table No. 2, is recommended for commercial tests and as a convenient form of abridging the longer form for publication when saving of space is desirable. For elaborate trials, it is recommended that the full log of the trial be shown graphically, by means of a chart. (Appendix XXXVIII.)

TABLE NO. 1.

DATA AND RESULTS OF EVAPORATIVE TEST,

Arranged in accordance with the Complete Form advised by the Boiler Test Committee of the American Society of Mechanical Engineers. Code of 1899.

Made by.......... ....of................boiler at..................to determine...

....

Principal conditions governing the trial ....

....

....

Kind of fuel * ....

Kind of furnace ....

State of the weather...

Method of starting and stopping the test ("standard" or "alternate," Art. X. and XI., Code)..

1. *Date of trial* ....
2. *Duration of trial*... hours.

Dimensions and Proportions.

(A complete description of the boiler, and drawings of the same if of unusual type, should be given on an annexed sheet. (See Appendix X.)

3.	*Grate surface* ....*width*........*length*........*area*........	sq. ft.
4.	Height of furnace..	ins.
5.	Approximate width of air spaces in grate.....................	in.
6.	Proportion of air space to whole grate surface.................	per cent.
7.	*Water-heating surface*..................	sq. ft.
8.	*Superheating surface*..	"
9.	Ratio of water-heating surface to grate surface................	— to 1.
10.	Ratio of minimum draft area to grate surface	1 to —

* The items printed in italics correspond to the items in the "Short Form of Code."

Average Pressures.

11.	*Steam pressure by gauge*	lbs. per sq. in.
12.	*Force of draft between damper and boiler*	ins. of water
13.	Force of draft in furnace	" "
14.	Force of draft or blast in ashpit	" "

Average Temperatures.

15.	Of external air	deg.
16.	Of fireroom	"
17.	Of steam	"
18.	Of feed water entering heater	"
19.	Of feed water entering economizer	"
20.	*Of feed water entering boiler*	"
21.	*Of escaping gases from boiler*	"
22.	Of escaping gases from economizer	"

Fuel.

23.	Size and condition	
24.	Weight of wood used in lighting fire	lbs.
25.	*Weight of coal as fired* *	"
26.	*Percentage of moisture in coal* †	per cent.
27.	*Total weight of dry coal consumed*	lbs.
28.	*Total ash and refuse*	"
29.	Quality of ash and refuse	
30.	Total combustible consumed	lbs.
31.	*Percentage of ash and refuse in dry coal*	per cent.

Proximate Analysis of Coal.

(App. XII.)

		Of Coal.	Of Combustible.
32.	Fixed carbon	per cent.	per cent.
33.	Volatile matter	"	"
34.	Moisture	"	——
35.	Ash	"	——
		100 per cent.	100 per cent.
36.	Sulphur, separately determined	"	"

* Including equivalent of wood used in lighting the fire, not including unburnt coal withdrawn from furnace at times of cleaning and at end of test. One pound of wood is taken to be equal to 0.4 pound of coal, or, in case greater accuracy is desired, as having a heat value equivalent to the evaporation of 6 pounds of water from and at 212 degrees per pound. ($6 \times 965.7 = 5{,}794$ B. T. U.) The term "as fired" means in its actual condition, including moisture.

† This is the total moisture in the coal as found by drying it artificially, as described in Art. XV. of Code.

Ultimate Analysis of Dry Coal.

(Art. XVII., Code.)

	Of Coal.	Of Combustible.
37. Carbon (C)	per cent.	per cent.
38. Hydrogen (H)	"	"
39. Oxygen (O)	"	"
40. Nitrogen (N)	"	"
41. Sulphur (S)	"	"
42. Ash	"	——
	100 per cent.	100 per cent.
43. Moisture in sample of coal as received	"	"

Analysis of Ash and Refuse.

44. Carbon	per cent.
45. Earthy matter	"

Fuel per Hour.

46. *Dry coal consumed per hour*	lbs.
47. Combustible consumed per hour	"
48. *Dry coal per square foot of grate surface per hour*	"
49. Combustible per square foot of water-heating surface per hour.	"

Calorific Value of Fuel.

(Art. XVII., Code.)

50. *Calorific value by oxygen calorimeter, per lb. of dry coal*	B.T.U.
51. *Calorific value by oxygen calorimeter, per lb. of combustible*	"
52. Calorific value by analysis, per lb. of dry coal*	"
53. Calorific value by analysis, per lb. of combustible	"

Quality of Steam.

(App. XV. to XIX.)

54. *Percentage of moisture in steam*	per cent.
55. *Number of degrees of superheating*	deg.
56. Quality of steam (dry steam = unity). (For exact determination of the factor of correction for quality of steam see Appendix XVIII.)	

Water.

(App. I., IV., VII., VIII.)

57. *Total weight of water fed to boiler* †	lbs.
58. Equivalent water fed to boiler from and at 212 degrees........	"
59. *Water actually evaporated, corrected for quality of steam*	"

* See formula for calorific value under Article XVII. of Code.

† Corrected for inequality of water level and of steam pressure at beginning and end of test.

60. Factor of evaporation *.................................... lbs.
61. Equivalent water evaporated into dry steam from and at 212 degrees. † (Item 59 × Item 60.)......................... "

Water per Hour.

62. *Water evaporated per hour, corrected for quality of steam*...... "
63. *Equivalent evaporation per hour from and at 212 degrees* †...... "
64. *Equivalent evaporation per hour from and at 212 degrees per square foot of water-heating surface* †...................... "

Horse-Power.

65. *Horse-power developed. (34½ lbs. of water evaporated per hour into dry steam from and at 212 degrees, equals one horse-power)* ‡... H. P.
66. *Builders' rated horse-power*.................................. "
67. *Percentage of builders' rated horse-power developed*............ per cent.

Economic Results.

68. *Water apparently evaporated under actual conditions per pound of coal as fired. (Item 57 ÷ Item 25.)*...................... lbs.
69. *Equivalent evaporation from and at 212 degrees per pound of coal as fired.* † *(Item 61 ÷ Item 25.)*....................... "
70. *Equivalent evaporation from and at 212 degrees per pound of dry coal.* † *(Item 61 ÷ Item 27.)*............................ "
71. *Equivalent evaporation from and at 212 degrees per pound of combustible.* † *(Item 61 ÷ Item 30.)*....................... "

(If the equivalent evaporation, Items 69, 70, and 71, is not corrected for the quality of steam, the fact should be stated).

Efficiency.

(Art. XXI., Code.)

72. *Efficiency of the boiler; heat absorbed by the boiler per lb. of combustible divided by the heat value of one lb. of combustible* §.... per cent.
73. *Efficiency of boiler, including the grate; heat absorbed by the boiler, per lb. of dry coal, divided by the heat value of one lb. of dry coal*.. "

---

* Factor of evaporation $= \frac{H-h}{965.7}$, in which H and h are respectively the total heat in steam of the average observed pressure, and in water of the average observed temperature of the feed.

† The symbol "U. E." meaning "Units of Evaporation," may be conveniently substituted for the expression "Equivalent water evaporated into dry steam from and at 212 degrees," its definition being given in a foot-note.

‡ Held to be the equivalent of 30 lbs. of water per hour evaporated from 100 degrees Fahr. into dry steam at 70 lbs. gauge pressure. (See Introduction to Code.)

§ In all cases where the word combustible is used, it means the coal without moisture and ash, but including all other constituents. It is the same as what is called in Europe "coal dry and free from ash."

Cost of Evaporation.

74. *Cost of coal per ton of —— lbs. delivered in boiler room.........*	$
75. Cost of fuel for evaporating 1,000 lbs. of water under observed conditions....	$
76. *Cost of fuel used for evaporating 1,000 lbs. of water from and at 212 degrees.......*	$

Smoke Observations.

(App. XXXIV. and XXXV.)

77. Percentage of smoke as observed..............................	per cent.
78. Weight of soot per hour obtained from smoke meter...........	ounces.
79. Volume of soot per hour obtained from smoke meter	cub. in.

Methods of Firing.

80. Kind of firing (spreading, alternate, or coking)................
81. Average thickness of fire....................................
82. Average intervals between firings for each furnace during time when fires are in normal condition ....
83. Average interval between times of levelling or breaking up....

Analyses of the Dry Gases.

84. Carbon dioxide (CO_2)................	per cent.
85. Oxygen (O)......	"
86. Carbon monoxide (CO)	"
87. Hydrogen and hydrocarbons................................	"
88. Nitrogen (by difference) (N)	"
	100 per cent.

TABLE NO. 2.

DATA AND RESULTS OF EVAPORATIVE TEST,

Arranged in accordance with the Short Form advised by the Boiler Test Committee of the American Society of Mechanical Engineers. Code of 1899.

Made by..................on...............boiler, at...................to determine...
Kind of fuel.... ....
Kind of furnace...

Method of starting and stopping the test ("standard" or "alternate," Art. X. and XI., Code) ....

Grate surface..................	sq. ft.
Water-heating surface	"
Superheating surface...	"

Total Quantities.

1. Date of trial...	
2. Duration of trial......................................	hours.
3. Weight of coal as fired*...................................	lbs.
4. Percentage of moisture in coal*.................	per cent.
5. Total weight of dry coal consumed..........................	lbs.
6. Total ash and refuse........	"
7. Percentage of ash and refuse in dry coal....................	per cent.

* See foot-notes of Complete Form.

8. Total weight of water fed to the boiler*....................	lbs.
9. Water actually evaporated, corrected for moisture or superheat in steam..	"
10. Equivalent water evaporated into dry steam from and at 212 degrees*..	"

Hourly Quantities.

11. Dry coal consumed per hour................................	lbs.
12. Dry coal per square foot of grate surface per hour...........	"
13. Water evaporated per hour corrected for quality of steam....	"
14. Equivalent evaporation per hour from and at 212 degrees*...	"
15. Equivalent evaporation per hour from and at 212 degrees per square foot of water-heating surface*	"

Average Pressures, Temperatures, etc.

16. Steam pressure by gauge	lbs. per sq. in.
17. Temperature of feed water entering boiler..................	deg.
18. Temperature of escaping gases from boiler..................	"
19. Force of draft between damper and boiler.........	ins. of water.
20. Percentage of moisture in steam, or number of degrees of superheating	per cent. or deg.

Horse-Power.

21. Horse-power developed (Item 14 ÷ 34½)*...................	H. P.
22. Builders' rated horse-power................................	"
23. Percentage of builders' rated horse-power developed.........	per cent.

Economic Results.

24. Water apparently evaporated under actual conditions per pound of coal as fired. (Item 8 ÷ Item 3)................	lbs.
25. Equivalent evaporation from and at 212 degrees per pound of coal as fired.* (Item 10 ÷ Item 3)......................	"
26. Equivalent evaporation from and at 212 degrees per pound of dry coal.* (Item 10 ÷ Item 5)...................... ...	"
27. Equivalent evaporation from and at 212 degrees per pound of combustible.* [Item 10 ÷ (Item 5 − Item 6)]............	"

(If Items 25, 26, and 27 are not corrected for quality of steam, the fact should be stated.)

Efficiency.

28. Calorific value of the dry coal per pound............	B. T. U.
29. Calorific value of the combustible per pound................	"
30. Efficiency of boiler (based on combustible)*.......	per cent.
31. Efficiency of boiler, including grate (based on dry coal)......	"

Cost of Evaporation.

32. Cost of coal per ton of —— lbs. delivered in boiler-room	$
33. Cost of coal required for evaporating 1,000 pounds of water from and at 212 degrees...............	$

*See foot-notes of Complete Form.

APPENDICES TO CODE OF 1899.

APPENDIX I.

RELATIVE WEIGHTS OF WATER AND FUEL.

The elaborate directions and multiplicity of details provided for in the foregoing Code should not divert the minds of amateurs from the fact that the principal elements to be ascertained in a boiler test are the weight of water evaporated and the weight of the fuel required to produce such evaporation. If the Code be scanned closely with this thought in mind, it will be found that many of the elaborate provisions are intended to secure accuracy in determining these important elements. It is true that there are provisions embodied which do not refer directly thereto, but it is necessary that all available data be obtained so that comparisons can be made with the performances of other boilers, for the purpose of adjusting contracts, for general information, as a guide in the selection of fuel, or for improvements in the future.

Moreover, the determination of the two primary elements, to wit: the weights of water and of coal, are not as easy as would seem to an amateur. Many of the older members of the profession have again and again seen boiler tests conducted by inventors and manufacturers who supposed they were obtaining honest reports from their employees, without realizing a trait of human nature which actuates a man whose livelihood depends upon the success of another. Some workmen will make the results come out as they suppose their employers wish them, and if there is any coal to be had in the vicinity that has not been weighed, it will be purloined, a shovelful at a time; and if men of this class are expected to tally the number of tanks of water fed into a boiler, although instructed to be strictly honest and accurate, there will a doubt arise in their minds whether a tally has been made or not, and another tally be made under the influence of such doubt. It is therefore necessary to call the attention of amateurs and young engineers to checks which have been provided to prevent errors in weighing or tallying. It is urged that Article XIII. and other provisions of the Code be particularly studied in connection with the subsequent remarks of different members of the profession, contained particularly in Appendices III., IV., V., VI., VII.,

VIII. It will be found that all agree that the coal should be weighed and water measured or weighed at practically regular intervals, and that in every case the *time* be put down when a bucket of coal is dumped or a tank of water let down, when, by simple reference to the clock, all disputes as to neglected tallies will be eliminated. C. E. E.

Appendix II.*

OBJECT OF THE TEST.

In preparing for and conducting trials of steam boilers, the specific object of the proposed trial should be clearly defined and steadily kept in view.

1. If it be to determine the efficiency of a given style of boiler or of boiler setting under normal conditions, the boiler, brickwork, grates, dampers, flues, pipes, in short, the whole apparatus should be carefully examined and accurately described, and any variation from a normal condition should be remedied if possible, and, if irremediable, clearly described and pointed out.

2. If it be to ascertain the condition of a given boiler or set of boilers with a view to the improvement of whatever may be faulty, the conditions actually existing should be accurately observed and clearly described.

3. If the object be to determine the relative value of two or more kinds of coal, or the actual value of any kind, exact equality of conditions should be maintained if possible, or, where that is not practicable, all variations should be duly allowed for.

4. Only one variable should be allowed to enter into the problem ; or, since the entire exclusion of disturbing variations cannot usually be effected, they should be kept as closely as possible within narrow limits, and allowed for with all possible accuracy.

J. C. H.

Appendix III.

GENERAL OBSERVATIONS.

All observations are to be made by the expert, either personally or by his assistants. No statement of any kind is to be

* This and several other Appendices are copied from the report of the Committee of 1885. (See List of Appendices, p. 111.) Those signed J. C. H. were contributed to the Code of 1885 by the late John C. Hoadley.

received from the owner or persons in charge of the boiler. All possibility of anything that would falsify the results must be closely guarded against; all pipes not used must be taken away or blank flanges inserted.

The two great points that are to be determined in every test of a steam boiler, whatever the special and precise purpose of such test may be, are the pounds of fuel burned and the pounds of water evaporated.

To arrive at these we need to know, first, the pounds of fuel put into the furnace, and, second, the pounds of water fed into the boiler.

To ascertain these facts with certainty is the fundamental requisite in all cases. The possibility of an error in either of these respects throws doubt upon all the results or indications of the test. The coal supplied to the furnace and the water fed to the boiler should, therefore, each be ascertained in a manner that proves its own correctness and excludes doubt.

All tests of this nature are properly regarded with suspicion. I often myself read of tests and results that I put no faith in, and the same must be true of every one who is experienced in this matter. I am therefore strenuous on this point, that a system of firing and a system of measuring the feed-water should be employed that will prove the correctness of the record, and, if errors are made, will clearly expose them.

If possible the steam generated should be condensed by passing it through a surface condenser, where it is cooled by a strong current of water in a closed chamber. By this means the number of thermal units added may be ascertained with precision.

A boiler test cannot be conducted properly when it is complicated by being combined with an engine test.

C. T. P.

Appendix IV.

PRECAUTIONS TO BE OBSERVED IN MAKING A BOILER TEST.

It should be steadily kept in mind that the principal observations to be made are the quantities of coal consumed and of water evaporated. If these quantities are ascertained accurately, and the conditions made the same at the beginning and end of the test, the most important requisites of a boiler trial will be secured. Other observations have their value both for scientific and practical purposes, but are in most cases subsidiary.

Boiler tests are often undertaken with insufficient apparatus and assistance. It is possible for a single person to test one boiler, or even several in a battery, but it requires a great deal of labor to do so, and in many cases such person would be so fatigued as to be liable to make a simple error vitiating the results. He would, moreover, at no time be able to give proper oversight to the test, so as to prevent accidental or unauthorized interferences. It is very desirable, in fact almost indispensable, that an assistant be detailed to weigh the coal, and another to weigh or measure the water; if calorimeter tests are to be undertaken, still another assistant should be provided. The engineer in charge is then left free to oversee the work of all, and relieve either temporarily when necessary. Engineers are frequently called upon to make boiler trials in connection with parties whose interests are antagonistic to a fair test, and frequently the voluntary assistance of busybodies is likely to produce errors in the results. It is therefore essential to have trustworthy assistants, and those of sufficient calibre not to be confused by interested parties, who will frequently endeavor in the most plausible manner to make out that a certain measure of coal has been already tallied, or that a certain tank of water has not been tallied.

In the first engine trials at the American Institute Exhibition (1869), in the Centennial boiler trials (1876), and since in private trials respecting performance of boilers as between the contractor and purchaser, the writer has arranged for both interests to take the data at the same moment, with instructions, if agreement could not be had, that the difference be at once referred to him.

In weighing the coal, the barrow or vessel used should be balanced on a scale and then filled to a certain definite weight. The laborer will soon learn to fill a vessel to the same weight within a few pounds by counting the number of shovels thrown in, when the change of a lump or two to or from a small box alongside the scale will balance it.

The water may be measured in one tank by filling it to one mark and pumping down to another, but this involves stopping the pump when filling the tank, thereby failing to maintain uniformity of conditions. Two tanks arranged so that each can be filled and emptied alternately are much better. A still better plan is to have a settling tank to pump from and a measuring tank which is emptied into it, and this plan is improved by setting the measuring tank on a scale, and actually weighing the water. For large operations three tanks are necessary: a lower tank to pump from, and two measuring tanks, one of which is filling while the other is being emptied. The writer has made several double measuring tanks with a horizontal section like the figure "8," there being a partition between the two tanks lower than the rim of the tanks. Water is conducted at will in either of the two tanks by a pipe swinging over the partition. One tank is allowed to fill until the water in it overflows into the other (which has been emptied and the cock shut), when the filling pipe is shifted into the empty tank, and as soon as the water level subsides in the full one the water in that tank is allowed to flow out, the cock shut before the other tank is filled, and the operation repeated.

A simple tally should never be trusted. Nothing seems more reliable to an inexperienced observer than to mark 1, 2, 3, 4, with a diagonal cross mark for 5; but when there are waits of several minutes between the marks, and several operations performed after a tally is made, there will be confusion in the mind whether or not the tally has been actually made. The tallies both of weights of coal and of tanks of water should be written on separate lines, the time noted opposite each, and the records always made at the beginning or termination of some particular operation; for instance, in weighing coal at the time only when the barrel or bucket is dumped on the fire-room floor. It is desirable to have a number of coincident records of coal and water throughout the trial, so that in case of accident it may be held to have ended at one of such times. The uniformity of the operations may also be tested in this way from time to time. For this reason it will be found convenient to fire from a wheelbarrow set on a scale and to have a float or water-gauge connected with the tank from which the water is pumped; by which means the coal and water used may, in an evident way, be ascertained for any desired interval.

C. E. E.

Appendix V.

WEIGHING THE COAL.

Where practicable, a box consisting of sides, back, and bottom, capable of holding 500 pounds of coal for each boiler having 25 square feet fire-grate area, and in proportion for larger grates, should be placed on scales conveniently located for shovelling from it upon the fire grate.

The exact time of weighing each charge of, say, 500 pounds should be noted and the net weight, whatever it be, set down. The box should be balanced by a fixed counterpoise, so that the readings of the scale beam may be net pounds of coal.

On the instant of closing the fire door after each firing, the weight should be taken and the exact time noted as well as the weight. The box should be completely emptied each time, and the accuracy of the counterpoise observed, and, if necessary, adjusted. The differences of weight at each firing will give the several quantities fired; the differences of time will give the intervals in minutes and seconds between successive firings; and the differences of time between the successive charges—500 pounds, more or less—on the scales will afford a check on the record of the firing. A chart or diagram should be plotted from the figures, which will clearly show the degree of regularity with which firing has been carried on, and reveal any omission or error.

J. C. H.

Appendix VI.

WEIGHING THE COAL.

I would recommend that on a test no coal be brought into the furnace room except as follows:

A barrow to be employed, and be loaded each time at the coal pile with an equal amount, say 600 pounds, of coal, weighed on platform scales at the pile. The time when it is thus wheeled into the furnace-room to be noted. The barrow to be wheeled upon another platform scale before the furnace for the following purpose:

In separate columns, the times of charging the furnace to be noted, and the reading of the scales after each charging. The coal to be shovelled from the barrow directly into the furnace.

Now here the log would show at once, by the great inequality of the intervals, if a barrow-load of coal had been added or omitted, and the weights charged on the fire would check the barrow-loads, and should also show the rate of firing.

No other coal being convenient to the furnace, reasonable watching will give assurance that none is surreptitiously added to the fire. C. T. P.

APPENDIX VII.

WEIGHING THE WATER.

The best way is to have two tanks capable of holding 1,200 to 1,800 pounds—say 20 to 30 cubic feet; or two weighing tanks and one feeding tank, 144 to 216 gallons, each placed on a pair of scales, to be filled and emptied alternately. To avoid suspicion of leakage of stop-cocks, it is better to draw out the water by a flexible pipe or suction hose put alternately into the two tanks. The time of each weighing of each tank, to be designated as tank No. 1 and tank No. 2, should be accurately noted, and a method of checking the weighings by a diagram or chart, as in respect to the coal, should be adopted. J. C. H.

APPENDIX VIII.

MEASURING THE FEED WATER.

I would recommend that on all tests of any magnitude the water be fed to the boilers from a single tank of known capacity. That the tank be always filled so as to overflow while the feed pump is stopped, and also the communication to it is closed.

That the inlet pipe shall terminate above the tank so that its orifice is always visible. That after the supply has been shut off, and the overflow has ceased, the communication to the feed pump be opened and the pump be started. That the water be drawn down to a point that is determined by a line on a graduated rod attached to a float that has been well painted so as not to absorb the water; and that then the pump be stopped, communication with it be closed, and the tank be refilled.

The time of starting the pump each time to be carefully noted.

The regularity of the intervals would leave no room for doubt as to the number of tanks that had been emptied. The watch of opposite interests would insure the accuracy of the line at which the pump is stopped each time, and at which the test was closed.

C. T. P.

Appendix IX.

KEEPING TIME OF OBSERVATIONS.

All time-keepers should be set at the start, and compared at the close ; a gong should be used to give a signal for all observations designed to be synchronous and isochronous, in order that such observations may be conveniently arranged.

J. C. H.

Appendix X.

DESCRIPTION OF BOILER.

The report should include a complete description of the boiler, which, for special boilers, should be written out at length, but generally can conveniently be presented in tabular form substanially as follows :

Type of boiler.
Diameter of shell.
Length of shell.
Number of tubes.
Diameter " "
Length " "
Diameter of steam drum.
Width of furnace.
Length of furnace.
Kind of grate bars.
Width of air spaces.
Ratio of area of grate to area of air spaces.
Area of chimney.
Height of chimney.
Length of flues connecting to chimney.
Area " " " " "

GOVERNING PROPORTIONS.

Grate surface.

Heating surface { Water. Steam. Total.

Area of draft through or between tubes.

Ratio grate to heating surface.

" draft area to grate.

" " " " total heating surface.

Water space.

Steam space.

Ratio grate to water space.

" " " steam space.

C. E. E.

Appendix XI.

DETERMINING THE MOISTURE IN COAL.

Until recently two methods of determining moisture in coal have been in common use—first, the one usually adopted in boiler testing, which consists in drying a large sample, fifty pounds or more, in a shallow pan placed over the boiler or flue ; second, the method usually followed by chemists, of drying a one-gram sample of pulverized coal at 212 degrees Fahr., or a little above, for an hour, or until constant weight is obtained. Both methods are liable to large errors. In the first method the temperature at which the drying takes place is uncertain, and there is no means of knowing whether the temperature obtained is sufficient to drive off the moisture which is held by capillary force or other attraction within the lumps of coal, which, at least in case of bituminous coals, seem to be as porous as wood, and as capable of absorbing moisture from the atmosphere. The second method is liable to greater errors in sampling than the first, and during the process of fine crushing and passing through sieves a considerable portion of the moisture is apt to be removed by air-drying. In an extensive series of boiler tests made by the writer in the summer of 1896, it became necessary to find more accurate means of determining moisture than either of those above described. It was found that by repeated heating at gradually increasing temperatures from 212 degrees up to 300 degrees or over, and weighing at intervals of an hour or more, that the weight of coal continually decreased until it became nearly constant, and then a very slight increase took place, which increase became greater on further repeated heatings to temperatures above 250 degrees. It has often been stated that if coal is heated above 212 degrees Fahr. volatile matter will be driven off; but repeated tests on seventeen different varieties of coal mined in western Pennsylvania, Ohio, Indiana, Illinois, and Kentucky invariably showed a gradual decrease of weight to a minimum, followed by the increase as stated above, and in no single case was there any perceptible odor or other indication of volatile matter passing off below a temperature of 350 degrees. The fact that no volatile matter was given off was further proved by heating the coal in a glass retort and catching the vapor driven off in a bottle filled with water and inverted in a basin ; the air displaced from the retort by expansion due to the heating displacing the water in the bottle. When the retort was cooled, after being heated to 350 degrees in an oil bath, the air thus expanded contracted, and returned from the bottle to the retort, leaving the bottle full of water as at the beginning of the heating, showing that no gas had been given off, except possibly such exceedingly small amount as might be absorbed by the water. The method described in Section XV. of the report was then adopted as the best available method of determining the moisture in these coals. Its accuracy was further checked by other methods, as follows: 1. A lump of Illinois coal which had been found by heating to 300 degrees to contain 14 per cent. of moisture was exposed to the air in a closet for two months, and it gradually reabsorbed from the atmosphere all the moisture that had been driven off. 2. Another sample of the same coal was placed in a dessicator with concentrated sulphuric acid, and it lost practically the same percentage of moisture in two months that was given off by the heating. 3. Seven other samples of different coals were similarly treated for six weeks, and all of them lost within about one per cent. of the amount that duplicate samples had lost by heating, and the difference in each case was lost by a single heating for an hour to 280 degrees.

The new method of drying and its results were communicated by the writer to Prof. R. C. Carpenter of Cornell University, shortly after they were made, and he thereupon began experimenting with the method, and fully confirmed the writer's conclusions. In a letter dated May 18, 1897, he says: "We have investigated the moisture question, and find that in all the samples tested, some four or five in number, there is no appreciable loss between temperatures of 250 and 350 degrees; at least, the loss is less than our means of weighing." In his paper on "Hygrometric Properties of Coals," presented at the Hartford meeting (*Transactions*, vol. xviii., p. 948), he says:

"With the most volatile coals there is no sensible loss of weight due to the driving off of volatile matter under a temperature of 380 degrees Fahr., and with anthracite coal there is no sensible loss under a temperature of 700 degrees Fahr."

W. K.

APPENDIX XII.

PROXIMATE ANALYSES OF COAL.

For comparing the proximate analyses of different coals, it is desirable that they should be reported in a uniform style. The four constituents determined by heating in a crucible should be given and their sum should equal 100 per cent. When sulphur is determined it should be stated separately, and it should not be subtracted from the fixed carbon and the volatile matter (half from each, as is the custom of some chemists, or 0.4 from one and 0.6 from the other, as is the custom of others), since it cannot be known what proportion of sulphur escapes from the crucible with the volatile matter and what proportion is burned with the fixed carbon. The carbon ratio—that is, the ratio of fixed carbon to volatile matter—should also be stated, preferably as percentages of their sum, thus: 40 per cent. volatile matter, 60 per cent. fixed carbon, which is equivalent to a carbon ratio of $1\frac{1}{2}$.

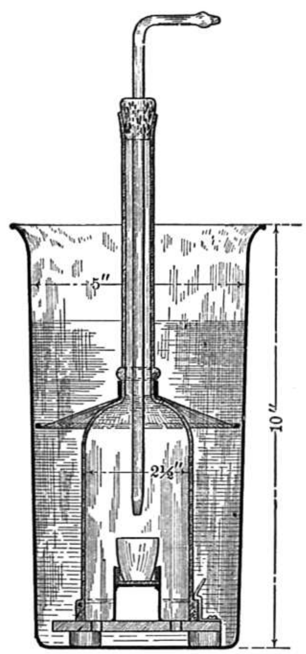
The proximate analysis is a most valuable means of identifying the general character of the coal. First, the amount of volatile matter, expressed as a percentage of the combustible, distinguishes between the anthracite, the semi-bituminous, and the bituminous coals. Second, among the bituminous coals the moisture is an important guide to the character of the coal, Third, the ash is also a criterion of the coal's value. Fourth, the sulphur taken in connection with the ash is also an indication of the value of the fuel, as high sulphur generally is found in a coal which clinkers badly, and with which it is difficult to obtain the rated capacity of a boiler.

W. K.

Appendix XIII.

COAL CALORIMETER.

The coal calorimeter which the writer employs is that described in a paper on " A Coal Calorimeter," read at the Chicago meeting in 1893, and published in the *Transactions*, vol. xiv., page 816. The details of the instrument are shown in the accompanying cut (Fig. 1). It consists of a glass beaker 5 inches



BARRUS' COAL CALORIMETER
Boiler Test Com.

FIG. 1.

in diameter and 11 inches high, which can be obtained of most dealers in chemical apparatus. The combustion chamber is of special form, and consists of a glass bell having a notched rib around the lower edge, and a bead just above the top, with a tube projecting a considerable distance above the upper end. These have thus far been made by J. W. Staniford, 36 Hanover

Street, Boston, and they are inexpensive. The bell is $2\frac{1}{2}$ inches inside diameter, $5\frac{1}{2}$ inches high, and the tube above is $\frac{5}{8}$ inches inside diameter, and extends beyond the bell a distance of 9 inches. The base consists of a circular plate of brass, 4 inches in diameter, with three clips fastened on the upper side for holding down the combustion chamber. The base is perforated, and the under side has three pieces of cork attached, which serve as feet. To the centre of the upper side of the plate is attached a cup for holding the platinum crucible in which the coal is burned. To the upper end of the bell, beneath the bead, a hood is attached, made of wire gauze, which serves to intercept the rising bubbles of gas and retard their escape from the water. The top of the tube is fitted with a cork, and through this is inserted a small glass tube which carries the oxygen to the lower part of the combustion chamber. This tube is movable up and down, and to some extent sideways, so as to direct the current of oxygen to any part of the crucible, and adjust it to a proper distance from the burning coal.

There is no patent on the instrument, and, with the above description, any one interested can, with a little trouble, secure an outfit on this plan. In addition to the apparatus here shown there is required a tank of oxygen, such as the calcium light companies furnish, scales for weighing water, and delicate balances for weighing coal, besides a delicate thermometer for taking the temperature of the water, and another for showing the temperature of the atmosphere. The former should be graduated to tenths of a degree Fahr.

In the writer's work with the instrument the quantity of coal used for a test is one gram, and of water 2,000 grams. In working out the heat units, allowance is made for the specific heat of the calorimeter, either by calculation or by experiment. Radiation is allowed for by commencing the test with a temperature as many degrees below the atmosphere as the temperature rises above the atmosphere at the end of the test. When very smoky coals are used, the sample is mixed with a small proportion of anthracite of known calorific value ; and when anthracite coal is used, a small percentage of bituminous coal is likewise mixed with it.

Samples of two bituminous coals submitted by Mr. Kent of the Committee, one of which was a highly volatile coal, were tested in this instrument, and a sample of the same submitted to Mr. Henry J. Williams of Boston for analysis. The analyses gave the following results based on dry coal :

	No. 1.	No. 2.
Carbon	71.84 per cent.	82.27 per cent.
Hydrogen	4.81 "	4.70 "
Nitrogen	1.58 "	1.56 "
Oxygen	13.98 "	5.34 "
Ash	6.74 "	4.93 "
Volatile sulphur	1.05 "	1.20 "
	100.00	100.00

The calorific values worked out from these analyses, and those given by the calorimeter, are presented in the following table, the formula used for obtaining the total heat of combustion from the analysis being $145 \times C + 625 \times \left(H - \frac{O}{8}\right)$.

	Number.	B. T. U. Based on Dry Coal.	B. T. U. Based on Combustible.
Calorimeter	1	12,705	13,646
Analysis	1	12,323	13,208
Calorimeter	2	14,631	15,320
Analyses	2	14,452	15,197

It will be seen that in one case the two results agree within less than one per cent., and in the other case within about three per cent.

The writer has used this instrument for over seven years, and has tested over 200 samples of coal with it. The results always seem consistent with one another, and they agree substantially with those obtained from reliable analyses in cases when these have been made. G. H. B.

Appendix XIV.

Comparative Calorimetric Tests of Coals.

The writer, in his paper on "The Efficiency of a Steam Boiler," presented at the St. Louis meeting, May, 1896 (*Transactions*, vol. xvii., p. 649), expressed the opinion that the variations in results of calorimetric tests of coal "throw doubt upon all calorimetric 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." The results of tests of two coals by three different calorimeters were given in the paper. Mr. Barrus has since made tests of the same coals, using his own calorimeter, and they have been analyzed by Mr. Henry J. Williams, by Mr. C. H. Benedict, and also by some senior students of an engineering college in connection with their thesis work. The results of all the calorimeter tests and of the heating value calculated from the analyses are given below. Coal No. 1 was from Jackson Co., Ohio, and No. 2 from New River, W. Va.

	Heating Value per Lb. Coal, B. T. U.		Heating Value per Lb. Combustible, B. T. U.		Ratio (2)÷(1)
	(1)	(2)	(1)	(2)	
Carpenter Calorimeter	13,170	15,200	14,620	16,210	1.109
Thompson Calorimeter (Boston)	11,913	13,066	13,302	13,799	1.037
Thompson Calorimeter (St. Louis)	11,894	13,527	....	....	......
Barrus Calorimeter	12,705	14,631	13,646	15,320	1.123
Analysis, Williams	12,323	14,452	13,208	15,197	1.150
Analysis, Students	10,786	14,016	12,145	14,885	1.226
Analysis, Benedict	....	15,215	....	15,967	......

The results of Mr. Barrus's calorimetric test and of Mr. Williams's analyses show a fairly satisfactory agreement, but they are so much below the results of the Carpenter calorimeter, and so much above the results of the Thompson calorimeter, that the true heating value of these coals is still a matter of doubt. The results of the analysis of coal No. 1 by the students is so far below the results of the other tests of the same coal that it is of interest only in showing what great errors in analyses are possible. The ratio of the heating values of the combustible of coals No. 1 and 2 show that the relative values as well as the absolute values obtained by different calorimeters are apt to vary widely.

Mr. Benedict's analysis is given by Professor Carpenter, as follows, on dry coal: C, 85.07; H, 5.01; N, 0.82; O, 3.79; Ash, 4.71; S, 0.30; calculated heat value, 15,215 British thermal units. The samples furnished to all the experimenters were identical. The coal was crushed in a coffee mill, thoroughly mixed, and several small bottles were filled with samples of the crushed coal at the same time.

More recently the writer has obtained comparative figures by three different calorimeters and by analysis of two samples of Mt. Olive (Ill.) coal, as follows:

	Heating Value per Lb. Combustible, B. T. U.		Ratio (2)÷(1)
	(1)	(2)	
Prof. R. C. Carpenter, Carpenter Calorimeter	13,700	13,800	1.007
Prof N. W. Lord, Mahler Calorimeter	13,870	13,968	1.007
Prof. W. B. Potter, Thompson Calorimeter	13,687	13,787	1.007
Analysis by Ricketts & Banks	14,020	13,955	0.996
Average	13,819	13,878	1.004

All of these results show a remarkably close agreement. The greatest variation, that between the result by the Thompson calorimeter and by analysis, is only 2.4 per cent. These figures would indicate that the Thompson calorimeter is fairly reliable, but a very different conclusion must be drawn from the results of the tests by two Thompson calorimeters of the Jackson and the New River coals, which are far below the results obtained by the Carpenter and the Barrus calorimeters.

The conclusion to be drawn from the two series of tests tabulated above is that closely concordant results may be obtained from different calorimeters when properly handled by expert chemists, and that these results will agree with the results calculated from accurate analyses; but that occasionally very erroneous results may be obtained, and that a single calorimetric test unchecked by comparison with a test by another calorimeter is to be regarded with suspicion, especially when the test is made with a Thompson calorimeter, when the reported heating value per pound of combustible is low compared with results of other tests of coal from the same region, and when the boiler efficiency calculated from such calorimetric test is high.

W. K.

Appendix XV.

DETERMINATION OF THE MOISTURE IN THE STEAM.

The throttling steam calorimeter, first described by Professor Peabody in the *Transactions*, vol. x., page 327, and its modifications by Mr. Barrus, vol. xi., page 790; vol. xvii., page 617; and by Professor Carpenter, vol. xii., page 840; also the separating calorimeter designed by Professor Carpenter, vol. xvii., page 608, which instruments are used to determine the moisture existing in a small sample of steam taken from the steam pipe, give results, when properly handled, which may be accepted as accurate within 0.5 per cent. (this percentage being computed on the total quantity of the steam) for the sample taken. The possible error of 0.5 per cent. is the aggregate of the probable error of careful observation, and of the errors due to inaccuracy of the pressure gauges and thermometers, to radiation, and, in the case of the throttling calorimeter, to the possible inaccuracy of the figure 0.48 for the specific heat of superheated steam, which is used in computing the results. It is, however, by no means certain that the sample represents the average quality of the steam in the pipe from which the sample is taken. The practical impossibility of obtaining an accurate sample, especially when the percentage of moisture exceeds two or three per cent., is shown in the two papers by Professor Jacobus in *Transactions*, vol. xvi., pages 448, 1017.

In trials of the ordinary forms of horizontal shell and of water-tube boilers, in which there is a large disengaging surface, when the water level is carried at least 10 inches below the level of the steam outlet, and when the water is not of a character to cause foaming, and when in the case of water-tube boilers the steam outlet is placed in the rear of the middle of the length of the water drum, the maximum quantity of moisture in the steam rarely, if ever, exceeds two per cent.; and in such cases a sample taken with the precautions specified in Article XIV. of the Code may be considered to be an accurate average sample of the steam furnished by the boiler, and its percentage of moisture as determined by the throttling or separating calorimeter may be considered as accurate within one-half of one per cent. For scientific research and in all cases in which there is reason to suspect that the moisture may exceed two per cent., a steam separator should be placed in the steam pipe, as near to the steam outlet of the boiler as convenient, well covered with felting, all the steam made by the boiler passing through it, and all the moisture caught by it carefully weighed after being cooled. A convenient method of obtaining the weight of the drip from the separator is to discharge it through a trap into a barrel of cold water standing on a platform scale. A throttling or a separating calorimeter should be placed in the steam pipe, just beyond the steam separator, for the purpose of determining, by the sampling method, the small percentage of moisture which may still be in the steam after passing through the separator.

The formula for calculating the percentage of moisture when the throttling calorimeter is used is the following:

$$w = 100 \times \frac{H - h - k(T - t)}{L},$$

in which w = percentage of moisture in the steam, H = total heat, and L = latent heat per pound of steam at the pressure in the steam pipe, h = total heat per pound of steam at the pressure in the discharge side of the calorimeter, k = specific heat of superheated steam, T = temperature of the throttled and superheated steam in the calorimeter, and t = temperature due to the pressure in the discharge side of the calorimeter, = 212° Fahr. at atmospheric pressure. Taking $k = 0.48$ and $t = 212$, the formula reduces to

$$w = 100 \times \frac{H - 1146.6 - 0.48\,(T - 212)}{L}$$

W. K.

Appendix XVI.

CORRECTION FOR RADIATION FROM THROTTLING CALORIMETERS.

The formulæ usually given for determining moisture in a throttling calorimeter, including that given above by Mr. Kent, make no allowance for radiation from the exterior surfaces of the instrument. It is true that this allowance is small and does not affect the results but a small fraction of 1 per cent.; but it nevertheless exists, and should properly be taken into account. In my own work I have found that the radiation reduces the temperature of the wire-drawn steam some 6 degrees, and this represents about .3 of 1 per cent. of moisture. My practice is to allow for the radiation by determining the normal for the instrument, as described in Appendix XVII.

It should be noted here that this normal can be readily determined when the calorimeter is attached to a horizontal section of the steam pipe, and the condensing surface immediately above the sampling pipe is thus reduced to a minimum.

G. H. B.

Appendix XVII.

COMBINED CALORIMETER AND SEPARATOR.

The form of steam calorimeter which the writer uses is termed the "1895 pattern" universal steam calorimeter, and is a modification of the one described in the *Transactions*, vol. xi., page 790. It is illustrated in the accompanying cut (Fig. 2), which is reprinted from page 618, vol. xvii., in the *Transactions*. It consists of a throttling calorimeter and separator combined, the latter being attached to the outlet where the steam of atmos-

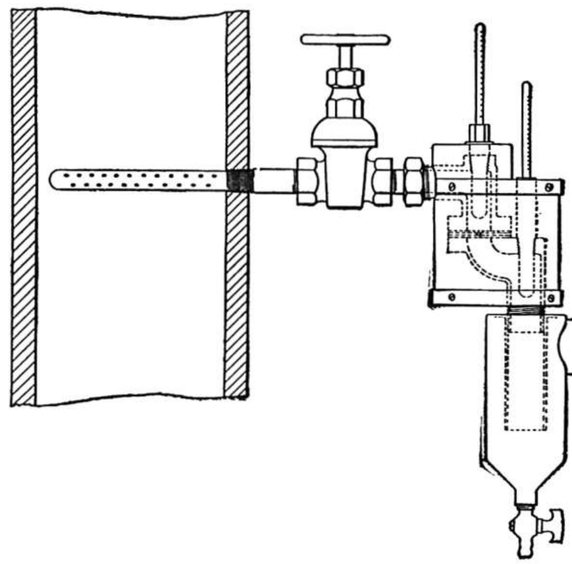


Fig. 2.

pheric pressure is escaping. If the moisture is too great to be determined by the readings of the two thermometers, the separator catches the balance, and the total quantity of moisture is made up in part of that shown by the thermometers, and in part of that collected from the separator. The percentage of moisture shown by the thermometers is obtained by referring the indication of the lower thermometer to the normal reading of that thermometer with dry steam, and dividing the fall of temperature by the constant of the instrument for one per cent. of moisture. The normal reading is determined by observing the indications when steam in the main pipe is in a quiescent state, and the constant is a quantity varying uniformly from

21 degrees at 80 pounds pressure to 20 degrees at 200 pounds pressure. The percentage of moisture, if any, discharged from the separator, is found by dividing its quantity corrected for radiation by the total quantity of steam and water passing through the instrument in the same time, as ascertained by experiment, and multiplying the result by 100.

G. H. B.

Appendix XVIII.

CORRECTIONS FOR QUALITY OF STEAM.

Given the percentage of moisture or number of degrees of superheating, it is desirable to develop formulæ showing what we have termed "the factor of correction for quality of steam," or the factor by which the "apparent evaporation," determined by a boiler test, is to be multiplied to obtain the "evaporation corrected for quality of steam." It has been customary to call the proportional weight of steam in a mixture of steam and water "the quality of the steam," and it is not desirable to change this designation. The same term applies when the steam is superheated by employing the "equivalent evaporation," or that obtained by adding to the actual evaporation the proportional weight of water which the thermal value of the superheating would evaporate into dry steam from and at the temperature due to the pressure. "The factor of correction for quality of steam" in a boiler test differs from the "quality" itself, from the fact that the temperature of the feed water is lower than that of the steam.

Let

Q = quality of moist steam as described above.

Q_1 = the quality of superheated steam as described above.

P = the proportion of moisture in the steam.

k = the number of degrees of superheating.

F = the factor of correction for the quality of the steam when the steam is moist.

F_1 = the factor of correction for the quality of the steam when the steam is superheated.

H = the total heat of the steam due to the steam pressure.

L = the latent heat of the steam due to the steam pressure.

T = the temperature of the steam due to the steam pressure.

T_1 = the total heat in the water at the temperature due to the steam pressure.*

J = the temperature of the feed water.

J_1 = the total heat in the feed water due to the temperature.*

Therefore, for moist steam:

(1) . . . . $Q = 1 - P$

(2) . . . . $P = 1 - Q$

(3) . . . . $Q + P = 1$

See also Equation (6).

With both the condensing and throttling calorimeters the water and steam are withdrawn from the boiler at the temperature of the steam, and with a separator the water can only be accurately measured when under pressure, so that the difference between the steam and the moisture in the steam, as they leave the boiler, is simply that the former has received the latent heat due to the pressure, and the latter has not. There is, however, imparted to the water in the boiler, not only the latent heat in the portion evaporated, but the sensible heat due to raising the temperature of all the water from that of the feed water to that of the steam due to the pressure.

In Equation (3) the proportional part Q receives from the boiler both the sensible and the latent heat, or the total heat above the temperature of the feed $= Q\,(H - J_1)$ thermal units, and the part P the difference in sensible heat between the temperatures of the steam and of the feed water $= P\,(T_1 - J_1)$ thermal units. If all the water were evaporated, each pound would receive the total heat in the steam above the temperature of the feed, or $H - J_1$. "The factor of correction for the quality of the steam," when there is no superheating, is therefore

$$(4)\ .\ F = \frac{Q\,(H - J_1) + P\,(T_1 - J_1)}{H - J_1} = Q + P\left(\frac{T_1 - J_1}{H - J_1}\right)$$

The superheating of the steam requires 0.48 of a thermal unit for each degree the temperature of the steam is raised, so

* Most tables of the properties of steam and of water are based on the total heat of steam and water above 32 degrees Fahr. For such tables the total heat in the water at a given temperature is equal approximately to the corresponding temperature minus 32 degrees. Exact values should, however, be taken from the tables.

for k degrees of superheating there will be $0.48k$ thermal units per pound weight of steam, and the "factor of correction for the quality of the steam," with superheating is:

$$(5) \quad . \quad . \quad . \quad F_1 = \frac{H - J_1 + 0.48k}{H - J_1} = 1 + \frac{0.48k}{H - J_1}$$

See also Equation (7).

With the throttling calorimeter the percentage of moisture, P, or number of degrees of superheating, is determined as explained in Appendices XV. and XVI.

Since the invention of the throttling calorimeter (Appendix XVI.), the use of the original condensing, or so-called barrel, calorimeter is no longer warranted. Accurate results should, however, be obtained by condensing all the steam generated in the boiler, and this plan has been followed in certain cases. It has, therefore, been thought desirable to add other formulæ applicable to condensing calorimeters. The following additional notation is required:

W = the original weight of the water in calorimeter, or weight of circulating water for a surface condenser.

w = the weight of water added to the calorimeter by blowing steam into the water, or of "water of condensation" with a surface condenser.

t = total heat of water corresponding to initial temperature of water in calorimeter.

t_1 = total heat of water corresponding to final temperature in calorimeter.

Evidently, then:

$W(t_1 - t)$ = the total thermal units withdrawn from the boiler and imparted to the water in calorimeter.

$\frac{W}{w}(t_1 - t)$ = the thermal units per pound of water withdrawn from the boiler and imparted to the water in calorimeter, from which should be deducted $T_1 - t_1$ to obtain the number of thermal units per pound of water withdrawn from the boiler at the pressure due to the temperature, T.

Since only the latent heat, L, is imparted to the portion of the water evaporated, the quality Q, or proportional quantity evaporated, may be obtained by dividing the total thermal units per pound of water abstracted at the pressure due to the temperature, T, by the latent heat, L. Hence, as given in Appendix XVII., 1885 Code, with some differences in notation:

$$(6) \quad . \quad . \quad Q \text{ and } Q_1 = \frac{1}{L}\left[\frac{W}{w}(t_1 - t) - (T_1 - t_1)\right]$$

The value Q applies when the second term is less than unity. P may be derived therefrom by substitution in Equation (2) and F from Equation (4).

Q_1 applies when the second term of the above equation is greater than unity, which shows that the steam is superheated, and, as in this case, the heating value of the superheat has already been measured by heating the water of the calorimeter; the proportional thermal value of the same, in terms of the latent heat, L, is represented directly by $Q_1 - 1$, and we have as the factor of correction for the quality of the steam, with superheating:

$$(7) \quad . \quad . \quad F_1 = \frac{H - J_1 + L\,(Q_1 - 1)}{H - J_1} = 1 + \frac{L\,(Q_1 - 1)}{H - J_1}$$

See also Equation (5).

When the quality is greater than 1, or equals Q_1, the number of degrees of superheating is:

$$(8) \quad . \quad . \quad . \quad k = \frac{L(Q_1 - 1)}{0.48} - 2.0833L\,(Q_1 - 1)$$

C. E. E.

Appendix XIX.

THE QUALITY OF SUPERHEATED STEAM.

The quality of the superheated steam is determined from the number of degrees of superheating by using the following formula:

$$Q = \frac{L + 0.48\,(T - t)}{L},$$

in which L is the latent heat in British thermal units in one pound of steam of the observed pressure, T the observed temperature, and t the normal temperature due to the pressure. This normal temperature should be determined by obtaining a reading of the thermometer when the fires are in a dead condition and the superheat has disappeared, this temperature being observed when the pressure as shown by the gauge is the average of the readings taken during the trial. Observations being made by the same instrument, errors of gauge or thermometer are practically eliminated. G. H. B.

Appendix XX.

EFFICIENCY OF THE BOILER.

The efficiency of the boiler, including the grate, or the efficiency based on coal, is the quotient arising from dividing the heat absorbed by the boiler by the heating value of the total amount of coal supplied to the boiler, including the coal which falls through the grate. It may be conveniently calculated by multiplying the number of pounds of water evaporated from and at 212 degrees Fahr. into dry steam per pound of dry coal by 965.7, and dividing the product by the heating value in British thermal units of one pound of dry coal.

The efficiency of the boiler, not including the grate, or the efficiency based on combustible, is the quotient arising from dividing the heat absorbed by the boiler by the heating value of the combustible burned. It may be calculated by multiplying the number of pounds of water evaporated from and at 212 degrees Fahr. into dry steam per pound of combustible by 965.7, and dividing the product by the heating value in British thermal units of one pound of combustible; the term "combustible" being defined as coal dry and free from ash, or the coal supplied to the boiler less its moisture and the ash and unburned coal which falls through the grate or is otherwise withdrawn from the furnace.

The efficiency of the boiler, not including the grate (or the efficiency based upon combustible) is a more accurate measure of comparison of different boilers than the efficiency including the grate (or the efficiency based upon coal), for the latter is subject to a number of variable conditions, such as size and character of the coal, air-spaces between the grate bars, skill of the fireman in saving coal from falling through the grate, etc. It is, moreover, subject to errors of sampling the coal for drying and for analysis, which affect the result to a greater degree than they do the efficiency based upon combustible, for the reason that the heating value of per pound of combustible of any sample selected from a given lot, such as a car-load, of coal is practically a constant quantity and is independent of the percentage of moisture and ash in the sample; while the sample itself, upon the heating value of which the efficiency based on coal is calculated, may differ in its percentage of moisture and ash from the average coal used in the boiler test.

When the object of a boiler test is to determine its efficiency as an absorber of heat, or to compare it with other boilers, the efficiency based on combustible is the one which should be used; but when the object of the test is to determine the efficiency of the combination of the boiler, the furnace, and the grate, the efficiency based on coal must necessarily be used.

It has been proposed that in reporting the efficiency of a boiler when the fuel used contains hydrogen, the efficiency should be considered to be the sum of the percentage of the heating value of the fuel which is utilized by the boiler in making steam and of the percentage of that heating value which is lost in the shape of latent heat in the moisture in the chimney gases, which moisture is formed by the burning of the hydrogen. This latent heat may amount to over three per cent. of the total heating value of the fuel. The reason assigned for this proposal is that, since it is impossible for this heat to be utilized by the boiler because the gases are discharged at a temperature above 212 degrees Fahr., it should not be charged against the boiler. The writer does not consider it advisable that this method of reporting the efficiency should be adopted (1) because it is opposed to the generally accepted definition of efficiency, which is the useful work received from an apparatus divided by the work (or heat value of the fuel) put into it; (2) because in order to calculate it, it is necessary to know both the percentage of hydrogen in the coal and whether or not all of this hydrogen has been burned to H_2O, the first requiring an analysis of the coal, which is not always obtainable, and the second an analysis of the gases for hydrogen, which cannot be obtained with any approximation to accuracy with our present methods of sampling and analyzing gases; and (3) because it is opposed to the almost universal custom in reporting boiler tests. It is true that the latent heat of the H_2O in the chimney gases cannot be utilized (unless an economizer which discharges its gases below 212 degrees is used), and it is not the fault of the boiler that it cannot be utilized. It may be considered the misfortune of the boiler, when tested with hydrogenous coal, similar to the misfortune under which an engine labors when it is tested while supplied with a condenser which gives a vacuum of less than 30 inches of mercury. The engine might give a higher efficiency with a vacuum of 30 inches than it would with one of 27 or 28 inches; but it is not customary to credit the engine with the efficiency which it loses on account of the imperfect vacuum.

Since it is well understood that a boiler cannot show quite as high an efficiency (as commonly defined) when using bituminous coal high in hydrogen as when using anthracite nearly free from hydrogen, no harm is done, and much confusion is avoided, by reporting the efficiency as the percentage of the heating value of the coal which is actually utilized in making steam. The fact that bituminous coal is used is always stated in the report of a test made with that coal. If desired, a statement may also be made in the "heat balance" of the approximate or estimated percentage of heat which is lost in the latent heat of the moisture in the chimney gases, together with the loss due to moisture in the coal.

W. K.

Appendix XXI.

DISTRIBUTION OF THE HEATING VALUE OF THE FUEL.

In the operation of a steam boiler the following distribution of the total heating value of the fuel takes place:

1. Loss of coal or coke through the grate.

2. Unburned coal or coke carried in the shape of dust or sparks beyond the bridge wall.

3. Heating to 212 degrees the moisture in the coal, evaporating it at that temperature, and evaporating the steam made from it to the temperature of the flue gases = weight of the moisture in pounds × [(212 degrees $- t$) + 966 + 0.48 ($T - 212$)], in which T is the temperature (Fahr.) of the flue gases and t the temperature of the external air.

4. Loss of heat due to steam which is formed by burning the hydrogen contained in the coal, and which passes into the chimney as superheated steam = 9 times the weight of the hydrogen × [$(212 - t) + 966 + 0.48\,(T - 212)$].

5. Superheating the moisture in the air supplied to the furnace to the temperature of the flue gases = weight of the moisture × $0.48\,(T - t)$.

6. Heating of the gaseous products of combustion (not including steam) to the temperature of the flue = their weight × 0.24 $(T - t)$.

7. Loss due to imperfect burning of the carbon of the coal and to non-burning of the volatile gases.

8. Radiation from the boiler and furnace.

9. Heat absorbed by the boiler, or useful work.

Item 1 depends upon the size of the spaces between the grate bars; upon the kind of grate, as a plain, shaking, or travelling grate; upon the size of the coal; upon the character of the coal, as it requires to be more or less distributed on the grate in order to get a sufficient supply of air through it; upon the rate of driving of the furnace, rapid driving with some coals requiring more frequent shaking or cleaning of the grate than slow driving; and upon the skill of the fireman.

Item 2 depends upon the nature and fineness of the coal and upon the force of the draft. It is usually so small as to be inappreciable in its effect upon the results of the trial of a stationary boiler driven with natural draft, but in locomotives, with rapid rates of combustion, it often becomes quite important.

Item 3 depends upon the amount of moisture in the coal.

Item 4 depends upon the amount of hydrogen in the coal.

Item 5 depends upon the amount of moisture in the air. The moisture in the air may be obtained from its temperature and relative humidity, as determined by a wet-and-dry-bulb thermometer, by reference to hygrometric tables. The loss of heat due to the moisture in the air will rarely exceed 0.25 per cent. of the heating value of the fuel, and it may usually, therefore, be neglected.

Item 6 depends chiefly upon the type and proportions of the boiler, and upon the rate at which it is driven. This item is usually the largest of all the heat losses.

Items 3, 4, 5, and 6 depend also on the temperature of the flue gases.

Item 7 depends upon the character of the coal and of the furnace, and upon the skill of the fireman. This loss may be very large, 20 per cent. or more of the heating value of the coal, when highly bituminous coals are used in a furnace not adapted to them.

Item 8 depends chiefly upon the type, size, and setting of the boiler, and, when expressed as a percentage of the total heat of the fuel, upon the rate at which it is driven.

Item 9 is the heat absorbed by the boiler, or the useful work. It is also the difference between the total heating value of the coal and the sum of the losses of items 1 to 8 inclusive.

W. K.

Appendix XXII.

OBSERVATION BLANKS.

The observations taken during the test should be recorded on a series of blanks prepared in advance, so as to be adapted for the purpose of the trial. The number of sheets and the number of items on each may be varied to suit the number of observers and the work designated for each. It will be found convenient and desirable to have the blanks for the coal and water observations independent of those for general observations, and in general independent of each other. In all cases the first column of the coal record and of the water record should be devoted to the time; stating, for instance, when a particular barrow of coal is dumped or a particular tank of water let down. Error is best avoided by having separate columns for gross weights, tare and net weights, even though the tare be constant. The feed-water record should contain a column for temperature in case the same is taken in the tank, and also a column for height of water in glass gauge on boiler, which is to be noted when tank is emptied if the feed pump or injector is directly connected thereto.

C. E. E.

Appendix XXIII.

HORSE-POWER.

The writer's preference for rating boilers in horse-power is:

Capacity to evaporate into dry steam, *i.e.*, not containing over three per cent. of entrained water, and the water actually entrained allowed for and deducted:

1. 34½ pounds of water from and at 212 degrees, equal to
2. 30 pounds of water of $t = 100$ degrees under $p = 70$ pounds per square inch above one atmosphere; with easy firing, moderate draft, and ordinary fuel, implying good economy, and capability of fifty per cent. increase to meet emergencies.

As to the last condition, "capability of fifty per cent. increase to meet emergencies"—

It must be obvious that a boiler which, under most favorable conditions of fuel, draft, firing, and everything else, is just capable of evaporating into dry steam 3,450 pounds of water from 212 degrees into the atmosphere, with open safety valve—or, what comes to the same thing, 3,000 pounds from $t = 100$ degrees to $p = 70$ + atmosphere—could not be called a 100 horse-power boiler with any propriety. Good ordinary practical conditions should do that, with satisfactory economy; and then fifty per cent. more should be obtainable to meet a sudden call or to supply a brief deficiency. J. C. H.

Appendix XXIV.

STEAM UNITS.

All measurements of the quantity of heat are based on the *thermal unit*, which, for British measures, equals the quantity of heat required to raise the temperature of one pound of pure water at or near its freezing-point one degree Fahr.*

The unit commonly used to express the evaporative power of the fuel is the quantity of heat required to evaporate one pound of water at a temperature of 212 degrees under the ordinary pressure of the atmosphere corresponding to that temperature. This was called by Rankine a "peculiar thermal unit," and its value given at 966.1 British thermal units, but has since been called the "*unit of evaporation*," which term is adopted in the foregoing general report of the committee. Its value, however, in the prominent American tables is given at 965.7 thermal units.

The *mechanical equivalent* of a thermal unit equals very nearly 778 foot-pounds of work, but the power that can be utilized practically per unit of heat depends on so many conditions that a universal standard of work or power (the rate of work) based on heat units is impossible. Compound engines operated with high steam slightly superheated require a little over 14 pounds of feed-water evaporated per hour, while there are still in use poor engines, ill-proportioned steam pumps, and the like that require over 60 pounds, or say one cubic foot, of water per hour, which was considered as about equivalent to a horse-power of steam in the days of Watt. It has of late years, however, been well ac-

* Compare "Rankine on Steam Engine," Art. 208; "Porter on the Richards Indicator," page 43.

cepted that 30 pounds of feed-water per hour is a fair standard of horse-power for average good high-pressure engines, such as are used for manufacturing purposes. Bearing in mind that this quantity of steam must be furnished by the boiler under actual conditions, the writer, in preparing the report of the Committee of the Judges of Group XX. appointed to test the boilers at the Centennial Exhibition, suggested to his associates, Messrs. Charles T. Porter and Joseph Belknap, that the value of the "commercial horse-power of a boiler be fixed at 30 pounds of water evaporated at 70 pounds gauge-pressure from a temperature of 100 degrees." * This standard, having been adopted in the foregoing report of the Committee of the American Society of Mechanical Engineers, may be considered as established both by precedent and authority. It is fixed as equal to 34½ units of evaporation per hour, and is, for all practical purposes, equal to 33,333 thermal units per hour, making it convenient to obtain the horse-power by multiplying the total number of thermal units derived from the fuel per hour by 0.00003. It is of interest also to note that a cubic foot of steam at 70 pounds gauge-pressure weighs $\frac{1}{5}$ of a pound avoirdupois, so that a commercial horse-power on the above basis is also represented by 150 cubic feet of steam per hour at 70 pounds pressure.†

In preparing the general report of the judges of Group XX., Centennial Exposition, it was observed that if a boiler supplying any kind of pumping machinery be proportioned to utilize 10,000 heat units per pound of coal consumed (corresponding to an evaporation of about 9 pounds of water at 70 pounds gauge-pressure from a temperature of 100 degrees), the number of foot-pounds of work obtained in the engine for each thermal unit would also represent the duty in millions of foot-pounds per 100 pounds of coal. ‡ From this it will be seen that the commercial

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* See report of committee at page 131 of the "Report of the Judges of Group XX." International Exh., 1876. J. B. Lippincott & Co., Philadelphia.

† In administering the steam supply of the New York Steam Company, the writer provided for selling steam at a fixed rate per thousand "*kals*," explaining that a "*kal*" meant a pound of water evaporated into steam. This term has been in use in that business since February, 1883, and has proved so convenient that the writer has suggested that it can possibly be utilized to express the unit of the commercial horse-power above referred to. On this basis a boiler horse-power would equal simply 30 "kals" per hour. See "Estimates for Steam Users," Vol. V., *Transactions* Am. Soc. Mech. Engineers, page 284.

‡ See "Report of Judges of Group XX.," Cent. Exh., pp. 21 and 115.

horse-power above referred to corresponds to a duty of 59.4 millions of pounds lifted one foot high with 100 pounds of coal, which is about the average duty of the simpler class of pumping engines, but not of first-class engines. Evidently, for the better class of steam machinery of all kinds, the steam-producing capacity of the boiler must be made to conform to the actual amount of steam to be used by the engines. Any standard of the horse-power of a boiler necessarily relates simply to its steam-producing capacity, referred to the arbitrary standard of a horse-power above mentioned. C. E. E.

Appendix XXV.

DISCREPANCY BETWEEN COMMERCIAL AND EXPERIMENTAL RESULTS.

The final result sought by manufacturers, in initiating tests of steam or other machinery in actual use, is the value of the work done measured in dollars and cents. In some cases the broad question is raised as to the saving that may be accomplished by installing improved boilers, engines, or other machinery; but more generally it is desired to ascertain what can be done to produce saving with the apparatus already in place under the actual conditions that prevail at the particular location. In both these cases it is necessary to ascertain the average cost of the work done commercially previous to the test. Frequently, in fact generally, this important fact will not be ascertained by an elaborate trial, for the reason that everything will be put in order for the test, and all details of the trial be conducted so carefully that the losses due to average carelessness or want of skill in the past will be eliminated, the engineer making the test will not receive proper credit, and the owners on seeing the report may conclude that they are already doing very well, and perhaps continue old methods with fancied security. If the cost of the output of the factory for a given time were ascertained in terms of the coal burned during the same time, and compared with the corresponding cost for the time of the trial, the latter would frequently be found to be one-eighth to one-third less than the former, and it might not be possible to tell what had caused the difference; for instance, whether it was due to putting in order the machinery prior to the tests, to greater care exercised by the fireman under the spur of careful watching, or whether, as is usually claimed, the coal was different, etc., etc. The losses are generally due in the main to the carelessness of the firemen. It follows, therefore, that the cost of the power under average conditions must be obtained in some quiet way preliminarily. Frequently the comparison of the output of the factory with the coal burned will not be sufficiently accurate, and it will be necessary to devise some corresponding check which will not interfere with the regular routine of the establishment. The work of the boilers may be checked by arranging a meter so as to continuously measure the feed water; and its record, compared with the total weight of coal *purchased*, will frequently give the check desired. Such a check becomes more difficult when it is desirable to ascertain the performances of particular boilers, and the coal supply is common to all boilers; but by assigning particular weighed carloads of coal to the particular boilers, without any intimation to the firemen that they are being watched, it may be possible to ascertain the average performance of the boilers used for the particular purpose. Preliminary experiments of this kind conducted without notice to employees, and continued through a long period, will furnish a basis for comparison with elaborate tests, and it will then be possible to point out clearly where the several losses have taken place, and the testing engineer will get the credit for the saving shown.

C. E. E.

Appendix XXVI.

RECORDING STEAM GAUGE.

A good recording steam gauge, Edson's or other, carefully adjusted, should be used and accurately compared with the steam gauge at stated intervals. Such an automatic record, nicely integrated, is a good check on the record of the steam gauges.

J. C. H.

Appendix XXVII.

PYROMETER.

So far as known to me the only way to measure temperatures between 600 or 700 degrees Fahr., or above the range of the air thermometer, and 2,500 or 2,700 degrees Fahr., or up to the melting point of commercial platinum, is by the platinum water-pyrometer.

One form of this pyrometer is described in the journal of the Franklin Institute, Vol. 84, pp. 169 and 252, September and October, 1882. J. C. H.

PYROMETER.

The temperature of the escaping gases should be ascertained, not by pyrometers, but by means of certified mercury thermometers introduced at a number of different points in the same plane transverse to the flue. The velocity of the current should be ascertained at each of these points. The distance of the transverse plane of observation from the boiler should be noted.

C. T. P.

Appendix XXVIII.

DRAFT GAUGE.

Some instruments for indicating the force of chimney draft:

a. A bent glass tube filled with water.

b. A bent tube with two fluids.

c. An encased aneroid.

d. A differential pressure gauge.

The encased aneroid, having inches of mercury indicated by spaces of about 2 inches, divided to $\frac{1}{500}$, answers well. The case is airtight, and by means of a three-way cock the interior of the case may be put alternately in communication with the external air and with any flue into which a suitable pipe is inserted.

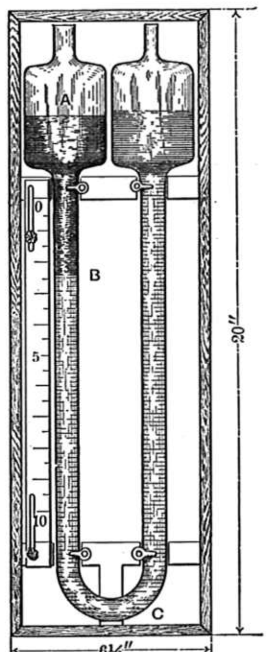
The differential pressure gauge was devised and put to use at the Massachusetts Institute of Technology, and similar instruments should be manufactured for sale. I will not attempt to describe it further than to say that a column of water in a glass tube, acting on a small diaphragm, balances the weight of the movable parts when a large diaphragm is in equilibrium of pressure. Now if this large diaphragm have chimney pressure on the inner side and atmospheric pressure on the outside, the difference of pressure will be shown by a rise of water in the glass tube to a height proportioned to the ratio of the areas of the small and large diaphragms.

Draft should be measured in different parts of the flue, in order to detect infiltration of air through cracks in the brickwork and through the brickwork itself. J. C. H.

Appendix XXIX.

DRAFT GAUGE.

The ordinary form of draft gauge, consisting of the U tube, containing water, lacks sensitiveness when used for measuring small quantities of draft. An instrument (Fig. 3) which the writer has used satisfactorily for a number of years multiplies the ordinary indications as many times as desired. It consists



BARRUS' DRAFT GAUGE
Boiler Test Com.

Fig. 3.

of a U tube made of ½-inch glass, surmounted by two larger tubes, or chambers, having a diameter of 2½ inches, as shown in the cut. Two different liquids which will not mix, and which are of different color, are used, one occupying the portion *A B*, and the other the portion *B C D*. The movement of the line of demarcation is proportional to the difference in the areas of the chambers and of the U tube below. The liquids generally employed are alcohol colored red and a certain grade of lubricating oil. A multiplication varying from eight to ten times is obtained under these circumstances; in other words, with $\frac{1}{4}$-inch draft the movement of the line of demarcation is some two inches.

The instrument is calibrated by referring it to the ordinary U-tube gauge.

G. H. B.

Appendix XXX.

DRAFT GAUGE.

The accompanying sketch (Fig. 4) represents a very sensitive and accurate draft gauge recently constructed by the writer. A light cylindrical tin can *A*, 5 inches diameter and 6 inches high,

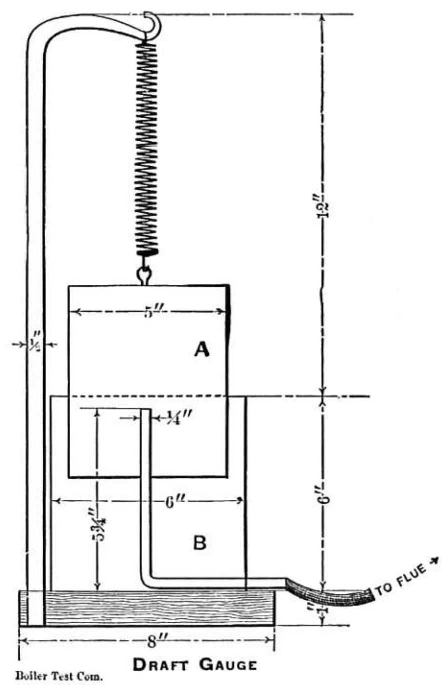


Fig. 4.

is inverted and suspended inside of a can *B*, 6 inches diameter, 6 inches high, by means of a long helical spring. Inside of the larger can a $\frac{1}{4}$-inch tube is placed, with one end just below the level of the upper edge, while the other end passes through a hole cut in the side of the can, close to the bottom, solder being run around the tube so as to close the hole and make the can water-tight. The can is filled with water to within about half an inch of the top, and the inner can is suspended by the spring so that its lower edge dips into the water, the height of the support of the spring being adjusted accordingly.

The small tube being open at both ends, the air enclosed in the can A is at atmospheric pressure, and the spring is extended by the weight of the can. The end of the tube which projects from the bottom of the can being now connected by means of a rubber tube with a tube leading into the flue, or other chamber, whose draft or suction is to be measured, air is drawn out of the can A until the pressure of the remaining air is the same as that of the flue. The external atmosphere pressing on the top of the can A causes it to sink deeper in the water, extending the spring until its increased tension just balances the difference of the opposing vertical pressures of the air inside and outside of the can. The product of this difference in pressure, expressed as a decimal fraction of a pound per square inch, multiplied by the internal area of the can in square inches, equals the tension of the spring (above that due to the weight of the can) in pounds or fraction of a pound. The extension of a helical spring being proportional to the force applied, the distance travelled downward by the can A measures the force of suction; that is, the draft. The movement of the can may conveniently be measured by having a celluloid scale graduated to 50ths of an inch fastened to the side of the can A, and a fine pointer fixed to the upper edge of the can B, almost touching the scale.

To reduce the readings of the scale to their equivalents in inches of water column, as read on the ordinary U-tube gauge, we have the following formulæ:

Let

P = force in pounds required to stretch the spring 1 inch.

E = elongation of the spring in inches.

A = area of the inner can in square inches.

d = difference in pressure or force of the draft in pounds per square inch.

D = difference in pressure in inches of water = $27.71d$.

$$EP = Ad = \frac{AD}{27.71} = 0.0361AD$$

$$D = \frac{27.71EP}{A}$$

$$E = \frac{0.0361AD}{P}$$

The last equation shows that for a constant force of draft the elongation of the spring or the movement of the can may be increased by increasing the area of the can or by decreasing the strength of the spring. The strength of the spring may be increased, that is, its sensitiveness may be decreased, by increasing either its length or the diameter of the helix, or by decreasing the diameter of the wire of which it is made. We thus have at command the means of making the apparatus of any desired degree of sensitiveness.

Applying the above formulæ, let it be required to determine the movement of the can corresponding to a draft of 1 inch of water column, the can A having a diameter of 5 inches = 19.63 inches area, and the spring of such a strength that 0.1 pound elongates it 1 inch. Here $P = 0.1$; $A = 19.63$; $D = 1$.

$$E = \frac{0.0361 \times 19.63}{0.1} = 7.09 \text{ inches.}$$

That is, the instrument multiplies the readings of the U tube 7.09 times. The precision of the instrument is, however, far greater than this figure would indicate; for in the U tube it is exceedingly difficult to read with precision the difference in height of the two menisci, while with this apparatus readings in the scale may easily be made to $\frac{1}{50}$ inch, which, with the multiplication of 7, is equivalent to $\frac{1}{350}$ of an inch of water column. The instrument may also be calibrated by directly comparing its readings with those of an ordinary U-tube gauge. W. K.

Appendix XXXI.

SAMPLING FLUE GASES.

Very great diversities in the composition of flue gases often exist in the same flue at the same time. To obtain a fair sample, it has been found sufficient to have one orifice to draw off gases through for each 25 square inches of cross section of flue. The pipes must be of equal diameter and of equal length. One-quarter-inch gas pipes, all alike at the ends, and of equal lengths, answer well. Similar steel tubes will be still better.* These should be secured in a box or block of galvanized sheet iron, equal in thickness to one course of brick, in such a manner that the open ends may be evenly distributed over the area of the flue *A* (Fig. 57*a*), and their other open ends enclosed in the receiver *B*. If the flue gases be drawn off from the receiver *B* by four tubes, *CC*, into a mixing box, *D*, beneath, about 3-inch cube, a

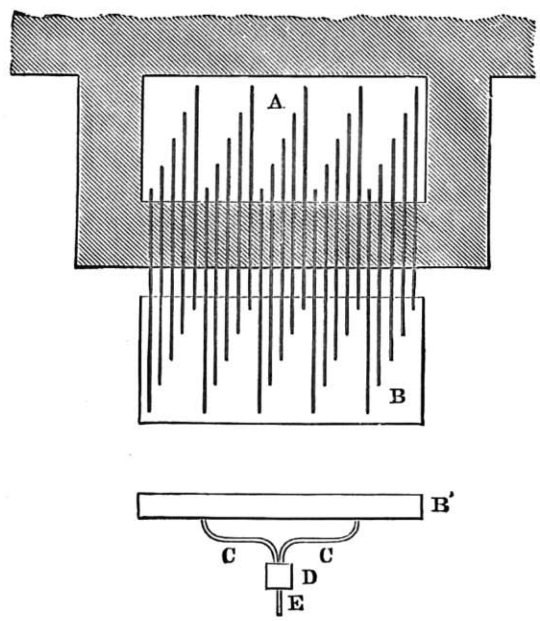


Fig. 5.

good mixture can be obtained. Two such "samplers," one above the other a foot apart, in the same flue, will furnish samples of gases which show by analysis the same composition.

J. C. H.

* Because smoother and more uniform.

Appendix XXXII.

COMPUTATION OF THE WEIGHT OF THE CHIMNEY GASES FROM THE ANALYSIS BY VOLUME OF THE DRY GAS.

Two methods of calculating from the analysis by volume of the dry chimney gases the number of pounds of dry chimney gases per pound of carbon, or the weight of air supplied per pound of carbon, have been given by different writers. These may be expressed in the shape of formulæ as follows:

$$\text{(A) Pounds dry gas per pound C} = \frac{11CO_2 + 8O + 7(CO + N)}{3(CO_2 + CO)}$$

$$\text{(B) Pounds air per pound C} = 5.8\,\frac{2(CO_2 + O) + CO}{CO_2 + CO}$$

Formula A may be derived from the method of computation given in Mr. R. S. Hale's paper on "Flue-Gas Analyses," *Transactions*, vol. xviii., p. 902, and formula B from the method given in Peabody and Miller's "Treatise on Steam Boilers." Both are based on the principle that the density, relatively to hydrogen, of an elementary gas (O and N) is proportional to its atomic weight, and that of a compound gas (CO and CO_2) to one-half its molecular weight. Both formulæ are very nearly accurate when pure carbon is the fuel burned, but formula B is inaccurate when the fuel contains hydrogen, for the reason that that portion of the oxygen of the air supply which is required to burn the hydrogen is contained in the chimney gas as H_2O, and does not appear in the analysis of the dry gas.

The following calculations of a supposed case of combustion of hydrogenous fuel illustrates the accuracy of formula A and the inaccuracy of formula B. Assume that the coal has the following analysis: C, 66.50; H, 4.55; O, 8.40; N, 1.00; water, 10.00; ash and sulphur, 9.55—total, 100. Assume also that one-tenth of the C is burned to CO, and nine-tenths to CO_2; that the air supply is 20 per cent. in excess of that required for this combustion; that the air contains one per cent. by weight of moisture; and that the S in the coal may be considered as part of the ash. We then have the following synthesis of results of the combustion of 100 pounds of coal:

	O from Air	N = $O \times \frac{77}{23}$	Total Air	CO_2	CO	HO_2
59.85 lbs. C to $CO_2 \times 2\frac{2}{3}$	159.60	534.31	693.91	219.45	.....	.....
6.65 " C to CO $\times 1\frac{1}{3}$	8.87	29.70	38.57	......	15.52	.....
3.50 " H to $H_2O \times 8$	28.00	93.74	121.74	......	.....	31.50
	196.47	657.75	854.22	......	.....	.....
1.05 " H to H_2O } 8.40 " H to H_2O }	......	......	......	......	.....	9.45
10.00 " Water	......	......	......	......	.....	10.00
1.00 " N	......	1.00	......	......	.....	.....
9.55 " Ash and S	......	......	......	......	.....	.....
100.00	......	......	......	......	.....	.....
Excess of air 20 per cent.	39.29	131.55	170.84	......	.....	.....
	......	......	1,025.06	......	.....	.....
Moisture in air 1 per cent.	......	......	......	......	.....	10.25
Total wt. of gases, 1,125.67 =	39.29	790.30	......	219.45	15.52	61.20
Total dry gases, 1,064.56						

	O	N		CO_2	CO	
Total dry gases, by weight, %	3.69	74.24	......	20.61	1.546	.....
Total dry gases, by volume, %	3.508	80.656	......	14.252	1.584	.....

Total gases 1,125.76 + ash and S 9.55 = 1,135.31 total products.
Total air 1,025.06 + moisture in air 10.25 + coal 100 = 1,135.31.
Dry gas per pound coal 10.6456 ; per pound carbon = 10.6456 ÷ 665 = 16.008.
Dry air per pound coal 10.2506 ; per pound carbon = 10.2506 ÷ 665 = 15.414.

Computation of the weight of dry gas and of air per pound C—

Formula A :

$$\text{Dry gas per pound C} = \frac{14.252 \times 11 + 3.508 \times 8 + 82.240 \times 7}{3(14.252 + 1.584)} = 16.008 \text{ pounds.}$$

Formula B :

$$\text{Air per pound C} = 5.8\,\frac{2(14.252 + 3.508) + 1,584}{14.252 + 1.584} = 13.589 \text{ pounds.}$$

The error in the last result is 15.414 — 13.589 = 1.825 pounds.

Professor D. S. Jacobus gives another formula for the air per pound of carbon, in which the error of formula B is almost entirely avoided. It is

Formula C :

$$\text{Air per pound C} = \frac{7N}{3(CO_2 + CO)} \div 0.77, \text{ or } \frac{N}{0.33(CO_2 + CO)},$$

in which N, CO_2, and CO are the percentages by volume of these gases. Making the computation, from the data of the above analysis, we have :

$$\text{Air per pound C} = \frac{80.656}{0.33(14.252 + 1.584)} = 15.434 \text{ pounds, the}$$

true value being 15.414 pounds. W. K.

Appendix XXXIII.

THE ORSAT APPARATUS FOR ANALYZING FLUE GASES.

For the past three years the writer has made extensive use of the Orsat apparatus in his boiler testing, and has found the work not only interesting, but exceedingly instructive and valuable. Its chief value lies in the guide which it affords in determining what kind of firing is most advantageous where the fuel is bituminous coal. That the instrument is reliable and useful for the purposes noted is quickly ascertained, and without any very extended practice. When the thickening up of the fire is invariably attended with an increase in the percentage of carbonic oxide, and a reduction in the percentage of oxygen, as the writer has found, he feels at once assured that the instrument is not a plaything, or something that is influenced in unexplained ways by whim or caprice, but rather that it is an important adjunct to the engineer's outfit. In applying the results of analyses to working out the heat balance of a boiler test, the writer's results on various types of boilers, and with various fuels, have furnished a very satisfactory account of the distribution of the heat. The "unaccounted for" quantity has ranged from 2.1 per cent. up to 7 per cent. in different cases. He has never found that quantity a minus one.

As to sampling the gases, the writer has found satisfactory results from using a single tube unperforated, which extends into the flue to a central point, care being taken to so locate the inlet end that it will receive what would be considered a fair sample. In using the Orsat apparatus, it is important that the connecting tube between the flue and the instrument should be tight, and that care be taken to thoroughly exhaust the pipe of air before the sample is drawn. This, however, applies quite as much to one apparatus as to another. It is important, too, that the connections and stopcocks about the instrument itself should be tight and carefully manipulated. It is of the first importance that the absorbing liquids be in good condition. It is well for the engineer himself to make the cuprous chloride which is required for absorbing the carbonic oxide, and to frequently renew it in the apparatus.

The writer has found it desirable to locate the gas apparatus on the boiler-room floor, near by the furnaces where the fires are being handled, and carry the gases from the flue to the Orsat by means of a lead pipe of small bore. The apparatus can then be manipulated in plain view of all the operations going on in the fire-room, and in that way he can time the drawing of samples to good advantage. By using proper judgment as to when to draw the sample, satisfactory results can be obtained from analyses covering momentary drawings. For the purposes of the boiler test and working of the heat balance, it is preferred, however, that the drawings should cover the entire period which elapses between two successive firings.

The successful manipulation of the Orsat apparatus is not a thing which requires expert chemical knowledge, for it can be properly handled by anyone, after a little practice, who is familiar with the operation of instruments of measurement.

G. H. B.

Appendix XXXIV.

SMOKE MEASUREMENTS.

In a series of competitive trials between two furnaces which the writer made in June, 1897, for the Detroit Water Works, a method of obtaining a continuous record of the quantity of smoke was introduced, which seems to him of great value in making specific what has heretofore been based upon the judgment of the person conducting the observations. The method referred to consisted simply in suspending, at a suitable point in the smoke passage between the boiler and the flue, a smooth, flat, brass plate, having its face at right angles to the direction of the current. This plate served to collect a certain portion of the soot which was carried along by the waste gases, and indirectly furnished a means of sampling the gas in respect to its smokiness. The plate was 24 inches long and $\frac{7}{8}$ of an inch wide, and it presented a surface amounting to 21 square inches. Being inserted through a hole in the top of the flue, and suspended by a wire, the hole being covered, the plate could be readily withdrawn from its place whenever desired, and the collection of soot removed by the use of a stiff brush. This was done every two hours during the progress of the trial. The quantity of soot which collected on this plate varied according to the type of the furnace and the character of the fuel, as also according to the conditions of the firing and the working conditions of the boiler. The records of the smoke-measuring device, and those of the ocular observations of the chimney, were in accord with each other. The quantity of soot which was collected, reduced to the hourly rate, varied in these tests from nine milligrams to 184 milligrams. The method has not as yet been tried in the case of a flue carrying very dense smoke.

G. H. B.

Appendix XXXV.

THE RINGELMANN SMOKE CHART.

Professor Ringelmann, of Paris, has invented a system of determining the relative density or blackness of smoke, which has been communicated to the writer by Mr. Bryan Donkin, of London, and published in *Engineering News* of November 11, 1897. In making observations of the smoke proceeding from a chimney, four cards ruled like those in the cut, together with a card printed in solid black and another left entirely white, are placed in a horizontal row and hung at a point about 50 feet from the observer and as nearly as convenient in line with the chimney. At this distance the lines become invisible, and the cards appear to be of different shades of gray, ranging from very light gray to almost black. The observer glances from the smoke coming from the chimney to the cards, which are numbered from 0 to 5, determines which card most nearly corresponds with the color of the smoke, and makes a record accordingly, noting the time. Observations should be made continuously during say one minute, and the estimated average density during that minute recorded, and so on, records being made once every minute. The average of all the records made during a boiler test is taken as the average figure for the smoke density during the test, and the whole of the record is plotted on cross-section paper in order to show how the smoke varied in density from time to time. A rule by which the cards may be reproduced is given by Professor Ringelmann as follows:

Card 0. All white.

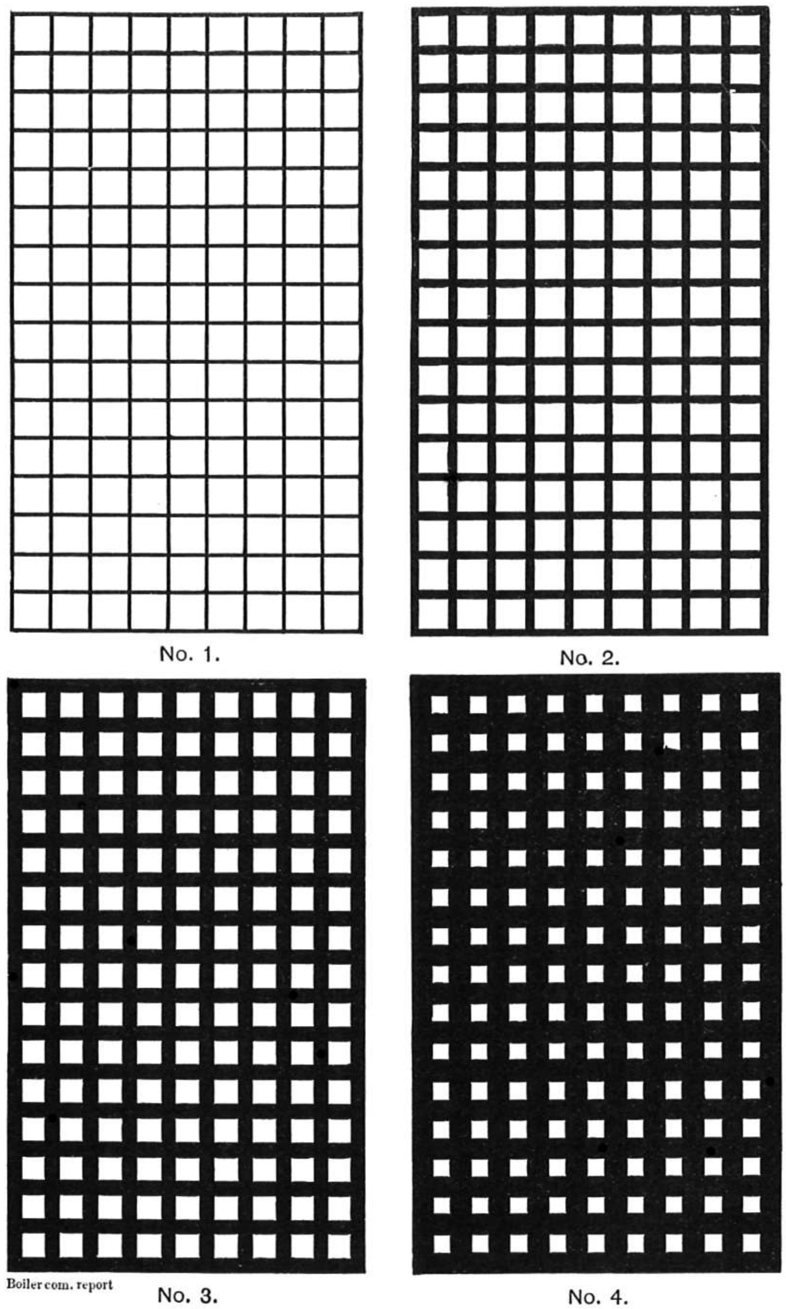
Fig. 6.—Card 1. Black lines 1 mm. thick, 10 mm. apart, leaving spaces 9 mm. square.

Fig. 6.—Card 2. Lines 2.3 mm. thick, spaces 7.7 mm. square.

Fig. 6.—Card 3. Lines 3.7 mm. thick, spaces 6.3 mm. square.

Fig. 6.—Card 4. Lines 5.5 mm. thick, spaces 4.5 mm. square.

Card 5. All black.



THE RINGELMANN SCALE FOR GRADING THE DENSITY OF SMOKE.

FIG. 6.

The cards as printed on page 98 are much smaller than those used by Professor Ringelmann, but the thickness and the spacing of the lines are the same.

W. K.

Appendix XXXVI.

STARTING AND STOPPING A TEST.

Of the two methods of starting and stopping a test, the so-called "standard" method and the "alternate" method, the writer prefers the latter, believing that the errors in the estimation of the quantity and condition of the small amount of coal left on the grate after cleaning are less than the errors of the "standard" method, which are due: first, to cooling of the boiler at the beginning and end of the test; second, to the imperfect combustion of the fuel at the beginning; and third, to excessive air supply through the thin fire while burning down before the end of the test.

A special caution is needed against a modification of the "alternate" method, which has been adopted by some testing engineers within the past few years. It consists in taking the starting and the stopping times each at a time subsequent to the cleaning, say after 400 pounds of coal has been fired since the cleaning. There are two sources of serious error in this method, one causing an incorrect measurement of the coal, the other an incorrect measurement of the water. Suppose 200 pounds of hot coke are left on the grate at the end of cleaning and 400 pounds of fresh coal are added by the end of, say, half an hour after cleaning. If the coal left at the end of the cleaning, and the boiler walls also, are very hot, and the coal is highly volatile and dry, and the pieces of such size as not to choke the air supply, the fire may burn so briskly that at the end of the half-hour the fuel value of the partly burned coal left out of the total 600 pounds is equivalent only to 200 pounds of coal. If, on the contrary, the hot coke on the grates at the end of the cleaning, and the boiler walls, are considerably cooled, if the fresh coal fired is moist and of small size, such as the slack of run-of-mine bituminous coal, which is often found in one portion of a pile in greater quantity than in another, the fire during the half-hour may burn so sluggishly that the coal and coke on the grate at the end of the half-hour may have a fuel value equal to 400 pounds of coal. If, in this case, it is assumed that the quantity and condition of the coal at the end of the half-hour after cleaning are the same at the starting and stopping time, and if the fire burned briskly during the half-hour before starting and slowly during the half-hour before stopping, the boiler will be charged with more coal than was actually burned. If, on the contrary, the coal burns away more slowly during the half-hour after the cleaning before the starting time and more rapidly during the half-hour before the end of the test, the boiler is not charged with as much coal as was actually burned.

The error in water measurement is due to the fact that the condition of the fire, and especially the quantity of flaming gases arising from it, influences the height of the water level. A bright hot fire, or a fire with an abundance of burning gas proceeding from it, causes the water level to rise; while anything that cools the furnace, such as freshly fired coal, an open fire door, or a check to the draft, causes the water level to fall. A rise or a fall of several inches in a few seconds frequently occurs when bituminous coal is used. If the water level is noted at the starting of the test, when it is raised by a bright fire, and at the end of a test, when it is depressed by the stoppage of violent ebullition or of rapid circulation, due to the cooling of the fire, the boiler will be credited with more water than was really evaporated, and *vice versa*.

The only correct times to be noted as the starting and the stopping times are when the smallest amount of fuel is on the grate and when it is in the most burned-out condition; that is, just before firing fresh coal after cleaning, and when the water level is in its most quiet condition and the least raised by ebullition; that is, after the furnace door has been kept open for some time for cleaning and the furnace therefore is in its coolest state. This condition of fire and of water level can be duplicated immediately after cleaning the fire; but there is no certainty of duplication of any condition when there is a bright fire and consequent rapid steaming.

These statements are not based upon theoretical considerations, but are the results of many experiments made by the writer to determine the best starting and stopping times. In a long series of tests with bituminous coals no less than six different times were recorded as starting times and as many as stopping times, and the coal apparently used and the water apparently evaporated recorded and calculated for each. These times were: *A*, before opening the first or right-hand door to clean the fire; *B*, after cleaning the first half of the furnace and just before firing fresh coal; *C*, after cleaning the second half of the furnace; *D*, after 200 pounds of fresh coal had been fired; *E*, after 400 pounds; *F*, after 600 pounds. By plotting the apparent water evaporation between *A* and *F*, both for starting and for stopping times, it was seen that there was nearly always an apparent negative evaporation between *B* and *D*, and sometimes between *B* and *C* and between *B* and *E*, due to the correction for height of observed water level, the level rising rapidly, being much greater than the water fed by the pump. There was often no similarity of appearance of the plotted diagrams between *A* and *F* at the beginning and at the end of the same test. The possible error of water measurement due to taking *A*, *D*, *E*, or *F* as the starting time was sometimes as much as 2,000 pounds of water, or about 3 per cent. of the whole amount evaporated in a ten-hour test. The record of water evaporated between the stopping and starting times *C* occasionally differed considerably from that taken between the *B* start and stop, due to the fact that sometimes between *B* and *C* there was a sudden lighting up of the fresh coal on the cleaned side of the furnace, while at other times the fire would not light up brightly until after the *C* point had passed. It was therefore decided that the *B* time, when the furnace was the coldest and the water level at the lowest, was the only time which could be accepted as the true starting and stopping time. W. K.

Appendix XXXVII.

STARTING AND STOPPING A TEST.

Between the "standard" method and the "alternate" method of starting and stopping a test I believe the standard method, if properly followed, is the more reliable of the two for determining absolutely correct and unquestionable results. One of the important matters which the standard method determines accurately is the absolute quantity of ash and refuse. In the case of the alternate method it is extremely difficult to obtain the quantity of ash in such a way as to be positively reliable, for the reason that in cleaning the fire it is hardly possible to leave the same amount of ash, clinkers, and refuse mixed with the coal at one time as at the other. When the fire is started new with wood, and burned out at the end of the trial, as it is in pursuing the standard method of starting and stopping, there is absolutely no chance of making an error of this nature. The tendency of nearly all parties concerned in a boiler test is to have the boiler make a good showing, and it is the rule rather than the exception that the fire at the end of the test is burned lower, if anything, than it was at the beginning, so as to surely give the boiler all the advantage to which it is entitled. With this tendency the cleaning of the fire at the end of the test is apt to be less thorough than at the beginning, so that in the first place no fuel will be lost, and in the second place that the bed of coal may not be reduced in thickness any lower than is absolutely necessary. The result is that the bed of coal at the end is apt to contain more waste material, which belongs with the ashes, than it does at the beginning, and this is one of the reasons why the alternate method of starting and stopping a test is objectionable.

There appears to be confusion in the minds of some experts as to the facility with which a new fire can be started with wood. They appear to hold the belief that there is apt to be a great loss in getting a new fire started in this way, a loss which occurs not only in the matter of time, but also in the matter of combustion and heat. I have made a great many tests, using the standard method of starting and stopping, and my experience has been that, so far as facility of manipulation is concerned, it is perfectly easy and satisfactory to use the standard method. With a suitable quantity of dry pine wood, preferably in the form of edgings, or 1-inch boards which have been split into narrow pieces, it is quite feasible to draw the old fire, kindle a new one, and have the boiler under steam in practically a normal condition of running, with the coal selected (supposing this to be a good quality of bituminous or semi-bituminous coal), inside of 15 minutes' time. My opinion is that the objections which have been raised to starting with wood fires is due to the fact that suitable preparation has not been made in the matter of furnishing a proper kind of wood cut into proper shape. Certainly, it is impossible to start a satisfactory new fire if the supply of wood contains any appreciable quantity of wet material or hard wood, or wood which is in thick pieces which do not readily ignite. I have myself had difficulty in starting a test under these circumstances, and I have no doubt that experts who have found the standard method objectionable have encountered the same obstacle, and they probably base their objections, largely at least, on these unnecessary difficulties.

G. H. B.

Appendix XXXVIII.

CHART SHOWING GRAPHICALLY THE LOG OF A TRIAL.

The well-known method of plotting observations and data on cross-section paper and making a chart applying to the test is a useful means of representing the exact uniformity of conditions existing during a trial. Such a chart is illustrated in the appended cut (Fig. 7), in which the abscissæ represent times, and the ordinates, on appropriate scales, the various observations and data. G. H. B.

Appendix XXXIX.

CONTINUOUS DETERMINATIONS OF CARBONIC ACID IN FLUE GASES.

Various forms of apparatus have been devised for showing continuously the percentage of carbonic acid in waste gases, and instruments of this kind, if reliable, serve a useful purpose in the management of the fires during the progress of a test. Among these instruments may be mentioned the "gas balance" of Alphonse Custodis, the Ardnt "econometer," and the Uehling and Steinbart "gas composimeter." G. H. B.

Appendix XL.

MEASURING RADIATION FROM CERTAIN TYPES OF BOILERS.

(*Contributed by Mr. R. S. Hale, Member of the Society.*)

While the heat lost by radiation is only a small amount of the total heat if the boiler is well covered, yet it is important enough to be considered, and in the case of certain internally fired boilers, such as the ordinary upright vertical, the Manning, the marine, the Thorneycroft, etc., it can be easily determined by

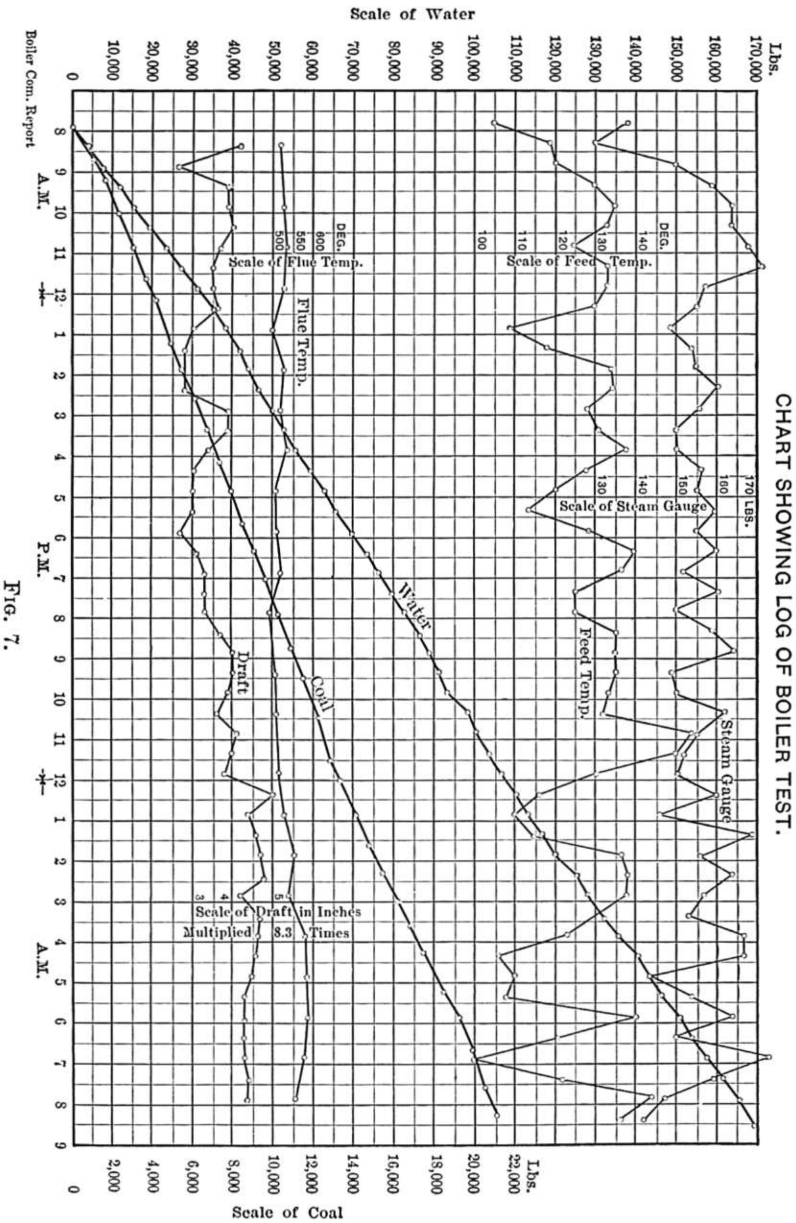


CHART SHOWING LOG OF BOILER TEST.
Scale of Water
Lbs.
Scale of Coal
Scale of Feed Temp.
Scale of Flue Temp.
Scale of Steam Gauge
Scale of Draft in Inches Multiplied 8.3 Times
Water
Coal
Draft
Flue Temp.
Feed Temp.
Steam Gauge
A.M.
P.M.
Boiler Com. Report

FIG. 7.

at least two methods. If the boiler is covered completely (or nearly so) with any boiler covering for which the rates of flow of heat can be or have been determined, then the total loss of heat is easily computed. Thus, Norton's tests (*Transactions*, vol. xix., p. 729) give the flow per square foot per hour at various differences of temperature for many frequently used coverings. Now if the temperature of the steam and of the air and the total exposed area is known, the loss from the whole boiler per hour is easily computed, and this loss divided by the total heat supplied in the same time gives the percentage loss by radiation. If the boiler is only partially covered, the loss from the covering and from the bare iron can be computed separately.

The second method of determining the radiation loss is, after drawing the fire, to shut all doors and dampers tight, and then to note the time necessary for the steam pressure to fall say ten or twenty pounds. The fall in pressure gives the data from which the fall in temperature can be computed by means of the steam tables, and the total loss of heat in thermal units is equal to the weight of iron and water multiplied by their respective specific heats and the fall of temperature. This divided by the time gives the total heat units lost by radiation per hour, and the percentage loss by radiation is found as before by dividing by the total heat supplied.

Strictly speaking, this is the radiation at the average pressure during the radiation test, but if the pressure does not fall over 20 per cent. (20 pounds in 100 or 30 pounds in 150), the result may be considered close enough to the radiation at the initial pressure, so far as this error is concerned.

It should be noted that the first method given does not apply unless the boilers are internally fired. Neither does the second method apply if there is any brick in the furnace, or setting, since the method depends on the assumption that the temperature of the water and iron corresponds to the steam pressure, which would not be true of the brick. The second method is also apt to give high results, as it is almost impossible to absolutely close the doors and dampers, and air leaking past them carries heat up the chimney, in addition to the true radiation. Nevertheless, the determination of the radiation by these methods takes but little time or trouble, and should be done whenever the type of boiler and conditions allow. Usually both methods are available, if either is, and in such case both methods should be used and the results noted. The lower result of the two methods is the more apt to be correct, and should be taken.

It should be noted that if the temperature of the air in the boiler-room is greater than the temperature of the external air, the difference is due to radiation from the boiler, and if in making up the heat balance the temperature of the air in the boiler-room is taken as a base, the radiation necessary to heat up this air should be noted. If, however, the temperature of the external air is taken as a base in making up the heat balance, this loss cancels out, as it is returned to the boiler in the entering air. The loss by radiation as measured by either of the methods given above is, of course, in addition to the radiation that is utilized by heating the moving air before it enters the boiler.

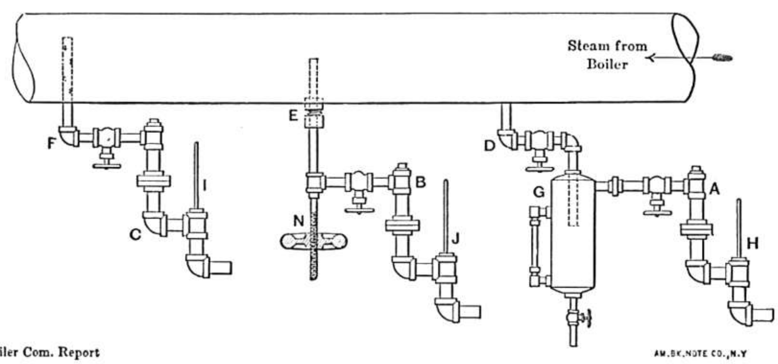
Appendix XLI.

DETERMINATION OF THE MOISTURE IN STEAM FLOWING THROUGH A HORIZONTAL PIPE.

(*Contributed by D. S. Jacobus, Member of the Society.*)

In some cases it is impossible to place the sampling nozzle in a vertical steam pipe rising from the boiler as recommended in Article XIV. of the Code. When this is the case and it is possible to connect to a horizontal steam pipe, the arrangement of throttling calorimeters shown in Fig. 8 gives satisfactory results.

The calorimeter *A* is attached to the separator *G*, which is in turn attached to the under side of the steam pipe by the nipple *D*. The nipple *D* is made flush with the bottom of the pipe. The calorimeter *B* is attached to a nozzle having no side holes, which passes through the stuffing-box *E*. This nozzle is adjustable so that the steam can be drawn from any height in the pipe. When in its lowest position it is flush with the bottom of the pipe. The calorimeter *C* is attached to the perforated nipple *F*. The calorimeters are placed at some distance from an elbow or bend, so that if there is moisture in the steam it tends to run along the bottom of the pipe. This moisture will flow into the nipple D and collect in the separator G. Nearly all the moisture may sometimes be drawn out in this way, and if the calorimeters B and C indicate dry steam, the weight of moisture collected in G represents the entire moisture in the steam. The three calorimeters are all covered in the same way to diminish radiation, and the normal reading of the thermometers I and J used in the calorimeters B and C can ordinarily be obtained by placing them in the calorimeter A. The perforated nipple F serves to show that there is no moisture distributed through the steam, and in the case of a sudden belch of moisture it will indicate the same. Barrus calorimeters were used in our tests, and the calorimeter A, combined with the separator G, forms in reality a Barrus Universal Calorimeter. With a prop-



Boiler Com. Report

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FIG. 8.

erly constructed separator, the steam passing through the calorimeter A will be practically dry with as high as sixty pounds of moisture drawn from the separator per hour, and, until this limit is exceeded, the normal readings of the thermometers used in the calorimeters B and C may be obtained by placing them in the calorimeter A, as has already been stated.

In some cases the calorimeter C is omitted and the amount of moisture is determined by means of the separator, with the adjustable nozzle at E and the separator and calorimeter A.

The percentage of priming P for the steam passing through the calorimeters B and C is given by the formula,

$$P = \frac{48}{L}(N - T),$$

where
P = the percentage of priming;
N = the normal reading, in degrees Fahrenheit, obtained by placing the thermometers in A;
T = the reading when placed in either B or C;
L = the latent heat at the pressure of the steam in the steam main in British thermal units per pound.

It is best to employ the normal reading, as Mr. Barrus recommends, in calculating the moisture corresponding to the readings of a throttling calorimeter, and not the formula given in Appendix XV. of the Code; for if the formula given in Appendix XV. is used, the mercury thermometer used to measure the temperature of the steam, after passing through the orifice, must be corrected for the error produced in not heating the entire length of the stem, and must also be corrected to make the readings correspond with those that would be given by an air thermometer. The radiation of the calorimeter must also be determined by a separate experiment, and allowed for. When the normal reading is taken, as Mr. Barrus recommends, all errors of radiation and corrections for the thermometers are eliminated.

The normal reading should be obtained either by connecting the calorimeter to a vertical nipple, with no side holes, which projects upward in a horizontal steam-pipe, in which the steam is in a quiescent state, or it should be obtained by connecting the calorimeter to a separator which is known to remove all the moisture. The normal reading should not be determined when the calorimeter is attached to a horizontal nipple with side holes, placed in a vertical pipe, because should this be done the readings may be low on account of moisture, which may fall through the steam and cling to the nozzle, and, finally, be drawn into the calorimeter.

The results given by a throttling calorimeter cannot be relied on within one-fifth of one per cent., because experiments have shown that the quality of the "dead steam" used in obtaining the normal readings may vary by this amount.* As the quality of the "dead steam" may not be that of the steam used by Regnault in his experiments, there may be a still greater error. When the formula given in Appendix XV. of the Code is used, the probable error is not eliminated, for a study of Regnault's

* *Transactions*, Vol. XVI., p. 466.

Experiments shows that the value used in the formula for the specific heat of superheated steam may be slightly in error for the conditions involved in a throttling calorimeter. Experiments have shown that the two methods of computing the moisture agree within one-fifth of one per cent. when the proper corrections are made for radiation, and when the temperatures are reduced to the equivalents by an air thermometer.* These experiments were made at the single pressure of 80 lbs. per square inch above the atmosphere, and it has not been shown that the two methods agree within this amount at all pressures, but as there should be no discrepancy provided the specific heat factor remains constant for the conditions involved, it is probable that the two methods agree very nearly with each other at all pressures.†

What is needed, are tests to compare the quality of "dead steam" with the quality of the steam used in Regnault's Experiments, and until this is done throttling calorimeter results cannot be relied upon within one-fifth of one per cent., and may be in greater error than this amount.

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* *Transactions*, Vol. XVI., p. 460.

† It must not be inferred from this that the author considers the specific heat of steam to be the same at all pressures. On the contrary, he has made experiments which show that this is not the case.

LIST OF RULES FOR CONDUCTING BOILER TRIALS, CODE OF 1899.

LIST OF APPENDICES TO CODE.

* Contributed by members of the Society and accepted by the Committee for publication in the Appendix.