CLXVIII.

REPORT OF COMMITTEE ON A STANDARD METHOD OF STEAM-BOILER TRIALS.

To the American Society of Mechanical Engineers.

GENTLEMEN:

Your Committee, to whom was intrusted the consideration of the subject of Standard Methods of Testing of Steam-boilers, and the duty of preparing a Code of Regulations for such tests, have the honor to present the following report:—

1. The importance of establishing a method of trial of steam-boilers that should determine their steaming capacity under any given set of conditions, and their economy in the use of fuel, is so thoroughly understood and so definitely recognized by engineers engaged in the design and construction, or management and use of them, that it has been thought, by all, that some system of testing should be settled upon, for general use, which may be relied upon to give all the facts needed in relation to the performance of boilers, with substantial accuracy, and yet with least possible expenditure of time and money, and a method which may be adopted by any fairly skilful engineer, without the use, so far as it can be avoided, of unusual forms of apparatus.

It has been the duty of your committee to examine carefully the methods of testing boilers now practised, to consider to what extent they present advantages or disadvantages, and finally to frame a Code of Instructions, embodying what they consider to be the best methods of experiment and the most satisfactory plan of working up and stating results. In this labor they have met with all the difficulties which usually attend an attempt to reconcile the opposing views of those who are acknowledged to be authorities on the subject, and to combine the various advantages possessed by systems in use among such members of the profession. Their object has been, not to prescribe a regulation method of test that shall be considered as representing the most complete possible system, and as giving results exact to the degree that would be satisfactory in purely scientific work, but to propose a code for daily use by the practising engineer which may be relied upon for substantial accuracy to limits of error within the range of commercial requirements, one that may be adopted by any engineer deserving of a place within the ranks of the profession, and one that may be followed closely under ordinary circumstances of every-day experience.

It has, however, also been attempted to present, independently, a view of the refinements of recent practice in this matter which may be of service to the engineer who finds it desirable and possible to attempt work of scientific exactness, and of the utmost possible completeness.

2. The object of a trial of a steam-boiler, as your committee understands it, is to determine with great precision what is the quantity of steam that a boiler can supply continuously and regularly under definitely prescribed conditions; what is the condition, and therefore the commercial value, of that steam; what is the amount of fuel demanded to produce that steam-supply; what is the character of the combustion, and what are the actual conditions of operation of the boiler when at work, all of which should be presented in a report stating the results thus determined. The conditions prescribed for one trial may differ greatly from those demanded for another trial of the same, or of another boiler, and those differences of circumstances are often the essential matters to be studied, and their effect noted upon the performance of the boiler which is the subject of the report. In any case, however, it is assumed that the conditions under which the boiler is to be worked are to be definitely stated, and the engineer conducting the experiments is expected to ascertain as exactly as possible the facts which go to determine the performance of the boiler, and to state them with accuracy, conciseness, and thoroughness.

In the attempt to ascertain those facts by observation of the actual performance of the boiler, the engineer meets with some serious difficulties, and finds it necessary to use the most perfect apparatus, and to exercise the utmost care and skill. In even so simple a matter as the weighing of coal and the measurement of water, errors are often found where least expected, and they may make their appearance even in the work of painstaking and experienced practitioners. In conducting a steam-boiler trial, the weight of the water supplied to the boiler must be exactly determined; the weight of the fuel consumed must be similarly obtained; the state of the steam made must be determined, and those quantities must be noted at such frequent intervals, during the test, that the log will exhibit every irregularity of operation, and its effect upon the performance of the apparatus. To secure thoroughly satisfactory results, it is also necessary to know whether the combustion is perfect or imperfect, and to what extent the character of the combustion, as well as the other conditions and facts noted, are due to the excellences or the defects of the boiler, and what to external conditions.

3. In the tests of boilers made in earlier times, these determinations were made with comparative crudeness of method, and the results of such methods were such as would be considered to-day grossly inaccurate. The coal consumed was in large part estimated, and no pains were taken to ascertain the amount of unevaporated water carried over with the steam. It thus often happened that results were reported that were far beyond the utmost possible efficiency; the evaporation of water was sometimes reported at a higher figure than theoretical perfection would yield; and it has only been within a very recent period that it has been possible to judge what is the real performance of the standard types of steam-boiler, under ordinary circumstances, from the reports published, in many cases, as the work of engineers of reputation.

A great change has been gradually taking place both in the sentiments and in the practice of engineers engaged in this department of professional work, and it has come to be considered that the exact determination of power and economy of a steam-boiler demands the exercise of all the care, skill and perfection of method, and of apparatus, required in the prosecution of any purely scientific investigation. It is now demanded that the weights of fuel and of water, the perfection of the combustion, the quality of the steam, and the temperatures of feed water and of furnace flue, shall be determined with an accuracy that shall be within the limits of error of good instruments; that, wherever possible, a system shall be adopted which shall permit of checking and verification of the reported results, and which shall make it as nearly as possible certain that no error can enter the work without prompt detection and correction. It is further demanded that all important work of this kind shall be done in substantially the same way, in order that comparisons may be easily made without the necessity of going through long and troublesome calculations in the effort to reduce the reports to be compared to a common basis.

4. This sentiment, and these demands, can evidently be complied with only by the establishment of some standard unit of measure

of the power of the boiler, and of evaporative efficiency, and some definite and standard method of conducting the test. This standard unit of measure must be simple, easily defined, and convenient in application; the standard method of trial of boilers must be prescribed by a code of rules so concise and yet so definite that every member of the profession may be able to adopt them. The scheme must also be so complete that, if carefully and exactly followed, the precise value of the boiler may be ascertained with certainty. The method of record of facts determined must be such as will exhibit all the essential quantities in tabular form, and unobscured by the introduction of unessential figures.

5. Such a code of rules has been proposed by a joint committee of the Union of German Engineers and of the Central Union of Associations for the Care of Steam Boilers, and this set of regulations may be considered as the embodiment of the best ideas of our Continental colleagues on this subject. Your committee have examined this document with care, and find themselves in full accord with its proposers in the main, while obliged to offer some modifications of the scheme which are thought to make it more effective and more acceptable to American engineers. The Code of Rules for Use in Trials of Steam-Boilers which your committee proposes is herewith submitted and will be found appended to this report.

6. The first provision of the code is that the object of the test to be made shall be precisely stated, and carefully kept in view during the whole trial, and during the preparation of the report. This object may be the determination of the steaming capacity, of the maximum efficiency, or of the quality of steam supplied by the boiler under specified conditions; or it may be the comparison of the qualities of various fuels. These objects cannot all be attained at one time, and maximum steaming capacity and maximum economy of fuel are, almost invariably, if not always, the result of incompatible conditions. The method of handling the steam generator will therefore differ as one or the other of these objects is to be sought.

It is next provided that the boiler to be tested shall be exactly measured, in order that data may be obtained for subsequent calculations. These measurements should be taken before the trial, not only because that is usually the most convenient time, but also because this preliminary measurement may sometimes lead to the discovery of defects of construction, as well as of proportions, that may suggest modifications of the plan of test previously laid down.

The boiler is then to be put in the best possible order, in every respect, so that its observed merits or defects may not be obscured by accidental conditions having no relation to such merits or defects.

7. It is provided that an understanding shall be reached, before the trial, in regard to the kind of fuel to be used. Neglect of this precaution sometimes leads to needless misunderstandings, and avoidable criticism of the results reported. It is proposed that, where no reason of controlling importance exists to the contrary, the best obtainable coal shall be selected, for the reason that it is thought that a boiler can be better judged, and the results of its trial may be more satisfactorily compared with similar trials of other boilers when the very best work of which it is capable is done by it. The differences between separate lots of the best coals are less than the differences between separate lots of inferior fuels, and the comparison is thus less difficult where the former are used. To secure still more exact knowledge of the influence of the quality of the fuel upon the performance of the boiler, it is considered advisable to have an analysis made of the coal used in all cases in which it can be done.

8. The establishment of the correctness of all the apparatus to be employed in the test is the first of the preliminaries to their use. The standardization of the instruments is a matter of supreme importance, since upon their accuracy the whole work of the engineer is dependent. It is also a work demanding, in most cases, unusual skill and care, and, to be satisfactory, must generally be performed either at the manufacturer's or at the office of the engineer conducting the trial. The scales can usually be standardized by the official sealer of weights and measures, and sealed by him; the water meters, if used, can be readily tested by the use of the scales so sealed; the thermometers are, as a rule, best tested by their makers, and should be sent to the maker for test immediately before and directly after the test. The engineer often has a carefully preserved standard with which they may be compared in his own office. The same remarks apply to the examination of the gauges used, which should be standardized both before and after their use. The apparatus used in connection with the calorimeter, in the determination of the quality of the steam made, demand exceptional care in this process; they are rarely of sufficient delicacy and accuracy to give perfectly satisfactory single determinations, even at the best, and the use of ordinary commercial instruments, carelessly standardized, or not at all, cannot be too strongly depre-

cated. Where it is unavoidable, the use of coarsely graduated thermometers and roughly constructed scales may be permitted, but only then when a very large number of observations are taken, and an average thus obtained which may be fairly expected to fall within reasonable limits of error—say within one per cent.

9. The precautions to be taken before beginning a trial are prescribed in some detail, since your committee consider them of great importance, and have known of serious embarrassment arising by their neglect.

The method of starting and of stopping the trial is prescribed in a form which seems to your committee best as a whole. This is a very important matter, and yet is one upon which engineers of experience and acknowledged authority are not in complete accord. Your committee, for this, and also for the other reason, that the plan here proposed may not be always practicable, prescribe a second or alternative method, which may be adopted for such cases, or, where the engineer conducting the test is confident of being able to do better work than by the first of the two methods. The principles to be adhered to in this matter, as in every other detail of the operation of testing a boiler, are easily specified, but they are not always as easy of practice. All conditions should be as exactly the same at the beginning and at the end of the test as they can possibly be made. The period of the trial, and the times of stopping and of starting, should be capable of being exactly fixed, and the method of test should be such as should permit of the commencement and the end occurring at these exactly defined times, or, as an alternative, they should be such that the work done by the boiler during the less precisely determinable time of beginning and ending of the trial should be as nearly as possible *nil*, so that a slight error as to time may not appreciably affect the results. The "Standard Method" proposed by your committee is considered to meet these requirements as fully as any method in use. The alternative method is regarded as the next best.

10. During the trial, the essential provision should be the preservation of the utmost possible uniformity of working conditions throughout the whole period of the trial. Every irregularity gives rise to more or less loss of efficiency and to uncertainty in regard to the correctness of the reported figures. The nearer the working of the boiler is kept to the final average for the trial, the better.

11. Your committee consider the method of keeping the record of the test as no less important than the method of test itself.

Perfect uniformity of operation within the boiler-room, and maximum efficiency of boiler, are best attainable where a system of record is adopted which allows of that regularity being shown at all times; and records in proper form are the best possible security against error of observation. The committee are unanimous in recommending that graphical methods be adopted wherever it is found practicable to employ them. Such methods of record also exhibit most satisfactorily the accordance with or the deviation from the uniformity of operation considered so desirable on the score of efficiency and accuracy. Your committee present a form of record blank which they consider as concise as is ever desirable in any important trial; and would prefer, in special cases, a more, rather than a less, complete record.

12. It is proposed by your committee as desirable that, when practicable, analyses of the escaping gases should be made. This is an operation of great simplicity, and can easily be made familiar to any engineer who chooses to take the trouble of learning it. If, for any reason, it is not found convenient to make the analysis in the office of the engineer, he can readily have the work done, at little expense, by intrusting his samples to a chemist of known skill and reliability. This provision is made as a part of the code, on the ground that it is only by a knowledge of the proportion of constituents of the flue-gases that it can be determined whether the combustion is complete, whether the products of combustion are diluted with excess of air, and whether the fuel used has been so burned as to give its best effect. Such analyses also enable the engineer to ascertain the best method of burning the fuel. The code prescribes the precautions to be taken when this detail is carried into effect.

13. The establishment of the value of the "Unit of Evaporation," and that of the "Commercial Horse-power" of the boiler, are matters which have been considered by your committee to be of essential importance to the settlement of a thoroughly complete standard method of trial, and of a perfectly satisfactory system of reporting results.

It has been evident to every observer that the sentiment above alluded to, as having arisen among engineers during the present generation, in favor of reducing the whole matter of testing boilers to an acknowledged standard system, has led to the endeavor, on the part of the most able among practitioners, to determine standards with which to compare results obtained in such trials. The two most essential standards are those just referred to. The trials of boilers are made under a wide range of actual conditions, the steam pressure, the temperature of feed-water, the rate of combustion and of evaporation, and, in fact, every other variable condition, differing in any two trials to such an extent that direct comparison of the totals obtained, as a matter of information relating to the relative value of the boilers, or of the fuel used, becomes out of the question. It has thus gradually come to be the custom to reduce all results to the common standard of weight of water evaporated by the unit weight of fuel, the evaporation being considered to have taken place at mean atmospheric pressure, and at the temperature due that pressure, the feed-water being also assumed to have been supplied at that temperature. This is, in technical language, said to be the "equivalent evaporation from and at the boiling point" (212° Fahr.). This standard has now become so generally and so indisputably incorporated into the science and the practice of steam engineering that your committee, even were they acquainted with any other equally satisfactory unit, would hesitate to recommend anything else. They would simply express their approval of the adoption, and recommend the permanent retention of this, which, as has been previously proposed, they would denominate the "*Unit of Evaporation*," *i. e.*, one pound of water at 212° F. evaporated into steam of the same temperature. This is equivalent to the utilization of 965.7 British thermal units per pound of water so evaporated. The relative economy of the boiler would then, as is customary, be expressed by the number of units of evaporation obtained per pound of combustible.

14. The character and magnitude of the unit to be chosen to express the "power" of the steam-boiler is not as well settled; and your committee find themselves compelled to take up, in this matter, a subject which has attracted much attention among engineers, and which remains, nevertheless, unsettled. It is evident that, since the boiler is simply an apparatus for the generation of steam, and since the province of the steam-engine is to develop power from that steam, by the conversion of heat into mechanical energy; and since, furthermore, the engine develops power with a degree of efficiency which may vary enormously with differences in construction and operation of that machine, it cannot be properly said that we have any natural unit of power for rating steam-boilers. The most nearly scientific system of power rating yet proposed is, perhaps, that which considers the power of a boiler to be that ex-

pended by it in driving all the steam which it makes out against the pressure of the atmosphere, a system which does not, however, meet the wants of engineers. What is needed is a standard unit of boiler-power which may be used commercially in rating boilers, and in specifications prescribing the power to be demanded by the purchaser and guaranteed by the vender. It is evident that such a unit would not, if established, serve as a gauge of the power to be actually obtained from any given combination of engine and boiler, since the power so obtained must be measured by the indicator at the engine, and not at the boiler, and since in so measuring power, the economy and efficiency of the boiler would be elements left entirely out of the account. The best that can be done is obviously to assume a set of practically attainable conditions under which it would be fair to assume that the boiler may be properly expected to be operated in average good practice, and to take the power so obtainable as the measure of its power to be used in commercial and engineering transactions. The unit which has been most generally assumed, up to the present time, is the weight of steam demanded per horse-power per hour by a fairly good steam-engine. The magnitude of this quantity has been gradually and constantly decreasing from the earliest period of the history of the steam-engine. In the time of Watt, one cubic foot of water per hour per horse-power was thought a fair allowance; at the middle of the present century, ten pounds of coal was still not an unusual figure for the consumption per hour per horse-power, and five pounds, equivalent to about forty pounds of feed-water, was a good allowance for the best engines. After the introduction of the modern forms of expansively working engines, this last figure was reduced twenty-five per cent., and the most recent improvements have still further lessened the consumption of fuel and of steam. By general consent, it seems likely that the unit which will meet with final acceptance for general purposes, in the estimation of boiler-power, is not far from thirty pounds of dry steam per horse-power per hour. This represents the performance of good mill engines of the non-condensing type. Large engines, with condensers, or compounded cylinders, will do better by from twenty to thirty per cent. Your committee have concluded to recommend thirty pounds as the unit of boiler-power.

15. But it remains to be determined under what circumstances this figure shall be taken as standard. It is on this subject that practitioners, and the members of your committee as well, are not

fully agreed. Nevertheless it is, in their opinion, advisable that some definite set of conditions be prescribed to be taken as standard without waiting for complete accordance of opinion throughout the profession.

The Committee of Judges of the Centennial Exhibition, to whom the trials of competing boilers at that exhibition were intrusted, met with this same problem, and finally agreed to solve it, at least so far as the work of that committee was concerned, by the adoption of the unit, 30 *pounds of water evaporated into dry steam per hour from feed-water at* 100° *Fahrenheit, and under a pressure of seventy pounds per square inch above the atmosphere*, these conditions being considered by them to represent fairly average practice. The quantity of heat demanded to evaporate a pound of water under these conditions is **1110.2** British thermal units, or **1.1496** units of evaporation (such as are here adopted and proposed for general use). The unit of power proposed is thus equivalent to the development of 33,305 heat-units per hour, or 34.488 units of evaporation. The arguments in favor of the retention of this unit of power without modification are: (1) It is, to a certain extent, established, being the only unit proposed by authority, up to the present time, which has been accepted to any important extent by practitioners; (2) It is considered by its proposers, and probably by engineers generally, fairly to represent good average practice in the application of steam-power, as exhibited in the operation of engines and boilers under ordinary actual working conditions. Both of these arguments are deemed by your committee to be valid and deserving of careful consideration. The abandonment of an already established standard is always confusing, and should not be permitted without the most cogent of reasons.

Another standard unit, which has been proposed to your committee, and strongly urged as preferable to the above, is that represented by the evaporation of thirty pounds of feed-water into dry steam "*from and at the boiling point*," at mean atmospheric pressure (212° F.) The arguments in favor of this unit are the following: (1) In the determination of the unit of evaporation to be used in steam-boiler practice, it has been generally, and probably unanimously, decided by engineers that the evaporation shall be reckoned as having been effected at the boiling point from water assumed also to be supplied at that temperature, and that one pound thus evaporated shall be the unit. This being the established unit of evaporation, consistency and convenience both dictate that the power of the boiler should be expressed in the same unit, or some handy multiple thereof; (2) It is submitted that the reduction of this unit to an exact multiple of the unit of evaporation will greatly facilitate calculations, inasmuch as the work done by the boiler is to be reduced to the same standard of feed-temperature and temperature of evaporation; (3) By the adoption of this unit, the trouble and risk of error coming from the attempt to use a factor as proposed above, differing from the multiple of the already accepted factor by 14.96 per cent., may be entirely avoided; (4) The unit last proposed is equivalent to 26.09 pounds of water evaporated from 100° Fahr. into steam at 70 pounds pressure, and is claimed to be itself more nearly representative of good average practice than the centennial unit.

Your committee has carefully weighed the arguments relating to these standards, as they were presented in writing by their respective advocates, and, after due consideration, has determined to accept the Centennial Standard, the first above mentioned, 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° *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° Fahr. into steam at the same temperature. This standard is equal to 33,305 thermal units per hour.*

It is the opinion of this committee that a boiler rated at any stated number of horse-powers should be capable of developing that power with easy firing, moderate draught and ordinary fuel, while exhibiting good economy; and further, that the boiler should be capable of developing at least one-third more than its rated power to meet emergencies at times when maximum economy is, not the most important object to be attained.

Any increase of temperature derived from a feed-water heater acted upon by the products of combustion escaping from a boiler should not be credited to the evaporative efficiency of the boiler

* According to the tables in Porter's Treatise on the Richards Steam Engine Indicator, which tables the committee would recommend for general acceptance by engineers, an evaporation of 30 pounds of water from 100° F., into steam at 70 pounds pressure is equal to an evaporation of 34.488 pounds from and at 212°; and an evaporation of 34½ pounds from and at 212° F., is equal to 30.010 pounds from 100° F., into steam at 70 pounds pressure.

The "unit of evaporation" being equal to 965.7 thermal units, the commercial horse-power = 34.488 × 965.7 = 33,305 thermal units.

except by agreement; and in the latter case accurate tests can be made only with feed-water of the average temperature used during the regular operation of the boiler.

The code presented by your committee is necessarily, as has been already indicated, condensed to the utmost possible extent consistent with exactness, and essential completeness. In matters of detail, it must be left to the engineer to carry out the evident spirit and intent of the code by devising his own methods; and it may be expected that every engineer will be competent to supplement the directions here given, as far as is necessary.

In order, however, to exhibit the extent to which he may work up such details, and to present the views of the members of the committee more fully, both in matters in which they agree and in those in which differences of views exist, an appendix is added to the report, in which memoranda written out by them are given describing details of work more fully than they are given in the code, and expressing individual opinions in regard to such matters as have seemed to each of such importance as to demand special notice. Each of these notes is signed with the initials of the writer.

Respectfully submitted.

WM. KENT,
J. C. HOADLEY,
R. H. THURSTON, } *Committee.*
CHAS. E. EMERY,
CHAS. T. PORTER,

CODE OF RULES FOR BOILER TESTS.

PRELIMINARIES TO A TEST.

I. *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. (Appendix I.)

II. *Measure and record the dimensions*, position, etc., of grate and heating surfaces, flues and chimneys, proportion of air space in the grate surface, kind of draught, natural or forced.

III. *Put the Boiler in good condition.*—Have heating surface clean inside and out, grate bars and sides of furnace free from clinkers, dust and ashes removed from back connections, leaks in masonry stopped, and all obstructions to draught removed. See that the damper will open to full extent, and that it may be closed when desired. Test for leaks in masonry by firing a little smoky fuel and immediately closing damper. The smoke will then escape through the leaks.

IV. *Have an understanding with the parties* in whose interest the test is to be made as to the character of the coal to be used. The coal must be dry, or, if wet, a sample must be dried carefully and a determination of the amount of moisture in the coal made, and the calculation of the results of the test corrected accordingly.

Wherever possible, the test should be made with standard coal of a known quality. For that portion of the country east of the Alleghany Mountains good anthracite egg coal or Cumberland semi-bituminous coal may be taken as the standard for making tests. West of the Alleghany Mountains and east of the Missouri River, Pittsburgh lump coal may be used.*

V. *In all important tests* a sample of coal should be selected for chemical analysis.

VI. *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. (Appendix VI. and VII.)
3. Thermometers and pyrometers for taking temperatures of air, steam, feed-water, waste gases, etc. (Appendix X. to XIII.)
4. Pressure gauges, draught gauges, etc. (Appendix IX., XIV., and XV.)

VII. *Before beginning a test*, the boiler and chimney should be thoroughly heated to their usual working temperature. If the boiler is new, it should be in continuous use at least a week before testing, so as to dry the mortar thoroughly and heat the walls.

VIII. Before beginning a test, the boiler and connections should be free from leaks, and all water connections, including blow and extra feed pipes, should be disconnected or stopped with blank flanges, except the particular pipe through which water is to be fed

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* These coals are selected because they are about the only coals which contain 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.

to the boiler during the trial. In locations where the reliability of the power is so important that an extra feed pipe must be kept in position, and in general when for any other reason water pipes other than the feed pipes cannot be disconnected, such pipes may be drilled so as to leave openings in their lower sides, which should be kept open throughout the test as a means of detecting leaks, or accidental or unauthorized opening of valves. During the test the blow-off pipe should remain exposed.

If an injector is used it must receive steam directly from the boiler being tested, and not from a steam pipe, or from any other boiler.

See that the steam pipe is so arranged that water of condensation cannot run back into the boiler. If the steam pipe has such an inclination that the water of condensation from any portion of the steam-pipe system may run back into the boiler, it must be trapped so as to prevent this water getting into the boiler without being measured.

STARTING AND STOPPING A TEST.

A test should last at least ten hours of continuous running, and twenty-four hours whenever practicable. 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. To secure as near an approximation to exact uniformity as possible in conditions of the fire and in temperatures of the walls and flues, the following method of starting and stopping a test should be adopted:

X. *Standard Method.*—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 of starting the test and the height of the water level while the water is in a quiescent state, just before lighting the fire.

At the end of the test, remove the whole fire, clean the grates and ash pit, and note the water level when the water is in a quiescent state; record the time of hauling the fire as the end of the test. 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 pump after test is completed. It will generally be necessary to regulate the discharge of steam from the boiler tested by means of the stop valve for a time while fires are being hauled at the beginning and at the end of the test, in order to keep the steam pressure in the boiler at those times up to the average during the test.

XI. *Alternate Method.*—Instead of the Standard Method above described, the following may be employed where local conditions render it necessary :

At the regular time for slicing and cleaning fires have them burned rather low, as is usual before cleaning, and then thoroughly cleaned ; note the amount of coal left on the grate as nearly as it can be estimated; note the pressure of steam and the height of the water level—which should be at the medium height to be carried throughout the test—at the same time ; and note this time as the time of starting the test. 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 the same amount of fire, and in the same condition, on the grates as at the start. The water level and steam pressure should be brought to the same point as at the start, and the time of the ending of the test should be noted just before fresh coal is fired.

DURING THE TEST.

XII. *Keep the Conditions Uniform.*—The boiler should be run continuously, without stopping for meal-times or for rise or fall of pressure of steam due to change of demand for steam. The draught being adjusted to the rate of evaporation or combustion desired before the test is begun, it should be retained constant during the test by means of the damper.

If the boiler is not connected to the same steam pipe with other boilers, an extra outlet for steam with valve in same should be provided, so that in case the pressure should rise to that at which the safety valve is set, it may be reduced to the desired point by opening the extra outlet, without checking the fires.

If the boiler is connected to a main steam pipe with other boilers, the safety valve on the boiler being tested should be set a few pounds higher than those of the other boilers, so that in case of a rise in pressure the other boilers may blow off, and the pressure be reduced by closing their dampers, allowing the damper of the boiler being tested to remain open, and firing as usual.

All the conditions should be kept as nearly uniform as possible, such as force of draught, pressure of steam, and height of water. The time of cleaning the fires will depend upon the character of the fuel, the rapidity of combustion, and the kind of grates. When very good coal is used, and the combustion not too rapid, a ten-hour test may be run without any cleaning of the grates, other than just before the beginning and just before the end of the test. But in case the grates have to be cleaned during the test, the intervals between one cleaning and another should be uniform.

XIII. *Keeping the Records.*—The coal should be weighed and delivered to the firemen in equal portions, each sufficient for about 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 first of each new 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 record of the test may be divided into several divisions, if desired, at the end of the test, to discover the degree of uniformity of combustion, evaporation and economy at different stages of the test. (Appendix II. and III.)

XIV. *Priming Tests.*—In all tests in which accuracy of results is important, calorimeter tests should be made of the percentage of moisture in the steam, or of the degree of superheating. At least ten such tests should be made during the trial of the boiler, or so many as to reduce the probable average error to less than one per cent., and the final records of the boiler test corrected according to the average results of the calorimeter tests.

On account of the difficulty of securing accuracy in these tests, the greatest care should be taken in the measurements of weights and temperatures. The thermometers should be accurate to within a tenth of a degree, and the scales on which the water is weighed to within one-hundredth of a pound. (Appendix XVII. to XXI.)

ANALYSES OF GASES.—MEASUREMENT OF AIR SUPPLY, ETC.

XV. 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 not necessary in tests for commercial purposes. These are the measurement of the air supply, the determination of its contained moisture, the measurement and analysis of the flue gases, the determination of the amount of heat lost by radiation, of the amount of infiltration of air through the setting, the direct determination by calorimeter experiments of the absolute heating value of the fuel, and (by condensation of all the steam made by the boiler,) of the total heat imparted to the water.

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 XVI.)—and the analyses should be intrusted only to a thoroughly competent chemist, who is provided with complete and accurate apparatus.

As the determinations of the other variables mentioned above are not likely to be undertaken except by engineers of high scientific attainments, and as apparatus for making them is likely to be improved in the course of scientific research, it is not deemed advisable to include in this code any specific directions for making them.

RECORD OF THE TEST.

XVI. A "log" of the test should be kept on properly prepared blanks, containing headings as follows:

Time.	Pressures.			Temperatures.					Fuel.		Feed Water.	
	Barometer.	Steam Gauge.	Draught Gauge.	External Air.	Boiler Room.	Flue.	Feed Water.	Steam.	Time.	lbs.	Time.	lbs. or c. ft.

REPORTING THE TRIAL.

XVII. The final results should be recorded upon a properly prepared blank, and should include as many of the following items as are adapted for the specific object for which the trial is made. The items marked with a * may be omitted for ordinary trials, but are desirable for comparison with similar data from other sources.

Results of the trials of a..
Boiler at..
To determine..

1. Date of trial..................................			
2. Duration of trial..................................	hours.		
DIMENSIONS AND PROPORTIONS.			
Leave space for complete description. See Appendix XXIII.			
3. Grate surface....wide....long....Area........	sq. ft.		
4. Water-heating surface........................	sq. ft.		
5. Superheating surface........................	sq. ft.		
6. Ratio of water-heating surface to grate surface.			
AVERAGE PRESSURES.			
7. Steam pressure in boiler, by gauge...........	lbs.		
*8. Absolute steam pressure......................	lbs.		
*9. Atmospheric pressure, per barometer..........	in.		
10. Force of draught in inches of water...........	in.		
AVERAGE TEMPERATURES.			
*11. Of external air..................................	deg.		
*12. Of fire room..................................	deg.		
*13. Of steam..................................	deg.		
14. Of escaping gases..............................	deg.		
15. Of feed-water..................................	deg.		
FUEL.			
16. Total amount of coal consumed †..............	lbs.		
17. Moisture in coal..............................	per cent.		
18. Dry coal consumed..............................	lbs.		
19. Total refuse, dry........pounds =............	per cent.		
20. Total combustible (dry weight of coal, Item 18, less refuse, Item 19)........................	lbs.		
*21. Dry coal consumed per hour....................	lbs.		
*22. Combustible consumed per hour..............	lbs.		
RESULTS OF CALORIMETRIC TESTS.			
23. Quality of steam, dry steam being taken as unity.			
24. Percentage of moisture in steam..............	per cent.		
25. No. of degrees superheated..................	deg.		

* See reference in paragraph preceding table.

† Including equivalent of wood used in lighting fire. 1 pound of wood equals 0.4 pound coal. Not including unburnt coal withdrawn from fire at end of test.

WATER.			
26. Total weight of water pumped into boiler and apparently evaporated*	lbs.		
27. Water actually evaporated, corrected for quality of steam ††	lbs.		
28. Equivalent water evaporated into dry steam from and at 212° F. ††	lbs.		
*29. Equivalent total heat derived from fuel in British thermal units ††	B. T. U.		
30. Equivalent water evaporated into dry steam from and at 212° F. per hour	lbs.		
ECONOMIC EVAPORATION.			
31. Water actually evaporated per pound of dry coal, from actual pressure and temperature ††	lbs.		
32. Equivalent water evaporated per pound of dry coal from and at 212° F. ††	lbs.		
33. Equivalent water evaporated per pound of combustible from and at 212° F. ††	lbs.		
COMMERCIAL EVAPORATION.			
34. Equivalent water evaporated per pound of dry coal with one-sixth refuse, at 70 pounds gauge pressure, from temperature of 100° F. = Item 33 multiplied by 0.7249	lbs.		
RATE OF COMBUSTION.			
35. Dry coal actually burned per square foot of grate surface per hour	lbs.		
*36. Consumption of dry coal per hour. Coal assumed with one-sixth refuse. †† Per sq. ft. of grate surface	lbs.		
*37. Consumption of dry coal per hour. Coal assumed with one-sixth refuse. †† Per sq. ft. of water heating surface	lbs.		
*38. Consumption of dry coal per hour. Coal assumed with one-sixth refuse. †† Per sq. ft. of least area for draught	lbs.		
RATE OF EVAPORATION.			
39. Water evaporated from and at 212° F. per sq. ft. of heating surface per hour	lbs.		
*40. Water evaporated per hour from temperature of 100° F. into steam of 70 pounds gauge pressure. †† Per sq. ft. of grate surface	lbs.		
*41. Water evaporated per hour from temperature of 100° F. into steam of 70 pounds gauge pressure. †† Per sq. ft. of water heating surface	lbs.		
*42. Water evaporated per hour from temperature of 100° F. into steam of 70 pounds gauge pressure. †† Per sq. ft. of least area for draught	lbs.		

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

†† The following shows how some of the items in the above table are derived from others:

Item 27 = Item 26 × Item 23.

Item 28 = Item 27 × Factor of evaporation.

Factor of evaporation $= \frac{H-h}{965.7}$, H and h being respectively the total heat

COMMERCIAL HORSE-POWER.			
43. On basis of thirty pounds of water per hour evaporated from temperature of 100° F. into steam of 70 pounds gauge pressure, (= $34\frac{1}{2}$ lbs. from and at 212°) ††....................	H. P.		
44. Horse-power, builders' rating, at.....square feet per horse-power..............................	H. P.		
45. Per cent. developed above, or below, rating ††..	per cent.		

APPENDIX TO CODE.

I. 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

units in steam of the average observed pressure and in water of the average observed temperature of feed, as obtained from tables of the properties of steam and water.

Item 29 = Item 27 × $(H - h)$.

Item 31 = Item 27 ÷ Item 18.

Item 32 = Item 28 ÷ Item 18 or = Item 31 × Factor of evaporation.

Item 33 = Item 28 ÷ Item 20 or = Item 32 ÷ (per cent. 100 — Item 19).

Items 36 to 38. First term = Item 20 × $\frac{6}{5}$

Items 40 to 42. First term = Item 39 × 0.8698.

Item 43 = Item 29 × 0.00003 or = $\frac{\text{Item 30}}{34\frac{1}{2}}$.

Item 45 = $\frac{\text{Difference of Items 43 and 44}}{\text{Item 44}}$.

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.

II. 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 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.

III. 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-guage 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.

As to calorimeter tests, note from the special article on that subject (Appendix XVII.), that the results are liable to be untrustworthy simply from an improper connection to the boiler. Scales and thermometers very finely graduated are desirable, but if they cannot be procured, good instruments with medium graduations carefully standardized may be employed, when if the observer will take the precaution mentioned in the appended article of the writer on calorimeter experiments, and simply make each record according to his best judgment at the time, the average of the results will be substantially accurate, although the several experiments may disagree somewhat with each other.

C. E. E.

IV. WEIGHING THE COAL.

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

V. 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 lbs. 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 shoveled 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.

VI. 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.

VII. 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.

VIII. 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.

IX. 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.

X. AIR THERMOMETER.

The air thermometer is the best instrument for taking the temperature of flues, smoke boxes, etc., from 300° to 700° or 750° F. These instruments cost but a trifle, $3 to $5, and can be made anywhere, by any competent expert, or by any one of his assistants under his direction, and can be relied on from ordinary temperatures, say 60° to 90°, up to any temperature which glass will bear without deformation. Ordinary machine-divided paper scales can be used with them. The great point is to deprive the interior of the bulb and tube of all moisture, and to fill the bulb and the upper half of the leg of the inverted syphon connected with the bulb, with dry air. (Appendix XI.). The expansion of dry air is practically uniform for all useful ranges of temperature, and its volume is directly proportioned to its temperature from absolute zero, say 461.2° F. below zero F., equal to 493.2° F. below the temperature of melting ice, to which the conventional zero of the air thermometer, at the accurately observed and noted temperature of the air when the mercury in the two legs of the inverted syphon is exactly level—the tubes being exactly vertical—can be conveniently referred. For instance, if the temperature of the air when the mercury in the two legs is level, be 73.8° F., add to this 461.2°, and we have 541.0° F. absolute, as the true absolute temperature corresponding to our zero.

To double this temperature—1082° F. absolute (equal to 1082° — 461.2° = 620.8° F. above zero F.), would double the volume of the air; but the volume being nearly constant—since the capacity of the tube may generally be disregarded, a difference of level will be produced in the height of the mercury in the two legs of the inverted syphon exactly equal to the height of the mercury column in a mercurial barometer at the time. No correction for capillarity is required, since the negative capillarity is equal in the two legs. No correction for temperature is required, unless the temperature of the *mercury* in the air thermometer is higher than that of the mercury column of the barometer. If there is an observable difference, it must be corrected for, at the rate of 0.0001 per degree F.

There should be at least two of these air thermometers, three would be safer, in readiness for each test, to avoid disappointment by accident. The legs of the inverted syphon must be vertical, but the tube from the upper end of the leg to the bulb may be straight, or bent to any angle.

For the determination of the heat of flue gases, this instrument is indispensable, up to the limit of the softening of glass; but since no flue will always, or even usually, contain volumes of gas of equal temperature throughout at the same instant, at least two tubes of gas-pipe, welded up at the lower end, and filled with mercury, should be placed in opposite sides of the flue, near the air thermometer, for observing the differences with chemical thermometers graduated on the glass. Sir Wm. Thompson highly commends thermometers incased in hermetically sealed glass tubes, with scales graduated on paper for use up to a point below the temperature required to scorch the paper. Dampness being excluded by the glass case, the paper scales are of unchangeable length, and the graduations and figures are very distinct and legible. J. C. H.

XI. DESCRIPTION OF AN AIR THERMOMETER OF CONSTANT VOLUME (AFTER REGNAULT), AND OF THE MODE OF CONSTRUCTING AND USING THE SAME.

This instrument may be made in many forms, and of materials of several kinds—metals, or glass, or metal and glass. A simple, inexpensive, and convenient form* consists of a U tube of about

* Constructed and brought to my notice by Mr. Fred W. Prentiss. Originally devised by Regnault.—J. C. H.

three-eighths of an inch external diameter (Fig. 87) and about one-sixteenth of an inch calibre, or a little less; having a short leg about 39 inches long, and the other leg longer by 12 inches or more; the latter surmounted by a bulb blown out of the tube, $1\frac{5}{8}$ inches in diameter, $6\frac{5}{8}$ inches in extreme length, and 5 inches long in its straight, cylindrical portion.

The two legs, or branches, of the U, are 2 inches apart between centers.

They are separate tubes, each one bent to a right angle, by a curve of short radius, ground square and true at the ends which are to meet, and hermetically united by a short coupling of rubber tubing, firmly bound on each with wire.

In blowing the bulb, a small, short tube, about $\frac{1}{16}$ inch in calibre and 2 or three inches long, is formed on top for use in making the instrument—to be sealed by fusion when it is done.

Having formed the U tube by uniting its branches, the next thing to be done is to dessicate its interior perfectly and to fill it with dry air. For this purpose it is put in any covenient position—reclining, probably—a piece of rubber tubing is secured to the small tube on top of the bulb and connected with a U tube about 6 inches long in its branches, and $\frac{5}{8}$ inch or $\frac{3}{4}$ inch in diameter, filled with dry lumps of chloride of calcium and surrounded by crushed ice, to lower its temperature, and the temperature of the air passing through it to about 32° F., at which point air parts with a larger portion of its moisture than at any higher temperature.

An aspirator is now connected by a piece of rubber tube with the open end at the short branch of the instrument, and a stream of air is drawn in through the chloride of calcium tube and discharged by the aspirator.

A simple and efficient form of aspirator is merely a piece of $\frac{1}{4}$-inch gas-pipe, bent, when hot, into three or four sharp zigzags, with an inlet at its upper extremity for water, and at its side for air.

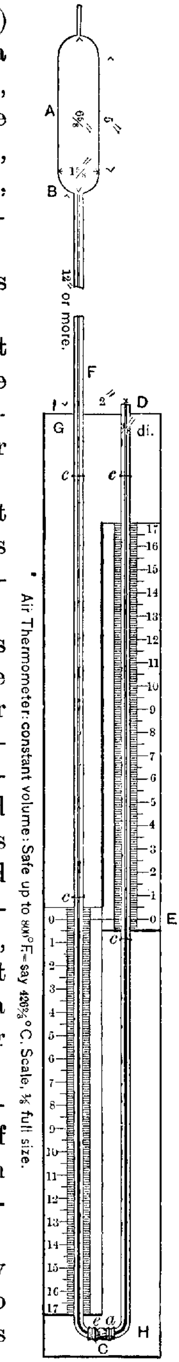

FIG. 87.

A stream of water flowing through the zigzag tube draws air in at the side orifice, and the air becoming entangled with the water, flows off with it, its place being supplied through the chloride of calcium tube and the U tube of the thermometer. This operation can be carried out conveniently in any office or other room supplied with a flow of water and a set wash-basin; and once arranged, requires only so much attention as to see that it remains undisturbed.

When the tube is completely dessicated (in so far as air at 32° F. will give up its moisture to chloride of calcium), which will be in about four or five hours, shut off the water, bend over the rubber tube connecting the calcium-chloride tube with the bulb, or, another rubber tube connected with the outer branch of the calcium-chloride tube, so as to prevent any mixture of moist air with the dry air in the bulb and U tube, and lay the instrument on its side in such a manner that the longer branch shall slope from the bulb down to the rubber coupling, and that the shorter branch shall also slope from the rubber coupling down to the extremity of this branch, which should be kept closed by the finger until it is immersed in mercury, to prevent the admixture of moist air. If the mercury is in a wide, shallow dish, like a plate or a saucer, the sloping end of the branch may be immersed in it sufficiently; or a short piece of glass tube coupled on *in advance*, when preparations were made for the dessicating process, may be held down in the mercury. Then apply the lips to the calcium-chloride tube or to the rubber tube connected therewith, and, by inspiration of breath, draw out air from the bulb until the mercury, forced into the shorter branch, fills it, and shows just beyond the rubber coupling in the lower end of the long branch. Then pinch the rubber tube, set the instrument upright (keeping the open end of the shorter branch closed with the finger until it is upright). See that the branch tubes are exactly vertical; carefully relieve the pinched rubber tube, so that air may escape, until the surface of the mercury in the two branches is exactly level; then pinch the rubber tube and fuse and seal the small glass tube into a little button on top of the bulb. Now hang up an accurate chemical thermometer, graduated on the tube, close beside the bulb, until this thermometer and the bulb and the dry air inside of it are certain to have come to a common temperature, and read and note this temperature; and make a distinct and permanent mark on the back-board of the instrument, at the level of the mercury in the two branches.

This back-board may be 4 or 5 inches wide, $\frac{1}{2}$ to $\frac{5}{8}$ inch thick, and about as long as the shorter branch, and the tube may be secured to it by little staples of annealed iron wires, going around (*i. e.* over) the tube, and through holes in the back-board; and twisted together at the back. A bit of soft leather at the staple, between the board and the tube, will form a secure bed for the tube, and obviate danger of breaking. Such staples are indicated on the drawing, at *c*, *c*, *c*. There may be two such staples at the bottom, passing over the rubber coupling, to further aid in keeping the two parts (branches) of the U tube in proper position. At the same time that the temperature is noted, note also the height of the mercury column of a barometer. On the air thermometer, hanging in my office, the notes are:

"Temperature 81.5° F.

"Barometer, Hg, 31.03 in."

Scales, as indicated on drawing, complete the instrument. For these, engine-divided paper scales will answer; and they may be graduated to inches and tenths of inches, as I have indicated, or to millimeters.

Since the instrument is to be used chiefly or wholly for temperatures above any atmospheric temperature at which it may be set, the scale on the long leg need not exceed much above, nor that on the short leg much below, the level line; but a $\frac{1}{2}$ inch, or an inch may be worth while, if the instrument is set as high as 80° F., for convenience of comparison with ordinary thermometers.

FOR USING THE INSTRUMENT:

Let t_1 = temperature at which thermometer is set.

t_2 = temperature sought from observation.

$\pm h$ = difference of level of mercury, when the thermometer was set; + when mercury is highest in short leg; − when mercury is highest in long leg; $h = o$, when mercury is level at the noted temperature when the thermometer is set.

Let b_1 = mercury column of barometer when the thermometer was set.

b_2 = mercury column of barometer at the time of observation.

$\pm h_2$ = difference of level of mercury in the two branches when observed:

Then:

$$t_2 = \left[(461.2 + t_1)\frac{(b_2 \pm h_2)}{(b_1 \pm h_1)}\right] - 461.2$$

If made of good hard glass, this instrument is safe at 800° F., say $426\frac{2}{3}$° C., and will not be very likely to fail at under 850° F., say $454\frac{2}{3}$° C.

The part of the tube below the bulb *BI*, may be of any convenient length, and may be bent as at *F*, to any angle to suit requirements of location. J. C. H.

XII. PYROMETER.

So far as known to me the only way to measure temperatures between 600° or 700° F., or above the range of the air thermometer, and 2500° or 2700° F., 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.

XIII. 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.

XIV. DRAUGHT GAUGE.

Some instruments for indicating the force of chimney draught:

a. A bent glass tube filled with water.

b. A bent tube with two fluids.

c. An incased aneroid.

d. A differential pressure gauge.

The incased aneroid, having inches of mercury indicated by spaces of about two inches, divided to $\frac{1}{500}$, answers well. The case is air tight, 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 diaphragm.

Draught should be measured in different parts of the flue, in order to detect infiltration of air through cracks in the brick-work and through the brick-work itself. J. C. H.

XV. DRAUGHT GAUGE.

Mr. C. P. Higgins, of Philadelphia, has recently made the draught gauge shown in the sketch (Fig. 88). The gauge is filled with water above the level of the horizontal tube, so as to leave a bubble of air about half an inch long near one end of the horizontal tube when the water is level in the side tubes. The inside diameter of the two vertical tubes being the same, say half an inch, and the diameter of the horizontal tube one-eighth of an inch, a draft equal to one inch of water, or which will cause the difference in the level of the two tubes to be one inch, will cause the bubble to move eight inches in the horizontal tube.

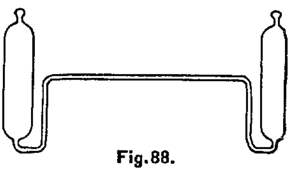

Fig. 88.

The readings of the ordinary U tube draught gauge are thus multiplied by 8, with the additional advantage that the position of the air bubble can be read more accurately than the difference of level in the ordinary gauge. The scale applied to the horizontal tube requires to be standardized for the ratio of areas of the small and large tubes and for irregularities in the calibre of tubes.

W. K.

XVI. 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 sq. inches of cross section of flue. The pipes must be of equal diameter and of equal length. $\frac{1}{4}$ in. 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

* Because smoother and more uniform.

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 inclosed in the receiver *B*. If the flue gases be drawn off from the receiver *B* by four tubes, *C C*, into a mixing box, *D*, beneath, about 3 inch cube, a good mixture can be obtained.

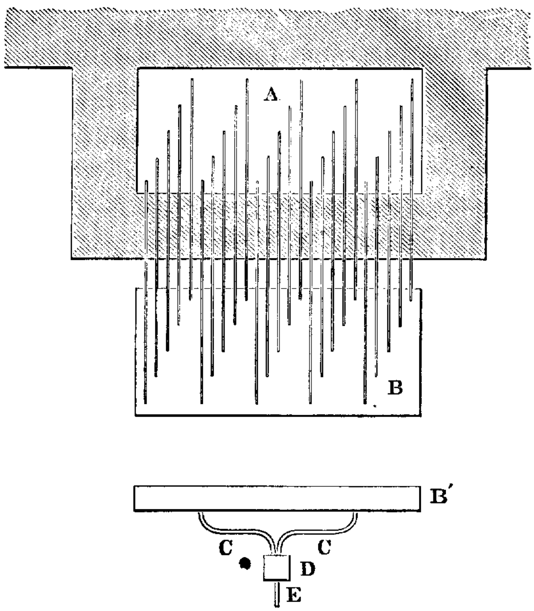

FIG. 57*a*.

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.

XVII. CALORIMETER EXPERIMENTS.

In all boiler experiments it is important to ascertain the quality of the steam, *i. e.*, 1st, whether the steam is "saturated" or contains the quantity of heat due to the pressure according to standard experiments; 2d, whether the quantity of heat is deficient, so that the steam is wet; and 3d, whether the heat is in excess and the steam superheated. The best method of ascertaining the quality of the steam is undoubtedly that employed by a committee which tested the boilers at the American Institute Exhibition of 1871–2, of which Professor Thurston was chairman; but this plan cannot always be adopted. When all the steam generated is not condensed, the method of making the connection for the purpose of taking out a sample is of the utmost importance. Unless great care be exercised, the results will frequently show that the steam is superheated when the boiler has no superheating surface. The cause of this is pointed out at p. 82 of the writer's general report on the exhibits referred to the Judges of Group XX., Centennial Exhibition. It is not fair to take the steam direct from the boiler, for if there be no steam circulation at that point the steam will of course show dry. The samples should be taken from the main steam pipe, but not from the bottom, as this would take all the water draining to that point. The method of taking it through a perforated pipe crossing the main steam pipe is sure to cause difficulty whenever the velocity of steam flowing to the calorimeter is sufficient to reduce the pressure in the supply pipe, for in such case the temperature of the steam in that pipe falls at the inlet, and the steam of full pressure and higher temperature flowing through the main pipe adds heat to that flowing into the calorimeter pipe, so that the latter, when referred to the pressure from which it is derived, shows superheating. The same effect takes place in a less degree when the steam for the calorimeter is taken through a lateral opening of small diameter, the metal surrounding the opening being kept warm by the current passing through the main pipe, and imparting its heat to the steam flowing in the lateral pipe to the calorimeter. To avoid this difficulty, the writer recommends making the lateral opening leading to the calorimeter 1½ to 2 inches in diameter, and then at a little distance from the main pipe, say 1 foot, reducing the supply pipe to calorimeter to ¾ or ½ inch diameter.

For general use the writer prefers the ordinary barrel calorimeter, which has the advantage over a continuous calorimeter operating at a slow rate of flow, that with the latter the condensation in the connecting pipes may cause the small quantity of steam flowing to the calorimeter to be moist, and thereby vitiate the results. With the barrel calorimeter it is desirable to heat the water promptly, so that the question of condensation in connecting pipes is of minor importance. At the same time the quantity of steam drawn off should not be so great, in connection with that passing to other points, as to cause the boiler to foam, or to reduce the pressure.

The practice of the writer is to use a barrel, holding preferably 400 lbs. of water, which is set upon a platform scale, and provided with a cock or valve for allowing the water to flow to waste. I have always provided a small propeller made with blades simply cut out of a disc of sheet iron, twisted to give the pitch and bolted on to the bottom of a vertical rod supported in a wooden step in the bottom of the barrel, and passing through a cross piece on the top of the barrel. The rod terminates at the top in a crank, and a collar is placed on the vertical shaft under the upper support. A fixed thermometer is run through a cork in the bunghole of the barrel. The pipe conducting the steam from the main steam pipe is made of graduated sizes, as previously referred to, and the smaller pipe provided near the calorimeter with a valve connected by means of a coupling with a rubber hose. In the coupling is to be placed a disc of metal, provided with a regulating hole of from $\frac{3}{16}$ to $\frac{1}{4}$ inch in diameter.

To operate the calorimeter the barrel is filled with water, the weight and temperature ascertained, steam blown through the hose outside the barrel until the pipe is thoroughly warmed, when the hose is suddenly thrust in the water, and the propeller operated until the temperature of the water is increased to the desired point, say about 110° usually. The hose is then withdrawn quickly, the temperature noted, and the weight again taken. The object of the particular details adopted will be readily understood. The simple propeller insures a uniform heating of the whole of the water. The little disc in the supply pipe enables the stop valve in pipe from boiler to be opened wide without drawing off so large a quantity of steam as to lower the pressure or produce priming. To avoid the jar when the steam hose is in the water, it is better to cut some lateral holes in the hose near its lower end. In this way a circulation is induced through the holes which prevents most of the jar and noise.

The weight of water in calorimeter should be increased proportionally to the weight and specific heat of all metal exposed to changes of temperature with the water. An addition of one-ninth of the weight of the propeller and submerged portion of shaft and fastenings will be substantially correct if the apparatus be made of iron.

The importance of errors of measurement or observation are inversely proportional to the magnitudes of the quantities. The weight of water added by condensation of steam being comparatively small, it must be weighed accurately, say within a quarter of one per cent. The writer has done this on an ordinary platform-scale in good order by using a second movable poise, in addition to the customary one, and of one-tenth its weight. In weighing, the lighter poise is adjusted to bring the free end of the beam to a fixed mark. The same result may be obtained by loading the platform with small known weights to bring the lever to a fixed point each time, and deducting such weights from the reading of scale in regular notches.

The above must be considered a makeshift, but a valuable one. When possible, delicate scales should be employed, and, in the opinion of the writer, better satisfaction can be obtained in this direction than by the use of the more complicated apparatus required to weigh the water of condensation separately.

In making the calculations the following notation and formula prepared by the writer for the report of the Committee having in charge the testing of the boilers of the Centennial Exhibition will be found convenient:

Let W = original weight of water in calorimeter.
Let w = weight of water added by heating with steam.
Let T = total heat in water due to the temperature of steam at observed pressure.
Let H = total heat of steam at observed pressure.
Let l = latent heat of steam at observed pressure = $(H - T)$.
Let t = total heat of water corresponding to initial temperature of water in calorimeter.
Let t' = total heat in water corresponding to final temperature of water in calorimeter.
Let Q = quality of steam.

Then

(1) $$Q = \frac{1}{l}\left(\frac{W}{w}(t' - t) - (T - t')\right).$$

Then when $Q < 1$, percentage of moisture in steam = $100 (1 - Q)$.

When $Q > 1$, number of degrees steam is superheated = $2.0833 \, l\,(Q - 1)$.

The later practice of the writer when there are a large number of calculations to be made is as follows:

Add to above notation the following:
Let m = percentage of moisture in steam.
Let s = number of degrees steam is superheated.

Let A = number of heat units lacking per pound of steam condensed. Equals quantity in parenthesis, Equation (2).

Let Σ = sign of summation. To be read: Sum of values of—

Let n = number of experiments to be averaged.

Then

$$(2) \qquad m = \frac{1}{l}\Big(\overbrace{(H - t') - \frac{W}{w}(t' - t)}^{A}\Big).$$

$$(3) \qquad Q = 1 - m.$$

When A or m is minus.

$$(4) \qquad s = -\ 2.0833\, A.$$

Averaging several experiments

$$(5) \qquad m = \frac{\Sigma A}{n\, l}.$$

$$(6) \qquad s = -\ 2.0833\ \frac{\Sigma A}{n}.$$

C. E. E.

XVIII. NOTE ON USE OF THE BARREL CALORIMETER.

In the use of the barrel calorimeter not less than 300 lbs. of water should be used, and it is an advantage, when practicable, to cool the water by means of pulverized ice. By vigorous agitation the water may thus be cooled to 36° F., or even 34° F., in a few minutes, when the remaining ice is to be completely removed. As the ice floats on the surface, this can be readily done. The weight of steam condensed can thus be often doubled, and still the temperature of the water not be raised above 100° F., at which point no sensible loss of heat will be suffered through evaporation. The greater the weight of steam condensed, the less will be the unavoidable percentage of error.

If the barrel be covered with a non-conductor, it will be found that no sensible change in the temperature of the water will take place in a long time.

C. T. P.

XIX. EFFECT OF SMALL ERRORS OF OBSERVATION IN CALORIMETER TESTS.

Suppose a case in which errors of observation occur, as in the following table:

	OBSERVED READING.	TRUE READING.	AMOUNT OF ERROR.
Weight of condensing water, corrected for equivalent of apparatus, W	200.5 lbs.	200 lbs.	½ pound.
Weight of condensed steam, w	9.9 "	10.0 "	$\frac{1}{10}$ "
Pressure of steam by gauge, P	78. "	80 "	2 pounds.
Original temperature of condensing water, t	44.5°	45°	½ degree.
Final " " " t'	100.5°	100°	½ "

The formula for calculation is

$$Q = \frac{1}{H - T}\left(\frac{W}{w}(h - h_1) - (T - h_1)\right)$$

in which Q = quality of the steam, dry saturated steam being unity.

H = total heat of steam at observed pressure.
T = " " water " "
h = " " condensing water, original.
h_1 = " " " " final.

		Moisture per cent.	Error per cent.
Substituting in the formula the "true readings" in the table, we have for the value of	$Q = 0.9874$	= 1.26	= 0.
All readings true except $W = 200.5$,	$Q = .9906$	= 0.94	= 0.32
" " " $w = 9.9$,	$Q = 1.0000$	= 0.00	= 1.26
" " " $P = 78.$,	$Q = .9880$	= 1.20	= 0.06
" " " $t = 44.5$,	$Q = .9989$	= 0.11	= 1.15
" " " $t' = 100.5$,	$Q = .9994$	= 0.06	= 1.20
" " incorrect	$Q = 1.0272$	= (minus)	= 3.98

The last case, $Q = 1.0272$, is equivalent to 50.2 degrees superheating.

The errors above noted are all such as may easily occur even with good apparatus. The condensing water being usually weighed in a barrel on an ordinary platform scale, an error of ½ a pound could easily be made if the scale were not carefully tested and standardized. To make as small an error as $\frac{1}{10}$ of a pound in the weight of the condensed steam, when it is weighed in the bulk with the condensing water, taking the difference of readings before and after the test, is almost more than can be expected. The probable error of such a method of weighing the condensed steam is usually more than a quarter of a pound. The error in this weight is the most important of all those given in the table, showing dry steam, $Q = 1.00$, instead of 1.26 per cent. moisture, the true result. If the error of the weight of the condensed steam were $\frac{1}{4}$ lb., it would be equivalent to an error of 3 per cent. in the calculated moisture in the steam, and consequently of 3 per cent. in the total result of the boiler test. The error of steam pressure, 2 lbs., is well within the limit of error of many steam gauges, but as seen in the result, it is the least important of all the errors, giving 1.20 per cent. moisture instead of 1.26 per cent. The errors of $\frac{1}{2}$ a degree in temperature of condensing water are also quite important, and show the necessity of having thermometers carefully standardized. The effect of an error of weighing the condensed steam is so serious, and it is so likely to occur, that in the writer's opinion the method of making tests with a barrel on a platform scale, without any special weighing of the condensed steam, is so inaccurate that it should be discouraged, or at least that the results obtained by it should be considering as having a probable error of 3 per cent. It is questionable whether averaging a large number of results so obtained will give any greater approach to truth, for the errors of weighing in a barrel on a coarse platform scale, of the condensed steam together with the condensing water, due to personal equation, to absorption and evaporation of water, to error of sliding or stationary poise, and to friction of scale are apt to be, comparatively, constant, and may by no means be expected to balance each other. W. K.

XX. COIL CALORIMETER.

The following is a description of a calorimeter, which the writer has found to give fairly good results, but sufficient experiments have not yet been made with it to determine its limit of error.

A surface condenser is made of light weight copper tubing $\frac{3}{4}''$ in diameter and about 50′ in length, coiled into two coils, one inside of the other, the outer coil 14″ and the inner 10″ in diameter, both coils being 15″ high. The lower ends of the coils are connected by means of a brazed T-coupling to a shorter coil, about 5′ long, of 2″ copper tubing, which is placed at the bottom of the smaller coil and acts as a receiver to contain the condensed water.

The larger coil is brazed to a $\frac{3}{4}''$ pipe, which passes upward alongside of the outer coil to just above the level of the top of the coil and ends in a globe valve, and a short elbow pipe which points outward from the coil. The upper ends of the two $\frac{3}{4}''$ coils are brazed together into a T, and connected thereby to a $\frac{3}{4}''$ vertical pipe provided with a globe valve, immediately above which is placed a three-way cock, and above that a brass union ground steam tight. The upper portion of the union is connected to the steam hose, which latter is thoroughly felted down to the union. The three-way cock has a piece of pipe a few inches long, attached to its middle outlet and pointing outward from the coil.

A water barrel, large enough to receive the coil and with some space to spare, is lined with a cylindrical vessel of galvanized iron. The space between the iron and the wood of the barrel is filled with hair felt. The iron lining is made to return over the edge of the barrel, and is nailed down to the outer edge so as to keep the felt always dry. The barrel is furnished also with a small propeller, the shaft of which runs inside of the inner coil when the latter is placed in the barrel. The barrel is hung on trunnions by a bail by which it may be raised for weighing on a steelyard supported on a tripod and lifting lever. The steelyard for weighing the barrel is graduated to tenths of a pound, and a smaller steelyard is used for weighing the coil, which is graduated to hundredths of a pound.

In operation the coil, thoroughly dry inside and out, is carefully weighed on the small steelyard. It is then placed in the barrel, which is filled with cold water up to the level of the top of the globe valves of the coil and just below the level of the three-way cock, the propeller being inserted and its handle connected. The barrel and its contents are carefully weighed on the large steelyard; the steam hose is connected by means of its union to the coil, and the three-way cock turned so as to let the steam flow through it into the outer air, by which means the hose is thoroughly heated; but no steam is allowed to go into the coil. The water in the barrel is now rapidly stirred in reverse directions by the propeller and its temperature taken. The three-way cock is then quickly turned, so as to stop the steam escaping into the air and to turn it into the coil; the thermometer is held in the barrel, and the water stirred until the thermometer indicates from five to ten degrees less than the maximum temperature desired. The globe valve leading to the coil is then rapidly and tightly closed, the three-way cock turned to let the steam in the hose escape into the air, and the steam entering the hose shut off. During this time the water is being stirred, and the observer carefully notes the thermometer until the maximum temperature is reached, which is recorded as the final temperature of the condensing water. The union is then disconnected and the barrel and coil weighed together on the large steelyard; the coil is then withdrawn from the barrel and hung up to dry thoroughly on the outside. When dry it is weighed on the small scales. If the temperature of the water in the barrel is raised to 110° or 120° the coil will dry to constant weight in a few minutes. After the weight is taken, both globe valves to the coil are opened, the steam hose connected, and all of the condensed water blown out of the coil, and steam allowed to blow through the coil freely for a few seconds at full pressure. When the coil cools it may be weighed again, and is then ready for another test.

If both steelyards were perfectly accurate, and there were no losses by leakage or evaporation, the difference between the original and final weights of the barrel and contents should be exactly the same as the difference between the original and final weights of the coil. In practice this is rarely found to be the case, since there is a slight possible error in each weighing, which is larger in the weighing on the large steelyard. In making calculations the weights of the coil on the small steelyard should be used, the weights on the large steelyard being used merely as a check against large errors.

It is evident that this calorimeter may be used continuously, if desired, instead of intermittently. In this case a continuous flow of condensing water into and out of the barrel must be established, and the temperature of inflow and outflow and of the condensed steam read at short intervals of time, as in Mr. Geo. H. Barrus's calorimeter described below. W. K.

XXI. THE BARRUS CALORIMETER.

The Barrus Calorimeter (Fig. 57) is of the continuous type, and consists essentially of a small surface condenser. The accompanying cut shows its general features. The steam enters by the pipe *j*, which is a common half-inch iron steam pipe. The condensing surface, *a*, is a continuation and enlargement of the supply pipe, and is an ordinary one-inch iron pipe with a length of 12 inches of exposed surface. This pipe is under the full pressure of steam.

The condensed water which amounts to about 50 pounds per hour under 80 pounds per square inch of steam pressure, collects in the lower part of the apparatus, where its level is shown in the glass, *e*, and is drawn off by means of the drip valve, *d*. The injection water, previously cooled to a temperature of 40° Fahr., or less, enters the wooden vessel, *o*, through the valve, *b*. Here it circulates around the condensing pipe, being carried downward to

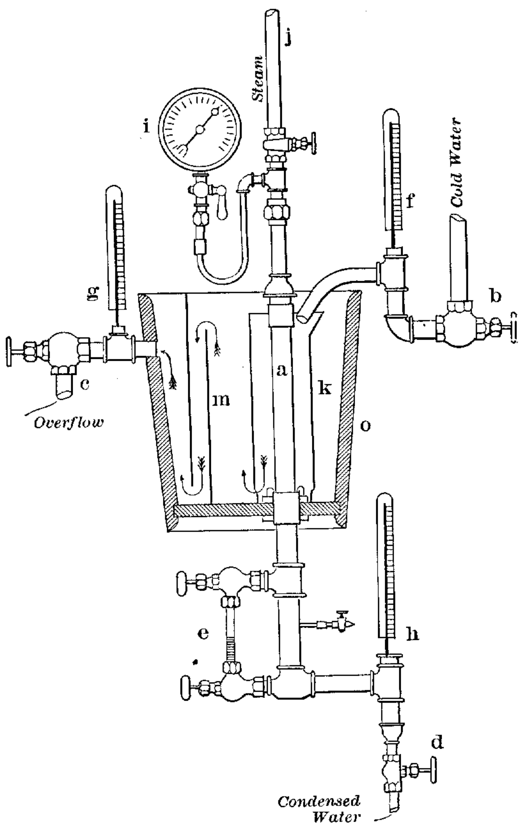

Fig.57.

the bottom by means of the tube, *k*, and it overflows at the pipe, *c*, after passing through the mixing chambers, *m*. The amount of water admitted is regulated so as to secure a temperature at the overflow of 75° or 80°, or the approximate temperature of the surrounding atmosphere. The thermometers, *f* and *g*, which are read to tenths of a degree, show the temperature of injection and overflow water, and the thermometer, *h*, shows that of the condensed water.

The overflow water and the condensed water is in each case collected in a system of weighing tubs. The steam pipe down to the surface of the water, and the pipes embraced in the lower part of the apparatus, are covered with hair felt.

When once in operation, this calorimeter can be worked any number of hours desired. By making observations with sufficient frequency, accurate mean readings can be obtained for either a long or a short period. There is no wire-drawing of the steam, and no allowance to be made for specific heat of the apparatus. The only correction to be made that is of material amount is that for radiation from the pipes covered with hair felt, and this can be accurately determined in each particular case by an independent radiation experiment, made when the condenser vessel is empty.

Below are the approximate data and results of an experiment under 80 lbs.:

Condensed water, 50 lbs. per hour.

Injection water, 1,100 lbs. per hour.

Injection water heated from 35° to 75°= 40°.

Temperature condensed water, 300°.

Condensed by radiation from steam pipe, 1 lb. per hour.

$$\text{Total Heat} = \frac{1100 \times 40}{50 - 1} + 300^\circ = 898^\circ + 300^\circ = 1198^\circ.$$

W. K.

XXII. REPORTING THE RESULTS.

As to reporting the results of boiler tests—two things are necessary, in order to make the reports, (*a*,) generally intelligible, and, (*b*,) strictly comparable.

1. The number of pounds of water actually evaporated under stated (actual) conditions of feed-water temperature and steam-gauge pressure, into steam containing not over three per cent. of entrained water, by each pound of coal burned—coal of good mercantile quality, dry; water dried out of a sample and allowed for, or, containing not over one-half per cent. of surface moisture, by actual experiment of drying samples. In this latter case, the one-half per cent. of water in the coal, like the three per cent. of entrained water in the steam, and the stated quantity of ashes and refuse in the coal, are taken in for the sake of representing usual conditions. So much for *general intelligibility.*

2. The equivalent evaporation in pounds of water of $t = 212°$ F. converted into dry saturated steam of one atmosphere pressure,

=760 mm= 29.92 in. mercury,—with one pound of *dry* combustible consumed. This for *strict comparability.*

It is obvious, if attention be given to the subject—too often neglected—that all the surface water in the coal, if not ascertained and allowed for, will appear as combustible and disappear as water evaporated.

For example, two per cent. of water in the coal, passing over the bridge wall and going up chimney, leaving no weight to represent it in the "ashes and residue," will increase the item of "combustible" by two per cent. of the gross weight of the coal; and if ashes and residue = $\frac{1}{6}$ of the gross weight, the addition will be 2% × $\frac{6}{5}$ = 2.4%. At the same time, about two-ninths of one per cent. of the water evaporated will escape observation, going up chimney unnoticed.

There should also be introduced into general practice an equivalent statement of

3. The equivalent evaporation in pounds of water from feed-water temperature = 100° F. into usual steam containing not over three per cent. entrained water of seventy pounds per square inch pressure by steam gauge above 1 atmosphere = 760 mm. = 29.92 inches mercury—for each pound of commercial coal containing not over one-sixth ashes and residue including surface water; one pound of such commercial coal being capable of imparting to the water, in a boiler of good proportions, about 10,000 British thermal units.

J. C. H.

XXIII. REPORTING THE TEST.

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 substantially 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 draught through or between tubes.
Ratio grate to heating surface.
" draught area to grate
" " " " total heating surface.
Water space.
Steam space.
Ratio grate to water space.
" " " steam space.

C. E. E.

XXIV. OBSERVATION BLANKS.

The observations taken during a test should be recorded on a series of blanks prepared in advance so as to be adapted to the purposes of the trial. The number of sheets and the particular items on each may be varied to suit the number of observers and the work designated for each. The following are copies of observation blanks used in the Centennial trials with a few lines of figures inserted, without reference to each other, for the purposes of illustration. The columns should of course be of sufficent length to contain the number of observations expected.

C. E. E.

LOG OF TRIAL OF BOILER.

NO. 1.—RECORD OF FEED-WATER.

1	2	3	4	5	6	7	8
TIME.	TANK A.			TANK B.			HEIGHT OF WATER IN GLASS.
	Initial Weight.	Final Weight.	Temperature.	Initial Weight.	Final Weight.	Temperature.	
Hrs. Min. *a.m.*	Lbs.	Lbs.	Deg. Fah.	Lbs.	Lbs.	Deg. Fah.	Ins.
5.22	......	....	..	......	.....	....	7
6.19	1442.5	136	63	......	.....	....	0
6.40	......	.....	..	1421 5	169.5	63.5	6
7.05	1447	131.5	68	......	.....	....	6
7.28	......	.....	..	1431.5	193.5	67	7
8.00	1445.5	316	67	......	.....	....	5

Deduct 56.25 pounds of feed-water for difference of level in boiler.

LOG OF TRIAL OF BOILER

NO. 2.—GENERAL OBSERVATIONS—COAL AND ASHES.

9	10	11	12	13	14	15	16	17	18	19	20	21
TIME.	STEAM PRESSURE.	TEMPERATURES. (Fahrenheit.)					COAL AND ASHES.				BAROMETER.	HEIGHT OF WATER IN GLASS.
		Air.	Fire-Room.	Steam.	UPTAKE. Ther.	UPTAKE. Pyr.	Coal Weighed out on Floor.	Coal Consumed.	Coal found in Ashes.	Weight of Ashes. *Net.*		
Hrs. Min. *a.m.*	Lbs.	Deg.	Deg.	Deg.	Deg.	Deg.	Lbs.	Lbs.	Lbs.	Lbs.	Ins.	Ins.
9.22	70	49	88	310	....	375	230.5	170	578	304.5	30.20	10
10.00	70	51	82	299	....	401	229.5	Wood.	....	....	....	7
10.30	70	57	83	308	....	446	229.5	235.5	....	....	....	3
11.00	70	..	80	309	....	446	229.5	229	...	....	....	0.5
11.30	70	55	80	299	....	432	223.5	221.5	....	....	....	10
12.00	70	..	80	298	....	444	231	227	....	....	....	8

LOG OF TRIAL OF BOILER.

NO. 3.—RECORD OF CALORIMETER EXPERIMENTS.

22	23	24	25	26	27	28
TIME.	WATER.			TEMPERATURES. (Fahrenheit.)		STEAM PRESSURE.
	Weight of Barrel.	Initial Gross Weight.	Final Gross Weight.	Initial	Final.	
Hrs. Min. *a.m.*	Lbs.	Lbs.	Lbs.	Deg.	Deg.	Lbs.
5.35	80.5	400	412.5	73.5	106.125	70 —66
5.55	80.5	400	413.375	68.25	110.50	70 —67
6.15	80.5	400	411.375	72.50	111	70 —68.5
6.35	80.5	400	417.25	66	122	70 —68
6.55	80.5	400	415.125	67.5	114.25	70 —64
7.15	80.5	400	416	74.5	122.25	70 —66
7.35	80.5	400	411.75	74.5	113.75	69 —70
7.55	80.5	400	413.25	72.5	115.25	70 —65
8.15	80.5	400	413.25	71	112.75	70 —62

XXV. 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. $34\frac{1}{2}$ pounds of water from and at 212°, equal to

2. 30 pounds of water of $t = 100°$ under $p = 70$ pounds per square inch above one atmosphere; with easy firing, moderate draught, 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, draught, firing, and everything else, just capable of evaporating into dry steam 3,450 pounds of water from 212° into the atmosphere, with open safety valve—or, what comes to the same thing, 3,000 pounds from $t=100°$ to $p=70+$atm. 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.

XXVI. 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° 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 772 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 honr, 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 accepted 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. Chas. 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

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

gauge-pressure from a temperature of 100°."* 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 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 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.†

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°), 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 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

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

† 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.

simply to its steam-producing capacity, referred to the arbitrary standard of a horse-power above mentioned.

C. E. E.

XXVII. MEMORANDUM RELATIVE TO A STANDARD METHOD OF TRIAL-TEST FOR STEAM-BOILERS.

The method customarily pursued in the course of the work of the Mechanical Laboratory of the Stevens Institute of Technology, as instituted by the writer, and that practiced in his own professional work, has usually been such as to secure data sufficient to enable the observer to fill out all the columns of the Log-blank and Table of Performance, copies of which are appended.

In starting the trial, which is usually of at least ten hours' duration, it is customary, where it can be conveniently done, to get up steam with a fire of wood, which is raked out after steam has begun to form freely, and the trial commences with the introduction of a new fire, in which wood is used to ignite the coal, and is charged as a certain percentage of its weight of coal—forty per cent. is probably as accurate as need be. The damper should be carefully closed during the few minutes required to perform this operation. Toward the end of the time fixed for the trial, the steam-pressure and height of water are made as nearly identical with the same conditions at the beginning as is possible, the fire is burned as low as the skill of the fireman and supervising engineer will permit, and when the end of the trial is recorded, the fire is hauled, the coal and ashes weighed dry, no more water being used in cooling them as they are drawn than is absolutely necessary for the comfort of the fireman, and never sufficient to leave any portion of the mass in the slightest degree damp.

Where it is impracticable to start with a new fire, and to remove the fire at the end of the trial, it is preferred to begin and end the trial with the cleaning hour, the quantity of coal being then most easily estimated and identical conditions being thus most readily approximated.

The steam-pressure is read from a gauge which it is intended shall always be carefully standardized both before and after the trial. The same precaution should be taken with all instruments used whenever possible.

During the trial, all the conditions are kept as nearly uniform as is possible, and as exactly those for which the boiler is designed as is practicable. The supply of feed-water and of fuel, the pressure of steam, the frequency of firing or "stoking" are to be made definitely constant. A continuous feed rather than an intermittent supply of water is much preferred, and the injector is preferred where choice of instrument is permitted. The customary mode of feeding is, however, often best, whatever that may be. Determinations of the character of the steam made are considered essential in every case. The open, or "barrel," calorimeter of Hirn has been generally employed, making the number of observations sufficient to give a small margin of probable error. It is hoped that the relative value of the different forms may after a time be so well determined as to permit the acceptance of some one as a standard. The intermittent instrument consisting of a coil of pipe in a vessel of water and the continuous calorimeter, such as was proposed by Van Buren some years ago, and used by Skeel and the writer, and modifications since made by many others, are capable of doing good work; but engineers greatly differ in their estimates of their relative value, and the simplest form is at present in most general use, probably because of its portability, or the ease with which it can be improvised. Could it be done, the method of condensing all the steam made, as practiced at the American Institute trials of 1871, would be always adopted, in preference to the system of "sampling."

In the analysis of gases, the apparatus made by Greiner and Linke is found convenient when it is considered necessary to make such analyses. In fuel analysis, Monroe's system of carbon determination of by the use of lead oxide is probably as easy and as satisfactory as any for general use. More complete analyses are intrusted to a professional chemist, and are made in the chemical laboratory. The draught-gauge used is that designed by Mr. Allen for the Hartford Steam Boiler Insurance Co.

General Principles.—In the operation of conducting a trial of a steam-boiler, we have, usually, a single, well-understood object in view, and the engineer should accustom himself to carefully define that object in his own mind, and to as carefully describe that object in his instructions and regulations for the proposed trial. The whole operation can then be carried on with that point distinctly in view, and the proposed end can then be accomplished with maximum economy of time and labor, as well as with greatest exactness. The observations must be made by the engineer conducting the trial, or by his assistants, with this object distinctly in mind, and each should have a well-defined part of the work assigned him, and should assume responsibility for that part, having a distinct understanding in regard to the extent of his responsibility, and a good idea of the extent and nature of the work done by his colleagues, and the relations of each part to his own. No observations should be permitted to be made by unauthorized persons for entrance upon the log; and no duties should be permitted to be delegated by one assistant to another, without consultation and distinct understanding with the engineer in charge. The aim of the observers is, in all cases, to obtain an exact determination of the weight of fuel used, its proportion of combustible matter effective in developing heat, the exact weight of water evaporated under the known conditions of the trial, into steam, the determination of the character of that steam, and often the nature of the combustion and the composition of the furnace-gases. Each of these distinct objects requires the determination of certain well-defined quantities, and the observer to whom each set of observations is intrusted should, whenever possible, be made sufficiently well acquainted with the object to be attained, and the method to be pursued in reaching it, to be able to make his own readings with accuracy, and to work up the results correctly. It is only after he has acquired this knowledge that he can be expected to do his work without direct supervision, and with satisfactory precision. The trial should, wherever possible, be so conducted than any error that may occur in the record may be detected, checked, or, if advisable, removed, by some process of mutual verification of related observations. It is in this direction that the use of graphical methods of record and automatic instruments have greatest value. We should lose no opportunity to introduce both.

Weighing Fuel.—Several methods of weighing fuel have been found very satisfactory, in the writer's experience; but he is inclined to make it an essential feature of either that the weights shall be made by one observer, and checked by another, at as distant a point as is convenient. The weighing of the fuel by one observer, at the point of storage, and the record at that point of times of delivery, as well as of weights of each lot, and the tallying of the number and record of the time of receipt, at the furnace-door, will be usually found a safe system. The introduction of unweighed coal, whether by accident, or by design on the part of some interested person, can never be too carefully guarded against. The failure to record any one weight, which is a not unknown accident, leads to similar error, and can only be certainly prevented by an effective method of double observation and check.

Weighing Feed-Water.—The same remarks apply, to a considerable extent, to the weighing of the water fed to the boiler. A careful arrangement of weighing apparatus, a double set of observations, where possible, and thus safe checks on the figures obtained, are essential to certainty of results. With good men at the tank, and with small demand for water, a single tank can be used; but two are preferable, in all cases, and three should be used if the work demands very large amounts of feed-water, as at trials of very large boilers, or of "batteries." The more uniform the water supply, as well as the more steady the firing, the less the liability to mistake in making the record.

Character of Steam.—It has been the endeavor of every engineer conducting trials of boilers, of late, to secure correct determinations of the quantity of water entrained with the steam, or of the degree of superheating, where superheating occurs. This is, however, a matter of considerable difficulty. It was, so far as the writer is aware, first proposed and attempted by Hirn, the distinguished French engineer and physicist, who, many years ago, used what is now known as the tank, or barrel, calorimeter for this purpose. A jet of steam from the boiler was led into a tank containing a considerable mass of water, and condensation was allowed to go on until the water had acquired as high a temperature as was convenient. The amount of "priming" was then calculated by a comparison of the amount of heat transferred to the barrel, by the weight of steam taken from the boiler, with the amount that would be transferred by the same weight of perfectly dry steam.

This method was in use some years when the continuous calorimeter was proposed by Van Buren. This form was adopted by a committee, of which the writer was chairman, in the year 1875, in making tests of "sectional" boilers, the instrument used being designed by the late Mr. Theron Skeel, a member of the committee. The results of its work were satisfactory to the committee.

The method of testing the character of steam made in boilers by this system of sampling seemed somewhat open to doubt in respect to its accuracy, when used by Hirn, and, for a long time the writer looked for an opportunity to determine with certainty what is the real amount of priming, under ordinary conditions of operation, in the common forms of boiler. This was finally offered in the year 1871, when as chairman of a committee on boiler trials for the American Institute, it became necessary to arrange for a comparison of several competing boilers of, fortunately, widely different types and forms. Through the liberality of Mr. J. B. Root, and with the earnest co-operation of Mr. Chas. T. Porter and others of the then exhibitors, it was rendered possible to construct a large surface-condenser, in which to condense *all* the steam made by each boiler during its trial. The arrangements were made with great care, and conducted under the writer's own personal direction and supervision, by carefully selected observers, and with the most cheerful and gratifying co-operation on the part of all the competing exhibitors. The result was the determination, with the most satisfactory certainty, of the real amount of total priming, as ascertained by observation of the total amount of water passing off as steam, and of the total amount of water carried out of the boiler unevaporated. Two of the boilers superheated their steam slightly; the others primed from three to seven per cent. The main object of the investigation, the determination of the question whether sampling steam can give fairly correct measures of the character of the mass, was in the writer's opinion well settled affirmatively by these experiments.

As to the best form of calorimeter, the writer is not yet fully satisfied, and hopes to find a way of making one that shall be at once simple, easily transported, and accurate. He has a strong impression that it will be a continuous calorimeter, but has very little doubt that improvements in accessory apparatus now in progress may make the Hirn form of instrument, sooner or later, a satisfactory one. The best work thus far has been done probably by the intermittent form of coil condenser, although experience with the continuous instrument has been very encouraging. Mr. Hoadley has done some beautiful work, and the apparatus described by Mr. Kent gives a means of checking weights which is a very useful and almost essential improvement upon that type of instrument.

A steam-boiler trial in which the quality of the steam is not, at least approximately determined, cannot be accepted to-day as giving any reliable measure of the efficiency of a boiler.

Near the end of the series of data recorded in the blanks appended, are columns intended to include the constants, as derived from the trial, for introduction into the formulas of Rankine for efficiency of boiler and of the writer for that of chimney. It was the writer's expectation to be able, in course of time, to accumulate such an extensive set of data in this form as would enable Rankine's formula to be adjusted for use in all trials of the usual forms of boiler, and with our native fuels. The American fuels, and our common boilers, cannot be estimated, in respect to efficiency, by the use of that formula, with the degree of exactness that is desirable. The writer has been accustomed, in making such estimates, as a rule, to adopt a value of the constant multiplier less by about ten per cent. than that given by the author of the formula. It is hoped that an opportunity, ere long, will be afforded to make the comparison here alluded to.

R. H. T.

TABLE I.

LOG OF TRIAL

OF

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MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TEST MADE

At ....

....

on ....

$$x = \frac{U - wh}{H - h}$$

$$\frac{\frac{U}{w} + t - T}{0.48} = \text{Degrees of Superheating.}$$

TIME.	PRESSURES.			TEMPERATURES.					WEIGHTS.			REMARKS.
	Baro-meter.	Steam Gauge.	Draught Gauge.	External Air.	Boiler Room.	Fuel.	Feed Water.	Steam.	Fuel.	FEED-WATER. Per Meter.	FEED-WATER. Per Tank.	

PRIMING TESTS.

NO.	TIME.	STEAM PRESSURES.	CALORIMETER. WEIGHTS. Condensing Water. W	CALORIMETER. WEIGHTS. Wet Steam. w	CALORIMETER. TEMPERATURE. Initial. t''	CALORIMETER. TEMPERATURE. Final. t'	CALORIMETER. TEMPERATURE. Range. $R = t' - t''$	HEAT UNITS PER POUND FROM BOILER. Water. t	HEAT UNITS PER POUND FROM BOILER. Steam. T	Heat trans-ferred to Calorimeter. $W \times R = U$	Heat from Steam. $H = T - t'$	Heat from Water. $h = t - t'$	Steam run into Calorimeter. x	Percentage of Priming. y	SUPERHEATING. Degrees.	SUPERHEATING. Heat Units.	REMARKS.

AVERAGE AND TOTAL RESULTS OF TRIAL

OF

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TRIAL MADE *FUEL.*

at ....

on ....

COMPOSITION.

Number of Trial.	Date of Trial.	Length of Trial.	Areas.				Ratio of Grate to Heating Surface.	Average Temperatures.				Average Pressures.			Consumption of Fuel.			Ashes.		Total Combustible.	Remarks.
			Grate.	Heating Surface.	Super-heating Surface.	Least Cross-Section of Flues.		Boiler Room.	External Air.	Entrance to Chimney.	Feed-Water.	Barometer.	Steam Gauge.	Draught Gauge.	Total.	Per square foot of Grate per hour.	Per sq. ft. of Heating Surface per hour.	Total.	Proportion of Total Fuel.		
		Hours.	sq. ft.	sq. ft.	sq. ft.	sq. ft.		Fahr.	Fahr.	Fahr.	Fahr.	ins.	lbs.	ins.	lbs.	lbs.	lbs.	lbs.	per ct.	lbs.	

Apparent Evaporation.									Real Evaporation.											
Per Pound of Fuel.			Per Pound of Combustible.			Per square foot of Heating Surface, per Hour.			Per Pound of Fuel.			Per Pound of Combustible.			Per square foot of Heating Surface, per Hour.			Square feet of Heating Surface Required to Evaporate one Cubic foot of Water.		
From actual temperature of Feed-Water and at actual steam pressure.	Equivalent from and at 212° F.	Equivalent from 212° F. and at actual steam pressure.	From actual temperature of Feed-Water and at actual steam pressure.	Equivalent from and at 212° F.	Equivalent from 212° F. and at actual steam pressure.	From actual temperature of Feed-Water and at actual steam pressure.	Equivalent from and at 212° F.	Equivalent from 212° F. and at actual steam pressure.	From actual temperature of Feed-Water and at actual steam pressure.	Equivalent from and at 212° F.	Equivalent from 212° F. and at actual steam pressure.	From actual temperature of Feed-Water and at actual steam pressure.	Equivalent from and at 212° F.	Equivalent from 212° F. and at actual steam pressure.	From actual temperature of Feed-Water and at actual steam pressure.	Equivalent from and at 212° F.	Equivalent from 212° F. and at actual steam pressure.	From actual temperature of Feed-Water and at actual steam pressure.	Equivalent from and at 212° F.	Equivalent from 212° F. and at actual steam pressure.
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	sq. ft.	sq. ft.	sq. ft.

TABLE II.—*Continued.*

TOTAL WATER FED TO BOILER.			AVERAGE PRIMING.	TOTAL WATER PRIMED.	WATER EVAPORATED INTO DRY STEAM.			REMARKS.
From actual temperature of Feed-Water and at actual steam pressure.	Equivalent from and at 212° F.	Equivalent from 212° F. and at actual steam pressure.			From actual temperature of Feed-Water and at actual steam pressure.	Equivalent from and at 212° F.	Equivalent from 212° F. and at actual steam pressure.	
lbs.	lbs.	lbs.	per cent.	lbs.	lbs.	lbs.	lbs.	

Average Amount of Superheating.	EVAPORATION FROM AND AT 212° F., EQUIVALENT TO TOTAL HEAT UNITS DERIVED FROM FUEL.			EFFICIENCY.			VALUES OF A AND B IN $F = A\sqrt{H} \pm B$.		HORSE-POWER.		REMARKS.
	Per pound of Fuel.	Per pound of Combustible.	Per sq. foot of Heating Surface, per hour.	Experimental.	Estimated.	$R = \frac{\text{Experimental.}}{\text{Estimated.}}$	A	B	Rated.	Actual.	
Fahr.	lbs.	lbs.	lbs.	per cent.	per cent.						

CLXVIII.—*A.*

DISCUSSION OF THE REPORT ON A STANDARD METHOD OF CONDUCTING STEAM BOILER TRIALS.

Presented to the American Society of Mechanical Engineers.

NOTE.—The Report of the Committee was formally presented at the New York Meeting of the Society, November, 1884. On account of its thoroughness and magnitude it was not discussed at that meeting, but it was ordered that it should be printed and sent to all the members before the spring meeting, that it might receive their careful examination. The discussion of that Report being made a special order for the second session of the meeting of May, 1885, the following suggestions were presented. They are printed in direct connection with the Report to which they relate, for convenience of reference, although constituting a part of the Proceedings of Part II., and belonging to the XIth Meeting.

The Society accepted the Report, but for reasons of policy clearly brought out in that part of the Discussion which is printed in a special Appendix, decided *not* to adopt the Report officially, although the trend of debate was decidedly favorable to it, but voted simply that the discussion be printed in full in the Transactions. The discussion was as follows:

Prof. W. P. Trowbridge.—The committee state in their Report very clearly and definitely the objects of a trial or test of a steam boiler, and present a code of rules for such tests which will doubtless meet with general approval. Their recommendations looking to the establishment of a unit of boiler-power appear to me, however, to be wanting in the exactness and precision which should characterize the definition of so important a unit; and I beg to offer my views on that part of the Report which treats of the subject, actuated only by the feeling that before final action by the Society is taken, this unit should be considered from all points of view, and especially in its commercial bearings and aspects.

There seems to have been a diversity of opinion in the committee as to whether the "unit of boiler power" should be expressed in terms of the "unit of evaporation," or in terms of another and different unit of evaporation first introduced and employed by the judges at the Centennial Exposition: the arguments in favor of the latter being that it has already been established by *authority*, that it conforms to general practice, and that it is now a generally accepted unit.

None of these arguments appear to me to be strictly tenable.

The unit adopted by the distinguished judges at the Centennial has not been sanctioned, nor enjoined by any statute, State or National, as far as I am aware, and has no binding force anywhere in commercial transactions.

The action of this Society, embracing as it does mechanical engineers from all parts of the country, will go further in establishing any particular unit *authoritatively*, if this term can be applied to such action, than an announcement from any other source. It is moreover doubtful, I think, whether the centennial unit, so called, has become an accepted unit in all parts of the country. In commercial transactions between buyers and sellers of boilers I think it may be positively asserted that this unit has not yet been even extensively adopted.

I would strongly urge, with great deference, however, to the majority of the committee, and to members who may agree with them, that the most rational mode of expressing the unit of boiler-power is to express it in terms of the universally accepted unit of evaporation. This conforms to custom in establishing systems of weights and measures, and also to general practice, which has tacitly recognized the old unit of evaporation as that which is to be employed in estimating the performance of a boiler. I say old unit of evaporation, meaning the "evaporation of one pound of water from and at 212° F." which the committee recommend to be retained; the retention of this unit and the establishment of another and a like unit in connection with the unit of boiler-power seems a duplication of units of a similar kind, which is apt to lead to confusion; and which at least seems unnecessary.

If the unit of boiler-power recommended by the committee be adopted, viz., "30 pounds of water evaporated from feed water of 100° F. temperature and at 70 pounds pressure," which is merely 30 of the new units of evaporation, there will still be needed a reduction to find from the actual performance of a boiler its power estimated by the standard unit. The claim that this new unit of evaporation conforms "more nearly to practice" than the old does not make this reduction any more simple, and has little importance, it seems to me, when we consider what an indefinite expression "average practice" is in this connection.

Whichever unit of evaporation be adopted, whether the old or the new, or both, there is still a want of precision in the recommendations of the committee in defining the "unit of boiler-power," especially if this unit is to be of commercial value in aiding the buyers and sellers of boilers to a better understanding in their transactions. And this want of exactness is likely, I think, if not corrected, to render of little importance which unit shall be adopted, or whether it is worth while to define the unit of evaporation or unit of power with such extreme precision, while other factors on which the power cf a boiler essentially and in a higher degree depends, are introduced under the very general and often embarrassing term "average practice."

In the language of the committee, "what is needed is a *standard unit of boiler-power* which may be used *commercially*, in *rating boilers*, and in *specifications* presenting the power to be *demanded by the purchaser* and *guaranteed by the vender*." (The italics in the quotation are mine.)

This is a distinct and clear statement; and such a unit, if it can be established, will serve a purpose of very great importance, as it will tend to prevent misunderstandings between buyers and sellers of boilers, and thus possess an element of real commercial value.

The principal commercial considerations in the sale and purchase of a boiler are its "capacity" or "power," and its economy. If the unit of boiler-power as defined by the committee is sufficiently exact for commercial transactions, then it must be admitted that capacity for evaporation and economy depend so little on the quantity of fuel burned in a given time, that variations in the performance of the same boiler, or of different boilers, under varying rates of combustion are so slight that these variations need not be taken definitely into account.

The committee define the unit of boiler-power, practically, in the following manner: "An evaporation of 30 pounds of water per hour from a feed water temperature of 100° F. into steam at 70 pounds pressure," "with *easy firing, moderate draught*," "*ordinary fuel, and good economy*."

As far as purchaser and vender are concerned this definition seems to me analogous to one which should define a mode of calculating the cubic contents of a *particular* building by stating that the ground area is to be measured with great care by a standard unit of measure, and the number of square feet in the ground plan should then be multiplied by — the height of an average ordinary building.

To specify more particularly the case under consideration, let us refer to the results of the experiments of Mr. Isherwood, which give the capacity or amount of evaporation, and the economy of the same boiler under different rates of combustion or draught. Representing the number of pounds of anthracite coal burned per hour on each square foot of grate surface of a marine tubular boiler (having 25 square feet of heating surface to 1 of grate surface), by the numbers in the first horizontal line below,

6.	8.	10.	12.	14.	16.	18.	20.	22.	24.
10.5	10.4	10.1	9.5	8.9	8.2	7.7	7.3	7.	6.8

the numbers in the second horizontal line will represent the number of pounds of water evaporated from and at 212° F. by each pound of coal burned. The figures would apply also very well to all horizontal tubular boilers having the same proportions as the marine tubular boilers of the experiments; and they represent the law for all boilers, in a general way, in regard to the diminution of efficiency or economy with increased draught or rate of combustion.

It is easy to see what a large range of performances might possibly fall under the designation "easy firing," "moderate draught," and "good economy." It is doubtful whether the members of the committee themselves, if asked, would all select the same numbers as the proper interpretation of these terms, if they should decide separately and without consultation with each other. Ordinary buyers and sellers would certainly differ widely, the buyer being more at a disadvantage because it would rest with him to prove, in case of disagreement, that he did *not* get what he bargained for.

A horizontal tubular boiler employed for steam-heating purposes might, for instance, be considered as working under a "moderate draught" if it burned 8 pounds of coal per hour on each square foot of grate surface; and again a boiler absolutely the same in every respect might be demanded for manufacturing purposes where the rate of combustion was to be 14 pounds of coal per hour for each square foot of grate surface. Both might be claimed to answer the definition of "average practice" under the special conditions of use.

The difference in the power and economy of the boiler under these separate conditions may be easily calculated on the basis of the above experiments.

In the first case the boiler evaporates 83.2 pounds of water per hour for each square foot of grate surface, and in the second case 124.6 pounds per hour for each square foot of grate. The power in the second case is just 50 per cent. greater than in the first, while the economy of evaporation is less in the second case by the ratio $\frac{8.9}{10.4}$: or a difference of evaporation per pound of coal of 1.5 pounds of water, and for each square foot of grate surface a difference of 41.4 pounds of water—a difference which is not measured by a small fraction of the "unit of power" recommended, but which absorbs one and one-third of these units for each square foot of grate surface.

If the boiler has 12 square feet of grate surface it will develop, employing 30 pounds of water as the basis for 1 H.P., 33.28 horse-power, and in the second 49.84 horse-power, a difference of 16.5 horse-power.

This example shows, I think, how important it is in establishing a "unit of boiler-power," which may be "prescribed" in specifications by the purchaser, and "guaranteed by the vender" that some definite rate of combustion or draught should be taken into account, since this is the *principal element* which governs both power and economy.

It might be well also to recommend certain standard proportions of heating to grate surface, etc., for boilers of various classes, inasmuch as these proportions have also an important bearing.

The Novelty Iron Works published, some years ago, an advertising pamphlet, in which were given the proportions of boilers of various classes, and their capacities for evaporation.

The calculations were made, I believe, by Mr. Emery, a member of the committee.

The proportions of heating to grate surface were for

Plain Cylinder	Boiler	$\frac{1}{11}$
Cylinder Flue	"	$\frac{1}{17}$
Cylinder Tubular	"	$\frac{1}{27.6}$
Stationary Locomotive	"	$\frac{1}{28}$

The rates of evaporation of these boilers were respectively (the water being supposed fed at a temperature of 60°, and evaporated at 80 pounds pressure) for each square foot of grate surface of the

Plain Cylinder	Boiler	53.	pounds.
Cylinder Flue	"	60.6	"
Cylinder Tubular	"	64.4	"
Locomotive	"	66.1	"

Another shop, in another part of the country, might adopt very different proportions of heating to grate surface, etc., and assume very different rates of combustion; and there would be, and probably is, such diversity of practice in this respect in different parts of the country, that unless some more explicit rule can be recommended than "easy firing, moderate draught, and good economy," it would be quite as well to say that the unit of boiler-power shall be an average quantity of water (30 to 40 pounds) evaporated from an average temperature of feed water, at an average pressure, with an average draught and average economy.

I would suggest, however, that the manufacturer or seller of a boiler should be held responsible for the proportions of his boilers, or in other words their economy; this would include the proportion of heating to grate surface, draught areas, etc., and the buyer should be responsible for the draught, over which he has generally exclusive control, and that under these circumstances the "unit of boiler-power" might be (adopting the old unit of evaporation), *an evaporation of* 35 * *pounds of water from and at* 212° *F., when the rate of combustion is not less than* 10 *pounds of ordinary coal on each square foot of grate surface.*

This would not only furnish a fair standard of comparison for different classes of boilers, but it would, with the exception of locomotives, cover the greatest range of commercial transactions.

I am aware that in a trial test it might be difficult to burn exactly 10 pounds of coal on each square foot of grate surface; but some specified minimum rate of combustion seems better than the very general designations of "average" or "moderate"—terms which if used in specifications would be certain to *invite*, rather than to *prevent* and ward off, misunderstandings and litigations. In the example I have given such a misunderstanding might possibly occur involving 16 horse-power in a boiler of very common size.

With the definition of the unit of boiler-power which I have proposed above, such a misunderstanding could not well happen. If ten pounds of coal (or any other proper number of pounds) be adopted as the *minimum* rate for which the boiler-power is guaranteed, the buyer would know that if he burned more than this amount he would get more power than he bargained for with less economy, and if he burned less he would get less power than he bargained for with perhaps greater economy; but the seller would be in no way responsible for the variations in the rates of combustion, as specified in the contract between them, this specification being an essential part of the definition of the "unit of boiler-power."

Since preparing the above I have conferred with Professor C. B. Richards, of the Sheffield Scientific School of Yale College, and

* In the discussion as presented at the meeting this figure read 30 pounds, and the subsequent discussion had reference to that figure.—*Ed.*

am very glad to concur in the following suggestion made by him. In the unit which I have suggested above the question of economy is still left indefinite.

Professor Richards suggests that the rate of combustion be referred to the heating surface instead of to the grate surface. The "Unit of Power" will then include both the rate of combustion and the economy. We concur in the belief, also, that 30 pounds of water evaporated is too low a number even with the committee's unit of evaporation.

It can hardly be said that the *average* non-condensing steam engine supplies 1 horse-power for each 30 pounds of water evaporated, but taking into consideration the recommendation of the committee that when a boiler is ordered it is well to order one which has one-third more capacity than the application of their unit would call for, the following unit of boiler power is presented, amended according to Professor Richards' suggestions: 40 *pounds of water evaporated from and at* 212° *F., with a rate of combustion of not more than* $\frac{4}{10}$ *pounds of good ordinary coal per square foot of water-heating surface.*

For ordinary horizontal tubular boilers this will give an evaporating power of about 3.25 pounds of water per square foot of heating surface, or about eight pounds of water from feed water of 160° F., and at 80 pounds pressure per pound of coal, and about 12 square feet of heating surface will give a horse power.

The adoption by the public of the *Mechanical Engineers' Standard* of boiler-power would then render it unnecessary for purchaser and vender to make any reference to rate of combustion, as it would be implied in the standard unit.

The President.—I think there is perhaps a difference of opinion among engineers, in the first place, as to the pressure under which trials of boilers should be made, and it would be well to discuss that point whether it is advisable to accept the recommendation of the committee as to carrying on a test under a pressure of 70 pounds or atmospheric pressure.

Mr. Kent.—I do not understand that the committee report in favor of any pressure whatever, and Prof. Trowbridge makes no reference to any pressure whatever. The question under discussion is the question of the unit of horse-power.

Mr. Root.—The principal thing it seems to me is to have a unit. It doesn't make much difference what it is. In 1867 I published a rating for horse-power. At that time the question came up what was a horse-power in steam boilers. Almost every one claimed that a cubic foot per horse-power according to the old English idea was the right thing. Studying up the subject I found that any good engine ought to produce a horse-power on 23 or 24 pounds of water, and it would be a very poor engine that would not produce a horse-power on 30 pounds of water. So I adopted and published that as the rate of the boilers I sold—30 pounds of water evaporated from a temperature of 212°. That, I believe, was the start to this whole thing as to the rating of horse-power of steam boilers. Now I do not see that it makes very much difference so long as it is a settled thing. The question of what a horse-power is becomes very important sometimes, especially where there is a disagreement, and the matter comes before the Courts. It is very important then to have some unit, though as I said I don't know that it makes much difference what that unit is, and while I think that a unit of 30 pounds evaporated from a temperature of 212° is a fair unit, still the Centennial unit is all right, I should think, from the indorsement that it has had by eminent engineers. Now, when it comes to the matter of testing boilers to ascertain their rate of economy, a great deal of time, a great deal of talent has been expended on that, and when you go into a labored test of the steam boiler, and make a calorimeter test, I think I know some engineers that can appreciate the amount of work there is in it.

Then there is another point in regard to it. That is, that people do not generally understand it. You may figure the thing up, and go through with all your different equations, and then put it before a boiler user, " Why," he says, " I don't understand this. For me to put any confidence in this I would have to hire an expensive engineer to interpret it for me." At the time of the Centennial the committee had different ideas as to taking that test. Previous to that time I had gone through with one or two of those tests. I made up my mind that there ought to be a simple way of getting at the evaporative capacity of a boiler. Now the whole point lies in the amount of expansion that is put into the water that is pumped into the boiler, and if you can have something in the shape of a steam meter that you can put on a boiler and take an account of the number of cubic feet of steam that is delivered from that boiler per minute, you have the whole thing. If the boiler primes and carries over water, you don't get so many cubic feet of steam to the pound of coal burned. There is the fact, and it gives you the whole result; but I think that this matter of steam boiler tests is simply expending too much time in making figures. It would be better to put on the boiler a steam meter that would give you the number of cubic feet of steam that the boiler turns out per pound of coal.

Mr. Kent.—Can you give me such a meter?

Mr. Root.—I can give you a drawing.

Prof. Webb.—Mr. Root seems to suppose that the object of this portion of the report is that the public may be enabled better to understand tests and calculations in which it may be used; it seems to me, however, to be exactly the opposite. A distinguished engineer, now present, said at the Pittsburgh meeting in support of a proposed new name for the unit of evaporation, that the customer would not know how much it was. Now it seems to me evident that after the tests and calculations are completed, and we know that a certain boiler will supply to the water within it so many thermal units per hour, the result of the tests is in a shape to be understood by any business man, who would need to know in addition simply the number of thermal units needed per hour for his particular engine. In order, however, to prevent any such understanding, and for reasons unintelligible to a business man, unscientific, and upon which the committee differed among themselves, we are to divide the number of thermal units by 33,305—no simpler number would do—and call the result some kind of a horse-power. I can appreciate differences in horses, but supposed a horse-power to be a fixed amount of mechanical energy. To be a commercial unit it should be fixed by law. If it is to be called a *commercial* horse-power, Prof. Trowbridge is right in claiming that in any attempt to establish such a unit the exact value chosen for it is of little consequence unless the normal conditions under which it is to be used be laid down with equal definiteness and authority. But it has been said in answer to Prof Trowbridge that it is intended to be *scientific* rather than commercial; I do not see anything scientific in the quantities chosen, or their relations to each other or to fundamental units, nor are the numbers proposed easy to remember or use. These quantities—30 pounds of water, 70 pounds pressure, 34½ evaporation units—how long have they been and how long may we expect them to remain a fair average of every day practice, or have they indeed been shown to *be* such an average in reality. To my mind it would be simpler and better to express results in *thermal units per hour*, and at all events not to express them in horse-powers which are very far from being horse-powers. After the adoption of such a unit as that proposed, it would seem to me appropriate to fix upon some one notch of the Birmingham, or other, gauge as a unit for the thickness of boiler plates, and to name it a *commercial inch,* so that a customer may have as little knowledge of the actual thickness of his boiler as he will have of its power. Such a standard notch might be made and placed with the Secretary for safe-keeping, with a statement that it was equal to so many thousandths of an inch, and although in actually measuring the thickness of plates a micrometer caliper reading to thousandths of an inch would be used, the result of such measurement would never be used in business until it had been divided by the proper number to reduce it to the "commercial inch." Suppose, for instance, that the No. 1 notch of the Birmingham gauge were adopted; then the number of thousandths would need to be divided by 300 (ten times the number of pounds of water chosen for the "commercial horse-power") to get the number in "commercial inches," and then a customer would be just enough confused as to the thickness of his boiler to give it up with the explanation—that's the way boilers are sold. I begin to understand what this new horse-power is for.

Mr. Kent.—The remarks of Prof. Trowbridge appear to be based upon a misconception of the meaning of the terms used in the report. I do not think it is open to the charge which he makes of want of exactness and precision in the definition of a boiler horse-power. The discussion repeatedly speaks as if there were "two units of evaporation" considered in the report, as in the words "another and different unit of evaporation first introduced by the judges at the Centennial Exhibition."

The report uses the words "unit of evaporation" in one sense only. Only one such unit was considered, and the report is consistent throughout in giving it one definition, namely: one pound of water at 212° F. evaporated into steam of the same temperature. This definition is given on page 8 of the report and is substantially repeated on page 11, where the unit of boiler horse-power is said to be considered to be equal to 34½ units of evaporation; that is, 34½ pounds of water evaporated from a feed-water temperature of 212° F. into steam at the same temperature. The report of the committee cannot possibly be misunderstood upon this subject. The unit of evaporation is a constant of nature of the utmost scientific precision of definition, being the exact amount of heat needed to evaporate a pound of pure water into steam at the mean atmospheric pressure at the sea level.

The unit of boiler horse-power is an entirely different unit, and is considered in paragraphs 14 and 15 of the report. There was no possible difference of opinion among the members of the committee concerning the definition of a unit of evaporation, but there were numerous differences at first concerning the unit of boiler horse-power to be recommended. So carefully was this matter considered that each member presented his individual views in writing and, after a great deal of argument in which numerous proposed units were considered, a unanimous vote was at last reached in favor of the unit which is defined on page 11:—30 pounds of water from a feed-water temperature of 100° F. into steam at 70 lbs. pressure, or 34½ units of evaporation. The figure of 30 lbs. of steam per horse-power had become so generally considered by engineers as a fair average consumption of steam in engines that it was advisable to adopt that figure if at all possible; but it was also advisable, for the purpose of securing ease in calculation, to make the unit of boiler horse-power a multiple of the unit of evaporation. It was found that 34½ units of evaporation were the equivalent of the evaporation of 30 lbs. of water from 100° F. to 70 lbs. steam pressure—within $\frac{1}{30}$ of one per cent., according to the best steam tables procurable. As this error is far within the limit of error of instrumental observation in boiler testing, and is probably within the limit of error of the steam tables, it was considered right to neglect it and, therefore, after the definition of a boiler horse-power as "an evaporation of 30 lbs. of water per hour from a feed-water temperature of 100° F. into steam at 70 lbs. pressure," there were inserted the words "which shall be considered to be equal to 34½ units of evaporation. This standard is certainly not open to the charge of want of exactness and precision. Prof. Trowbridge says, page 3:

"The committee define the unit of boiler power practically in the following manner:

"An evaporation of 30 lbs. of water per hour from a feed-water temperature of 100° F. into steam at 70 lbs. pressure with easy firing, moderate draught, ordinary fuel and good economy."

It is only by a mixing of two separate paragraphs of the report that any such meaning can be derived from it. The definition on page 11 says: "In all standard trials the commercial horse-power be taken as an evaporation of 30 lbs.," an absolute and unconditional statement to which the words expressing the condition of "easy firing, moderate draught, ordinary fuel and good economy," have no relation whatever. These quoted words are in a separate paragraph from that in which the standard horse-power is defined and relate to an entirely different subject, namely: the *rating* of boilers, or the horse-power they should be called in selling or advertising them. Is it possible that Prof. Trowbridge has misunderstood what the unit of boiler horse-power is for, and that he thinks it is to be used not as a measure of work actually done; that is, water actually evaporated in a boiler trial, but as a standard for measuring boilers for sale—for giving them a rating in the market? If so, he has misapprehended the object of a boiler test, which is to determine how many horse-power the boiler actually develops at the time, not how many horse-power it should be rated at or sold for. Just as in a test of an engine, we apply an indicator or a brake, not to determine what horse-power the engine should be called in selling it, or in advertising it in a catalogue, but what horse-power it actually develops at the time of trial, and with what economy of steam it develops the same; so in a boiler trial we weigh the water evaporated and the coal used, not to determine the question what the horse-power of the boiler should be called in selling it, but what horse-power it develops under the conditions existing when the test is made, and with what economy it develops such horse-power. The horse-power in an engine test is the measure of the work done during the test, the unit of horse-power being defined as 33,000 foot lbs. of work per minute. The horse-power of a boiler in a boiler test is the work it does during the test, but as the work done by a boiler cannot be expressed in foot-pounds of work as it can in an engine test, we give the term horse-power as applied to boilers a different definition, viz.: 30 pounds of water evaporated. The words "commercial horse-power" or "boiler horse-power," have been used by the committee as a technical term to signify the horse-power of a boiler, as above defined, and to distinguish it from engine horse-power, defined as 33,000 foot-pounds of work per minute. We would have used the word "nominal" instead of "commercial," but it might have been misunderstood as having some relation to the term "nominal horse-power," as it is still used in England in measuring engines, but which is obsolete in this country. The word commercial is perhaps not a good word and may possibly have led some to suppose it applied to the rating for sale, but no other word was suggested which did not seem more objectionable.

I think the paragraph on page 11 relating to the rating of a boiler is clear enough to the comprehension of most engineers, but it might be paraphrased as follows to make it still plainer: While the commercial horse-power is, as above stated, an evaporation of 30 lbs. of water, etc., which standard is to be used as a measure of work actually done in a boiler test, it is the opinion of the committee that a boiler should not be called 100-horse-power (or rated at 100 horse-power) merely because it evaporated 30 x 100 = 3,000 lbs. of water per hour in a boiler test, unless it is capable of that evaporation with easy firing, moderate draught and ordinary fuel, while exhibiting good economy; and, further, that it should be capable of developing 130 commercial horse-power (such commercial horse-power being defined as above 30 x 130 = 3,900 lbs.) of water per hour.

Prof. Trowbridge, introducing a standard of his own (viz.: an evaporation of 30* pounds of water from and at 212° F. *when the rate of combustion is not less than* 10 *pounds of ordinary coal per square foot of grate surface*), says "in establishing a unit of boiler power which may be prescribed in specifications by the purchaser and guaranteed by the vender some definite rate of combustion or draught should be taken into account, since this is the *principal element* (italicized by Prof. Trowbridge) which governs both power and economy."

As an example of the practical working of such a standard, suppose a boiler rated at 100 horse-power should be guaranteed by the vender to develop 120 horse-power on trial. It is tested and it evaporates 4,500 lbs. of water per hour, and the rate of combustion is only 9 lbs. of coal per square foot of grate. How is it possible to determine the horse-power developed by Prof. Trowbridge's standard? Suppose the same evaporation is obtained when 11 lbs. of coal is reached, what then is the horse-power?

The rate of combustion or draught is not only not the principal element which governs both power and economy, but it is frequently not an element at all, since both power and economy may be made independent of the rate of combustion per square foot of heating-surface or of the force of the draught. A boiler which under certain conditions of draught and rate of combustion de-

* See note on page 319.

velops 100 horse-power with an evaporation of 9 pounds of water per pound of coal, may be made to give the same results with a very different draught and rate of combustion, by simply shortening or lengthening the grate surface to correspond with the increase or diminution of the force of the draught.

The same criticisms apply of course to the other proposed standard of 40 pounds of water evaporated from and at 212° F., with a rate of combustion of not more than $\frac{4}{10}$ pounds of good ordinary coal per square foot of water-heating surface.

Let us apply the new standard to the above special case and assume that the boiler had 1,500 square feet of heating surface, evaporating 4,500 lbs. and burned 500 lbs. of coal per hour. The grate surface now disappears from the problem; the rate of combustion of $\frac{500}{1500} = 0.333$ lbs. per square feet of water heating surface—what is the horse-power obtained in the test? But suppose the heating surface is only 1,000 square feet and the same evaporation is obtained from the same coal but it is burned at $\frac{500}{1000} = 0.5$ lbs. per square foot of water-heating surface, what is the horse-power obtained? Surely, this example is sufficient to show the absurdity of attempting to make an absolute unit of work done dependent upon such a variable condition as the rate of combustion.

Prof. Trowbridge makes another suggestion, that it might be well to recommend certain standard proportions of heating to grate furnace, etc., for boilers of various classes. The committee intentionally refrained from doing anything of the kind. Their duty was to recommend a set of rules for testing boilers, and not a set of rules for building them.

Mr. Babcock.—I agree with Prof. Trowbridge in part. I think that he is sound when he says we do not want two units; one unit is sufficient. Now a unit of evaporation, as the committee says, is a standard thing: it is scientific; it is not dependent on thermometers or on measures of length or breadth; it is definite, and may be easily determined by means of an ordinary balance, and is therefore a proper thing to use. Let us accept that as a unit and measure our horse-power by it. Our committee have done this, but only as an alternative. For regular use they have assumed an entirely arbitrary unit which they call a unit of horse-power. They seem to have been led to that unit because of a desire to retain the number 30, which Mr. Root first published as a measure of horse-power. I see no particular advantage in retaining the 30; and therefore I see no need of making a conventional unit to fit it. 33 units of evaporation would have given a number which is familiar to engineers in connection with horse-power, being the same as the number of thousand foot pounds in the engine horse-power. 33 units of evaporation and 33,000 foot pounds form something nearly akin, are easily remembered, and seem to be a part of the same general notation.

Another unit is suggested by them, the heat-unit. That is a scientific term and there would seem to be good reasons for adopting it. 33,000 heat units, a measure nearly equivalent to the committee's, would have similar advantages to 33 units of evaporation. Insomuch I agree with Prof. Trowbridge. I do not agree with him in respect to what is a boiler horse-power. It should have nothing whatever to do with the rates of combustion either on a square foot or grate, or a square foot of heating surface. In fact, Prof. Trowbridge's argument overthrows his unit; he shows us that on plain cylinder boilers there should be one square foot of grate to every eleven square feet of heating surface, while on return tubular boilers the proportions should be 1 to 28. Now, then, if you apply his unit of horse-power to those two different boilers it will not fit at all. The conditions destroy each other. There is no question but that a boiler will give a better economy at one rate of evaporation than at another; that is, at one particular rate of evaporation it will give its best economy. There is a maximum. I could not give it in definite figures, they would vary with different boilers, but it would approximate a curve of this form (Fig. 225). If we take for vertical values the quantity of water evaporated, and for horizontal the quantity of coal burned per unit of surface, we will find that the curve of capacity will rise nearly regularly at first, gradually falling off in ratio as the combustion increases. Now if we wish to represent the economy in pounds of water evaporated per pound of coal, it would be by a curve starting from nothing, running up very quickly to a maximum, which will be nearly maintained for a while, then falling away in an increasing ratio. The best work of the boiler would be done within the vertical lines A and B—and its commercial horse-power should be somewhere within that range, which will vary, however, with the kind of boiler. This diagram will answer for any boiler by varying the scales of values.

Mr. Root.—In regard to this matter of economy I think there is just as much in adjusting the rate of combustion and the temperature of the furnace, compared with the terminal temperature of the flue, as there is between the initial and the terminal pressures in the steam-engine. If you reduce your grate surface and burn a large amount of coal per square foot, the result is, as I have found in a great many cases, to reduce the temperature of the gases passing off through the flue, and the reverse is the case when the furnace temperature is reduced. The result is, when you put up your temperature by a higher rate of combustion in the furnace, that the part of the boiler adjacent to the furnace,

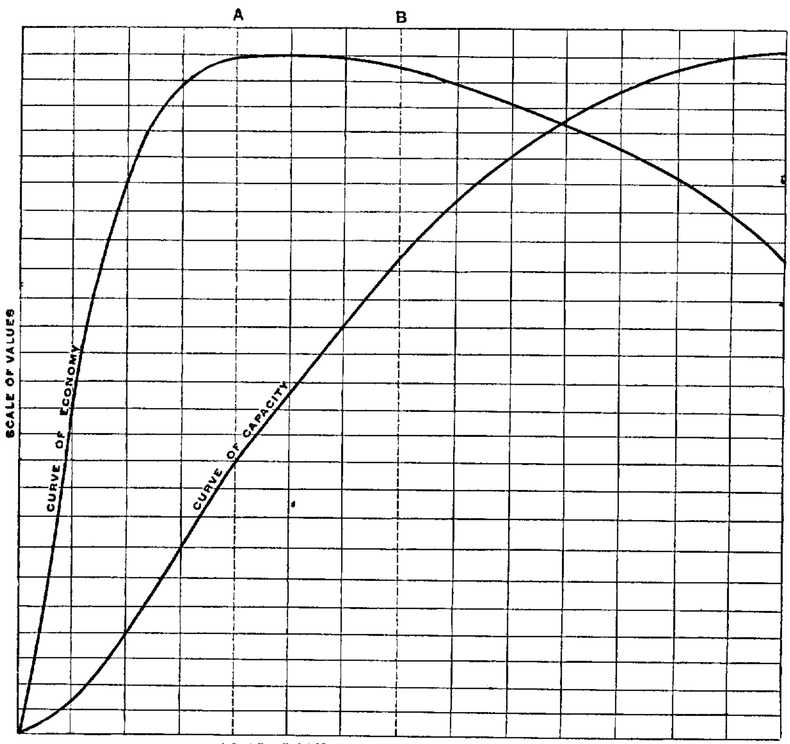

FIG. 225

being subjected to a higher temperature, takes up a great amount of the heat generated by the coal at that point. That leaves a less amount of the heat to be absorbed in the run through the outlet of the flues to the chimney. I found that by reducing the area of the grate and putting up the temperature of the furnace to a very high point I actually reduced the temperature of the gases in the flue. I think that is the point that varies all these equations and curves that you may make, and that results will be varied by the proper proportion of grate surface and flue areas.

J. F. Holloway.—As I understand, Mr. Kent proposes to eliminate from this discussion a great many of these points which were referred to, and I understand him to say that he simply proposes to give to you the water and the coal and you are to get the best results out of that. He might use as an illustration the fact that the horse-power of a horse going over the country is not dependent on a variety of conditions. In the case of fast horses in a race, where the intent is that the horse shall have a fair start and the one that gets under the wire first is to be considered the best horse, what is known as jockeying often comes in. I do not know that the same thing comes in boiler tests; but if it does, it is in such ways as are suggested by differences in the way the firing is done, and the way the damper is handled, and other such manipulations. The point that Mr. Kent means, I suppose, is that all we have to do with is the result in the end. Having those two elements to begin with, we get the best results out of them —what should be the starting and what should be the end; the intervals between the two being left to the best jockey.

Mr. C. E. Emery.—I feel assured that the pressure of other duties has prevented Prof. Trowbridge from making the thorough examination necessary to appreciate the full value of all the conditions which are to be considered in discussing the unit of boiler-power as suggested in the Report. The discussion states, on its third page: "The committee define the unit of boiler-power practically in the following manner: "An evaporation of 30 pounds of water per hour, from a feed-water temperature of 100° F. into steam at 70 pounds pressure," "with easy firing, moderate draught," "ordinary fuel and good economy." The Report of the committee states:

"Your committee has carefully weighed the arguments relating to these standards, as they were presented in writing by their respective advocates, and, after due consideration, has determined to accept the Centennial Standard, the first above mentioned, 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° *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° Fahr. into steam at the same temperature. This standard is equal to 33,305 thermal units per hour.

"It is the opinion of this committee that a boiler rated at any stated number of horse-powers should be capable of developing that power with easy firing, moderate draught and ordinary fuel, while exhibiting good economy; and further, that the boiler should be capable of developing at least one-third more than its rated power to meet emergencies at times when maximum economy is not the most important object to be attained."

With the above quotation before us, where is the want of "exactness and precision" in the unit of boiler power, which is referred to? Is it implied that the unit should be stated in units of evaporation? It is so stated in the Report but not in the quotation from it. It is also stated in thermal units.

It would not be unnatural that criticism should be called out from an active engineer approaching the subject hastily and failing to find in the Report a complete treatise on all the conditions which affect the performance of boilers. It is stated in the discussion: "The principal commercial considerations in the sale and purchase of a boiler are its 'capacity' or 'power' and its 'economy.'" This statement is unobjectionable, but simple as it is, it includes a range of problems entirely outside the scope of the subject referred to the committee, and involves conditions which it would be impossible to embody in formulating rules for general use. The committee attempted only to write a report on "a standard method of conducting steam-boiler trials." The question is, whether the report submitted furnishes rules for conducting such trials with sufficient elaboration to make the results obtained practically accurate and comparable one with another. In order to show the power of a boiler it was necessary to fix a standard of boiler-power, and the power developed by a boiler at any given time can be compared with this standard and accurately stated. The committee cannot dictate to manufacturers and users of boilers all over the country what rate of combustion they shall employ, either per square foot of grate as proposed in the first modification of Prof. Trowbridge, or per square foot of heating surface as proposed in the second modification by Profs. Trowbridge and Richards. One of Prof. Trowbridge's own illustrations is well calculated to prove this. He refers to some of my work for the Novelty Iron Works some 16 years ago, where I gave the proportions of grate to heating surface of a plain cylinder boiler, 1 to 11; of a cylinder flue boiler, 1 to 17; and of a cylinder tubular boiler, 1 to 28. It is well to add, however, that in the circular I gave the relative evaporations as 1 for the plain cylinder, 1.14 for the cylinder flue, and 1.32 for the cylinder tubular, to show purchasers what kind of boilers it was for their interest to buy. The proportions fixed were not notions of my own; they were founded on the average proportions of similar boilers then in use. Such boilers are still in use. For utilizing waste heat where fuel is cheap the plain cylinders will probably continue to be used for years, and on account of bad water the cylinder flue boilers will probably continue to be used in the West, indefinitely. The proposition to conduct boiler trials of these different kinds of boilers at the same rate of combustion per square foot of heating surface is preposterous, as the cylinder flue and tubular boilers would not nearly give the power usually obtained from them in regular practice.* Moreover, the proportions of many other boilers sold in the market vary nearly as much as those referred to, so the proposed modification would be rarely applicable. The purpose of a boiler trial is not to dictate what the power and economy shall be, but to ascertain what they are.

Of course the same boiler can be operated at different powers, and of course a very large increase in the power of a boiler may be obtained without very largely reducing its economy, but the power and economy during each particular trial can be ascertained definitely by the rules presented.

The particular quantity of water evaporated selected as one horse-power should not be confounded with the question of what shall be the rated horse-power of a boiler. The manufacturer of a boiler may rate his boiler at any power he chooses. If a test be made, the actual power developed under the particular conditions will be ascertained under the rules given. If the question, as to whether or not a boiler is of a given power, be submitted to an engineer, he may by measurement of its size and proportions, in connection with its chimney and setting, determine approximately how much water it will evaporate, and thereby determine its power by the rule, or he may obtain the results more accurately by actual trial. If the builder has guaranteed a certain economy, that can be determined beyond peradventure. There will be no dispute about it, simply because there is only one way of expressing economy.

* Only eleven twenty-eighths of regular power in one case and seventeen twenty-eighths in the other.

There have been difficulties however when only a certain power was guaranteed, for the reason that there were great differences of opinion as to the value of a horse-power, which it is now proposed to settle. The two questions are entirely independent. An engineer in determining whether or not a boiler is of a certain horse-power under the rules, should be guided by the suggestion of the committee that the boiler should produce "that power with easy firing, moderate draught, and ordinary fuel," and further that the boiler "should be capable of developing at least one-third more than its rated power to meet emergencies at times when maximum economy is not the most important object to be attained."

Evidently a boiler must have some surplus power in order to enable the fireman to keep the steam pressure steady when manipulating his fires, when the day is dull or the fuel poor. Frequently, too, the regular fireman is absent, and there are many other contingencies which will at once suggest themselves to the practical engineer. Personally I should like to have seen the provision of one-third surplus power made more prominent. The committee after a full discussion thought it should come in simply as a suggestion, since the actual power developed in a particular trial could always be stated in terms of the standard. The members of the committee differed somewhat in opinion at first, more particularly however as to details, and it required considerable discussion, but I am happy to say little compromise, to bring about a full agreement. When the committee had nearly finished their work and were settling the details of the Report, it was informally suggested to make the standard exactly 33,000 British Thermal Units per hour, so that it would be numerically the same as the number of foot-pounds per minute constituting an actual horse-power, and again 33,333 B. T. U. were suggested to facilitate the calculations, but the general feeling of the committee was against any change whatever. The members had come to think alike. They believed that the standard fixed by the Judges of the Centennial Exhibition so nearly expressed their convictions as to what the value of a horse-power should be that it should be adopted without question. The members who were not on the Centennial Committee were apparently most earnest in opposing any change whatever.

Mr. Babcock thinks that the value of a horse-power should be stated only in "units of evaporation," and other speakers feel that confusion will arise by adopting any other standard. It will be observed, however, that the committee fixed the standard in three alternative forms, in one of which it is stated in "units of evaporation." The object of first stating the standard in the form used by the Centennial Committee, to wit: 30 pounds of water evaporated per horse-power per hour at a gauge pressure of 70 pounds from a temperature of 100°, and afterwards stating that this is equivalent to 34½ units of evaporation or pounds of water evaporated from and at 212°, is simply that the former more nearly expresses the result under actual practical conditions. Engines are not operated at atmospheric pressure, and the feed water is rarely 212°; but very many engines are operated at or about 70 pounds pressure, and the feed-water temperature of 100° is easily obtained in average practice. If a manufacturer compares the amount of coal and water used for a given time, as shown by his coal bills and a properly connected water meter, he should be able to ascertain an average number of horse-powers used, approximating that shown by an elaborate trial. If an engine requires 30 pounds of feed water per horse-power per hour, the boiler must furnish that amount of power for each horse-power under actual conditions, and any owner or practical superintendent who had watched a trial as closely as some do, on inspecting a report stated in units of evaporation would say that his engine did not require 34½ pounds of water per horse-power per hour, but only 30 pounds, as he had checked the figures. The practical man would be right. Water evaporated from and at 212° certainly has nothing to do with an *engine* trial. *The engine and boiler units should correspond*, so that the boiler will furnish and the engine use not only the same actual quantity but numerically the same number of units of water. Hence *the horse-power of a boiler should be expressed primarily in such manner that scientific corrections to a standard basis will not greatly vary the apparent result.*

Prof. Webb, in his remarks, goes still further and claims that the British Thermal Unit should always be used, and that the other methods of stating the value of a horse-power only confuse the matter. What would the practical boiler owners and superintendents say about confusion if the results were only stated in British Thermal Units? The answer is evident. Now which should govern, language comprehensible to men who own and operate the thousands of horse-power of boilers and engines now in use, or to those who have little or nothing, practically, to do with them? It is the duty of the schools to teach principles, but to learn to apply them in practicable ways. We should all keep in mind Rankine's definition of Science, which is, substantially, that it is a combination of *Theory* and *Practice.* In this matter it seemed better to the committee to announce a practical standard that all could understand, and then fix its value definitely on a scientific basis. *The value of the unit of horse-power announced is* 33,305 *British Thermal Units per hour*, which being stated in the Report definitely fixes the standard. It also equals 34½ units of evaporation, within one-thirtieth of one per cent., and this value is also stated so that parties who desire to use it in that form can do so.

It may be interesting also to put on record here some reasons why 30 pounds of water per horse-power per hour, evaporated under actual conditions, is considered equal to one horse-power, rather than to any greater or less amount. Very small engines use 40, 50, and sometimes even 60 pounds of water per horse-power per hour, while large engines working expansively, in factories, require 22 to 24 pounds only, some results being reported still lower. Compound engines well adapted for their work require still less. Small engines are, however, generally furnished in connection with the boilers which are to supply them with steam. In many cases the engine and boilers are practically a unit, as in the case of portable engines. So also for factory purposes boilers are furnished to supply particular engines with steam, and generally by the parties furnishing the engines—in any case by those who understand most of the conditions of the problem. The unit of boiler horse-power should therefore be most applicable to intermediate sizes. It is a fact easily proven that from 50 to 75 horse-power can readily be obtained in a modern engine, using steam expansively but non-condensing, for less than 30 pounds of water per horse-power per hour, which indicates that 30 pounds is ample to allow for the increased consumption due to such ordinary derangements as occur in average practice. It was thought, however, that 30 pounds of water evaporated per hour from and at 212°, which is the equivalent of only 26.1 pounds of water, evaporated under average actual conditions, would be insufficient to produce a horse-power in average engines of moderate size. The standard selected, 30 pounds of water, evaporated at 70 pounds gauge pressure from a temperature of 100°, was considered to be the better compromise, one which more nearly corresponded with the views expressed by others previously, and which moreover possessed the advantage of having been previously promulgated by the judges who conducted the test at the Centennial Exhibition.

Mr. Root has suggested that boilers should be tested with a steam meter in order to avoid the necessity of many of the elaborate details provided for in the code. I applied a steam meter to a boiler lately, and was very much surprised in observing it. The boiler was one of twenty or more supplying steam to our mains. The discharge from the boiler was through a check valve, and the meter showed that the boiler took a rest every time it was fed with fuel or water. No matter how carefully these operations were performed, no steam passed out of the boiler for a little time afterwards. This could not have taken place if the boiler had been operated singly to furnish a regular supply of steam. In such case the water in the boiler would have kept up the supply temporarily after firing or supplying feed to the boiler, and the pressure would have varied slightly. In the case referred to, the other boilers kept up the pressure, and the boiler simply stopped generating steam momentarily until there was a slight excess of pressure within it to raise the check valve. The quantity of steam passing through the meter was shown by the position of a pencil moving over a ribbon traversed by clock-work, so that the records were a series of hills and hollows varying with the management of the boiler, condition of the fire, etc. The depressions which showed that no steam was passing were very short generally.

This statement will be deficient without a brief explanation of the construction of the meter. The velocity of steam in our pipes, for the losses of pressure desired, is about 80 feet per second, so that it was practically impossible to construct a displacement meter. Such a meter would necessarily have as large a displacement per unit of time as the engine it was supplying. Several velocimeters were tried, but, as is common with this class of mechanism, they varied their rate not only with the quantity flowing through, which could have been allowed for, but with the friction of the apparatus, and the latter, in steam machinery, is liable to variation on account of wear and the difficulty of maintaining lubrication. We had to go back to the principle of blowing steam through a graduated orifice with a constant head or difference of pressure. This method is as accurate as any other, depending as it does upon the well-known principle of the laws of gravitation. The meter I developed consists substantially of a piston valve regulating rectangular openings of definite size and operated by a weighted piston, the weight being so adjusted to the diameter of the piston as to require 2 lbs. difference of pressure to lift it, and this difference of pressure is by means of the weighted piston automatically maintained between the inlet and discharge sides of the meter openings. The motion of the piston is transferred outside the cylinder by means of a rock shaft and levers, and its position is continuously recorded on a ribbon of paper set in motion by a clock, as previously explained. A fixed pencil also marks on the paper a line of reference. The heights of the diagrams at various points are in proportion to the quantities of steam flowing at the respective times, the average height is proportioned to the average quantity of steam used, while the area is proportioned to the total quantity of steam used for the time considered. In practice the areas are ascertained by means of special planimeters designed for the purpose. The necessity of using a clock and recording mechanism on every meter was at first thought to be a misfortune, but it proved a blessing in disguise. One great drawback of the steam business is that janitors and employees will waste it. They leave it on at night so that the buildings will be warm in the morning, and not require them to be on hand as early as they would if the steam had been shut off. In many places during the winter steam is not shut off from one week's end to another, and is consequently used 168 hours in the week instead of about 60, as expected. In well-ventilated buildings the quantity used during the night does not appear to vary materially from that used during the day, so that naturally great complaints arise as to the amount of the bills. Owners are disposed to believe the statements of their janitors or other employees whom they have trusted so many years, and not until they are confronted with the charts showing carelessness, and perhaps have tested the accuracy of the registers by privately seeing steam shut down at particular times and then asking for reports from us, will they believe that the amounts of the bills are due to a want of care on their own premises, and not to the greediness of the corporation, as they are too willing to claim.

Mr. Root.—I see that the gentleman has come to the meter idea after all, and I think it would be well if that would take the place, in the reports of the trials of steam boilers, of so much figuring and so many equations that the majority of people cannot understand. I will ask Mr. Emery how accurate this appears to be and how much trouble there is in working it. Is it liable to get out of order? If the weight of the steam is increased by being loaded with water I should think the rate of flow should be changed.

Mr. C. E. Emery.—If it is in order I will be happy to say anything in regard to the matter. No experiments have been made to ascertain the variations in flow due to moist steam. Our large pipes act as steam drums, the water of condensation separates readily and flows along the bottom until it is removed by a trap, so that the quality of the steam is about the same at all places. In regard to the accuracy of the apparatus, I will say that each meter is accurate when it works freely. We have attempted to make the meters exact duplicates, so as to avoid rating every one by actual test. This involved all the difficulties in any manufacture due to making parts interchangeable, which have been successfully overcome. We are however still rating every meter by actual test, so that there will be no question as to the accuracy of the records. It is desirable to have the meters fit closely and yet move with absolute freedom. The meters are made reliable by using comparatively heavy weights. The piston of a $1\frac{1}{2}$ inch meter weighs 30 lbs., so if the resistance to motion be $\frac{1}{10}$ of a lb. the difference of pressure is affected $\frac{1}{300}$ of 2 lbs. or $\frac{1}{150}$ of 1 lb. We find that some of the meter cylinders slightly change shape after being heated up for a time and it is necessary to scrape the bearing points. We have however some meters in use two years which have not been touched. Fortunately small resistances do not affect the results. Variations in demand cause a movement of the piston, and even when supplying a constant quantity of steam for heat a slight variation of steam in the boiler-house will cause slight variations in the pencil record of the meter; the pencil rising as the steam pressure falls and falling as the steam pressure rises, within very small limits. The record is therefore evidently correct for the average steam pressure. The slight undulations also correct errors due to the minor resistances, for the pencil falls as much short of reaching the absolutely correct higher limit as it does of reaching the corresponding lower limit, so that the average is absolutely correct. Lastly, the slack motion in the connections is also eliminated in the same way, when it is less in amount than the movement of the pencil due to reasons named. We are thus able to study the diagrams the same as indicator diagrams, and to tell from their appearance whether or not the meter is in order. A straight line on the diagram is always regarded with suspicion. A test of the meter is immediately made to see if it will respond to changes in the position of the delivery valve. We desire to see a slight undulation in the line even where the demand for steam is very regular.

Mr. Barrus.—I regret that the Report of the committee does not recommend a simple standard method of making calorimetric tests of the dryness of steam. But perhaps the memorandum describing Mr. Emery's barrel calorimeter was thought sufficient. If so, I beg to criticise the method he describes. In one respect, I believe it is inaccurate. My object in writing this, is, 1st, to state wherein the inaccuracy consists; 2d, to present for consideration the data and results of some experiments that support my views; and 3d, to offer a self-evident remedy.

Mr. Emery's memorandum on the thirty-fifth page of the Report and the 290th of the volume (next to the last paragraph) reads, "The weight of water in calorimeter should be increased proportionally to the weight and specific heat of all metal exposed to changes of temperature with the water. An addition of one-ninth of the weight of the propeller, and submerged portion of shaft and fastenings, will be substantially correct, if the apparatus be made of iron."

I have used the barrel calorimeter to a considerable extent, and have found that the wooden material of the barrel itself absorbs heat derived from the steam, in the same way as the metal referred to, but to less extent. I have been in the habit of making an allowance for the effect of the wood, and as it amounts to from 1 to 3 per cent. of the heat given up by the steam, it has appeared to me an important correction. Mr. Emory's memorandum makes no reference to the matter, and herein the method appears to me in error.

In support of this view, I submit the following data and results of some experiments with a barrel calorimeter, which I have undertaken for this special object.

The calorimeter was constructed essentially like the one Mr. Emery's memorandum recommends. Its principal difference was in the propeller, which was made of pine wood. There was no metal in the barrel excepting two or three iron plugs screwed in from the outside, used for stopping holes; and the $1\frac{1}{4}$-inch iron nipple with its elbow and outlet valve, which was attached to the bottom.

The wood of the barrel was oak, three-quarters of an inch thick. The barrel held, when filled, about 350 lbs. of water.

Although the object of the experiments was to find the amount of heat absorbed by the wood of the barrel, they were made to embrace complete calorimetric tests.

The method adopted was as follows: The barrel was filled to a certain mark and steam admitted till the temperature reached as near as might be 110° F. The propeller was set to work to equalize the temperature, and then the barrel was emptied. After observing the weight of the empty barrel, the cold water supply valve was opened and the barrel filled to the same mark as before. During the operation of filling, the temperature of the inflowing water was observed at intervals of half a minute, a thermometer being set in the supply pipe for the purpose. It required about three minutes' time for the complete filling. The temperature of the water in the barrel was again made uniform by the use of the propeller, and the temperature observed from a thermometer held in the hand and immersed in the open barrel. The weight of the filled barrel was taken and steam blown through the hose till all the drip disappeared. Then the hose was dropped into the barrel and steam admitted with full force. When the temperature of the water reached 110°, as near as might be, the steam was shut off, the hose carefully removed from the barrel, and the propeller operated till the temperature became uniform. The weight and temperature were again observed, and the experiment was finished. This course was followed in each experiment of the series, and the same length of time was occupied in similar operations.

Four consecutive trials gave respectively for total heat of the steam, 1197, 1191, 1198, 1199.

The full log of the third trial is given below, and is representative of all the others.

1. Steam of previous trial shut off at....................2.49—30.
2. Water of previous trial emptied at....................2.54—30.
   Temperature at 111.7° F.
3. At 2.58– 0 Weight of empty barrel................82 lbs. 4oz.

	Time.		Temperature.
4.	At 2 58-30	Open cold water supply	53.5°
	" 59- 0	" " " "	50.8
	" 59-30	" " " "	50.6
	" 3 00- 0	" " " "	50.6
	00-30	" " " "	50.5
	' 01- 0	" " " "	50.5
	01-30	Shut off cold water	50.5
		Average	50.8°

5. At 3 03-30	Weight of barrel	383 lbs. 10 oz.
6. " 3 05- 0	Temperature of water in barrel	53.3°
7. " 3 07- 0	Open steam valve.	
8. " 3 12- 0	Shut steam valve.	
9. " 3 14- 0	Weight of barrel	400 lbs. 6 oz.
10. " 3 15- 0	Temperature of water in barrel	111.6°
Steam pressure by gauge		71.5 lbs.

It will be seen from this log that the cold water gained in passing into the barrel 2.5° of temperature. Subsequent experiments showed that 0.5 of a degree was absorbed from the atmosphere, which had a temperature of 88° F. The remaining 2.0 degrees is that due to the heat that was stored in the wood on the previous experiment. This is $3\frac{4}{10}$ per cent. of the heat given out by the steam. In the other experiments of the series, the number of degrees received from the wood was, in the first 1.7°, in the second 1.9°, and in the fourth 1.8°. I hold that these quantities measure the allowance that should be made for the specific heat of the wood in barrel. In this particular calorimeter the allowance amounts to over 30 thermal units of total heat, which corresponds to what would be called over three per cent. of moisture in the steam.

The remedy for the error of Mr. Emery's method, if my reasoning is sound, is to take for the initial temperature, not that of the cold water in the barrel, but that of the cold water flowing into the barrel corrected for the heat derived from the atmosphere.

I would say that the scales used in weighing the water on the tests were sensitive to a change of half an ounce in weight, and the thermometers, graduated to fifths of a degree, could be easily read to tenths, and were found substantially correct when compared with each other and with standards.

I am indebted to Prof. Lanza of the Mass. Institute of Technology, where the tests were made, for permission to use some of the apparatus in the steam engineering laboratory of the Institute for the purpose.

I would call attention also to the fact that the report of the committee suggests no rules for the treatment of the unburned and unconsumed coal, which, during the progress of a test, falls through the grates. Tests that are made for commercial purposes call for the determination of the amount of *coal* consumed, without regard to the amount of *combustible.* In the case of anthracite coal an appreciable percentage of the coal that is fired finds its way through the grates into the ash pit, either in an unburned or in a partially burned condition. The amount depends somewhat upon the width of air spaces in the grates, but however small the spaces may be, within the limits of practical use, small pieces of coal may always be found in the ashes.

I would suggest that in the case of anthracite coals which are larger in size than those termed "buckwheat," the pieces of coal, whether partially or wholly unburned, which will pass through a screen having meshes one-quarter inch square in the clear, be classed as *ashes*, and those that fail to pass through such a screen be classed as *refuse coal*. The weight of the refuse coal should be deducted from that of the coal which is fired, in order to determine the weight of coal actually consumed. My own custom has been to select and screen a sample of the ashes, refuse coal, and clinkers, and thus determine the proportion which the refuse coal bears to the whole weight, without going through the labor of screening the whole quantity.

Since the above was written, I have repeated the calorimeter experiments, using, instead of the wooden barrel, a metal tank.

The tank was $19\frac{1}{2}$ inches in diameter, $23\frac{1}{2}$ inches deep, and was made of No. 15 B. W. G. wrought iron, the inside of which was tinned. It had two handles, but no other attachments. Its weight was 34 pounds 14 ounces, and all of this, except a rim of metal at the top three inches wide, representing about 1.28 pounds weight, was exposed to the changes of temperature of the water. In using this calorimeter, according to the directions of Mr. Emery's memorandum, the weight of water should be increased by $\frac{33.6}{9} = 3\frac{7}{10}$ pounds, provided the vessel be of iron. It may be regarded as wholly iron, the tin lining being very thin.

Calorimeter tests were made with this apparatus in a similar manner to that described for the barrel calorimeter, except that only one initial temperature of the cold water was observed, and that *after* the water had entered the tank.

Three consecutive experiments, made under the same conditions of place and circumstances as those made with the barrel calorimeter, gave for total heat of the steam, 1196, 1200, and 1197 respectively. The data of the first of these tests, which is representative of all, are as follows:

1. At 12.28 Weight of empty tank including the hair felt underneath.... ....37 lbs.
2. At 12.31 Weight of tank filled with cold water....251 lbs. $8\frac{1}{2}$ oz.
3. At 12.33 Temperature of cold water in tank............52.9°
4. At 12.34 Let on steam.
5. At 12.37 Shut off steam.

6. At 12.40 Weight of tank filled with cold water....261 lbs. 2 oz.
7. At 12.41½ Temperature of warm water in tank..........101.1°
Pressure of steam by gauge..............................73 lbs.
Temperature of atmosphere...............................73°

The close agreement that exists between the results obtained by the two methods, is proof, to my mind, of the correctness of the method described for working the barrel calorimeter.

I would submit also the following formal suggestions, as covering these and some of the other points in which I think the Report of the committee could be improved.

1. Amendment to Section X.

Change the beginning of the second paragraph so as to read as follows:

At the end of the test, remove the whole fire *as soon as one-fourth part, as near as may be estimated, has become dead,* clean the grates, etc.

2. Amendment to Section XIV.

Insert the following words between the first and second paragraphs:

On all except tests for scientific purposes, the standard form of calorimeter shall be one of the barrel type, made of iron or other metal, suitable correction for the thermal equivalent of which shall be allowed. In conducting calorimetric tests the final temperature of the water shall be carried only so far above the temperature of the surrounding atmosphere as the initial temperature is below that point.

3. Amendment to the tabular record, Section XVII.

Insert between lines No. 19 and No. 20 the following new line:

Proportion of refuse that fails to pass through a screen having meshes one-quarter of an inch square in the clear.

Mr. C. E. Emery.—Mr. Barrus was kind enough to send me a copy of his intended discussion in relation to a proposed method of correcting the results when using a barrel calorimeter to allow for the specific heat of the wood in the barrel. It is true that the influence of any mass of material may be ascertained from its weight and specific heat, or, as Mr. Barrus proposes, by the change such mass makes in the temperature of another mass of known weight; for instance, the water in the calorimeter.

A correction for the specific heat of the wood in the barrel is desirable if its influence is of any considerable moment. Mr. Barrus does not fix the amount of the correction with sufficient definiteness to prove that it is important. If his experiments are worked out in detail, it will be found that they show superheating when the temperature of the entering water is taken before, instead of after, it enters the barrel. A portion of the increased temperature he ascribes to the absorption of heat from the air but he does not state how he determines this amount. I communicated with him, asking distinctly in regard to this, but he does not answer the question. Are we to infer since the experiments by his method will show superheating, that all the heat in excess of what he considers ought to have been shown, should be credited as having been derived from the air ? Unless he explains how his correction for the air was obtained we have a right to assume that both the air correction and the correction for the barrel are determined from the same experiments, or else that his data are deficient and therefore of no value. Of course if we explain the correction the first way, a wide field is opened at once for conducting calorimeter experiments according to any person's notion of how much heat is derived from the air. By reducing the quantity of heat supposed to be derived from the air it is possible to increase that derived from the steam, as the sum of the two is what is shown by the experiments. If this be considered unfair, then where is the fairness in assuming that the quantity of heat derived from the air would be constant under varying conditions? The question arises: What would be such difference when the hose is held six inches above the water's surface compared with that derived when it is held sixteen inches above it? What would be the difference in result when the stream is directed against the stirring apparatus or the side of the barrel so as to become dispersed and thereby expose a larger quantity of surface to the air compared with that when the stream enters unbroken?

The work Mr. Barrus has undertaken is desirable, as all additional investigation in relation to physical experiments is desirable, but certainly in the shape he has left it, no valuable information is conveyed. The wooden apparatus he used for stirring was undoubtedly well calculated to absorb water, which, as it was heated and cooled, would have something to do with the changes of temperature which he describes. It is evidently better to make the propeller or stirring apparatus of iron, which will not absorb water and which will change temperature rapidly so as to correspond to that of the water, and the weight of which can be accurately ascertained. Similar considerations apply to the barrel or vessel itself which holds the water. It is undoubtedly better to make it of metal, as thin as it will keep its shape, to protect it carefully with felt or even eider down, if available, as Mr. Hoadley did with his calorimeter, and then allow for the weight of metal heated and cooled with the water, according to the rule given in my memoranda. An apparatus of this kind is somewhat permanent in its nature and rather bulky to send to a distance. The results with barrel calorimeters, when the experiments are made in the manner suggested in my memoranda, have heretofore agreed fairly well with the results obtained with more delicate apparatus, and the barrel method has therefore been considered sufficiently accurate for practical purposes. The absorption of water by the wood of the barrel probably makes more difference with the results than anything else. In most cases I have used barrels previously employed for holding oil or spirituous liquor, and did not suppose that there could be any great error in the results, due to the specific heat of the wood. I think it would be well thoroughly to oil the interior surface of the barrel in any case, so as to prevent the absorption of water.

I trust Mr. Barrus will not be discouraged, but continue his experiments until he is willing to publish the entire details, and obtains results which will correspond among themselves. While on this subject, I wish particularly to call attention to the necessity of publishing all the details of experiments, even those which do not appear to conform to others. The ascertainment of general laws has been postponed simply from the lack of detail in the records of previous experiments. Full details will frequently aid others in tracing a law the underlying principles of which differ altogether from preconceived notions. Some engineers think it necessary to omit from their records any mention of deficiencies in the apparatus used, which might appear to militate against the accuracy of the results of the experiments, imagining that their own good intentions will excuse such omission. I have known a really capable engineer to furnish an engine-builder with elaborate tables of the performance of his engine under certain varying conditions which were to be tested, without any reference whatever in the report to the fact that the boiler from which the steam was derived leaked an amount equaling some fifteen to twenty-five per cent. of the amount of steam used by the engine. It may be that the method was not very inaccurate for merely comparative experiments, using about the same quantity of steam in each case; but to say that these particular experiments should be published to the world in comparison with others made with other engines, under different conditions, would be very questionable, as the absolute amount of water leaking from a boiler when not supplying steam freely, might vary considerably when the circulation of the water was active and the fires burning briskly. In any case all conditions should be stated in the report sufficiently in detail to enable others to judge of the manner in which the experiments were conducted and their general reliability—it being necessary to assume the honesty and good intentions of the observer in all cases until the contrary is proven.

Mr. Kent.—Referring to the note of Mr. Barrus upon the treatment of unconsumed coal which falls through the grates during a boiler test, I am of the opinion that no allowance should be made for such coal, but that it should be counted in with the ashes. In a commercial test made to determine the relative commercial value of two kinds of coal, it is evident that, other things being equal, the coal which, through extreme friability or other cause, crumbles into dust and runs through the grates is less valuable in practice than one which holds itself up on the grates. If allowance should be made for the dust or small particles of such coal which fall through the grates, it might lead to an erroneous conclusion in regard to the commercial value of such coal.

If allowance should be made, as Mr. Barrus suggests, it might be claimed that allowance should also be made for such unconsumed coal as was blown into the chimney by the force of the draught; and also for the heat wasted by carrying too much air through the fire. The suggestion that "at the end of the test the pieces of coal, whether partially or wholly unburned, that pass through a screen having meshes ¼ inch square be classed as ashes, and those that fail to pass through such a screen be classed as refuse coal" is liable to several objections. Such a treatment of the refuse adds another complication to the boiler test, which is already sufficiently troublesome, and would not be likely to meet general approval by all who have to make boiler tests. Such an arbitrary classification of refuse coal and ashes is inaccurate and unscientific, and the extent of its inaccuracy will be different with different coals.

If a boiler test is made to determine the absolute economy of the boiler with reference to its filling a guarantee, it is not fair to the purchaser of the boiler to make an allowance for the coal passing through the grates, since such coal is actually lost in practice, and, if allowed for, the result of the test would be larger than could be obtained in practice. If the test is made to determine not the absolute economy, but the comparative economy between two furnaces, or two methods of firing, or two kinds of coal, one of the elements of value in any particular furnace, method of firing, or kind of coal, is that of the quantity of coal which goes through the grates. In such case, therefore, it would be improper to allow for such coal.

Mr. Barrus's suggestion to select and screen a sample of the ashes, refuse coal and clinkers, instead of screening the whole quantity, is also open to the objection that, to select a sample which should be an absolute average of such a heterogeneous mass, which varies in its composition during every hour of the test, would be a matter of considerable difficulty, and there would always be doubt as to its accuracy.

Mr. Barrus.—In view of Mr. Kent's objections, so far as they apply to tests for determining the economy between different methods of firing, different kinds of coal, and, it might be added, different forms of grates, I would suggest that in tests of this kind the amount of *refuse coal* that passes through the grates be determined and the result recorded, but that no allowance be made for the same in determining the weight of coal consumed. In tests for all other purposes, however, and especially in those which are made to find the efficiency of the boiler itself, I would strenuously urge that the allowance be made for this refuse coal. There is such a variety of forms of grates in use on the same types of boilers that the matter appears to me an imperative one.

I must utter my protest against Mr. Kent's objection that the treatment named "adds another complication to the boiler test, which is already sufficiently troublesome, and would not be likely to meet general approval by all who have to make boiler tests." The person who finds or expects to make boiler testing *anything else but troublesome*, has had a different experience from mine in the matter. We cannot make or expect to make the work easy, but we can do the work right if it is worth while to do it at all. It is my wish that the code be one which can be referred to, and, as far as possible, followed without qualification.

The burden of Mr. Emery's criticism to my note regarding the allowance to be made for the specific heat of the wood of a barrel calorimeter, appears to be that in my experiments, the heat added to the water might be derived to a principal extent from the atmosphere.

I would say that this could not be the case. The 0.5° that is given for the heat derived from this source was obtained in the following manner: The barrel was filled to the mark with cold water and emptied, and this was done a number of times so as to abstract all of the heat from the wood of the barrel. The water from the supply pipe was then admitted in the same manner and under the same circumstances as described for conducting a calorimetric test, the temperature of the inflowing water was observed, and, after having been made uniform by working the propeller, the temperature was observed of the water in the barrel. This test was made again with identical results, and I repeat that the heat derived from the atmosphere added 0.5° to the water while that derived from the atmosphere and from the hot wood of the calorimeter on the main tests added from $2\frac{2}{10}$ to $2\frac{5}{10}$ degrees.

I would be glad to hear from Mr. Emery as to how he can reconcile the close agreement of the two sets of tests, one made with a wooden tank with no other allowance than that of using for the initial temperature that of the *inflowing water* corrected for the heat derived from the atmosphere, and the other being made with a metal tank with an allowance according to his own method.

(ADDED SINCE THE MEETING.)

Mr. Barrus.—Prof. Lanza has called my attention to a reason for the varying results which often occur in a series of calorimetric tests, although they all appear to be made in precisely the same manner. He suggests that the variations may be caused by changes in the temperature of the steam pipe due to changes of pressure. If the pressure is rising when the test is made, the pipe absorbs heat from the steam and causes an increase in the amount of moisture. If, on the other hand, the pressure is falling, heat that has been stored in the metal goes back to the steam and causes a decrease in the amount of moisture. Experimental evidence, which I will refer to, leads me to believe that this effect may become a powerful one. I was once engaged in testing the quality of steam taken from the exhaust pipe of a 15 horse-power non-condensing engine working with saturated steam. A series of tests was made to determine the effect of various back pressures. A high back pressure was carried for the first test and subsequently lower pressures were tried. In one instance the test with a lower pressure was made directly after the new conditions for that test had been established. The result came out very differently from the preceding one. There was a large decrease in the amount of moisture shown. A little reflection made it plain that the metal of the cylinder and exhaust pipe, which had been overheated by the high pressure of the previous trial, had not had time to assume their normal temperature before the second experiment was made. Hence the variation in the results of the calorimetric tests.

Mr. Babcock.—The admirable Report of the committee is to be commended. It is so complete, and discusses the several points so fully that there is little more can be said upon the subject. The question of the best method of determining the condition of the steam, as to dryness, is one of considerable importance. The appendices to the Report point out some of the difficulties in the way of such a determination, and suggest several points to be observed in order to secure accuracy. None too great stress is laid upon them. With the best apparatus, and the greatest care, it is doubtful if even approximately accurate results can be obtained. I have plotted a number of series of such tests, and have never yet found one in which there were not very erratic results. In several instances the average led to impossible conclusions, as, for instance, superheated steam with no superheating surface. Mr. Emery has pointed out the possibility of this being due to the imparting of heat from the steam, in consequence of a reduction of pressure in the pipe through which the quantity tested was taken. Though, theoretically, this is possible, the quantity of heat which might be imparted is quite insignificant, and could not materially affect the result.

To show this, let us take the construction used at the Centennial test, where Mr. Emery first pointed out this possible action. The calorimeter was supplied through a $\frac{3}{4}$ inch pipe inserted horizontally across the main pipe, and provided with perforations of greater area than the pipe, directed toward the current of steam. Outside the main pipe an inserted nipple reduced the bore to $\frac{1}{2}$ inch, to regulate the velocity of flow, and at the end of the $\frac{3}{4}$ inch pipe was a common $\frac{1}{2}$ inch globe valve, connecting with a 1 inch rubber hose which was inserted in the water. The pipe was well felted. We thus have two half-inch openings with a chamber between. As demonstrated by Prof. Blake, the pressure in the intermediate chamber under such circumstances is $\frac{4}{5}$ the initial pressure, which in this case was 85 pounds absolute; and by Rankine's ready formula ($\frac{p}{70}$ = the flow of steam in pounds per second per unit of area into a pressure less than one half of p), we find $\frac{85}{70} \times \frac{4}{5} \times 60 = 58.3$ lbs. per minute outflow for 1 inch area. The area of opening in the $\frac{1}{2}$ inch valve is 0.3 inch, and the coefficient of such an opening is 0.8; hence $58.3 \times 0.3 \times 0.8 = 13.99$, say 14 lbs. actual discharge per minute. What would be the reduction in pressure, due to such a flow, within the portion of the pipe inclosed in the steam? We have no record of the openings into the pipe, but as they are stated to have been in excess of the area of the pipe, it is fair to treat it as if the end of the pipe was open. The head required to overcome the resistance of the opening, and produce the velocity is $h = 1.505 \frac{v^2}{2g}$, and is measured by $h = \frac{144\delta}{D}$; δ being the difference in pressure per square inch, and D the density, or weight per cubic foot, of the steam. But $v = \frac{W}{Da}$, W being weight delivered per second, and a = area of opening in square feet. Substituting and reducing, we get

$$\delta = .000162 \frac{W^2}{Da^2},$$

or, when W is weight per minute, and a is expressed in square inches,

$$\delta = .000933 \frac{W^2}{Da^2}.$$

The true area of a "$\frac{3}{4}$" inch pipe is 0.553 sq. inches, and the weight per cubic foot of steam at 85 lbs. is 0.198. W, we have seen, is 14. Substituting we find δ = 3.25 lbs. loss of pressure, equal to a difference of temperature of 3° between the steam in main pipe and that in the calorimeter pipe.

If this latter were filled with water, it would transmit thereto 330 heat units per hour per square foot, internal surface per degree difference of temperature. It is not probable that it would do the same to steam, but we will assume that it may. If the pipe projects into the steam 6 inches, its internal surface would be $\frac{2.6 \times 6}{144}$ =.108 sq. ft. and $\frac{.108 \times 330 \times 3}{60}$ = 1.782 heat units, transmitted to the steam per minute. But the 14 lbs. steam discharged per minute represent 14 × 1178 = 16492 heat units, and $\frac{1.782}{16492}$ = .000108, or $\frac{1}{100}$ of 1 per cent. possible superheating.

In this calculation I have made no account of the effect of friction in the pipe, which would modify it somewhat, but only to reduce the quantity delivered, and therefore the proportional superheating; for the quantity varies directly as the velocity, while the head, and consequent difference of temperature, varies as the square of the velocity.

But this almost infinitesimal amount of superheating would be more than lost before the steam reaches the barrel of the calorimeter, by radiation from the pipe, be it ever so carefully felted. A $\frac{3}{4}$ inch pipe, covered with 1 inch wool felt, and canvased, will lose 24 heat units per hour, per foot run. If we assume that this pipe was 10 feet long, which is probably a fair average, the loss would be $\frac{24 \times 10}{60} = 4$ heat units per minute, or $\frac{4}{1.782} = 2.24$ times as much as the possible superheating. It will be necessary, therefore, to look somewhere else for the cause of a calorimeter test showing superheating, where such a result is impossible.