CXLVII.

RULES FOR CONDUCTING BOILER TESTS.

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My object in bringing this paper before the members of the American Society of Mechanical Engineers, is not to add to their store of knowledge of a subject on which most of them are already well informed, but to open a discussion which may eventually lead to the adoption of a set of rules for conducting boiler tests which may be generally accepted among engineers as a standard code of practice.

The necessity for such standard rules is becoming apparent, as greater attention is being paid to economy of fuel, and as there is greater competition among builders of steam boilers and engines to supply the demand for such economy. Hitherto there have been no such rules, and every engineer who makes a boiler test makes a rule for himself, which may be varied from time to time to suit the convenience or interests of the party for whom the test is made.

As a result of the confusion of methods of making tests there is a great lack of concordance of results in tests of the same boilers when made by different engineers. Reports of tests are frequently made, and sometimes published, in which the evaporation of water per pound of fuel is greater than is theoretically possible in a perfect boiler. Communications often appear in the engineering and industrial weekly press which show that there exists a serious doubt in many minds of the accuracy of boiler tests which are made, even by eminent engineers.

The advisability of the adoption of a standard method of boiler testing has been felt abroad as well as in this country. Two societies in Germany, the Union of German Engineers and the Central Union of Associations for the Care of Steam Boilers, recently appointed a joint committee, which drew up a code for the testing of steam boilers and engines, an abstract of which is published in the "American Engineer," of August 24th and 31st, 1883. The German Code is scarcely such an one as is likely to find favor in this country, but it is desirable that some code be adopted here which would find general acceptance. The rules appended hereto are offered as a proposition for such a code, and the

intelligent criticism of our members is requested, to the end that the rules may be amended and put into such form that they will be likely to be adopted in practice.

It is especially desirable that some standard method of starting and stopping the test should be adopted. I believe that the method preferred by the writer, and therefore included in the proposed set of rules, will be more generally criticised than any other of the rules, and, therefore, the reasons will here be given for the preference, mentioning some of the arguments for and against both this and the alternate methods.

METHOD OF STARTING AND STOPPING TESTS.

The conditions of the boiler and furnace should be in all respects the same at the end as at the beginning of a test. The steam pressure and the water level should be 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.

It is difficult to secure uniformity in all of these conditions. Several methods to secure a near approximation to uniformity may be practised, of which four methods will here be considered.

1st. Start the test when the boiler is in full working order with fires level on the grates and in ordinary working condition, and stop the test when fires are at the same height and in same condition as at the beginning.

The most serious objection to this method is that it introduces an element of guess-work at the beginning and at the end of the test, both as to depth of fuel on the grate and its condition. It is difficult to estimate within an inch or two the depth of fuel on the grate with a dull fire and hard coal, but still more difficult when soft or flaming coal is used, and even if possible to estimate closely the quantity of fuel, it is not possible to judge correctly of its condition as to the amount of ash it contains or as to the amount of available heating power remaining in it. For this reason I think this method of starting and stopping a test should be rejected.

2d. When the fires have burned rather low, as for cleaning, remove rapidly all the fire from the grate, and clean the ash pit, and as quickly as possible start a fresh fire with weighed wood and coal noting the time of starting the test at the instant the fire is lighted. At the end, burn the fires low as at the beginning, and remove the whole fire, cleaning the grates, and noting the end of the test at the time when the grates are cleaned, taking note of the water level and

steam pressure, which should be, as nearly as possible, the same as at the beginning.

In this method an error is introduced both at the beginning and at the end. While there is no error in the estimation of the quantity of fuel used, a serious portion is wasted both at the beginning and at the end of the test by radiation, and by the passing of cold currents of air through the boiler. During the operation of drawing the fire, the walls of the furnace become cooled, and during the first half hour at least of the test, while the fire is being lighted, the fires are not burning as under ordinary working conditions, and probably not with usual economy of the fuel. At the end of the test, before opening the doors to clean, the walls of the furnace are very much hotter than they were in the beginning of the test, and a large portion of the excess of heat is lost, not being absorbed by the boiler before the ending of the test, but radiated during the cleaning, absorbed by the cold air which rushes in at the time of cleaning, or remaining in the walls after the end of the test. The heat remaining in the hot fuel withdrawn is also lost. The errors in this method are all against the boiler.

3d. The fires are burned low, as in the second method, but the time of starting the test is taken to be the instant just before opening the doors to clean grates. The water level and steam pressure are noted, and all the water fed from this time to the end of the test is credited to the boiler. The fires are then rapidly cleaned and a fresh fire started with weighed wood and coal, which is charged to the boiler. At the end of the test the fires are burned low as at the beginning, and the end of the test is taken to be the time at which the doors are opened to remove the coal from the grates, the water level and the steam pressure being noted at the same time.

In this method the error is that due to the cooling of the walls of the furnace by radiation and by cold currents of air during the cleaning of the grates at the beginning of the test, and also that due to imperfect combustion during the time of lighting the fresh fire; the error being always against the boiler.

In both the second and third methods the fire removed from the grates contains a large portion of unburned coal. This is sometimes picked out and its weight deducted from that of the coal fired, but such picking can never be accurately done, and the result always shows a higher than the true percentage of ash. If the boiler test is made for the purpose of determining the quality of

the coal, as well as the efficiency of the boiler with such coal, the second and third methods are thus unfavorable to the coal, since there is more unburned coal removed from the grates than there would be in ordinary working conditions.

In a test in which the capacity of the boiler is an essential feature to be determined, the second and third methods also give unfavorable results, since of the total time of the test, for at least half an hour,—while the fresh fire is being lighted, and again when the fires are being burned down at the close,—the boiler will not give its usual capacity.

4th. At the regular time for slicing and cleaning fires have them burnt 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, and 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.

The principal error in this method is that of estimation of the quantity and condition of the fire upon the grates. The condition of the fire is made as nearly uniform as possible by burning down and cleaning, and the error in estimation of quantity is lessened by the fact that the quantity on the grate after cleaning is less than at any other time.

On account of the various errors and inconveniences necessarily attending the first, second and third methods of making a test, the writer is inclined to favor the fourth method. Recognizing the existence of an error of uncertain quantity in the estimation of the quantity and condition of the fire upon the grate at the beginning and end of the test, it will always be less than the unavoidable error against the boiler due to the cleaning of the grates and lighting of fresh fires, as in the second and third methods, and less than the error in estimating the thickness and condition of fires as in the first method.

Where extreme accuracy is desirable, as in a competitive test between rival boiler-makers, the fourth method will be still preferred, but then a test should be made not less than twenty-four hours long, the working to be continuous during the whole time. The longer the test the less the percentage of error.

With these preliminary observations, the proposed code of rules will now be given, which are respectfully submitted to the Society for discussion.

RULES.

PRELIMINARIES TO A TEST.

I. *Establish the good condition of the boiler.*—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.

II. *See that the blow-off valve is perfectly tight*, and that there are no leaks of water from the boiler. During the test the blow-off pipe should remain exposed, and any water which escapes from it should be measured, or preferably it should be closed by a cap.

III. *See that there is no other feed pipe connected* with the boiler than the one which delivers the measured water, also that all connections with other boilers, either in water or steam spaces, are stopped with blind flanges instead of valves. 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.

All connections to or from the boiler should be broken except those in use during the test. Thus if both pump and injector are attached to the boiler, the one or the other should be disconnected.

IV. *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.

V. *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 Allegheny Mountains, anthracite egg coal, or Cumberland semi-bituminous coal should be taken as the standard for making tests. West of the Allegheny mountains and east of the Missouri River, Pittsburgh lump coal should be used.*

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

VII. *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.

(3) Thermometers and pyrometers for taking temperatures of air, steam, feed water, waste gases, etc.

(4) Pressure gauges, draught gauges, etc.

VIII. *Measure and record the dimensions*, position, etc., of grate and heating surfaces, flues, chimneys, etc.

IX. *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.

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:

* 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.

At the regular time for slicing and cleaning fires have them burnt 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; and 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.

1. *Keep the conditions uniform.*—The boiler should be run continuously, without stopping for meal times or for rise of pressure of steam due to increased demand for steam. The draught being adjusted by means of the damper to the rate of coal combustion desired before the test is begun, it should not be changed during the test.

If the boiler is not connected to the same steam-pipe with other boilers, an extra outlet for steam should be provided, in case the pressure should rise to that at which the safety valve is set; and in case of such rise of pressure it should 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 draft, 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.

2. *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. 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 temperature of feed and pressure of steam 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 degrees of uniformity of combustion, evaporation, and economy, at different stages of the test.

When the pressure of steam and temperature of feed are nearly constant, half-hourly observations of each will be sufficient; but when there is considerable variation, observations should be made more frequently, and the figures recorded should be the averages for each interval of time rather than the figures which are observed at the end of the interval.

3. *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 degreee of superheating. At least ten such tests should be made during the trial of the boiler, 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, the scales on which the condensed steam is weighed to within one-hundredth of a pound.

REPORTING THE TEST.

The final results should be recorded upon a properly prepared blank, and should contain the following items:

1. Heating surface	.....	sq. ft.
2. Grate surface (ft. in. long x ft. in. wide)	.....	sq. ft.
3. Ratio of heating to grate surface	.....	
4. Kind of fuel used	.....	
5. Duration of test	.....	
6. Average steam pressure	.....	lbs.
7. Average temperature of feed	.....	deg.
8. Pounds of coal burned	.....	lbs.
9. Pounds of refuse	.....	lbs.
10. Pounds of combustible	.....	lbs.
11. Per cent. of refuse	.....	per cent.
12. Coal burned per sq. ft. grate per hour	.....	lbs.
13. Total water evaporated	.....	lbs.
14. Water evaporated per hour	.....	lbs.
15. Water evaporated per sq. ft. heating surface per hour	.....	lbs.
16. Water evaporated per lb. coal—actual conditions	.....	lbs.
17. Water evaporated per lb. combustible—actual conditions	.....	lbs.
18. Water evaporated per lb. coal—from and at 212°	.....	lbs.
19. Water evaporated per lb. combustible from and at 212°	.....	lbs.
20. Quality of steam. (Moisture or superheating)	.....	
21. Rated horse-power. (Builder's rating)	.....	H. P.
*22. Horse-power developed at 30 lbs. of water evaporated per hour from and at 212°	.....	H. P.
23. Per cent. above (or below) rated capacity	.....	per cent.
24. Temperature of boiler room	.....	deg.
25. Temperature of flue gases	.....	deg.
26. Force of draught in inches of water	.....	inches.

DISCUSSION.

Mr. Le Van.—Mr. President, Mr. Kent prefers 212 degrees. The objection to that is that we have a great many condensing engines now, and the condensing water does not exceed 120 degrees, and very few feed-water heaters average over 180 degrees. I think 100 degrees would be a better standard, and the reduction could be made just as easily, of course.

* The customary method of rating horse-power is 30 lbs. of water per horse-power per hour from a feed-water temperature of 212° into steam at 70 lbs. pressure above the atmosphere, which is equal to 30.985 lbs. from feed at 212° into steam of the same temperature. The writer prefers the calculations both of economy and horse-power to be made on the basis of evaporation from and at 212°, for the sake both of uniformity and of convenience in calculation.

Mr. Kent also says that he prefers averaging the fires at the commencement and end of the test. That is mere guess-work. If you want accuracy, you never guess at it. So I think we shall have to adopt some method of arriving at the amount of fuel on the grates other than that suggested.

I would say further that the pressure stated by him, 70 pounds per square inch, is not considered sufficient at the present day, with the introduction of electric lights, and small high speed engines. Higher pressure must be carried to produce the power. You will find the majority of boilers now are carrying 100 pounds, and, in fact, we would like to have 150 pounds pressure per square inch. Consequently we shall have to increase the pressure in any standard we may adopt.

Mr. N. W. Pratt.—(Presented in writing, and read by the secretary.) In regard to the method of starting and stopping boiler tests as proposed by Mr. Kent, a different plan would eliminate two of the possibilities for error as far as the fuel is concerned and the amount that is actually appropriated for the use of the boiler. I would make the following suggestions:

Given a boiler to be tested at, say, 75 pounds pressure. Arrange the safety valve to carry pressure up to 100 pounds. Start the fires, and get everything in good working condition, with the safety valve loaded to 100 pounds, and raise steam to that pressure. Clean the fire thoroughly, spread it evenly over the grates, estimate its thickness, remove the 25 pounds extra weight on the safety valve, allowing the steam to blow off, and call "Time" when 75 pounds is reached.

Just before the time for stopping the test, reload the safety valve to 100 pounds, raise steam to this pressure, clean the fires thoroughly, spread the coal, estimate its thickness, remove the 25 pounds extra weight on safety valve, and call "Time" when steam reaches 75 pounds pressure again. Meanwhile haul the fire and quench the coal.

By this method the error due to the amount of air which passes into the furnace both at the starting and stopping of the test is eliminated, and the amount of coal on the grate in practically the same condition, as far as combustion is concerned, has been guessed at, at the beginning and end of the test. By weighing the quenched coal which is hauled from the grate at the end of the test after the fire has been cleaned, spread and estimated, a check will be made on the two guesses, and a definite weight of coal can be assumed

to have been on the grate in the same condition at the starting and stopping of the test. If the estimate on starting the test was that the cleaned fire was six inches thick, and the estimate at the end of the test was that the cleaned fire was four inches thick, by weighing the amount of quenched coal we have the amount of coal in the four inch fire, and by adding 50 per cent. will have the amount of coal in a six inch fire. It strikes the writer that this would, as far as possible, eliminate the question of admission of air into the furnace, while cleaning fires and the differences in temperature of furnaces and walls which occur if fresh fires are lit.

Mr. Charles E. Emery.—The rules proposed by the writer of the paper are, in my opinion, quite good in a general sense. They lack in detail, which the writer says was intentional, with a view of bringing out discussion. The lack of detail very often goes to the root of the matter. In looking over the portion of the paper which was not read, I find what I consider an error in the directions specified for the not uncommon method of raising steam to the required pressure before making test, then hauling fires and starting with a clean fire, and at the end again hauling fires. This is the second method mentioned in the paper, and the directions are, after hauling fires, etc., to "as quickly as possible start a fresh fire with weighed wood and coal, noting the time of starting the test at the instant the fire is lighted," and again provides for "noting the end of the test at the time the grates are cleaned." The time stated for starting and stopping the experiment are in my opinion wrong. The experiment should start when the boiler commences generating steam at a fixed pressure, and should be considered as ended when it ceases to generate steam at that pressure. To accomplish this I always arrange in starting and stopping a test of this kind that the boiler to be tested be disconnected entirely from other boilers, and the steam conducted away through an open pipe, regulated preferably by a safety valve. The operation then is, first to raise steam to the desired pressure, so that the safety valve previously adjusted, will blow freely; then the fires are to be hauled, new fires started, etc., and in the interim the water level is noted after the safety valve stops blowing, and the time of commencing test noted when the safety valve again blows on account of starting new fire. The ending of the test with position of water in gauge is to be noted when the safety valve closes after fires are hauled. The tank measurements would be those taken between these two intervals, and evidently all the water

that leaves the boiler in that time is evaporated by the fuel used during the test. The actual time the fuel is burning may vary a little from the above interval; but this, it seems to me, is the only way to obtain the absolute quantities both of fuel and water.

The method of making a "flying" start and stop is much simpler, and, after some experience, gives satisfactory results. The third method in the Rules—really a modification of the first—is much the safer of the two, as it proposes to estimate the fuel on the grates immediately after cleaning fires, when the quantity present—and therefore the possible error—is small.

By either method it is very essential that the feed be steady for some time previous and immediately up to the time of starting and stopping the experiment. It is very easy to run the pump rapidly for a short time before making the record, and thereby introduce considerable more water than for regular conditions, from the fact that the water will become heated in a short time and expand, changing materially the level in the glass. The difficulty of preventing this, at least to some degree, makes it at times desirable to produce uniformity at the beginning and end by stopping the feed entirely a number of minutes before starting and stopping, and noting the time in both cases when the water is evaporated down to a certain mark. To do this requires, however, that the experiment stop, not at the actual moment when fires are lowest after cleaning, but at a certain time after the fire has burned through. There are errors in either method of starting and stopping the test, but they become unimportant when a long test is made.

The difficulties incident to making accurate measurements apply to testing boilers as well as to other matters. Too often boiler tests are undertaken with a poor equipment and too little assistance. Often a person will attempt to make a boiler trial alone. It is possible for one to dodge around to the water tank, watch the firing, see that the coal is weighed, and between times get a few temperatures; but at the end of a reasonably long run he will be so tired that he will not know whether the work was thoroughly done or not. Much the better plan is to have an assistant at each point of observation, particularly one to weigh the coal and another one to measure the water. If calorimetric tests are undertaken, still another should be provided. The principal is then left free to oversee the work of all.

It is not uncommon to be obliged to make boiler tests where parties are present antagonistic to a fair test. Some of us have had ex-

perience with steam gauges set fast, water escaping through unexpected openings, fuel brought in surreptitiously, and the like. While much difficulty can be avoided by blanking off all unused pipe connections, still methods are found to cause inaccuracies, and as it is not pleasant to accuse others of dishonesty, it is always better to have enough help to prevent the possibility of so-called accidents or mistakes. It is also necessary to have assistants with sufficient calibre that they cannot be persuaded by interested parties that they have tallied a barrow of coal or that they have not tallied the last barrel of water, or the like. This brings up another feature, the method in which tallies should be kept. It may seem very simple, in a dignified body like this, to speak of the matter; but it is surprising how few can keep an accurate tally. One can put down 1, 2, 3, 4, and a cross-mark, but when there are waits of ten or fifteen minutes between marks, confusion often arises as to whether the last tally has already been made. The only way to prevent this is to take a special line on the record paper for each tally, and note opposite it the time of a particular portion of the operation; for instance, when a wheelbarrow load leaves the scale, or when the load is dumped on the floor, or when a particular valve is opened to let the water down to the pump, or something of that kind. Then, by weighing coal and feeding with even approximate regularity, it will be impossible to make a mistake of a whole measure of coal or of a whole tank of water. Simple checks of this kind are far more important than reading all the thermometers to tenths of a degree.

Again, as to the apparatus for measuring the water. Measurements can be made with one tank by filling to one mark and pumping down to another, but it is not the proper way to stop feeding while tank is filling. The feed should be regular, so that two tanks may be called a necessity, and three are better—two measuring tanks, used alternately, and a third tank from which the feed is taken. The latter should have parallel sides, so that differences in height can be checked off at regular intervals.

In regard to the quality of the steam, I think that the feature which was first brought out in my own report on Centennial tests in regard to the steam pipes from boiler to calorimeter, should be well considered. I will not enlarge the discussion by expressing an opinion as to the kind of calorimeter that should be used. The subject is large enough for a special paper; but any good calorimeter will often show superheating for a boiler having no superheating

surface, unless the connection to boiler be very large and reduced by a series of steps to the calorimeter, substantially as pointed out in the report previously referred to.* The reason is that if we withdraw steam rapidly through a small pipe tapped into a large one, the pressure and temperature of the steam in the small one will be reduced so that the entering steam will receive heat from the surrounding metal, the temperature of which will be kept up by the current of steam passing through the larger pipe. The consequence is that the steam in the small pipe shows more than its proper share of heat. By making the outlet leading to the calorimeter quite large, so that the steam flows into it without appreciable velocity, and then reducing at a distance from the main steam pipe, the small pipe can carry off no heat from a passing current. Even with this precaution, on ordinary barrel calorimeters a trifle of superheating will be shown at times with boilers having no superheating surface, but at other times a slight percentage of moisture will be found; so the average will show dry or nearly dry steam. The variations are due to small errors in observation, which, not being cumulative, offset each other in making the average.

Mr. Le Van.—Mr. President, I would like to say in regard to Mr. Pratt's observation about increasing the boiler pressure to 100 pounds, where the certificate calls for 75 pounds, that pressure cannot be carried, from the fact that most of our cities have rules for the inspection of boilers which would prevent it. If a boiler is tested to carry 75 pounds, the safety valve can only be set at 80, so that increasing the boiler pressure to more than five pounds would not be allowed.

In regard to checking the errors in coal, I would state that in a test we generally lay down coal enough for an hour's run—weigh it out. Each firing is weighed, and at the end of the hour we weigh the coal left over. All water is always weighed at the commencement of the test, at each charge of water to the boiler the difference is noted, and then what is left is weighed at the end. But I think you must find some other plan than guessing at the condition of the coal on the grate at the end of the trial. If anybody burns anthracite coal, and can tell about the condition of that coal by looking in the furnace, then I confess I do not know anything about it. Some anthracite coal will apparently be four inches thick when it is all ashes. Bituminous coal I have had no experience in

* Report of Group XX. Judges of the Centennial Exhibition, page 82.

to any extent, but I am satisfied that no proper test can be made where you have got to guess at any part of it.

Mr. Woodbury.—Mr. President, the question of the amount of coal at the beginning and the end of a test is a matter of assumption or of guess-work whose accuracy is dependent on a personal equation of those who have the matter in charge, and the graphical method can sometimes be used in that matter. A few years ago, I was connected with a duty test of a city pumping works in New England where I used the graphical method in this manner. Taking several sheets of diagram paper, I laid off horizontally the

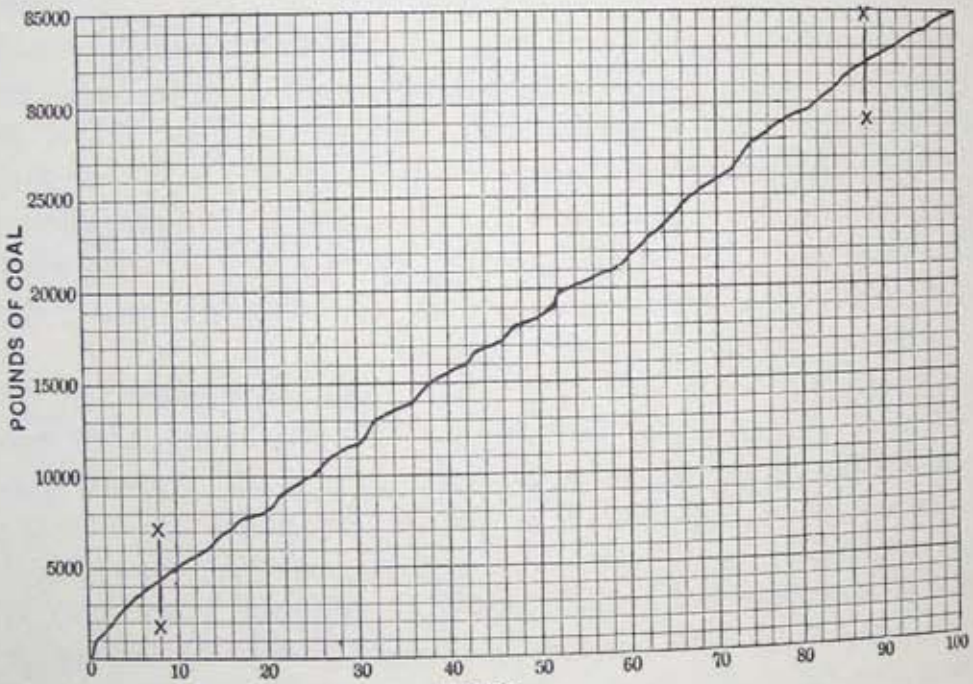

FIG. 66.

time, something over a hundred hours to the test—and the vertical ordinates represent the aggregate amount of coal fed down in front of the boilers; the whole diagram being about ten feet long. As each delivery of coal was made, the time was taken, as well as the weight of the coal, and that was platted on this diagram paper, and the subsequent one with its time added to it also platted. And so, as the assistant kept up the aggregate amount of coal, we knew at all times how much coal had been delivered to the boiler room, and the whole result was something like this (illustrating by means of blackboard drawing, Fig. 66). The man in charge of those boilers was not handicapped by the ten commandments in his desire to make as good a show as possible. When the test began the consumption of coal was rather more rapid. For a while it was

essentially the same, until a few hours previous to the time at which he supposed the test was to be brought to an end, and then he caused his men gradually to reduce the amount of coal in their barrows, and it fell off as shown at the right hand of the line. The time included between the lines ×, ×, was that taken for the duty trial.

This method would not apply to a test where the consumption of steam might be variable.

Mr. Nagle.—Mr. Woodbury's practice is also my own. If his rough sketch had been nearer to scale it would have shown the curve much steeper at the beginning and less steep at the end. There is no way in which the data of a boiler test can be so intelligently and satisfactorily studied that correct conclusions may be arrived at, as by the graphical method.

After the usual precautions have been taken and preparations made, let the steam pressure be at its ordinary working pressure, the water line at its usual point, clean out the furnace and ash-pan and make a new fire, noting the weight of fuel and *time*, which is the beginning of the test.

Prepare equal weight of fuel, say in 100 pound lots, and fire in the usual manner to keep up steam at its working pressure, but always noting the time the 100 pounds are thrown into the furnace.

As the water consumption is so much greater than the coal, it is not practicable to feed in like manner, but instead note the amount fed at regular intervals of time, say every 15 minutes. The water line can be, and should be, kept at the same point during the entire test. The steam pressure should be recorded every 15 minutes and maintained uniform throughout the test as near as may be, but it *must* be the same during the latter part of the test at all hazards.

When it is desirable to bring the test to a close, and no more fuel is fed, continue to burn all possible fire there can be got out of the fuel, until nothing but ash and clinker remain; keep up the water line to its normal point, but the steam pressure will necessarily fall. We have now data from which we can ascertain the truth of things.

The weight of all the fuel used and the weight of all ash and clinker, gives us the total net combustibles, or efficiency of the fuel.

Now make a diagram of the fuel, water, and steam pressure, to a scale that will permit the lines to run near each other, and it will be found that at the beginning of the test the coal line is far above

the water line, then for the greater part of the test it is parallel with it, and at the end it is more or less below it. *Theoretically*, the area of the coal line above the water line should be nearly equal to (a little greater than) the area below it at the end, but according to the bias or skill of the arranger, these areas will vary very much, and it is with a view of exposing the facts to sight that the graphical method protects us against erroneous conclusions.

We shall find that from one-half to three-quarters of an hour after the test began that the coal, water, and steam lines will run together, and this is the *true* beginning. During the continuance these lines may fluctuate, but near the end the steam line should be kept up with conscientious care, and when it can no longer be kept up and the water and coal lines are yet together, the *end* of the test proper has arrived, and the coal and water between these two points furnish the true basis for calculating the ratio of coal to water.

Mr. Woodbury.—Mr. Nagle calls my attention to what was an omission of statement. We did plat the amount of water fed into the boilers, and platted it on the same paper, at a scale of one-tenth that of the coal. So the evaporation being, of course, nearer ten pounds than any other even decimal, the lines were at a tolerably uniform angle with each other.

Mr. Porter.—Mr. President, there seems to be an erroneous assumption. The graphical line represents the coal that is added to the fire, and the assumption is that it represents the coal that is burned, and all that we want to know is the latter. Probably the graphical line representing the evaporation, if it were parallel with the graphical line representing the coal added to the fire, would demonstrate that the combustion kept pace exactly with the addition. A man in adding coal to a fire all day may increase or diminish the quantity of coal upon his fire. The graphical line would in be one case more steep, in the other would approach the horizontal. But the graphical line representing the evaporation of water will represent also the combustion of coal; and if that should be parallel with the line representing the addition of the coal, then it would show not only the addition but the combustion. But it seems to me that really the only experiments which will command approval, which will carry on their face the evidence that they are correct, are experiments in which the trial is commenced on a clean grate, and ended with a clean grate, what is left in the grate being carefully weighed. The fires are very deceptive. I do not think Mr. Le

Van has overstated the case of the appearance of fires. It is not possible for the difficulty to be overstated.

I was told once by an engineer that if a test was limited to five hours, he would undertake on that basis to run without any coal at all, and to satisfy any intelligent man using the furnace that he had as much coal at the end of the test as he had at the beginning—no doubt of it.

Professor Webb.—Mr. Chairman, I think if a very accurate test was to be made, I should endeavor to have the grate made independent of the boiler, and so arranged with scales that the whole—grate, coal, and ashes—could be weighed at any time without interfering with the progress of the combustion. In this way it would be known how fast it was burning away. I should want to connect the lower end of the water gauge with the bottom of the boiler, so as to allow for the unknown density of the water and steam mixture, and thus obtain an indication of the actual amount of water in the boiler.

Mr. Le Van.—Mr. President, I think the only remedy is to put a track under the boiler and run your grates in on wheels, and when the trial is finished run out the grates. There will be no guess-work in that. Probably that would not be a bad idea if properly arranged.

Mr. Porter.—I remember a case in which the matter of time was very important, where an observer who was under my direction noted the time at which the water tank was filled, and an observer who was placed by other parties to check our examination merely put down a mark every time the tank was filled. We had one more tankful than he had, but the fact that the hour and minute of filling the tank had been noted against each one of our entries, and that those intervals of time were uniform all day long, was conclusive, and he finally concluded that the tank must have been filled once while he was gone to dinner [laughter].

Mr. Leavitt.—Mr. President, Mr. Woodbury has made an allusion to the Ten Commandments. The same Board that made the test to which he has referred afterwards made a test in which I was interested. They probably had profited by experience, and one of my assistants who represented my side of the case told me that he could not get up out of his chair to go for any purpose out of the fire-room without having two or three assistants of the Commission after him to see whether he had any coal in his pocket [laughter].

Now, I think it is necessary on occasions like this to have it set down as a fact that the party who is interested in the boiler should be assumed to be a person who will both steal coal and open the blow-off valve, and that whenever any of the Commissioners are absent the safety-valve may possibly be raised [laughter].

The only way to get at an accurate test is, as Mr. Porter has said, to start with a clean grate, to end with a clean grate, and to weigh the refuse. There are certain errors which obtain from the fact that the boiler is cooled in removing the original fire, and is also cooled at the end; but if the trial is of sufficient duration these amount to very little. In one case that came under my observation, in a test of seventeen hours' duration, the evaporation from and at 212° was 12.32 pounds per pound of combustible, while the duty of the engine, which was tested at the same time (being a pumping engine), was one hundred and eleven and one-half millions per hundred pounds of coal. One confirmed the other.

The matter of estimating the fires, as I know from personal observation, is very uncertain. I was caught on this same platted line at the time referred to. It should never be known long beforehand when the trial is to close. I had a suspicion that the trial was to close at a certain time. My assistant, who was a pretty sharp fellow, had instructed the fireman to fire light. I came into the fire-room with two of the Commissioners who estimated the condition of the fires. The doors were opened, and the Commissioners said that the fires were as good as they were at the commencement. There was about 150 pounds to 200 pounds of coal on the fire-room floor, and I told the fireman to put that in the furnace to make sure we should be on the right side. I thought I was very generous, because it was going against myself. But the chairman of the Board, when he came to look at his platted line, put three or four hundred pounds more on top of that. Now, if we had made the test with a clean grate when we started and when we left off, there could not have been an error of 400 pounds. That is all out of the question. The cooling of the walls at the beginning and end of the test, which would take place in fifteen or twenty minutes at the most, would not begin to be that. It would not be fifty pounds. For this reason I am in favor of the absolute method.

Mr. Le Van has objected to Mr. Kent's method of reckoning at and from 212°. I think if he will reflect a little he will conclude that is the best, because tests are liable to be made at different pressures and under different conditions. One engine may feed at

180°. Another engine may have a Green Economizer and feed at 300° or 400°, but we want to get at a fixed standard, and if we take 212°, we have a basis from which anybody who is familiar at all with boiler tests can make the computation, and know what he has got.

Mr. Kent.—The first point I was going to reply to was Mr. Le Van's objection to 212 degrees being taken as a standard. I think that has been sufficiently answered by Mr. Leavitt.

As to Mr. Pratt's communication concerning raising the safety-valve to 100 pounds, raising the steam to that pressure, and then lowering it to the working pressure, and starting and stopping the test in that manner, I think Mr. Le Van answered that very satisfactorily—that boiler inspection rules will have a great deal to say against it. The objection I would make to it, in addition, is that, so far as I know, no test has yet been made in that way, and we will have to know a little more about that method of starting and stopping by experience before it would be safe for engineers to establish it as the standard method.

There seems to be a difference of opinion, as already shown here to-night, among engineers, as to how to start and stop a boiler test. Mr. Emery seems to prefer the flying start and stop. Mr. Porter and Mr. Leavitt believe in clean grates. My paper seems to have been misapprehended in the discussion in regard to the method which I prefer, which is not starting with level fires and stopping with level fires, and guessing at the quantity on the grate, for that is mentioned in my first method in the introduction, and I say also in this introduction that I believe that method should be rejected on account of too much guess-work. The method preferred by Mr. Porter and Mr. Leavitt is also objected to, on account of the losses by radiation and imperfect combustion during the beginning of the test, when you are firing with wood, and during the first hour or two of the test, when you have, perhaps, a ton of coal on the grate and do not know how much is being burnt, and how much combustible gas is passing up the chimney. The method which I prefer, and which is perhaps not clearly enough stated in the paper, is: Suppose the boiler is running straight ahead for a week. Periodically the fires are cleaned, say, every eight or ten hours with good anthracite egg coal, every four hours with poorer coal. At each period the fireman pushes back all the good coal on to the back part of the grate, and pulls out all the ashes and clinkers. At that time the coal he leaves in there is

a comparatively small quantity—not over one-half of the total amount in the grate. I have seen times when over a thousand pounds of ashes have been withdrawn from the fire, and the man would leave in, probably, from 600 to 800 pounds of bright coals. That amount when spread can be guessed at pretty nearly. The test is run through one, two, three or four of these periods between cleanings, or as many more as you want—a week, if you say so—and the test is stopped at one of those periodical times for cleaning. When the fire has been burned down to about the usual condition before cleaning, then the man cleans the fire as before, and he pushes back about the same quantity of coal, and you can see when it is pulled forward how much there is. By guessing on a smaller quantity, your error in guessing is less. I prefer in an accurate test to have the test run twenty-four hours, so that whatever error there is in the test will be smaller in proportion. The error in such a test would probably be not more than 100 pounds, which in a test where there is from 10,000 to 20,000 pounds of coal used is but a mere fraction.

I agree with all the speakers who spoke against starting and stopping with level fires, as guessed at ordinarily, because one man will look at a fire and say it is six inches, and another will say it is eight inches, or a foot, and twenty-four hours afterwards when they come to look at it they will not get within forty per cent. of a correct result, as regards the amount of combustible material in it, if it is not the same distance from a periodical cleaning time. Suppose a boiler to have 3,000 pounds of coal on the grate. Say half an hour after starting the fires, I suppose the value of combustible matter in that coal is at least eighty per cent. of the 3,000 pounds. Suppose, several hours after that, when the fire was in the same condition, as far as I could see, it might not contain over forty or fifty per cent. of combustible. So that it would be quite possible, as Mr. Porter said, to run a test without any coal at all.

Mr. Woodbury's graphical method is one which I have tried myself, and it is an exceedingly valuable method wherever the test is a long one. In a test that I made last week in which we started with clean grates, 3,000 pounds of coal were used in less than an hour. The total amount of coal used during twenty-four hours was only 16,000 pounds. In such a test the platted diagram would probably be of little service. In another case, where we started on a flying start with level fires, for a test of seventy-two hours, we had

better results, and got some good information out of the diagram, because during that test we varied the condition of things, in regard to the draught, and in regard to thin fires and thick fires. We would run, say, for fifteen or twenty hours with thin fires, frequent firing and light draught, and again run with thick fires and heavy draught, and we could see on the diagram better than in any other way exactly what the results were as to economy and capacity. And in that test, I may mention, we found that thin fires, frequent firing and light draughts gave the best results, both as to economy and capacity. Exactly the opposite conditions in every respect gave the next best results, and very near to these. And the very worst results were found somewhere between the two. You can get very good results out of a boiler in several different ways. It requires experiment with each boiler to get the best results. I would advise the use of the graphical method in all long tests, and wherever practicable, because the graphical method will generally tell you more about the test than you will learn from mere inspection of the figures.

In regard to the differences of opinion which have been shown here to night, I think if the subject had been discussed more fully, and if it had been written upon by the engineers, without reference to this set of rules, we would find still greater difference of opinion, in regard, first, to general principles, and secondly, and far more largely, as to detail. It all shows that the engineers need to-day some set of rules for testing boilers, and I have not brought in this particular set of rules with the idea that they are perfect and that none others should be adopted, but I want some standard set of rules, so that when engineers make a test they can say it is according to an approved standard. I think it would be in order to move the appointment of a committee of the Society to report on a standard set of boiler testing rules, which could be reported to the Society at the next meeting, whenever that is to be held. I do not suppose the Society will take any action in the matter further than to receive the report of the committee, but I think it would be a valuable thing to have such a report signed by a committee known to be composed of engineers of high standing.