

II.—STEAM BOILER TESTS AS A MEANS OF DETERMINING THE CALORIFIC VALUE OF FUELS.—BY D. W. ROBB.

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It will be recognized by those who use large quantities of fuel, especially of bituminous coals, that they differ very greatly in value, even coals which are taken from adjoining areas give very different results, so that it is sometimes puzzling to the consumer and difficult to decide upon the merits and proportionate values of the various fuels within his reach. It is likewise difficult to determine when the greatest practicable amount of work is being obtained from the fuel, and consumers are frequently subjected to great loss from the want of this knowledge. There are three recognized methods of determining the calorific value of coal, viz: by chemical analysis, by the use of a calorimeter, and by actual measurement of the water evaporated by a definite amount of fuel in a steam generator.

By the first method it is possible to ascertain the constituents of the fuel in their various proportions and to determine the theoretical heat value when combined with a definite proportion of pure oxygen, and approximately to compute the amount of heat which would be converted into work when combined with ordinary air, and consumed under usual conditions. But this becomes a complicated problem, as will be seen when it is considered that the heat absorbed and wasted in heating the non-combustible constituents of both the air and fuel must be taken into account and that these wastes vary with the amount of superfluous air admitted through the grate, and with the proportion of noncombustible matter in the fuel; therefore, any estimate of the practical value of a fuel deduced from chemical analysis can only be approximate.

In testing fuels by a calorimeter a sample of the fuel mixed with chlorate of potassium is placed in an open-mouthed copper vessel, which is submerged open mouth downward, like a diving bell, in a vessel containing a measured quantity of water, com-

bustion of the fuel takes place and the heat produced is absorbed by the water—the total quantity of heat being determined by the rise in temperature of the water. This method has some advantages over an analysis, and, if care is exercised in the selection of samples to be tested—or a large number of samples tested—is perhaps the best means of establishing a theoretical standard calorific value of a fuel; but the quantity tested is necessarily small, and may not fairly represent the fuel. It also leaves out the heat absorbed by the non-combustible portions of the air and fuel, which is an important factor in the combustion of fuel under ordinary conditions.

The method, by which the fuel is consumed under actual conditions and in large quantities; in evaporating water in a steam boiler is generally regarded as a test of the efficiency of the generator, rather than as a test of the value of the fuel; but somewhat extended observations of the performance of various steam generators, using similar grades of coal, has convinced the writer that the steam boiler test, when properly conducted, is quite as valuable as a means of determining the calorific value of fuel, and of comparing various fuels, as for finding the efficiency of the generator—in fact, the latter is the more uncertain of the two, because, unless a boiler is tested with fuel of a known calorific value, it is impossible to arrive at its actual efficiency, or to compare it fairly with any other form of generator.

In testing the heat of fuel in an ordinary steam boiler, two elements of uncertainty are introduced, viz, loss through imperfect combustion of the fuel, and the escape of gases at a higher temperature than the atmosphere; but as these losses, as well as the heat absorbed by the non-combustible portions of the air and fuel, are unavoidable in the present state of science, they should be taken into account in making a practical test of fuel, and strict accurancy only requires that the loss be uniform and minimum in result. Practical experience teaches that almost perfect combustion may be attained in any of the common forms of steam generator by careful and regular stoking, with a properly regulated air supply; and, that this skill is possessed by many ordinary stokers, who have no knowledge of the laws which

govern the combustion of fuels, will doubtless be admitted by many persons who have observed locomotive firemen or others who are compelled to get a high rate of steam production. It is, of course, impossible to transfer all the heat produced in combustion to the water in a generator, because the gases cannot be reduced below the temperature of the water or steam within the generator, and a certain temperature above the atmosphere is necessary to produce draught in the chimney; but it is quite possible to so proportion the grate surface to the heating surface of the boiler that the gases will be reduced to a certain minimum temperature and maintained at that temperature during a test. The temperature may be indicated by a pyrometer or high registering thermometer at the base of the chimney, and the rate of flow of the gases may be ascertained by the use of a draught-gauge. Frequently an attempt is made to analyse the waste gases. This gives an uncertain result on account of the difficulty of getting representative samples of the gases; but, from observation and examination of many tests, the writer believes it unimportant, if the stoking and air regulation receive proper attention. The surface of the grate should be so proportioned to the heating, or heat absorbing, surface of the generator that the gases will, when they reach the uptake, be reduced to, say, 400 Far. Skilful firing and air regulation will produce practically perfect combustion and uniform temperature.

Steam boiler tests, although attended with some difficulty, are quite within the reach of ordinary consumers, and deserve to be better understood and used more than they are. In addition to their value as a method of determining the heating properties of fuel, they furnish the best possible means of ascertaining the condition and efficiency of the generator and of checking, and if necessary correcting, waste on the part of the stoker. It is desirable that such tests should be made frequently, because steam boilers are very liable to deteriorate and become wasteful, especially when set in brick, through the cracking of the brick walls, as well as by the coating of heating surfaces with scale or other deposit on the inner, and soot or ashes on the outer, surfaces. It is quite practicable for steam users to have tests made

by their engineers and ordinary assistants, but it is preferable to have an occasional test made by a professional engineer who has had experience in making such tests, as he will have gained special knowledge which will enable him to detect and locate imperfections in the generator more readily than those unaccustomed to such work.

The writer would suggest to steam users the following practice: that one or more tests be made by an expert to determine the efficiency of the generator, and that he may direct any necessary repairs or corrections in the generator. After this has been done and a standard of efficiency established a good water meter should be inserted in the water supply pipe, so that a record of the water used may be continuously kept and the stoker or engineer should keep a log and make daily reports of the coal consumed and water evaporated. The meter readings will need correction if absolute accuracy is desired, but for practicable purposes this may not be necessary. It may seem like unnecessary labor and expense to weigh all the coal used, but a short trial will undoubtedly prove its value, as it will not only indicate constantly the condition of the generator, but to a certain extent be a check upon the working of the engine and the amount of power used by the establishment, and it will furnish a constant incentive to the engineer, stoker, and those in charge of the steam machinery, to improve its working and reduce the rate of fuel consumption to its lowest limits. A general practice of this kind throughout the country would induce a rivalry in the saving of fuel, parallel to that found in marine practice, where it is claimed a horse power is produced by from one and a half to two pounds of fuel per hour, instead of four to ten pounds, the last named quantity being not uncommon in ordinary steam plant, and would in the course of a few years cause an enormous saving to the country as well as to individual consumers.

Rules governing the standard system of boiler trial, adopted by the American Society of Mechanical Engineers, may be found in the transactions of that Society, Vol. VI, 1884. The following simple instructions will enable any steam user to conduct

a test of his boilers for the purpose of comparing the values of fuels, etc., after the efficiency of the generator has been established by a complete test by an expert, (observations of the quality of steam, strength of chimney draught and analysis of gases are omitted as they require special instruments and skilled manipulation.)

INSTRUCTIONS FOR CONSUMERS TEST.

A test to be of any value should be continued for not less than ten hours, and will require the constant attention of not less than four persons besides the regular attendants, appointed as follows: one or two men to weigh the coal, and one or two to attend to and weigh the water, one clerk to keep the log of the coal and water weighed, and one clerk to record the pressure of steam, temperature of feed water, temperature of chimney gases, and to keep a gross account of the coal and water as a check to the regular log. These should be careful men, well posted as to their duties. Three good platform scales will be required and two tanks, or clean tight casks, to weigh water in. Preparation should be made so that the water can all be delivered into two tanks, which are placed upon two platform scales, and the water pumped alternately from the tanks to the boiler, a piece of hose attached to the suction pipe of the pump or injector will be convenient to transfer from one tank to the other. It will be advisable to procure from reliable instrument makers, one or two accurate thermometers for the purpose of taking the temperature of the feed-water and chimney gases. The temperature of the feed-water should be taken by inserting a brass or copper cup in the feed pipe near its connection with the boiler; this cup may be filled with oil and the thermometer set in the oil. The temperature of the cold water before it enters the injector or feed water heater should also be taken. Great care should be exercised that all scales, steam gauges, etc., are correct, and that there are no leaks about the pumps, pipes or boiler, by which any water may escape without being evaporated; steam leaks are not material except as misrepresenting to consumption of the engine. The

temperature of escaping gases may be taken by inserting a brass or copper pipe with closed end in the smoke connection where it leaves the boiler ; this cup, which should reach the centre of the escaping gases, may be filled with oil and a high registering thermometer placed in it.

Previous to the hour for starting, say at 6.30 o'clock, steam should be up to the working pressure, and the tubes and all surfaces and flues should be swept clean. The ash pit should be cleaned and the first charge of kindling and coal, or the fuel to be used, should be weighed ; every man should be at his post ; those who are to note the various readings provided with ruled forms for recording the gross, tare, and net weights of fuel and water, and others for the pressure of steam temperatures of feed-water and escaping gases, which should be noted every quarter hour. At the hour for starting, the height of water in the boiler should be marked on the gauge glass, so that it may be brought to the same place at the close of the test, and the fire should be drawn quickly and replaced with the weighed kindlings and fuel, (wood kindlings are generally taken at 4-10 the value of coal by weight.) The working of the boiler may be conducted as usual in every way, the stoking should be done carefully, so that no waste may occur through dead spots or holes in the fire, or uneven distribution of fuel. If the fire be too thick, some of the gas will pass off unconsumed for want of sufficient air, and if the fire be too thin, too much air will be admitted. The draught or air supply should be regulated by the ash pit doors or registers, and an even fire and steady pressure of steam maintained throughout the test. If work is to be suspended at mid-day, or any time during the test, the drafts may be closed, the fire banked, and an attendant left in charge who will regulate the fire if necessary, so as to keep the pressure constant. At the close of the test the water should be brought to the same level in the boiler as at the beginning, and the fire withdrawn and deadened quickly with water. The remaining coal should be weighed and deducted from the quantity charged to the boiler, and the ashes may also be weighed. The net weights of coal and water may

then be summed up and the result of the test ascertained and recorded in the following manner :

Test of boiler at	day of	18
Kind of Boiler		
Dimensions		
No. tubes		
Size of fire-box		
Grate surface	sq. ft.	
Heating surface	"	
Height of chimney		
Size	"	
Duration of test	hours.	
Kind of fuel		
Boiler pressure (by gauge)		lbs.
Temperature of feed-water entering boiler		deg. Far.
" " " pump or injector		"
" " escaping gases		"
Total fuel consumed		lbs.
Percentage of moisture in fuel		per cent.
Equivalent dry fuel		lbs.
Total weight of ash		"
Equivalent combustible		"
Total water evaporated		"
Water evaporated per hour		"
" " per pound of dry fuel		lbs.
" " " " " from and at 212°		"
" " " " combustible " " "		"
Horse power developed		

The above particulars are determined in the following manner :
 The pressure of steam and temperatures of feed-water, and gases are taken from the average readings of the same.

The total quantities of fuel, ash and water, are taken from the net summing of log, great care being taken that no error is made. The percentage of moisture in fuel is determined by drying a sample of the fuel for 24 hours and getting the difference between the wet and dry weights, which difference is multiplied by 100 and divided by the weight of sample before drying.

The equivalent dry fuel is found by multiplying the total quantity of fuel by the percentage of moisture and dividing by 100, which is deducted from the total quantity of fuel. The equivalent combustible is found by deducting the total amount of ash from the total quantity of fuel.

The water evaporated per hour is the total quantity of water divided by the number of hours duration of test.

The water evaporated per pound of dry fuel is the total quantity of water divided by the total quantity of dry fuel.

The water evaporated per pound of fuel from and at 212° is found by multiplying the water evaporated per pound of fuel by the total heat, or heat units, of one pound of steam at the average pressure, less the total heat of one pound of feed-water before entering the boiler or injector, if one be used, and dividing the product by 966 which is the total heat, in units, of one pound of steam at 212°.

The horse power is determined by deducting the total heat units of one lb. of feed water at the average temperature before entering boiler or injector, if one be used, from the total heat units of one pound of steam at the average pressure, and multiplying the product by the quantity of water evaporated per hour and dividing by 1110, (which are the heat units required to raise one pound of water from 100° and evaporate it at 70 lbs. pressure), the quotient should be divided by 30, which will give the horse power according to the American standard. The following is an example of this method of finding the horse power.

Total quantity of water evaporated = 2000 lbs.

Steam pressure (by guage), 60 lbs.

Temperature of feed water before entering boiler or injector, 40°.

Total heat of 1 lb. of steam at 60 lbs. pressure = 1175 B. T. U.

“ 1 “ feed water, at 40° = 8 B. T. U.

$1175.7 - 8 \times 2000 \div 1110.3 = 210.33 \div 30 = 70 \text{ H. P.}$

Example of finding the equivalent evaporation from and at 212°.

Water evaporated per lb. of fuel, 10 lbs.

Average pressure by guage, 60 “

“ temperature of feed water, 40°.

Total heat of 1 lb. steam of at 60 lbs. pressure, 1175.710 heat units.

Total heat of 1 lb. of feed water at 40°. 8. heat units.

EXAMPLE :

$$10. \times 1175.710 - 8. \div 966 = 12.08 \text{ lbs.}$$

In comparing fuels, as with the efficiency of the boilers, the quantity of water evaporated per pound of fuel, from and at 212° should always be used. The actual quantity of water evaporated per pound of fuel will differ with variations of temperature of the feed-water entering the boiler, and also with the steam pressure or temperature at which the steam leaves the boiler, but the quantity evaporated per pound of fuel from and at 212° allows for these variations and gives a true comparison of the value of fuel if the efficiency of the generator is constant, or of the efficiency of the generator if the calorific value of the fuel is known. The temperature of saturated or dry steam always corresponds with the pressure, but if from any cause the steam be not dry, it will carry away less heat in proportion to weight, or, if the steam be superheated by contact of the products of combustion with the steam surface of the boiler, it will carry away more heat. In either case the result of the test will be vitiated, unless the quality of the steam be ascertained and accounted for. This is usually done by means of a calorimeter, one of the best of which, known as the "Barrus Calorimeter," was designed by Mr. Geo. H. Barrus, of Boston. No attempt has been made to ascertain or account for the quality of steam in the simple test given because it would complicate the work, and it is intended that a professional test of the boiler should include this important item, and, if the boiler is found abnormal in this respect, the expert should either give directions for the removal of the cause, or provide a formula for the correction of the error due to wet or superheated steam in future tests.

The following table will be found useful in ascertaining the equivalent rates of evaporation horse-power, etc.

