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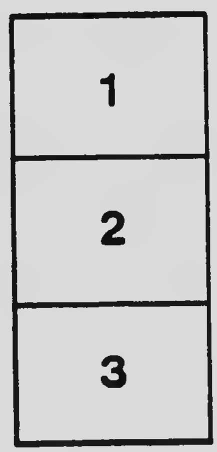

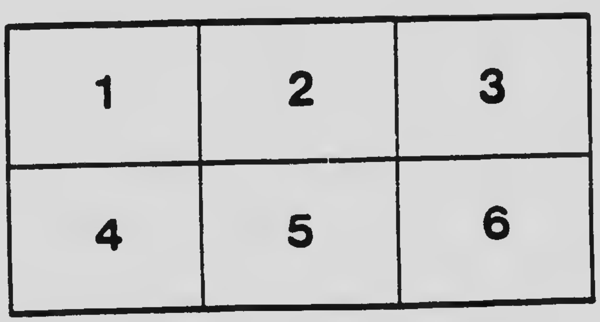

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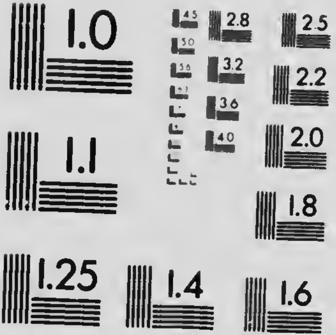

CANADA
DEPARTMENT OF MINES
HON. E. L. PATENAUDE, MINISTER; R. G. McCONNELL, DEPUTY MINISTER.

MINES BRANCH
EUGENE HAANEL, PH.D., DIRECTOR.

BULLETIN No. 17

The Value of Peat Fuel for the Generation of Steam

BY
John Blizard, B.Sc.

OTTAWA
GOVERNMENT PRINTING BUREAU
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LETTER OF TRANSMITTAL.

DR. EUGENE HAANEL,
Director Mines Branch,
Department of Mines,
Ottawa.

Sir,—

I beg to submit, herewith, a report on the results of the boiler trials carried out at the Fuel Testing Station, Ottawa, with peat fuel, in accordance with instructions received from Mr. B. F. Haanel, Chief of Division of Fuels and Fuel Testing.

I have the honour to be, Sir,

Your obedient servant,

(*Signed*) **John Bl[illegible]d.**

Ottawa, February 15, 1917.

PREFACE.

The subject matter of the accompanying report, "The Value of Peat Fuel for the Generation of Steam," forms the third and last of the series comprising the investigation undertaken some years ago to determine the value of peat fuel for the production of power. The former reports, "The Utilization of Peat Fuel for the Production of Power," and "Peat, Lignite, and Coal," dealt mainly with the production of power through the media of gas producers and internal combustion engines, while this report sets forth the results obtained with peat when burned on the grate bars of two distinct types of steam generators.

An examination of the results set forth, and described in detail, will show that under favourable conditions and circumstances, peat fuel can be economically utilized for the production of power through the media of the steam generator and steam engine. But the controlling factor which determines the feasibility of using peat fuel for steam generation is the cost of winning this form of fuel and delivering it to the steam power plant in a sufficiently dry state. That this cost of the peat fuel delivered to the plant must be less than that of a quantity of good steam coal equivalent in heating value, in order to permit of its competition, is apparent to all who have knowledge of, or experience in, the use of low grade fuels. Moreover, when considering the utilization of peat fuel for the generation of steam on a large scale, the important fact that peat fuel, as it is manufactured by the only economic process known to-day, is much bulkier than coal possessing equivalent heating value, must not be lost sight of. Hence, the storage of a sufficient quantity of peat fuel necessary to permit of the continuous operation of a power plant without disastrous interruption, becomes a problem of great importance, and one which must be considered and worked out with the greatest care—if the economy resulting from the use of this low grade fuel is to be realized.

Further, the handling of large quantities of peat fuel involves problems of a more or less serious nature—on account of its bulkiness, and low heating value, which latter necessitates the burning of an appreciably larger quantity than would be the case when burning a steam coal of good quality. On the other hand, the fact that peat fuel burns freely to a fine, easily handled ash—permitting of its almost complete combustion—must not be ignored. The cost of handling the ash in this case can be reduced to a minimum.

The maximum cost per ton which peat fuel can stand, and still compete with coal, is governed by the cost of steam coal at the place where the power plant is located. There is, however, a fixed minimum cost, determined by the cost of its manufacture, below which peat fuel cannot compete with coal. Speaking generally, it is safe to say that peat fuel for steam-raising cannot compete with good steam coal costing $5 or less a ton. But as the price of coal increases, as has been the case in the immediate past, and promises to do so at a more rapid rate in succeeding years—peat fuel for steam generation, wherever large deposits of peat suitable for fuel purposes are available, will become a very serious competitor of coal. Economy and efficiency, however, are the keynote of these modern times, and, in the future, it is hardly likely that any form of fuel will be utilized for steam generation for the production of power unless steam is indispensable to the carrying out of some chemical process, or other industry. So far as the generation of power is concerned, the more economical method to employ is the conversion of the peat fuel into a combustible gas which can, in this form, be burned in a gas engine or used for the different heating furnaces in metallurgical works.

Many of the peats so far examined in this country have a very high nitrogen content, which can be recovered in the form of ammonia, when the peat is burned in a by-product recovery producer. In this manner, many of our peat bogs can become the source of one of the most valuable artificial fertilizers—ammonium sulphate—the demand for which is continually increasing.

As regards the necessity for utilizing the enormous quantities of heat energy lying dormant in the vast peat bogs distributed throughout the Provinces of Ontario and Quebec, much has been written, and need not be reiterated here.

(*Signed*) **B. F. Haanel,**
Chief Engineer,
Division of Fuels and Fuel Testing.

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THE VALUE OF PEAT FUEL FOR THE GENERATION OF STEAM.

THE VALUE OF PEAT FUEL FOR THE GENERATION OF STEAM.

INTRODUCTORY.

The boiler trials described in this bulletin were conducted for the purpose of obtaining information concerning the value of peat as a fuel for the production of steam. The value of a fuel for this purpose cannot be expressed by a single co-efficient, since the fuel may be required for raising steam under very diverse circumstances and conditions, but the most comprehensive measure of its value is the ratio of the weight of steam produced to the weight of fuel burned to produce it.

This ratio depends upon the calorific value of the fuel; the conditions prevailing at the time it is burned; and the construction and design of the apparatus for burning the fuel, and absorbing heat for steam generation.

The calorific value of a fuel represents its total energy, and is usually expressed in British Thermal Units[1] per pound, or calories per kilogram. This energy is liberated by combustion, and its quantity is determined by burning a known weight of the fuel in pure oxygen in a calorimeter, and measuring the heat absorbed in cooling the products of combustion to the initial temperature of the fuel and oxygen.

When a fuel is to be used for steam generation, it is desirable to evaporate as large a quantity of water as possible per unit quantity of fuel. It is impossible, under commercial conditions, to use all the heat of the fuel for this purpose, since, in order to accomplish this, it would be necessary to burn the fuel completely, and to utilize all the heat thus generated by cooling the products of combustion, the excess air, and the ash, to the temperature prevailing before combustion took place.

When burned under a boiler, a portion of the heat of the fuel is dissipated in the following fo: .s of unused energy:—

1. Unburnt solid combustible.
2. Unburnt gaseous combustible.
3. Heat carried off in the chimney gases.
4. Heat lost by radiation, and removal of hot clinker and ash.

The remaining portion of the energy of the fuel is used for steam generation: the ratio of the quantity so used to the total energy of the fuel fired being termed the thermal efficiency of the boiler. The boiler trials were carried out in such a manner that, the efficiency of the boiler could be calculated, and the losses of heat energy separated into their respective components.

The information obtained may be used directly to compare the steam-raising value of peat with that of other fuels, when the results of tests carried out with other fuels under similar conditions are available; otherwise, extreme care must be taken to make allowance for the change in these conditions before any comparison is made.

By comparing the results of the trials— in which peat fuel was burned under different conditions—additional information may be acquired which will be useful in adapting apparatus for the economical use of this fuel for

[1]The unit of heat used in this report is the Mean British Thermal unit, or B. Th. U. which is 1/180th part of the quantity of heat required to raise 1 pound of water from 32° F. to 212° F.

steam-raising. Other factors can be deduced from the results of the tests, which may be useful in estimating the cost of handling the ash and clinker, of supplying the air to the grates, etc. These factors have reference to the quantity, method and difficulty of removing ash and refuse, strength of draft, pounds of flue gas per pound of fuel, etc.

The trials described in these tests comprise a series of **seven**: four of which were carried out in a Babcock and Wilcox water-tube boiler, and three in an internally fired boiler of the portable locomotive type. The trials with the water-tube boiler were carried out at approximately the same rate of steaming which obtained during other tests in which coal and lignite were used, and the results obtained are, therefore, comparable with those of the latter tests. The fuel was hand-fired, by an experienced fireman, throughout the series.

The peat fuel used in these tests was manufactured by the Anrep process, at the peat plant operated by the Mines Branch, Department of Mines, at Alfred, Ontario, during the season of 1911. (See Bulletin No. 4).

The moisture content of the peat was rather low for this class of fuel (16 to 20 per cent), hence care should be taken when estimating the steaming properties of a peat with the results obtained in these tests as a basis, to allow for a higher moisture content equal say, to that of the peat fuel usually supplied to the market.[1] The peat used was of excellent quality, and contained only a small percentage of dust.

Personnel.—Valuable aid was rendered by Mr. E. S. Malloch, B.Sc., who took full charge of the tests from time to time; constructed the curves contained in the report; and made the calculations required.

The Chemical department of the Fuel Testing Division—under the superintendence of Mr. E. Stansfield, M. Sc.—was entirely responsible for the fuel and gas analyses.

Mr. A. W. Mantle, Mechanical Superintendent of the Fuel Testing Station, was responsible for the satisfactory working conditions of the boiler and equipment, and assisted in taking readings during the trials.

[1] For further particulars concerning the effect of moisture content in peat on its calorific power, see "Peat, Lignite, and Coal," by B. F. Haanel.

PART I.

METHOD OF CONDUCTING TESTS.

Precautionary measures.—Both boilers were examined before commencing the series of trials, and put into good condition. About one hour before starting each trial, the soot was removed from the tubes by means of a steam blast. In order to bring the boiler brick-work, fittings, etc., to their working temperature at the time of commencing the trial, the boiler was always operated the day before. The fires were then banked overnight, and the boiler again run for about 1½ hours before starting. Special care also was taken to examine the boiler before and during operation for under-water leakages, and any leakage water from the feed pump glands was returned to the feed tank.

Starting and stopping the trial.—When stopping the trial, an effort was made to bring the temperature of the furnace and boiler, the quantity of live fuel and ash on the grates, the water level, and the steam pressure, into the same condition as at the beginning.

In the case of most fuels, difficulty is encountered in estimating the condition of the fuel bed at the beginning and end of a trial. In these trials the peat was burned in a very thin bed, with practically no ash present; and it burned so rapidly that the fires could be judged with comparative ease.

Care was also taken to clean out the ash-pit before the trial, and again immediately at the end of the trial.

Peat fired, ash and refuse removed.—The peat was weighed in lots of about 80 pounds, and the time of commencing to fire each lot was noted.

The ash and refuse taken from the grate and ash pit during the trial were weighed immediately on removal and then slaked. A sample of the entire quantity of peat burned during each trial was taken and sent to the chemical laboratory for the determination of its ash and moisture content. A determination also was made of the combustible content of a sample of the refuse removed from the grate and ash-pit.

An ultimate analysis and a calorimetric determination were made of the sample of peat taken for the first trial, and these results were used in conjunction with the approximate analysis for each test, in order to estimate the calorific value and chemical composition of the peat fired and refuse removed during each trial.

Water evaporated.—All the feed-water was weighed and delivered to a graduated feed tank, from which it was delivered by pumps to the boiler. The water content of the boiler was observed by measuring the height of the water level in the gauge glass, which had been graduated previously by direct experiment. It was thus possible to compute the quantity of water evaporated at any time during the trial. These computations were made every fifteen minutes and were used to regulate the rate of working of the boiler, to its prearranged load.

The temperature of the feed-water was read every fifteen minutes from a mercury thermometer.

Quality of the steam.—The steam pressure was observed every fifteen minutes by means of a pressure gauge; but since the steam formed was wet, it was necessary to use a steam calorimeter to determine the total heat, and dryness fraction. This calorimeter was of the throttling type, and was so attached, that the steam was sampled at the moment it left the boiler.

Draft.—In the first series of trials, the draft pressures below the fire bars, in the combustion chamber and in the flue leaving the boiler, were observed every fifteen minutes. In the second series the pressure was observed only in the smoke box. Sloping gauges with oil as the fluid, reading to one-hundredth of an inch of water, were used for these measurements.

Flue temperature.—The temperature of the flue gas was observed every fifteen minutes by means of a Bristol electrical pyrometer. The fire end of this pyrometer was placed in the centre of the flue near its junction with the top of the boiler, and close to the flue gas sampling tube.

Collection and analysis of the flue gas.—A hard glass tube, encased in an iron pipe, extended through the wall of the flue, so that its open end was at the centre of the flue. Through this tube, which led to the chemical laboratory, a continuous stream of gas was drawn, from which samples for analysis were taken under a constant head over periods of from 20 to 30 minutes each.

PART II.

THE WATER-TUBE BOILER TRIALS.

General description and principal dimensions of boiler.—The boiler (see Fig. 1) used for these trials, was made by Babcock & Wilcox, Ltd., and is of their marine type, many of which are to be found in large power houses, industrial factories, and warships. The greater part of the heating surface of this boiler consists of ten vertical sections of tubes. Each section comprises a nest of inclined straight tubes, which connect water boxes or headers; while the front headers, which are at a higher level than the back ones, are connected by horizontal tubes to the steam space. The back or lower headers are connected by short vertical tubes to the water space of a horizontal drum, which extends the full width of the boiler.

The feed water enters the steam and water drum near the water level, and descends through the back headers to the inclined tubes. In this portion, heat is absorbed and steam is formed in bubbles, which causes the water and steam to ascend the tubes, and pass through the up-take headers and horizontal return tubes to the steam and water drum. The steam and water on entering the drum, impinge on a baffle plate, which causes the water to be thrown downwards; while the steam proceeds round the ends of the baffle plate to the steam space, which it leaves through a perforated dry-pipe.

The combustion chamber is enclosed on four sides with brick, while the roof consists of a series of large inclined tubes, above which is a double row of small inclined tubes. A light, fire-tile baffle, is placed over the latter, and extends across the full width of the boiler, and a little more than half way towards the front. This compels the gases to proceed towards the front of the boiler. The gases are then further deflected in such a manner that they are caused to traverse the upper nests of tubes three times before leaving the boiler.

The boiler is enclosed by casing plates, lined on the inside with refractory material, which is in contact with the hot gases. These casing plates are enclosed by steel plates, with which they form an air space for the purpose of reducing radiation losses.

All the exposed parts of the steam drum, main steam valve, and steam pipe, up to the throttling calorimeter connexion, were thoroughly lagged with non-conducting material.

Grate bars of a special corrugated type, supplied by the manufacturers, were employed in tests No. 71 and No. 73; while for trial No. 72, ordinary straight bars were used.

A summary of the leading particulars of the boiler is as follows:—

Heating surface (tubes)............................633 sq. feet.
Heating surface (drum, etc.)........................ 44 sq. feet.
Total heating surface.............................. 677 sq. feet.

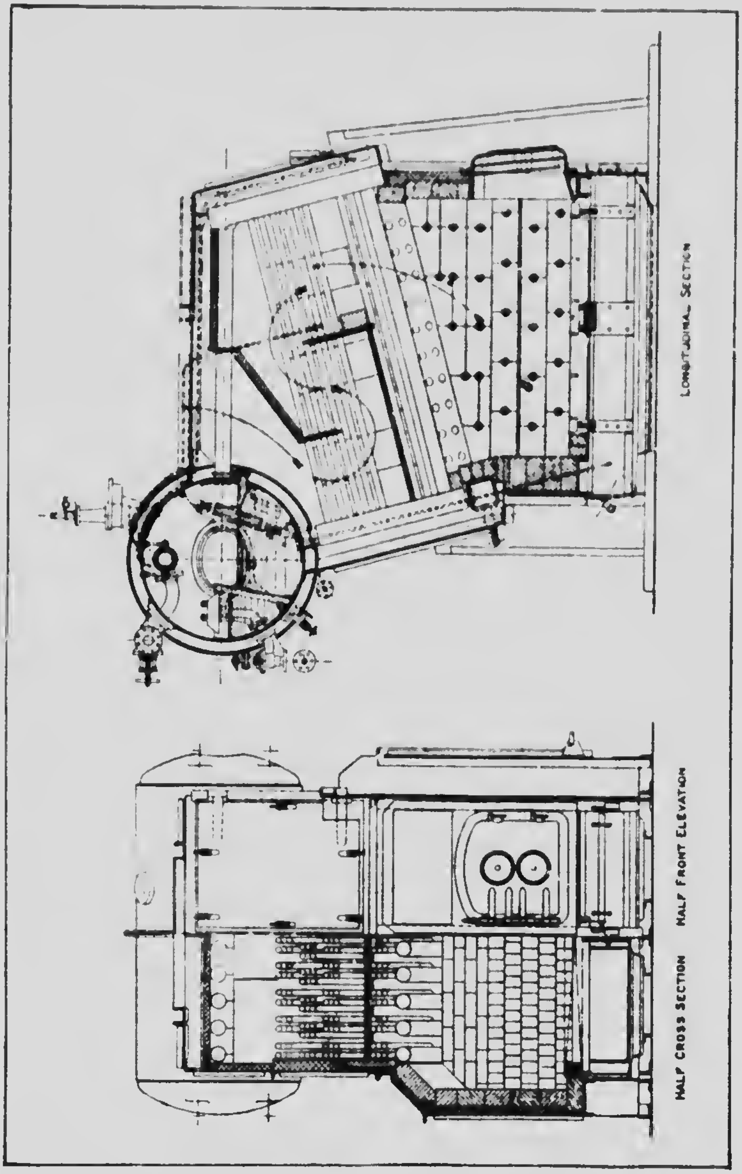


Fig. 1. Babcock and Wilcox Marine Tube Boiler.

	Trial No. 71.	Trials Nos. 72 & 73.
Width of grate..............	4'-9½"	6'-9½"
Length of grate........................	4'-10"	5'-7"
Grate surface (excluding dead plate).......	23·2 sq. ft.	37·9 sq. ft.
Ratio heating surface to grate surface... .	29	18
Approximate width of air spaces between fire bars..........................	¼"	½" (72) ¼" (73)
Grate area occupied by air space, per cent of total grate area.......	30	50 (72), 30(73)
Capacity of water space, cubic feet =	57	
Capacity of steam space, cubic feet =	48	
Working pressure, lbs. per sq. in. =	1[illegible]	

Boiler Auxiliaries.

Feed pumps, and heater.—The feed water, which was heated by a steam coil, could be fed to the boiler by either of two independent feed pumps.

Fan.—The products of combustion were exhausted by means of a steel plate fan.

Firing.—The firing throughout the tests was done by hand; the same fireman being employed for the whole series of tests.

Results of trials 71, 72, and 73

A full list of the averages of the observations and results will be found at the end of Part II. The outstanding features of the results will be considered in detail, as follows:—

During this series of trials the grate bars, and grate area were altered, with a consequent variation in the rates of combustion and steaming. All the trials were approximately of 10 hours duration. Longer trials were unnecessary on account of the fact that, extremely light fires were carried, which reduced the possibility of error, due to the relative quantity of fuel on the grate at the beginning and end of the trial.

The following table (I) shows the principal changes in conditions and fuel quality during the series:—

TABLE I.

Trial.	Moisture per cent in peat.	Gross calorific value B. Th. U. per lb.	Grate area sq. ft.	Air space in grate bars.	Fuel per sq. ft. of grate area per hour. lbs.	Evaporation per hour. lbs.
71	15·7	8070	23·2	¼"	20·5	1950
72	15·7	8070	37·9	½"	15·5	2322
73	20·3	7590	37·9	¼"	15·0	2250

Quality of peat.—From the above table it will be seen, that for trial 73 the moisture content was higher, while the calorific value was lower than for the other trials.

Fig. 1. Babcock and Wilcox Marine Tube Boiler.

Grate area, and air space, as affecting draft required.—The draft required to burn a fuel depends upon the rate of combustion, area of air space, and width of air space. The following table (II), shows how the draft increased with the amount of dry fuel burnt per square foot of air opening in the bars per hour.

TABLE II.

Trial.	Dry peat per hour.		Draft, difference of pressure, above and below bars.
	Lbs. per sq. ft. of grate.	Lbs. per sq. ft. of air space in grate.	
72	13	26	0·11 inches.
73	12	40	0·18 "
71	17	57	0·23 "

Effect of grate area and air openings on incombustible matter in refuse. Table III shows the trials arranged in the order of increasing total air space through the grate bars.

It will be seen from table III, that for trials 71 and 73 the effect of enlarging the grate area and still using the corrugated bars, was to increase the amount of ash removed from the ash-pit, and to decrease that taken from above the bars. This is to be expected since the trials are all of approximately the same duration, so that with the same fuel and same grate bars the ash falling between the bars should increase with the area. Since the proportion of the total ash falling through the bars was greater in trial 73 than in trial 71, and since the combustible content of this portion of the refuse was very low, the total refuse removed for that trial—expressed as a percentage of the dry fuel fired—was reduced from 6·1 to 4·9; and the loss due to combustible in the ash and refuse was reduced from 1·8 to 1·4 per cent. In trial 72 it will be seen that the bars were so wide and the air space so large as to obviate the necessity of cleaning the fires at all during the trial; but since more combustible passed through the bars, the loss due to combustible in ash and refuse was increased to 2·3 per cent.

From the foregoing it will be observed that the most efficient grate bar would be one having an air space intermediate in size between the two used; that is to say one with an air space sufficiently large to permit the ash to fall through without taking an undue proportion of combustible with it. This requirement has been met by the grate bars used for the portable boiler trials in which as will be seen by referring to those trials, the loss due to combustible in the refuse did not exceed one-half of one per cent.

Effect of Grate Area and Air Openings on Character of Flue Gas.

Table IV shows the effect of the combustion per square foot of air space upon the composition of the dry flue gas.

TABLE III

Trial.	Total area of air space. Sq. ft.	Width of air space between fire bars.	Total ash and refuse removed. lbs.		Combustible content of ash and refuse. Per cent.	Total ash and refuse removed per cent of dry fuel fired.	Combustible in ash and refuse per cent of combustible fired.
			From ash pit.	From above bars.			
71	7	$\frac{1}{4}''$	34	207	28·5	6·1	1·8
73	11	$\frac{1}{4}''$	78	146	27·6	4·9	1·4
72	19	$\frac{1}{2}''$	278	None	38·7	5·6	2·3

TABLE IV.

Trial.	Dry fuel burnt per sq. ft. of air space.	Draft, difference of pressure above and below bars.	Flue gas, per cent by volume.			Ratio $\frac{\text{Free oxygen.}}{\text{Combined oxygen.}}$
			CO_2	CO	O_2	
72	26	0·11	10·5	1·1	8·8	0·80
73	40	0·18	8·9	0·8	10·7	1·15
71	57	0·23	8·6	0·6	11·1	1·25

During these three trials, air was admitted to the fuel bed through the fire door, in order to reduce the percentage of unburnt carbon monoxide. This quantity of supplementary air was difficult to regulate; in fact during trial 72, the draft over the fire was so slight, that it was necessary to partially close the ash-pit door to allow a greater portion of air to be drawn over the fuel bed. It will be seen upon examining the table, that the ratio of free oxygen to combined oxygen increased with increased combustion per square foot of air opening; this is probably due for the most part, to the fact that the draft also increased, hence the supplementary air supply over the bars was greater. Another explanation is that the smaller air spaces decreased the facility for the removal of ash by gravity, thus leaving the combustible portion of the fuel less accessible to the air.

Flue gas losses.—By referring to table (V) it will be seen that the smallest total loss due to the heat leaving, in the dry flue gas, occurred in trial 72; and for this trial the ratio of the pounds of flue gas per pound of carbon is smallest.

The effect of increasing the supply of air in order to reduce the quantity of unburnt carbon monoxide will be considered by supposing that the average flue gas analysis for trial 71 is obtained from that of trial 72, by admitting an additional supply of air to the latter gas. The requisite amount of air per 100 volumes of flue gas would be 26·2 volumes, made up of 5·5 volumes of oxygen, and 20·7 volumes of nitrogen; and 0·3 volumes of CO must take up 0·15 volumes of oxygen, forming 0·3 volumes of CO_2 in order to effect the change. The total volume after admitting the air and burning 0·3 volumes of CO would be (126·2−0·15) = 126·05 volumes of flue gas, composed of (10·5 + 0·3) volumes of CO_2, (1·1 − 0·3) volumes of CO, (8·8 + 5·5 − 0·15) volumes of oxygen and (79·6 + 20·7) volumes of nitrogen; these expressed as percentages will be 8·6 CO_2; 0·6 CO; 11·2 O_2; and 79·6 N_2, or practically the same composition as the gas for trial 71. It will be seen from this that 0·3 volumes of CO have been burned with the additional supply of 26·2 volumes of air, or a ratio of air to gas of 87.

It may be stated at the outset, that with so large a ratio of air to gas the heat of the reaction, $2CO + O_2 = 2CO_2$ would suffice to raise the air temperature only about 207° F.—that is, from 70° F. to 277° F. The temperature of the exit gases in the boiler is considerably higher than this, therefore it will be clear that, since the products of combustion of this separate reaction leave the boiler at a temperature considerably higher than the theoretical temperature of combustion, it must receive heat from the remainder of the flue gas, and thus reduce the efficiency of the boiler

TABLE V.

Trial No.	Dry Flue Gas. Per cent by volume.				Lbs. dry flue gas per lb. carbon.	Flue gas temperature on leaving boiler. °F	Loss, per cent, of energy in fuel fired, due to:		
	CO_2	CO	O_2	N_2			Total heat of dry flue gas.	Unburnt CO.	Total dry flue gas loss.
71	8·6	0·6	11·1	79·7	27·0	720	24·0	3·8	27·8
72	10·5	1·1	8·8	79·6	21·6	760	20·1	5·4	25·5
73	8·9	0·8	10·7	79·6	25·6	715	21·9	4·8	26·7

as a whole. For the purpose of comparing the net result of the additional air supply, the quantity of steam present in the flue gases (9 volumes) must also be considered, making the total volumes (100 + 9) and (126 + 9) respectively.

The result of burning the carbon monoxide may then be investigated as follows: in the first case (trial 72) 109 volumes of flue gas leave the boiler at a temperature of 760° F., and the change in total heat of the gas between this temperature and the air temperature (70° F.) represents a loss. In the second case, 135 volumes of flue gas leave the boiler at a temperature of 720° F., from which the heat loss may again be calculated, the air temperature being 70° F.; from this latter loss the heat energy given up in burning the 0·3 volumes of carbon monoxide must be subtracted, and the difference compared with the loss in the first case.

For convenience in working, the unit of volume is taken as representing the volume occupied by a gram-molecule; the unit of heat chosen is the small calorie, and the temperature is measured on the centigrade scale.

The mean thermal capacities of the two gases at constant pressure are taken as 7·3 and 7·2 calories per gram-molecule, respectively.

The loss in the first case for a difference between the air and flue gas temperatures of 690° F. (383° C.) is $7 \cdot 3 \times 383 \times 109 = 305{,}000$ calories; the loss in the second case, where the temperature difference is 650° F. (361° C.), is $7 \cdot 2 \times 361 \times 135 = 351{,}000$ calories, while the heat gained by burning 0·3 volumes of carbon monoxide is $0 \cdot 3 \times 68{,}000 = 20{,}400$, or with sufficient accuracy 20,000 calories, giving the net loss in the second case as $351{,}000 - 20{,}000 = 331{,}000$ calories. The additional air supply has had a net effect, therefore, of increasing the loss from 305,000 calories to 331,000 calories, or 26,000 calories. It is probable, however, that the actual loss was less, owing to the heat gained by the combustion of hydrogen and methane, neither of which gases were determined in the gas analysis.

In order to observe the effect of the air supply upon the economical working of the boiler, a diagram has been prepared (see Fig. 2) showing the losses due to carbon monoxide (A), and the heat as sensible heat and latent heat of steam (B) leaving with the flue gas plotted on a base representing the ratio of the actual air supplied, to the air required for complete combustion with no excess of oxygen. The data used for the computation of the results plotted were taken from trial 72. Reference to these curves will show that the losses due to the sensible heat of the flue gas and the latent heat of the steam in the flue gas (B) increase, while the loss due to unburnt carbon monoxide (A) decreases with increased air supply. Above these curves is a third curve (C), which shows the total loss, or the sum of the ordinates for the two lower curves. It will be noticed that the two losses compensate one another to a large degree, while the general tendency is for the total loss to increase with increased air supply. This increase, however, is very small, and is most noticeable for values of air supply ratio exceeding 2·0. Reference to Fig. 3 shows that the ratio of 2·0 and over, corresponds to values of carbon dioxide + carbon monoxide, per cent of 10·0 and less. It would appear, therefore, that with the conditions prevailing during this trial the principal factor to be guarded against is an excessive air supply. Further, the comparatively large percentages of carbon monoxide, while representing a loss in themselves, were always found in a gas high in carbon content so that this loss was compensated for by a decrease in the sensible heat lost in the flue gas.

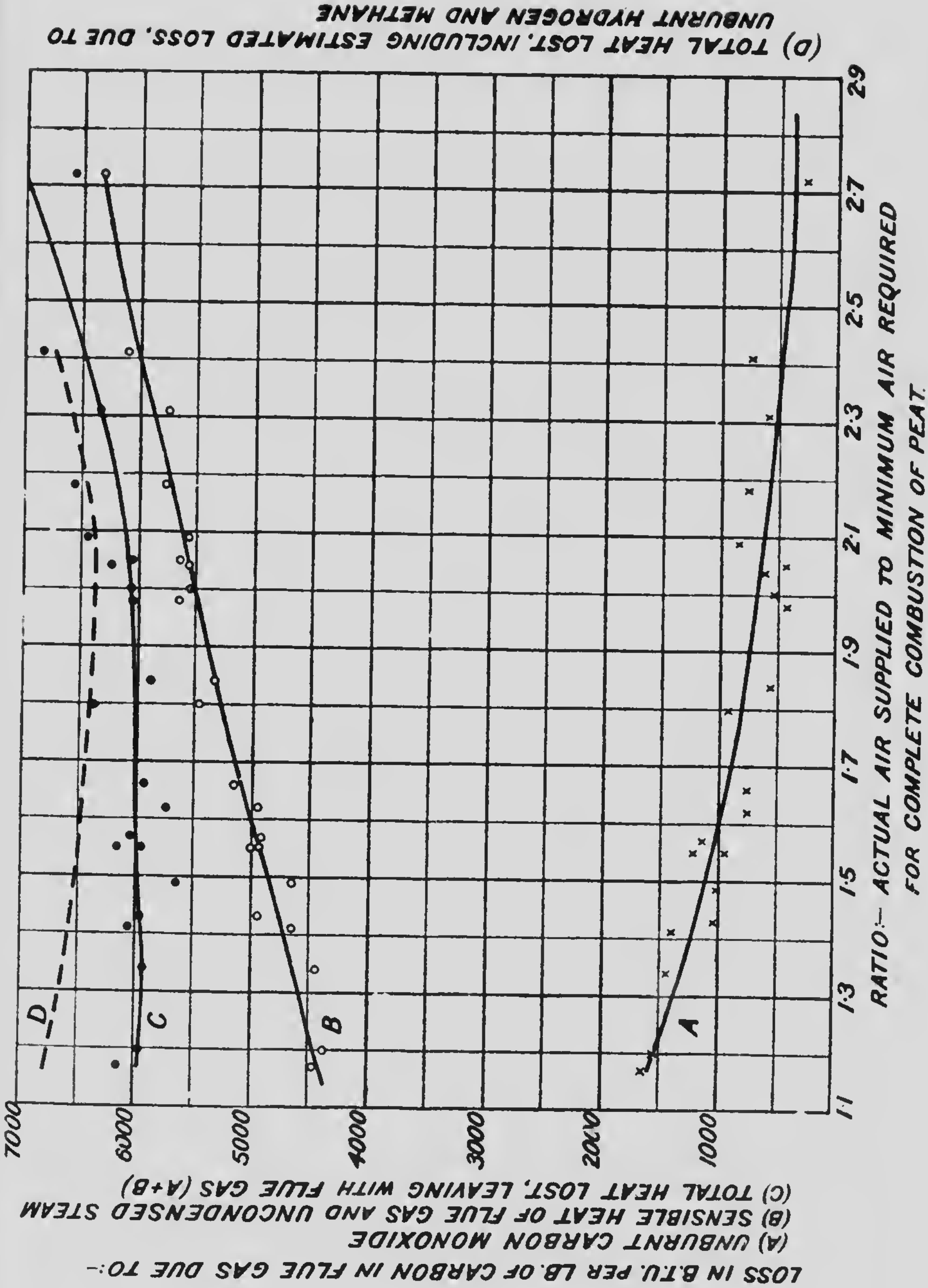

(D) TOTAL HEAT LOST, INCLUDING ESTIMATED LOSS, DUE TO UNBURNT HYDROGEN AND METHANE
LOSS IN B.T.U. PER LB. OF CARBON IN FLUE GAS DUE TO:-
(A) UNBURNT CARBON MONOXIDE
(B) SENSIBLE HEAT OF FLUE GAS AND UNCONDENSED STEAM
(C) TOTAL HEAT LOST, LEAVING WITH FLUE GAS (A+B)
7000
6000
5000
4000
3000
2000
1000
RATIO:- ACTUAL AIR SUPPLIED TO MINIMUM AIR REQUIRED FOR COMPLETE COMBUSTION OF PEAT.
1·1
1·3
1·5
1·7
1·9
2·1
2·3
2·5
2·7
2·9
A
B
C
D

Fig. 2.

It must not be inferred from these remarks that this carbon monoxide content is a negligible loss. It is not; but with the boiler used it was not possible to release this energy without incurring other, and, in some cases, greater losses, due to an excessive supply of air to burn it. With a larger combustion chamber, a suitable warm air supply over the bars, and thorough mixing of the gases, it should be possible to burn this gas, and to utilize from 55 to 65 per cent of the energy liberated, for steam generation.

Later investigations of a more complete nature (see supplementary trial No. 115, page 41) have shown that combustible gases other than carbon monoxide are present in the flue gas when burning peat, and it may be taken as a rough approximation that the unused energy in these gases amounts to one-half of that remaining latent as carbon monoxide. Based on this assumption, a further curve (D) has been constructed a distance above (C) equal to one-half of the ordinates of curve (A). Curve (D) then represents the estimated total heat lost per pound of carbon, including the heat lost due to unburnt gases, which were undetected during trial 72. An examination of this curve (D) shows that the total loss tends to increase for both an increasing and decreasing air supply, and that it reaches a minimum value between the air ratios of 2·0 and 2·1.

TABLE VI.

Trial No.	Equivalent evaporation from and at 212° F.			Efficiency per cent, based on higher calorific value.	
	Lbs. per lb. of fuel as fired.	Lbs. per lb. of dry fuel.	Lbs. per lb. of comb. consumed.	Fuel as fired.	Combustible consumed.
71	4·10	4·87	5·22	49·3	50·3
72	3·96	4·70	5·10	47·6	49·2
73	3·95	4·96	5·36	50·5	51·7

Economic Results.—This table shows the principal economic results. It will be noted that there is little difference in the results for the evaporation per lb. of fuel as fired, though, it will be seen, the best performance of the boiler was during trial 73, when the fact is taken into consideration that the moisture content of the fuel was nearly 4 per cent higher for this trial, and the calorific value per lb. of fuel as fired about 6 per cent lower. If the other items for trial 73 be compared with those for the remaining trials, it will be noted also that they show up this trial to advantage.

It may be well to recall that trial 73 was carried out with the large grate area and corrugated bars. It seems, therefore, that this grate area and type of bar were the best combination used during these three tests.

In order to compare the results of these trials, in which peat was used as a fuel, with trials using the same boiler with other fuels, a diagram has been prepared (see Fig. 4), which shows the evaporation per lb. of fuel, plotted upon a base representing the gross calorific value of the fuels tested. The diagonal lines are lines of constant efficiency.

It will be observed that the efficiency generally lies between 50 and 60 per cent, and that the efficiency in the peat trials was somewhat low by comparison.

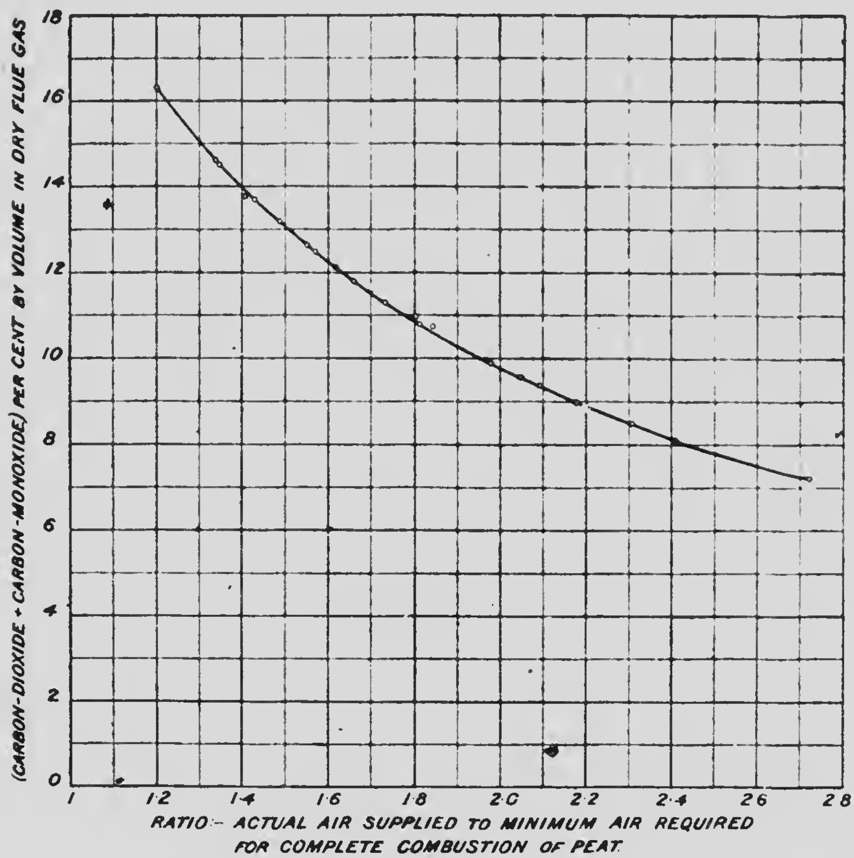


Fig. 3.

Heat balance. TABLE VII.

No. of trial.....	71	72	73
Heat used for steam-raising and thermal efficiency of the boiler	49·3	47·6	50·5
Heat loss due to total heat of the dry flue gas..............	24·0	20·1	21·9
Heat loss due to total heat of superheated steam in the flue gas	8·9	9·0	9·7
Heat loss due to combustible unconsumed:—			
(a) solid combustible..............................	2·0	3·2	2·2
(b) carbon monoxide..............................	3·8	5·4	4·8
Radiation and unaccounted for losses....................	12·0	14·7	10·9
Total energy in fuel as fired........................	100·0	100·0	100·0

The actual losses are shown in Table VII, in the form of a heat balance. These losses differ principally from those already obtained from other boiler trials, in that the loss due to superheated steam in the flue gas; to radiation; to unaccounted for losses; and to unburnt carbon monoxide, are higher than in those trials previously conducted with coal and lignite as a fuel.

The percentage loss due to the steam varies with the amount of hydrogen in the fuel, the calorific value of the fuel, the flue gas temperature, and air temperature. If a constant air temperature of 72° F. be assumed, then, where H is the percentage of total hydrogen in the fuel, all of which is supposed to pass off with the flue gas as steam; I, the total heat of 1 pound of steam, at the temperature T° F. of the flue gas, and Q the calorific value of the fuel in B.Th.U. per pound, the percentage loss due to the steam is:—

$$\frac{9H}{Q}[I-(72-32)] = \frac{9H}{Q}(I-40);$$

for low pressures and large specific volumes the total heat, I, is equal to $0{\cdot}477T + 1054{\cdot}5$ B. Th. U. per pound; the above formula then becomes:—

$$\frac{H}{Q}(9130 + 4{\cdot}29\ T);$$

for a good coal $\frac{H}{Q}$ is about $\frac{4{\cdot}2}{12920} = \frac{1}{3080}$ while for peat as used in trial 73, $\frac{H}{Q} = \frac{6{\cdot}3}{7590} = \frac{1}{1200}$; the percentage losses due to the total heat of the steam are, therefore:—

$$\frac{1}{3080}(9130 + 4{\cdot}29\ T) \text{ and } \frac{1}{1200}(9130 + 4{\cdot}29\ T)$$

$$\text{or } 2{\cdot}96 + \frac{T}{718} \text{ and } 7{\cdot}61 + \frac{T}{280}$$

respectively for the coal and the peat. The maximum variation of the average flue temperature for all the trials so far carried out with this boiler is from 600° F. to 760° F.; which variation could not affect the loss due to steam by more than 0·6 per cent. It is clear then, that this loss is dependent almost entirely on the $\frac{H}{Q}$ ratio of the fuel; while the large loss in the case of peat is due to a characteristic of the fuel, and is unavoidable with ordinary methods of steam-raising. It is for this reason that the net or lower calorific values of fuels are of greater value than the gross or higher calorific values for comparing the value of fuels for steam-production.[1]

The loss due to radiation, and other losses are especially high for these trials, as compared with other trials with this boiler, in which coal was used as a fuel.

A portion of this loss is due undoubtedly, to the escape of unburnt gases. The only combustible gas which could be detected by the apparatus used for analysing the flue gas during these trials was carbon monoxide.

Another short trial (No. 115) has since been conducted, wherein the gas analysis is more complete. A report of this trial may be found on pages 41, and 42.

[1] See Report No. 331, Part II, page 70, for further remarks by the author on higher and lower calorific value of fuels.

Concluding Remarks.—The peat used for steam-raising in these trials proved to be a good fuel, easily handled, and giving no troubles due to clinker or ash. It burned with a long flame and considerable light coloured smoke.

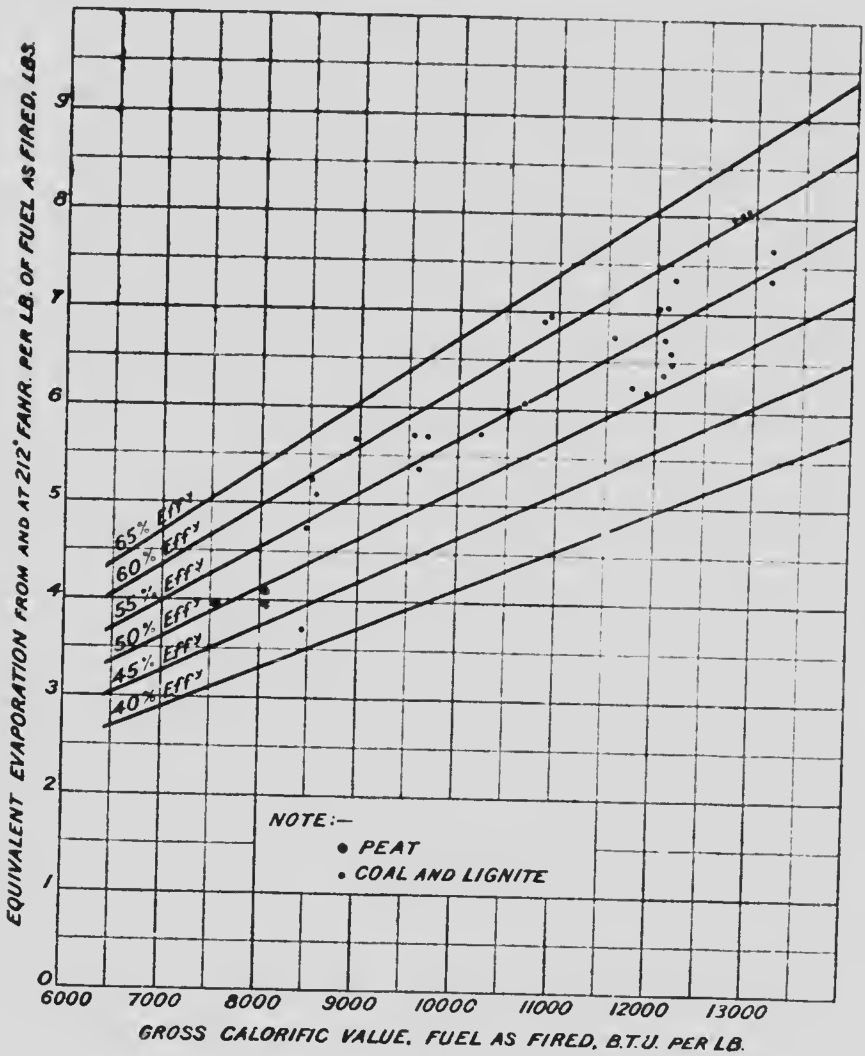


Fig. 4.

The best results were obtained with a large grate with small air-space, and a fuel consumption of 15·0 pounds per square foot per hour. The corrugated grate bars used for trials 71 and 73, with ¼" air space, were better than the bars used for trial 72, in which ½" air spaces were employed;

but the loss due to combustible leaving with the refuse would be reduced by using bars with a greater facility for permitting ash to fall through them than that possessed by the corrugated type, and with a smaller air space than that possessed by the bars with the larger air space.

It is noteworthy that the highest efficiency was obtained with the fuel highest in moisture content. The actual additional loss due to the extra moisture content was about 0·6 per cent.

The efficiency in all three trails was low; which may be attributed, in part, to the superheated steam in the flue gas, due to the high ratio of hydrogen content to calorific value. The loss due to this cause cannot be mitigated to any extent.

The total losses due to dry flue gas do not compare unfavourably with those for other fuels, though the loss due to carbon monoxide is high.

There is no doubt that there was a loss due to unburnt hydrocarbons and hydrogen, and that the total loss due to unburnt gases was so high as to warrant a large and specially constructed combustion chamber, in order to ensure more complete combustion when burning this fuel.

NOTE:—It is not to be inferred that the higher efficiency shown in this trial is attributable to the greater moisture content of the peat, but that other conditions offset the losses due to the additional steam which escaped with the flue gases during trial 73.

TABLE VIII.

SUMMARY OF RESULTS OF BOILER TRIALS 71, 72, AND 73.

Type of Boiler, Babcock and Wilcox Marine Water-tube.

	SITE OF TRIAL.	**FUEL TESTING STATION, OTTAWA.**		
1.	Boiler trial No.	71	72	73
2.	Date of trial	May 18.	May 26.	June 1, 1915.
	Particulars of Boiler.			
3.	Kind of fire bars	Corrugated	Plain	Corrugated
4.	Width of grate	4'-9½"	6'-9½"	6'-9½"
5.	Length of grate	4'-10"	5'-7"	5'-7"
6.	Area of grate	23·2	37·9	37·9 sq. ft.
7.	Width of air space	¼"	½"	¼"
8.	Proportion of air space to whole grate surface	30	50	30 per cent.
9.	Water heating surface on tubes	633	633	633 sq. ft.
10.	Total water heating surface	677	677	677 "
11.	Ratio, heating surface to grate surface	29	18	18
	Starting and Stopping Trial. Alternate method (A.S.M.E.)			
12.	Time of starting trial	9-02	8-50	8-46 a.m.
13.	Time of stopping trial	6-50	6-48	6-46 p.m.
14.	Duration of trial	588	598	600 mins.
	FUEL AND REFUSE.			
	Proximate Analysis of Fuel as Fired.			
15.	Fixed carbon	25·6	25·6	24·1 per cent.
16.	Volatile matter	54·6	54·6	51·3 "
17.	Ash	4·1	4·1	4·3 "
18.	Moisture	15·7	15·7	20·3 "
	Ultimate Analysis of Fuel as Fired. Calorific value, etc.			
19.	Carbon	47·0	47·0	44·2 per cent.
20.	Hydrogen	6·1	6·1	6·3 "
21.	Sulphur	0·1	0·1	0·1 "

TABLE VIII.—*Continued.*

22.	Nitrogen	1·3	1·3	1·2 per cent.
23.	Oxygen	41·4	41·4	43·9 "
24.	Fuel ratio, fixed carbon to volatile matter	0·47	0·47	0·47
25.	Gross calorific value of fuel as fired per lb. (from calorimeter)	8070	8070	7590 B.Th.U.
26.	Net calorific value of fuel as fired per lb. (calculated from gross value)	7490	7490	6990 "
27.	Calorific value of dry fuel per lb. (from calorimeter)	9570	9570	9520 "
28.	Weight of fuel fired	4663	5844	5690 lbs.
29.	Weight of refuse removed from above the fire bars	207	none	146 "
30.	Weight of refuse removed from the ash-pit	34	278	78 "
31.	Combustible matter in total refuse removed	28·5	38·7	27·6 per cent.
	Average of Air and Flue Gas Observations.			
32.	Air pressure in ash-pit	0	0	0 ins. of water.
33.	Air pressure in furnace	−0·23	−0·11	−0·18 " "
34.	Air pressure in flue leaving boiler	−0·71	−0·35	−0·57 " "
35.	Temperature of air in boiler room	71	72	89 °F.
36.	Temperature of flue gas leaving boiler	720	760	715 °F.
37.	Barometric pressure	29·7	29·8	29·9 inches.
	Analysis of dry flue gas by volume.			
38.	Carbon dioxide	8·6	10·5	8·9 per cent.
39.	Oxygen	11·1	8·8	10·7 "
40.	Carbon monoxide	0·6	1·1	0·8 "
41.	Nitrogen	79·7	79·6	79·6 "
	Water and Steam.			
42.	Average temperature of feed water	124	118	115 °F.
43.	Total weight of water fed to the boiler, corrected for inequality of water level	17045	20500	19900 lbs.
44.	Average boiler steam pressure by gauge	99	101	94 lbs. per sq. in.
45.	Average calorimeter steam pressure by gauge	3·6	3·8	2·9 ins. of mercury.
46.	Temperature of steam in calorimeter	278	280	275 °F.
47.	Moisture content of steam	0·9	0·8	0·9 per cent.
	Total Quantities.			
48.	Duration of trial	588	598	600 mins.
49.	Weight of fuel as fired	4663	5844	5690 lbs.

48.	Duration of trial	588	598	600 mins.
49.	Weight of fuel as fired	4663	5844	5690 lbs.
50.	Weight of dry fuel fired	3931	4927	4535 lbs.
51.	Weight of combustible fired	3740	4687	4290 "
52.	Weight of refuse removed from ash-pit and grate (item 29 + item 30)	241	278	224 "
53.	Weight of combustible in refuse (item 31 × item 52 ÷ 100)	69	108	62 "
54.	Total unconsumed combustible from analysis (item 56 × item 53 ÷ item 55)	76	151	93 "
55.	Weight of ash in refuse (item 52 — item 53)	172	170	162 "
56.	Weight of ash in fuel fired	191	240	245 "
57.	Weight of combustible consumed (item 51 — item 54)	3664	4536	4197 "
58.	Weight of water fed to boiler corrected for inequality of water level	17046	20500	19900 "
59.	Weight of water evaporated corrected for moisture in steam	16930	20370	19750 "
60.	Equivalent water evaporated into dry steam from and at 212°F.	19120	23150	22490 "
	Ash and Refuse.			
61.	Ratio refuse removed from grate to total refuse removed (item 29 ÷ item 52)	0·86	0·0	0·65
62.	Total refuse removed per cent of fuel as fired (item 52 ÷ item 49 × 100)	5·2	4·8	3·9 per cent
63.	Total refuse removed per cent of dry fuel fired (item 52 ÷ item 50 × 100)	6·1	5·6	4·9 "
	Hourly Quantities.			
64.	Fuel fired per hour	476	586	569 lbs.
65.	Fuel fired per sq. ft. of grate surface per hour	20·5	15·5	15·0 "
66.	Dry fuel fired per sq. ft. of grate surface per hour	17·3	13·1	12·0 "
67.	Equivalent evaporation per hour, from and at 212°F	1950	2322	2250 "
68.	Equivalent evaporation per hour, from and at 212°F., per sq. ft. of heating surface	2·88	3·43	3·32 "
69.	Horse power developed (item 67 ÷ 34½)	56·5	67·3	65·2 "
	Economic Results.			
70.	Equivalent water evaporated per lb. of fuel as fired (item 59 ÷ item 49)	3·63	3·49	3·47 lbs.
71.	Equivalent evaporation from and at 212°F. per lb. of fuel as fired (item 60 ÷ item 49)	4·10	3·96	3·95 "
72.	Equivalent evaporation from and at 212°F. per lb. of dry fuel (item 60 ÷ item 50)	4·87	4·70	4·96 "
73.	Equivalent evaporation from and at 212°F. per lb. of combustible consumed (item 60 ÷ item 57)	5·22	5·10	5·36 "
	Efficiency.			
74.	Efficiency of boiler furnace and grate based on gross calorific value $\left(100 \times \frac{\text{item } 71 \times 970 \cdot 4}{\text{item } 25}\right)$	49·3	47·6	50·5 per cent.

TABLE VIII.—*Continued.*

75.	Efficiency of boiler furnace and grate based on net calorific value $\left(100 \times \frac{\text{item } 71 \times 970 \cdot 4}{\text{item } 26}\right)$	53·1	51·3	54·8 per cent.
76.	Combustible removed with refuse from ash-pit and grate, per cent of combustible fired	1·8	2·3	1·4 „
77.	Efficiency of boiler based on combustible consumed (item 74 × item 51 ÷ item 57)	50·3	49·2	51·7 „
	Flue Gases.			
78.	Dry flue gas per lb. of carbon (from gas analysis)	27·0	21·6	25·6 lbs.
79.	Dry flue gas per lb. of fuel as fired (from gas analysis)	12·4	9·8	11·1 „

Heat Balance, Based on Peat as Fired.

		B.Th.U.	Per cent.	B.Th.U.	Per cent	B.Th.U.	Per cent.
80.	Total heat value of 1 lb. of fuel as fired (gross calorific value)	8070	100·0	8070	100·0	7590	100·0
81.	Heat transferred to the water (and thermal efficiency)	3980	49·3	3840	47·6	3830	50·5
82.	Loss due to total heat of steam formed from moisture in fuel and combustion of hydrogen	720	8·9	730	9·0	730	9·7
83.	Loss due to total heat of the dry flue gases	1940	24·0	1620	20·1	1660	21·9
84.	Loss due to unburnt combustible in refuse	160	2·0	260	3·2	160	2·2
85.	Loss due to unburnt carbon monoxide	300	3·8	440	5·4	360	4·8
86.	Balance of heat account: errors of observation, and unmeasured losses, such as those due to escape of unburnt hydrocarbons and hydrogen: and to radiation	970	12·0	1180	14·7	850	10·9
	Total of lines 81 to 86: equal to line 80	8070	100·0	8070	100·0	7590	100·0

and hydrogen: and to radiation	970	12·0	1180	14·7	850	10·9
Total of lines 81 to 86: equal to line 80	8070	100·0	8070	100·0	7590	100·0

GENERAL NOTES.

Item 26. The net calorific value is calculated from the gross calorific value, by deducting from the latter the latent heat of the water condensed from the products of combustion by cooling to 60° F. The latent heat of steam at 60° F. is taken as 1,055 B.Th.U. per lb.

Item 82. The loss due to the total heat of the steam present in the flue gases leaving the boiler is calculated by taking the difference between the total heat of 1 pound of steam at its pressure and temperature when leaving the boiler with the flue gases, and the heat of 1 pound of liquid at the temperature of the air; and multiplying the difference by the pounds of steam, per pound of fuel, present in the products of combustion.

Item 83. The loss due to the total heat of the dry flue gases is equal to the weight of dry flue gases per pound of fuel multiplied by the difference of flue gas and air temperatures, which product is multiplied by the mean specific heat of the gas at constant pressure.

GENERAL NOTES ON TRIAL No. 71.

Times of cleaning fire: twice, at 1.00 p.m. and 1.30 p.m.: also at 6.05 p.m. and 6.20 p.m.
Air regulations over bars. Air admitted over bars through grills in fire doors, doors open slightly for a portion of the trial.

GENERAL NOTES ON TRIAL No. 72.

Times of cleaning the fire. Fire was not cleaned during the trial.
Air regulations over bars. Fire door opened a little and ash-pit door partially closed.

GENERAL NOTES ON TRIAL No. 73.

Times of cleaning fire. Once at 6.10 p.m. and 6.30 p.m.
Air regulations over bars. All grills in the fire door were left open.

GENERAL REMARKS, TRIALS 71, 72, 73.

Smoke. Considerable quantities of chocolate coloured smoke were given off.
Flame. The peat burned with a long flame.
Clinker. No clinker was formed during the trials.
Fire Thickness. Thin fires were kept throughout the tests.

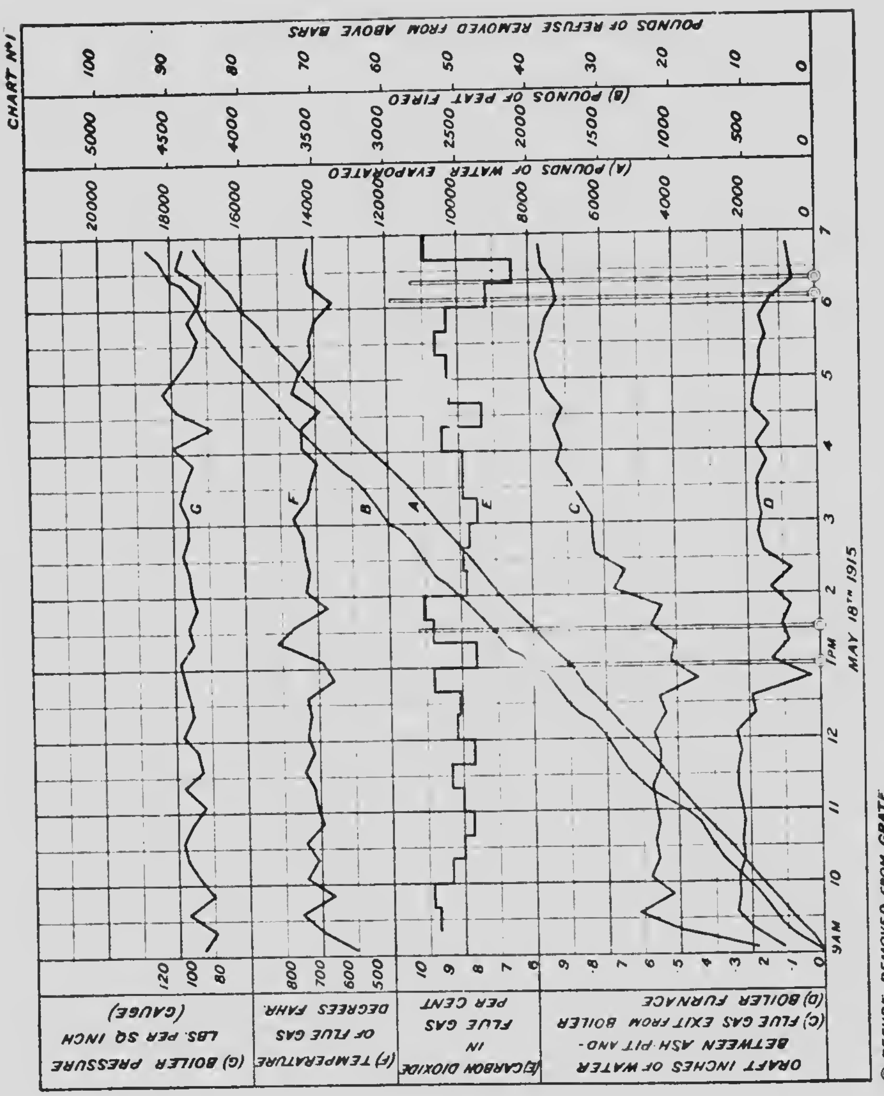


CHART No 1
POUNDS OF REFUSE REMOVED FROM ABOVE BARS
(B) POUNDS OF PEAT FIRED
(A) POUNDS OF WATER EVAPORATED
(G) BOILER PRESSURE LBS. PER SQ INCH (GAUGE)
(F) TEMPERATURE OF FLUE GAS DEGREES FAHR.
(E) CARBON DIOXIDE IN FLUE GAS PER CENT
DRAFT INCHES OF WATER BETWEEN ASH-PIT AND- (C) FLUE GAS EXIT FROM BOILER (D) BOILER FURNACE
MAY 18TH 1915
© REFUSE REMOVED FROM GRATE

Trial No. 71.

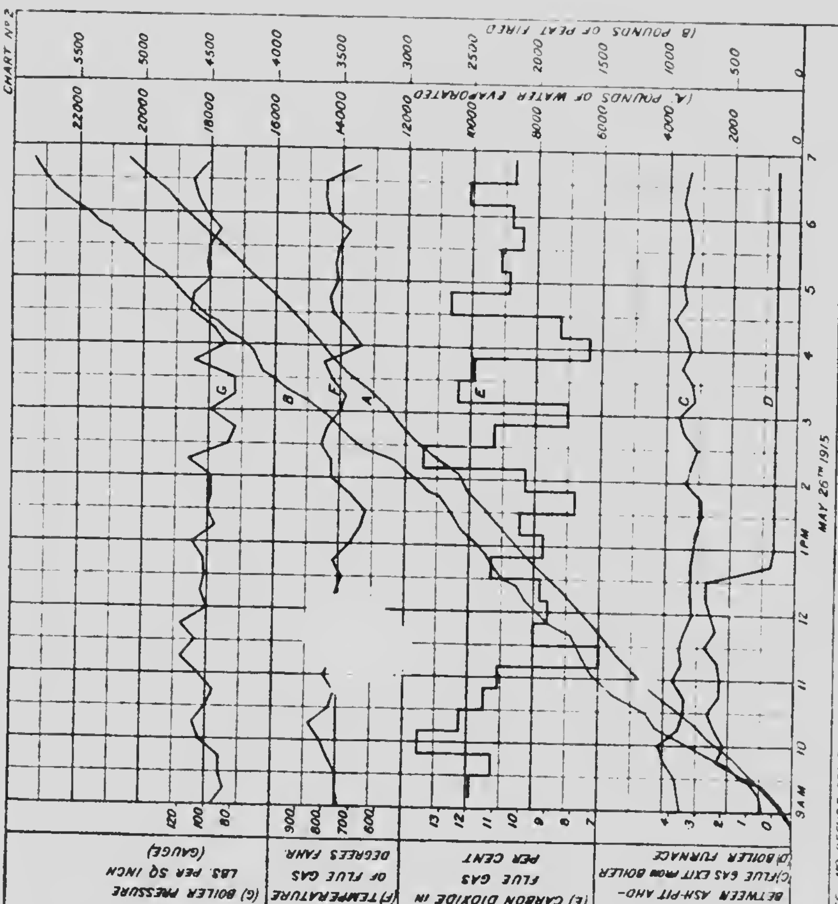


CHART No 2
(A) POUNDS OF WATER EVAPORATED
(B) POUNDS OF PEAT FIRED
(G) BOILER PRESSURE LBS. PER SQ INCH (GAUGE)
(F) TEMPERATURE OF FLUE GAS DEGREES FAHR.
(E) CARBON DIOXIDE IN FLUE GAS PER CENT
DRAFT INCHES OF WATER BETWEEN ASH-PIT AND- (C) FLUE GAS EXIT FROM BOILER (D) BOILER FURNACE
MAY 26TH 1915
NOTE - NO REFUSE REMOVED FROM ABOVE BARS

Trial No. 72.

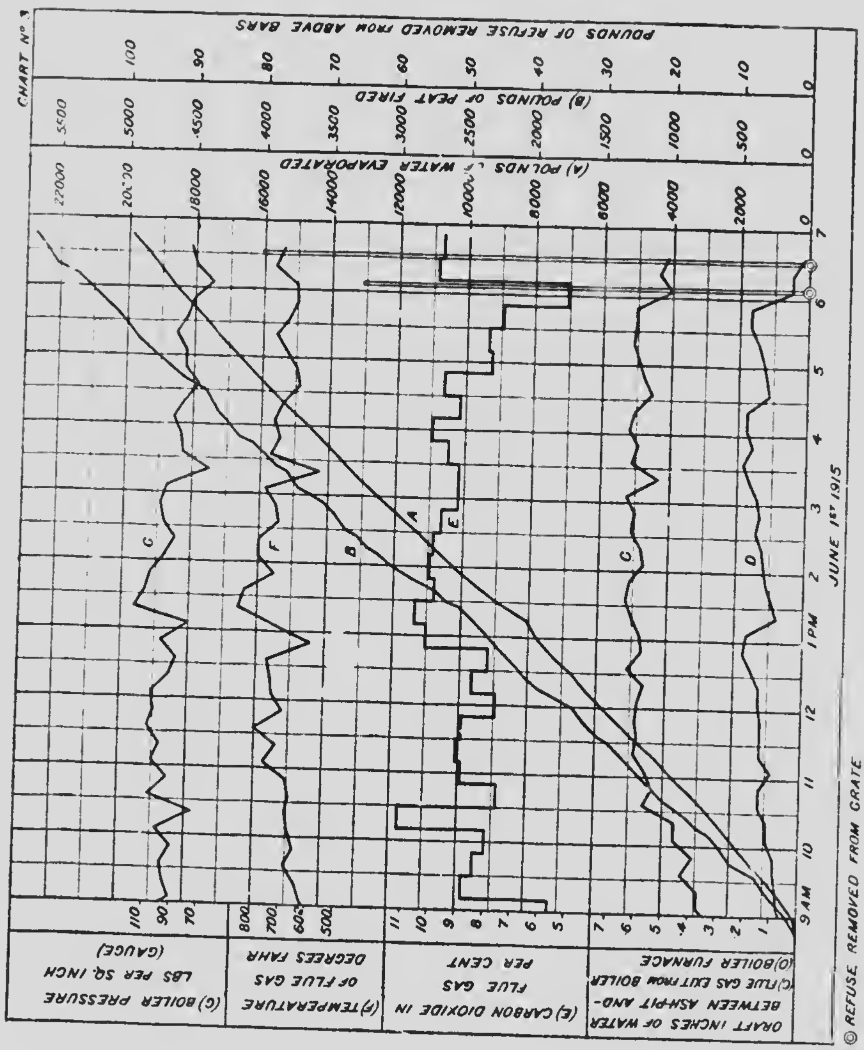


CHART No 3
POUNDS OF REFUSE REMOVED FROM ABOVE BARS
(B) POUNDS OF PEAT FIRED
(A) POUNDS OF WATER EVAPORATED
(G) BOILER PRESSURE LBS PER SQ. INCH (GAUGE)
(F) TEMPERATURE OF FLUE GAS DEGREES FAHR
(E) CARBON DIOXIDE IN FLUE GAS PER CENT
DRAFT INCHES OF WATER BETWEEN ASH-PIT AND- (C) FLUE GAS EXIT FROM BOILER (D) BOILER FURNACE
JUNE 1st 1915
REFUSE REMOVED FROM GRATE

PART III.

THE PORTABLE BOILER TRIALS

The second series of trials were carried out on a boiler of the portable locomotive type, which was used to supply steam to a single cylinder engine of about 30 H.P.[1]

A photograph of this boiler is shown in Plate I, and a longitudinal section in Fig. 5.

Furnace and grate.—The boiler is internally fired, that is to say, the combustion chamber is surrounded by water-cooled heating surface on all sides, except the base, which is occupied by the fire bars, which are of the straight type, with ¼" air space.

Heating surface.—The heating surface is made up of the firebox walls, 40=2¼" tubes, and the tube plates. The greatest rate of heat transmission takes place through the firebox walls, which are exposed to the radiation of the burning fuel.

Possibility of air leaks.—The possibility of air diluting the products of combustion in this type of boiler is reduced to a minimum, since the only mode of entrance is through the grate bars and fire door.

Radiation.—The boiler is covered with non-conducting material over its cylindrical portion only, the remainder being left exposed.

Feed water.—The boiler is supplied with three distinct pieces of apparatus for water supply: a hand pump, an exhaust steam injector, and a feed pump operated by an eccentric, keyed to the crank shaft of the engine; the latter only, was used during the trials.

Draft.—An exhaust steam nozzle is provided to induce a draft; but since the boiler smoke stack was connected to a high chimney, the nozzle was unnecessary, and natural draft only was used for these trials.

Firing.—The firing was carried out by hand.

A summary of the leading particulars of the boiler is as follows:—

Heating surface, (firebox)	39 sq.ft.
" " (tubes)	168 "
" " (smoke box, tube plate)	8 "
Total heating surface	215 ft.
Width of grate	3'–0"
Length of grate	3'–0"
Area of grate	9 sq. ft.
Ratio, heating surface to grate surface	24
Approximate width of air spaces between fire bars	¼"
Grate area occupied by air space, per cent of total grate area	31
Capacity of steam space, cu. ft.	15
Capacity of water space, cu. ft.	35
Working pressure, lbs. per sq. in.	100

[1]This locomobile was supplied by Messrs. Munktells, of Eskilstuna, Sweden, to furnish power at the Government peat bog, Alfred, Ont.

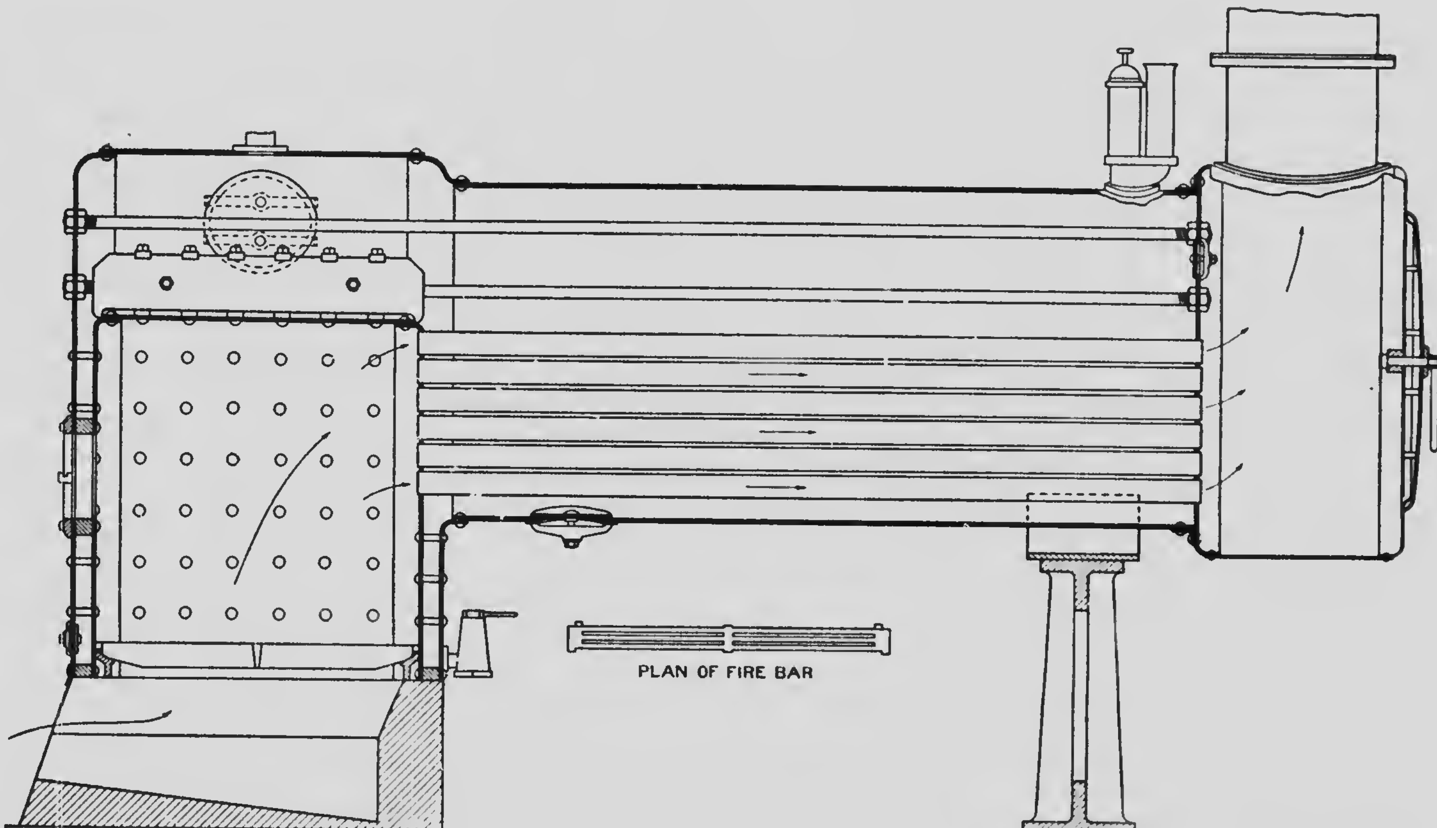


Fig. 5. Portable boiler: locomotive type.

Fig. 5. Portable boiler: locomotive type.

PLATE I.

Locomobile engine and boiler.

RESULTS OF TRIALS 83, 84, and 85.

TABLE IX.

Trial.	Moisture per cent in peat.	Gross calorific value, B.Th.U. per lb.	Equivalent evaporation per hour, lbs.	Peat fired per sq. ft. of grate per hour, lbs.	Draft in stack, inches.	Equivalent evaporation from and at 212° F. per lb. of peat. lbs.
83	19·2	7730	621	17·7	0·11	3·89
84	20·1	7570	802	23·8	0·14	3·74
85	19·2	7710	1054	37·9	0·22	3·09

Quality of Peat.—It will be seen by this table, that there was little variation in the quality of the peat.

Change of Rate of Working.—The rate of evaporation was changed for each trial, and the increased rate of firing was accompanied by an increase in the draft, and decrease in the evaporation per pound of fuel.

Change of Regulation of Air Supply.—For the supply of air over the bars, small holes in the fire door were provided by the makers of the boiler. So high, however, was the carbon monoxide content of the flue gas—in spite of an extremely thin fuel bed—that during trials 83 and 84 the fire door was opened a little to admit air, in order to burn this gas more completely. During trial 85, it was found impossible to carry the load with an open fire door, so during that trial the fire door itself was kept closed, and air admitted above the bars only through the small holes in the door.

TABLE X.

Trial.	Per cent by volume.				Lbs. Dry flue gas per lb. carbon.	Flue gas Temperature, °F.	Heat loss per cent of energy in fuel fired.		
	CO_2	CO	O_2	N_2			Total heat of the dry flue gas.	Unburnt carbon monoxide.	Total loss in dry flue gas.
83	10·0	1·4	9·0	79·6	21·9	690	18·9	7·2	26·1
84	10·5	1·5	8·2	79·8	20·8	690	17·9	7·4	25·3
85	12·6	4·7	4·0	78·7	14·5	750	13·7	16·1	29·8

Composition of, and losses due to, flue gas.—The ...st striking feature of the flue gas composition (Table X), is the very ... a carbon monoxide content, and this, it will be seen, is especially high for trial 85, during which very little air was admitted above the fuel bed. The total dry flue gas losses for the first two trials compare favourably with the same loss for this fuel when burnt under the water-tube boiler, in which the total losses were 27·8, 25·5, and 26·7 per cent, respectively; while that for trial 85 is not so high as might at first be expected from a gas containing 4·7% carbon monoxide, which is equivalent to a heating value of 15 B.Th.U. per cubic foot of flue gas. The high percentage of carbon monoxide obtained from this boiler is to be attributed to the small water-cooled firebox, which arrests the combustion of the burning gases.

On referring to the heat balance sheet (Table XI), it will be seen that the boiler efficiency for trial 85 was much lower than those efficiencies for the two previous trials; and one obvious reason for this is, that the total dry flue gas losses were largest for this trial, due to incomplete combustion of the carbon monoxide, thus increasing the heat loss to a greater extent than it was reduced by decreasing the air supply per unit weight of fuel.

TABLE XI.

Heat balance.

	83.	84.	85.
Heat used for steam generation	48·8	48·0	38·9
Loss due to total heat of the dry flue gases,	18·9	17·9	13·7
Loss due to total heat of superheated steam leaving with flue gas..	9·8	9·9	10·0
Loss due to unconsumed combustible:—			
(a) unburnt carbon monoxide	7·2	7·4	16·1
(b) combustible in ash and refuse	0·2	0·5	0·4
Heat loss due to radiation and unaccounted for ..	15·1	16·3	20·9
Total heat in fuel as fired.	100·0	100·0	100·0

The loss in efficiency for trial 85, however, is only partially explained by the total dry flue gas loss, and the only remaining loss which is materially greater for this trial is that due to "radiation and unaccounted for."

If the radiation loss be considered, it will be seen that, since the boiler is internally fired, all the heat lost by radiation must pass by conduction, ... he steam or water, through the shell.

Since the steam and water temperatures were approximately the same for the series of tests, the radiation rate for all three tests must have been approximately the same; and for the trials in which the rate of steaming was smallest the loss of heat by radiation expressed as a percentage of the heat generated was greatest.

For trial 85, therefore, the percentage of radiation loss was least, so that the increase in the "radiation and unaccounted for" loss must be due solely to the "unaccounted for" loss, which means that the flue gas contained unburned gases which were undetected by gas analysis.

Loss due to combustible in ash and refuse.—In the heat balance sheet, it will be noticed that the loss due to this cause is extremely small, which shows the fire bar supplied by the makers to be admirably suited for this fuel. All the ash passed through the grate very easily, and it was unnecessary to clean the fires at all during these trials.

TABLE XII.

Abstracts of results of boiler trials 71, 72, 73, 83, 84, 85.

	Water-tube boiler.			Fire-tube boiler.		
No. of Trial.	71	72	73	83	84	85
Net calorific value of fuel as fired, B.Th.U. per pound ...	7490	7490	6990	7130	6970	7110
Peat fired per hour . lbs.	476	586	569	160	214	341
Peat fired per square foot of grate surface per hour.. ll .	20·5	15·5	15·0	17·7	23·8	37·9
Equivalent evaporation per hour from and at 212° F .... lbs.	1950	2322	2250	621	802	1054
Equivalent evaporation per hour per square foot of heating surface. lbs.	2·88	3·43	3·32	2·89	3·73	4·9
Pounds of dry flue gas per pound of peat.	12 4	9·8	11·1	9 8	9·1	6·5
Temperature in flue leaving boiler, ° F	720	760	715	690	690	750
Equivalent evaporation from and at 212° F. per lb. of peat as fired...... lbs.	4·10	3·96	3·95	3·89	3·74	3·09
Thermal efficiency of boiler furnace and grate, based on the net calorific value, per cent...	53·1	51·3	54·8	52·9	52 1	42·2

General remarks.—Table XII has been prepared in order to compare the results obtained from the trials with the water-tube and fire-tube boilers, respectively. From this table it will be seen that if trial 85 be excluded, the efficiencies of the remaining 5 trials do not vary by more than $3\frac{1}{2}$ per cent, and also that the performance of the smaller fire-tube boiler compares very favourably with that of the larger water-tube boiler at low rates of steaming. The performance at full load (Trial 85) of the fire tube boiler was very poor, and was due to the escape of unburnt gases, the result of having too small a firebox.

The provision of a larger and more suitable firebox would undoubtedly improve the economical working of this boiler, but as such a change would interfere with its essential qualities of portability and compactness, it is unlikely that it would prove practicable.

TABLE XIII.

SUMMARY OF RESULTS OF BOILER TRIALS 83, 84, AND 85.

Type of Boiler, Portable Locomotive.

SITE OF TRIAL.	FUEL TESTING STATION, OTTAWA.		
1. Boiler trial No	83	84	85
2. Date of trial	Oct. 1	Oct. 5	Oct. 26, 1915.
Particulars of Boiler.			
3. Kind of furnace: water enclosed, with plain grate bars			
4. Width of grate ...	3′–0″	3′–0″	3′–0″
5. Length of grate	3′–0″	3′–0″	3′–0″
6. Area of grate	9	9	9 sq. ft
7. Width of air space	¼″	¼″	¼″
8. Proportion of air space to whole grate surface	31	31	31 per cent
9. Water heating surface on tubes	168	168	168 sq. ft
10. Total water heating surface	215	215	215 "
11. Ratio, heating surface to grate surface	24	24	24
Starting and Stopping Trial. Alternate method A.S.M.E.			
12. Time of starting trial	9·30	9·11	9·01 a.m.
13. Time of stopping trial	5·28	5·11	4·59 p.m.
14. Duration of trial	478	480	478 mins.
FUEL AND REFUSE			
Proximate Analysis of Fuel as Fired.			
15. Fixed carbon ..	24·5	24·0	24·5 per cent.
16. Volatile matter	52·2	51·2	52·1 "
17. Ash	4·1	4·7	4·2 "
18. Moisture.	19·2	20·1	19·2 "
Ultimate Analysis of Fuel as Fired. Calorific value, etc.			
19. Carbon	45·0	41·4	44·9 per cent
20. Hydrogen	6·3	6·3	6·3 "
21. Sulphur	0·1	0·1	0·1 "

TABLE XIII.—*Continued.*

22.	Nitrogen	1·[illegible]	1·2	1·2	per cent.
23.	Oxygen	43·3	43·6	43·3	"
24.	Fuel ratio, fixed carbon to volatile matter	0·47	0·47	0·47	
25.	Gross calorific value of fuel as fired per lb. (from calorimeter)	7730	7570	7710	B. Th. U.
26.	Net calorific value of fuel as fired per lb. (calculated from gross value)	7130	6970	7110	"
27.	Calorific value of dry fuel per lb. (from calorimeter)	9560	9470	9550	"
28.	Weight of fuel fired	1271	1715	2720	lbs.
29.	Weight of refuse removed from above the fire bars	none	none	none	
30.	Weight of refuse removed from the ash-pit	27	33	76·5	"
31.	Combustible matter in total refuse removed	4·3	6·6	7·5	per cent.
	Average of Air and Flue Gas Observations.				
32.	Air pressure in ash-pit	—	—	—	
33.	Air pressure in furnace	—	—	—	
34.	Air pressure in flue leaving boiler	−0·11	−0·14	−0·22	ins. of water.
35.	Temperature of air in boiler room	70	70	68	° F.
36.	Temperature of flue gas leaving boiler	690	690	750	° F.
37.	Barometric pressure	29·9	29·6	29·8	ins.
	Analysis of dry flue gas by volume.				
38.	Carbon dioxide	10·0	10·5	12·6	per cent.
39.	Oxygen	9·0	8·2	4·0	"
40.	Carbon monoxide	1·4	1·5	4·7	"
41.	Nitrogen	79·6	79·8	78·7	"
	Water and Steam.				
42.	Average temperature of feed water	59	60	54	° F.
43	Total weight of water fed to the boiler, corrected for inequality of water level	4242	5504	7209	lbs.
44.	Average boiler steam pressure by gauge	95	94	79·5	lbs. per sq. in.
45.	Average calorimeter steam pressure by gauge	0·44	0·80	0·1	ins. of mercury.
46.	Temperature of steam in calorimeter	230	232	217	° F.
47.	Moisture content of steam	2·9	3·2	3·6	per cent.
	Total Quantities.				
48.	Duration of trial	478	480	478	mins.
49.	Weight of fuel as fired	1271	1715	2720	lbs.
50.	Weight of dry fuel fired	1027	1370	2198	"
51.	Weight of combustible fired	975	1289	2084	"

50.	Weight of dry fuel fired	[illegible]	[illegible]	2720 lbs.
51.	Weight of combustible fired	1027	1370	2198 "
		975	1289	2084 "
52.	Weight of refuse removed from ash-pit and grate (item 29 + item 30)	27	33	77 lbs.
53.	Weight of combustible in refuse (item 31 × item 52 ÷ 100)	1	2	6 "
54.	Total unconsumed combustible from analysis (item 56 × item 53 ÷ item 55)	2	6	9 "
55.	Weight of ash in refuse (item 52 − item 53)	26	31	71 "
56.	Weight of ash in fuel fired	52	81	114 "
57.	Weight of combustible consumed (item 51 − item 54)	973	1283	2075 "
58.	Weight of water fed to boiler corrected for inequality of water level	4242	5504	7209 "
59.	Weight of water evaporated corrected for moisture in steam	4135	5374	7007 "
60.	Weight of water evaporated into dry steam from and at 212°F.	4946	6418	8398 "
	Ash and Refuse.			
61.	Ratio refuse removed from grate to total refuse removed (item 29 ÷ item 52)	0·0	0·0	0·0
62.	Total refuse removed per cent of fuel as fired (item 52 ÷ item 49 × 100)	2·1	1·9	2·8 per cent.
63.	Total refuse removed per cent of dry fuel fired (item 52 ÷ item 50 × 100)	2·6	2·4	3·5 "
	Hourly Quantities.			
64.	Fuel fired per hour	160	214	341 lbs.
65.	Fuel fired per sq. ft. of grate surface per hour	17·7	23·8	37·9 "
66.	Dry fuel fired per sq. ft. of grate surface per hour	14·3	19	31 "
67.	Equivalent evaporation per hour, from and at 212°F.	621	802	1054 "
68.	Equivalent evaporation per hour, from and at 212°F., per sq. ft. of heating surface	2·89	3·73	4·9 "
69.	Horse power developed (item 67 ÷ 34½)	18	23·2	30·5 "
	Economic Results.			
70.	Equivalent water evaporated per lb. of fuel as fired (item 59 ÷ item 49)	3·25	3·13	2·57 lbs.
71.	Equivalent evaporation from and at 212°F. per lb. of fuel as fired (item 60 ÷ item 49)	3·89	3·74	3·09 "
72.	Equivalent evaporation from and at 212°F. per lb. of dry fuel fired (item 60 ÷ item 50)	4·81	4·69	3·82 "
73.	Equivalent evaporation from and at 212°F. per lb. of combustible consumed (item 60 ÷ item 57)	5·08	5·00	4·05 "
	Efficiency.			
74.	Efficiency of boiler furnace and grate based on gross calorific value $\left(100 \times \frac{\text{item } 71 \times 970\cdot4}{\text{item } 25.}\right)$	48·8	48·0	38·9 per cent.

TABLE XIII.—*Continued.*

75. Efficiency of boiler furnace and grate based on net calorific value $(100 \times \frac{\text{item } 71 \times 970 \cdot 4}{\text{item } 26.})$	52·9	52·1	42·2 per cent.
76. Combustible removed with refuse from ash-pit and grate, per cent of combustible fired	0·10	0·16	0·30 "
77. Efficiency of boiler based on combustible consumed (item 74 x item 51+ item 57)	49·0	48·2	39·0 "
Flue Gases.			
78. Dry flue gas per lb. of carbon (from gas analysis)	21·9	20·8	14·5 lbs.
79. Dry flue gas per lb. of fuel as fired (from gas analysis)	9·8	9·1	6·5 "

Heat Balance, Based on Peat as Fired.

	B.Th.U.	Per cent.	B.Th.U.	Per cent	B.Th.U.	Per cent
80. Total heat value of 1 lb. of fuel as fired (gross calorific value)	7730	100·0	7570	100·0	7710	100·0
81. Heat transferred to the water (and thermal efficiency)	3770	48·8	3630	48·0	3000	38·9
82. Loss due to total heat of the steam formed from moisture in fuel and combustion of hydrogen	760	9·8	750	9·9	770	10·0
83. Loss due to total heat of the dry flue gases	1460	18·9	1350	17·9	1060	13·7
84. Loss due to unburnt combustible in refuse	15	0·2	40	0·5	30	0·4
85. Loss due to unburnt carbon monoxide	560	7·2	560	7·4	1240	16·1
86. Balance of heat account: errors of observations, and unmeasured losses such as those due to the escape of unburnt hydrocarbons and hydrogen; and to radiation	1165	15·1	1240	16·3	1610	20·9
Total of lines 81 to 86; equal to line 80	7730	100·0	7570	100·0	7710	100·0

GENERAL NOTES.

For further particulars concerning items 26, 82, 83, see remarks on trials 71, 72, 73.

GENERAL REMARKS ON TRIALS 83, 84, 85.

Air Regulation. The fire door was left open for trials 83 and 84 to admit air over bars. During trial 85, air was admitted over the bars through the small holes in the fire door only.

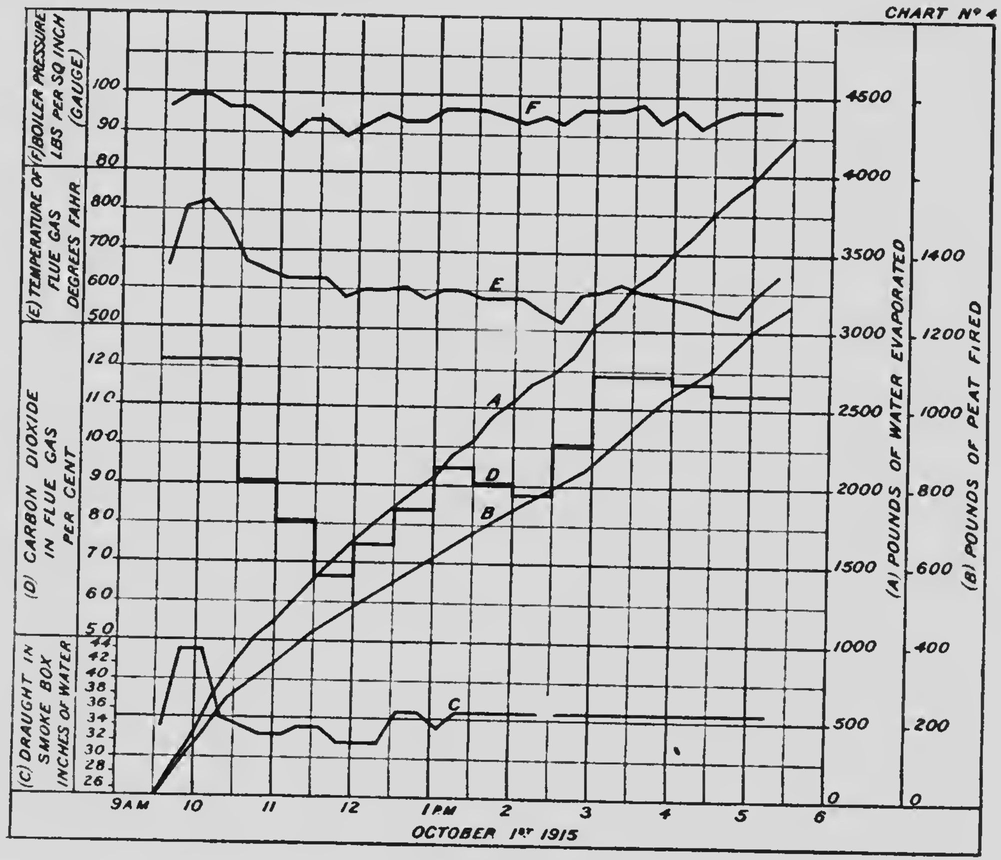
Smoke. Considerable quantities of chocolate coloured smoke were given off.

Flame. Long, filled the combustion chamber.

Clinker. No clinker was formed during the trials.

Cleaning. The fire was not cleaned during any of the trials.

Flame. Long, filled the combustion chamber.
Clinker. No clinker was formed during the trials.
Cleaning. The fire was not cleaned during any of the trials.



Trial No. 83.

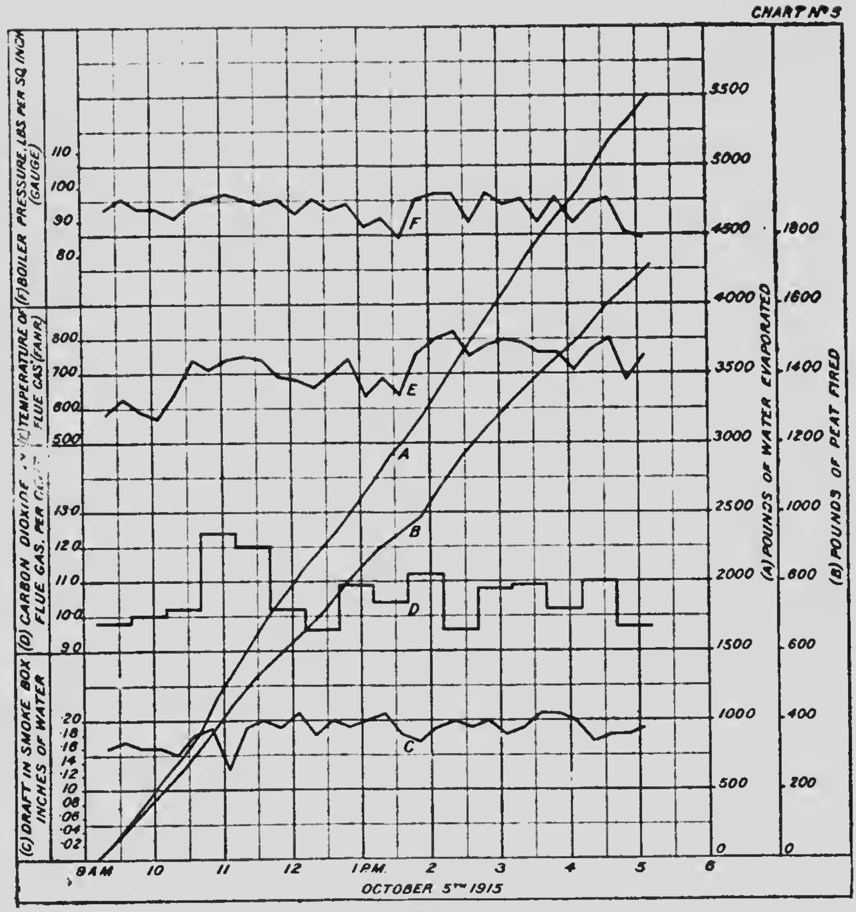


CHART Nº 3
(F) BOILER PRESSURE, LBS PER SQ INCH (GAUGE)
(E) TEMPERATURE OF FLUE GAS (FAHR)
(D) CARBON DIOXIDE IN FLUE GAS, PER CENT
(C) DRAFT IN SMOKE BOX INCHES OF WATER
(A) POUNDS OF WATER EVAPORATED
(B) POUNDS OF PEAT FIRED
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OCTOBER 5TH 1915

Trial No. 84.

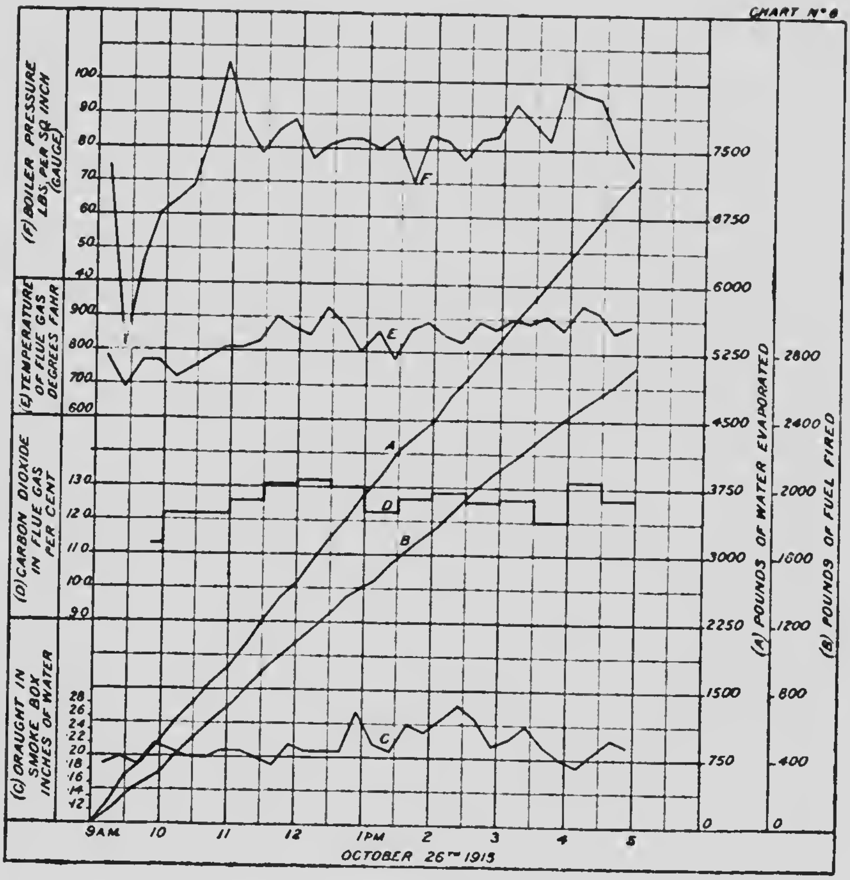
CHART Nº 8
(F) BOILER PRESSURE LBS. PER SQ. INCH (GAUGE)
(E) TEMPERATURE OF FLUE GAS DEGREES FAHR
(D) CARBON DIOXIDE IN FLUE GAS PER CENT
(G) DRAUGHT IN SMOKE BOX INCHES OF WATER
(A) POUNDS OF WATER EVAPORATED
(B) POUNDS OF FUEL FIRED
9 A.M. 10 11 12 1 P.M. 2 3 4 5
OCTOBER 26TH 1915

Trial No. 85.

PART IV.

SUPPLEMENTARY TRIAL (No. 115).

A boiler trial of short duration was conducted on Dec. 18th, 1916, in order to determine the total combustible gases present in the flue gas, when burning peat.

In the previous trials, the flue gas analysis apparatus was equipped only for the detection of carbon monoxide; but in this subsequent trial, arrangements were made—in analysing the flue gases—to determine the total combustible gases present: which was calculated on the assumption that they were made up entirely of carbon monoxide, methane, and hydrogen.

The trial lasted for 2¼ hours, during which 1358 pounds of peat were burnt, and was carried out on the Babcock and Wilcox boiler, provided with the same grate bars and grate area as for trial No. 71.

The peat used was manufactured at Alfred, Ont., and contained 19·1 per cent of moisture, and 4·8 per cent of ash: the gross calorific value being estimated at 7670 B.Th.U. per pound.

Seven samples of gas were taken, each over a period of twenty minutes.

The full results of each analysis are appended (Table XIV) and the percentage of heat in the original peat fired which remained latent as combustible gases is calculated on the assumption that for every 100 pounds of carbon present in the peat fired, 98 pounds are present in the flue gas.

TABLE XIV.

Gas Analyses, for Trial 115.

Sample No.	1.	2.	3.	4.	5.	6.	7.	Average.
Per cent by volume, Carbon dioxide............	9·6	10·2	9·6	11·3	11·1	10·8	11·6	10·6
Oxygen....................	10·2	9·5	9·2	7·9	8·2	8·8	7·6	8·8
Carbon monoxide..........	0·7	0·8	0·9	1·2	1·5	0·7	1·2	1·0
Methane..................	0·09	0·07	0·05	0·15	0·15	0·00	0·12	0·09
Hydrogen................	0·17	0·19	0·30	0·26	0·30	0·22	0·31	0·25
Nitrogen..................	79·24	79·24	79·95	79·19	78·75	79·48	79·17	79·26
Heat present in flue gases, per cent of heat in peat fired as:—.....								
Carbon monoxide...........	3·9	4·2	5·1	5·5	6·9	3·6	5·4	4·9
Methane..................	1·6	1·1	0·9	2·2	2·2	0·0	1·7	1·4
Hydrogen................	1·0	1·0	1·7	1·2	1·4	1·1	1·4	1·3
Total....................	6·5	6·3	7·7	8·9	10·5	4·7	8·5	7·6

An examination of **Table XIV** will show that the loss due to unburnt carbon monoxide represents only about two-thirds of the total loss due to the escape of combustible gases. Based on these results, use will be made of the approximation that the loss due to the unmeasured incombustible gases during trials 71, 72, 73, 83, 84, and 85, was in each case equal to one-half of the measured loss due to carbon monoxide, the unaccounted for losses would then be reduced from 12·0 per cent, 14·7 per cent, and 10·9 per cent; to 10·1 per cent, 12·0 per cent and 8·5 per cent for those trials carried out on the water tube boiler. These figures while still high, are not so conspicuously high as before.

In applying the same assumption to the trials on the fire-tube boiler, the unaccounted for losses are reduced from 15·1 per cent, 16·3 per cent, and 20·9 per cent, to 11·5 per cent, 12·6 per cent, and 12·9 per cent, respectively, which are much more uniform. The percentages of heat in the peat fired which remains unused in the form of combustible gases may be estimated as 5·7, 8·1, and 7·2 for trials 71, 72, and 73, while for trials 83, 84, and 85, they are probably 10·8, 11·1, and 24·2, respectively.

It is clear that an increase of from 3 to 4 per cent in the thermal efficiency of the boiler might be expected for the first three trials, and of from 5 to 12 per cent for the three latter trials might be expected if all the combustible gases could be burned.

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