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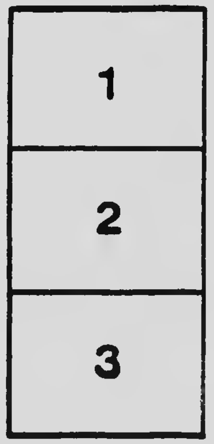
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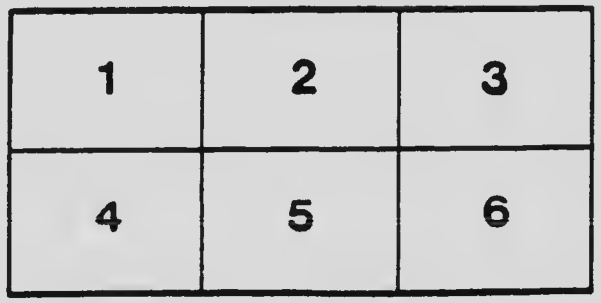
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ALBERTA LIGNITE

BY

HAANEL & BLIZARD

331

CANADA
DEPARTMENT OF MINES
Hon. Louis Coderre, Minister; R. G. McConnell, Deputy Minister.

MINES BRANCH
Eugene Haanel, Ph.D., Director.

Results of the Investigation of Six Lignite Samples Obtained from the Province of Alberta

BY

B. F. Haanel, B.Sc.
Chief of Fuels and Fuel Testing Division
AND
John Blizard, B.Sc.

OTTAWA
Government Printing Bureau
1915

No. 331

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 trials carried out at the Fuel Testing Station, Ottawa, 1913-14, with six commercial samples of lignitic coal, obtained from the Province of Alberta.

I have the honour to be,
Sir,
Your obedient servant,
(*Signed*) **B. F. Haanel.**

OTTAWA,
December 24, 1914.

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INVESTIGATION OF SIX LIGNITE SAMPLES OBTAINED FROM THE PROVINCE OF ALBERTA.

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ERRATA:

On pages 93 and 96 for "Canmore Coal Co., Ltd., Canmore, Alberta," read, "Georgetown Collieries Ltd., Canmore, Alberta."

On page 7, line 17 from bottom of page, for "G" read, "B".

Mines Branch Report No. 331, on—
Results of the Investigation of Six Lignite Samples obtained from the Province of Alberta.

INVESTIGATION OF SIX LIGNITE SAMPLES OBTAINED FROM THE PROVINCE OF ALBERTA.

RESULTS OF THE INVESTIGATION OF SIX LIGNITE SAMPLES, OBTAINED FROM THE PROVINCE OF ALBERTA.

INTRODUCTORY.

Investigation of Lignite Coal.

An investigation of the coals of Canada was begun some years ago at McGill University, under the auspices of the Mines Branch of the Department of Mines. That portion of the investigation undertaken by McGill University was completed about three years ago; since then the work has been continued and extended at the Fuel Testing Laboratories of the Mines Branch, Department of Mines, Ottawa.

The investigation, in general, includes all the coals of Canada: comprising their chemical analyses—both proximate and ultimate; the determination of their calorific power; their value as fuels for the production of a power or fuel gas when burned in a gas producer; and for the generation of steam when burned under a boiler. The results of such an investigation should definitely show the best use to which the different fuels can be applied. The producer employed at McGill University was of small capacity, viz: 30 H.P., and was scarcely large enough to furnish concordant results which would prove of value from a commercial standpoint. Its design, moreover, was not specially suited for the gasification of lignite, although the results obtained with it plainly indicated what might be expected in a larger and specially designed producer. In order to bring an investigation of this character within the domain of commercial practice, the Mines Branch had installed a well-known commercial type of producer, specially designed and constructed to gasify in the most efficient manner all bituminous coals and lignites, and, in short, to answer all the strictest requirements of commercial practice. This producer is of the double zone type—built by the Westinghouse Machine Co.

The value of the various solid fuels, for steam-raising purposes, is determined by burning them in the fire-box of a Babcock and Wilcox marine water tube boiler. Arrangements are being made to install in connexion with this boiler a specially constructed combustion chamber, by means of which it is hoped to obtain much better results than have hitherto been realized, when burning lignite coals.

Owing to extensive alterations, and the installation of new apparatus at the Fuel Testing Station, the investigation of the commercial samples of lignite (obtained about two years ago from lignite mines in operation in the Province of Alberta) was not begun until August, 1913; and these tests were not completed until recently, owing to the limited staff then at the disposal of the Mines Branch—for this class of work. The installation of the boiler plant was not completed until January, 1914; so that the steaming tests of these coals were not concluded until the beginning of April.

The investigation of the value of coals for the production of a power or fuel gas, so far carried out, has been confined to the non-by-product recovery producer; but inasmuch as many of the coals of Canada contain comparatively high percentages of nitrogen, the recovery of this valuable element, in the by-product recovery producer, would, in many cases, prove to be a profitable undertaking. But, when the principal object in view is the production of power, or of a fuel gas, the non-by-product recovery type will serve to indicate the value of the various coals tested as fuels for the other types. When by-product recovery is not attempted, the aim is the complete gasification of all the combustible components of the fuel, and this implies the destruction of the tarry components in the case of fuels high in volatile matter, whether such destruction is accomplished by burning the tar within the producer, or by its decomposition by chemical reaction into fixed combustible gases. In the Westinghouse double-zone producer, the tarry matter distilled from the coal is partially burned and partially decomposed into fixed combustible gases, so that the final gas leaving the producer contains, as a rule, only a trace of tar, which is separated by passing through a simple water scrubber. The gas is thus, in a simple and efficient manner, practically freed from any deleterious matter.

In those portions of Canada which are too far distant from bituminous coal supplies, but which are well provided with lignite deposits, the production of power through the media of the gas producer and gas engine will prove to be the most efficient method. Indeed, this applies at the present time, to almost all the coals, especially those rich in nitrogen; but the application is especially pertinent in the case of lignites, which are not well suited for burning under boilers.

The municipal power plant in the city of Edmonton serves as an excellent example of the comparative value of the lignites —obtained in the vicinity—for steam-raising, and the production of a power gas, since this plant is equipped with the most modern steam power units, and contains, in addition, one producer gas power unit. In this case, the producer gas power plant has proved to be the more economical, in spite of the disproportionate capital charge against it.

Not only is producer gas an excellent fuel for the production of power, but it also serves as an excellent substitute for town or retort gas for many varied purposes. It has, for example, been utilized in England with great success for heating metal furnaces, and for other industrial purposes, and the field for the employment of this kind of gas for domestic purposes is very large indeed, especially where a cheap and satisfactory domestic fuel cannot be obtained. Producer gas, though lower in heating value than town or retort gas, can, nevertheless, be sold at a much lower price per 1,000 heat units than the latter, and when burned under the proper conditions will produce a temperature sufficiently high for many metallurgical purposes.

The tests of the six commercial samples of lignite obtained from six of the principal producing mines in the vicinity of Edmonton, show that they are all well adapted for utilization in the gas producer. The gas, after passing the simple water scrubber, was practically free from tar or solid matter; and when burned in the cylinder of the gas engine, left no residues of any kind. The composition of the gas, moreover, for most of the lignites tested, did not vary to any appreciable extent throughout the trials. Considerable difficulty was anticipated from packing of the fuels in the producer, and the consequent production of high suctions, owing to the finely divided condition the lignites usually assume when subjected to heat, or when exposed to the air. No trouble, however, from this source was experienced, and the suctions, though higher than in the case of coking coals, were not excessive. Clinkering was not noticeable to any marked extent, except in the case of one of the lignites; and in this, as well as in every other case, poking readily relieved the trouble.

It must be borne in mind that the producer used for these trials was designed for a coking, bituminous coal, hence its interior dimensions were such that the expansion of the fuel in passing down towards the bottom zone was allowed for. This property of a bituminous coal when heated, necessitated an increase in the area of the cross-section of the upper zone, from the top towards the annulus, or gas offtake, and a large volume for the lower zone. In the case of lignite, the reverse phenomenon is observed, for, instead of an expansion of the fuel as the volatile matter is distilled off, a contraction occurs. For this reason the coning of the upper zone should be the reverse of that necessary for coking coal; and since the percentage of fixed carbon is much less in the case of lignite, and the volume of the fuel passing into the lower zone is also very much less, this portion of the producer should be made with a much smaller volume, in addition to a change in its shape. Such alterations in the design whenever deemed necessary can be easily made, and should be worked out for the special fuel under consideration.

Notwithstanding the fact that the producer was not, in every detail, designed for the use of lignite, the results were very satisfactory.

The heating value of the gas appears to be rather low in certain cases; but this, under commercial conditions and continuous operation could be appreciably increased. The average net calorific value of the gas generated in this type of producer should be in the vicinity of 115 B.T.U. per cubic foot.

The recovery of the nitrogen content of the fuel contained in the ammonia formed in the producer, would not, in any sense, prove profitable in this type of producer, as will readily be seen by referring to the results of the tests. These determinations were made with a view to rendering the tests as complete as possible. Some of the lignites were burned in the Körting, double-zone, peat gas producer, in order to ascertain their behaviour when gasified in this type of producer. The results were not unsatisfactory, although the thermal efficiency did not, in any case, approach that obtained with the Westinghouse producer. The Körting producer was designed for the exclusive use of peat fuel; but the fact that as clean a gas, with as high a heating value, can be obtained with lignite as with peat, when burned in this producer, is not without interest.

Lignite is not a difficult fuel to gasify in an ordinary well-designed producer, hence should prove an excellent fuel for the production of power, or fuel gas, when utilized in this manner. Where water power does not exist, this method of developing power should prove profitable, as well as economical.

Part II of this report contains the results of the boiler trials on the coals tested in the producer. The results set forth in the accompanying tables will show that, under certain and favourable conditions, lignite can be satisfactorily burned under a boiler for steam-raising, when employing the usual grate bars, and when the fuel is hand fired. Better results could be obtained with specially constructed combustion chambers, provided with mechanical stokers. However, no provision was made for comparing the relative efficiency of the two methods of firing and burning the fuel.

As is stated in the report, the rate of steaming was kept as nearly constant as possible for all the fuels burned, so that no opportunity was provided for observing the behaviour of the various lignites when burned under different conditions, and, while the importance and value of carrying out several trials on the same class of coal under different conditions as regards rate of steaming, etc., was recognized, this could not be done owing to the limited quantity of each sample sent to Ottawa.

ACKNOWLEDGMENTS.

The samples sent to Ottawa for investigation—both mine and commercial samples—from the Province of Alberta were obtained through the office of Mr. John Stirling, Chief Inspector of Mines for that Province: who is co-operating to this extent in the investigation. In the selection of commercial samples an effort has been made to obtain samples from those mines, only, which are operating on a commercial scale, and which are regular producers for the market.

All chemical work entailed in these tests was conducted under the supervision of Mr. Edgar Stansfield, chief engineering chemist to the Division of Fuels and Fuel Testing. He was assisted by Dr. Carter, assistant engineering chemist, and Mr. Meldrum. Mr. A. W. Mantle, superintendent of the Fuel Testing station, acted as one of the assistants during these tests.

(*Signed*) **B. F. Haanel.**

Dec. 28, 1914.

PART I.

PRODUCER TESTS.

BY

B. F. Haanel and John Blizard.

TYPES OF PRODUCERS EMPLOYED IN THE TESTS.

The two producers employed in these tests were evolved from the simple up-draft type, or, from a combination of this and the simple down-draft type.

UP-DRAFT PRODUCERS.

A simple form of this type of producer, which clearly illustrates the principle of operation, is shown in Fig. 1. The fuel is charged through G, and the air and steam required for combustion are admitted through A, below the fire bars. The gas off-take is situated near the top of the producer, at G, which is placed at a considerable distance above the fuel level. The air and steam in passing upward, through the reaction zone, interact with the hot carbon, and a combustible gas is thus formed which leaves by the exit G. It will be seen that the tarry matter, which is distilled from the fuel, passes off with the gas, without coming into contact with the carbon in the combustion zone, consequently, it takes no part whatever in the formation of the final gas. If, therefore, a large proportion of the total heating value of the fuel is contained in such tarry matter, the thermal efficiency of the process will be very low, since, as pointed out, this tarry matter leaves the producer, undecomposed. In addition to the inefficient manner in which such a producer converts the heat of a fuel into a useful gas, the fact that the gas is heavily laden with tarry matter—which must be removed by tar extractors before it can be utilized in a gas engine—must not be overlooked. In most cases where a fuel is gasified for the primary purpose of generating power, the formation of tar constitutes a nuisance, and, in order to remove this objection, the down-draft type of producer was devised.

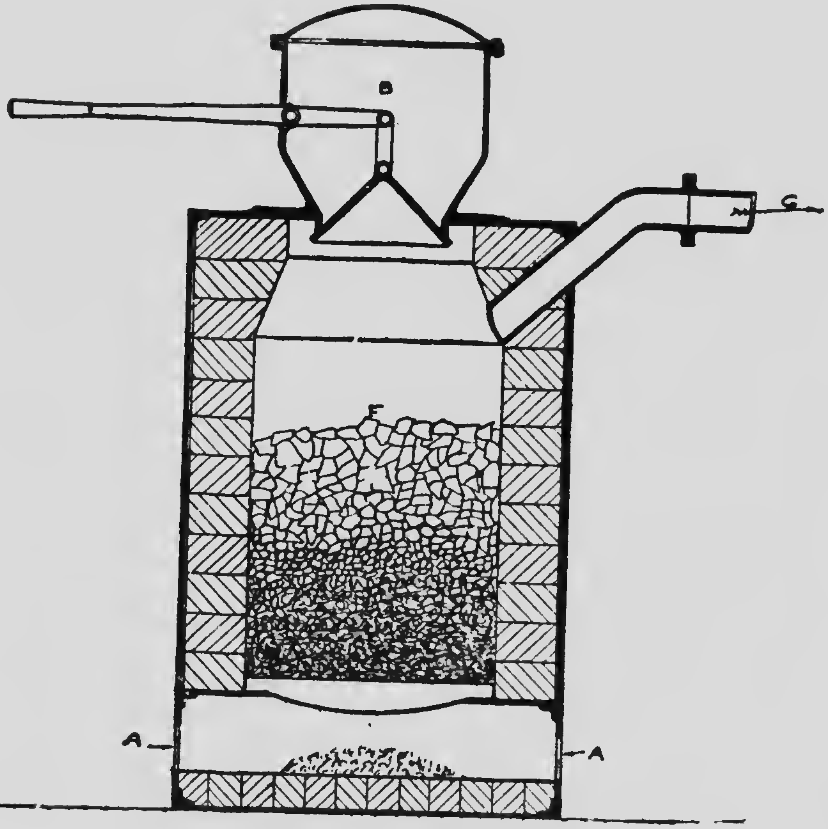

Fig. 1. Simple form of up-draft gas producer.

DOWN-DRAFT SUCTION PRODUCER.

In this type of producer, the air, and steam if required, are admitted at the top, and in passing downwards through the reaction zone of the producer, form, by interaction with carbon, a gas which leaves by an exit situated below the combustion zone. Fig. 2 shows an illustration of a producer of this type which was used for the coal tests carried out at McGill University. The fuel, with this type of producer, is also charged through the top; but since the draft is in a downward direction no gases escape from the charging door. Such an arrangement permits the poking of the fuel bed through this charging door, also the

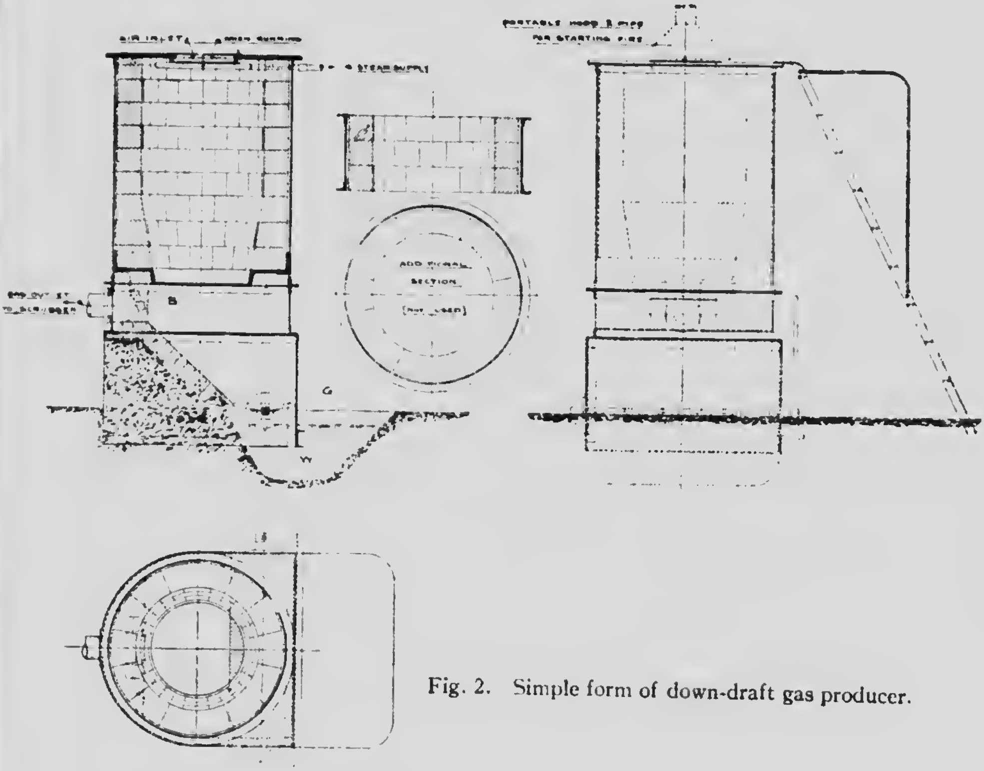

Fig. 2. Simple form of down-draft gas producer.

direct observation of the fire. By referring to Fig. 2, it will be plainly seen that all the volatile matter which is distilled from the fuel must pass down through the hot fuel bed before leaving at the exit situated at or just below the combustion zone; hence it comes into intimate contact with the incandescent carbon of the reaction zone, and is either decomposed into permanent gases or is partially burned and partially decomposed. The result—however the reaction proceeds—is a gas practically free from tar, and a higher thermal efficiency for the process of gasification. With this type of producer an appreciable quantity of combustible matter passes below the gas outlet, without being completely burned, and since this cannot, in a practical manner, be recovered, it is lost as far as the process is concerned, and tends, therefore, towards a decrease in the thermal efficiency of the system. This constitutes the principal objection to this type, though in many other ways such a producer is quite satisfactory.

COMBINED UP-DRAFT AND DOWN-DRAFT PRODUCER.

This type of producer was designed for the purpose of combining all the advantages of the up- and down-draft types, and at the same time eradicating their objectionable features. It will readily be seen from the following description that, with such a producer, it is theoretically an easy matter to decompose all the moisture and volatile matter distilled from a fuel, and to insure the complete combustion of all the combustible matter passing into the lower zone. In such a producer, fuel is charged at the top, where air and steam inlets are situated; while air and steam, only, are admitted to the bottom of the lower zone. The gas formed is drawn off at the middle of the producer, hence the final producer gas is a mixture of the gas formed in the upper and lower zones. Although the gas formed in the upper zone is more or less uneven in its composition, owing to the charging of green fuel from time to time, the composition of the gas formed in the lower zone can be kept approximately constant; since this zone is operating continuously on hot coke or carbon

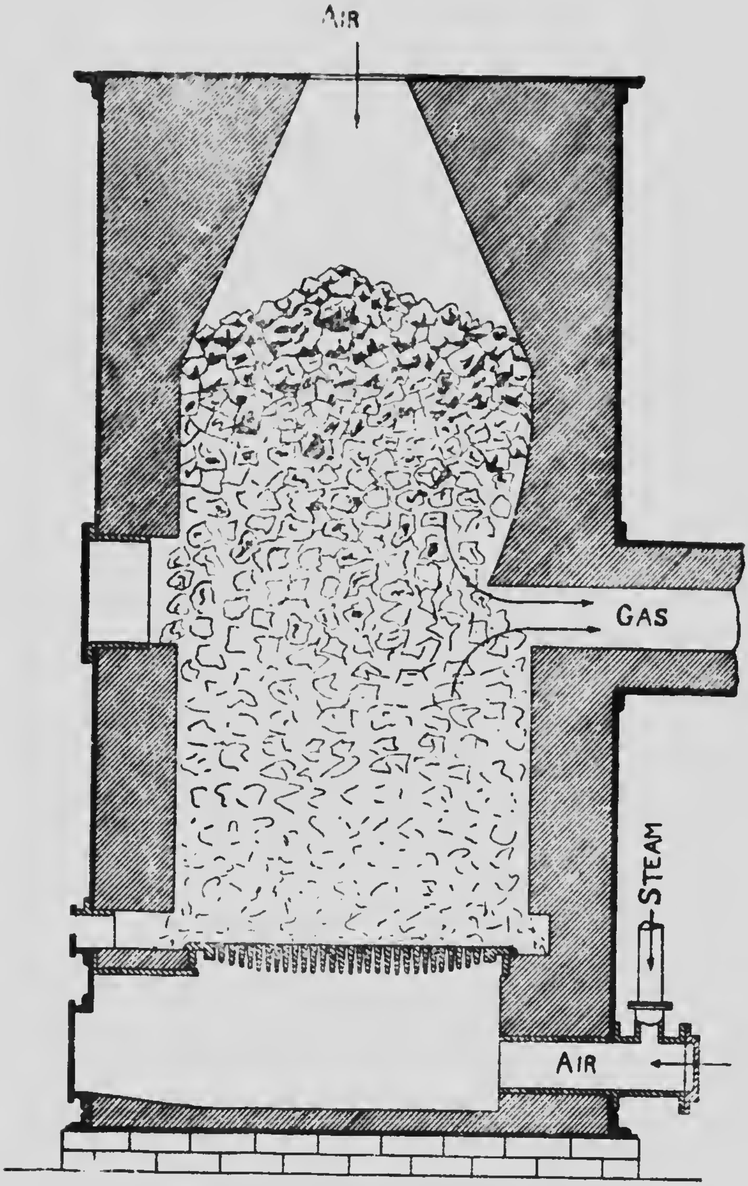

Fig. 3. Combined up-draft and down-draft gas producer.

resulting from the coking process going on in the upper zone. From this it follows that, by employing two zones in the manner above described, theoretically a gas can be produced which will be less sensitive, as regards its chemical composition, to changes taking place in the charging zones. This may be said to constitute still another advantage over the other types of producer previously discussed. A producer constructed upon this principle is shown in Fig. 3.[1]

The Westinghouse producer employed at the Fuel Testing Station for most of the tests to be described, operates upon precisely the same principle, although its construction and method of operation are somewhat different. In short, the functions of the two zones of this producer may be described as follows: the upper zone serves the purpose of distilling the moisture and volatile matter from the fuel, thus supplying coke, or tar free combustible matter, to the lower zone. In this zone, gas is also formed from the volatile matter, moisture, and hot carbon, interacting in their downward path. In the lower zone the tar free combustible matter, or coke—depending on the fuel employed—interacts with the air and steam admitted through the tuyere situated at the bottom of the producer.

DOUBLE ZONE PRODUCER: BOTH ZONES OPERATING WITH UP-DRAFT.

For the gasification of fuels high in volatile matter and moisture, a producer designed on this principle is very efficient. The Körting, double zone, peat gas producer, (see Fig. 4) is constructed according to this principle. The fuel is charged into hoppers A, A, from which it falls upon two sloping grates C, C. Theoretically, the combustion in this portion of the producer should be just sufficient to distil the volatile matter and moisture from the green fuel. In practice, however, the fuel consumed here exceeds that theoretically required. The tar free fuel passes through a restricted canal to a second zone situated directly beneath, and here combustion is carried to completion. The upper zone gas charged with moisture and tarry matter is caused to pass through the opening D and downcommer E to

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[1] Illustration taken from the Proceedings of the Institution of Mechanical Engineers, 1911.

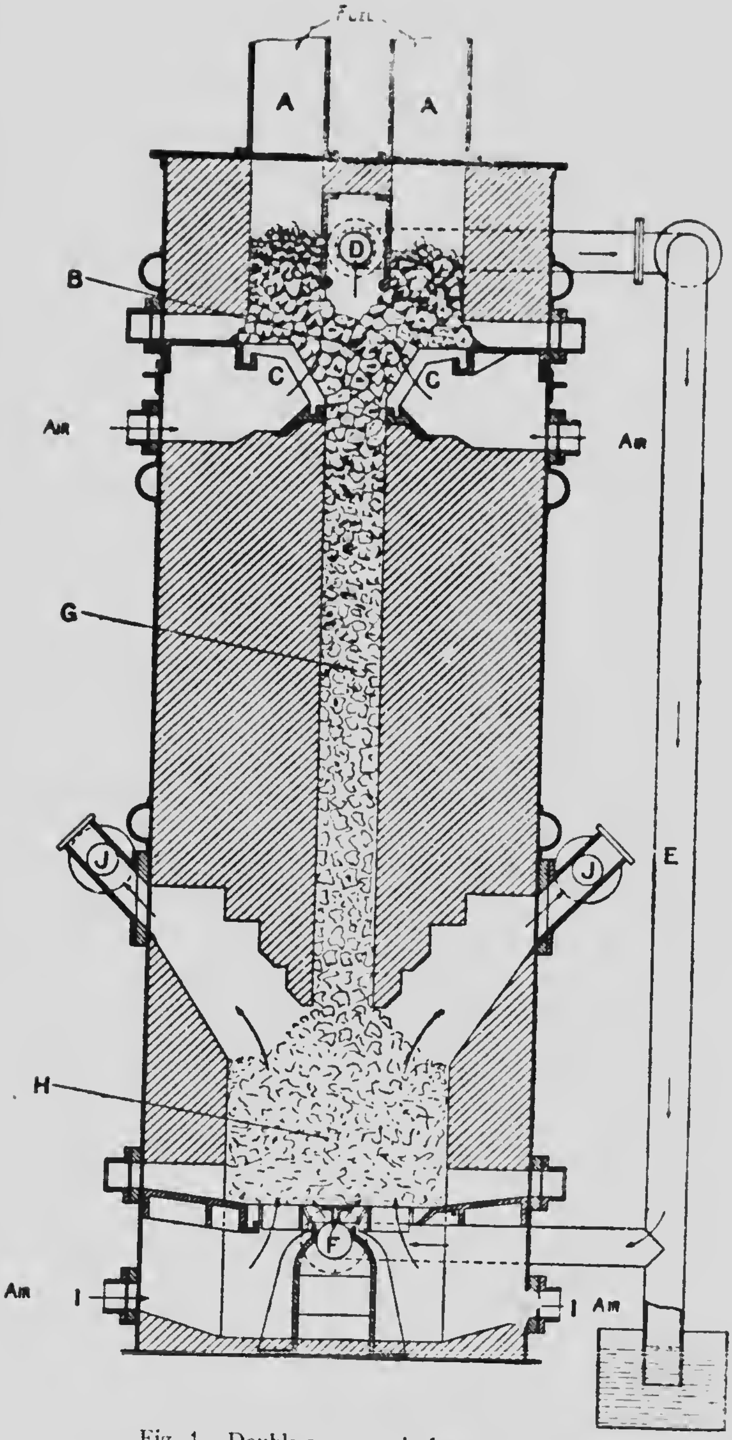


Fig. 4. Double zone, up-draft gas producer.

the chamber F, situated directly beneath the grate bars of the lower zone. From this point, the gases pass upward through the bed of incandescent carbon to the two offtakes J, J, situated on either side of the producer. The formation of producer gas is accomplished almost entirely in the lower zone. Here the gases resulting from the combustion of fuel in the upper zone together with air admitted through openings I, I, pass upwards through the hot carbon. As a consequence, reaction takes place between the hot carbon and the air, moisture, and, to a certain extent, the tarry matter. The moisture is decomposed, forming free hydrogen, carbon monoxide, and carbon dioxide; while the carbon dioxide contained in the upper zone gases is partially reduced to carbon monoxide. The tarry matter is partly decomposed into permanent combustible gases, and is also, to a certain extent, burned. Theoretically, such a process should result in a tar free gas; but in actual practice this is never the case, and a tar extractor of some description must be interposed in the system for the purpose of purifying the gas sufficiently for use in the gas engine.

DISCUSSION ON THE COMBINED UP-DRAFT AND DOWN-DRAFT TYPE OF PRODUCER.

This type of producer has been evolved to supply the requirement for a gas generator capable of producing a gas from bituminous coals sufficiently clean for utilization in a gas engine without first passing through the usual train of purifying apparatus. The simple form of down-draft producer, described elsewhere, was a partial solution to the difficulties produced by the presence of tar in the gas—but this type on the other hand possessed certain disadvantages which offset to a certain degree the advantage otherwise gained. Fairly good results were obtained with the down-draft producer used during the trials conducted at McGill University for the Department of Mines. A rotary tar extractor was employed which gave satisfactory results for some of the trials; but in others considerable trouble was experienced with tar, which necessitated cleaning of the extractor while the trial was in progress. In the case of lignites, very little or no tar was present in the gas, and, in certain instances, the trials were run satisfactorily without using either the tar extractor or a sawdust scrubber—the only cleaning agent being a wet coke scrubber. The efficiency of this producer when gasifying lignitic coals varied between 49·5 and 65·7 per cent; whereas in the trials with the Westinghouse double zone producer, at Ottawa, on similar fuels, the efficiencies ranged between 71·8 and 62·0 per cent. The better results obtained with this producer may be attributed, partly, to its larger capacity, but more particularly to the fact that the combustible matter passing into the lower zone is more completely burned. The refuse drawn from the former producer contained from 44·4 to 53·4 per cent of combustible.

The advantages of the double zone producer over either of the other two types may be summarized as follows:—

(1) The practically complete combustion of all the fuel charged.

(2) The formation of a tar free gas.

(3) Absence of auxiliary tar extracters or other gas purifying devices.

(4) A final gas composed of a mixture of the gases generated in the two zones of the producer, hence less variation in compostition due to charging green fuel, since the gas formed in the lower zone is practically constant as regards its composition.

When a coking, bituminous coal is burned in this type of producer, instead of the formation of tar, lamp black is produced to a greater or less degree, depending on the method of manipulation adopted. This lamp black is readily separated from the gas in its passage through the water scrubber.

DESTRUCTION OF THE TARRY VAPOURS.

The heavier hydrocarbon vapours are either split up into fixed combustible gases, or are burned within the producer itself. It is not unlikely that both of these agencies are effective to a certain degree, but it is also quite probable that the major portion of the tarry matter is burned. Where the heavy hydrocarbon vapours are oxidized the products of combustion are carbon dioxide, carbon monoxide, and steam, in proportions depending on the temperature. These products of combustion may again be reduced or oxidized in their passage through the hot carbon to the offtake. If carbon dioxide, CO_2 is formed, then its reaction with carbon according to the reversible reaction:—

$$CO_2 + C \rightleftharpoons 2CO$$

will result in the formation of carbon monoxide; but while this reaction may proceed to a certain degree, it is quite likely that a further and reverse reaction takes place, and that the carbon monoxide is again decomposed, during its passage through the cooler portion of the fuel bed, into carbon dioxide and free carbon. The presence of this latter reaction is confirmed since free carbon in the form of lamp black is contained in the final gas. Methane also occurs as a component of the gas in more or less variable proportions—but always in comparatively small quantities. It must be borne in mind, when considering the reactions which are likely to obtain in any producer, that while, theoretically, the column of fuel can be divided into distinct zones where certain reactions will take place, that in practice, no such division can be accurately made, owing to the impossibility of maintaining uniform combustion throughout the whole area of the fuel bed. This is due in part to the heterogeneous forms and sizes of the individual pieces of fuel which permits the passage of more air through some portions of the bed than others. Consequently, isolated zones of high temperature may exist where least expected, and these will, to some extent, alter the expected reactions.

The combustion of the hydrocarbons as a means of removing the tarry matter will now be considered in more detail. The process of burning the hydrocarbons to carbon dioxide, carbon monoxide, and steam, renders the coking process of the fuel more simple, and makes it an easier matter to approach the ideal condition for a double zone producer, viz., that of delivering only fixed carbon to the lower or up-draft portion. In order that the products formed by the combustion of the tarry matter may be decomposed into combustible gases, it is necessary that sufficient fixed carbon be present to effect the required reactions.

Before passing to a description of analyses of the tests, it will be of interest to examine the chemical analyses of the lignites tested, as to their suitability for operation under the ideal conditions outlined above. For these conditions it will be assumed that the reactions take place according to two of the following three equations, viz: "A" for the reaction between carbon dioxide and carbon, and either "B" or "C" for the reaction between steam and carbon. The chemical reactions are:—

A. $CO_2 + C = 2CO$
B. $H_2O + C = H_2 + CO$
C. $2H_2O + C = CO_2 + 2H_2$

It will further be assumed that "fixed carbon"—an empirical term employed by chemists in reporting their analyses of coal—represents pure carbon.

According, then, to the assumption that carbon dioxide and steam are reduced as shown above, it is evident from A, that one pound of carbon in the volatile matter requires one pound of carbon in the fixed carbon, for its subsequent reduction after its combustion to carbon dioxide, and from B, that one pound of hydrogen in the volatile matter requires 6 pounds of fixed carbon, and from C, that one pound of hydrogen requires 3 pounds of fixed carbon.

TABLE I.

Comparative Analysis of Coals Tested.

PER 100 LBS. OF FUEL AS CHARGED.

Name of coal.	Fixed carbon in coal as charged	Carbon in volatile matter.	Hydrogen.	Fixed carbon required to reduce carbon dioxide and steam A+B.	Fixed carbon required to reduce carbon dioxide and steam A+C.	Surplus fixed carbon A+B reaction.	Surplus fixed carbon A+C reaction.
Tofield....	36·7	13·7	6·6	53·3	33·5	−16·6	3·2
Rosedale..	43·4	13·9	5·8	48·7	31·3	− 5·3	12·1
Gainford..	43·8	10·0	5·0	40·0	25·0	+ 3·8	18·8
Cardiff collieries	40·4	11·7	6·4	50·1	30·9	− 9·7	[illegible]
T[illegible]n City	41·3	12·8	5·9	48·2	30·5	− 6·9	[illegible]
Pembina..	43·9	10·0	5·5	43·0	26·5	− 0·9	[illegible]

From the above table it will be seen that in one case only, that of the Gainford coal, is there a surplus of fixed carbon after the reactions A and B have been effected. As the reversible reaction $CO_2 + H_2 \rightleftharpoons CO + H_2O$ is constantly taking place, neither B nor C could take place exclusively, in an ordinary producer, but the right hand side of the reversible reaction will predominate as the temperature rises. A further inference from the above table is, that with the exception of the reaction A and B, calculated for the Gainford coal, there will be an excess of steam present supplied by the coal itself after the reactions have been completed. For such fuels, therefore, as those considered, it would seem inadvisable to admit steam to the down-draft zone except in those cases where it is desired for the purposes of operation, to decrease the temperature. Of the eight trials of lignites carried out at McGill University with the simple down-draft producer, steam was introduced in only three cases. The moisture contents of the lignites in these three cases were 16·1; 12·6; and 7·8 per cent, respectively. In all the trials described herein, no steam was admitted to the upper zone of the producer.

In the actual operation of a double zone producer it is impossible to completely burn and subsequently reduce the tarry vapours by the methods described. Instead of this perfection being attained, either the products of combustion of the tarry vapours are not completely reduced, or the tarry vapours leave the producer partly unburned. The successful operation of such a producer will, therefore, lie between the burning and reduction of the volatile matter without permitting an undue proportion of gases to escape in the form of carbon dioxide and steam. By such a method of operation, a practically tar free gas can be obtained.

Objective of Tests.

The tests were carried out for the purpose of determining: (1) the efficiency of the conversion of the fuel into gas; (2), the quality of the gas produced; (3) the quantities of tar present in the gas and the suitability of the gas for use in a gas engine; and (4) the difficulties encountered in the operation of the producer.

Other information was obtained such as the quantity of ammonia in the gas, and the quantity of water used for cooling and cleaning the gas; the variation in the efficiency of the producer for the different tests is also accounted for as far as possible. Further, comparison is made possible between the utilization of the fuel in two types of producers.

METHOD OF CARRYING OUT TESTS, AND OBSERVATIONS THEREON.

Fuel Quality, and Composition. The accurate sampling of the fuel charged is an important item in tests of this character, and should be carried out for fuels which change so rapidly as lignite, immediately before a test. The consumption of fuel during a test is determined by accurately weighing all the coal charged and by judging the conditions of the fuel bed at the beginning and end of the test.

DETERMINATION OF THE QUALITY OF THE FUEL.

Immediately before each trial the fuel to be tested was carefully sampled. For sampling so large a quantity of fuel it was found convenient to employ the *third* shovel method: i.e., the entire quantity of coal was shovelled over, and every third shovelful of coal was thrown into a heap by itself; after crushing, this was then again reduced in the same manner; and finally quartered down to a comparatively small sample, from which a laboratory sample was taken, and put into a sealed jar, for further examination. The fuel was in every case charged into the producer or boiler furnace without being subjected to any preliminary treatment, such as crushing or screening.

FUEL CHARGED.

The fuel before charging was weighed on a standard scale, and a record was kept of the fuel level during the entire test.

STARTING AND STOPPING THE TESTS.

The producers were started from a small fire, which was gradually built up with an up-draft.

Before starting the trial, gas was drawn off for several hours, until conditions became normal. At the beginning of the trial the fuel levels were observed; all ash was removed from the ash pit of the Körting producer, and the ash level adjusted in the Westinghouse producer so that the incandescent fuel was just visible through the lower sight-holes.

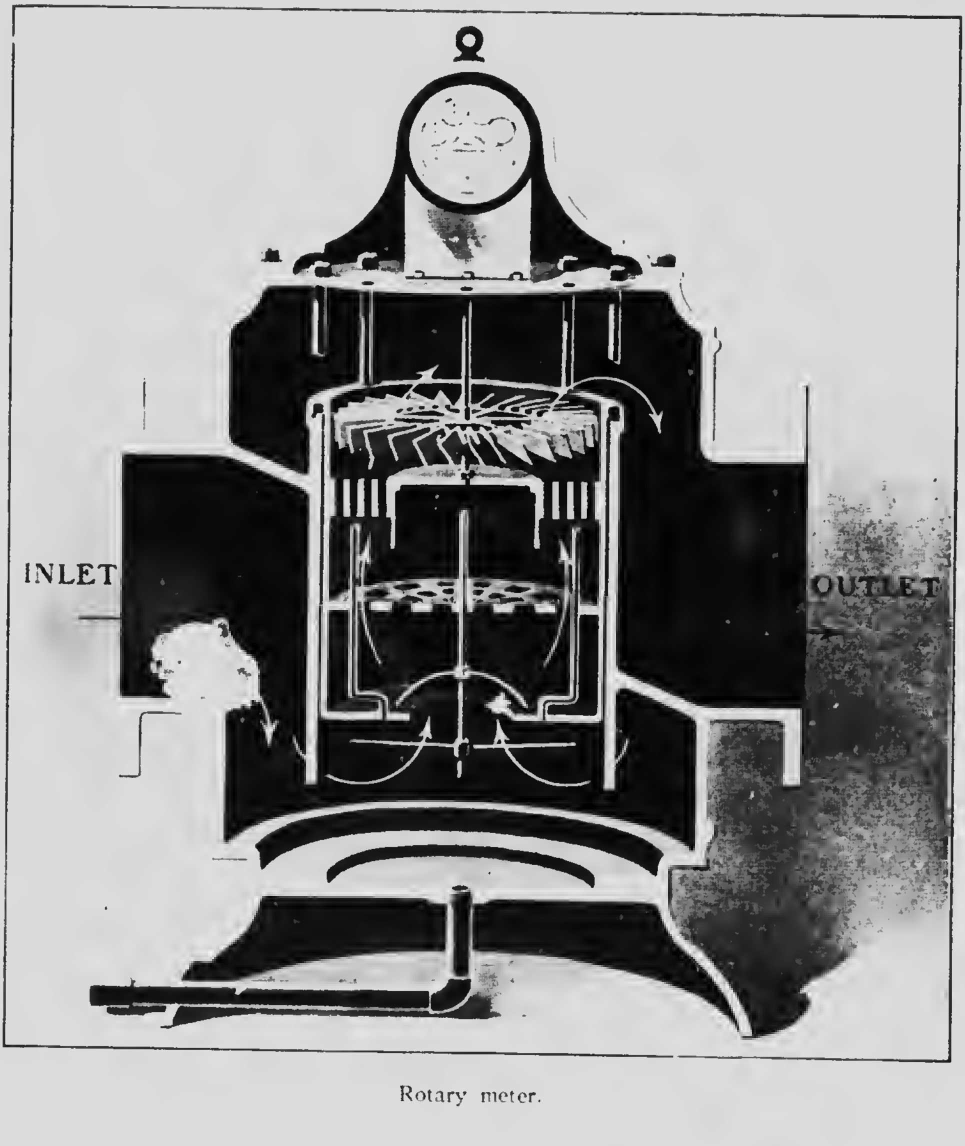
Before stopping the tests, the conditions in the producer were made to approximate, as far as possible, to the conditions obtaining at the beginning. In the case of the Westinghouse producer, accurate knowledge of its interior condition is almost an impossibility, and is likely to give rise to serious errors in the estimation of the fuel consumption unless the trial is conducted for a period of sufficient duration to reduce any such errors to a negligibly small percentage of the total fuel charged.

Possible Errors due to Change in Fuel Contents at the Beginning and End of a Test in the Westinghouse Producer.

If the average fuel contents of the producer are assumed to weigh 45 pounds per cubic foot, the total weight of the fuel—on this assumption—will be 6,500 pounds; and since the total fuel charged during the trials varied from 6,215 to 10,881 pounds, it will be seen that the ratio of the fuel in the producer, to that charged, is very high. In estimating, therefore, the condition of the fuel in the producer at the beginning and end of a test, a large error may be introduced—sometimes exceeding 1000 pounds; hence the duration of the test should be long enough to reduce the above ratio to such an extent that such an estimate will not introduce an appreciable error.

With a view to checking any serious error in the estimation of the fuel bed, two consecutive lines on the summary sheet show the quantities of carbon charged, and that leaving with the gas, per hour. In every trial, except No. 46, the carbon charged exceeds that leaving with the gas.

In trial No. 46, the fuel contents of the producer was depleted during the trial to the extent of 340 pounds of carbon, which seems to point to the fact that there is probably a still



Rotary meter.

greater depletion than this, owing to the carbon being associated with other combustible matter.

Table II calculated for the Westinghouse producer trials, shows the efficiency (A) calculated to allow for the difference in the carbon charged and carbon removed as permanent gas. For purposes of comparison the efficiency (B) representing the ratio of the heat in the gas produced during the trial to that of the coal charged is included in the table.

TABLE II.

Efficiency representing the Ratio of Heat of Gas Produced to that of the Coal Charged.

Trial.	Fuel.	Efficiency A	Efficiency B.
38	Tofield..........................	67·5 per cent	66·9 per cent
39	Tofield..........................	62·6 " "	62·0 " "
40	Rosedale.......................	66·0 " "	65·2 " "
45	Gainford.......................	66·2 " "	65·6 " "
46	Cardiff Collieries...............	71·4 " "	71·8 " "
47	Twin City......................	60·9 " "	60·9 " "

Production of Gas.

Quantity. The quantity of gas used was measured by means of a "Rotary Meter." This meter is shown in Plate I, and operates on the principle of the anemometer. The working parts consist, principally, of a turbine wheel with vanes set at an angle of about 45 degrees. This wheel is carried by a central shaft, which is pivotted at the top and bottom in jewelled bearings, in order to reduce friction. This shaft actuates the recording mechanism by means of a worm wheel. A series of guides are placed just below the turbine wheel for the purpose of directing the flow of the gases before they impinge on the moving vanes. A light non-return valve at the bottom of the meter prevents a return flow of gas. A small quantity of the gas is by-passed through the tubes, shown to the right and left of the non-return valve, in order to ensure rotation of the turbine at small rates of gas flow.

CALIBRATION OF GAS METER.

At the conclusion of the gas producer tests the meter was calibrated. The method employed consisted in comparing the meter readings with calculated volumes based on data obtained from the resistance to flow of air through sharp orifices in thin plates. For this purpose air boxes were employed, which were of similar construction to those used by Professor R. J. Durley, at McGill University, and described by him in a paper (No. 081) read before the American Society of Mechanical Engineers, in December, 1905. The rate of flow was calculated from the formula $Q=0\cdot0137\ Cd^2\sqrt{\frac{i\,P}{T}}$ where Q = flow of air in lbs. per second.

C = a coefficient (about $0\cdot6$) found from the above mentioned experiments.

d = diameter of orifice in inches.

i = difference of pressure on the two sides of the plates measured in inches of water.

P = mean pressure of air in pounds per square foot.

T = absolute temperature of the air in degrees Fahrenheit.

The difference in pressure between the two sides of the orifice plate was measured by means of an inclined gauge, reading to one hundredth of an inch of water.

The results of the calibration tests showed that, between the range of flow of 11,000 and 2,000 cubic feet of gas per hour, the meter reading was 13 per cent too high. The meter readings taken during the trial have been corrected by that amount in the final results.

ANTI-PULSATOR.

Between the meter and engine an anti-pulsator was interposed. This apparatus takes the place of a gas bag, and is used to correct the periodic change in the rate of flow, which is otherwise inevitable when the gas is being used by a gas engine.

READINGS OF GAS METER.

Readings of the gas meter and observations of the temperature and pressure of the gas passing through were made every half hour during the test.

QUALITY OF THE GAS.

The gas was analysed every hour, and its calorific value determined every half hour for short period tests, and every two hours for the trials of longer duration.

The gas samples for analyses were taken over a short space of time[1], and analysed in the Randall and Barnhardt apparatus. The calorimeter used was the "Boys."

A description of these pieces of apparatus will be found in Part IX, Vol. II, of "An Investigation of the Coals of Canada," published by the Mines Branch. The method there described was modified to the extent that methane and hydrogen were determined by slow combustion in a special pipette attached to the apparatus.

A continuous graphical record of the calorific power of the gas was kept by means of the Smith Recording Gas Calorimeter. This instrument is fully described in the Report on the Utilization of Peat Fuel.[2]

Determination of Tar and Ammonia in the Offtake Gas.

Immediately after the gas left the producer, a sample was continuously withdrawn through a pipe introduced into the offtake, having its open end turned to face the flow of the gas. The tar was extracted from the gas sample by means of a Brady tar filter, which consisted of a thimble of strong filter paper, through which the gas had to pass. This thimble was fixed tightly around a metal collar, through which the gas entered, and was surrounded by a metal jacket, the jacket being maintained at a temperature high enough to prevent condensation of water by means of an electrically heated sleeve. After

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[1] Except for trial 56 where continuous sampling was used.

[2] Mines Branch Report No. 154.

passing the filter, the gas was drawn through two wash bottles containing dilute sulphuric acid (one part acid to four parts water) to remove the ammonia, and finally passed through an ordinary gas meter. The measured volume of gas was then returned to the main stream from the producer by connecting up the meter to a tap at a point in the pipe near the Root's blower. At this point the suction is so much greater than at the offtake, that the gas can be readily drawn through the filter, bottles, etc. The filter thimble was weighed, and the reading of the meter taken before and after each experiment, so that the amount of tar in the gas could be determined. The results obtained were calculated to give the weight of tar per 1,000 cubic feet of gas.

From time to time, as the volume of the liquid in the bottles grew too great, the wash bottles were rinsed out, and the ammonia in the solution determined. Fresh acid was then put into the bottles for the next experiment. The increase in weight of the two wash bottles gave the quantity of water, plus ammonia, in the gas.

The ammonia was determined as follows: The liquid from the bottles was made up to a definite volume; an aliquot part of this volume taken, and caustic soda added until the solution was strongly alkaline. The solution was distilled and the ammonia set free absorbed by a measured volume of decinormal sulphuric acid; the acid remaining unneutralized by ammonia was then titrated back with decinormal caustic soda. From this can be calculated the amount of ammonia in the aliquot part distilled, and so the total quantity of ammonia in the gas.

Determination of Tar in the Purified Gas.

This was carried out by means of a Sargent tar filter. The apparatus consisted of a metal case, containing a wire gauze, which served to support in a horizontal position a filter paper of 11 cm. diameter; underneath the gauze was an electric lamp to heat the filter paper so that condensation of water could be prevented. The gas entered from above, passed through the filter paper, being thereby cleaned of tar, and left at the bottom of the apparatus. The gas was then measured by a meter, and burned. The filter paper was weighed before and after each experiment and, from the increase in weight and the volume of gas passed through, the amount of impurities per thousand cubic feet of the gas could be calculated.

The time of each experiment was not kept constant; but the filter papers were left until the tar collected in quantities large enough to be weighed, this being readily shown by a slackening off in the rate of flow of gas through the meter.

Temperatures and Pressures.

For the trials on the Körting producer the following readings were taken, at half-hourly intervals: the temperatures of the gas leaving the upper zone, and of the final gas leaving the producer, as shown by a Thwing electrical pyrometer; the pressures of the gas, as shown by water manometers at the base of the stand-pipe on the producer which conducts the gas from the upper to the lower zone, and at the exits of the producer, the coke scrubber, the tar filter, and the dry scrubber.

For trials on the Westinghouse producer readings were taken at half-hourly intervals, as follows:—

The temperature of the gas leaving the producer, as shown by a Bristol electrical pyrometer; the pressures of air entering the producer, and of the gas formed, shown by means of water manometers placed at the top and bottom air entrances to the producer, at the producer exit, scrubber exit, and blower exit.

The temperature of the saturated air blast was observed in the pipe leading from the vaporizer to the entrance to the lower zone.

Water Supplied for Cleaning and Cooling the Gas.

All the water supplied for these purposes passed through a meter, and records of its readings were kept.

General record. A general record of events during the trial was kept. On this sheet the behaviour of the fuel, time of poking the producer, etc., were recorded.

Description of the Westinghouse Double Zone Bituminous Suction Gas Producer.

A Westinghouse gas producer plant, similar to that installed in the Fuel Testing Station, is shown in ideal section, and perspective, in Fig. 5, and Plate II, respectively. The general path of the gas, after it leaves the producer, can be readily traced by referring to Fig. 5. The plant, in general, consists of a producer, gas washer, gas exhauster, pressure regulating gasometer, and gas mixing header. The gas formed in the two zones leaves the producer at its middle portion, and is conducted away through a large vertical pipe to the gas washer, etc.

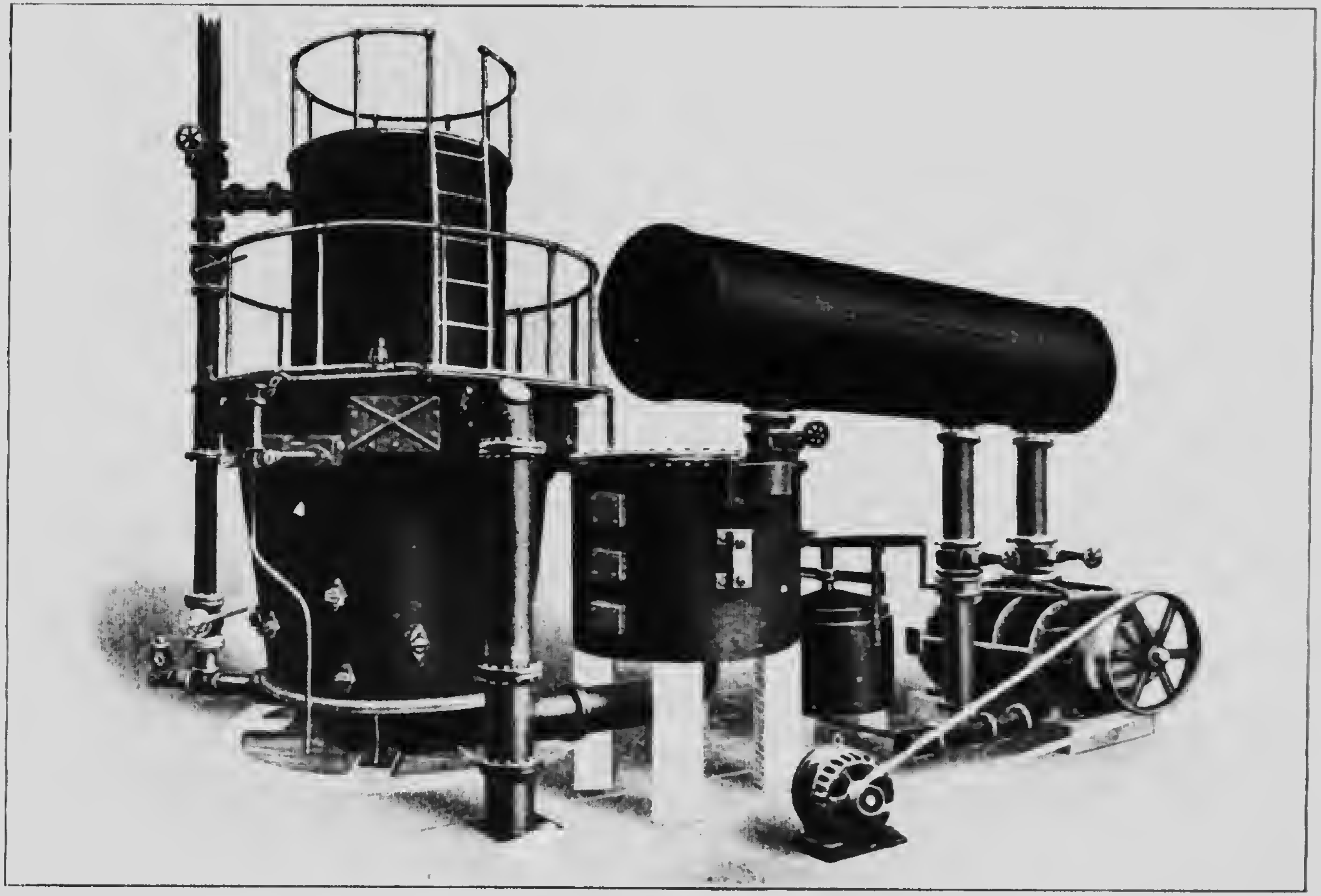
The lower end of this pipe is submerged in a water seal, into which the waste water from the scrubber passes off with any impurity it may remove.

From the vertical pipe the gas is conducted to the bottom of the scrubber, through which it passes upwards. From the gas washer the gas passes into a large horizontal receiver, and then passes to a rotary positive exhauster, driven by an electric motor. The blower maintains a suction on its producer side and a pressure on its opposite side.

For purposes of regulation, a by-pass connects the pressure and suction side of the system. In this by-pass are placed two valves, the one operated by hand, and the other operated by a small gas holder.

This pressure regulating gasometer is shown in Plate II, to the right of the blower. As the pressure in the gasometer rises, the bell rises, and through a system of levers opens the by-pass valve, thereby reducing the pressure. The pressure at which it is intended to operate the plant may be regulated by moving a sliding weight along the lever over the bell, thereby increasing or decreasing the force against which it has to move. A position of equilibrium will then be maintained by the bell rising until the gas pressure is balanced by the force on the bell. It will be observed that, as the bell rises, less of its height will be immersed in the water, thereby increasing the weight of the bell to be supported by the gas pressure, and so rendering a condition of stable equilibrium possible. If the demand for gas

PLATE II.



Westinghouse, double zone, gas producer plant.

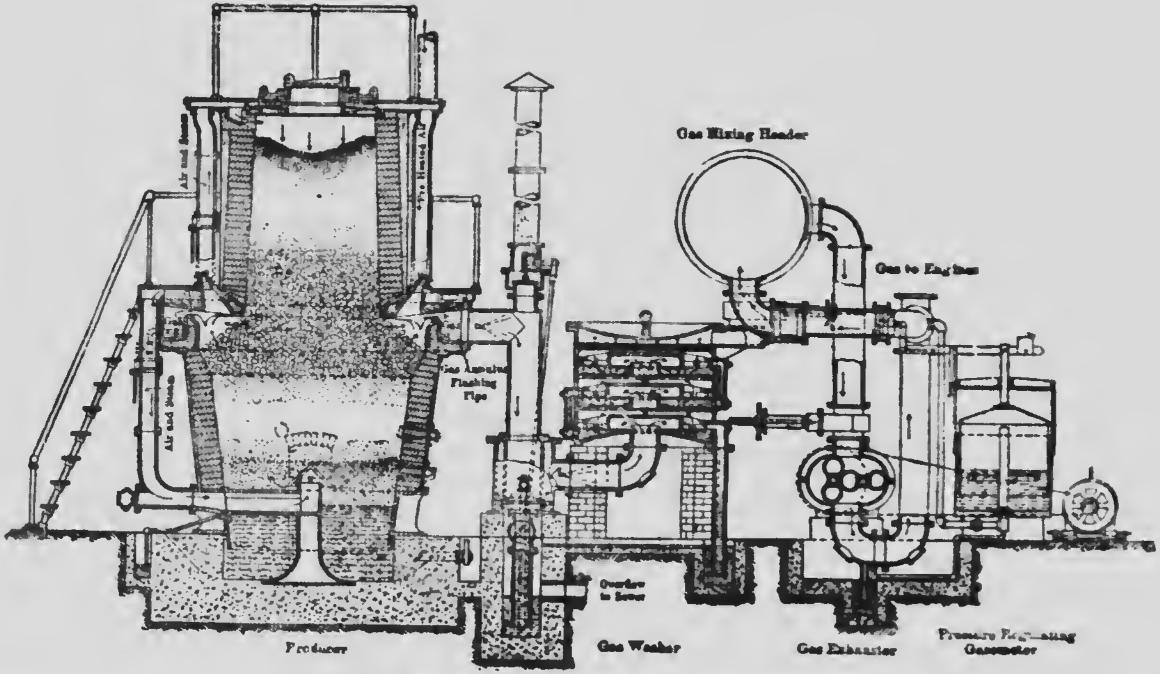


Fig. 5. Westinghouse, double zone, gas producer plant.

increases, the pressure in the gasometer will fall, which causes it to close the by-pass valve and thus deliver more gas to the source required, and reduce the quantity returning to the suction side of the exhauster.

This combination of a gas receiver and by-pass assures the thorough mixing of the gas, which consequently decreases the variation in quality of gas, due to the charging of fuel and the poking of the producer.

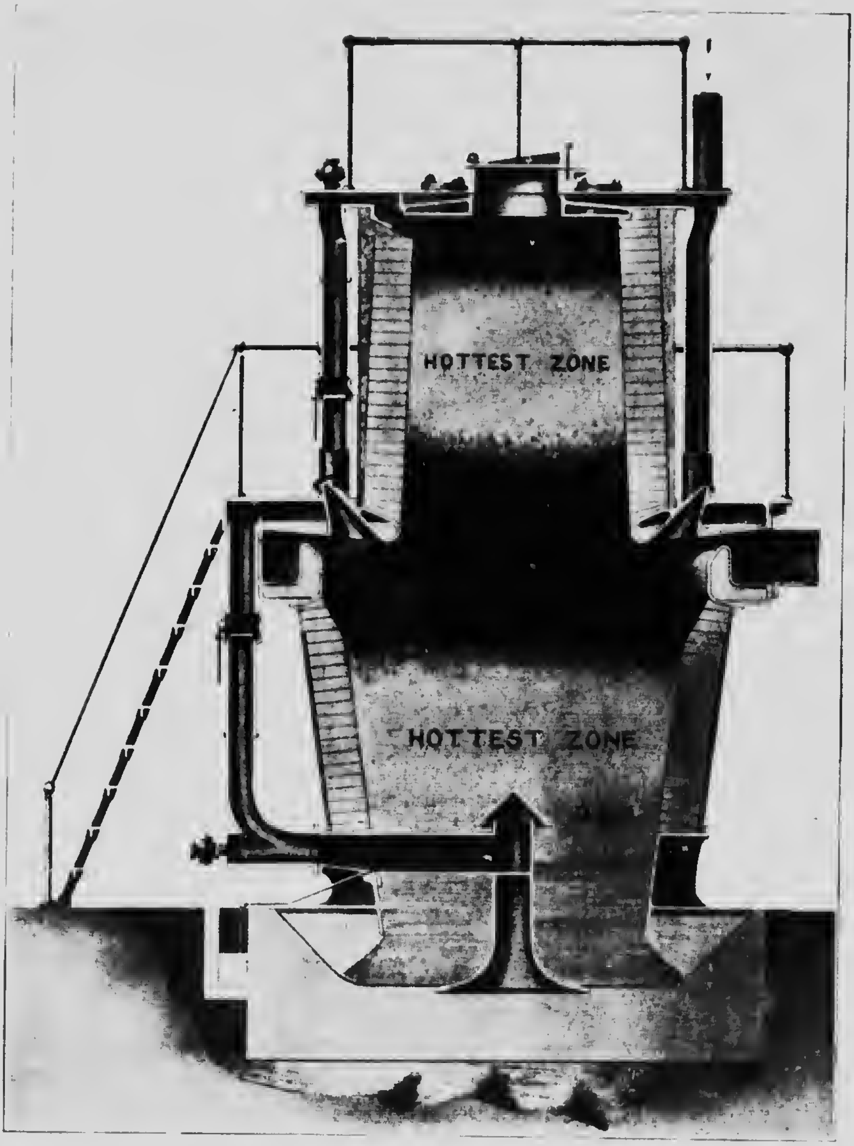
The gas, after leaving the exhauster, proceeds to the gas engine or other place, where it is desired to use it.

THE PRODUCER.

By referring to Figs. 5 and 6, and Plate III, which show vertical sections through the Westinghouse double zone producer, it will be seen that the producer consists of two zones, the upper one operating on the down-draft principle, while the lower operates on that of the up-draft.

There are three distinct air entrances. (See Plate III.) The air entrance on the right hand side of the cover of the producer admits air to the chamber formed by this cover. After being preheated in this chamber, the air passes down a vertical pipe to a hollow annular casting, which forms the vaporizer. The water, which is kept at a constant level in the vaporizer at about two inches from its top, is heated by the escaping gases from the fuel bed, which in their passage to the exit are compelled to come into contact with the walls of the vaporizer.

The air, after passing over the water of the vaporizer and becoming saturated with moisture, may proceed to either the upper or lower fuel bed, according to whether the valves in the two vertical pipes, leading to the air entrances of the upper and lower zones, are open or closed. In the event of the temperature in the vaporizer exceeding that due to the boiling point of water at atmospheric pressure, this air inlet cannot be employed, since steam will pass to the atmosphere by the air inlet pipe, consequently, instead of saturated air proceeding to the combustion zone, steam alone will leave the vaporizer. No provision for preheating the air in this manner is made on the producer installed at the Fuel Testing Station, since the top cover is water, instead of air, cooled. The two other air en-



Westinghouse, double zone gas producer: vertical section.

trances referred to are situated at the top and bottom left hand side of the producer. The air from these passes directly to the fuel bed, and the quantity desired is controlled by valves placed at the respective inlets. By regulating the ratio of the air received directly from the atmosphere to that passing over the vaporizer the quantity of steam entering the producer may be adjusted as required. The air admitted to the upper zone has free access to the full area of the upper fuel level; the air admitted to the lower zone passes through a central tuyere.

It is often found convenient, when no steam is being used in the upper zone, to leave the fuel door, at the top of the producer, open for the admission of air.

The producer is brick-lined round its sides, except for that portion occupied by the cast iron vaporizer. The upper zone is composed of a steel shell, between which and the brick lining is a space filled with sand. The lower zone of the producer, consists of a steel shell lined up to the vaporizer with fire-brick. The lower portion of this zone consists of a cast iron truncated cone, on which the producer proper rests. This portion is water sealed, as shown, and is supported by three cast iron columns, which rest on the concrete floor of the basin forming the water seal. The ashes are removed from the water seal through the space between the bottom of the producer shell and the floor of the water basin.

Poke-holes are provided at the top of the producer, and above the vaporizer. The outside diameter of the upper section is less than the inside diameter of the lower section; this construction makes the lower half of the producer entirely accessible from the poke-holes in the vaporizer. Poking may also be carried on through the fuel entrance, and through two rows of staggered poke-holes situated at about the level of the tuyere of the lower zone.

DESIGNS OF THE COMBUSTION ZONE

The form of the interior of the producer proper may be examined by reference to Figs. 6 and 7. Fig. 6 shows a section through the producer itself, and Fig. 7 shows, diagrammatically, the area of the fuel bed for varying depths of fuel. From a perusal of these figures, it is apparent that the

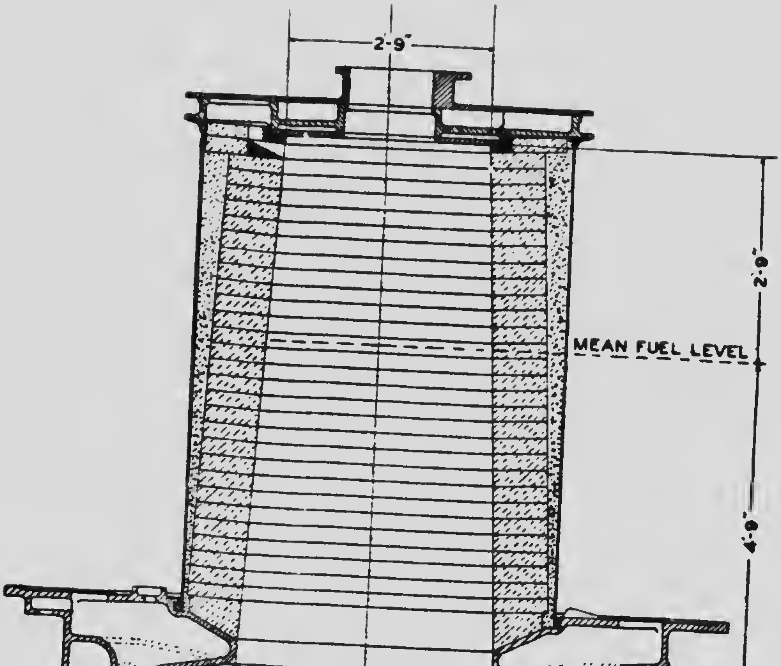


Fig. 6. Westinghouse gas producer: vertical section.

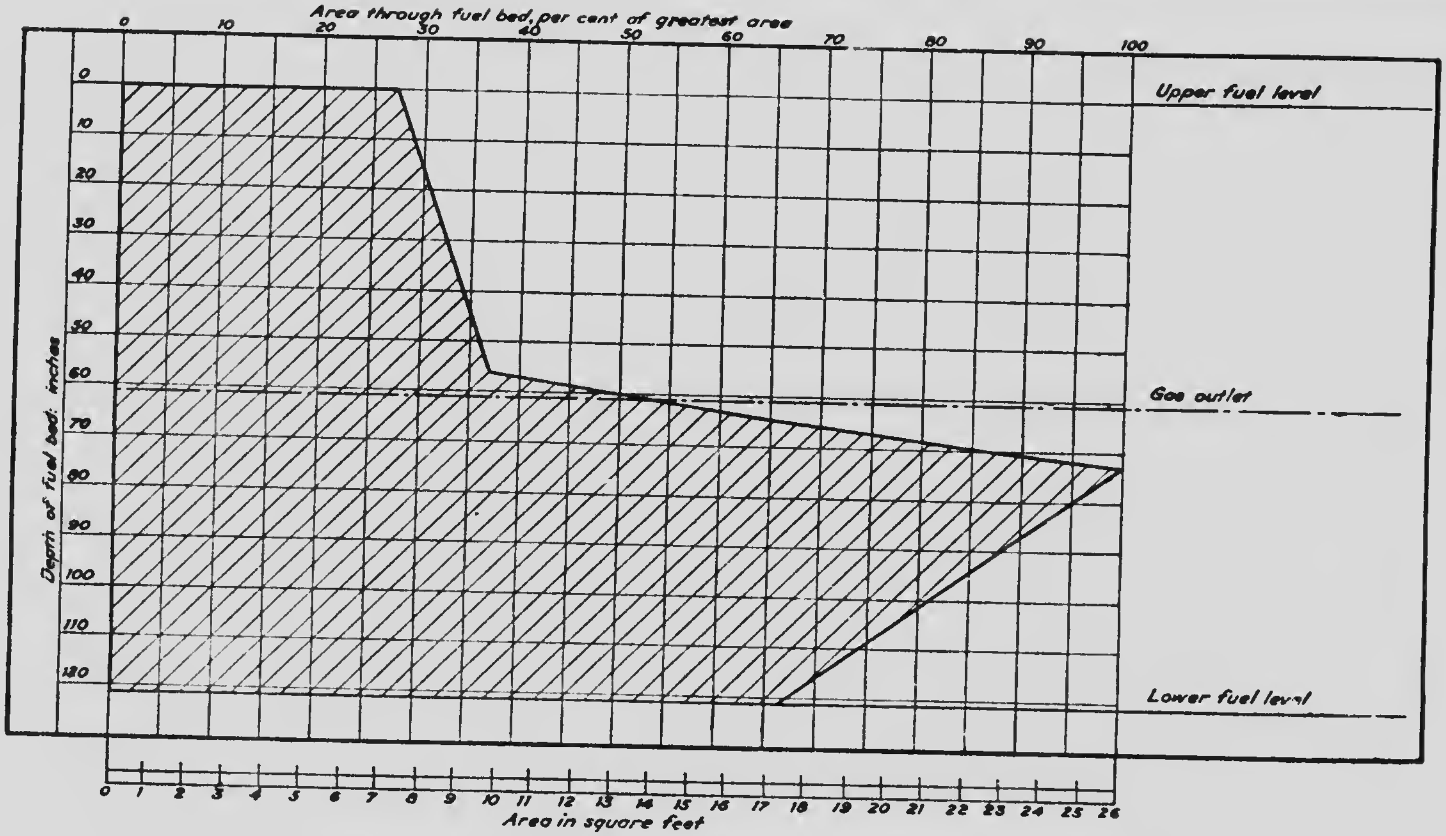


Fig. 7. Diagram showing change of area with fuel depth, in Westinghouse gas producer.

sectional area of the fuel space increases as the fuel descends through the upper zone, and decreases through the lower zone. The producer volume, occupied by fuel, above the gas outlet, (see Figs. 6 and 7) is 40 cubic feet; while the volume, measured from midway between the lower poke-holes to the level of the centre line of the gas outlet, is 100 cubic feet.

The mean area of the upper fuel bed is about 8½ square feet; while that of the lower is 21 square feet. The sectional area of the main upper fuel bed is increased by nearly 40 per cent, for a change of 56 inches in depth; while the lower fuel bed decreases by nearly 40 per cent, for a change in depth of 4 feet. The increasing section in the upper zone is to allow for the swelling of a coking coal, thereby causing a more uniform flow through the producer.

In the lower zone the fuel is being continually reduced in volume, owing to its combustion, and the reduction in diameter preserves a uniform flow on the same principle. Observation of the burning of the lignites tested, showed that this fuel shrinks during its passage through the upper zone, leaving an air space between the fuel bed and producer walls. It would appear, therefore, that a decreasing sectional area in the upper zone—rather than an increasing one—would prove more suitable for fuels such as lignite or peat.

The total depth of incandescent fuel in the producer is affected by two independent variables, namely, the total rate of gasification, and the ratio of the gasification in the upper zone to that taking place in the lower zone. Suppose the ratio of gasification in the two zones to remain constant, then, as the total rate of gasification is increased, a greater depth of burning fuel will result, since a definite time is required for the reactions to take place. As the ratio of the gasification in the upper zone to that of the lower increases, for the same total rate of gasification, similar reasoning shows that the depth of the combustion zone in the upper bed will increase to a greater extent than the lower combustion zone depth will decrease.

In the operation of a double zone producer, it is difficult to ascertain the exact ratios of gasification in the two zones and the depths of incandescent fuel therein. The resistance to the passage of gas through the two zones is easily measured by means of water gauges; these differences of pressure, however, are affected by the condition of the fuel bed as well as by the velocity of flow of the gas, so that they only give an approximate idea of the relative operation of the two zones. In trial No. 39, the air supply to the lower zone was measured by observing the passage of air through an orifice in a plate, which showed that 53 pounds of air passed to the lower zone per hour; and that the total air supply—computed from the gas analyses and meter readings—amounted to 317 pounds per hour, which would show that about one-sixth of the total air supply was taken by the upper zone, or a ratio of one to five; while the resistance of the upper fuel bed to the passage of gas was three times that of the lower. In the future, provision will be made for determining, directly, the air supply to both zones.

The position of the combustion zones in the fuel bed is likewise difficult to determine, the level of the top of the combustion zone in the top zone may of course be observed directly; and in the case of the lower zone an effort was made to maintain the position of the combustion zone at a level midway between the two lower rows of poke-holes. How far these zones extend from these points is a matter for conjecture.

The high volatile and high moisture contents of the lignites used in these tests rendered it necessary to perform the greater portion of the work in the upper zone, using the lower to reduce such fuel as must inevitably be entrained with the ash leaving the upper zone.

While the area of the lower fuel bed is greater than is actually necessary from theoretical considerations for lignite fuels, a practical advantage of its increased diameter is that poking round the annulus is rendered easier, as has already been pointed out.

Purification of the Gas.

A baffle plate is placed in the gas offtake, to serve the purpose of removing the heavier particles of tar, dust, etc., which may be carried over by the gas from the producer.

THE WASHER.

The gas washing apparatus is shown in Plate IV. It is constructed of cast iron, and is divided by horizontal diaphragms into three compartments. Before entering this washer, the gas is cooled and cleaned to some extent by means of a series of water sprays, admitted at several points along the vertical pipe. After leaving the vertical pipe, the gas enters the washer beneath a cast iron bell, the lower edge of which is submerged in water. Extending outwards from the bell and beneath the water level in the compartment is a finely perforated metal plate. The gas forces its way under the edge of the bell and passes up through the perforated plate; by so doing the gas forms a series of small bubbles. These bubbles pass up through about one inch of water. The same operation is repeated for the two other sections of the washer. Water is introduced by means of spray nozzles as shown, and the overflow from the top compartment passes into the middle compartment through the connexion shown at the right just below the gas outlet. From the middle compartment the water overflows into the lower compartment through a similar connexion shown on the left. From the bottom compartment it passes out through the water sealed waste pipe shown at the right.

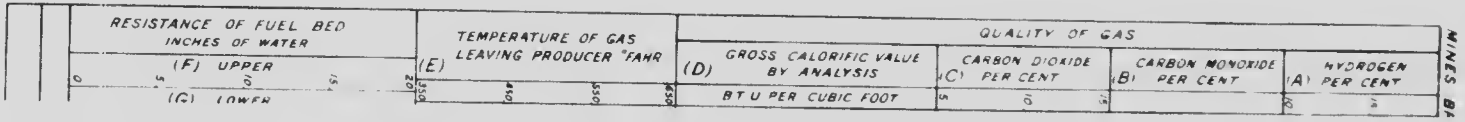
Any desired depth of water may be maintained over the perforated plates, by means of adjustable weirs.

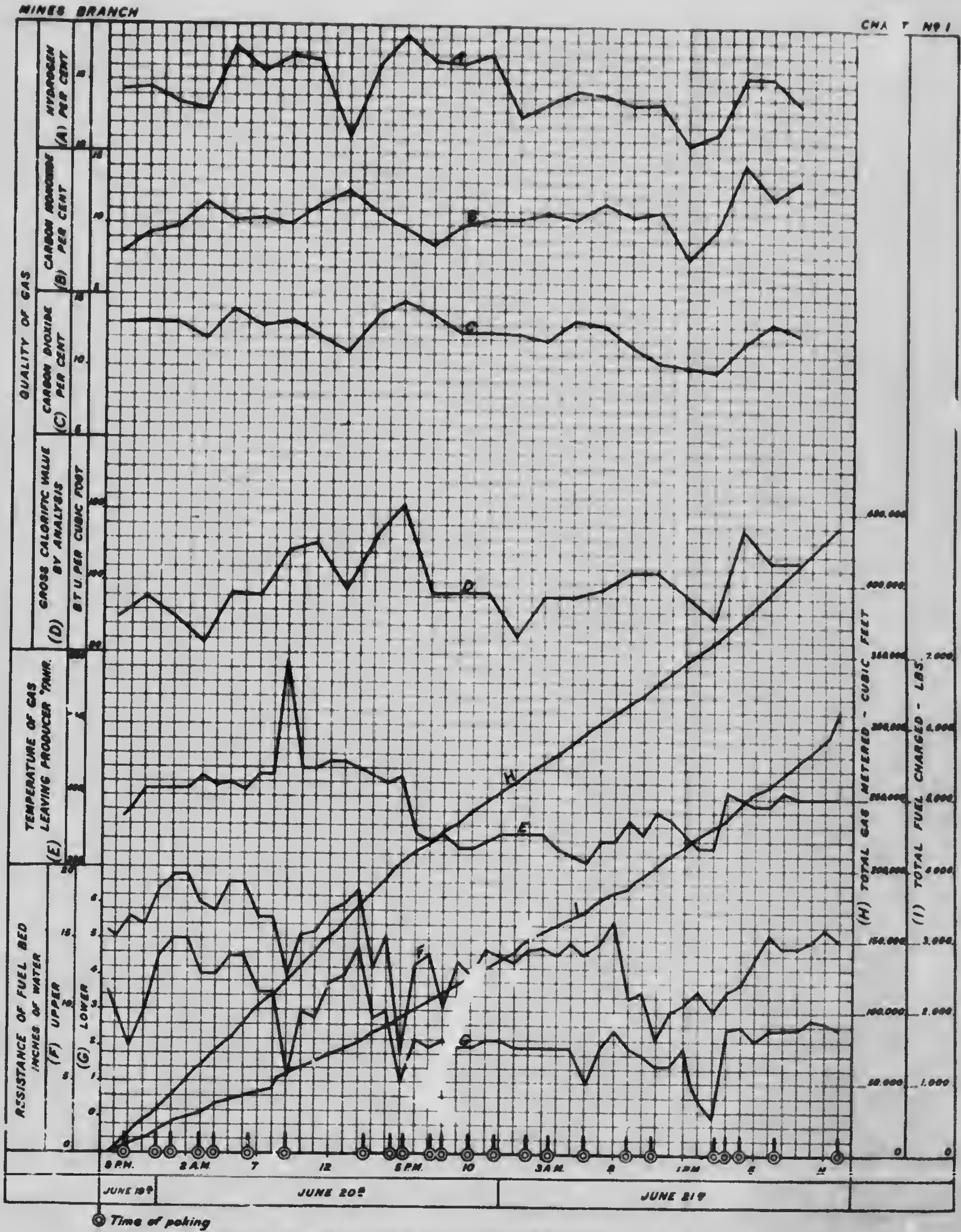
After leaving the washer, the gas enters a simple form of water separator which is not shown in the illustration.

PRODUCER TRIALS.

Tofield Lignite—Trials Nos. 38, 39, and 44.

Three trials were carried out on this fuel, viz., trials No. 38 and 39 in the Westinghouse producer, and trial No. 44 in the Körting producer. *Trial No. 38* was of 51½ hours' duration only, owing to the blocking of the gas outlet with dust; this was the only trouble which necessitated the shortening of any of the trials. *Trial No. 39* was of 72 hours' duration and the producer was operated at a slightly greater rate of gasification than No. 38. The efficiency of the latter trial was about five per cent greater


MINES B
RESISTANCE OF FUEL BED INCHES OF WATER
(F) UPPER
(G) LOWER
0
5
10
15
20
TEMPERATURE OF GAS LEAVING PRODUCER °FAHR
(E)
350
450
550
650
QUALITY OF GAS
(D) GROSS CALORIFIC VALUE BY ANALYSIS
BTU PER CUBIC FOOT
(C) CARBON DIOXIDE PER CENT
5
10
15
(B) CARBON MONOXIDE PER CENT
(A) HYDROGEN PER CENT
10
14

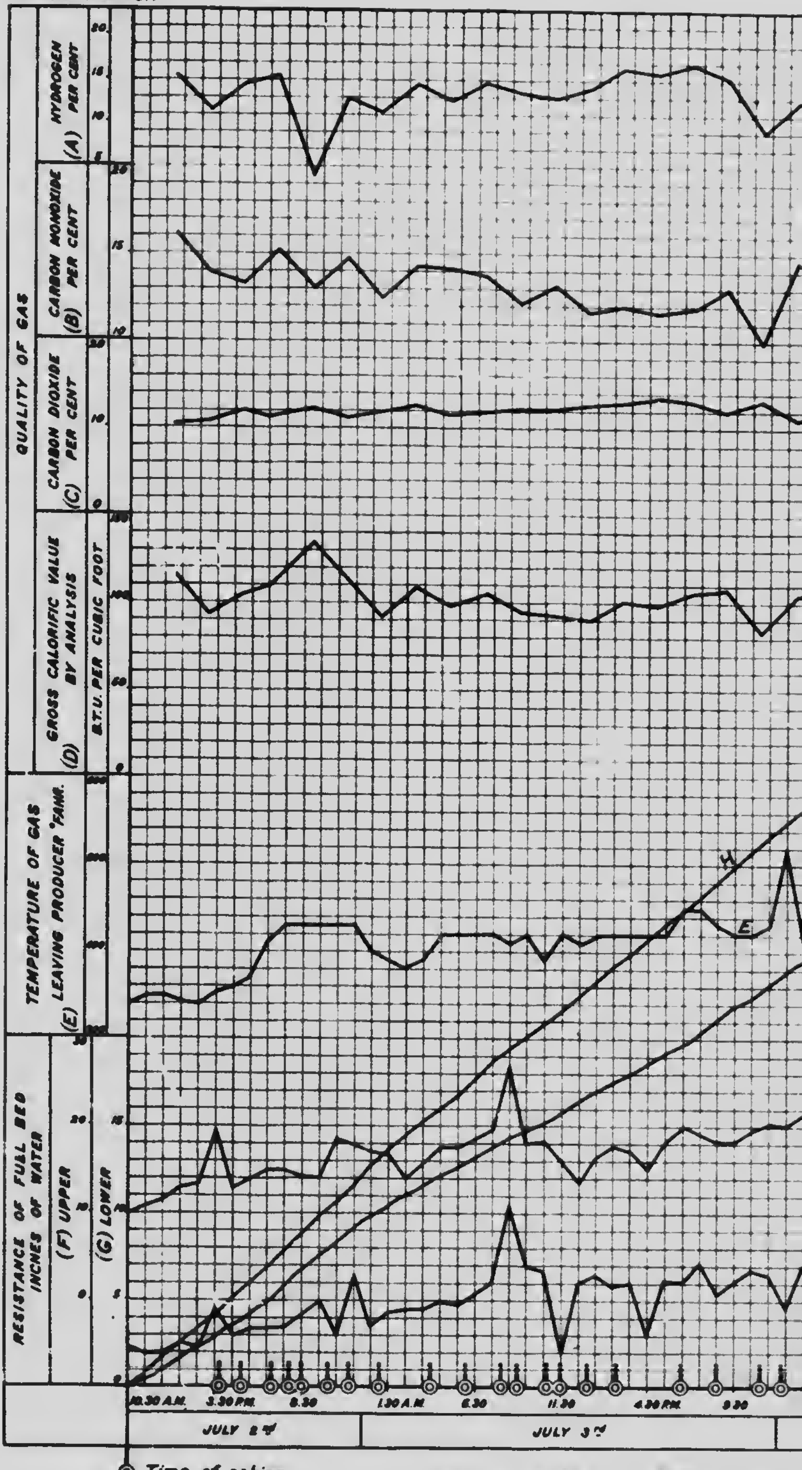


TEST No. 38. FUEL: TOFIELD LIGNITE. WESTINGHOUSE PRODUCER.

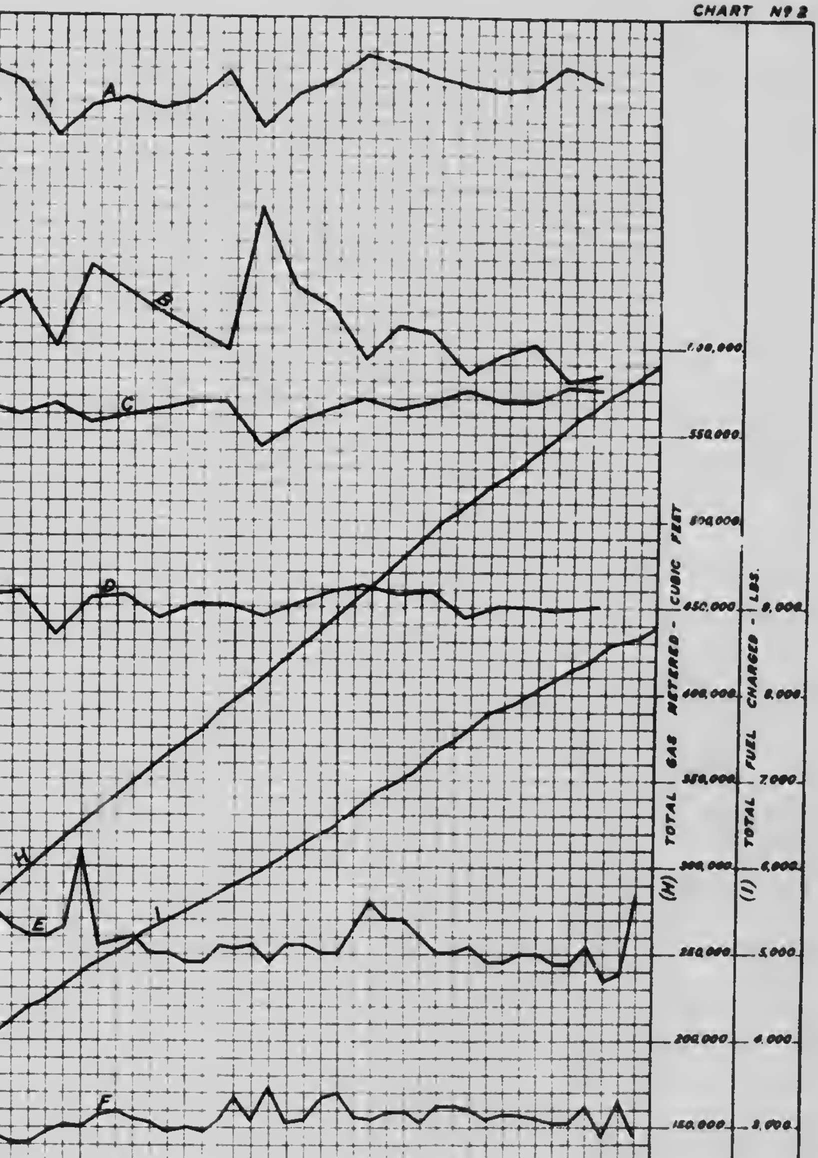
	RESISTANCE OF FUEL BED INCHES OF WATER	TEMPERATURE OF GAS	QUALITY OF GAS			
	(F) UPPER	(E) LEAVING PRODUCER °FAHR	(D) GROSS CALORIFIC VALUE BY ANALYSIS	(C) CARBON DIOXIDE PER CENT	(B) CARBON MONOXIDE PER CENT	(A) HYDROGEN PER CENT

MINES B

MINES BRANCH

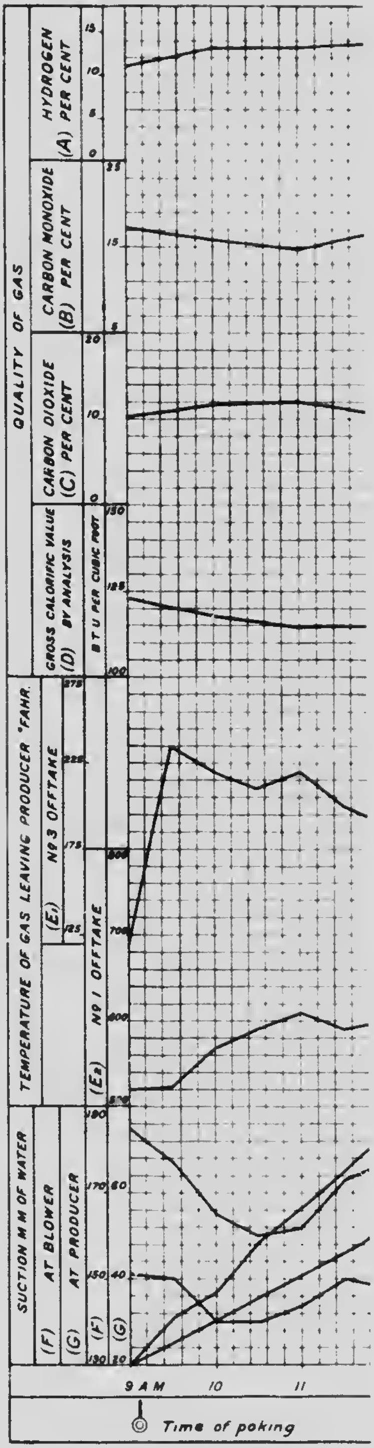


TEST No. 39. FUEL: TOFIELD LIGNIT



D LIGNITE, WESTINGHOUSE PRODUCER.

MINES BRANCH



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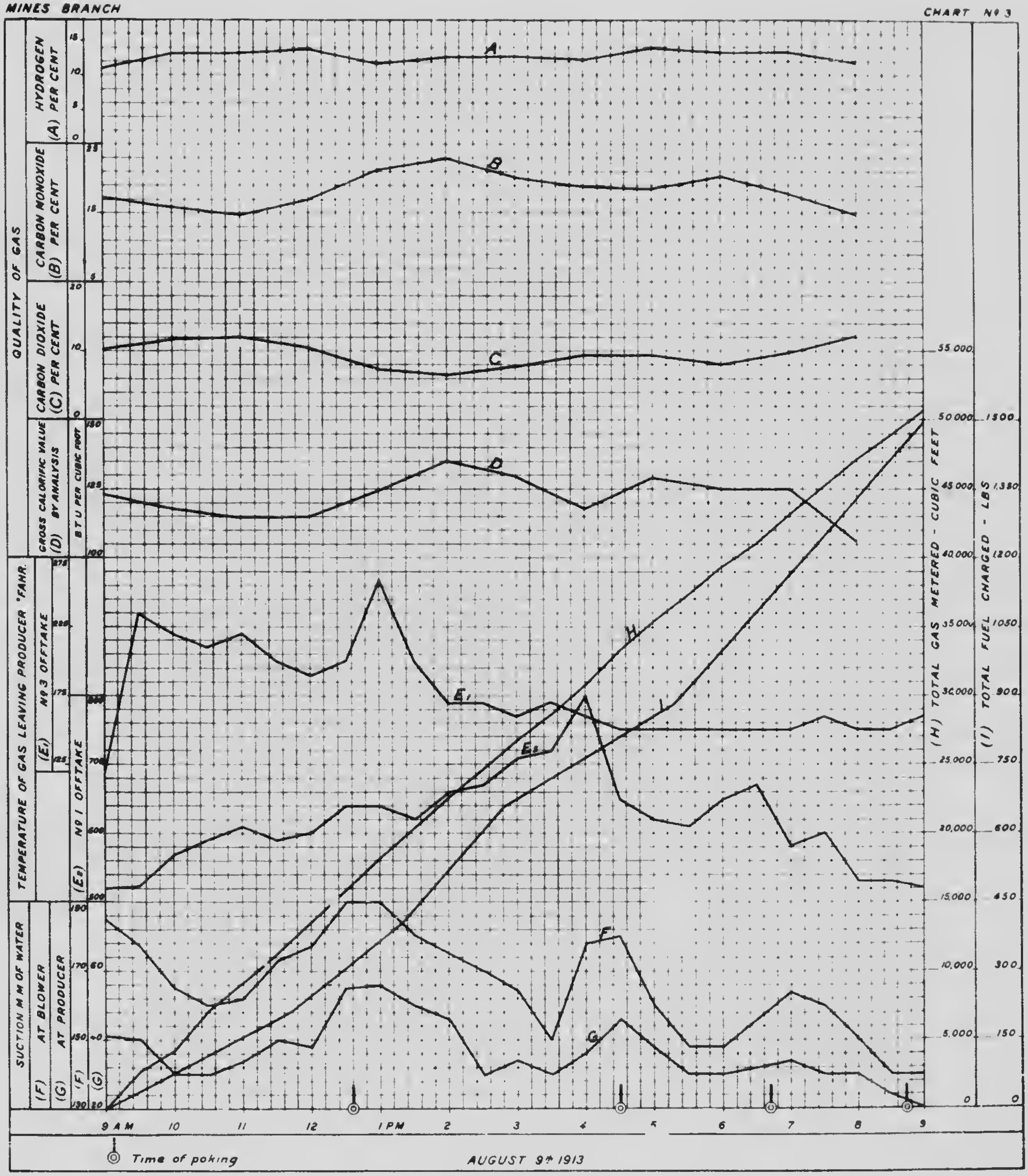
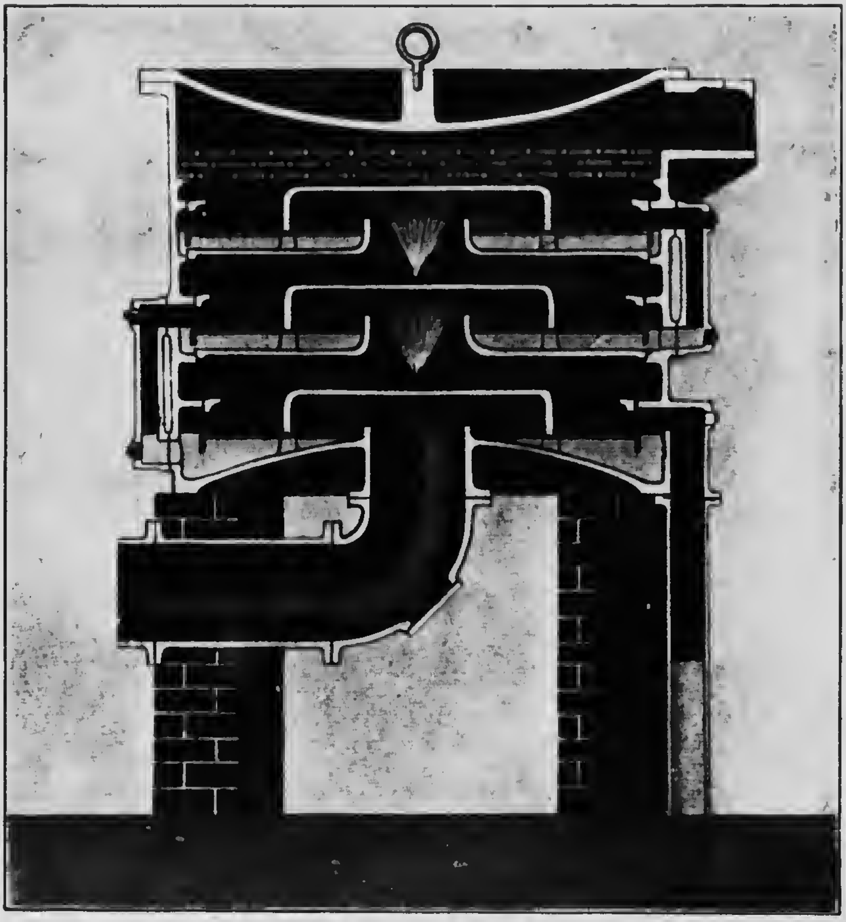


TEST No. 44. FUEL: TOFIELD LIGNITE. KORTING PRODUCER.

PLATE IV.



Section through gas washer.

than for trial 39, which is due to the greater quantity of hydrogen and hydro-carbons present in the gas as is shown by the gas analyses. Since the ratio of the resistance of the upper to the lower fuel bed during trial 38 was greater than in trial 39, it is likely that a greater portion of the total gas produced was formed in the upper zone than for trial 39.

The fuel clinkered to some extent in both tests; but this offered no real difficulty to the operation of the producer.

In both trials the resistance to the flow of gas through the upper zone was high while the temperatures of the final gas, as determined at the gas offtake, was approximately the same. The high resistance observed in the upper zone is due to the finely divided condition which the fuel assumed after being subjected to heat.

Trial No. 44. An examination of the results of this test, which was conducted in the Körting producer, shows a marked difference to those of the two trials carried out with the same fuel in the Westinghouse producer. A comparison of the analyses of the gases produced in trial 44 with those of trials 38 and 39 will show that the carbon monoxide has increased, while the hydrogen and carbon dioxide have decreased. This has caused an increase in the heating value of the gas. The increase in the carbon monoxide indicates that a higher temperature existed in the reaction zone. This is further borne out by the higher temperature of the escaping gases. No steam from an external source was admitted to the lower zone.

The quantity of tar per cubic foot of the final gas was much higher for this trial than for the two former trials, which shows that the Westinghouse producer delivers a cleaner gas. The lower efficiency may be principally accounted for when the relative quantities of carbon charged and carbon in the gas are compared in the summary of results. From these results it will be seen that the former is much in excess of the latter, which indicates that the low efficiency is due to unconsumed fuel, i.e., carbon is contained in both the tar and the ash, which of course will not be accounted for in the purified gas.

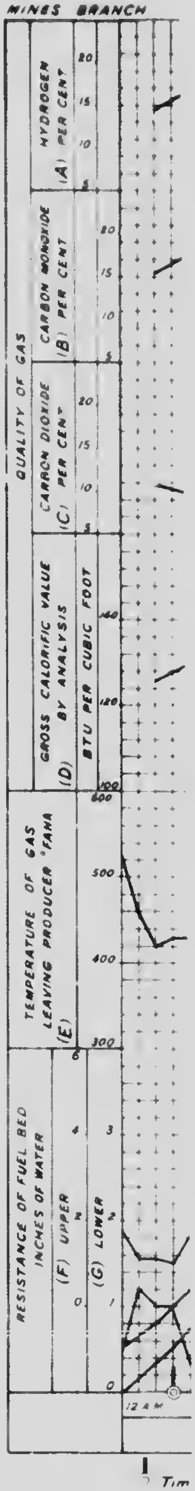
Rosedale Coal—Trials Nos. 40 and 43.

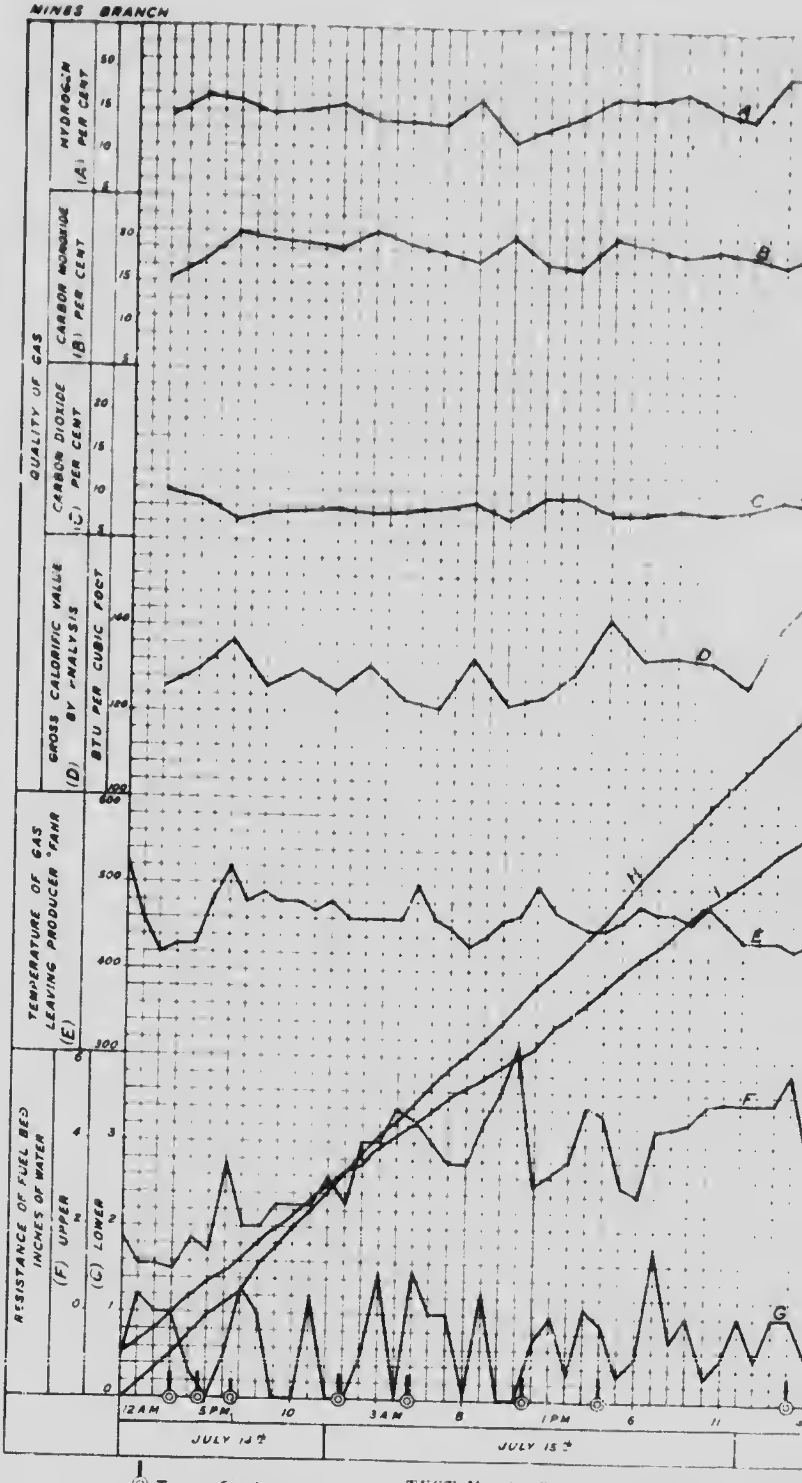
Two trials were carried out on this fuel, trial No. 40 in the Westinghouse producer and No. 43 in the Körting.

Trial No. 40. The fuel during this trial gave very little trouble in the producer, and the gas was of high calorific value, which is due to the high percentages of hydrogen and carbon monoxide contained in the gas. These, in fact, were higher during this trial than for any of the other trials carried out in the Westinghouse producer. The higher heating value of the gas was, however, accompanied by a greater quantity of tar in the gas than in the other trials. The suction on the producer was lower than for any other trial with the Westinghouse producer in spite of the fact that the rate of gasification was high. This was principally due to the fact that the fuel did not pack so closely as the others, since its physical character was the least affected by heat; hence it did not disintegrate into finely divided particles.

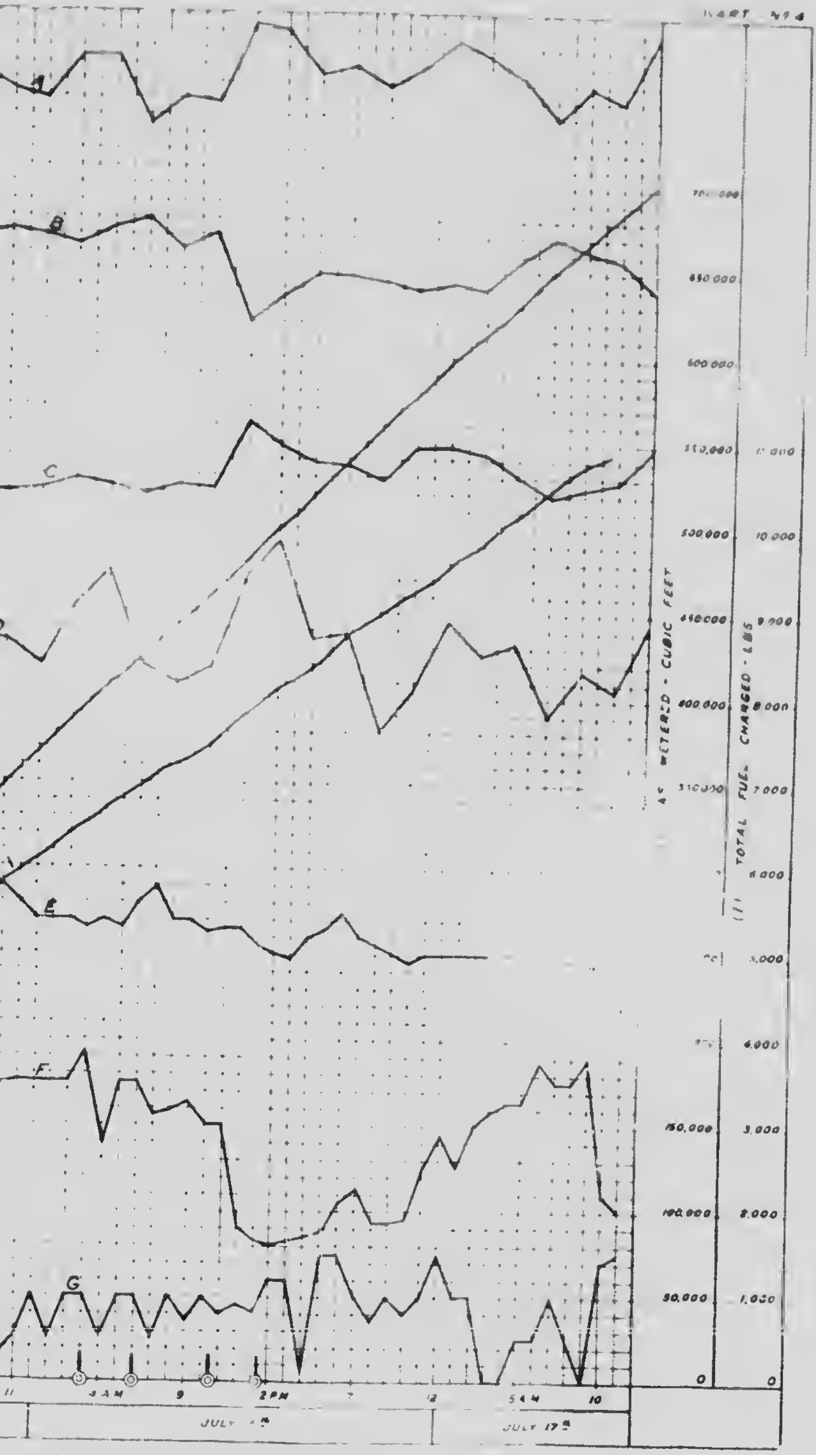
The fuel was very easily manipulated in the producer and the only unsatisfactory characteristic of the trial was the high percentage of tar in the gas. However, this in noway rendered the operation of the engine difficult.

Trial No. 43. During this trial Rosedale coal was gasified in the Körting producer. As in the previous trials conducted with this producer, the carbon monoxide content of the gas is higher than that of the gas produced from the same fuel when burned in the Westinghouse producer. The calorific value of the gas, however, is less for this trial than for trial No. 44, in which the Körting producer was used, and the thermal efficiency of the producer is nearly twenty per cent lower than for trial No. 40. The total combustible charged amounted to 750 lbs., of which 140 lbs. was removed with the ash from the grates. This means that only four-fifths of the fuel was consumed, which accounts for the low producer efficiency. No difficulties whatever were encountered in the operation of the producer, and the engine ran well on the gas produced.

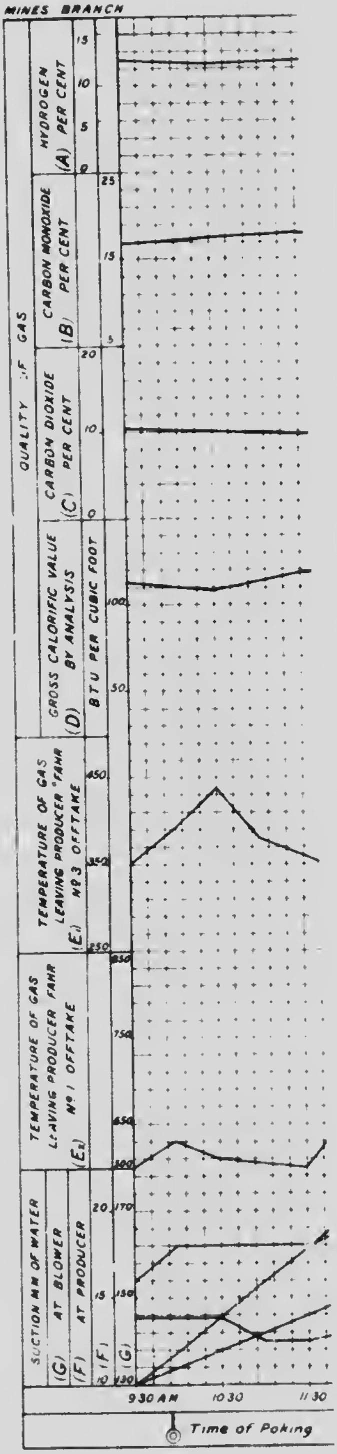

MINES BRANCH
QUALITY OF GAS
HYDROGEN
(A) PER CENT
5
10
15
20
CARBON MONOXIDE
(B) PER CENT
5
10
15
20
CARBON DIOXIDE
(C) PER CENT
5
10
15
20
GROSS CALORIFIC VALUE
BY ANALYSIS
(D) BTU PER CUBIC FOOT
100
120
140
TEMPERATURE OF GAS
LEAVING PRODUCER °FAHR
(E)
300
400
500
600
RESISTANCE OF FUEL BED
INCHES OF WATER
(F) UPPER
0
2
4
6
(G) LOWER
0
1
2
3
12 A.M.
Tim

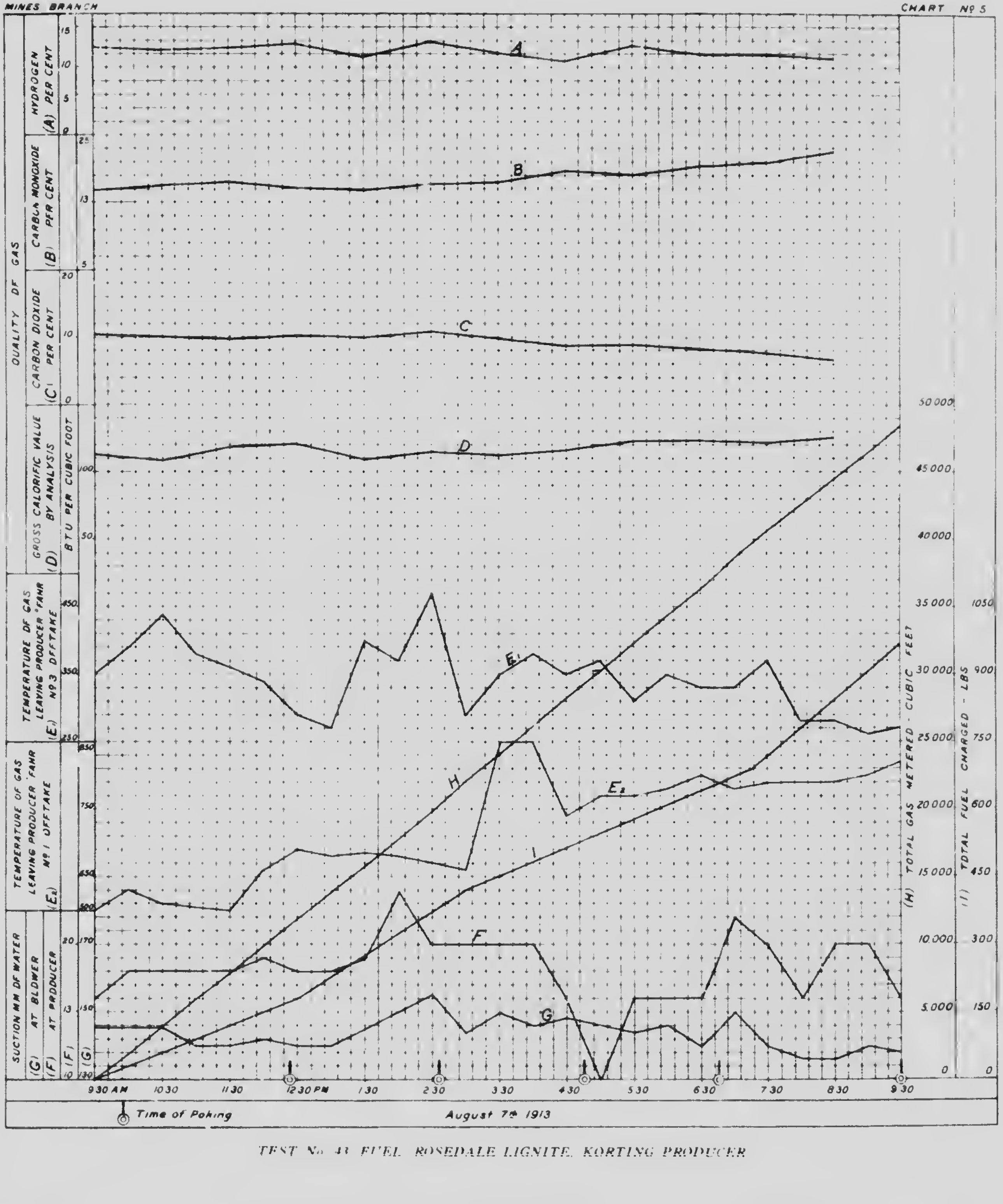


TEST No. 40. FUEL ROSEDALE LIGNIT



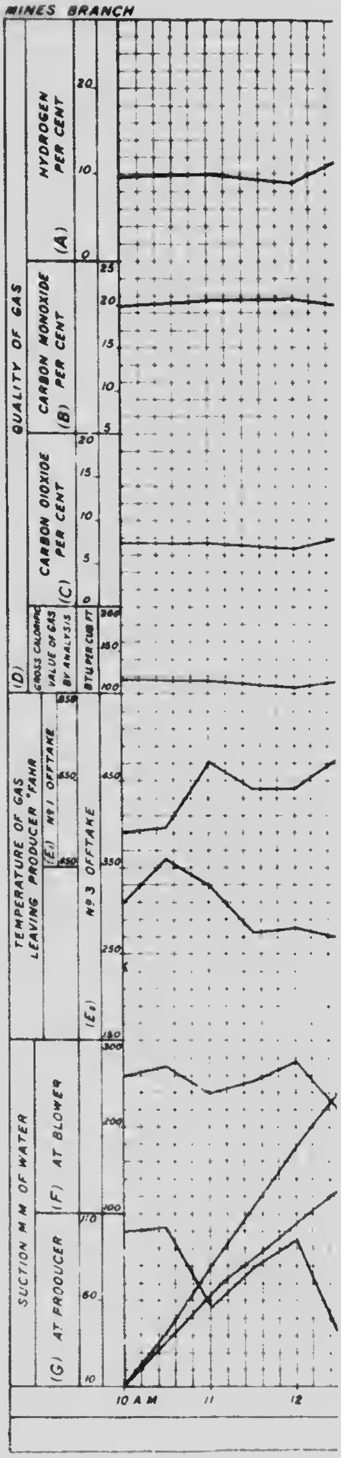
LIGNITE. WESTINGHOUSE PRODUCER

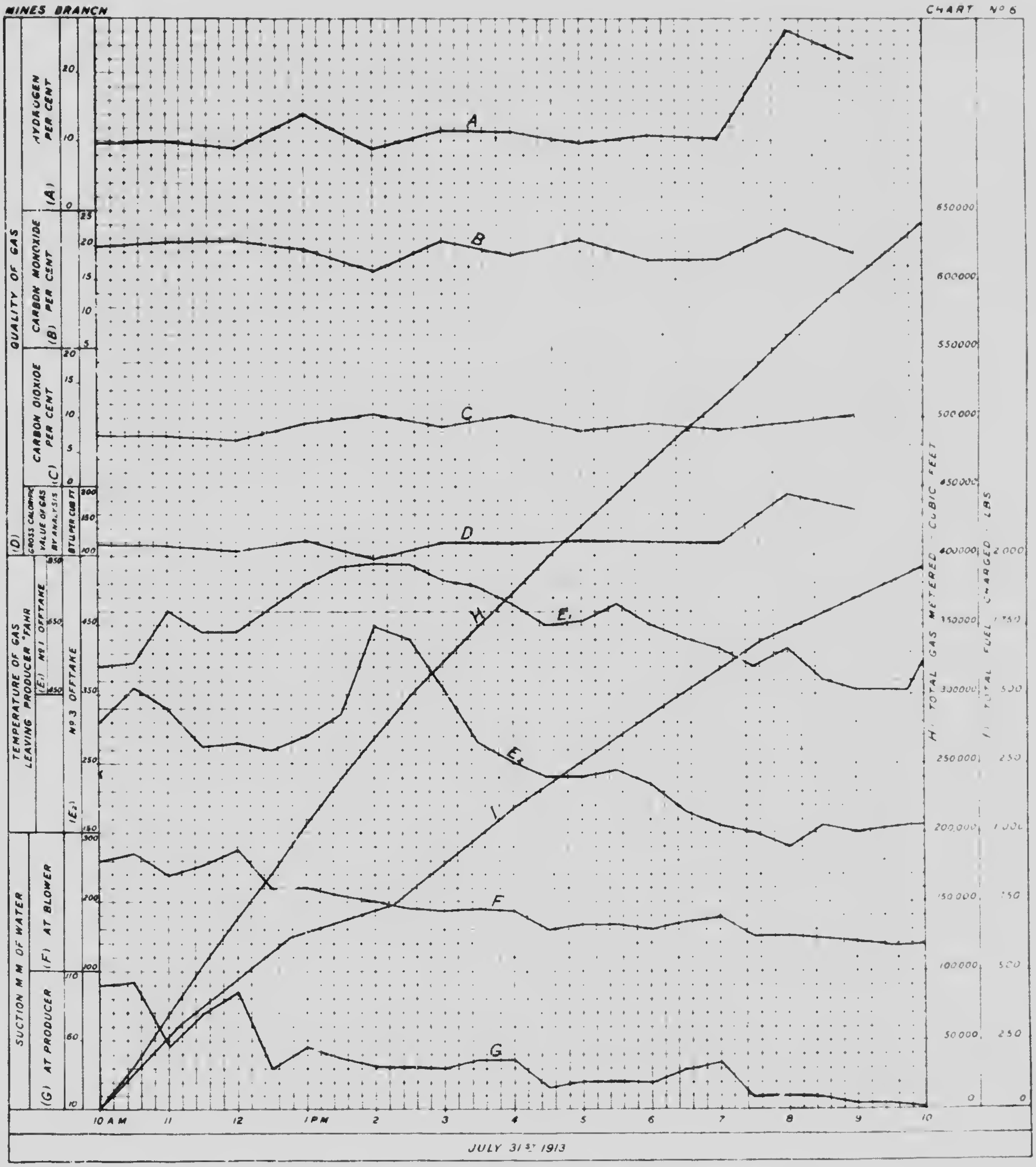

MINES BRANCH
QUALITY OF GAS
(A) HYDROGEN PER CENT
15
10
5
0
(B) CARBON MONOXIDE PER CENT
25
15
5
(C) CARBON DIOXIDE PER CENT
20
10
0
(D) GROSS CALORIFIC VALUE BY ANALYSIS BTU PER CUBIC FOOT
100
50
(E1) TEMPERATURE OF GAS LEAVING PRODUCER °FAHR Nº3 OFFTAKE
450
350
250
(E2) TEMPERATURE OF GAS LEAVING PRODUCER FAHR Nº 1 OFFTAKE
850
750
650
500
SUCTION MM OF WATER
(G) AT BLOWER
(F) AT PRODUCER
(F)
(G)
20
15
10
170
150
130
9 30 AM
10 30
11 30
Time of Poking



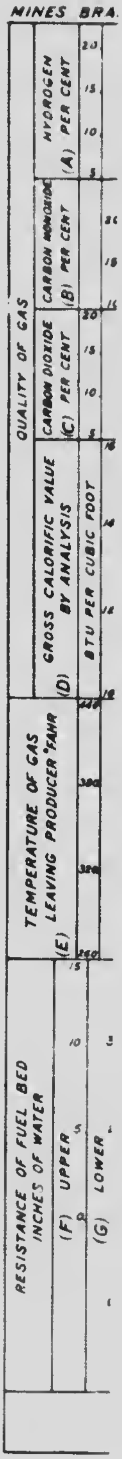
TEST No. 43 FUEL ROSEDALE LIGNITE. KORTING PRODUCER

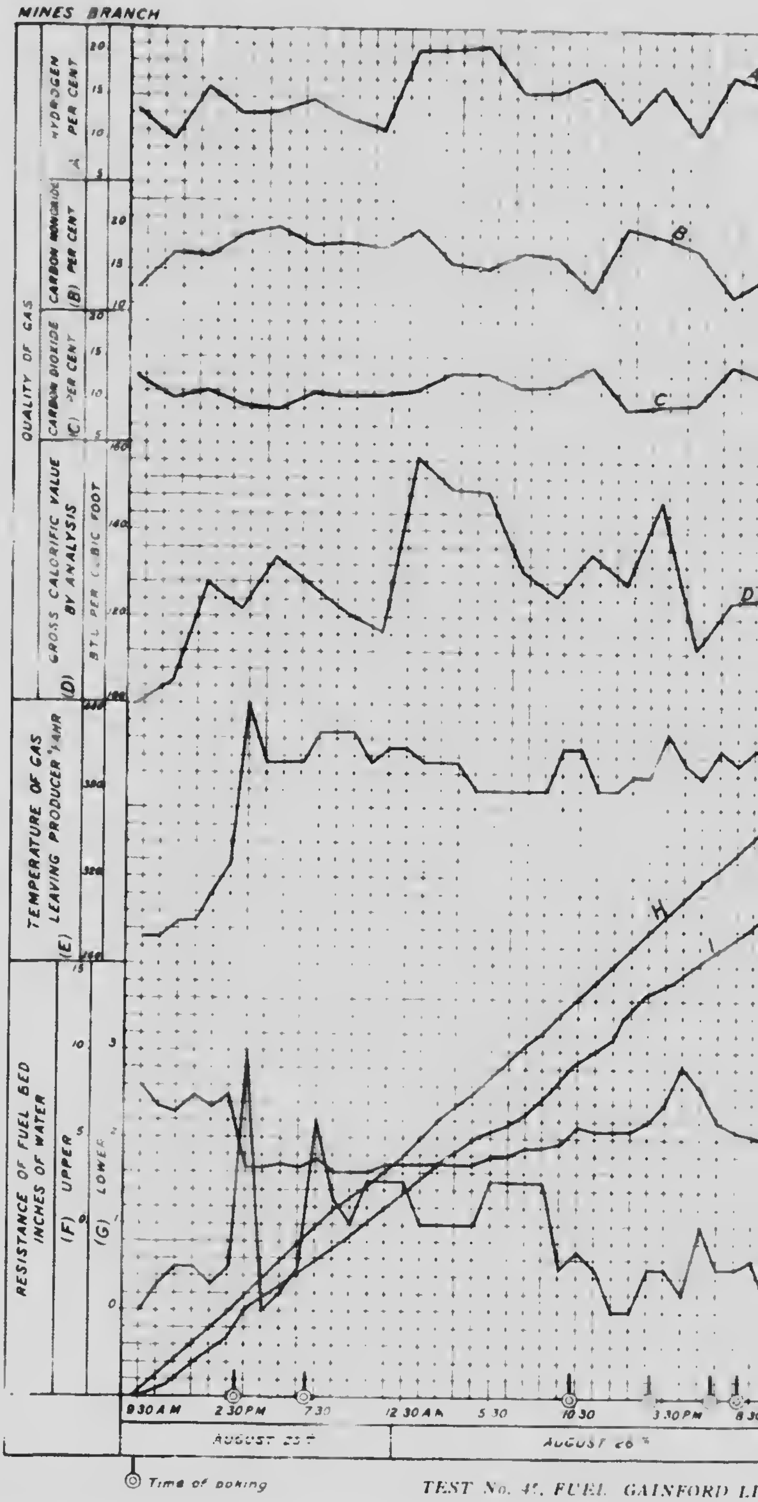
MINES BRANCH



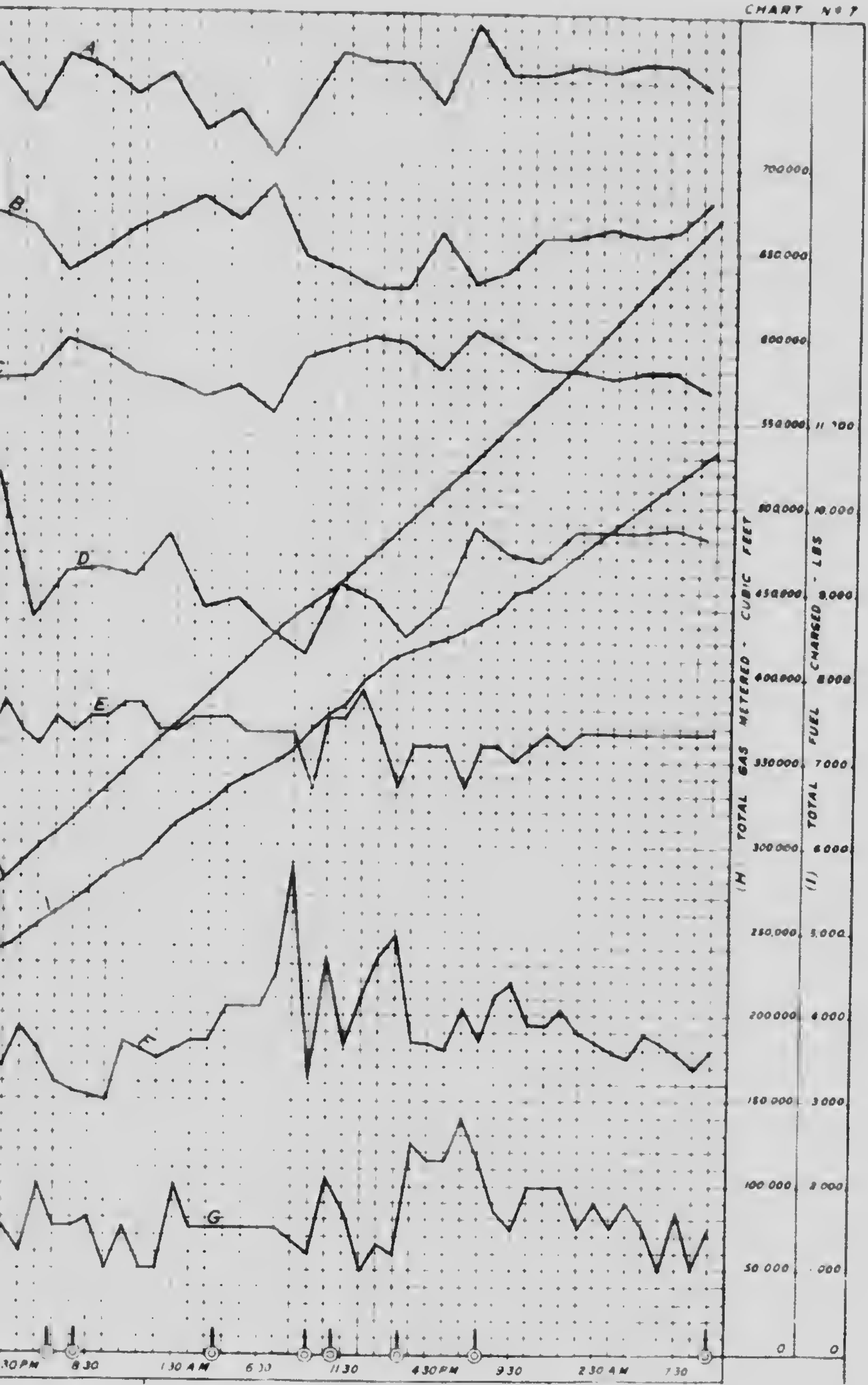


TEST No. 42. FUEL: GAINFORD LIGNITE. KORTING PRODUCER


MINES BRA
QUALITY OF GAS
(A) HYDROGEN PER CENT
5
10
15
20
(B) CARBON MONOXIDE PER CENT
(C) CARBON DIOXIDE PER CENT
5
10
15
20
(D) GROSS CALORIFIC VALUE BY ANALYSIS BTU PER CUBIC FOOT
(E) TEMPERATURE OF GAS LEAVING PRODUCER °FAHR
RESISTANCE OF FUEL BED INCHES OF WATER
(F) UPPER
0
5
10
15
(G) LOWER



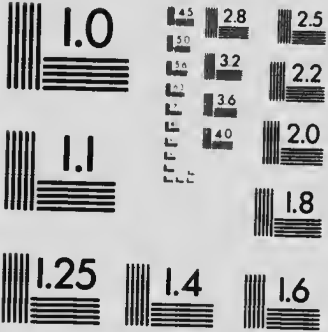
TEST No. 45. FUEL GAINFORD LI



NFORD LIGNITE, WESTINGHOUSE PRODUCER

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



APPLIED IMAGE Inc
1653 East Main Street
Rochester, New York 14609 USA
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(716) 288 - 5989 - Fax

Gainford Coal—Trials No. 42 and 45.

Trial No. 45 was conducted with the Westinghouse producer, while for trial No. 42, the Körting producer was employed.

For trial No. 45, the efficiency and quantity of gas produced were very similar to that obtained with Rosedale coal. A comparison of the proximate analyses of the two fuels also shows great similarity, so analogous results might well be expected. There is, however, a marked difference in the cleanliness of the gas produced from the two fuels; the Gainford coal produced only 9·1 grams of tar per 1000 cubic feet of uncleaned gas, while for that of the Rosedale coal the tar content was 23·4 grams per 1000 cubic feet. The resistance of the fuel beds to the passage of gas was low—but the ratio of the resistance of the upper zone to that of the lower zone was very high. This indicates that either the rate of gasification in the upper zone was high or that the resistance of the fuel in that zone was greater. It is probable that the incandescent fuel zone was deeper during this trial than in trial No. 40, on Rosedale coal, which would account for the lower tar content of the gas with this coal.

Trial No. 42, conducted with the Körting producer, again showed that the gas produced contained a higher percentage of carbon monoxide and lower percentage of carbon dioxide and hydrogen than in that obtained from the same fuel when gasified in the Westinghouse producer. The calorific value of the gas for both trials was, however, the same. The tar present in the gas was very high, and although after cleaning it still contained 12·6 grams per 1000 cubic feet, this did not interfere with the successful operation of the gas engine.

The quantity of refuse removed amounted to 514 lbs. (dry) of which 161 lbs. were ash and 353 lbs. combustible matter. The fuel charged contained 165 lbs. of ash and 1469 lbs. combustible. The ratio of combustible consumed to combustible charged, or (1469−353) to 1469, is therefore 0·76, and the efficiency of the producer based on combustible consumed is 45 per cent, which is very low.

The fuel clinkered badly during this trial, and, therefore, is not suitable for this type of producer without an arrangement being provided for admitting steam to the lower zone.

Cardiff Colliery—Trial No. 46.

In trial No. 46, coal from the Cardiff Colliery was gasified in the Westinghouse producer. This fuel required considerable attention, owing to its tendency to clinker and adhere to the lining of the producer. For this reason, it is doubtful whether the trial could have been prolonged 20 or 30 hours longer. In spite of its high moisture content (20 per cent) it is probable that the admission of steam to the upper fuel zone would have improved the behaviour of the coal, at least in so far as regards clinkering. The resistance of the upper fuel bed was high and the exit temperature of the gas, at the offtake, was higher than for any of the other trials carried out with the Westinghouse producer, except that of trials 47 (Twin City) and 56 (Pembina).

The analysis of the gas showed a fairly low percentage of carbon monoxide and a high percentage of hydrogen. The content of tar per cubic foot was, however, exceptionally low.

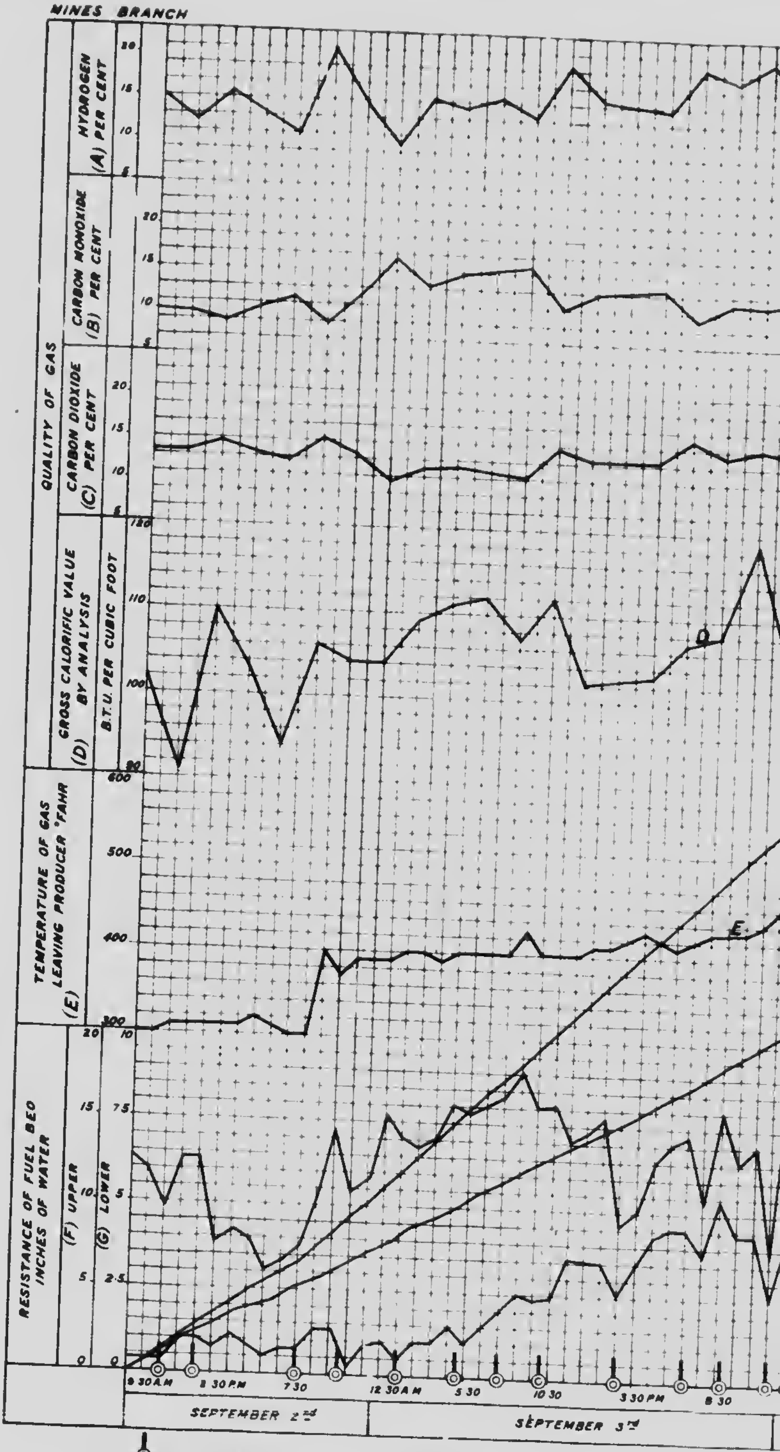
The high efficiency of this fuel based on the coal as charged is discounted by the figures showing that the carbon leaving as gas per hour is greater than that charged. The ratio of carbon in gas to carbon charged is 1·07, and if the efficiency quoted (71·8 per cent) be reduced proportionately to this amount, an efficiency of about 67 per cent will result.

Twin City Coal—Trial No. 47.

Only one trial (No. 47) was run with this fuel. As with the Cardiff coal, considerable trouble was experienced with clinkering. These clinkers formed rings near the top and round the vaporizer, which proved very difficult to break up.

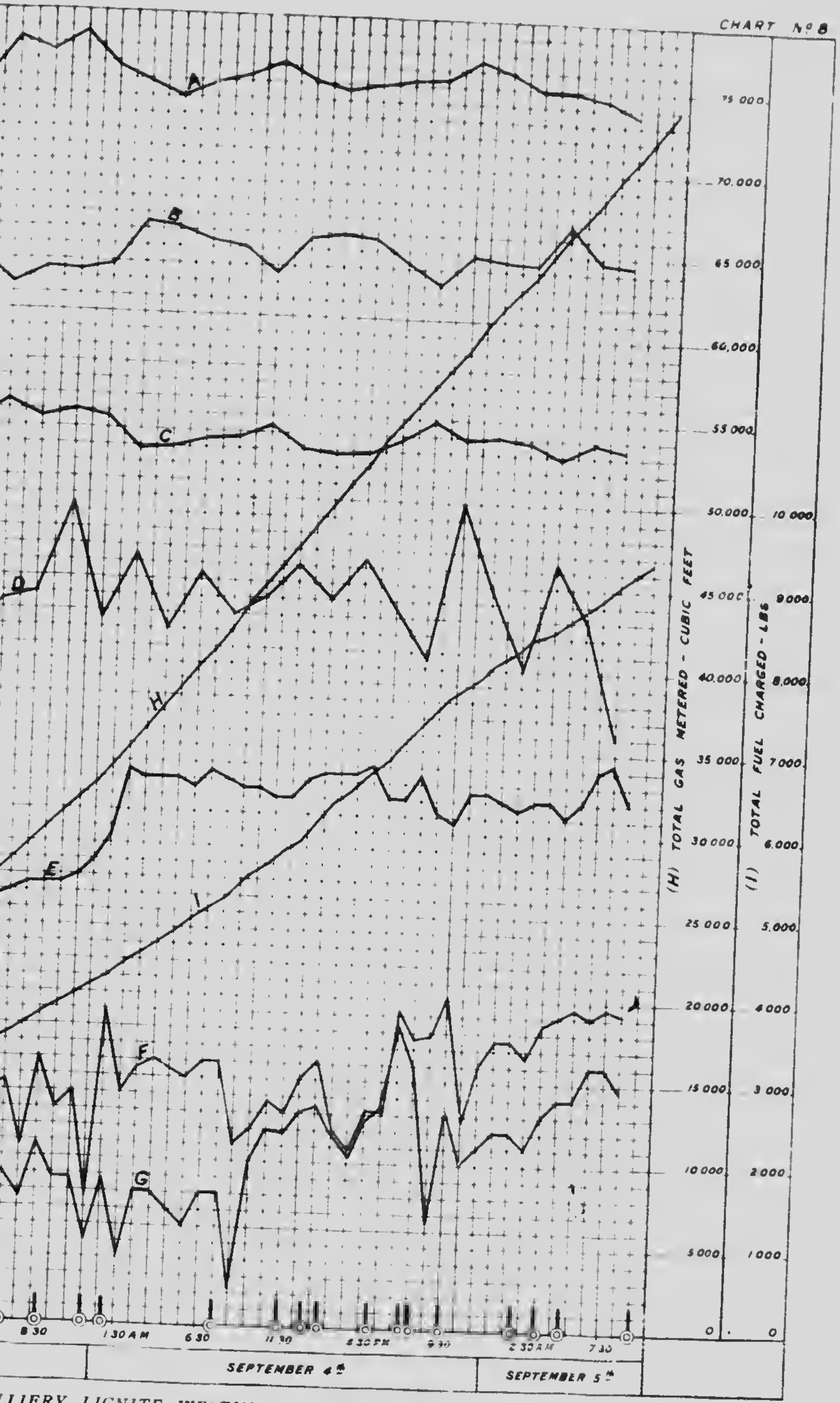
An examination of the fuel bed resistances indicates that the proportion of fuel burned in the lower zone during this trial was greater than in any of the other trials on this type of producer. From a comparison of this trial with the other trials carried out with the Westinghouse producer, it will be

	RESISTANCE O BED INCHES OF R		(E) TEMPERATURE OF GAS LEAVING PRODUCER °FAHR	QUALITY OF GAS			
	(F) UPPER			(D) GROSS CALORIFIC VALUE BY ANALYSIS	(C) CARBON DIOXIDE PER CENT	(B) CARBON MONOXIDE PER CENT	(A) HYDROGEN PER CENT

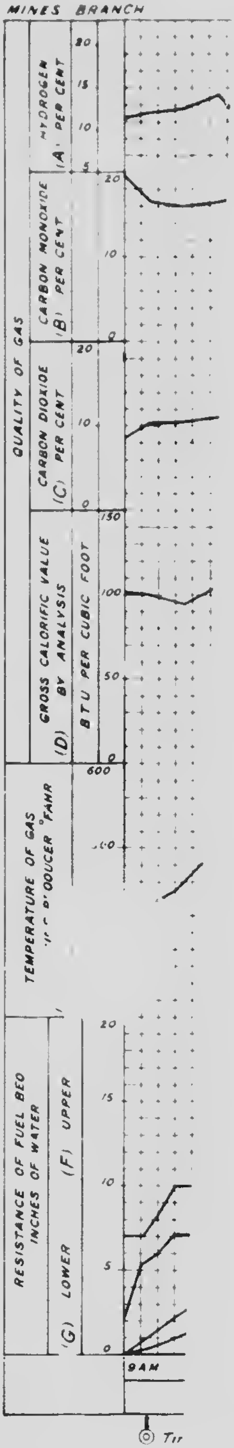


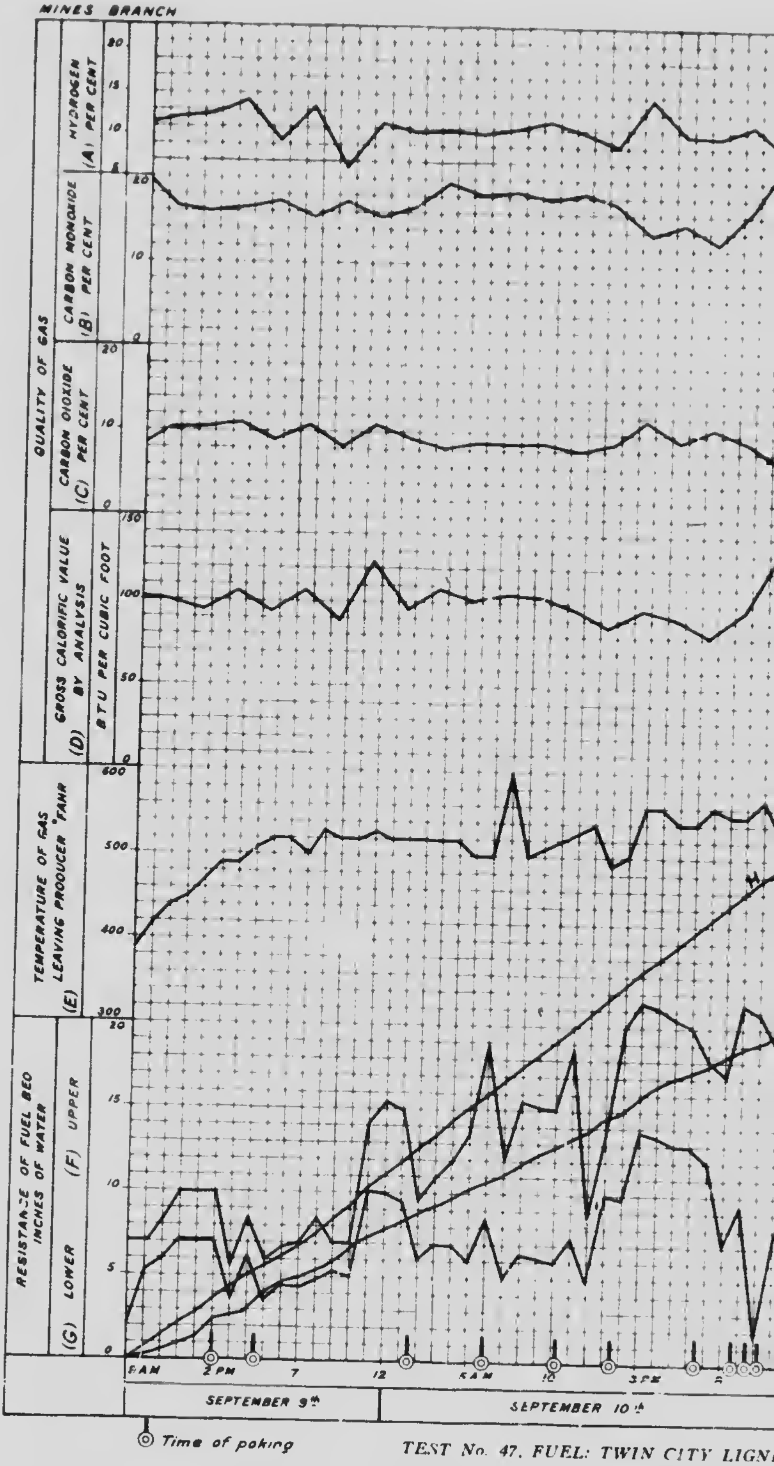
Time of poking

TEST No. 46. FUEL: CARDIFF COLLIERY, L

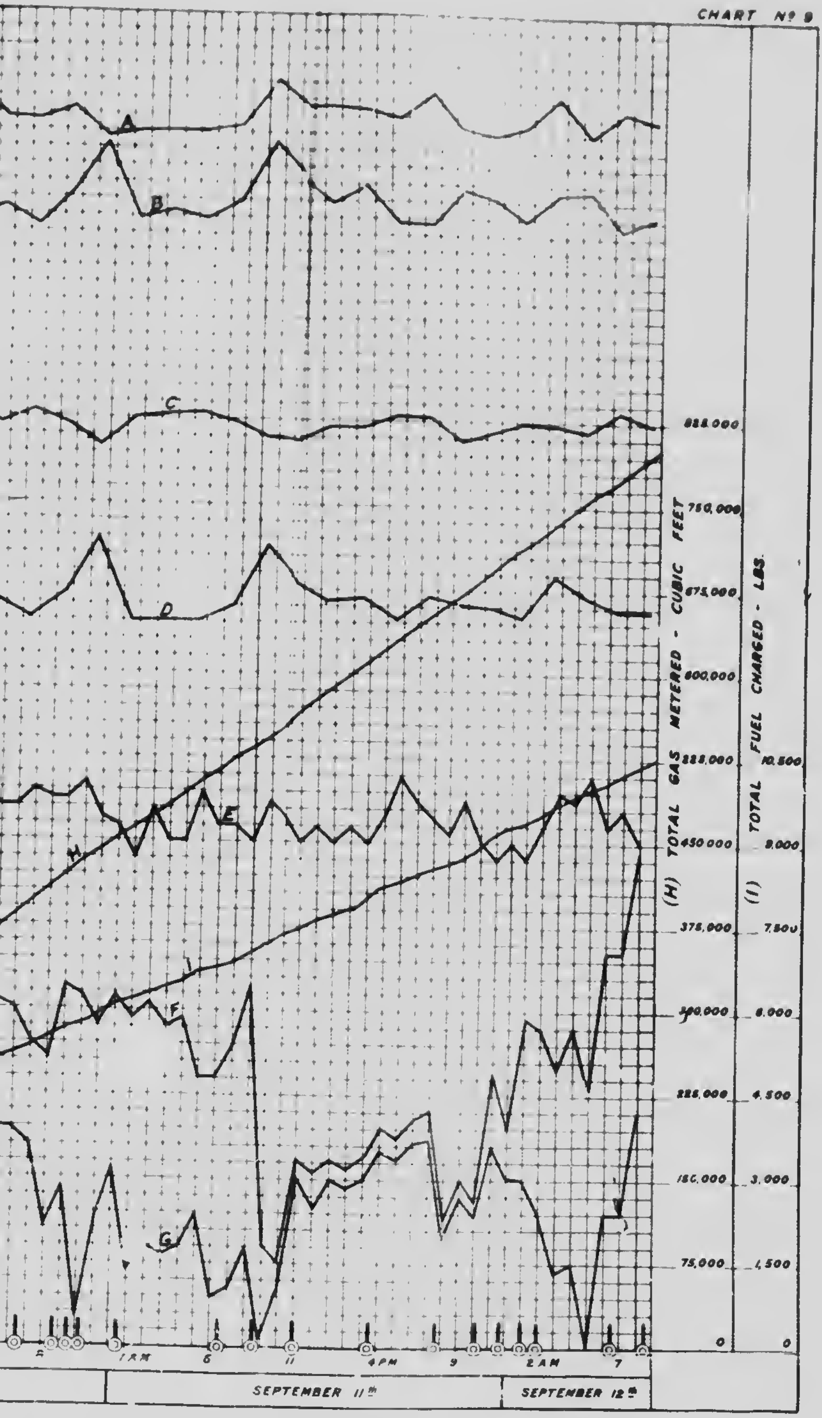


LLIERY. LIGNITE. WESTINGHOUSE PRODUCER.


MINES BRANCH
QUALITY OF GAS
(A) HYDROGEN PER CENT
(B) CARBON MONOXIDE PER CENT
(C) CARBON DIOXIDE PER CENT
(D) GROSS CALORIFIC VALUE BY ANALYSIS
BTU PER CUBIC FOOT
TEMPERATURE OF GAS
°FAHR
RESISTANCE OF FUEL BED INCHES OF WATER
(F) UPPER
(G) LOWER
20
15
10
5
0
150
100
50
600
9 AM
Tr

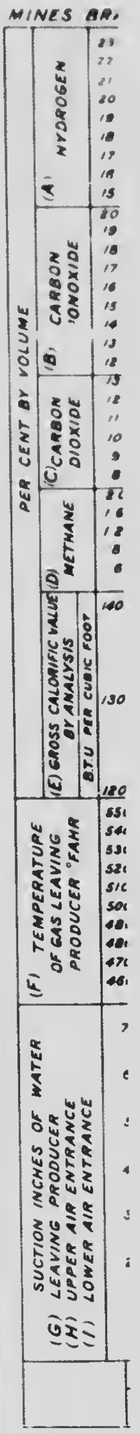


TEST No. 47. FUEL: TWIN CITY LIGN

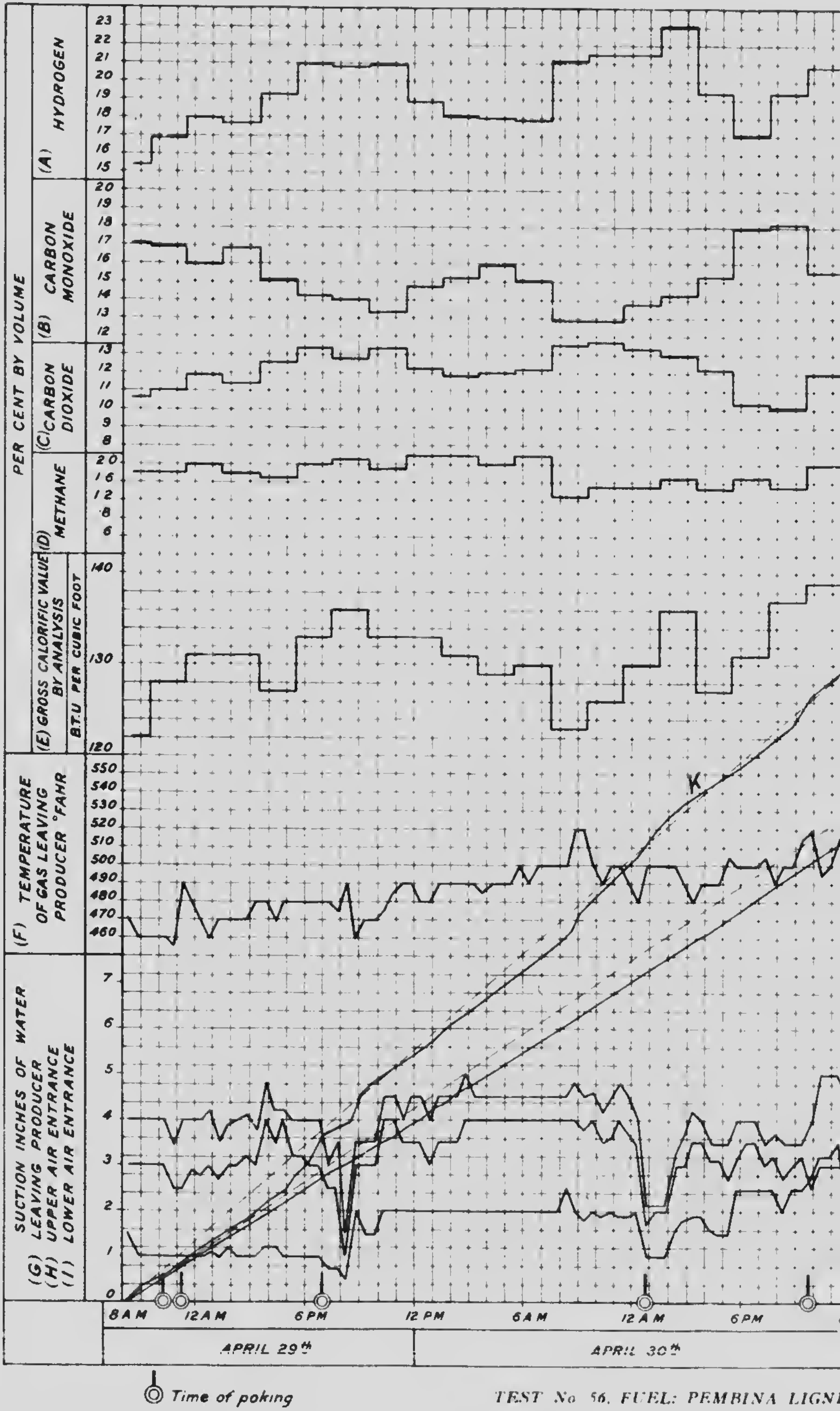


ITY LIGNITE, WESTINGHOUSE PRODUCER.

PER CENT BY VOLUME

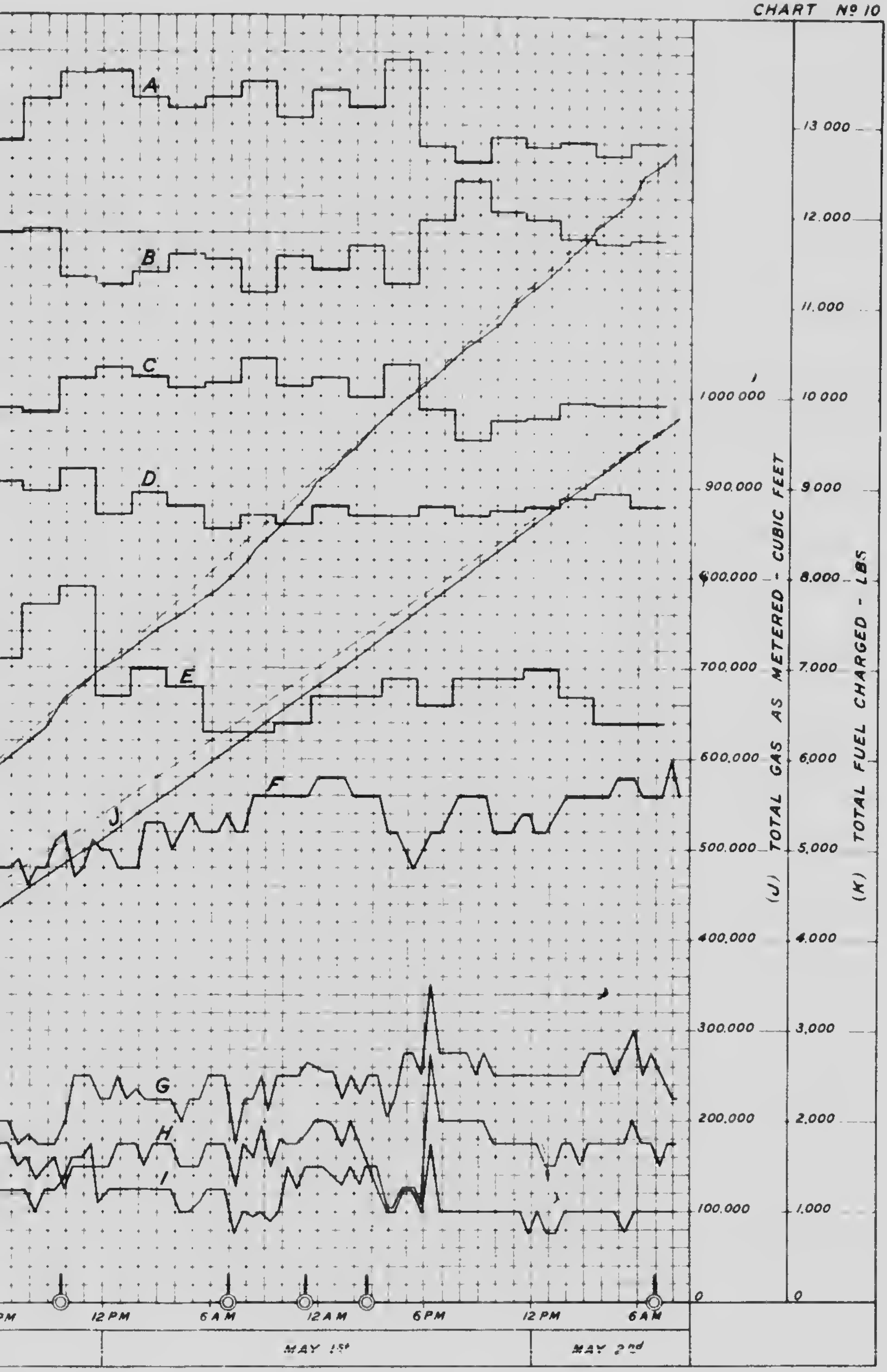

MINES BR
PER CENT BY VOLUME
(A) HYDROGEN
23
22
21
20
19
18
17
16
15
(B) CARBON MONOXIDE
20
19
18
17
16
15
14
13
12
(C) CARBON DIOXIDE
13
12
11
10
9
8
(D) METHANE
20
16
12
8
6
(E) GROSS CALORIFIC VALUE BY ANALYSIS
B.T.U PER CUBIC FOOT
140
130
120
(F) TEMPERATURE OF GAS LEAVING PRODUCER °FAHR
(G) SUCTION INCHES OF WATER LEAVING PRODUCER
(H) UPPER AIR ENTRANCE
(I) LOWER AIR ENTRANCE
7

MINES BRANCH



TEST No 56. FUEL: PEMBINA LIGNI

CHART Nº 10



NA LIGNITE, WESTINGHOUSE PRODUCER.

seen that the ammonia, carbon dioxide, and hydrogen contents of the gas were the lowest; while the temperature of the gas leaving at the offtake was the highest. From this it is obvious that too high a temperature prevailed in the producer and that a better gas would have resulted with the admission of more steam. It will be observed, also, that the gasification of the fuel was carried on at a greater rate than in the previous tests, to which may be partly attributed the high temperature. The gas during this test was clean.

The thermal efficiency of the producer was low, which may be attributed to the insufficient supply of steam to the lower zone, or to too small a rate of gasification in the upper zone.

Pembina Coal—Trial No. 56.

Producer trial No. 56 was run continuously from April 29 to May 2, 1914, on a commercial sample of coal received from the Pembina Coal Co. of Alberta. The gas producer employed for this test was the Westinghouse double zone type. The producer was operated continuously for several hours before the official test was begun. The actual test covered a period of 72 hours which together with the period the producer was operated previously, made the actual time of continuous operation on Pembina coal over 100 hours.

During the major portion of the test, the gas engine was run on the producer gas generated in order to determine the suitability of this gas for power purposes. The results showed conclusively that this lignitic coal was admirably suited for the generation of a power gas in a gas producer of this type. No difficulties from clinkers or irregularities in the calorific power of the gas were observed and the suctions in the different parts of the producer were remarkably uniform and unusually low throughout the test—one reading only during the entire trial showed a suction greater than six inches.

The manipulation of the producer, when burning this coal, offers no difficulties whatever; the fuel feeds regularly and little or no poking is required. This is in large part due to the absence of the formation of clinkers. The gas generated was not only very uniform as regards its chemical composition and heating value but was particularly free from tar or even lamp black.

Plate V shows a series of tar cards taken at the beginning of the trial and at regular intervals thereafter until the conclusion of the trial. Card No. 1 is of a yellowish colour, contains considerable tar and oily matter; card No. 2 is of a greyish yellow colour, contains less tar and oil, but shows traces of lamp black. Cards 3 and 4 are very nearly free from tar and oil, but contain considerable lamp black. Cards 5 and 6 taken near the end of the trial contain nothing but lamp black. These series of cards show that the producer was gradually approaching its proper condition and that the gas was practically tar free when the last two cards were taken.

The thermal efficiency of the process of gasification was not determined on account of an accident to the anti-pulsator during the trial. This anti-pulsator is interposed between the gas meter and the gas engine and serves the purpose of minimizing the effect of the pulsations of the gas engine upon the meter readings. For this reason it is quite impossible to state with any degree of accuracy the efficiency of the producer during the trial. The analyses of the gas produced, however, show conclusively that the efficiency was not less than 60 per cent—assuming the condition of the producer to be the same at the beginning and end of the test. The efficiency above stated was calculated on the lower calorific power of the gas. It is quite probable that the actual efficiency would have been much higher than 60 per cent.

The following table sets forth some of the more important results of the test:—

Summary of Results of Gas Producer Trial 56.

Date of trial: April 29 to May 2, 1914.
Duration of trial: 72 hours.
Fuel: run of mine.
Source of fuel: Pembina Coal Co., Ltd.
Producer: Westinghouse double zone.

Tar cards taken during the trial on Pembina lignite.

Proximate analysis of fuel as charged.

Fixed carbon	Per cent	43·9
Volatile matter	“ “	27·6
Ash	“ “	10·3
Moisture	“ “	18·2

Calorific values of fuel.

Fuel as charged,	B.T.U. per lb.	8,930
Dry fuel	“ “ “	10,910

Average pressures and temperatures.

Suction at upper entrance to producer,	Inches of water	3·0
“ “ lower “ “ “	“ “ “	2·3
“ “ producer exit	“ “ “	4·4
“ leaving scrubber	“ “ “	12·5
Pressure leaving exhauster	“ “ “	2·9
Temperature of gas leaving producer, °F.		510

Total fuel charged.

Fuel as charged during trial,	lbs.	12,727
Dry fuel charged	“ “ “	10,410

Quality of gas.

Analysis by volume, (continuous sampling)

Carbon dioxide	Per cent	11·7
Carbon monoxide	“ “	16·1
Hydrogen	“ “	19·0
Methane	“ “	1·5
Ethylene	“ “	0·1
Oxygen	“ “	0·7
Nitrogen	“ “	50·9
Inflammable gas	“ “	36·7
Calorific value from analysis, gross,	B.T.U. per cubic foot	129
“ “ “ “ net	“ “ “ “	118
Tar in uncleaned gas,	grams per 1,000 cu. ft.	9·5
“ “ cleaned	“ “ “ “ “ “	2·7
Nitrogen (as ammonia) in uncleaned gas,	grams per 1,000 cu. ft.	23·2

Fuel charged per hour.

Fuel as charged, per hour, lbs.	177
Dry fuel charged per hour, "	145

Poking and fuel level.

No. of times fuel was poked	10
Average height of upper fuel level above centre line of gas outlet	6′-1″

Practical Value of the Gas Produced.

The gas produced from the several lignites tested was used in the gas engine in order to ascertain its suitability for the production of power. The gas engine employed for this purpose was of only 60 B.H.P., while the capacity of the producer was considerably greater. Only a portion of the gas generated could, therefore, be used in this manner.

In every case the engine operated satisfactorily, although in certain cases the calorific value of the gas was rather low. The principal fact to be considered is the cleanliness of the gas. The quantity of tar and solid matter after leaving the wet scrubber was of so small an amount that no trouble was experienced from the deposition of tar on the valves, piston rings, and cylinder. As a matter of fact, the engine could be run for an indefinite period before the necessity for cleaning the various moving parts, exposed to the flow of gas, would arise. Therefore, the gas generated in this type of producer from those lignites tested is eminently suited for power purposes.

The value of the gas for steam-raising or for the generation of heat for industrial purposes was not investigated. It is, however, quite probable that no difficulties would arise were the gas to be utilized for such purposes.

It will be noted that, in the summary of results, values have been given showing the consumption of fuel per B.H.P. hour. These values are all based on the performance of an engine, the overall efficiency of which is 25·45 per cent, i.e., which has a heat consumption of 10,000 B.T.U. per hour per B.H.P. developed. This heat consumption is representative of the average performance of a well designed gas engine, when it is operated in the vicinity of its rated load.

TABLE III.

Summary of Results of Gas Producer Trials.

Note: "W" signifies the Westinghouse producer, and "K" the Körting producer.

Name of Fuel	Tofield			Rosedale		Gainford		Cardiff Collieries	Twin City
No. of Trial	38	39	44	40	43	42	45	46	47
Producer	W	W	K	W	K	K	W	W	W
Date of trial, 1913	June 19-21	July 2-5	Aug. 9.	July 14-17	Aug. 7.	July 31	Aug. 25-28	Sept. 2-5	Sept. 9-12
Duration of trial, hours	51·5	72	12	72	12	12	72	72	72
Proximate analysis of fuel (as charged)									
Fixed carbon, Per cent	36·7	36·7	37·3	43·4	43·7	43·8	43·8	40·4	41·3
Volatile matter, " "	29·8	29·8	30·2	33·6	33·8	30·8	30·8	31·6	33·3
Ash, " "	8·5	8·5	7·5	6·5	7·2	8·4	7·7	8·0	7·3
Moisture, " "	25·0	25·0	25·0	16·5	15·3	17·0	17·7	20·0	18·1
Ultimate Analysis of Fuel (as charged)									
Carbon, Per cent	50·4	50·4	50·9	57·3	57·7	53·8	53·8	52·1	54·1
Hydrogen " "	6·6	6·6	6·7	5·8	5·7	5·0	5·1	6·4	5·9
Oxygen, " "	33·3	33·3	33·7	28·7	27·7	30·6	31·2	32·2	31·2
Nitrogen, " "	0·9	0·9	0·9	1·3	1·3	1·6	1·6	1·1	1·1
Sulphur, " "	0·3	0·3	0·3	0·4	0·4	0·6	0·6	0·2	0·4
Ash, " "	8·5	8·5	7·5	6·5	7·2	8·4	7·7	8·0	7·3
Calorific Values of Fuel by Calorimeter									
Calorific value of fuel as charged per lb. B. T. U.	7,990	7,990	8,080	9,650	9,720	9,040	9,040	8,770	9,160
Calorific value of dry fuel per lb., B. T. U.	10,650	10,650	10,770	11,560	11,470	10,890	10,980	10,960	11,180
Calorific value of combustible per lb. B. T. U.	12,020	12,020	11,970	12,530	12,540	12,120	12,120	12,180	12,280
Average Pressures, Temperatures, etc.									
Temperature of gas leaving producer, °F	427	408	620	442	720	642	390	461	519
Temperature of gas leaving upper zone, °F			176		340	255			
Resistance of upper fuel bed, Inches of water	14·4	19·0	0·2	4·0	0·1	0·1	6·6	14·0	14·1
" " lower " ", Inches of water	2·5	6·1	1·4	0·7	0·7	1·7	0·5	3·6	7·2
Suction at final scrubber, Inches of water	21·7	25·9	6·5	10·8	5·7	7·5	13·3	21·1	20·5

Total Quantities									
Fuel charged during trial, lbs	6,215	8,761	1,350	10,884	968	1,969	10,686	9,320	10,641
Dry fuel charged during trial, lbs	4,661	6,571	1,013	9,088	820	1,634	8,795	7,456	8,715
Combustible in fuel charged during trial, lbs	4,133	5,826	911	8,381	750	1,469	7,972	6,710	7,938
Carbon in fuel charged during trial, lbs	3,132	4,415	687	6,236	559	1,059	5,749	4,556	5,757
Gas (moist at 60°F. and 14·7 lbs. per sq. in.) supplied by producer during trial, cu.ft.	366,680	487,360	41,308	580,530	40,011	52,270	548,010	[illegible],640	666,790
Quality of Gas									
Analysis by volume, per cent.									
Carbon dioxide, " "	12·5	12·5	9·6	10·4	9·1	8·7	11·2	12·8	9·4
Carbon monoxide, " "	10·6	12·2	18·3	17·3	18·6	19·3	16·6	13·5	16·5
Hydrogen, " "	14·6	14·1	12·6	16·7	12·4	12·9	15·0	15·3	11·0
Methane, " "	1·8	1·7	2·2	2·1	1·7	2·2	2·4	1·4	0·8
Ethylene, " "	0·0	0·0	0·1	0·0	0·1	0·1	0·1	0·0	0·1
Oxygen, " "	2·4	1·7	1·0	0·5	0·9	1·2	0·7	1·0	1·5
Nitrogen, " "	58·1	57·8	56·2	53·0	57·2	55·6	54·0	56·0	60·7
Inflammable gas, " "	27·0	28·0	33·2	36·1	32·8	34·5	34·1	30·2	28·4
Cal. value from analysis, gross, B. T. U. per cu. ft.	100	103	123	131	117	126	126	106	97
Cal. value from analysis, net, B. T. U. per cu. ft.	90	94	114	120	109	117	116	97	91
Cal. value from Boy's calorimeter (gross) B. T. U. per cu. ft.	101	94	127	127	118	125	125	108	93
Tar in uncleaned gas, grams per 1,000 cu. ft.	10·6	12·9	56·3	23·4		45·0	9·1	4·5	5·3
Tar in cleaned gas, grams per 1,000 cu. ft.	1·0	0·6	14·9	7·9	......	12·6	1·5	0·1	0·2
Nitrogen in uncleaned gas, grams per 1,000 cu. ft.	11·0	14·6	27·9	23·[illegible]		12·6	21·2	9·4	1·5
Hourly Quantities									
Fuel charged per hour, lbs	120·6	121·7	112·5	151·2	80·7	161·1	148·4	129·5	147·8
Dry fuel charged per hour, lbs	90·5	91·3	84·4	126·2	68·3	136·2	122·1	103·6	121·0
Combustible charged per hour, lbs	80·2	80·9	75·9	116·4	62·5	122·1	110·7	93·2	110·2
Carbon charged per hour, lbs.	60·8	61·3	57·3	86·6	46·6	[illegible]	79·9	67·5	80·0
Carbon leaving as permanent gas per hour lbs	55·5	55·2	32·6	75·0	40·8	41·3	72·2	72·2	77·8
Tar in uncleaned gas per hour, lbs.	0·166	0·191	0·428	0·417		0·336	0·153	0·083	0·108
Tar in cleaned gas per hour, lbs	0·016	0·009	0·113	0·140		0·121	0·025	0·002	0·004
Nitrogen, as ammonia, in uncleaned gas per hour, lbs	0·173	0·216	0·212	0·415		0·121	0·355	0·173	0·031
Nitrogen in coal, charged per hour, lbs	1·08	1·10	1·01	1·96	1·05	2·62	2·37	1·42	1·63
Gas (moist at 60°F and 14·7 lbs. per sq. in.) produced per hour, cu. ft	7,120	6,700	3,450	8,070	3,330	4,360	7,610	8,340	9,260
Calorific value of coal charged per hour, B. T. U	964,000	972,000	909,000	1,459,000	784,000	1,483,000	1,342,000	1,135,000	1,354,000

TABLE III.—(*Continued*)

Name of Fuel	Tofield			Rosedale		Gainford		Cardiff Collieries	Twin City
No. of Trial	38	39	44	40	43	42	45	46	47
Producer	W	W	K	W	K	K	W	W	W
Hourly Quantities: —*continued*									
Calorific value of gas produced per hour B. T. U. (lower value)	645,000	603,000	400,000	952,000	365,000	507,000	880,000	814,000	824,000
Water supplied to producer and scrubbers per hour, Imp. gals.	719	752	71;	608	649	722	453	698	857
Horse Power (based on assumption that 10,000 B. T. U. = 1 H. P.)									
Gross horse power developed by producer..	64·5	60·3	40·0	95 2	36·5	50 7	88 0	81 4	82·4
Net " " " " allowing for power taken by the exhauster	62·2	58·3	....	93 9	....		86 4	78 9	80 0
Poking and Fuel Level									
No. of times fuel was poked	29	37	6	11	5	5	12	34	26
Average height of upper fuel level above centre line of gas outlet	....	5′—1″	....	4′—6″	....		4′—8″	4′—11″	4′—8″
Economic Results									
Gas (moist at 60°F. and 14·7 lbs. per sq. in.) produced per lb. of fuel charged, cu. ft.	59 0	55·1	30·6	53·3	41 3	26 5	51 3	64 4	62 6
Gas (moist at 60°F. and 14·7 lbs. per sq. in.) produced per lb. of dry fuel charged, cu. ft.	78 6	73 4	40·7	63 9	48 8	32 0	62 3	80 6	76 5
Gas (moist at 60°F., and 14·7 lbs. per sq. in.) produced per lb. of combustible charged, cu. ft.	88·7	82·8	45 4	69 2	53·3	35 5	68 7	89·4	84 0
Water used in scrubbers per 1,000 cu. ft. of gas produced, imp. gals.	101	112	208	75	195	166	60	84	93
Nitrogen recovered as ammonia, per cent. of nitrogen in fuel charged	16·0	19·6	21·0	21·2		4 6	15 0	12·2	1 9
Fuel as charged per hour, per gross H. P..	1·87	2·02	2·81	1 59	2·21	3 23	1 69	1 59	1·79
" " " " net H.P.	1·93	2·09	....	1·61			1 72	1·64	1·85
Dry fuel charged per hour, per gross H.P...	1·40	1·51	2·11	1·32	1 87	2·68	1 39	1·27	1 47
" " " " net H. P.	1·45	1·57	....	1·34			1 41	1·31	1·51

Efficiency									
Efficiency of process of gas production, based on fuel charged, and net calorific value of the gas, per cent............	66·9	62·0	44·0	65·2	46·6	34·2	65·6	71·8[1]	60·9
Efficiency of process of gas production and cleaning, based on fuel charged—net calorific value of the gas and allowing for the power used by the exhauster, per cent..........................	64·5	59·9	....	64·3	....	....	64·4	69·6	59·1

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[1] Note: See remarks on high efficiency of this trial, on page 38.

Conclusions.

The results of the trials show that all the lignites tested were eminently suited for the production of gas when burned in the gas producer. The operation of the producer in no case presented serious difficulties, although some trouble, in certain of the trials, was experienced from clinkering. The majority of the lignites, however, were remarkably free from components giving rise to the formation of clinkers. Steam admitted into the upper zone would very likely reduce the tendency to clinker; but when no provision for the introduction of steam is provided, careful poking will have to be resorted to when the lignites utilized produce bad clinkers. Throughout the trials, which were of long duration, the gas was remarkably uniform in chemical composition and free from tar or solid matter such as dust.

No trouble whatever was experienced from the burning of the gas in a gas engine, and these lignites may therefore be said to be eminently suited for the production of power in this manner.

The labour required for the operation of a producer and gas engine of the capacity employed during the tests is very small. One operator when properly trained would prove sufficient to handle such a plant per shift.

The quantity of cooling water required to clean and cool the gas is not excessive, and on account of the small amount of the by-products carried away with the water leaving the scrubber, no trouble should be experienced in sufficiently cleaning the water for use over and over, in case the supply of water is a serious matter.

In certain of the lignites, the nitrogen content is sufficiently high to make its recovery as ammonia or ammonium sulphate, under favourable circumstances, profitable.

It has been shown that a slacked lignite behaves exceedingly well when burned in the gas producer and that the cheaper grades can therefore be utilized for the production of gas and power.

PART II.

BOILER TESTS.

BY

John Blizard.

OBJECT OF TESTS.

The boiler tests described in this report were conducted for the purpose of ascertaining the commercial value of the different lignitic and other coals tested for steam-raising. In order to establish many important factors concerning the commercial value of any fuel for steam-raising, an investigation of this nature should not be limited to a single test, or only a few, but to a large number, in which the rate of steaming, ratio of heating surface to grate surface, size of combustion chamber, air-space in grate bars, thickness of fuel bed, and many other factors might be varied. In these tests, however, the quantity of each fuel available for such investigation limited the number of tests which could be made with each fuel, so that one trial only was conducted with each. This, of course, precluded any possibility of altering the boiler and furnace. In the several tests made with the lignites, obtained from different localities, an effort was made to keep the rate of steaming constant. The fuel was fired by hand throughout, and the thickness of fuel bed, and frequency of firing were adapted to suit the fuel being burned. These tests, therefore, serve to compare the boiler efficiencies obtained with different fuels for a particular rate of heat transmission, method of firing, grate setting, etc.

The data obtained from these tests, therefore will prove of value to those industries dependent on the various fuels found in the western provinces, when selecting a fuel to generate steam at the lowest cost.

An examination of the results herein set forth will show that, in some cases, it would prove feasible to increase the ratio of heating surface to grate surface for one fuel as compared with another, in the proposed design of a boiler plant intended to burn exclusively such a fuel. Again, observations concerning the behaviour of the fuel would suggest that some form of shaking grate might be employed to advantage in certain instances, thereby rendering possible the removal of ashes from the fuel bed without opening the fire door, consequently reducing heat losses and inconvenience in handling.

The above examples will serve to point out that the fuels employed in these tests must not be compared solely on their merits as fuels for steam-raising, but that other closely related conditions which obtained during the trials must be examined and considered in relation to the proposed plant for which the most suitable fuel is to be chosen.

Method of Conducting Tests.

Preliminary measures. All valves and fittings were carefully examined for leakage during a preliminary run of the boiler the day before the trial was begun. The fires were banked overnight at the termination of this run. The following morning the boiler was again run for one hour and a half before starting the trial proper, for the purpose of bringing the brick work, casings, etc., to the working temperature. The boiler tubes were thoroughly cleaned of any soot by a steam blast about one hour before the trial proper was started.

Duration of trial. The trial should be of such duration, that the error arising from misjudgment of the quantity of unburnt fuel on the grate bars is reduced to a negligible quantity. An error of one inch in judging the thickness of the fire in the present case would mean a possible error in the coal consumed of about two cubic feet, therefore, if the weight of green coal which will form one cubic foot of incandescent fuel is taken as 25 lbs.,[1] an error of 50 lbs. would be involved, or one per cent for a total fuel consumption of 5,000 lbs.; the error, however,

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[1] See Report of the Committee on Tabulating the Results of Steam Engine and Boiler Trials; the Institution of Civil Engineers, Vol. CXCV, p. 271. This report suggests 20 lbs. of large coal and 30 lbs. for small slack per cubic foot of incandescent fuel.

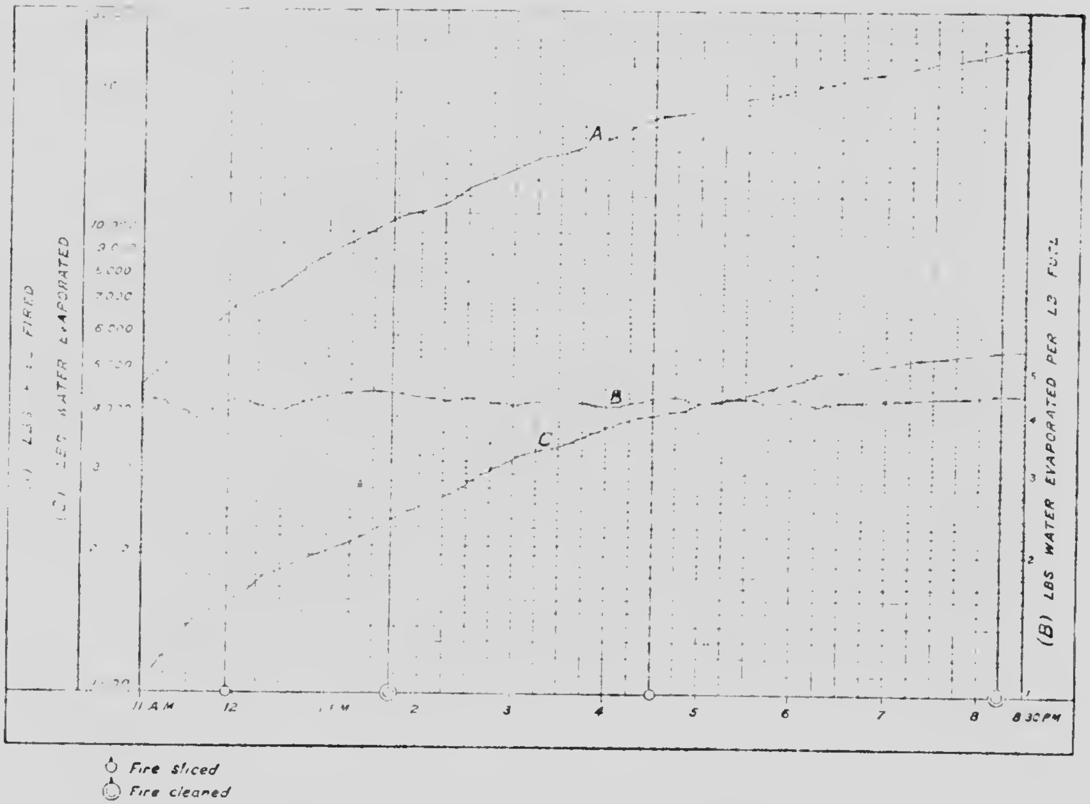


Fig. 8. Diagram showing evaporation per pound of fuel during boiler trial 51.

may easily amount to twice this amount, or 2 per cent. In order to minimize such error, the trials were conducted for a period of 12 hours, or 2 hours longer than the previous series carried out at McGill University, under the auspices of the Mines Branch of the Department of Mines.

Fig. 8 has been prepared to show the variation in the ratio of the water evaporated to the coal charged, during the final 9½ hours of trial 51. In this diagram the vertical distances are proportional to the logarithms of the numbers denoted at the side.

The ordinates of curves A and C are proportional to the logarithms of the quantities of water evaporated and coal fired, while the ordinates of curve B are equal to the distances between curves A and C. It will be seen that curve B represents $\text{Log. } A - \text{Log. } C = \text{Log } \frac{A}{C}$, or the logarithm of the pounds of water evaporated per lb. of fuel fired. The undulations of curve B are caused principally by the change of composition and thickness of the fuel bed.

It will be noticed that the greatest variations occur at or near the times of slicing or cleaning fires. Such changes are to be accounted for by the fact that, when it has been decided to slice or clean the fire, no fresh fuel is charged for some little time before doing so, while the actual operation is carried out with open fire-doors. This permits an inrush of air, which cools the boiler. Such operations as these affect the working of the boiler and the ultimate result of the trial. It is important, therefore, that during a trial the fires should be cleaned, when possible, at regular intervals, and at such times that the conditions of cleaning and slicing are properly represented in the trial.

Starting and stopping the trial. About half an hour before commencing the trial, the fire was carefully cleaned, and stoking was carried out in such a manner that, at the time of starting the trial, the grate was covered with a bed of thin fuel, the thickness and condition of which could be easily judged. At the same moment that the thickness and condition of the fire were estimated, observations were taken of the water levels in the boiler and feed tank.

The ash-pit was carefully cleaned immediately before commencing the trial. To bring the trial to a conclusion, the above procedure was repeated.

Coal consumption, ash and refuse removed. Coal was weighed out in lots of approximately 150 lbs., and when this quantity of coal had been fired the time was noted. All ash and refuse taken from above the bars was weighed on removal, and then slaked, while that removed from the ash-pit was also weighed at the end of the trial.

Sampling. Before the trial, the whole of the coal was sampled, and sent to the chemical laboratory for analysis, and calorimeter tests. The ash and refuse was also sampled and analysed.

Feed-water. All the feed-water was weighed in a tank, from which it passed to a second graduated feed-tank; from this the feed pumps delivered directly to the boiler. The boiler gauge glass was graduated to show at any moment the quantity of water in the boiler. Observations of the quantity of water evaporated were made every fifteen minutes. These observations were used to regulate the rate of working of the boiler to the prearranged load of 2,000 lbs. of steam per hour.

The temperature of the feed water was read every fifteen minutes.

Quality of steam. The heat energy of the steam was observed by means of a throttling calorimeter. Marks & Davis' steam tables were used for the calculations involved. The steam pressure was observed by means of a Dewrance pressure gauge, which was tested upon a standard gauge tester, and found to be without error.

Draft. The pressure was observed below the grate-bars in the combustion chamber, and in the flue leaving the boiler. Sloping gauges, of the Schaeffer & Budenberg type, reading to one hundredth of an inch, were used for these measurements.

Flue temperature. The temperature of the flue gas was observed as it left the boiler, by means of a Bristol electrical pyrometer. The temperature recorded is that of the gas in the centre of the flue, and as nearly as possible that of the gas as sampled for analysis.

Sampling and analysis of flue gases. The sample was taken from the centre of the flue leaving the boiler, through a hard glass tube encased in a wrought iron pipe. In trial 51, the samples for complete analysis were taken intermittently. In addition to the intermittent sampling, a further piece of apparatus was used in this test to indicate the percentage of carbon-dioxide contained in a sample taken continuously over a long period. This latter method involved the use of two meters, the first one of which measured the gas as it issued from the flue. On leaving the first meter, the gas was passed through a solution of caustic potash, after which, being depleted of carbon-dioxide, it was measured in the second meter. The difference between the two meter readings for the same period showed the quantity of carbon-dioxide extracted. The meter readings were then corrected for inaccuracy and differences of pressure and temperature: separate tests were made in order to compare the readings of the two meters. Owing to the variation in the correction factors to be applied to the meters from time to time, this scheme was abandoned as being too unwieldy and involving too much subsidiary work. In the later tests a sample was taken continuously over a period of twenty minutes and then analysed. The Randall & Barnhardt apparatus was used for the gas analyses.

Equipment of Plant.

Boiler. A Babcock & Wilcox, marine type, water tube boiler was employed, drawings of which are shown in Fig. 10. This boiler consists of one steam and water drum, 3′-6″ in diameter, connected to uptake and downtake headers by expanded tubes. There are ten sections of tubes expanded at the ends into the headers. The total number of tubes contained in these sections is ten large tubes, of $3\frac{15}{16}$″ diameter, and 156 small tubes, of $1\frac{13}{16}$″ diameter.

The baffle plates are so arranged that the products of combustion are compelled to pass three times across the tubes before leaving the boiler.

The boiler is enclosed in casings of wrought iron plates, fitted with fire refractory material, and provided with outer air casings.

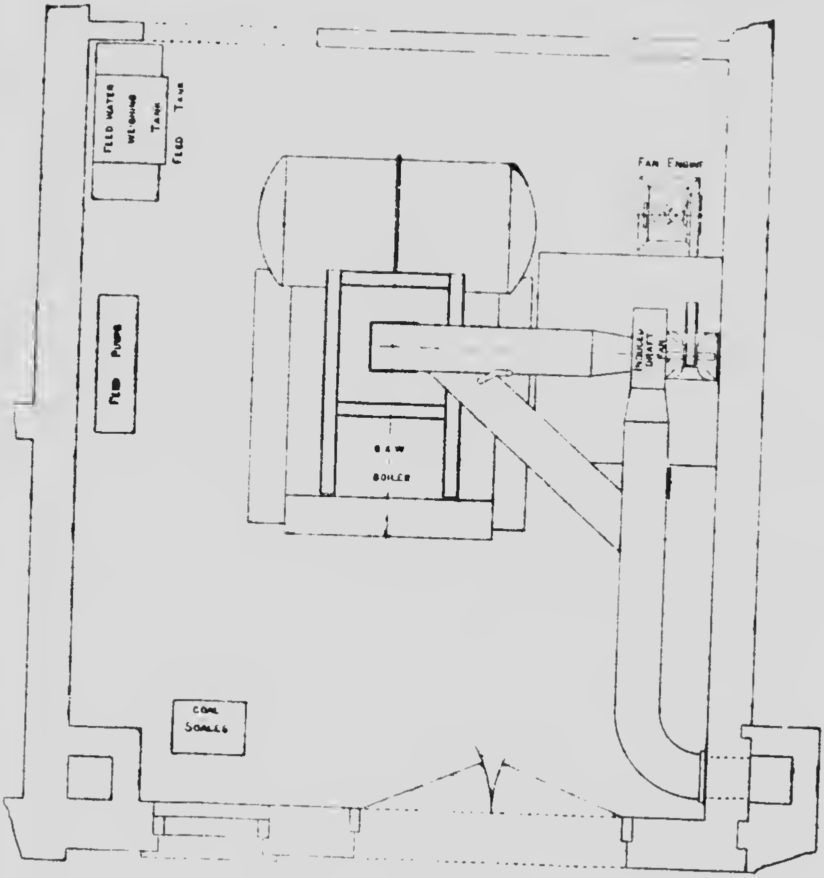


Fig. 9. Plan of boiler room.

The original plan of the boiler allowed for a grate surface of 38 square feet; however, to meet the present requirements the grate surface has been bricked off so as to be 4′—9½″ in length, by 4′—10″ in width, giving an area of 23·2 square feet.

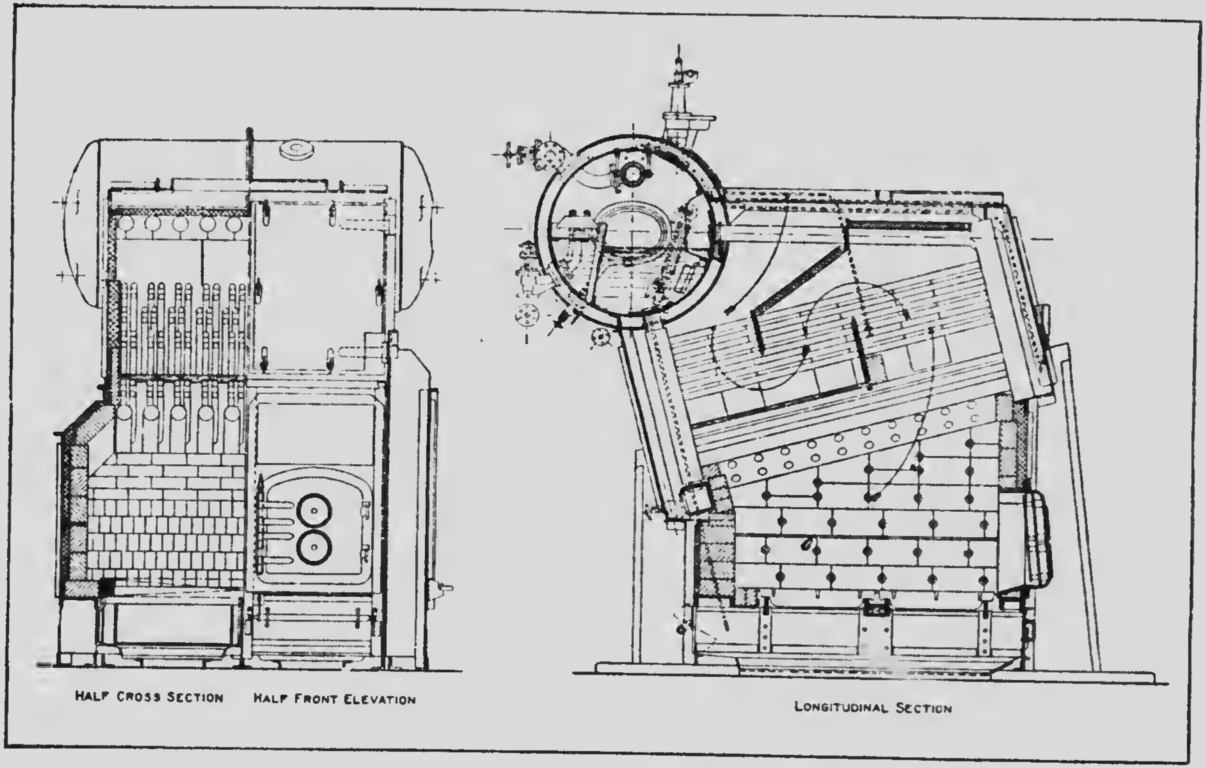


Fig. 10. Babcock and Wilcox marine type boiler.

The fire bars (see Fig. 11) are of a special corrugated type supplied by the makers of the boiler. The air spaces are ¼″ in width, giving an air opening 30 per cent of the total grate area, and were so constructed in order to retard, as far as possible, the passage of unburnt fuel to the ash-pit, without unduly restricting the air openings.

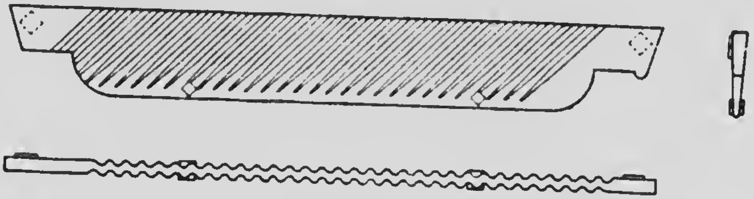


Fig. 11. Fire bars.

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

Heating surface (tubes)	633 sq. ft.
" " (drum, etc.)	44 " "
Total heating surface	677 " "
Width of grate	4′—9½″
Length of grate	4′—10″
Grate surface (excluding dead plate)	23·2 sq. ft.
Ratio heating surface to grate surface	29
Height, grate to lowest tier of tubes, front	51 inches
" " " " " " " back	34 "
Approximate width of air spaces	¼ inch
Grate area occupied by air space, per cent of total grate area	30
Capacity of water space, cubic feet	57
" " steam " "	48
Working pressure, lbs. per sq. in.	120

Apparatus for measuring feed water. Water from the city main was delivered to a 24″ × 24″ × 30″ wrought iron rectangular tank, mounted on standard platform scales. From this weighing tank the water was admitted by a valve to the feed tank, which was of wrought iron, and 24″ × 48″ × 54″ in dimensions.

Two entirely independent systems of pumping water to the boiler from the feed tank were provided. Both feed pumps were of the duplex steam-driven type, one with water pistons having steam cylinders 3" in diameter, water cylinders 2" in diameter, and a stroke of 4", the other having steam cylinders 4½" in diameter, water rams 3" in diameter, and a stroke of 4".

Draft. To obviate the necessity of erecting a high chimney, an induced draft installation was employed. The products of combustion were exhausted from the furnace by means of a 30" steel plate fan. The bearings of the fan were water cooled, and the fan was driven by means of a belt from a 3½" × 3" vertical engine, with throttling governor. The draft could be regulated by means of varying the speed of the engine, and by regulating the damper in the by-pass flue, which was so arranged as to obviate the flue gases passing through the fan when it was not in operation. The steam used by the fan engine was not deducted from the total steam evaporated, because the draft did not exceed that which is obtained under ordinary conditions with a chimney stack.

Results of Boiler Trials.

The results of the trials are given in the form of tables, in order that the principal results may be easily compared with one another, and with similar fuels tested at McGill (see Part VII, Vol. II, of "An Investigation of the Coals of Canada," published by the Mines Branch, Department of Mines). Previous remarks on boiler trials show that the boiler efficiency obtained with any particular fuel means little, unless it be compared with the efficiency obtained under similar conditions with other fuels. At the end of this report a list of observations and computations for each trial will be found, with remarks upon the behaviour of the respective fuels tested.

In the full tables made out for each individual trial the method of calculating the result is indicated where necessary. A heat balance is appended for each trial. The heat balance, however, can be regarded only as approximate, because of the following assumptions which were made in calculating the disposal of the heat energy of the fuel —

(a) That the sample of flue gas taken from the centre of the flue represents the average for the whole cross-section.

(b) That the temperature at the centre of the flue is the average temperature of the flue gas.

(c) That the solid matter leaving with the flue gas has the same chemical composition as the ash and refuse removed from the grate and ash-pit.

(d) That the combustible unconsumed has the same calorific value as the combustible in the fuel fired.

Such assumptions have been shown to be only approximately correct. However, it was not felt that any extra expense and labour which would have been incurred by more elaborate schemes for obtaining more accurate results would have been justified in trials of this nature.

Table IV shows an abstract of the principal results of the boiler tests carried out at Ottawa. An examination of all of the analyses shows that four of the fuels are lignitic in character, have a moisture content from 15 to 21 per cent, and are high in volatile constituents. The remaining fuel (Canmore, trial 54) is of a different nature, being much lower in volatile constituents and having the low moisture content of 2·9 per cent. When coal is burned, the volatile components are given off first, for which a certain amount of heat must be furnished, while the coke remains to be burned later. One effect of a large proportion of volatile matter and moisture with a periodic fuel supply to the furnace is to cause a wide variation in furnace temperature. Fig. 12 shows charts with the flue gas temperature recorded on a polar diagram. These charts were taken during trials 54 and 55, in which widely dissimilar fuels were tested. It will be noted that the average amplitude of the oscillations for trial 55, in which the volatile matter is 29·5 per cent, and the moisture 17·0 per cent, is much greater than for trial 54, wherein the coal contains 13·1 per cent of volatile matter, and 2·9 per cent moisture. In order to ensure complete combustion, the volatile components require to be kept at a high temperature and in-

TABLE IV

Abstract of Results of Boiler Trials at Ottawa.

1.	Trial No.	51	52	53	54	55	
2.	Fuel	Rosedale	Cardiff	Twin City	Canmore	Pembina	
3.	Duration of trial	720	720	720	720	720	Mins.
	Proximate Analysis of Fuel as fired.						
4.	Moisture	15·3	21·2	15·9	2·9	17·0	Per cent
5.	Fixed carbon	45·0	39·1	40·8	71·7	43·8	-
6.	Volatile matter	32·1	32·1	29·8	13·1	29·5	-
7.	Ash	7·6	7·6	13·5	12·3	9·7	-
8.	Calorific value of fuel as fired per lb.	9.600	8,570	8,530	12,920	8,980	B. T. U.
	Hourly Quantities.						
9.	Fuel as fired per hour	470	473	465	295	434	Lbs.
10.	Fuel as fired per hour per sq. ft. of grate surface	20·2	20·3	20·0	12·7	18·6	-
11.	Equivalent evaporation from and at 212 °F. per hour	2,554	2,404	2,427	2,377	2,456	-
12.	Equivalent evaporation from and at 212 °F. per hour per square foot of heating surface	3·77	3·55	3·59	3·51	3·63	-
	Average Temperatures, Pressures, etc.						
13.	Steam pressure by gauge, lbs. per sq. inch	108	108	107	105	109	-
14.	Temperature of feed water entering boiler	38·5	35·5	35	37	37·5	F
15.	Percentage of moisture in steam	0·9	0·8	0·8	0·8	1·0	Per cent.
16.	Pressure difference of draft, above and below bars	0·21	0·20	0·21	0·32	0·21	Inches
17.	Pressure difference of draft between flue gas exit and ash pit	0·57	0·46	0·63	0·68	0·63	-
18.	Flue gas temperature at boiler exit	730	670	690	630	645	F
	Flue Gas.						
19.	Average carbon dioxide per cent in dry flue gas, by volume	8·5	10·2	9·0	7·5	7·7	Per cent.
20.	Average carbon monoxide, per cent in dry flue gas, by volume	0·4	0·7	0·2	0·05	0·4	
21.	Lbs. of dry flue gas per lb. of carbon	28·0	22·9	27·1	32·8	30·6	Lbs.
22.	Heat loss due to escaping dry flue gas	25·5	18·9	22·7	24·0	24·7	Per cent
23.	Heat loss due to moisture escaping with flue gas	6·9	8·2	7·3	3·6	7·4	-
	Refuse removed from grate and ash-pit.						
24.	Total refuse removed per cent of fuel as fired	7·8	8·5	9·2	15·0	9·6	-
25.	Combustible in refuse removed per cent	14·8	14·9	18·9	27·7	16·1	-
26.	Combustible in refuse removed per cent. of combustible in fuel fired	1·5	1·8	2·5	4·9	2·1	-
	Economic result.						
27.	Equivalent water evaporated from and at 212° F per lb. of fuel as fired	5·43	5·08	5·22	8·05	5·67	Lbs.
28.	" " " " " 212° F. per lb. of dry fuel	6·41	6·45	6·21	8·29	6·83	-
29.	" " " " " 212° F per lb. combustible consumed	7·17	7·28	7·73	10·03	7·94	-
	Efficiency.						
30.	Heat utilized in steam-raising, per cent of total heat energy in fuel fired	54·9	57·5	59·4	60·4	61·2	Per cent.
31.	Heat utilized in steam-raising per cent of total heat energy in combustible consumed	55·9	58·6	62·2	63·9	62·8	-

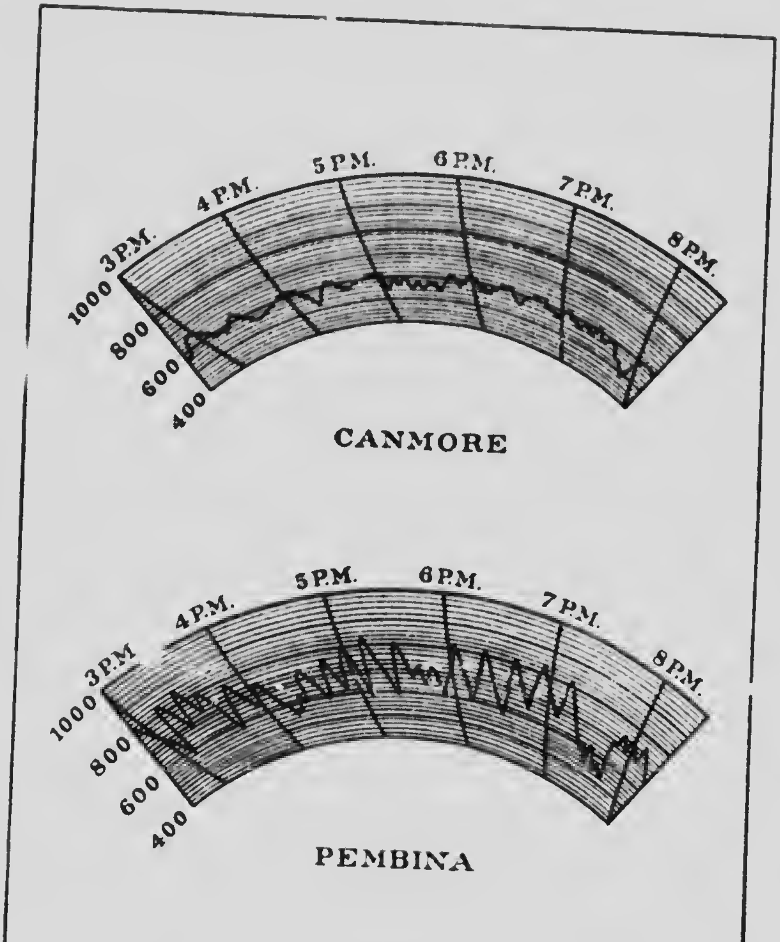


Fig. 12. Flue gas temperature diagrams for boiler trials 54 and 55.

timately mixed with warm air in a large combustion chamber; therefore, it is not surprising, in the case of the present trials, wherein these conditions did not prevail, to find from 0·2 to 0·7 per cent carbon monoxide in the flue gas from the lignitic fuels, whereas the trial with the Canmore coal showed only 0·05 per cent.

In order to burn successfully fuels containing a large percentage of volatile matter, and moisture, it is usual to drive off the volatile matter at the front of the grate, and, when it is mixed with air, cause it to strike an ignition fire brick arch, which is kept hot by being placed over the incandescent, partially coked fuel at the back of the grate. In this method, the fuel is fed to the front of the grate and is pushed forward gradually to the back, thus ensuring a hot fuel bed beneath the arch.

In the four tests with the lignites, air was admitted above the fire through the fire door; evidently the mixture of this air with the gases arising from the coal was incomplete, and the temperature too low, so that the gases reached the comparatively cold water heating surface, thus cooling the mixture below the ignition temperature, before the combustion was completed.

The equivalent evaporation of water from and at 212° F. per square foot of heating surface varied from 3·51 to 3·77 lbs. The rate of evaporation should have been the same throughout the series, but practical difficulties caused slight variations.

Little or no difficulty was experienced in burning the lignites, the clinker gave little trouble, and in trial No. 55, with Pembina fuel, all the refuse would have passed easily through a shaking grate. The loss in combustible removed with the ash and clinker did not in any case exceed 2½ per cent of that fired for the four lignites tested. Canmore coal was somewhat difficult to burn, necessitating a high draft and excessive air supply; further, in cleaning and slicing the fire, a larger percentage of combustible was removed than for the other trials.

With a view to forming a basis of comparison of the fuels tested, the following table (V) has been prepared, in order to show the amount of fuel supplied, and ash and clinker removed per thousand pounds of steam evaporated from and at 212°F.

TABLE V.

Boiler Trials 51 to 55 at Ottawa.

No. of trial.	Fuel.	Per 1,000 lbs. of steam generated.		
		Lbs. of fuel used.	Lbs. of refuse removed from grate.	Lbs. of refuse removed from ash pit.
54	Canmore............	124	14·7	3·9
55	Pembina............	177	12·7	4·2
51	Rosedale............	184	11·9	2·5
53	Twin City..........	191	14·0	3·7
52	Cardiff Collieries.....	197	12·4	4·4

Inspection of Table V shows the Canmore coal to be superior to the others, as an economical steam raiser; but the quantity of clinker removed from the grate is surprisingly high. The item of ash and clinker removed per 1,000 lbs. of steam, enters into the estimate of the cost of steam-raising with any particular fuel principally as a labour problem, therefore, the above figures should be consulted only in conjunction with the remarks upon the difficulties of removing this refuse. For instance, the refuse removed in the trial with Pembina fuel could easily have been passed through a shaking grate, a far simpler and more economical performance than removing the bulk of it from above the fire bars.

While the figures quoted to show the actual number of pounds of steam generated per pound of fuel constitute the most valuable information provided by these tests, other factors must be considered in conjunction with these. Where a particular fuel is to be used continuously, the boiler should be so designed as to suit that particular fuel, and greater improvements in boiler efficiency will be obtainable for some fuels than for others.

Results of Boiler Tests Carried out by the Dominion Government on Lignitic Fuels at McGill University and at Ottawa.

With a view to comparing the general results of tests so far completed on lignites, Table VI has been prepared.

This table shows the general results of trials both at McGill University and at Ottawa. For further information concerning the former trials, Part VII, Vol. II, of "An Investigation of the Coals of Canada," published by the Mines Branch, should be referred to. The mines from which these samples of lignitic fuels were obtained are:—

Souris Coal Field, Saskatchewan, Western Dominion Collieries, Ltd., Taylorton, Sask.

Edmonton Coal Field, Alberta, Parkdale Coal Co., Ltd., Edmonton, Alberta.

Belly River Coal Field, Alberta, Canada-West Coal Co., Ltd., Taber, Alberta; Galt Colliery, Alberta Railway & Irrigation Co., Lethbridge, Alberta.

At McGill University a Babcock and Wilcox land type boiler, with single drum and brickwork setting, was used. The following particulars are appended in order to compare the boiler used at McGill University with that used at Ottawa:—

Heating surface (tubes)	593 sq. ft.
" " (drum, etc.)	46 "
" " (total)	639 "
Grate surface	16·8 "
Width of grate	3·25 ft.
Length " "	5·17 "
Height, grate to lowest tier of tubes (at front)	24 inches
" " " " " (at back)	15 "
Fire bars, straight pattern, ¼" air space.	
Proportion air space to grate surface, per cent	30
Ratio heating surface to grate surface, 38·1 : 1	

The two series of tests carried out differed principally in the matter of duration, the Ottawa tests being longer than those at McGill, where the original intention was to run for 10 hours.

Unfortunately, the trials with Galt Colliery and Western Dominion Collieries, Ltd., fuel were only of 6·5 and 8·7 hours' duration respectively, owing to insufficient fuel. Both series of tests were in charge of the same observer, and the general scheme of procedure was the same, with the exception of the methods used for sampling the flue gases for analysis.

Intermittent samples of gas only were taken for analysis in the McGill tests, and for this reason the results of the gas analyses of the two series are not comparable with one another, and are not included in the table.

In order to compare the relative values of the boilers and their conditions of working as affecting their efficiency, two tests upon Canmore coal have been included in Table VI. These two samples came from the same district, and are very similar in composition. The carbon hydrogen ratio of the dry fuel is the same for both, and their calorific value differs by less than one per cent. The moisture in both is low. The Ottawa sample, however, contained 2·1 per cent more than the McGill sample. The results of the two tests show the efficiency of the boilers, based on combustible consumed, to differ only by 0·9 per cent. However, the losses due to combustible lost in ash and clinker are greater in the McGill than in the Ottawa tests, the combustible matter in ash and clinker amounting to 40·4 and 27·7 per cent respectively.

A further examination of the results of the tests will show that the grate efficiency is higher throughout in the Ottawa than in the McGill series. The smaller loss due to combustible in ash and clinker for the Ottawa tests may be attributed to the special type of grate bars used, and to the lower rate of combustion per square foot of grate area. The latter condition probably reduced the troubles which prevailed with the more intense combustion, while the corrugated grate bars were more effective, in preventing unburnt fuel from passing into the ash-pit than the ordinary straight pattern used in the McGill tests. Although the lignites burned at McGill gave a little more trouble than those at Ottawa, owing to clinkers, these difficulties disappeared somewhat by using steam beneath the fire bars. The Western Dominion lignite burned at McGill was an exception

TABLE VI.

Comparative Record of Boiler Trials at McGill University, and Fuel Testing Station, Ottawa.

Trial No.	54	45	63	65	52	53	[illegible]	55	64	66
Fuel	Canmore.	Canmore.	West. Dom. Coll's. Ltd.	Parkdale (Ed-m'ton)	Cardiff Coll's.	Twin City.	Rosedale.	Pembina.	Can. West Taber.	Galt Coll'y.
Location of boiler	Ottawa	McGill	McGill	McGill	Ottawa	Ottawa	Ottawa	Ottawa	McGill	McGill
Grate surface of boiler, square feet	23·2	16·8	16·8	16·8	23·2	23·2	23·2	23·2	16·8	16·8
Heating surface of boiler, square feet	677	639	639	639	677	677	677	677	639	639
Particulars of fuel and refuse:—										
Carbon, hydrogen ratio dry fuel	19·6	19·6	12·5	14·2	13·8	14·1	14·7	14·3	13·7	13·6
Moisture per cent in fuel as fired	2·9	0·8	29·7	19·7	21·2	15·9	15·3	17·0	11·3	8·3
Fixed carbon per cent of dry fuel	[illegible]	70·5	42·9	51·3	49·7	48·5	53·1	52·6	49·9	51·5
Volatile matter per cent of dry fuel	[illegible]	17·2	49·0	37·8	40·7	35·4	37·9	35·7	36·0	37·5
Ash per cent of dry fuel	12·6	12·3	8·1	10·9	9·6	16·1	9·0	11·7	14·1	11·0
Combustible matter in ash and clinker, per cent	27·7	40·4	32·7	44·7	14·9	18·9	14·8	16·1	53·6	26·6
Calorific value of fuel as fired per lb. B.T.U.	12,920	13,100	7,520	8,760	8,570	[illegible]	9,600	8,980	9,790	10,740
Calorific value of dry fuel per lb. B.T.U.	13,300	13,210	10,690	10,910	10,870	10,140	11,340	10,830	11,040	11,710
Ash and clinker removed per 1000 lbs. of water evaporated from and at 212° F., lbs.	18·6	20·0	14·8	18·4	16·8	17·7	14·4	6·9	31·2	16·1
Hourly Quantities:—										
Fuel fired per hour per sq. foot of grate surface, lbs.	12·7	16·5	31·5	24·9	20·3	20·0	20·2	18·6	26·3	22·4
Equivalent evaporation from and at 212° F. per hour per sq. foot of heating surface, lbs.	3·51	3·34	3·23	3·39	3·55	3·59	3·77	3·63	3·38	3·5
Equivalent evaporation from and at 212° F. per hour, lbs.	2,377	2,137	2,061	2,069	2,404	2,427	2,554	2,456	2,163	2,220
Average, Pressures, and Temperatures:—										
Steam pressure by gauge, lbs. per sq. inch	105	113·2	117·1	113·4	108	107	108	109	113·6	117·0
Pressure difference of draft, above and below bars, Inches of water	0·32	0·25	0·85	0·22	0·20	0·21	0·21	0·21	0·20	0·21
Flue gas temperature at boiler exit, ° F.	630	647	578	532	670	690	730	645	627	571
Economic results:—										
Equivalent water evaporated from and at 212° F. per lb. of fuel as fired, lbs.	8·05	7·74	3·91	4·98	5·08	5·22	5·43	5·67	4·91	5·92
Equivalent water evaporated from and at 212° F. per lb. of dry fuel fired, lbs.	8·29	7·80	5·57	6.18	6.45	6·21	6·41	6.83	5·54	6.45
Equivalent water evaporated from and at 212° F. per lb. of combustible consumed, lbs.	10·03	9·82	6·33	7·73	7·28	7·73	7·17	7·94	7·97	7·58
Efficiency of boiler:—										
Heat utilized in steam-raising, per cent of total heat energy in fuel used	60·4	57·0	50·3	54·7	57·5	59·4	54·9	61·2	48·4	53·0
Heat utilized in steam-raising, per cent of total heat energy in combustible consumed	63·9	63·0	52·5	60·8	58·6	62·2	55·9	62·8	59·9	55·7

to the above, as all the clinker would have passed easily through a shaking grate without the aid of steam beneath the bars.

The flue gas analyses in the McGill tests showed that the carbon monoxide varied from 0·8 to 1·7 per cent for the lignitic fuels, while only 0·1 per cent was recorded for the Canmore coal, which shows that here also the combustible gases arising from the lignites were incompletely burned.

The evaporation per square foot of heating surface was higher in the Ottawa than in the McGill series.

In view of the slight difference between the boiler efficiencies of the two Canmore fuels, the relationship between the composition of the various lignites and the boiler efficiencies obtained, has been investigated for both series as a whole. The effect of the moisture content of the fuel will be first considered.

Effect of Moisture.

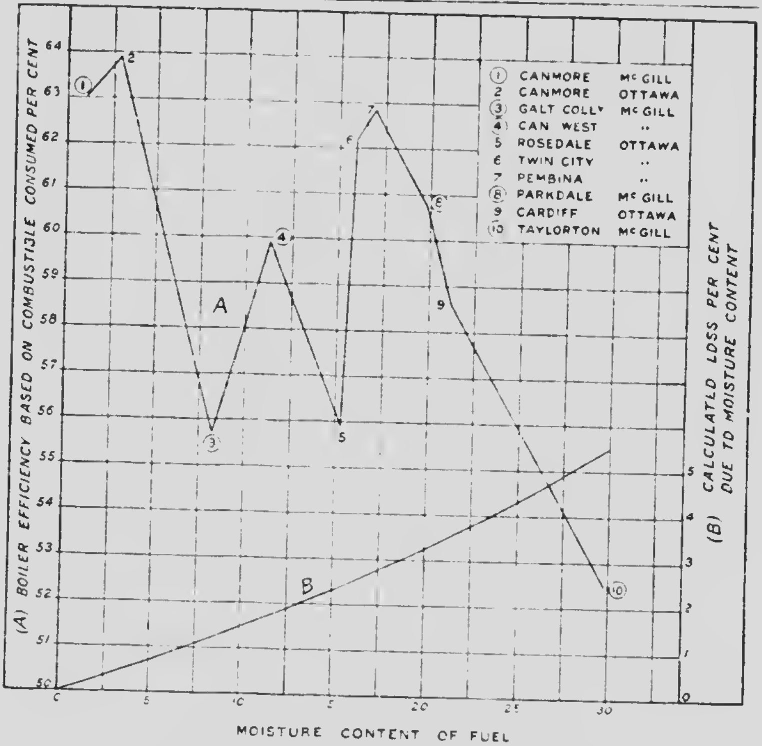
The reduction in efficiency of a boiler due to the free moisture content of the fuel escaping as superheated steam with the flue gases, is shown by the following calculations and table. Calculation of the heat required for the evaporation of the moisture and superheating of the steam formed for coals having a moisture content varying from 5 to 30 per cent, is based on the following assumption, viz., that the fuel had a calorific value on the dry sample of 10,500 B.T.U. per pound; that the air temperature was 60°F., and that the flue gases left at 700°F. The specific heat of steam is taken as 0·47 and the latent heat of steam as 970 B.T.U. per pound. The heat expended per pound of fuel as fired will be:—$W \times [(212-60)+970+0{\cdot}47(700-212)] = W \times 1351$ B.T.U. where $W =$ weight of moisture per pound of fuel.

For a constant air supply per pound of combustible, an increase in the moisture content of the fuel would decrease the furnace temperature; but no allowance was made for this in the above calculation as an approximate result is sufficient for the present purpose.

TABLE VII.

Heat Loss due to Moisture in Fuel.

Moisture per cent in fuel.	Per lb. of moist fuel		Loss of heat in evaporating moisture per cent of calorific value of fuel.
	Calorific value moist fuel, B. T. U.	B. T. U. to evap. moisture and superheat the steam formed.	
5·0	9975	67·5	0·68
10·0	9450	135·1	1·43
15·0	8925	202·6	2·27
20·0	8400	270·2	3·22
25·0	7875	337·7	4·29
30·0	7350	405·3	5·51



RELATION OF MOISTURE CONTENT OF FUEL TO BOILER EFFICIENCY (A), AND TO LOSS IN EFFICIENCY PER CENT AS CALCULATED IN TABLE (B)

Fig. 13. Diagram showing relation between moisture content of fuel and boiler efficiency.

An examination of the above table shows that an increase of 5 per cent in the moisture content of the fuel lowers the boiler efficiency by approximately one per cent only, for the figures cited.

With a view to ascertaining the connexion between the boiler efficiency and the moisture present in the fuel for the trials referred to, the diagram in Fig. 13 has been prepared, from which it will be seen that the loss due to the moisture content is not so predominant as to outweigh other factors by causing a decrease in boiler efficiency for every increase in moisture content. In the same figure a curve showing the loss of heat due to the moisture in the fuel calculated as for Table VII, has been plotted to the same scale.

In the preceding calculations, no account was taken of the loss due to the steam formed by the combustion of the hydrogen in the fuel. The relative proportion of the losses due to steam leaving in the flue gas, which was formed by the evaporation of the free moisture, and by burning hydrogen is shown by the following table:—

TABLE VIII.

Heat Loss due to Evaporation of Free Moisture, and Burning of Hydrogen in Flue Gases.

Boiler trial............	51	52	53	54	55
Fuel..................	Rosedale.	Cardiff.	TwinCity.	Canmore.	Pembina.
Flue gas temperature, °F................	730	670	690	630	645
Free moisture in fuel as fired. Per cent.....	15·3	21·2	15·9	2·9	17·0
Steam formed from hydrogen per 100 lbs. of fuel as fired.........	35·1	33·7	32·7	34·9	34·3
Loss per cent due to steam formed from free moisture in fuel	2·1	3·1	2·4	0·3	2·5
Loss per cent due to steam formed from hydrogen in fuel.....	4·8	5·1	4·9	3·3	4·9

From the foregoing table it will be seen that the flue gas loss due to steam formed by the combustion of hydrogen is greater than the loss due to that formed from the free moisture, and that the total loss due to the steam amounts to as much as 8 per cent in two cases.

The higher calorific value as determined by a compressed oxygen bomb-calorimeter was used throughout these tests. This calorific value so determined, includes the heat given up by the products of combustion in returning to the initial temperature and by the condensation of the whole of the steam, formed either from the combustion of hydrogen or by the evaporation of the moisture present in the fuel.

Since the latent heat of the steam thus formed is not available when the fuel is used for steam-raising in boilers, the lower calorific value is often used instead of the higher value. There is no definite agreement as to the exact allowance to be made for the heat liberated by the condensation of the steam; in English practice it is assumed in calculating the lower value that the steam is brought to a temperature of 60° F., but is not condensed. The latent heat of steam at 60° F. is 1058 B.T.U. per pound, therefore 10·58 B.T.U. must be deducted from the higher calorific value for each one per cent of steam formed, or where $H =$ the total hydrogen per cent in the fuel as fired, a deduction of $H \times 95 \cdot 2$ B.T.U. must be made from the higher calorific value.

For commercial work, the lower calorific value is to be preferred to the higher value and is in general use in Europe. The higher value is the one generally used in Canada, though the lower value is sometimes stipulated as the basis of efficiency for acceptance tests of steam boilers.

The higher and lower calorific values of the fuels used in trials 51 to 55, and the corresponding efficiencies have been calculated, and are as follows:—

TABLE IX.

Calorific Values of Fuels Tested in Trials 51 to 55, made at Ottawa.

Trial	51	52	53	54	55
Fuel	Rosedale.	Cardiff.	TwinCity.	Canmore.	Pembina.
Gross calorific value B. T. U. per lb. as fired	9,600	8,570	8,530	12,920	8,980
Net calorific value B. T. U. per lb. as fired	9,070	7,990	8,020	12,520	8,440
Boiler and grate efficiency based on the gross calorific value, per cent	54·9	57·5	59·4	60·4	61·2
Boiler and grate efficiency based on the net calorific value, per cent	58·1	61·7	63·2	62·3	65·1

From the relative values of the two figures for the boiler efficiency, it will be observed that there is an increase of from 3·2 to 4·2 per cent for the lignitic fuels and 1·9 per cent for the Canmore fuel when calculated upon the lower calorific values basis.

In cases where a boiler is guaranteed to give a certain efficiency such differences as the above may become of grave importance and care should be taken to stipulate beforehand, the exact basis upon which the results are to be calculated.

So many factors affect the boiler efficiency that it is difficult to trace any connexion between this efficiency and any particular factor. Fig 14 is interesting as showing the relation between the carbon hydrogen ratio in the dry fuel and the boiler efficiency of the lignites and lignitic coals tested at Ottawa and McGill.

The trials are not sufficient in number to arrive at any definite conclusion, but the diagram seems to indicate that a higher efficiency might be expected with coals of this type, as the carbon hydrogen ratio increases. It will be noted that the Rosedale fuel, which has the highest carbon hydrogen ratio of the lignites tested, has a comparatively low efficiency and is, therefore, represented by the isolated point on the right hand of the diagram. The boiler was steaming at a higher rate with the Rosedale fuel than with any of the other fuels, which partially accounts for the high flue gas temperature and comparatively low efficiency.

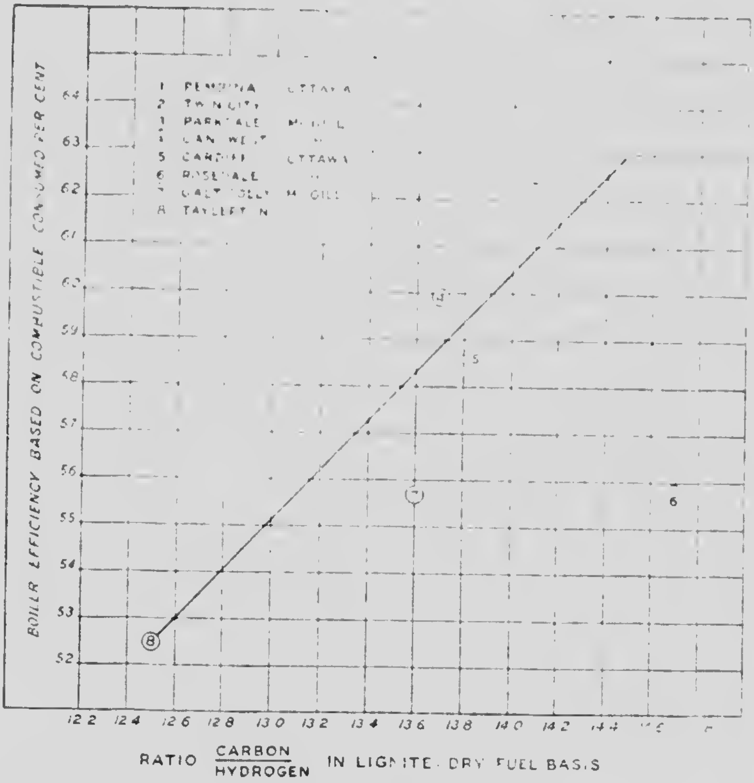


Fig. 14. Diagram showing relation between carbon-hydrogen ratio of dry fuel, and boiler efficiency.

Conclusions.

(*a*) The principal conclusion arrived at from the boiler trials with lignites is that the moisture content of the fuels up to 30 per cent does not materially affect the boiler efficiency, but that the carbon hydrogen ratio exercises the greater influence in this direction.

(*b*) The lower rate of consumption per square foot of grate surface in the Ottawa trials, combined with the more suitable type of grate bar improved the grate efficiency of these fuels.

(*c*) That fuels of this class require a specially large combustion chamber and brick ignition arch, arranged so as to effectively burn the large percentage of volatile matter contained.

APPENDIX.

BOILER TRIAL No. 51.

SUMMARY OF OBSERVATIONS.

Date of trial: March 18, 1914.

Source of fuel: Rosedale Coal and Clay Products Co., Rosedale, Alberta.

Type of boiler: Babcock & Wilcox, Marine, Water-tube.

Site of test: Fuel Testing Station, Ottawa.

Particulars of Boiler:—

1.	Kind of furnace: fixed bars, corrugated.	
2.	Grate surface: width, 4′—9½″; length, 4′—10″; area	23·2 sq. ft.
3.	Width of air space..	¼ inch.
4.	Proportion of air space to whole grate surface	30 per cent
5.	Water heating surface on tubes..	633 sq. ft.
6.	Total water heating surface	677 "
7.	Ratio, heating surface to grate surface	29

Starting and Stopping Trial, Alternate method (A.S.M.E.)

8.	Time of starting trial	8.30 a.m.
9.	Time of stopping trial	8.30 p.m.
10.	Duration of trial	12 hours.

Fuel and Refuse:—

11.	Size of fuel	Run of mine.

12. Analysis of fuel as fired:—

Ultimate	Per cent.	Proximate	Per cent.
Carbon.................	56·9	Fixed carbon..........	45·0
Hydrogen..............	5·6	Volatile matter........	32·1
Ash....................	7·6	Ash..................	7·6
Sulphur.................	0·6	Moisture..............	15·3
Oxygen and nitrogen (by difference)........	29·3		

13. Fuel ratio: Fixed Carbon—Volatile Matter.......................... 1·40

14. Calorific value of fuel as fired per lb. (from calorimeter)................ 9,600 B.T.U.

15. Calorific value of dry fuel per lb. (from calorimeter).....................11,340 B.T.U.

16. Weight of fuel fired................. 5,639 lbs.

17. Weight of refuse removed from above the fire-bars...................... 366 "

18. Weight of refuse removed from the ash-pit............................ 76 "

19. Combustible matter in total refuse removed......................... 14·8 percent.

Average of Air and Flue Gas Observations:—

20. Air pressure in ash-pit............... 0·0 inches.

21. Air pressure in furnace...............−0·21 "

22. Air pressure in flue leaving boiler......−0·57 "

23. Temperature of air in boiler house..... 79° F.

24. Temperature of flue gas leaving boiler.. 730° F

24a. Carbon dioxide in dry flue gas, (Continuous sampling)............ 8·5 per cent.

25. Analysis of dry flue gas by volume, (Intermittent sampling).

    Carbon dioxide................. 10·0 per cent.
    Oxygen........................ 9·7 "
    Carbon monoxide.............. 0·4 "
    Nitrogen..................... 79·9 "

26. Barometer reading............... ..... 29·57 inches.

Water and Steam:—

27. Average temperature of feed water.....	38·5 ° F.
28. Weight of water fed to the boiler corrected for inequality, of water level...	25,287 lbs.
29. Average boiler steam pressure by gauge	108 lbs. per sq. in.
30. Average calorimeter steam pressure by gauge..........................	4·8 inches of mercury.
31. Temperature of steam in calorimeter...	282° F.

General Notes:—

Average thickness of fuel bed: 4½ to 5 inches.

Times of slicing, levelling, or breaking up of fire: 10.50, 11.55 a.m., 4.30 p.m.

Times of cleaning fire: 8.15 a.m (before trial), 1.40 and 8.20 p.m.

Particulars of clinker: thin clinker spreads on bars, sticks a little.

Smoke: little smoke.

Flame: short flame.

Air regulation over bars: small amount of air admitted above bars.

Steam under bars: none.

Caking of coal: does not cake.

Could shaking grate be used? No.

State of weather: cloudy, overcast.

Remarks:—

Run of mine fuel, in hard lumps with small stuff, very little dust. Fuel is not broken up easily in firing.

BOILER TRIAL No. 51.

SUMMARY OF RESULTS.

Date of trial: March 18, 1914.

Source of fuel: Rosedale Coal & Clay Products Co., Rosedale, Alberta.

Type of boiler: Babcock & Wilcox, Marine, Water-tube.

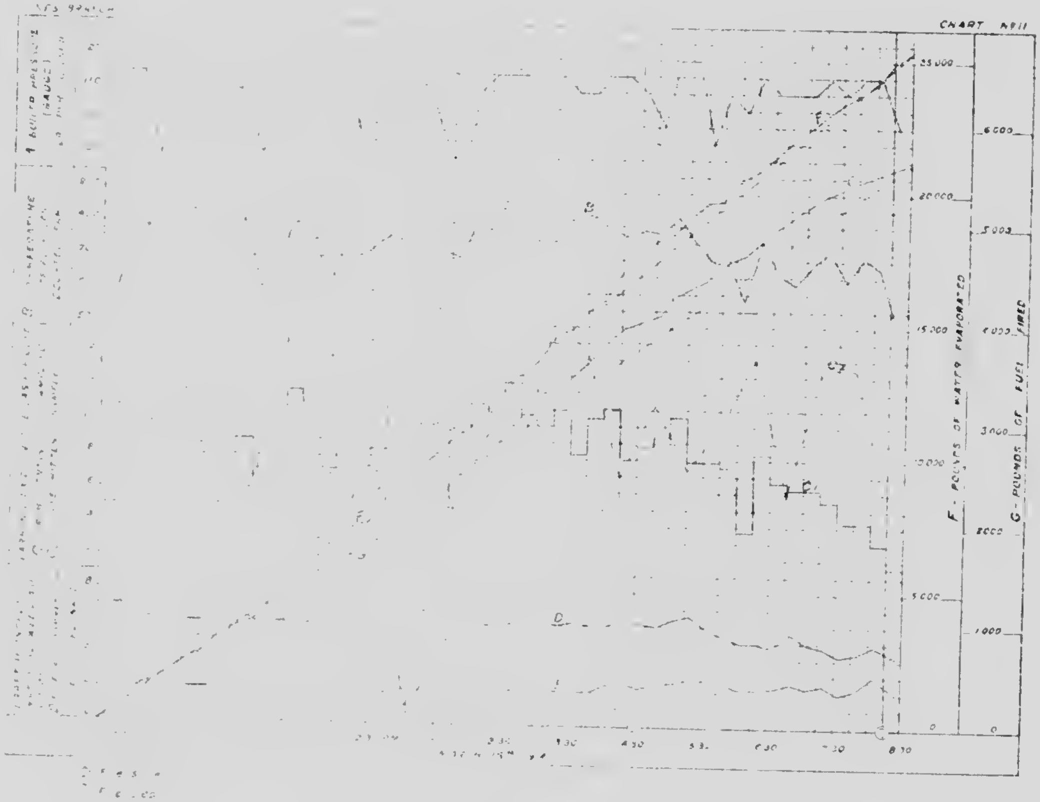
Site of test: Fuel Testing Station, Ottawa.

Total Quantities:—

32. Duration of trial	12	hours.
33. Weight of fuel as fired	5639	lbs.
34. Weight of dry fuel fired	4780	“
35. Weight of combustible fired	4350	“
36. Weight of refuse removed from ash pit and grate (Item 17 + Item 18)	442	“
37. Weight of combustible in refuse (Item 19 × Item 36 ÷ 100)	65	“
38. Total unconsumed combustible from analysis (Item 40 × Item 37 ÷ Item 39)	74	“
39. Weight of ash in refuse (Item 36 − Item 37)	377	“
40. Weight of ash in fuel fired	430	“
41. Weight of combustible consumed (Item 35 − Item 38)	4276	“
42. Weight of water fed to boiler, corrected for inequality of water level	25287	“
43. Weight of water evaporated, corrected for moisture in steam	25130	“
44. Equivalent water evaporated into dry steam from and at 212° F	30645	“

Ash and Refuse:—

45. Ratio, refuse removed from grate to total refuse removed (Item 17 ÷ Item 36)	0·83



Trial No. 51: Fuel—Rosedale lignite.

46. Total refuse removed per cent of fuel fired (Item 36÷Item 33×100)	7·8	
47. Total refuse removed per cent of dry fuel fired (Item 36÷Item 34×100)	9·3	

Hourly Quantities:—

48. Fuel fired per hour	470	lbs.
49. Fuel fired per sq. ft. of grate surface per hour	20·2	"
50. Dry fuel fired per sq. ft. of grate surface per hour	17·1	"
51. Equivalent evaporation per hour, from and at 212° F	2554	"
52. Equivalent evaporation per hour, from and at 212° F. per sq. ft. of heating surface	3·77	"

Average Pressures, Temperatures, Etc.

53. Steam pressure by gauge (lbs. per sq. in.)	108	
54. Temperature of feed water entering boiler	38·5°	F.
55. Pressure of draft between ash-pit and exit from boiler	0·57	ins.
56. Temperature of escaping gases from boiler	730°	F.
57. Percentage of moisture in steam	0·9	

Horse Power (A.S.M.E.):—

58. Boiler horse-power developed (Item 51÷34½)	74·0	

Economic Results:—

59. Equivalent water evaporated per lb. of fuel as fired (Item 43 ÷ Item 33)	4·46	lbs.

60. Equivalent evaporation from and at 212° F. per lb. of fuel as fired (Item 44 ÷ Item 33)	5·43 lbs.
61. Equivalent evaporation from and at 212° F. per lb. of dry fuel fired (Item 44 ÷ Item 34)	6·41 "
62. Equivalent evaporation from and at 212° F. per lb. of combustible consumed (Item 44 ÷ Item 41)	7·17 "

Efficiency and Loss due to Combustible in Refuse:—

63. Efficiency of boiler furnace and grate $100\left[\frac{\text{Item } 61 \times 970\cdot 4}{\text{Item } 15}\right]$..........	54·9 per cent.
64. Combustible removed with refuse from ash-pit and grate per cent of combustible fired (100 × Item 37 ÷ Item 35)............................	1·5 "
65. Efficiency of boiler based on combustible consumed (Item 63 × Item 35 ÷ Item 41)..................	55·9

Particulars of Firing:—

66. Kind of firing....Spreading on alternate sides.	
67. Average thickness of fire.............	5 inches.
68. Average interval between times of levelling and breaking up..........	144 mins.

Flue Gases:—

69. Dry flue gas per lb. of carbon (from gas analysis).....................	28·0 lbs.
70. Dry flue gas per lb. fuel as fired (from gas analysis).....................	15·7 "

Heat Balance Based on Fuel as Fired:

	Per lb. of fuel fired B. T. U.	Per cent of heat in fuel fired.
71. Heat absorbed by the boiler (and thermal efficiency)	5,270	54·9
72. Loss due to evaporation and superheat of moisture in fuel and that formed by combustion of hydrogen	670	6·9
73. Loss due to heat carried away in the dry flue gases	2,450	25·5
74. Loss due to carbon monoxide	260	2·7
75. Loss due to unconsumed combustible	160	1·7
76. Loss due to heat in hot ashes, to radiation, and unaccounted for	790	8·3
77. Total calorific value of fuel as fired	9,600	100·0

BOILER TRIAL No. 52.

SUMMARY OF OBSERVATIONS.

Date of trial: March 20, 1914.
Source of fuel: Cardiff Collieries Ltd., Cardiff, Alberta.
Type of boiler: Babcock & Wilcox, Marine, Water tube.
Site of test: Fuel Testing Station, Ottawa.

Particulars of Boiler:--

1. Kind of furnace: fixed bars, corrugated.
2. Grate surface: width 4′—9½″; length ′—10″; area: 23·2 sq. ft.
3. Width of air space.................... ¼ inch.
4. Proportion of air space to whole grate surface.......................... 30 per cent.
5. Water heating surface on tubes........633 sq. ft.
6. Total water heating surface............677 " "
7. Ratio, heating surface to grate surface... 29

Starting and Stopping Trial, Alternate Method (A.S.M.E.)

8. Time of starting trial..................8.30 a.m.
9. Time of stopping trial................ .8.30 p.m.
10. Duration of trial.....................12 hours.

Fuel and Refuse:—

11. Size of fuel: run of mine, varies from 4″ to 5″ lump to very small stuff.
12. Analysis of fuel as fired:—

Ultimate	Per cent	Proximate	Per cent
Carbon.................	51·5	Fixed carbon..........	39·1
Hydrogen..............	6·1	Volatile matter........	31·1
Ash.....................	7·6	Ash..................	7·6
Sulphur.................	0·2	Moisture.............	21·2
Oxygen and nitrogen (by difference).........	34·6		

13. Fuel ratio: Fixed Carbon—Volatile Matter...........................1·22
14. Calorific value of fuel as fired per lb. (from calorimeter).................8570 B.T.U.
15. Calorific value of dry fuel per lb. (from calorimeter)......................10870 B.T.U.
16. Weight of fuel fired...................5674 lbs.
17. Weight of refuse removed from above the fire-bars.......................357 lbs.
18. Weight of refuse removed from the ash-pit...........................127 lbs.
19. Combustible matter in total refuse removed......................... 14·9 per cent.

Average of Air and Flue Gas Observations:—

20. Air pressure in ash-pit................. 0·0 inches.
21. Air pressure in furnace................ – 0·20 "
22. Air pressure in flue leaving boiler....... – 0·46 "
23. Temperature of air in boiler house...... 87° F.
24. Temperature of flue gas leaving boiler... 670° F.

25. Analysis of dry flue gas by volume
(Continuous sampling)

Carbon dioxide.................... 10·2 per cent.
Oxygen.......................... 9·1 "
Carbon monoxide.................. 0·7 "
Nitrogen......................... 80·0 "

26. Barometer reading.................. 30·11 inches.

Water and Steam:—

27. Average temperature of feed water...... 35·5° F.
28. Total weight of water fed to boiler, corrected for inequality of water level.23,740 lbs.
29. Average boiler steam pressure by gauge..108 lbs. per sq. in.
30. Average calorimeter steam pressure by gauge........................... 4·4 inches of mercury.
31. Temperature of steam in calorimeter.....282° F.

General Notes:—

Average thickness of fuel bed: 6 inches.
Times of slicing, levelling, or breaking up of fire: 2.40; 5.10 p.m.
Times of cleaning fire: 8.10 a.m. (before trial); 12.30, 6.50; 8.10 p.m.
Particulars of clinker: hard, forms in fairly large pieces. does not stick to bars.
Smoke: very little.
Flame: rather short.
Air regulation over bars: a little air admitted above the grates.
Steam under bars: none.
Caking of coal: coal cakes a little.
Could shaking grate be used? Not applicable.
State of weather: clear, zero weather.

Remarks:—

Fuel crumbles easily, broken up a good deal.

BOILER TRIAL No. 52.

SUMMARY OF RESULTS.

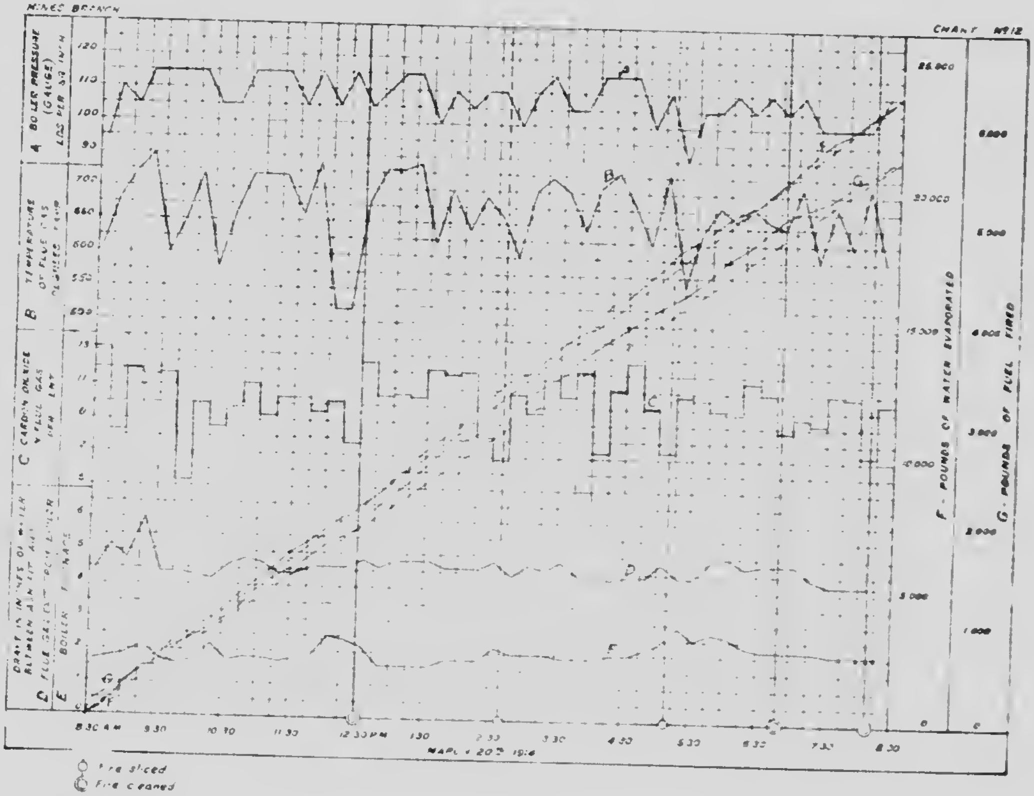
Date of trial: March 20, 1914.
Source of fuel: Cardiff Collieries, Cardiff, Alberta.
Type of boiler: Babcock & Wilcox, Marine, Water tube.
Site of test: Fuel Testing Station, Ottawa.

Total Quantities:—

32. Duration of trial.................. ..	12	hours.
33. Weight of fuel as fired................	5,674	lbs.
34. Weight of dry fuel fired...............	4,470	"
35. Weight of combustible fired...........	4,040	"
36. Weight of refuse removed from ash-pit and grate (Item 17 + Item 18).......	484	"
37. Weight of combustible in refuse (Item 19 × Item 36 ÷ 100)..........	72	"
38. Total unconsumed combustible from analysis (Item 40 × Item 37 ÷ Item 39)	75	"
39. Weight of ash in refuse (Item 36 – Item 37).............................	412	"
40. Weight of ash in fuel fired (Item 34 – Item 35)..........................	430	"
41. Weight of combustible consumed (Item 35 – Item 38).....................	3,965	"
42. Weight of water fed to boiler, corrected for inequality of water level.........	23,740	"
43. Weight of water evaporated, corrected for moisture in steam...............	23,599	"
44. Equivalent water evaporated into dry steam from and at 212°F...........	28,840	"

Ash and Refuse:—

45. Ratio, refuse removed from grate to total refuse removed (Item 17 ÷ Item 36)...........	0·74



Trial No. 52: Fuel—Cardiff colliery lignite.

46. Total refuse removed per cent of fuel fired (Item 36 ÷ Item 33 × 100)	8·5
47. Total refuse removed per cent of dry fuel fired (Item 36 ÷ Item 34 × 100)	10·8

Hourly Quantities:—

48. Fuel fired per hour....	473 lbs.
49. Fuel fired per sq. ft. of grate surface per hour....	20·4 "
50. Dry fuel fired per sq. ft. of grate surface per hour....	16·1 "
51. Equivalent evaporation per hour, from and at 212°F....	2,404 "
52. Equivalent evaporation per hour, from and at 212°F. per sq. ft. of heating surface....	3·55 "

Average Pressures, Temperatures, Etc.:—

53. Steam pressure by gauge (lbs. per sq. in.)	108
54. Temperature of feed water entering boiler	35·5°F.
55. Pressure of draft between ash-pit and exit from boiler....	0·46 ins.
56. Temperature of escaping gases from boiler....	670°F.
57. Percentage of moisture in steam....	0·8

Horse-Power (A.S.M.E.):—

58. Boiler horse-power developed (Item 51 ÷ 34½)....	69·7

Economic Results:—

59. Equivalent water evaporated per lb. of fuel as fired (Item 43 ÷ Item 33)	4·16 lbs.
60. Equivalent evaporation from and at 212°F. per lb. of fuel as fired (Item 44 ÷ Item 33)....	5·08 "

61. Equivalent evaporation from and at 212°F. per lb. of dry fuel fired (Item 44 ÷ Item 34)	6·45 lbs.
62. Equivalent evaporation from and at 212°F. per lb. of combustible consumed (Item 44 ÷ Item 41)	7·28 "

Efficiency:—

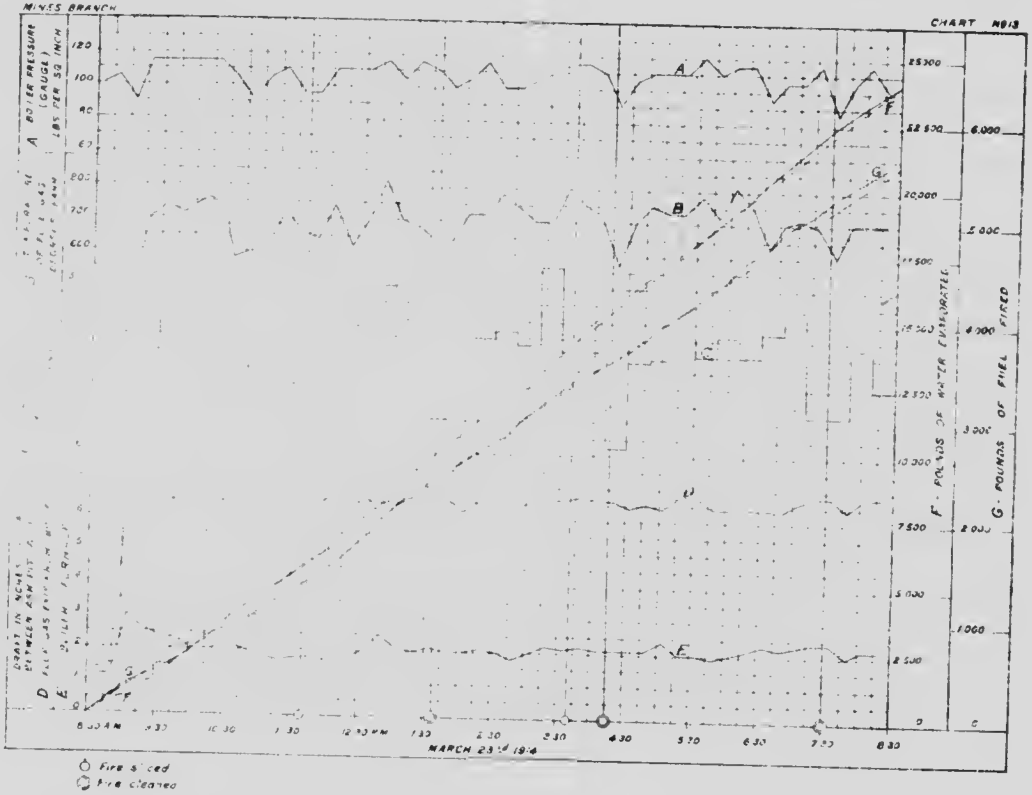
63. Efficiency of boiler furnace and grate $100\left[\frac{\text{Item 61} \times 970\cdot4}{\text{Item 15}}\right]$	57·5 per cent.
64. Combustible removed with refuse from ash-pit and grate per cent of combustible fired (Item 37 ÷ Item 35 × 100)	1·8 "
65. Efficiency of boiler, based on combustible consumed (Item 63 × Item 35 ÷ Item 41)	58·6 "

Particulars of Firing:—

66. Kind of firing	Spreading on alternate sides.
67. Average thickness of fire	6 inches.
68. Average interval between times of levelling and breaking up	144 mins.

Flue Gases:—

69. Dry flue gas per lb. of carbon (from gas analysis)	22·9 lbs.
70. Dry flue gas per lb. fuel as fired (from gas analysis)	11·6 "



Trial No. 53: Fuel—Twin City lignite.

Heat Balance, Based on Fuel as Fired.

		Per lb. of fuel fired B. T. U.	Per cent of heat in fuel fired.
71.	Heat absorbed by the boiler (and thermal efficiency)	4,930	57·5
72.	Loss due to evaporation and superheat of moisture in fuel and that formed by combustion of hydrogen	710	8·2
73.	Loss due to heat carried away in the dry flue gases	1,620	18·9
74.	Loss due to carbon monoxide	330	3·8
75.	Loss due to unconsumed combustible	160	1·9
76.	Loss due to heat in hot ashes, to radiation, and unaccounted for	820	9·7
77.	Total calorific value of fuel as fired	8,570	100·0

BOILER TRIAL No. 53.

SUMMARY OF OBSERVATIONS.

Date of trial: March 23, 1914.
Mine operator: Twin City Coal Co., Ltd., Edmonton, Alberta.
Type of boiler: Babcock & Wilcox, Marine, Water tube.
Site of test: Fuel Testing Station, Ottawa.

Particulars of Boiler:—

1. Kind of furnace: fixed bars corrugated.	
2. Grate surface: width 4′—9½″; length 4′—10″; area	23·2 sq. ft.
3. Width of air space	¼ inch.
4. Proportion of air space to whole grate surface	30 per cent
5. Water heating surface on tubes	633 sq. ft.
6. Total water heating surface	677 "
7. Ratio, heating surface to grate surface	29

Starting and Stopping Trial, Alternate method (A.S.M.E.)

8. Time of starting trial................ 8·30 a.m.
9. Time of stopping trial................ 8·30 p.m.
10. Duration of trial..................... 12 hours.

Fuel and Refuse:—

11. Size of fuel: run of mine, not very much small stuff.
12. Analysis of fuel as fired:—

Ultimate	Per cent	Proximate	Per cent
Carbon.................	51·3	Fixed carbon..........	40·8
Hydrogen...............	5·4	Volatile matter........	29·8
Ash....................	13·5	Ash...................	13·5
Sulphur................	0·3	Moisture..............	15·9
Oxygen and nitrogen (by difference)........	29·5		

13. Fuel Ratio: Fixed Carbon—Volatile Matter............................. 1·37
14. Calorific value of fuel as fired per lb. (from calorimeter)................. 8530 B.T.U.
15. Calorific value of dry fuel per lb. (from calorimeter)................. 10140 B.T.U.
16. Weight of fuel fired.................. 5577 lbs.
17. Weight of refuse removed from above the fire-bars....................... 408 "
18. Weight of refuse removed from the ash-pit.............................. 107 "
19. Combustible matter in total refuse removed.......................... 18·9 per cent.

Average of Air and Flue Gas Observations:—

20. Air pressure in ash-pit................ 0 inches
21. Air pressure in furnace............... −0·21 "
22. Air pressure in flue leaving boiler...... −0·63 "
23. Temperature of air in boiler house..... 85°F.

24. Temperature of flue gas leaving boiler..	690° F.
25. Analysis of dry flue gas by volume..... (Continuous sampling)	
Carbon dioxide....................	9·0 per cent
Oxygen.........................	10·8 “
Carbon monoxide.................	0·2 “
Nitrogen.........................	80·0 “
26. Barometer reading..................	29·85 inches

Water and Steam:—

27. Average temperature of feed water.....	35·0°F.
28. Total weight of water fed to boiler corrected for inequality of water level...	23965 lbs.
29. Average boiler steam pressure by gauge	107 lbs. per sq. in.
30. Average calorimeter steam pressure by gauge..............................	4·6 inches of mercury.
31. Temperature of steam in calorimeter...	282°F.

General Notes:—

Average thickness of fuel bed: 4 inches.

Times of slicing, levelling, or breaking up of fire: 11.40 a.m., 3.40 p.m.

Times of cleaning fire: 7.40 a.m. (before trial); 1.30, 4.15, 7.30 p.m.

Particulars of clinker: in hard and not very large lumps; does not spread over bars; sticks slightly.

Smoke: very little.

Flame: fairly long.

Air regulation over bars: a little air admitted over bars.

Steam under bars: none.

Caking of coal: does not cake.

Could shaking grate be used? No.

State of weather: clear.

BOILER TRIAL No. 53.

SUMMARY OF RESULTS.

Date of trial: March 23, 1914.
Mine operator: Twin City Coal Co., Ltd., Edmonton, Alberta.
Type of boiler: Babcock & Wilcox, Marine, Water tube.
Site of test: Fuel Testing Station, Ottawa.

Total Quantities:—

32. Duration of trial	12	hours.
33. Weight of fuel as fired	5,577	lbs.
34. Weight of dry fuel fired	4,690	"
35. Weight of combustible fired	3,940	"
36. Weight of refuse removed from ash-pit and grate (Item 17 + Item 18)	515	"
37. Weight of combustible in refuse (Item 19 × Item 36 ÷ 100)	97	"
38. Total unconsumed combustible from analysis (Item 40 × Item 37 ÷ Item 39)	175	"
39. Weight of ash in refuse (Item 36 − Item 37)	418	"
40. Weight of ash in fuel fired (Item 34 − Item 35)	750	"
41. Weight of combustible consumed (Item 35 — Item 38)	3,765	"
42. Weight of water fed to boiler, corrected for inequality of water level	23,965	"
43. Weight of water evaporated, corrected for moisture in steam	23,820	"
44. Equivalent water evaporated into dry steam from and at 212 °F	29,130	"

Ash and Refuse:—

45. Ratio, refuse removed from grate to total refuse removed (Item 17 ÷ Item 36)	0·79	

46. Total refuse removed per cent of fuel fired (Item 36 ÷ Item 33 × 100)..	9·2	
47. Total refuse removed per cent of dry fuel fired (Item 36 ÷ Item 34 × 100)	11·0	

Hourly Quantities:—

48. Fuel fired per hour..................	465	lbs.
49. Fuel fired per sq. ft. of grate surface per hour...................... ..	20·0	"
50. Dry Fuel fired per sq. ft. of grate surface per hour..................	16·8	"
51. Equivalent evaporation per hour, from and at 212°F.	2427	"
52. Equivalent evaporation per hour, from and at 212°F. per sq. ft. of water heating surface..................	3·59	"

Average Pressures, Temperatures, Etc.:—

53. Steam pressure by gauge (lbs. per sq. in.)............................	107	
54. Temperature of feed water entering boiler...........................	35°F.	
55. Pressure of draft between ash-pit and exit from boiler..................	0·63	inches.
56. Temperature of escaping gases from boiler...........................	690°F.	
57. Percentage of moisture in steam......	0·8	

Horse-Power (A.S.M.E.):—

58. Horse-power developed (Item 51 ÷ 34½).	70·4	

Economic Results:—

59. Equivalent water evaporated per lb. of fuel as fired (Item 43 ÷ Item 33)	4·27	lbs.

60. Equivalent evaporation from and at at 212°F. per lb. of fuel as fired (Item 44 ÷ Item 33)	5·22	lbs.
61. Equivalent evaporation from and at 212°F. per lb. of dry fuel fired (Item 44 ÷ Item 34)	6·21	“
62. Equivalent evaporation from and at 212°F. per lb. of combustible consumed (Item 44 ÷ Item 41)	7·73	“

Efficiency:—

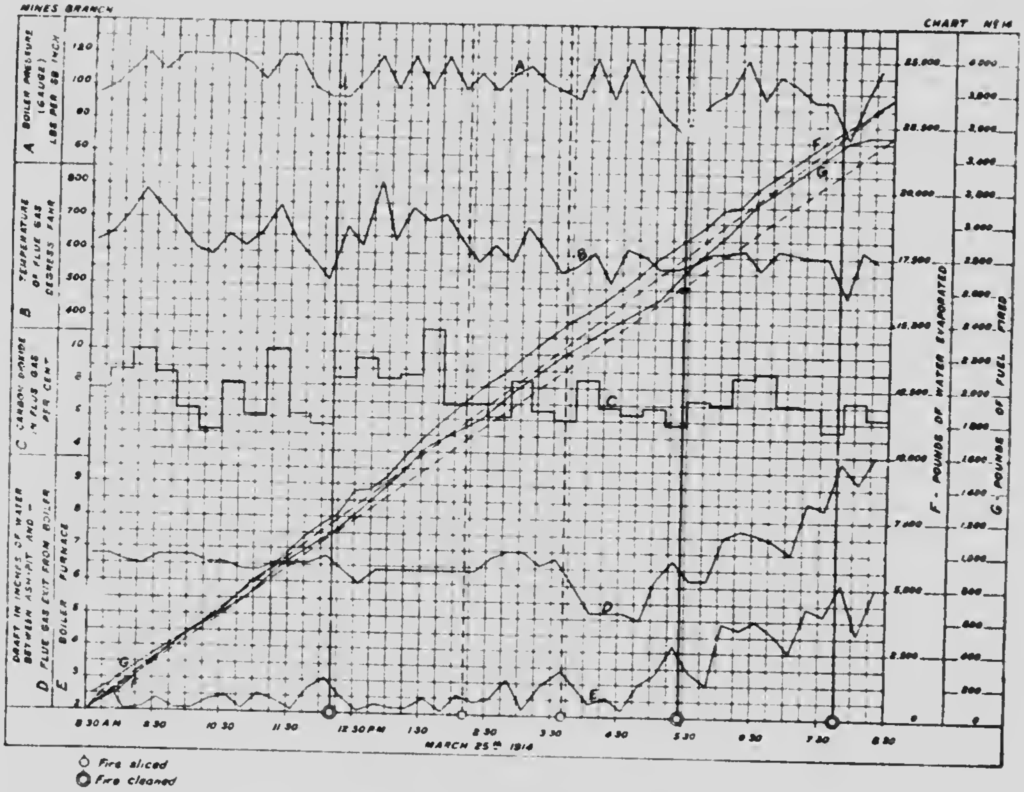
63. Efficiency of boiler furnace and grate $100\left[\frac{\text{Item } 61 \times 970\cdot4}{\text{Item } 15}\right]$	59·4	per cent.
64. Combustible removed with refuse from ash-pit and grate per cent of combustible fired (Item 37 ÷ Item 35 × 100)	2·5	“
65. Efficiency of boiler based on combustible consumed (Item 63 × Item 35 ÷ Item 41)	62·2	“

Particulars of firing:—

66. Kind of firing: hand, spreading on alternate sides.		
67. Average thickness of fire	4	inches.
68. Average interval between times of levelling and breaking up	140	mins.

Flue Gases:—

69. Dry flue gas per lb. of carbon (from gas analysis)	27·1	lbs.
70. Dry flue gas per lb. fuel as fired (from gas analysis)	13·3	“



Trial No. 54: Fuel—Canmore coal.

Heat Balance, Based on Fuel as Fired.

	Per lb. of fuel fired B. T. U.	Per cent of heat in fuel fired
71. Heat absorbed by the boiler and (thermal efficiency)	5,070	59·4
72. Loss due to evaporation and superheat of moisture in fuel and that formed by combustion of hydrogen	620	7·3
73. Loss due to heat carried away in the dry flue gases	1,940	22·7
74. Loss due to carbon monoxide	110	1·3
75. Loss due to unconsumed combustible	370	4·5
76. Loss due to heat in hot ashes, to radiation, and unaccounted for	420	4·8
77. Total calorific value of fuel as fired	8,530	100·0

BOILER TRIAL No. 54.

SUMMARY OF OBSERVATIONS.

Date of trial: March 25, 1914.
Mine operator: Canmore Coal Co., Ltd., Canmore, Alberta.
Type of boiler: Babcock & Wilcox, Marine, Water tube.
Site of test: Fuel Testing Station, Ottawa.

Particulars of Boiler:—

1. Kind of furnace: fixed bars, corrugated..	
2. Grate surface: width 4′—9½″; length 4′—10″; area	23·2 sq. ft.
3. Width of air space	¼ inch.
4. Proportion of air space to whole grate surface	30 per cent.
5. Heating surface on tubes	633 sq. ft.
6. Total heating surface	677 "
7. Ratio, heating surface to grate surface	29

Starting and Stopping Trial, Alternate Method (A.S.M.E.)

8. Time of starting trial.......... .... 8·30 a.m.
9. Time of stopping trial......... ..... 8·30 p.m.
10. Duration of trial...... .... 12 hours.

Fuel and Refuse:—

11. Size of fuel: run of mine, very small stuff.
12. Analysis of fuel as fired:—

Ultimate	Per cent.	Proximate	Per cent.
Carbon.............	76·2	Fixed carbon..........	71·7
Hydrogen..........	4·2	Volatile matter........	13·1
Ash	12·3	Ash	12·3
Sulphur........	0·8	Moisture...	2·9
Oxygen and nitrogen (by difference)..	6·5		

13. Fuel Ratio: Fixed Carbon—Volatile Matter............................ 5·47
14. Calorific value of fuel as fired per lb. (from calorimeter)................12,920 B.T.U.
15. Calorific value of dry fuel per lb. (from calorimeter)......................13,300 B.T.U.
16. Weight of fuel fired. .... 3,544 lbs.
17. Weight of refuse removed from above the fire-bars...................... 420 “
18. Weight of refuse removed from the ash-pit......................... 111 “
19. Combustible matter in total refuse removed......................... 27·7 per cent.

Average of Air and Flue Gas Observations:—

20. Air pressure in ash-pit........ ...... 0·0 inches.
21. Air pressure in furnace...............−0·32 “
22. Air pressure in flue leaving boiler......−0·68 “

23. Temperature of air in boiler house 82° F.
24. Temperature of flue gas leaving boiler 630° F.
25. Analysis of dry flue gas by volume
    (Continuous sampling)
    - Carbon dioxide.......... 7·50 per cent
    - Oxygen.................. 12·35 "
    - Carbon monoxide............ 0·05 "
    - Nitrogen................ 80·[illegible] "
26. Barometer reading.............. 30·12 inches.

Water and Steam:—

27. Average temperature of feed water 37° F.
28. Total weight of water fed to the boiler corrected for difference of water level in boiler .... [illegible]
29. Average boiler steam pressure by gauge [illegible]
30. Average calorimeter steam pressure by gauge.......................... 4·3 inches of mercury.
31. Temperature of steam in calorimeter... 281° F.

General Notes:—

Average thickness of fuel bed: 6 to 7 inches.

Times of slicing, levelling, or breaking up of fire: 2.10, 3.40 p.m.

Times of cleaning fire: 8.15 a.m. (before trial), 12.10, 5.25 and 7.45 p.m.

Particulars of clinker: small pieces, not sticking to bars removed easily.

Smoke: very little.

Flame: very little.

Air regulations over bars: a little air admitted over bars.

Steam under bars: none.

Caking of coal: does not cake.

Could shaking grate be used? Most of the clinker would pass through.

State of weather: clear.

Remarks:—

Owing to the formation of dead patches in the fire bed, it was necessary to frequently disturb the fire with the rake.

BOILER TRIAL No. 54.

SUMMARY OF RESULTS.

Date of trial: March 25, 1914.
Source of fuel: Canmore Coal Co., Ltd., Canmore, Alberta.
Type of boiler: Babcock & Wilcox, Marine, Water tube.
Site of test: Fuel Testing Station, Ottawa.

Total Quantities:—

32. Duration of trial	12	hours.
33. Weight of fuel as fired	3,544	lbs.
34. Weight of dry fuel fired	3,440	“
35. Weight of combustible fired	3,010	“
36. Weight of refuse removed from ash-pit and grate (Item 17 + Item 18)	531	“
37. Weight of combustible in refuse (Item 19 × Item 36 ÷ 100)	147	“
38. Total unconsumed combustible from analysis (Item 40 × Item 37 ÷ Item 39)	165	“
39. Weight of ash in refuse (Item 36 − Item 37)	384	“
40. Weight of ash in fuel fired (Item 34 − Item 35)	430	“
41. Weight of combustible consumed (Item 35 − Item 38)	2,845	“
42. Weight of water fed to boiler, corrected for inequality of water level	23,520	“
43. Weight of water evaporated, corrected for moisture in steam	23,370	“
44. Equivalent water evaporated into dry steam from and at 212° F	28,530	“

Ash and Refuse:—

45. Ratio, refuse removed from grate to total refuse removed (Item 17 ÷ Item 36)	0·79
46. Total refuse removed per cent of fuel fired (Item 36 ÷ Item 33 × 100)	15·0
47. Total refuse removed per cent of dry fuel fired (Item 36 ÷ Item 34 × 100)	15·5

Hourly Quantities:—

48. Fuel fired per hour	295 lbs.
49. Fuel per sq ft. of grate surface per hour	12.7 "
50. Dry fuel as fired per sq. ft. of grate surface per hour	12·3 "
51. Equivalent evaporation per hour, from and at 212° F.	2377 "
52. Equivalent evaporation per hour, from and at 212° F. per sq. ft. of heating surface	3·51 "

Average Pressures, Temperatures, Etc.:—

53. Steam pressure by gauge (lbs. per sq. in.)	105
54. Temperature of feed water entering boiler	37° F.
55. Pressure of draft between ash-pit and exit from boiler	0·68 ins.
56. Temperature of escaping gases from boiler	630 °F.
57. Percentage of moisture in steam	0·8

Horse-Power (A.S.M.E.)

58. Horse-power developed (Item 51 ÷ 34½)	68·9

Economic Results:—

59. Equivalent water evaporated per lb. of fuel as fired (Item 43 ÷ Item 33)	6·59 lbs.

60. Equivalent evaporation from and at 212°F. per lb. of fuel as fired (Item 44 ÷ Item 33) .... 8·05 lbs.

61. Equivalent evaporation from and at 212°F. per lb. of dry fuel fired (Item 44 ÷ Item 34) .... 8·29 "

62. Equivalent evaporation from and at 212°F. per lb. of combustible consumed (Item 44 ÷ Item 41) ...... 10·03 "

Efficiency:—

63. Efficiency of boiler furnace and grate

$$100\left[\frac{\text{Item }61\times 970\cdot 4}{\text{Item }15}\right]$$ ......60·4 per cent.

64. Combustible removed with refuse from ash-pit and grate per cent of combustible fired (Item 37 ÷ Item 35 × 100) .... 4·9 "

65. Efficiency of boiler based on combustible consumed (Item 63 × Item 35 ÷ Item 41) .... 63·9 "

Particulars of Firing:—

66. Kind of firing: hand, spreading on alternate sides.

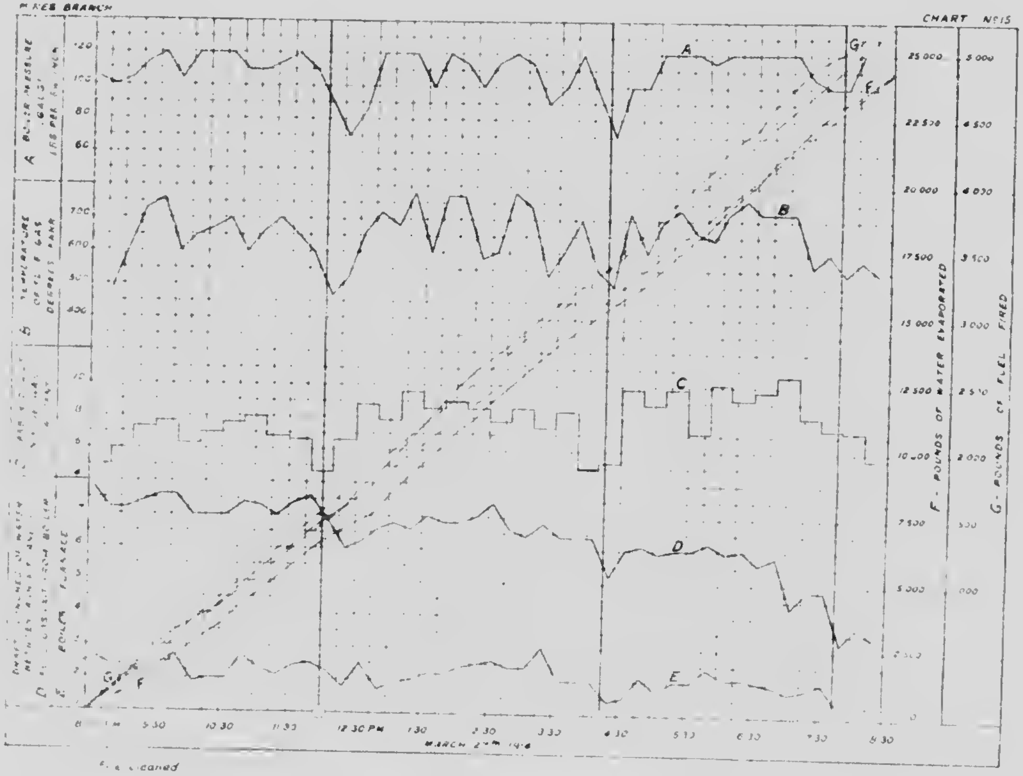
67. Average thickness of fire ....6 to 7 inches.

68. Average interval between times of levelling and breaking up ....144 mins.

Flue Gases:—

69. Dry flue gas per lb. of carbon (from gas analysis) .... 32·8 lbs.

70. Dry flue gas per lb. of fuel as fired (from gas analysis) .... 23·6 "



Trial No. 55: Fuel—Pembina lignite.

Heat Balance, Based on Fuel as Fired.

		Per lb. of fuel fired B. T. U.	Per cent of heat in fuel fired
71.	Heat absorbed by the boiler (and thermal efficiency)......................	7,810	60·4
72.	Loss due to evaporation and superheat of moisture in fuel and that formed by combustion of hydrogen	460	3·6
73.	Loss due to heat carried away in the dry flue gases..........................	3,100	24·0
74.	Loss due to carbon monoxide.............	50	0·4
75.	Loss due to unconsumed combustible.......	720	5·5
76.	Loss due to heat in hot ashes, to radiation and unaccounted for..	780	6·1
77.	Total calorific value of fuel as fired	12,920	100·0

BOILER TRIAL No. 55.

SUMMARY OF OBSERVATIONS.

Date of trial: March 27, 1914.
Mine operator: Pembina Coal Co., Ltd., Entwistle, Alberta.
Type of boiler: Babcock & Wilcox, Marine, Water tube.
Site of test: Fuel Testing Station, Ottawa.

Particulars of Boiler:—

1. Kind of furnace: fixed bars, corrugated.
2. Grate surface: width 4′—9½″; length 4′ –10″; area................. .... 23·2 sq. ft.
3. Width of air space.................... ¼ inch.
4. Proportion of air space to whole grate surface 30 per cent.
5. Water heating surface on tubes...... 633 sq. ft.
6. Total water heating surface.......... .. 677 " "
7. Ratio, heating surface to grate surface.. 29

Starting and Stopping Trial, Alternate Method (A.S.M.E.)

8. Time of starting trial................. 8·30 a.m.
9. Time of stopping trial................. 8·30 p.m.

10. Duration of trial.....................12 hours

Fuel and Refuse:—

11. Size of fuel: run of mine 2 to 5 inches not broken up. No small stuff.
12. Analysis of fuel as fired:—

Ultimate.	Per cent.	Proximate.	Per cent.
Carbon.................	54·4	Fixed carbon..........	43·8
Hydrogen..............	5·7	Volatile matter........	29·5
Ash....................	9·7	Ash..................	9·7
Sulphur................	0·2	Moisture...	17·0
Oxygen and nitrogen (by difference)........	30·0		

13. Fuel Ratio: Fixed Carbon—Volatile Matter.......................... 1·48
14. Calorific value of fuel as fired per lb. (from calorimeter)................. 8980 B.T.U.
15. Calorific value of dry fuel per lb. (from calorimeter).................10830 B.T.U.
16. Weight of fuel fired................... 5203 lbs.
17. Weight of refuse removed from above the fire-bars .... 374 "
18. Weight of refuse removed from the ash-pit.............................. 125 "
19. Combustible matter in total refuse removed........................... 16·1 per cent.

Average of Air and Flue Gas Observations:—

20. Air pressure in ash-pit................. 0·0 inches.
21. Air pressure in furnace................ −0·21 "
22. Air pressure in flue leaving boiler....... −0·63 "
23. Temperature of air in boiler house...... 74 °F.
24. Temperature of flue gas leaving boiler...645° F.

25. Analysis of dry flue gas by volume (Continuous sampling)	
Carbon dioxide	7·7 per cent.
Oxygen	12·1 "
Carbon monoxide	0·4 "
Nitrogen	79·8 "
26. Barometer reading	30·08 inches.

Water and Steam:—

27. Average temperature of feed water	37·5° F.
28. Total weight of water fed to boiler corrected for inequality of water level in boiler	24,325 lbs.
29. Average boiler steam pressure by gauge	109 lbs. per sq. inch.
30. Average calorimeter steam pressure by gauge	4·2 inches of mercury
31. Temperature of steam in calorimeter	280° F.

General Notes:—

Average thickness of fuel bed: 4 to 6 inches.
Times of slicing, levelling, or breaking up of fire: raked over at 3.15 p.m.
Times of cleaning fire: 7.45 a m. (before trial); 12.00, 4.15, 7.45 p.m.
Particulars of clinker: in soft small pieces, very easily removed.
Smoke: fair amount.
Flame: rather long.
Air regulations over bars: none.
Steam under bars: none.
Caking of coal: does not cake.
Could shaking grate be used? Very applicable.
State of weather: wet, cloudy.

BOILER TRIAL NO. 55.

SUMMARY OF RESULTS.

Date of trial: March 27, 1914.
Mine operator: Pembina Coal Co., Ltd., Entwistle, Alberta.
Type of boiler: Babcock & Wilcox, Marine, Water tube.
Site of test: Fuel Testing Station, Ottawa.

Total Quantities:—

32. Duration of trial	12	hours.
33. Weight of fuel as fired	5203	lbs.
34. Weight of dry fuel fired	4320	"
35. Weight of combustible fired	3810	"
36. Weight of refuse removed from ash-pit and grate (Item 17 + Item 18)	499	"
37. Weight of combustible in refuse (Item 19 × Item 36 ÷ 100)	80	"
38. Total unconsumed combustible from analysis (Item 40 × Item 37 ÷ Item 39)	97	"
39. Weight of ash in refuse (Item 36 − Item 37)	419	"
40. Weight of ash in fuel fired (Item 34 − Item 35)	510	"
41. Weight of combustible consumed (Item 35 − Item 38)	3713	"
42. Weight of water fed to boiler corrected for inequality of water level	24325	"
43. Weight of water evaporated, corrected for moisture in steam	24150	"
44. Equivalent water evaporated into dry steam from and at 212°F	29480	"

Ash and Refuse:—

45. Ratio, refuse removed from grate to total refuse removed (Item 17 ÷ Item 36)	0·75

46. Total refuse removed per cent of fuel fired (Item 36 ÷ Item 33 × 100)....	9·6
47. Total refuse removed per cent of dry fuel fired (Item 36 + Item 34 × 100)	11·6

Hourly Quantities:—

48. Fuel fired per hour.	434 lbs.
49. Fuel per sq. ft. of grate surface per hour	18·7 "
50. Dry fuel fired per sq. ft of grate surface per hour.........................	15·5 "
51. Equivalent evaporation per hour, from and at 212°F.....................	2456 "
52. Equivalent evaporation per hour, from and at 212°F., per sq. ft. of water heating surface.............	3·63 "

Average Pressures, Temperatures, Etc.:—

53. Steam pressure by gauge (lbs. per sq. in.)	109
54. Temperature of feed water entering boiler...........................	37·5 °F.
55. Pressure of draft between ash-pit and exit from boiler...................	0·63 inches.
56. Temperature of escaping gases from boiler...........................	645 °F.
57. Percentage of moisture in steam.......	1·0

Horse-Power (A.S.M.E.):—

58. Horse-power developed (Item 51 ÷ 34½)	71·2

Economic Results:—

59. Equivalent water evaporated per lb. of fuel as fired (Item 43 ÷ Item 33)....	4·64 lbs.
60. Equivalent evaporation from and at 212°F per lb. of fuel as fired (Item 44 ÷ Item 33).................... ...	5·67 "

61. Equivalent evaporation from and at 212°F. per lb. of dry fuel fired (Item 44 ÷ Item 34)	6·83 lbs.
62. Equivalent evaporation from and at 212°F. per lb. of combustible consumed (Item 44 ÷ Item 41)	7·94 "

Efficiency:—

63. Efficiency of boiler furnace and grate $100\left[\frac{\text{Item } 61 \times 970{\cdot}4}{\text{Item } 15}\right]$	61·2 per cent.
64. Combustible removed from ash-pit and grate per cent of combustible fired $100\left[\frac{\text{Item } 37}{\text{Item } 35}\right]$	2·1 "
65. Efficiency of boiler based on combustible consumed (Item 63 × Item 35 ÷ Item 41)	62·8 "

Particulars of Firing:—

66. Kind of firing: hand, spreading on alternate sides.	
67. Average thickness of fire	4 to 6 inches
68. Average interval between times of levelling and breaking up	240 mins.

Flue Gases:—

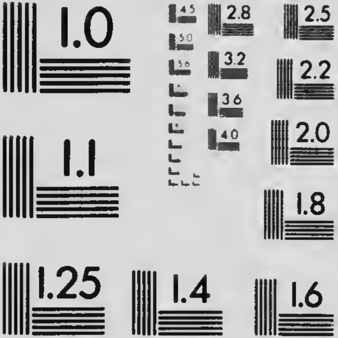
69. Dry flue gas per lb. of carbon (from gas analysis)	30·6 lbs.
70. Dry flue gas per lb. fuel as fired (from gas analysis)	16·2 "

Heat Balance, Based on Fuel as Fired.

		Per lb of fuel fired B. T. U.	Percentage of heat in fuel fired
71.	Heat absorbed by the boiler (and thermal efficiency)........	5,500	61·2
72.	Loss due to evaporation and superheat of moisture in fuel and that formed by burning hydrogen	660	7·4
73.	Loss due to heat carried away in the dry flue gases	2,220	24·7
74.	Loss due to carbon monoxide	270	3·0
75.	Loss due to unconsumed combustible	230	2·6
76.	Loss due to heat in hot ashes, to radiation, and unaccounted for	100	1·1
77.	Total calorific value of fuel as fired	8,980	100·0

MICROCOPY RESOLUTION TEST CHART

ANSI and ISO TEST CHART No. 2



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CANADA

DEPARTMENT OF MINES

HON. LOUIS CODERRE, MINISTER; R. G. MCCONNELL, DEPUTY MINISTER

MINES BRANCH

EUGENE HAANEL, PH.D., DIRECTOR

REPORTS AND MAPS

PUBLISHED BY THE

MINES BRANCH

REPORTS.

1. Mining conditions in the Klondike, Yukon. Report on—by Eugene Haanel, Ph.d., 1902.

†2. Great landslide at Frank, Alta. Report on—by R. G. McConnell, B.A., and R. W. Brock, M.A., 1903.

†3. Investigation of the different electro-thermic processes for the smelting of iron ores and the making of steel, in operation in Europe. Report of Special Commission—by Eugene Haanel, Ph.D., 1904.

5. On the location and examination of magnetic ore deposits by magnetometric measurements—by Eugene Haanel, Ph.D., 1904.

†7. Limestones, and the lime industry of Manitoba. Preliminary report on—by J. W. Wells, M.A., 1905.

†8. Clays and shales of Manitoba: their industrial value. Preliminary report on—by J. W. Wells, M.A., 1905.

†9. Hydraulic cements (raw materials) in Manitoba: manufacture and uses of. Preliminary report on—by J. W. Wells, M.A., 1905.

†10. Mica: its occurrence, exploitation, and uses—by Fritz Cirkel, M.E., 1905. (See No. 118.)

†11. Asbestos: its occurrence, exploitation, and uses—by Fritz Cirkel, M.E., 1905. (See No. 69.)

†12. Zinc resources of British Columbia and the conditions affecting their exploitation. Report of the Commission appointed to investigate —by W. R. Ingalls, M.E., 1905.

†16. *Experiments made at Sault Ste. Marie, under Government auspices, in the smelting of Canadian iron ores by the electro-thermic process. Final report on—by Eugene Haanel, Ph.D., 1907.

†17. Mines of the silver-cobalt ores of the Cobalt district: their present and prospective output. Report on—by Eugene Haanel, Ph.D., 1907.

* A few copies of the Preliminary Report, 1906, are still available.
† Publications marked thus † are out of print.

†18. Graphite: its properties, occurrence, refining, and uses—by Fritz Cirkel, M.E., 1907.

†19. Peat and lignite: their manufacture and uses in Europe—by Erik Nystrom, M.E., 1908.

†20. Iron ore deposit of Nova Scotia. Report on (Part I)—by J. E. Woodman, D.Sc.

21. Summary report of Mines Branch, 1907–8.

22. Iron ore deposits of Thunder Bay and Rainy River districts. Report on—by F. Hille, M.E.

†23. Iron ore deposits along the Ottawa (Quebec side)and Gatineau rivers. Report on—by Fritz Cirkel, M.E.

24. General report on the mining and metallurgical industries of Canada, 1907–8.

†25. The tungsten ores of Canada. Report on—by T. L. Walker, Ph.D.

26. The mineral production of Canada, 1906. Annual report on—by John McLeish, B.A.

†27. The mineral production of Canada, 1907. Preliminary report on—by John McLeish, B.A.

†27a. The mineral production of Canada, 1908. Preliminary report on—by John McLeish, B.A.

†28. Summary report of Mines Branch, 1908.

29. Chrome iron ore deposits of the Eastern Townships. Monograph on—by Fritz Cirkel. (Supplementary section: Experiments with chromite at McGill University—by J. B. Porter, E.M., D.Sc.)

30. Investigation of the peat bogs and peat fuel industry of Canada, 1908. Bulletin No. 1—by Erik Nystrom, M.E., and A. Anrep, Peat Expert.

32. Investigation of electric shaft furnace, Sweden. Report on—by Eugene Haanel, Ph.D.

47. Iron ore deposits of Vancouver and Texada islands. Report on—by Einar Lindeman, M.E.

†55. The bituminous, or oil-shales of New Brunswick and Nova Scotia; also on the oil-shale industry of Scotland. Report on—by R. W. Ells, LL.D.

58. The mineral production of Canada, 1907 and 1908. Annual report on—by John McLeish, B.A.

† Publications marked thus † are out of print.

NOTE. — *The following parts were separately printed and issued in advance of the Annual Report for 1907-8.*

†31. Production of cement in Canada, 1908.

42. Production of iron and steel in Canada during the calendar years 1907 and 1908.

43. Production of chromite in Canada during the calendar years 1907 and 1908.

44. Production of asbestos in Canada during the calendar years 1907 and 1908.

†45. Production of coal, coke, and peat in Canada during the calendar years 1907 and 1908.

46. Production of natural gas and petroleum in Canada during the calendar years 1907 and 1908.

59. Chemical analyses of special economic importance made in the laboratories of the Department of Mines, 1906-7-8. Report on—by F. G. Wait, M.A., F.C.S. (With Appendix on the commercial methods and apparatus for the analysis of oil-shales—by H. A. Leverin, Ch. E.)

Schedule of charges for chemical analyses and assays.

†62. Mineral production of Canada, 1909. Preliminary report on—by John McLeish, B.A.

63. Summary report of Mines Branch, 1909.

67. Iron ore deposits of the Bristol mine, Pontiac county, Quebec. Bulletin No. 2—by Einar Lindeman, M.E., and Geo. C. Mackenzie, B.Sc.

†68. Recent advances in the construction of electric furnaces for the production of pig iron, steel, and zinc. Bulletin No. 3—by Eugene Haanel, Ph.D.

69. Chrysotile-asbestos: its occurrence, exploitation, milling, and uses. Report on—by Fritz Cirkel, M.E. (Second edition, enlarged.)

†71. Investigation of the peat bogs, and peat industry of Canada, 1909-10; to which is appended Mr. Alf. Larson's paper on Dr. M. Ekenberg's wet-carbonizing process: from Teknisk Tidskrift, No. 12, December 26, 1908—translation by Mr. A. v. Anrep, Jr.; also a translation of Lieut. Ekelund's pamphlet entitled 'A solution of the peat problem,' 1909, describing the Ekelund process for the manufacture of peat powder, by Harold A. Leverin, Ch.E. Bulletin No. 4—by A. v. Anrep. (Second edition, enlarged.)

82. Magnetic concentration experiments. Bulletin No. 5—by Geo. C. Mackenzie, B.Sc.

† Publications marked thus † are out of print.

83. An investigation of the coals of Canada with reference to their economic qualities: as conducted at McGill University under the authority of the Dominion Government. Report on—by J. B. Porter, E.M., D.Sc., R. J. Durley, Ma.E., and others.
  - Vol. I—Coal washing and cooking tests.
  - Vol. II—Boiler and gas producer tests.
  - Vol. III—(Out of print.)
    - Appendix I
      - Coal washing tests and diagrams.
  - Vol. IV—
    - Appendix II
      - Boiler tests and diagrams.
  - Vol. V—(Out of print.)
    - Appendix III
      - Producer tests and diagrams.
  - Vol. VI—
    - Appendix IV
      - Coking tests.
    - Appendix V
      - Chemical tests.

†84. Gypsum deposits of the Maritime provinces of Canada—including the Magdalen islands. Report on—by W. F. Jennison, M.E. (See No. 245.)

88. The mineral production of Canada, 1909. Annual report on—by John McLeish, B.A.

NOTE.—*The following parts were separately printed and issued in advance of the Annual Report for 1909.*

  - †79. Production of iron and steel in Canada during the calendar year 1909.
  - †80. Production of coal and coke in Canada during the calendar year 1909.
  - 85. Production of cement, lime, clay products, stone, and other structural materials during the calendar year 1909.

89. Reprint of presidential address delivered before the American Peat Society at Ottawa, July 25, 1910. By Eugene Haanel, Ph.D.

90. Proceedings of conference on explosives.

92. Investigation of the explosives industry in the Dominion of Canada, 1910. Report on—by Capt. Arthur Desborough. (Second edition.)

93. Molybdenum ores of Canada. Report on—by Professor T. L. Walker, Ph.D.

100. The building and ornamental stones of Canada: Building and ornamental stones of Ontario. Report on—by Professor W. A. Parks, Ph.D.

102. Mineral production of Canada, 1910. Preliminary report on—by John McLeish, B.A.

† Publications marked thus † are out of print.

†103. Summary report of Mines Branch, 1910.

104. Catalogue of publications of Mines Branch, from 1902 to 1911; containing tables of contents and lists of maps, etc.

105. Austin Brook iron-bearing district. Report on—by E. Lindeman, M.E.

110. Western portion of Torbrook iron ore deposits, Annapolis county, N.S. Bulletin No. 7—by Howells Fréchette, M.Sc.

111. Diamond drilling at Point Mamainse, Ont. Bulletin No. 6—by A. C. Lane, Ph.D., with introductory by A. W. G. Wilson, Ph.D.

118. Mica: its occurrence, exploitation, and uses. Report on—by Hugh S. de Schmid, M.E.

142. Summary report of Mines Branch, 1911.

143. The mineral production of Canada, 1910. Annual report on—by John McLeish, B.A.

Note. *The following parts were separately printed and issued in advance of the Annual Report for 1910.*

†114. Production of cement, lime, clay products, stone, and other materials in Canada, 1910.
†115. Production of iron and steel in Canada during the calendar year 1910.
†116. Production of coal and coke in Canada during the calendar year 1910.
†117. General summary of the mineral production of Canada during the calendar year 1910.

145. Magnetic iron sands of Natashkwan, Saguenay county, Que. Report on—by Geo. C. Mackenzie, B.Sc.

†150. The mineral production of Canada, 1911. Preliminary report on—by John McLeish, B.A.

151. Investigation of the peat bogs and peat industry of Canada, 1910-11. Bulletin No. 8—by A. v. Anrep.

154. The utilization of peat fuel for the production of power, being a record of experiments conducted at the Fuel Testing Station, Ottawa. 1910-11. Report on—by B. F. Haanel, B.Sc.

167. Pyrites in Canada: its occurrence, exploitation, dressing and uses. Report on—by A. W. G. Wilson, Ph.D.

170. The nickel industry: with special reference to the Sudbury region, Ont. Report on—by Professor A. P. Coleman, Ph.D.

184. Magnetite occurrences along the Central Ontario railway. Report on—by E. Lindeman, M.E.

201. The mineral production of Canada during the calendar year 1911.—Annual report on—by John McLeish, B.A.

† Publications marked thus † are out of print.

NOTE.—*The following parts were separately printed and issued in advance of the Annual Report for 1911.*

181. Production of cement, lime, clay products, stone, and other structural materials in Canada during the calendar year 1911. Bulletin on—by John McLeish, B.A.

†182. Production of iron and steel in Canada during the calendar year 1911. Bulletin on—by John McLeish, B.A.

183. General summary of the mineral production in Canada during, the calendar year 1911. Bulletin on—by John McLeish, B.A.

†199. Production of copper, gold, lead, nickel, silver, zinc, and other metals of Canada, during the calendar year 1911. Bulletin on—by C. T. Cartwright, B.Sc.

†200. The production of coal and coke in Canada during the calendar year 1911. Bulletin on—by John McLeish, B.A.

203. Building stones of Canada—Vol. II: Building and ornamental stones of the Maritime Provinces. Report on—by W. A. Parks, PhD.

209. The copper smelting industry of Canada. Report on—by A. W. G. Wilson, Ph.D.

216. Mineral production of Canada, 1912. Preliminary report on—by John McLeish, B.A.

222. Lode mining in Yukon: an investigation of the quartz deposits of the Klondike division. Report on—by T. A. MacLean, B.Sc.

224. Summary report of the Mines Branch, 1912.

227. Sections of the Sydney coal fields—by J. G. S. Hudson, M.E.

†229. Summary report of the petroleum and natural gas resources of Canada, 1912—by F. G. Clapp, A.M. (See No. 224.)

230. Ecomomic minerals and mining industries of Canada.

245. Gypsum in Canada: its occurrence, exploitation, and technology. Report on—by L. H. Cole, B.Sc.

254. Calabogie iron-bearing district. Report on—by E. Lindeman, M.E.

259. Preparation of metallic cobalt by reduction of the oxide. Report on—by H. T. Kalmus, B.Sc., Ph.D.

262. The mineral production of Canada during the calendar year 1912. Annual report on—by John McLeish, B.A.

NOTE.—*The following parts were separately printed and issued in advance of the Annual Report for 1912.*

238. General summary of the mineral production of Canada, during the calendar year 1912. Bulletin on—by John McLeish, B.A.

† **Publications marked thus † are out of print.**

†247. Production of iron and steel in Canada during the calendar year 1912. Bulletin on—by John McLeish, B.A.

†256. Production of copper, gold, lead, nickel, silver, zinc, and other metals of Canada, during the calendar year 1912—by C. T. Cartwright, B.Sc.

257. Production of cement, lime, clay products, stone, and other structural materials during the calendar year 1912. Report on—by John McLeish, B.A.

†258. Production of coal and coke in Canada, during the calendar year 1912. Bulletin on—by John McLeish, B.A.

266. Investigation of the peat bogs and peat industry of Canada, 1911 and 1912. Bulletin No. 9—by A. v. Anrep.

279. Building and ornamental stones of Canada—Vol. III: Building and ornamental stones of Quebec. Report on—by W. A. Parks, Ph.D.

281. The bituminous sands of Northern Alberta. Report on—by S. C. Ells, M.E.

283. Mineral production of Canada, 1913. Preliminary report on—by John McLeish, B.A.

285. Summary report of the Mines Branch, 1913.

291. The petroleum and natural gas resources of Canada. Report on—by F. G. Clapp, A.M., and others:—
Vol. I.—Technology and Exploitation.

299. Peat, lignite, and coal: their value as fuels for the production of gas and power in the by-product recovery producer. Report on—by B. F. Haanel, B.Sc.

303. Moose Mountain iron-bearing district. Report on—by E. Lindeman, M.E.

305. The non-metallic minerals used in the Canadian manufacturing industries. Report on—by Howells Fréchette, M.Sc.

309. The physical properties of cobalt, Part II. Report on—by H. T. Kalmus, B.Sc., Ph.D.

320. The mineral production of Canada during the calendar year 1913. Annual report on—by John McLeish, B.A.

Note.—*The following parts were separately printed and issued in advance of the Annual Report for 1913.*

315. The production of iron and steel during the calendar year 1913. Bulletin on—by John McLeish, B.A.

316. The production of coal and coke during the calendar year 1913. Bulletin on—by John McLeish, B.A.

317. The production of copper, gold, lead, nickel, silver, zinc, and other metals, during the calendar year 1913. Bulletin on—by C. T. Cartwright, B.Sc.

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† Publications marked thus † are out of print.

318. The production of cement, lime, clay products, and other structural materials, during the calendar year 1913. Bulletin on—by John McLeish, B.A.

319. General summary of the mineral production of Canada during the calendar year 1913. Bulletin on—by John McLeish, B.A.

322. Economic minerals and mining industries of Canada. (Revised Edition).

323. The Products and by-products of coal. Report on—by Edgar Stansfield, M.Sc., and F. E. Carter, B.Sc., Dr. Ing.

331. The investigation of six samples of Alberta lignites. Report on—by B. F. Haanel, B.Sc., and John Blizard, B.Sc.

336. Notes on clay deposits near McMurray, Alberta. Bulletin No. 10—by S. C. Ells, B.A., B.Sc.

The Division of Mineral Resources and Statistics has prepared the following lists of mine, smelter, and quarry operators: Metal mines and smelters, Coal mines, Stone quarry operators, Manufacturers of clay products, and Manufacturers of lime; copies of the lists may be obtained on application.

IN THE PRESS.

291. The petroleum and natural gas resources of Canada. Report on—by F. G. Clapp, A.M., and others:—
Vol. II.—Occurrence of petroleum and natural gas in Canada.
Also separates of Vol. II, as follows:—
Part I, Eastern Canada.
Part II, Western Canada.

325. The salt industry of Canada. Report on—by L. H. Cole, B.Sc.

334. Electro-plating with cobalt and its alloys. Report on—by H. T. Kalmus, B.Sc., Ph.D.

338. Coals of Canada: Vol. VII. Weathering of Coal. Report on—by J. B. Porter, E.M., D.Sc., Ph.D.

344. Electrothermic Smelting of Iron Ores in Sweden. Report on—by Alfred Stansfield, D.Sc., A.R.S.M., F.R.S.C.

346. Summary report of the Mines Branch, 1914.

FRENCH TRANSLATIONS.

†4. Rapport de la Commission nommée pour étudier les divers procédés électro-thermiques pour la réduction des minerais de fer et la fabrication de l'acier employés en Europe—by Eugene Haanel, Ph.D. (French Edition), 1905.

26a. The mineral production of Canada, 1906. Annual report on—by John McLeish, B.A.

†28a. Summary report of Mines Branch, 1908.

56. Bituminous or oil-shales of New Brunswick and Nova Scotia; also on the oil-shale industry of Scotland. Report on—by R. W. Ells, LL.D.

81. Chrysotile-asbestos, its occurrence, exploitation, milling, and uses. Report on—by Fritz Cirkel, M.E.

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195. Magnetite occurrences along the Central Ontario railway. Report on—by E. Lindeman, M.E.

196. Investigation of the peat bogs and peat industry of Canada, 1909-10; to which is appended Mr. Alf. Larson's paper on Dr. M. Ekenburg's wet-carbonizing process: from Teknisk Tidskrift, No. 12, December 26, 1908—translation by Mr. A. v. Anrep; also a translation of Lieut. Ekelund's pamphlet entitled "A solution of the peat problem," 1909, describing the Ekelund process for the manufacture of peat powder, by Harold A. Leverin, Ch.E. Bulletin No. 4—by A. v. Anrep. (Second Edition, enlarged.)

197. Molybdenum ores of Canada. Report on—by T. L. Walker, Ph.D.

198. Peat and lignite: their manufacture and uses in Europe. Report on—by Erik Nystrom, M.E., 1908.

202. Graphite: its properties, occurrences, refining, and uses. Report on—by Fritz Cirkel, M.E., 1907.

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219. Austin Brook iron-bearing district. Report on—by E. Lindeman, M.E.

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231. Ecomomic minerals and mining industries of Canada.

233. Gypsum deposits of the Maritime Provinces of Canada—including the Magdalen islands. Report on—by W. F. Jennison, M.E.

263. Recent advances in the construction of electric furnaces for the production of pig iron, steel, and zinc. Bulletin No. 3—by Eugene Haanel, Ph.D.

264. Mica: its occurrence, exploitation, and uses. Report on—by Hugh S. de Schmid, M.E.

265. Annual mineral production of Canada, 1911. Report on—by John McLeish, B.A.

287. Production of iron and steel in Canada during the calendar year 1912. Bulletin on—by John McLeish, B.A.

288. Production of coal and coke in Canada, during the calendar year 1912. Bulletin on—by John McLeish, B.A.

289. Production of cement, lime, clay products, stone, and other structural materials during the calendar year 1912. Bulletin on—by John McLeish, B.A.

290. Production of copper, gold, lead, nickel, silver, zinc, and other metals of Canada during the calendar year 1912. Bulletin on—by C. T. Cartwright, B.Sc.

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Vol. I—Coal washing and coking tests.

IN THE PRESS.

179. The nickel industry: with special reference to the Sudbury region, Ont. Report on—by Professor A. P. Coleman, Ph.D.

204. Building stones of Canada—Vol. 11: Building and ornamental stones of the Maritime Provinces. Report on—by W. A. Parks, Ph.D.

223. Lode Mining in the Yukon: an investigation of quartz deposits in the Klondike division. Report on—by T. A. MacLean, B.Sc.

246. Gypsum in Canada: its occurrence, exploitation, and technology. Report on—by L. H. Cole, B.Sc.

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  Vol. II—Boiler and gas producer tests.
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      Coal washing tests and diagrams.
  Vol. IV—
    Appendix II
      Boiler tests and diagrams.

314. Iron ore deposits, Bristol mine, Pontiac county, Quebec, Report on—by E. Lindeman, M.E.

MAPS.

†6. Magnetometric survey, vertical intensity: Calabogie mine, Bagot township, Renfrew county, Ontario—by E. Nystrom, 1904. Scale 60 feet to 1 inch. Summary report 1905. (See Map No. 249.)

†13. Magnetometric survey of the Belmont iron mines, Belmont township, Peterborough county, Ontario—by B. F. Haanel, 1905. Scale 60 feet to 1 inch. Summary report, 1905. (See Map No. 186.)

†14. Magnetometric survey of the Wilbur mine, Lavant township, Lanark county, Ontario—by B. F. Haanel, 1905. Scale 60 feet to 1 inch. Summary report, 1905.

†33. Magnetometric survey, vertical intensity: lot 1, concession VI, Mayo township, Hastings county, Ontario—by Howells Fréchette, 1909. Scale 60 feet to 1 inch. (See Maps Nos. 191 and 191A.)

†34. Magnetometric survey, vertical intensity: lots 2 and 3, concession VI, Mayo township, Hastings county, Ontario—by Howells Fréchette, 1909. Scale 60 feet to 1 inch. (See Maps Nos. 191 and 191A.)

†35. Magnetometric survey, vertical intensity: lots 10, 11, and 12, concession IX, and lots 11 and 12, concession VIII, Mayo township, Hastings county, Ontario—by Howells Fréchette, 1909. Scale 60 feet to 1 inch. (See Maps Nos. 191 and 191A.)

*36. Survey of Mer Bleue peat bog, Gloucester township, Carleton county, and Cumberland township, Russell county, Ontario—by Erik Nystrom, and A. v. Anrep. (Accompanying report No. 30.)

*37. Survey of Alfred peat bog, Alfred and Caledonia townships, Prescott county, Ontario—by Erik Nystrom and A. v. Anrep. (Accompanying report No. 30.)

*38. Survey of Welland peat bog, Wainfleet and Humberstone townships, Welland county, Ontario—by Erik Nystrom and A. v. Anrep. (Accompanying report No. 30.)

*39. Survey of Newington peat bog, Osnabruck, Roxborough, and Cornwall townships, Stormont county, Ontario—by Erik Nystrom and A. v. Anrep. (Accompanying report No. 30.)

*40. Survey of Perth peat bog, Drummond township, Lanark county, Ontario—by Erik Nystrom and A. v. Anrep. (Accompanying report No. 30.)

†41. Survey of Victoria Road peat bog, Bexley and Carden townships, Victoria county, Ontario—by Erik Nystrom and A. v. Anrep. (Accompanying report No. 30.)

*48. Magnetometric survey of Iron Crown claim at Nimpkish (Klaanch) river, Vancouver island, B.C.—by E. Lindeman. Scale 60 feet to 1 inch. (Accompanying report No. 47.)

Note.—1. Maps marked thus * are to be found only in reports.
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*49. Magnetometric survey of Western Steel Iron claim, at Sechart, Vancouver island, B.C.— By E. Lindeman. Scale 60 feet to 1 inch. (Accompanying report No. 47).

*53. Iron ore occurrences, Ottawa and Pontiac counties, Quebec, 1908—by J. White and Fritz Cirkel. (Accompanying report No. 23.)

*54. Iron ore occrurences, Argenteuil county, Quebec, 1908—by Fritz Cirkel. (Accompanying report No. 23.) (Out of print.)

*57. The productive chrome iron ore district of Quebec—by Fritz Cirkel. (Accompanying report No. 29.)

†60. Magnetometric survey of the Bristol mine, Pontiac county, Quebec—by E. Lindeman. Scale 200 feet to 1 inch. (Accompanying report No. 67.)

†61. Topographical map of Bristal mine, Pontiac county, Quebec—by E. Lindeman. Scale 200 feet to 1 inch. (Accompanying report No. 67.)

†64. Index map of Nova Scotia: Gypsum—by W. F. Jennison.

†65. Index map of New Brunswick: Gypsum—by W. F. Jennison.

†66. Map of Magdalen islands: Gypsum—by W. F. Jennison.

(Accompanying report No. 84.)

†70. Magnetometric survey of Northeast Arm iron range, Lake Timagami, Nipissing district, Ontario—by E. Lindeman. Scale 200 feet to 1 inch. (Accompanying report No. 63.)

†72. Brunner peat bog, Ontario—by A. v. Anrep.

†73. Komako peat bog, Ontario—by A. v. Anrep.

†74. Brockville peat bog, Ontario—by A. v. Anrep

†75. Rondeau peat bog, Ontario—by A. v. Anrep.

†76. Alfred peat bog, Ontario—by A. v. Anrep.

†77. Alfred peat bog, Ontario: main ditch profile—by A. v. Anrep.

(Accompanying report No. 71.)

(Out of print.)

†78. Map of asbestos region, Province of Quebec, 1910—by Fritz Cirkel. Scale 1 mile to 1 inch. (Accompanying report No. 69.)

†94. Map showing Cobalt, Gowganda, Shiningtree, and Porcupine districts —by L. H. Cole. (Accompanying Summary report, 1910.)

†95. General map of Canada, showing coal fields. (Accompanying report No. 83—by Dr. J. B. Porter.)

†96. General map of coal fields of Nova Scotia and New Brunswick. (Accompanying report No. 83—By Dr. J. B. Porter.)

†97. General map showing coal fields in Alberta, Saskatchewan, and Manitoba. (Accompanying report No. 83—by Dr. J. B. Porter).

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†98. General map of coal fields in British Columbia. Accompanying report No. 83—by Dr. J. B. Porter.)

†99. General map of coal field in Yukon Territory. (Accompanying report No. 83—by Dr. J. B. Porter.)

†106. Geological map of Austin Brook iron bearing district, Bathurst township, Gloucester county, N.B.—by E. Lindeman. Scale 400 feet to 1 inch. (Accompanying report No. 105.)

†107. Magnetometric survey, vertical intensity: Austin Brook iron bearing district—by E. Lindeman. Scale 400 feet to 1 inch. (Accompanying report No. 105.)

†108. Index map showing iron bearing area at Austin Brook—by E. Lindeman. (Accompanying report No. 105.)

*112. Sketch plan showing geology of Point Mamainse, Ont.—by Professor A. C. Lane. Scale 4,000 feet to 1 inch. (Accompanying report No. 111.)

†113. Holland peat bog Ontario—by A. v. Anrep. (Accompanying report No. 151.)

*119–137. Mica: township maps, Ontario and Quebec—by Hugh S. de Schmid. (Accompanying report No. 118.)

†138. Mica: showing location of principal mines and occurrences in the Quebec mica area—by Hugh S. de Schmid. Scale 3·95 miles to 1 inch. (Accompanying report No. 118.)

†139. Mica: showing location of principal mines and occurrences in the Ontario mica area—by Hugh S. de Schmid. Scale 3·95 miles to 1 inch. (Accompanying report No. 118.)

†140. Mica: showing distribution of the principal mica occurrences in the Dominion of Canada—by Hugh S. de Schmid. Scale 3·95 miles to 1 inch. (Accompanying report No. 118.)

†141. Torbrook iron bearing district, Annapolis county, N.S.—by Howells Fréchette. Scale 400 feet to 1 inch. (Accompanying report No. 110).

†146. Distribution of iron ore sands of the iron ore deposits on the north shore of the River and Gulf of St. Lawrence, Canada—by Geo. C. Mackenzie. Scale 100 miles to 1 inch. (Accompanying report No. 145.)

†147. Magnetic iron sand deposits in relation to Natashkwan harbour and Great Natashkwan river, Que. (Index Map)—by Geo. C. Mackenzie. Scale 40 chains to 1 inch. (Accompanying report No. 145.)

†148. Natashkwan magnetic iron sand deposits, Saguenay county, Que.—by Geo. C. Mackenzie. Scale 1,000 feet to 1 inch. (Accompanying report No. 145.)

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†152. Map showing the location of peat bogs investigated in Ontario—by A. v. Anrep.

†153. Map showing the location of peat bog as investigated in Manitoba—by A. v. Anrep.

†157. Lac du Bonnet peat bog, Manitoba—by A. v. Anrep.

†158. Transmission peat bog, Manitoba—by A. v. Anrep.

†159. Corduroy peat bog, Manitoba—by A. v. Anrep.

†160. Boggy Creek peat bog, Manitoba—by A. v. Anrep.

†161. Rice Lake peat bog, Manitoba—by A. v. Anrep.

†162. Mud Lake peat bog, Manitoba—by A. v. Anrep.

†163. Litter peat bog, Manitoba—by A. v. Anrep.

†164. Julius peat litter bog, Manitoba—by A. v. Anrep.

*165. Fort Francis peat bog, Ontario—by A. v. Anrep.

(Accompanying report No. 151.)

†166. Magnetometric map of No. 3 mine, lot 7, concessions V and VI, McKim township, Sudbury district, Ont.—by E. Lindeman. (Accompanying Summary report, 1911.)

†168. Map showing pyrites mines and prospects in Eastern Canada, and their relation to the United States market—by A. W. G. Wilson. Scale 125 miles to 1 inch. (Accompanying report No. 167.)

†171. Geological map of Sudbury nickel region, Ont.—by Prof. A. P. Coleman. Scale 1 mine to 1 inch. (Accompanying report No. 170.)

†172. Geological map of Victoria mine—by Prof. A. P. Coleman.

†173. " Crean Hill mine—by Prof. A. P. Coleman

†174. " Creighton mine—by Prof. A. P. Coleman.

(Accompanying report No. 170.)

†175. " showing contact of norite and Laurentian in vicinity of Creighton mine—by Prof. A. P. Coleman. (Accompanying report No. 170.)

†176. " Copper Cliff offset—by Prof. A. P. Coleman. (Accompanying report No. 170.)

†177. " No. 3 mine—by Prof. A. P. Coleman. (Accompanying report No. 170.)

†178. " showing vicinity of Stobie and No. 3 mines—by Prof. A. P. Coleman. (Accompanying report No. 170.)

Note.—1. Maps marked thus * are to be found only in reports.
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†185. Magnetometric survey, vertical intensity: Blairton iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†185a. Geological map, Blairton iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†186. Magnetometric survey, Belmont iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†186a. Geological map, Belmont iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†187. Magnetometric survey, vertical intensity: St. Charles mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†187a. Geological map, St. Charles mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†188. Magnetometric survey, vertical intensity: Baker mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†188a. Geological map, Baker mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†189. Magnetometric survey, vertical intensity: Ridge iron ore deposits, Wollaston township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†190. Magnetometric survey, vertical intensity: Coehill and Jenkins mines, Wollaston township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†190a. Geological map, Coehill and Jenkins mines, Wollaston township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†191. Magnetometric survey, vertical intensity: Bessemer iron ore deposits, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†191a. Geological map, Bessemer iron ore deposits, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†192. Magnetometric survey, vertical intensity: Rankin, Childs, and Stevens mines, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 194.)

Note.—1. Maps marked thus * are to be found only in reports.
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†192a. Geological map, Rankin, Childs, and Stevens mines, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†193. Magnetometric survey, vertical intensity: Kennedy property, Carlow township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†193a. Geological map, Kennedy property, Carlow township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†194. Magnetometric survey, vertical intensity: Bow Lake iron ore occurrences, Faraday township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†204. Index map, magnetite occurrences along the Central Ontario railway—by E. Lindeman, 1911. (Accompanying report No. 184.)

†205. Magnetometric map, Moose Mountain iron-bearing district, Sudbury district, Ontario: Deposits Nos. 1, 2, 3, 4, 5, 6, and 7—by E. Lindeman, 1911. (Accompanying report No. 303.)

†205a. Geological map, Moose Mountain iron-bearing district, Sudbury district, Ontario, Deposits Nos. 1, 2, 3, 4, 5, 6, and 7—by E. Lindeman. (Accompanying report No. 303.)

†206. Magnetometric survey of Moose Mountain iron-bearing district, Sudbury district, Ontario: northern part of deposit No. 2—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)

†207. Magnetometric survey of Moose Mountain iron-bearing district, Sudbury district, Ontario: Deposits Nos. 8, 9, and 9A—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)

†208. Magnetometric survey of Moose Mountain iron-bearing district, Sudbury district, Ontario: Deposit No. 10—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)

†208a. Magnetometric survey, Moose Mountain iron-bearing district, Sudbury district, Ontario: eastern portion of Deposit No. 11—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)

†208b. Magnetometric survey, Moose Mountain iron-bearing district, Sudbury district, Ontario: western portion of deposit No. 11—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)

†208c. General geological map, Moose Mountain iron-bearing district, Sudbury district, Ontario—by E. Lindeman, 1912. Scale 800 feet to 1 inch. (Accompanying report No. 303.)

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†210. Location of copper smelters in Canada—by A. W. G. Wilson. Scale 197·3 miles to 1 inch. (Accompanying report No. 209.)

†215. Province of Alberta: showing properties from which samples of coal were taken for gas producer tests, Fuel Testing Division, Ottawa. (Accompanying Summary report, 1912.)

†220. Mining districts, Yukon. Scale 35 miles to 1 inch—by T. A. MacLean (Accompanying report No. 222.)

†221. Dawson mining district, Yukon, Scale 2 miles to 1 inch—by T. A. MacLean. (Accompanying report No. 222.)

*228. Index map of the Sydney coal fields, Cape Breton, N.S. (Accompanying report No. 227.)

†232. Mineral map of Canada. Scale 100 miles to 1 inch. (Accompanying report No. 230.)

†239. Index map of Canada showing gypsum occurrences. (Accompanying report No. 245.)

†240. Map showing Lower Carboniferous formation in which gypsum occurs in the Maritime provinces. Scale 100 miles to 1 inch. (Accompanying report No. 245.)

†241. Map showing relation of gypsum deposits in Northern Ontario to railway lines. Scale 100 miles to 1 inch. (Accompanying report No. 245.)

†242. Map, Grand River gypsum deposits, Ontario. Scale 4 miles to 1 inch. (Accompanying report No. 245.)

†243. Plan of Manitoba Gypsum Co.'s properties. (Accompanying report No. 245.)

†244. Map showing relation of gypsum deposits in British Columbia to railway lines and market. Scale 35 miles to 1 inch. (Accompanying report No. 245.)

†249. Magnetometric survey, Caldwell and Campbell mines, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 254.)

†250. Magnetometric survey, Black Bay or Williams mine, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 254.)

†251. Magnetometric survey, Bluff Point iron mine, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 254.)

†252. Magnetometric survey, Culhane mine, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 254.)

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†253. Magnetometric survey, Martel or Wilson iron mine, Calabogie district, Renfrew county, Ontario—by L. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 254.)

†261. Magnetometric survey, Northeast Arm iron range, lot 339 E.T.W. Lake Timagami, Nipissing district, Ontario—by E. Nystrom, 1903. Scale 200 feet to 1 inch.

†268. Map of peat bogs investigated in Quebec—by A v. Anrep, 1912.

†269. Large Tea Field peat bog, Quebec " "

†270. Small Tea Field peat bog, Quebec " "

†271. Lanoraie peat bog, Quebec " "

†272. St. Hyacinthe peat bog, Quebec " "

†273. Rivière du Loup peat bog " "

†274. Cacouna peat bog " "

†275. Le Parc peat bog, Quebec " "

†276. St. Denis peat bog, Quebec " "

†277. Rivière Ouelle peat bog, Quebec " "

†278. Moose Mountain peat bog, Quebec " "

†284. Map of northern portion of Alberta, showing position of outcrops of bituminous sand. Scale 12½ miles to 1 inch. (Accompanying report No. 281.)

†293. Map of Dominion of Canada, showing the occurrences of oil, gas, and tar sands. Scale 197 miles to 1 inch. (Accompanying report No. 291.)

†294. Reconnaissance map of part of Albert and Westmorland counties New Brunswick. Scale 1 mile to 1 inch. (Accompanying report No. 291.)

†295. Sketch plan of Gaspé oil fields, Quebec, showing location of wells. Scale 2 miles to 1 inch. (Accompanying report No. 291.)

†296. Map showing gas and oil fields and pipe-lines in southwestern Ontario. Scale 4 miles to 1 inch. (Accompanying report No. 291.)

†297. Geological map of Alberta, Saskatchewan, and Manitoba. Scale 35 miles to 1 inch. (Accompanying report No. 291.)

†298. Map, geology of the forty-ninth parallel, 0·9864 miles to 1 inch. (Accompanying report No. 291.)

†302. Map showing location of main gas line, Bow Island, Calgary. Scale 12½ miles to 1 inch. (Accompanying report No. 291.)

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†311. Magnetometric map, McPherson mine, Barachois, Cape Breton county, Nova Scotia—by A. H. A. Robinson, 1913. Scale 200 feet to 1 inch.

†312. Magnetometric map, iron ore deposits at Upper Glencoe, Inverness county, Nova Scotia—by E. Lindeman, 1913. Scale 200 feet to 1 inch.

†313. Magnetometric map, iron ore deposits at Grand Mira, Cape Breton county, Nova Scotia—by A. H. A. Robinson, 1913. Scale 200 feet to 1 inch.

Address all communications to—

DIRECTOR MINES BRANCH,
DEPARTMENT OF MINES,
SUSSEX STREET, OTTAWA.

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