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INVESTIGATIONS
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FUELS AND FUEL TESTING

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PART I

PART II

PART III

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Investigations in Ceramics and Road Materials (Testing and Research Laboratories).

Other reports on Special Investigations are issued as completed.

CONTENTS

PART I

PART II

PART III

ILLUSTRATIONS

Photographs

Drawings

TABLES

MINES BRANCH INVESTIGATIONS OF
FUELS AND FUEL TESTING, 1925

GENERAL REVIEW OF INVESTIGATIONS

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R. E. Gilmore, *Superintendent of Fuel Testing Laboratories*

The staff of the Division of Fuels and Fuel Testing was engaged during the year 1925 in conducting research work relating to the low-temperature carbonization of solid fuels; investigations relating to the distillation of oil shales; the comparative value of the different fuels sold on the market for household purposes; and special investigations relating to cokes, and the manufacture of peat into a marketable fuel. The regular routine work carried on from year to year in the laboratories, such as the analyses of liquid, solid, and gaseous fuels, and the analyses and determination of heating values of coal purchased by certain of the departments of the Federal Government, has considerably increased, and this has necessarily taken a large amount of the time of the chemical staff. In addition to the above-mentioned activities, the staff, both engineering and chemical, is called upon to examine processes, both tentative and in actual operation, for heat treating and utilizing fuels for various purposes. In laying out the work of this division the main objective is to plan such investigations and research as will most materially assist in the better utilization and development of the fuel resources of Canada. Although a large amount of the work carried out cannot be put in report form, certain investigations and other work are sufficiently far advanced, completed, or are of such a nature that the results obtained can be published. The papers included in this report, which are briefly reviewed hereunder, are representative of such investigations, research, and routine work.

Examination of Typical Cokes Sold in Canada as Household Fuels: by R. E. Gilmore, C. B. Mohr, and others. This report comprises the results obtained in the examination of thirty typical cokes sold in Canada during 1925. The main objective of the investigation was to obtain data which would permit the qualities of the different cokes sold as household fuels to be compared. In addition to proximate and ultimate analyses and the determination of calorific value, the comparative general characteristics of the cokes in respect to appearance, size, apparent density, and fusibility, were examined. An attempt was also made to differentiate between by-product cokes and gas cokes made in retorts and to distinguish between cokes of different structures in these two classes. The principal features of the results obtained are set forth in the summary at the end of the report. The average ash content of all the cokes examined (one sample excepted) was 9¼ per cent as compared with an average of 12½ per cent for eighteen samples of Pennsylvania anthracite which were recently examined in the

Fuel Testing Laboratories. Eighteen of the lower ash by-product cokes had an average ash content of 7½ per cent, which is roughly 50 per cent greater than the average ash content of Welsh anthracite sold on the market, and approximately half that of the higher ash content of Pennsylvania anthracites. The average calorific value for the eighteen by-product cokes was roughly 13,000 B.T.U. per pound, which is approximately midway between the averages for Pennsylvania and Welsh anthracites. The results of screen analyses showed considerable non-uniformity in respect to size designation and names of the different egg, stove, nut, pea, large, medium, and small sizes sold. Chemical analyses cannot in general be employed to differentiate between gas cokes and by-product cokes, but for this purpose a modified shatter test is of value. The pebble-mill tumbling test, which was described in the 1924 investigations of the division, when used in conjunction with the shatter test, served to distinguish between certain gas and by-product cokes of different appearance and structure but of practically the same apparent density. The calorific values of fifteen representative cokes calculated to the dry, ash-free basis were checked closely by calorific values calculated from the ultimate analyses. The use of the figure 14,220, the value of the heat of combustion of graphite, gave more satisfactory results in connexion with the calculated calorific values for coke than the figure 14,540, the heat of combustion for amorphous carbon, which is used in calculating the calorific value of coals. This indicates that the fixed carbon in the cokes examined was of graphitic nature rather than amorphous. A curve on which the calorific values on the dry, ash-free basis are plotted against volatile matter content, is included, inasmuch as it may be useful in calculating the approximate heating values of cokes of which only the ash and moisture contents are known.

Tests of Various Fuels in a Domestic Hot-Water Boiler at the Fuel Testing Station in Co-operation with the Dominion Fuel Board: by E. S. Malloch and C. E. Baltzer. This paper reviews the work which was performed by the authors and their assistants at the Fuel Testing Station during the past two years. Twenty-one domestic fuels were tested in a hot-water boiler, with a view to obtaining data for making a comparison of the relative value of these domestic fuels with American anthracite for heating purposes. The comparisons were made under conditions as similar as possible to those obtaining in the average household. The domestic hot-water heater employed during the investigation was of standard design and of the size usually found in an eight- or nine-room house. The duration of each test, which was from 72 to 120 hours, was so arranged that at least 1,000 pounds of fuel would be consumed during the test. With the larger number of the fuels four tests were conducted on each, viz., one test at low rate, two at intermediate rate, and one at high rate of combustion. The comparison of the various fuels with American anthracite was made upon the measure of heat transference. A comparison as to attendance and ease of handling the fire was only incidental and is only lightly touched upon in this paper.

Low-temperature Carbonization of Bituminous Coals: by R. A. Strong. In this investigation R. A. Strong studied the behaviour of three typical coals, viz., Sydney coal from Nova Scotia, Minto coal from New Brunswick, and Westmoreland coal from Pennsylvania, when submitted to carbonization at low temperatures. The latter coal, which is a standard gas coal, is included for comparative purposes. The objective of conducting low-temperature carbonization investigations is the examination of coals with respect to maximum yields and quality of tar oils, and to the general characteristics of the coke residue in comparison with the products obtained by high-temperature carbonization, as, for example, in the city gas and by-product coke industries. The results of the investigation included in this paper are but the beginning of a general survey of Canadian coking coals. Previous low-temperature carbonization research work was confined to non-coking coals. On the three coals cited above, thirty-four carbonization runs were made. A series of tests was conducted on each of the three coals according to the regular low-temperature carbonization method, at 400°, 500°, and 600° C. Additional runs were made on the Westmoreland coal, first, carbonization in the presence of steam, and then with the recirculation of the condensed gases. The latter tests were made for the purpose of testing the claims made by inventors and promoters to the effect that greater oil yields and a superior coke residue could be obtained by the process employing the recirculation of gas. The electrically heated lead bath method as previously used in the Fuel Testing Laboratories for special carbonization experiments on lignites and oil shales, was employed for all the tests conducted. The special feature of this method is that the rate of carbonization and maximum temperatures can be controlled within the described limits. The size of the sample employed in each run was 2,000 grammes (4½ pounds). Duplicate runs were made on a given coal at the same temperature and under the same conditions. A sufficient quantity of tar oils was obtained from such duplicate runs to permit the carrying out of ordinary analyses respecting specific gravity and distillation range, for special examination of the contents of phenols, unsaturated compounds, and for applying the tests for "primary tar."

The appearance and nature of the low-temperature coke residues varied considerably according to the different maximum temperatures of carbonization employed, as they did also for the different coals at the same temperature. At 600° C. (1100° F.) the temperature at which maximum oil yields were obtained, the coke from the Minto coal was quite porous and friable, whereas the cokes from the Sydney and Westmoreland coals were denser and more closely resembled the cokes obtained from high-temperature carbonization. The general characteristics of these low-temperature cokes, however, would have to be greatly improved before they could compete with the high-temperature cokes for household fuels. The volatile matter content of the cokes produced from the three coals when carbonized at 600° C. averaged slightly over 7½ per cent. This was sufficiently low to ensure their ready ignition and combustion with a smokeless flame. The oil yields at this temperature varied from 10·4 to 12·8 per cent by weight of the coals carbonized; the average of the two Canadian coals was 11·4 per cent, which is equal to approximately 23 Imperial gallons per ton, exclusive of the light oils in the gas. The gas yields from these two coals at 600° C. were 3,500 and 3,400 cubic feet per ton, respectively, and the average calorific value per cubic foot was 620 B.T.U.

An important result of the investigation was the refutation of the claims made by certain investigators that at a temperature of 700° F. (or at below the plastic coking stage) a satisfactory carbon residue could be produced, in addition to commercial yields of oil and gas. At a temperature of 350° to 450° C. (approximately 700° F.) Westmoreland coal, carbonized in the presence of steam, yielded a residue which remained in the individual, raw coal, lump form, but which still contained over 28 per cent volatile matter and when burned was not smokeless. At 700° F. there was practically no gas yield although the oil yield was only 30 per cent of the maximum obtained. At a temperature of 400° C. (750° F.) a carbonized residue containing an average of 27½ per cent volatile matter, smoky when burned, was produced along with gas and tar oil yields averaging 1,100 cubic feet and 12½ gallons per ton, respectively. It should be pointed out that the use of steam or gas circulation did not materially increase yields over those obtained by regular carbonization.

The examination of the tar oils showed that there was a considerable variation in respect to yield, density, distillation range, and tar acid content of the original crude tar, and of the different fractions, but the variation was found to be due to the proportion of tar acids (phenols, creosols, etc.) present, rather than to the neutral oil content. The tar acid content of the crude tar oils obtained from the three coals at 600° C. varied approximately from 19 to 24 per cent with an average of 22½ per cent. This tar acid content was fairly equally distributed in the following three fractions, viz., up to 225° C., 225° to 275° C., and above. The neutral oil content of the crude tar oils and of the fractions showed remarkable uniformity with respect to its specific gravity, distillation range, and amount soluble in concentrated sulphuric acid, and may, therefore, be considered as a suitable raw material for the production of gasoline and other petroleum oil products, either by ordinary or pressure-still (cracking) refining. The crude tar oils obtained at both 500° and 600° C. when examined according to Dr. Franz Fischer's definition of primary tar, conformed to all but one of the specifications. Inasmuch as the tar obtained at 300° C., which is well below the maximum temperature of carbonization of 500° C. specified by Fischer to ensure a "primary" tar, did not conform to the final solubility and naphtha test, it is concluded that this test cannot be considered to be applicable to the tars from all coals and that the definition of primary tar in this respect requires revision.

Effects of Continued Weathering on the Friability of Various Fuels: by J. H. H. Nicolls. This paper is a continuation of the friability experiments which were reported in the Investigations of Fuels and Fuel Testing for 1924. The effects of continued weathering (in an open shed) of different classes of solid fuels are reported. The comparative results of the eleven samples reported are of interest when taken in conjunction with the results of the previous weathering experiments.

Analyses of Coals and Other Solid Fuels: compiled by J. H. H. Nicolls, are given in three sections, viz:—

1. Analyses of coals native to Canada, pages 108 to 127. The analyses of coals comprising this section are arranged in order of provinces from east to west, as follows:—

Nova Scotia	10 samples of coal.
New Brunswick	1 sample "
Ontario	5 samples of peat and 1 of anthracite from Sudbury district.
Alberta	52 samples of coal.
British Columbia	45 "

For analyses of coals from Manitoba and Saskatchewan and the more complete analyses of coals, peat, etc., from the other provinces, the reader is referred to "Analyses of Canadian Fuels", Mines Branch Reports 479 to 483 inclusive (Bulletins 22 to 26); also to "Survey of Maritime Provinces Coals", Investigations of Fuels and Fuel Testing, 1923.

2. Analyses of coals submitted by the Department of Soldiers' Civil Re-establishment, pages 128 to 129. This section contains the analyses of 63 samples of coal, both Canadian and imported, submitted during 1925 by that department. The results are of importance inasmuch as they show the quality, as judged by chemical analyses, of typical coals delivered in Canada for steam-raising purposes. They are of importance also on account of the fact that the price paid was adjusted for bonuses and penalties according to the moisture, ash, and calorific value as shown by chemical analyses.

3. Analyses of miscellaneous solid fuels. This section comprises the following analyses:—

Pennsylvania anthracite....................	29 samples
Welsh and Scotch anthracite................	29 "
Low-volatile bituminous coals..............	11 "

Examination of Lubricating Oils after Use in Automobile Engines: by P. V. Rosewarne. This investigation was conducted for the purpose of ascertaining whether oils used for lubricating internal combustion motors could not be used to better advantage, and whether the used oil could not be rectified and used again for lubricating purposes. The paper comprises the results obtained during the investigation conducted during the last two years. The lubricating oils examined were obtained from automobile engines which were in actual use. The grade of gasoline, mileage the car was run, type of engine, and other particulars of interest are recorded for each oil tested. A total of 46 samples of used oil, obtained from as many tests in 8 different makes of cars, were examined. The outstanding conclusion of the investigation is that, contrary to public opinion, lubricating oils do not wear out. They do, however, become diluted with the heavier end fractions of gasoline and become contaminated with foreign matter and decomposition products. The degree of dilution and decomposition is indicated by increases in Baumé gravity and carbon content, according to the Conradson test. The filtered or settled used oils exhibited, after the removal of the diluent, slightly higher viscosities than the original oil. Centrifuging after thinning down with gasoline, followed by the removal of the gasoline by distillation, yielded a new oil almost as good as the original oil, but the vacuum distillation of the used crankcase oil yielded a refined product comparable to the new low-carbon lubricating oils on the market.

The Gasoline Survey for 1925: by P. V. Rosewarne and H. McD. Chantler. This is the third annual analyses survey of the gasoline sold in Canada, conducted by the Fuel Testing Laboratories. The results of the surveys indicate the changes which take place in the quality of the gasolines sold on the market from year to year, and are of value in connexion with the study of the future sources of gasoline from such raw materials as Canadian crude oils, shale oil, bituminous sand, and coal-tar oils. The gasolines sold in Canada during the summer of 1925 exhibited less marked variation in quality than those sold in 1924. The latter in this respect were inferior to those sold in 1923. However, the gasolines sold in Canada during the course of these surveys have been consistently of a good quality, the average each year being superior to that sold in the United States as reported in their semi-annual surveys, and of much better quality than that specified by the United States Federal Board for Government standard motor gasoline. The 1925 survey comprised a total of 73 samples obtained from 13 widely separated cities. These were examined and compared with 59 samples obtained from the same number of cities in 1924 and with 48 samples obtained from 10 cities in 1923. The samples for each of these surveys were collected by officers of the Department of Health in the different cities, under instruction from the Chief Analyst at Ottawa, to whom it is desired to make grateful acknowledgment for the valuable co-operation rendered.

Analyses of Oils and Liquid Fuels, compiled by P. V. Rosewarne, comprises two parts, viz:—

Section I—Examination of some Arctic animal oils.

Section II—Examination of crude and refined petroleum oils.

The animal oils examined were white seal oil, white porpoise oil, brown whale oil, and polar bear oil. Samples of these were sent in by the North West Territories and Yukon Branch of the Department of the Interior. In addition to an examination for relative heating and illuminating values the general characteristics of these oils as compared with other animal oils of commercial value, were studied. The results of this comparative examination are tabulated for the ready reference of those interested in the subject of animal oils.

The crude and refined petroleum oils examined and reported consist of the following:—

Crude petroleum	20 samples
Lubricating oils	16 "
Gasoline	36 "
Kerosene	14 "
Fuel oil	8 "

The analyses of crude petroleum comprised Canadian oils sent in from different parts of the Dominion. The gasoline and lubricating oils reported comprised samples which were not reported in the different gasoline survey samples and in "The Examination of Some Lubricating Oils Sold in Canada"—Investigations of Fuels and Fuel Testing, 1924. The analyses of the kerosene and fuel oil samples are presented as a matter of general interest.

Laboratory Distillation of Oil Shale with Circulation of Uncondensed Gases: by A. A. Swinnerton. The results reported in this paper are a continuation of a special investigation conducted on a standard oil-shale sample. The objective of continuing the distillation with circulation of the uncondensed gases was to enable a comparison of this method with other standard distillation methods to be made, and also to test the claims made by certain inventors and investigators respecting the value of employing the gas circulation principle. The results of the runs which were made are of interest and should be read in conjunction with "Distillation of Oil Shale—Comparison of Laboratory Methods," Investigations of Fuels and Fuel Testing, 1924, page 69. Distillation with the circulation of the uncondensed gases reported overall yields of crude oils slightly greater than those obtained by regular distillation, but the yields of light oils were less. The crude oil yield varied directly with the rate of distillation, and this in turn varied directly with the rate of gas circulation. When employing gas circulation as high as one-sixth of the total crude oil yield (i.e. over one-third of the yield of light oils) was scrubbed from the gas after condensing. The commercial development of a gas circulation system would, therefore, involve the extra expense of gas scrubbing. This disadvantage when considered in conjunction with the slightly reduced yield of oil suitable for refining into motor fuel, either by ordinary refining practice or by the new cracking processes, does not make the distillation of oil shale employing this principle, specially attractive.

PART I

I

EXAMINATION OF TYPICAL COKES SOLD IN CANADA AS HOUSEHOLD FUELS

R. E. Gilmore, C. B. Mohr, and others

Coke has found extensive use in Canada during recent years as a household fuel in place of imported anthracite coal. Coke is made from coking bituminous (soft) coals and may vary considerably according to the grade of coal used and the kind of retort or oven in which it is made. In order to determine the comparative quality of the cokes on the market as household fuels, samples of a number of typical cokes were collected and examined, and this report discusses the general characteristics of these cokes as well as their chemical analyses.

City gas is now made in Canada, both in what are known as gas retorts and in by-product ovens. Coke made in retorts is designated *gas coke,* whereas if made in the by-product ovens, it is termed *by-product coke.* In plants using retorts, gas is the main product, whereas in the by-product ovens the production of a coke of superior quality is the main feature. In central Canada gas coke is made in two types of retorts, viz., the D-shaped horizontal retorts of both the stop-end and through designs, and the Glover-West vertical retorts. In the D-shaped horizontal retorts, which are operated intermittently, the coal is charged in a thin layer into comparatively shallow retorts, there being considerable space between the surface of the coal and the top of the retorts. During coking the coal becomes plastic and swells, and due to the rapid evolution of the gas and short period of carbonization, the resulting coke is apt to be more porous and friable than the other kinds of cokes. In charging the D-shaped retorts, the coal is not crushed to a uniform small size, but is charged as lump coal, the sizes varying from two inches or more downwards. In the Glover-West installations the coal, in mixed lump sizes, is charged continuously into the top of the vertical, oval-shaped retorts, the rate of charging and movement through the retort depending on the rate of automatic discharge at the bottom, which is determined by the time required to drive off all the gas. In the operation of such continuous vertical retorts it is therefore evident that the coal is in movement during the swelling (coking) stage and during the subsequent evolution of gas; this tends to produce more porous coke than would be the case where the coal in large bulk is allowed to remain stationary, as in the by-product ovens and in the intermittent vertical retorts. Coke made in the Glover-West or similar continuous vertical retorts is thereby apt to be more porous and friable than by-product coke but is generally of closer structure than the D-shaped horizontal retort coke.

PLATE I

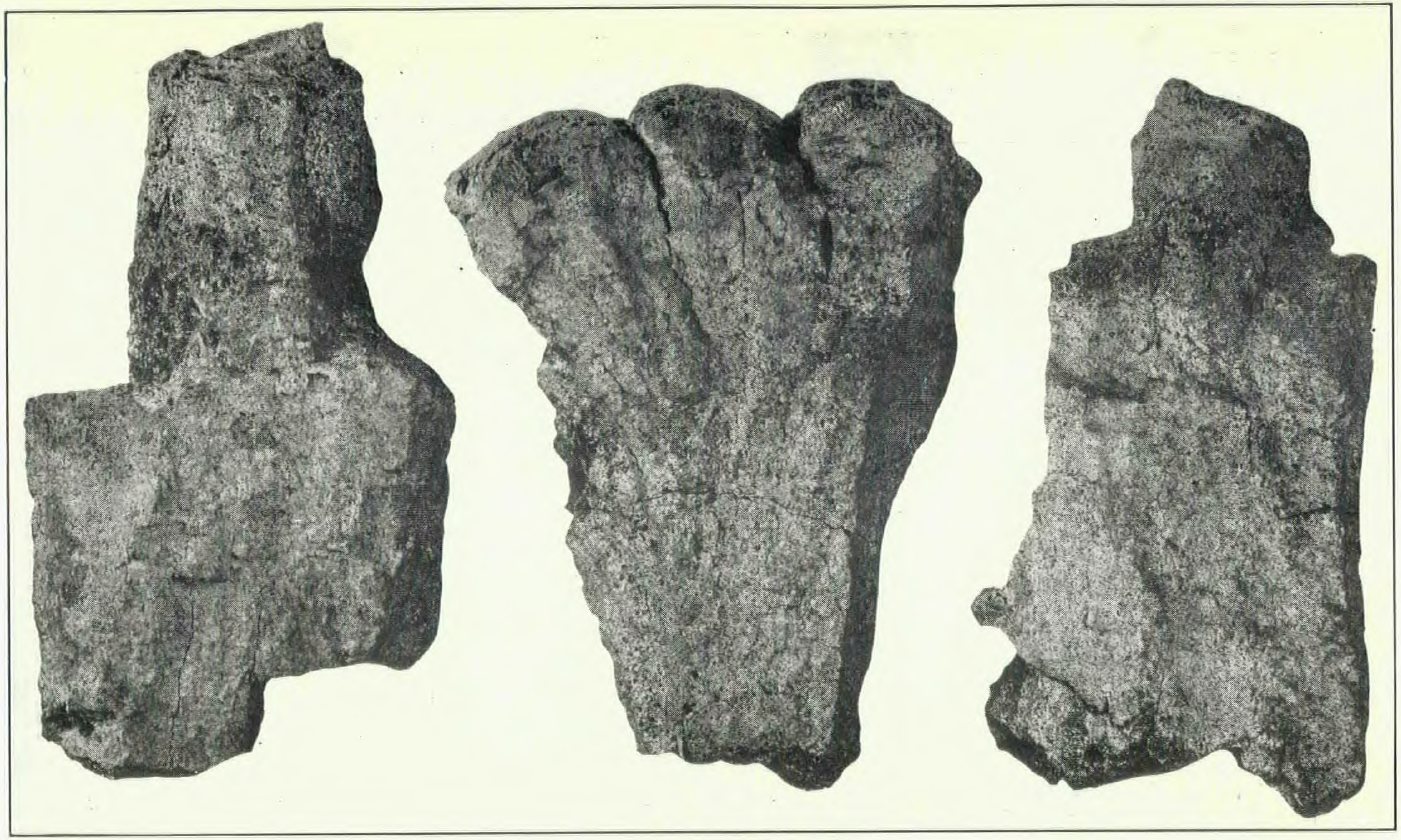

Fig. 1 (Lab. No. 3592)

Fig. 2 (Lab. No. 2632)

Fig. 3 (Lab. No. 3590)

Three typical by-product cokes showing the characteristic close structure of cokes made in intermittent (by-product) ovens. These cokes are greyish in colour, and when struck together have a metallic ring.

Plate II

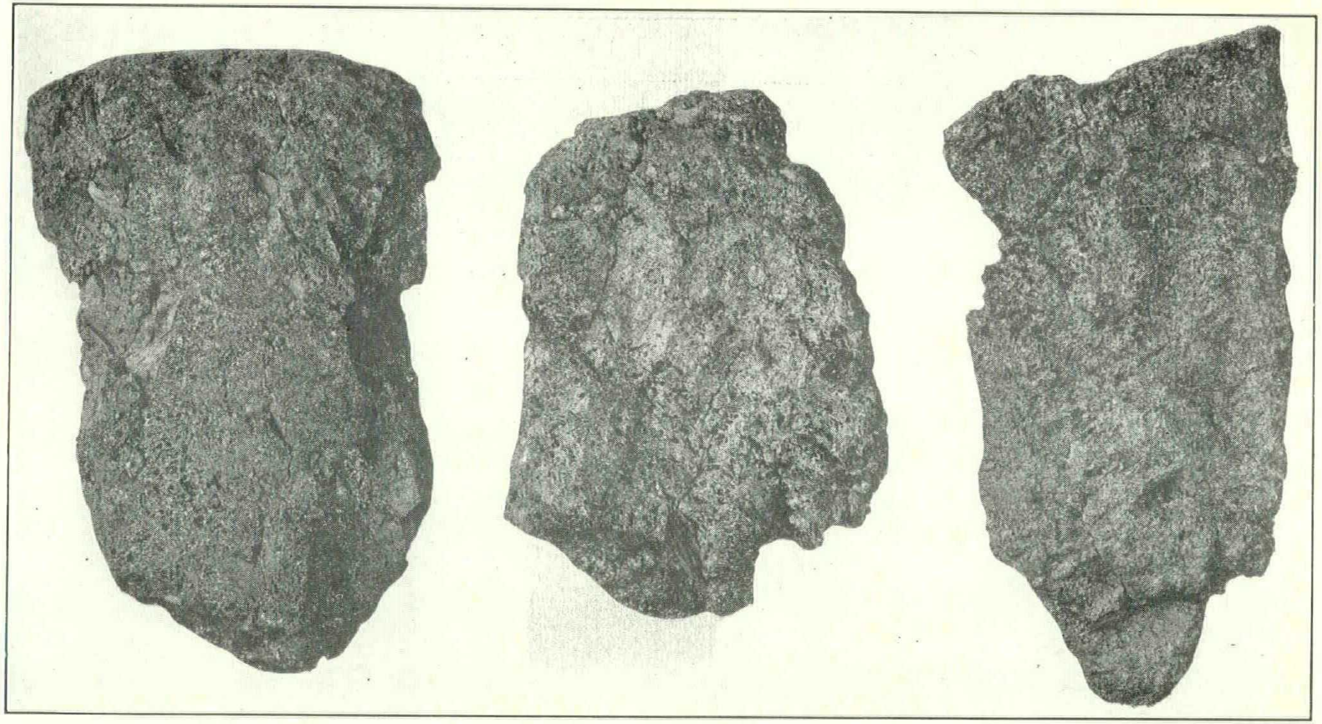

Fig. 1 (Lab. No. 3073) Fig. 2 (Lab. No. 3074) Fig. 3 (Lab. No. 3065)

Three typical gas cokes showing a comparatively open and porous structure. No. 3073 is a product of the D-shaped retorts, Nos. 3074 and 3065 being made in continuous vertical retorts.

In the by-product oven of the Koppers and Semet-Solvay design charges of 9 to 13 tons or more of coal are coked in a single oven which with an 11 to 12-hour coking period means a throughput of 20 to 25 tons per 24-hour day. In comparison the daily capacity of a bench of 9 D-shaped retorts is 10 to 22 tons or so depending on the size of the retorts and the time allowed between charging and discharging. The daily throughput of a setting of 4 of the smaller Glover-West retorts is 10 to 12 tons, and that of the larger continuous vertical retorts is practically double the capacity of the smaller size just cited. Hence the daily throughput of a single by-product oven is equal or more than that of a bench of 9 large size, D-shaped horizontal retorts, and approximately equal to that of a setting of 4 of the larger size, continuous vertical retorts.

For by-product oven coking, the coal charged is ground to pass a quarter-inch screen, and in certain cases is blended with a second coal to produce a coke of desired structure. During the fusing and subsequent evolution of gas stages, the coal is allowed to remain stationary under a definite pressure of the weight of the charge above and against the side walls of the retort. On opening the doors of the by-product oven for discharging, it is noticed that the coke has undergone a pronounced contracting reaction during the final stages and the coke after quenching is noticed to be less porous and denser than that coked rapidly in shallow layers or kept in motion during the coking stage as in the gas retorts. It is for this reason that by-product coke is more desirable as a domestic fuel. Formerly, coke made in the by-product oven was made almost exclusively for metallurgical purposes and was known as metallurgical or foundry coke. Recently, however, the so-called metallurgical coke has been used extensively for household purposes. The output of the oven is passed over a three-inch screen to meet the size qualifications for foundry coke, and the smaller sizes are graded into the ordinary egg, stove, nut, and pea sizes and sold as "domestic" coke. A metallurgical coke is graded mainly according to its hardness or toughness and not especially in respect to its low ash content and the fusible qualities of the ash. For household uses, the lower the ash content and the higher the fusibility temperature of the ash, the better. Hence when the demand is for domestic coke, the whole output of an oven or group of ovens or plant for that matter may be crushed and graded into the domestic sizes to produce from less expensive coals or blends a coke product inferior as metallurgical coke but of good quality for household use.

DESCRIPTION OF COKE SAMPLES

A large number of coke samples have been examined in these laboratories during the last few years. Of these only thirty samples are reported here, but as they are typical cokes from widely separated points, they should be representative of the cokes sold in different parts of the country. Most of the samples were sent in (at our request) from distributing firms, several of which were the manufacturers. The size of the samples forwarded varied from one hundred pounds to five hundred pounds or more. Inasmuch as they were grab samples, they do not necessarily represent the average coke sold over any considerable period of time, but they may be considered as roughly representative of the coke sold at the time the samples were sent in. Care, however, has been taken to ensure that the analyses reported below are near the average for all the samples of any particular coke on record at the Fuel Testing Laboratories. Of the total of thirty typical cokes given, seven were gas cokes, twenty were by-product cokes of different domestic sizes, and three were foundry coke. The laboratory number, name, kind and size of samples and general description of the same are as follows:—

2385—"Besco" by-product coke made from washed coal, as used for the manufacture of metallurgical coke in the Koppers ovens of the British Empire Steel Co. plant at Sydney. Sample received August, 1923.

3091—"Besco" by-product coke from the British Empire Steel Co. at Sydney, N.S. This sample was taken from a shipment received May, 1925, by the Fuel Testing Station for efficiency tests in domestic hot-water furnaces. The lot was apparently the company's regular coke similar in size to "nut" anthracite coal.

3374—"Besco" by-product coke from Sydney, N.S. This sample was from a shipment received September, 1925, described as their medium size 2-inch domestic coke, and consisted of a mixture of stove and nut sizes.

3073—Montreal gas coke, received May, 1925, from Montreal Light, Heat, and Power Co., Montreal, Que. Sample consisted of two bags of mixed sizes, produced in the D-shaped, through type, horizontal retorts in the Hochelaga plant.

3074—Montreal gas coke from the same company as above, but from the Glover-West vertical retorts in their LaSalle plant. This sample was received in May, 1925, and consisted of two bags of mixed sizes of coke.

2789—Ottawa gas coke from the Ottawa Gas (and Electric) Co., Ottawa, Ont. This sample was taken from a lot received August, 1924, at the Fuel Testing Station for tests in domestic hot-water furnaces, and was known as their "crushed" coke with about equal amounts of "stove" and "nut" sizes with a small proportion of "pea" size and smaller.

3065—Ottawa gas coke from the same company as above and made in their Glover-West vertical retorts. Samples received April, 1925.

2590—Dunbar by-product coke from the plant of the Semet-Solvay Co. at Dunbar, Pa. This sample was taken from a 2-ton lot received at the Fuel Testing Station, November, 1925, being part of two carloads imported and distributed in Ottawa for trial as a household fuel. It was described as "egg" coke, and in size corresponded to a mixture of what is known as "egg-" and "stove-" coal sizes.

2591—Penn-Canadian by-product coke received November, 1923, from a local dealer in Ottawa, being a grab sample of nut-size coke from the surface of a large pile in the yard.

3039—Solvay by-product coke received February, 1925, from a local dealer in Ottawa, being a grab sample of stove-size coke taken in similar way to the sample immediately above. The coke was described as "made in the Semet-Solvay ovens of the Hamilton By-product Coke Ovens Limited, at Hamilton."

2624—Toronto gas coke from the Consumers Gas Co., Toronto, Ont., received February, 1924, and described as "coke from their old plant". Sample consisted of a single bag of mixed sizes.

2625—Toronto gas coke received at the same time and from the same company as above, consisting of a bag of mixed sizes from their "New" plant.

3032—Solvay by-product coke, received January, 1925, from the Standard Fuel Company, Limited, Toronto, Ont. Sample consisted of a bag (100 pounds or more) marked "Buffalo egg coke," presumably having been made in Semet-Solvay by-product ovens in Buffalo, N.Y.

3033—Solvay by-product coke received from the same company and at the same time as above, but marked "Buffalo stove coke."

3034—Solvay by-product coke received January, 1925, from the Standard Fuel Company, Toronto. This sample was marked "Detroit nut coke" and was presumably made in Semet-Solvay by-product ovens in Detroit.

3035—Solvay by-product coke received from the same company and at the same time as above, but marked "Detroit pea coke."

2632—Hamilton by-product coke, received February, 1924, from Hamilton By-product Coke Ovens, Limited, Hamilton, consisting of a few bags of their standard domestic coke made at that time.

2945—Hamilton by-product coke from a 2-ton lot received December, 1924, at the Fuel Testing Station, from Hamilton. This coke was made in the Semet-Solvay ovens used for the manufacture of city gas. The sample was described as "egg coke," screen analysis showing it to correspond to a mixture of what is generally known as egg- and stove-coal sizes.

3066—Hamilton by-product coke. This sample, as well as the three samples listed immediately below, was received April, 1925, from the Hamilton By-product Coke Ovens, Limited, at Hamilton, Ont. This sample consisted of a bag of 100 pounds or so of their egg coke.

3067—Hamilton stove coke—one bag.

3068—Hamilton nut coke—one bag.

3069—Hamilton pea coke—one bag.

3588—Winnipeg by-product coke. This sample and the three listed immediately below were received November, 1925, from the Winnipeg Electric Company, Winnipeg, having been made in the Koppers by-product ovens used for the manufacture of city gas. The sample was their stove-size coke produced from coal No. 1, the other three samples being as follows:—

3589—Winnipeg by-product nut coke—coal No. 1.

3590—Winnipeg by-product stove coke—coal No. 2.

3591—Winnipeg by-product nut coke—coal No. 2.

3036—Vancouver gas coke, from the Vancouver Gas Co., Vancouver, consisting of a bag of their mixed-sized coke.

2287—By-product (blast furnace) coke received June, 1923, from the Steel Co. of Canada, Hamilton, Ont., and known as their "blast furnace grade," consisting of sizes not less than 1 inch and not over 3½ inches.

3497—Hamilton (by-product) foundry coke, received December, 1925, from Hamilton By-product Coke Ovens, Limited, Hamilton, Ont., and described as "foundry coke," over 3 inches in size.

3592—Besco (by-product) foundry coke received September, 1925, from the British Empire Steel Corporation Limited, at Sydney. Sample consisted of 500 pounds or so of their 3-inch foundry coke.

CHEMICAL ANALYSES

In Table I are tabulated the results of the chemical analyses of all the coke samples described above. The proximate analyses in respect to moisture, ash, volatile matter, and fixed carbon by difference are given for all of the thirty samples listed; the calorific values on the as-received, dry, and dry, ash-free bases being reported for all but one sample. The proximate analyses were made according to usual practice for solid fuels and the calorific value determinations carried out in an Emerson, oxygen bomb calorimeter. Table I also includes the ash fusibility temperature of twenty-one representative cokes and apparent density results of most of the coke samples listed; these determinations were made according to the standard methods prescribed by the American Society for Testing Materials.[1]

In Table II will be found the ultimate analyses of sixteen typical cokes arranged in groups according to the kind of retorts or ovens in which they were made. The calculated calorific values are ranged for comparison alongside the determined value on the dry basis and on the dry, ash-free basis.

DISCUSSION OF RESULTS

A comparison of the ash content of the different samples is of interest as it is a direct indication of the heating value of the coke and, other factors such as structure and apparent density being equal, is a good criterion of the comparative quality of the coke marketed. The by-product cokes varied roughly from 6½ to 13 per cent ash, the 18 lower ash samples averaging approximately 7·6 per cent, and the 5 samples having the higher ash content averaging 11·6 per cent. In comparison with the average ash content of Pennsylvania anthracite on the market which is not lower than 12½ per cent, the 5 cokes with ash content ranging from 10 to 13 per cent may be considered fair only, while the 18 ranging from 9 down to 6½ per cent, may be graded good to very good. The ash content of the gas cokes with one exception ranged from 8·8 to 12·9 per cent, the average of 6 samples being 10·6 per cent.

Relation of Ash Content to Calorific Value. The calorific values of the by-product cokes varied from slightly under 12,000 B.T.U. to nearly 13,500 B.T.U. per pound on the as-received basis; the average of 18 lower ash cokes was 13,070, and the average of 4 other by-product cokes having a higher ash content was 12,300 (to the nearest hundred B.T.U.). This corresponds roughly to the average of 12,500 B.T.U. per pound for 6 samples of gas coke with approximately the same ash content. Therefore there is practically no difference in respect to calorific value between the so-called gas cokes and the by-product cokes of equal ash content. A study of the B.T.U. per pound figures in the dry, ash-free basis columns in both Tables I and II reveals the average of twenty-nine values given to be 14,200.

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[1] See A.S.T.M. D. 22-24 and D. 167-24, respectively.

TABLE I

Analyses of Coke Samples

Lab. No.	Name of coke	Size	Proximate analysis (As-received basis)				Calorific value B.T.U. per pound			Sulphur %	Fusibility of ash ° F.	Apparent density water =1·0	Canadian wholesale distributing centre
			Moisture %	Ash %	Volatile matter %	Fixed carbon %	As-received basis	Dry basis	Dry, ash-free basis				
2385	Besco by-product	Small	0·2	6·4	0·9	92·5	13,120	13,140	14,050	......	2,110	(0·895)	Sydney, N.S.
3091	“	“	0·6	6·9	1·7	90·8	13,100	13,180	14,160	1·7	2,050	....	Montreal, Que.
3374	“	Medium	0·8	7·1	1·8	90·3	12,960	13,060	14,070	1·6	2,010	0·827	“
3073	Montreal gas coke	Mixed	2·4	10·3	5·8	81·5	12,590	12,910	14,420	1·0	2,370	0·790	Montreal, Que.
3074	“	“	1·0	10·0	2·4	86·6	12,560	12,680	14,100	0·7	....	0·790	“
2789	Ottawa gas coke	“Crushed”.	0·6	12·9	1·9	84·6	12,060	12,140	13,950	1·0	(2,650)	0·840	Ottawa, Ont.*
3065	“	“	0·2	12·1	1·9	85·8	12,230	12,260	13,950	1·0	....	0·860	“
(2590)	Dunbar by-product	Egg	0·5	13·1	1·3	85·1	11,970	12,040	13,860	1·9	2,270	....	“
2591	Penn-Canadian by-product	Nut	0·8	11·5	1·6	86·0	12,190	12,290	13,900	1·0	2,260	....	“
3039	Solvay (Hamilton) “	Stove	1·0	8·0	2·0	89·0	12,950	13,080	14,240	0·6	2,535	....	“
2624	Toronto gas coke	Mixed	0·6	8·8	2·7	87·9	12,810	12,900	14,140	0·9	(2,680)	0·800	Toronto, Ont.
2625	“	“	0·7	9·4	3·6	86·3	12,740	12,820	14,170	1·3	....	0·820	“
3032	Solvay (Buffalo) by-prod.	Egg	0·3	10·3	1·3	88·1	12,580	12,620	14,080	0·7	(2,700)	0·930	“
3033	“ “	Stove	0·3	8·7	1·7	89·3	12,900	12,930	14,180	0·6	2,630	0·965	“
3034	Solvay (Detroit) by-prod.	Nut	0·6	8·2	2·2	89·0	12,960	13,040	14,210	0·6	(2,700)	0·965	“
3035	“ “	Pea	0·8	12·1	1·8	85·3	12,380	12,480	14,220	0·7	2,570	0·980	“
2632	Hamilton by-product coke	Egg	(0·5)	8·6	1·6	89·3	12,520	12,590	13,770	0·9	2,425	....	Hamilton, Ont.
2945	“ “	“	0·5	8·5	1·7	89·3	12,940	13,010	14,220	0·7	....	....	“
3066	“ “	“	0·5	7·2	1·9	90·3	13,330	13,400	14,450	0·6	2,445	0·870	“
3067	“ “	Stove	1·5	7·1	2·1	89·3	13,090	13,290	14,320	0·5	2,450	0·860	“
3068	“ “	Nut	0·6	7·6	2·2	89·6	12,990	13,070	14,160	0·6	....	0·900	“
3069	“ “	Pea	0·4	7·4	3·1	89·1	13,360	13,420	14,490	0·5	....	0·865	“
3588	Winnipeg by-product coke	Stove	0·2	7·9	1·0	90·9	13,140	13,170	14,200	0·6	(2,700)	0·980	Winnipeg, Man.
3589	“ “	Nut	0·1	8·7	1·0	90·2	12,960	12,970	14,210	0·7	....	0·990	“
3590	“ “	Stove	0·0	7·3	0·8	91·9	13,090	13,090	14,120	0·5	(2,700)	1·025	“
3591	“ “	Nut	0·1	7·6	0·9	91·4	13,030	13,040	14,120	0·6	....	1·020	“
3036	Vancouver gas coke	Mixed	4·4	21·0	6·6	68·0	10,830	11,330	14,530	0·6	2,370	0·885	Vancouver, B.C.
3497	Hamilton foundry coke	Over 3″	0·6	7·3	3·3	88·7	13,450	13,540	14,600	0·6	....	0·845	Hamilton, Ont.
2287	Steel Co. blast furnace coke	Mixed	0·3	11·2	1·3	87·1	....	....	....	......	2,410	....	“
3592	Besco foundry coke	Over 3″	0·8	6·7	2·0	90·5	13,240	13,350	14,320	1·4	1,985	0·855	Sydney, N.S.

*Retail distributing centre.

NOTE.—Brackets on fusibility of ash figures indicate highest temperature observed in the determination at which temperature the ash had not fused; fusibility point, therefore, is higher than indicated.

TABLE II

Ultimate Analyses and Calorific Values of Typical Cokes

Lab. No.	Name of coke	Ultimate analysis (dry basis)						Calorific value B.T.U. per pound				Remarks
		Carbon %	Hydrogen %	Ash* %	Sulphur %	Nitrogen %	Oxygen† %	Dry basis		Dry, ash-free basis	Volatile matter (dry) %	Kind of oven or retort in which coke was made
								Calculated	Determined			
2624	Toronto gas coke..............	86·83	0·82	8·83	0·89	1·31	1·32	12,902	12,895	14,140	2·7	Horizontal D-retort.
3073	Montreal gas coke..............	83·50	1·53	10·54	1·09	1·50	1·87	12,867	12,905	14,420	5·9	" "
3074	"	87·30	0·67	10·12	0·68	1·04	0·13	12,858	13,676	(14,300)	2·4	Glover-West retorts.
2789	Ottawa gas coke...............	83·73	0·53	13·04	1·03	1·11	0·56	12,277	12,136	(14,120)	1·9	" "
3065	"	84·32	0·67	12·16	1·04	1·13	0·68	12,442	12,260	(14,160)	1·9	" "
2632	Hamilton by-product coke.....	87·21	0·59	8·70	0·94	0·81	1·75	12,801	12,590	(14,010)	1·7	Semet-Solvay ovens.
2945	" "	87·33	0·71	8·54	0·72	0·81	1·89	12,888	13,005	14,220	1·7	" "
3067	" "	89·81	0·77	7·20	0·54	0·97	0·71	13,270	13,284	14,320	2·2	" "
3069	" "	89·60	0·99	7·43	0·54	0·70	0·74	13,377	13,417	14,490	3·1	" "
3032	Buffalo by-product coke........	86·38	0·52	10·30	0·67	0·81	1·32	12,639	12,622	14,080	1·3	" "
3034	Detroit "	89·18	0·67	8·28	0·57	0·97	0·33	13,119	13,036	14,210	2·2	" "
3588	Winnipeg by-product coke......	89·96	0·30	7·95	0·60	1·07	0·12	13,002	13,173	14,200	1·0	Koppers ovens.
3590	" "	90·27	0·35	7·25	0·54	1·10	0·17	13,075	13,090	14,120	0·8	" "
2385	Besco by-product coke.........	89·84	0·38	6·43	1·80	0·89	0·75	13,080	13,142	14,050	0·9	" "
3091	" "	89·78	0·56	6·92	1·70	0·88	0·16	13,183	13,180	14,160	1·7	" "
3374	" "	89·20	0·63	7·19	1·55	(0·9)	0·53	13,137	13,061	(14,160)	1·8	" "

*Ash figure is that obtained in proximate analyses. †Oxygen by difference.

NOTE.—The formula used for the calculated calorific value on the dry basis was B.T.U. per pound=14,220 × carbon + 62,100 × hydrogen + 4,000 sulphur; where the determined calorific value was abnormally lower than the calculated, the dry, ash-free values shown in brackets were derived from the calculated figures, otherwise they were from the determined values.

This means that, knowing the moisture and ash content of a given coke, the calorific value may be calculated by multiplying the difference between 100 and the sum of the moisture and ash contents by 14,200, which will give the B.T.U. per pound for the coke on the as-received basis, accurate to within plus or minus 200 B.T.U. This, however, will apply only to cokes made from coking bituminous coals by high-temperature carbonization in which the volatile matter has been reduced to 3 per cent or less.

The Ash Fusibility Temperature of the different cokes examined varied from 2000° F. to over 2700° F. That is, all three classes are represented, viz:—

Class 1. Refractory (high fusible ash) above 2600° F.
Class 2. Ash of medium fusibility—2200° to 2600° F.
Class 3. Low or easily fusible ash—below 2200° F.

As pointed out in a previous publication,[1] those cokes with an ash fusibility above 2600° F. come in the same class as Pennsylvania anthracite and can be burned with practically no clinkering trouble. It will be noticed that two typical gas cokes and one by-product coke were in this class. The bulk of the by-product cokes, however, were in Class 2, i.e. with ash fusibilities ranging from 2200° to 2600° F.; in only one typical coke was the ash fusibility temperature below this range, i.e. in Class 3. As observed in actual burning tests and as reported in the reference just given, the freedom from troublesome clinkers does not depend solely on the fusibility of the ash but on the relation of the fusibility temperature and the ash content. With cokes having ash contents ranging from 9 to 13 per cent, indications are that in a properly controlled fire in an ordinary domestic hot-water furnace no appreciable clinkering will take place where the ash fusibilities are above the middle line of Class 2, viz., 2400° F. However, when the ash fusibility temperature falls below this line serious clinkering trouble may be experienced unless the ash content is at the same time proportionately reduced. With ash contents in the neighbourhood of 7 per cent it was found that cokes with ash fusibility as low as 2000° F. could be burned with no appreciable clinkering trouble. In this connexion it might be observed that the by-product coke samples with ash fusibilities below 2200° F., listed in Table I, have an average ash content of 6·8 per cent, and a high calorific value, averaging over 13,100 B.T.U. per pound, which make them desirable household fuels. With these cokes, as with all cokes in Classes 1 and 2, care must be taken to see that excessive rates of burning are avoided.

COMPARISON OF THE ANALYSIS OF COKE AND OF PENNSYLVANIA AND WELSH ANTHRACITES

As coke is used extensively as a substitute for anthracite as household fuel, a comparison of the different cokes with imported anthracite is of interest here. Although it is realized that the chemical analyses are of value only in conjunction with the general characteristics, such as size, structure, handling and burning qualities, etc., a comparison of the different gas and by-product cokes, mainly in respect to chemical analysis, is presented as follows:—

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[1] Mines Branch, Dept. of Mines, Canada, Investigations of Fuels and Fuel Testing, 1924, p. 4.

Kind of coke	Proximate analysis (as-received basis)				Calorific value B.T.U. per pound	
	Moisture %	Ash %	Volatile matter %	Fixed carbon %	As-received basis (determined)	Dry, ash-free (calculated)
By-product coke, average of 22 samples	0·5	8·4	1·7	89·4	12,950	14,210
Gas coke, average of 6 samples	0·9	10·5	3·0	85·6	12,520	14,130
Pennsylvania anthracite, average of 18 representative samples	3·2	12·7	5·9	78·2	12,520	14,900
By-product coke average of 4 (higher ash) samples	0·6	11·7	1·5	86·1	12,390	14,130
By-product coke, average of 18 (lower ash) samples	0·5	7·6	1·8	90·1	13,070	14,220
Welsh anthracite, average of 11 representative samples	2·3	4·8	8·0	84·9	14,210	15,300

From the above comparative results it is evident that the average heating value of the gas cokes and of the higher ash by-product cokes is approximately equal to that of average Pennsylvania anthracite, which means that with equal burning efficiency these cokes will, under practical conditions, give as much heat as Pennsylvania anthracite. The average heating value on the as-received basis of low-ash by-product cokes is over 13,000 as compared with an average of, roughly, 12,500 for Pennsylvania anthracite, which indicates that the former cokes contain 5 to 6 per cent more heat than the latter standard anthracite. When comparing these low-ash cokes with Welsh anthracite, however, it is to be noted that the Welsh anthracite contains from 8 to 9 per cent more heat than the cokes.

A comparison of the ash contents of the cokes examined with those of the anthracite is of interest. It is to be noted that a Pennsylvania anthracite should not contain more than 8½ per cent ash along with 3½ per cent moisture to have as high a heating value as a low-volatile matter content coke with 7½ per cent ash and ½ per cent moisture. A Pennsylvania anthracite, however, may contain as high as 13 per cent ash with 3 per cent moisture to equal a coke with 11 per cent ash and 1 per cent moisture. This is due to the higher volatile matter content of the anthracite, the calorific value per unit weight of which is greater than that of the (fixed) carbon content; the dry, ash-free B.T.U. per pound value for the Pennsylvania anthracite being 14,900 in comparison with 14,200 for the cokes. That is, a coke must have 2 per cent less ash along with 2 per cent less moisture to equal, in heating value, Pennsylvania anthracite averaging 12 to 13 per cent ash. In this connexion it is significant that the average ash content of 28 domestic coke samples listed was more than 3½ per cent lower in ash than average Pennsylvania anthracite.

COMPARISON OF APPARENT DENSITIES OF TYPICAL COKES

In appearance (Plates I and II) there is a distinct difference between the gas cokes and the by-product cokes, despite the fact that the comparative chemical analyses as given in Tables I and II fail to reveal any outstanding difference. The quality and to a certain extent the physical characteristics depend on the kind and quality of coal used in either case. In general, by-product coke is denser and more uniform than gas coke. In a given lot of gas coke, however, may be found pieces that look like by-product coke, hence in appearance and density, certain gas cokes may overlap certain by-product cokes. Outside of the general appearance, the apparent densities seem to be the best means of distinction between the different types of coke. A comparison of the apparent densities is as follows:—

—	Apparent density	
	Range	Average
Gas coke (3 samples made in D-shaped horizontal retorts).............	0·79 to 0·82	0·80
Gas coke (3 samples made in continuous vertical retorts)...............	0·79 to 0·86	0·83
By-product coke (3 samples of Besco coke).............................	0·83 to 0·90	0·86
By-product coke (5 Hamilton cokes)..................................	0·85 to 0·90	0·87
By-product coke (average of all samples tested)........................	0·84 to 1·02	0·92
Gas coke (average of all samples tested)..............................	0·79 to 0·86	0·82

From the above it will be noticed that whereas the average density of the gas cokes was 0·82 in comparison with 0·92 for the by-product cokes, the highest figure for certain gas cokes was higher than the lowest figure for certain by-product cokes. For example (*see* Table I) the apparent densities of samples Nos. 2789 and 3065, viz., Ottawa gas coke made in continuous vertical retorts from Westmoreland coal, were 0·84 and 0·86, as compared with 0·830 and 0·895 for samples Nos. 3374 and 2384, viz., Besco by-product coke made in Koppers ovens from Nova Scotia washed coal. The apparent densities of the Hamilton and Winnipeg cokes of approximately the same ash content as the Besco cokes ranged from 0·845 to 0·900 and 0·980 to 1·025 respectively. It is therefore evident that although the apparent density determination does serve to differentiate between gas cokes and by-product cokes in general, it is not a means of classifying cokes according to the kind of oven in which they were made, due to the varying grades and quality of coal used. However, inasmuch as the average apparent densities of the different cokes made in the different retorts and ovens do agree with what would be expected, indications are that for coke from the same coal, the apparent density would serve to classify the cokes according to the kind of retort or oven in which they were made.

SCREEN ANALYSES AND COMMENTS ON THE DIFFERENT SIZES

Although not carried out on more than half the samples received, screen analyses of typical cokes were made in order to examine the uniformity of the product marketed by the different firms under different size designations such as egg, stove, nut, pea, etc. For this purpose square mesh screens of 3-inch, 2-inch, 1½-inch, ¾-inch, and ½-inch mesh, respectively, were tentatively adopted and used. The different coke sizes resulting from the screen analyses were arbitrarily designated as follows:—

Through 3 -inch screen on 2 -inch (egg size).
" 2 - " " 1½ - " (stove size).
" 1½ - " " ¾ - " (nut size).
" ¾ - " " ½ - " (pea size).

Screen Analyses of Fifteen Samples

Lab. No.	Name and kind of coke	On 3-inch (foundry size) %	Through 3-inch on 2-inch (egg size) %	Through 2-inch on 1½-inch (stove size) %	Through 1½-inch on ¾-inch (nut size) %	Through ¾-inch on ½-inch (pea size) %	Through ½-inch (smalls and fines) %
3592	Besco foundry coke.......	40	35	12·0	8·0	2·5	2·5
3091	Besco—Small size by-product................	0	0	8	50·0	31·0	11·0
3374	Besco 2-inch by-product coke (medium).........	0	1	62·0	35·0	1·0	1·0
3497	Hamilton foundry coke...	80	10	8·0	....	0·5	1·5
2945	" egg coke........	0	29	58·0	11·0	1·0	1·0
3047	" stove coke......	0	11	67·0	21·0	0·0	1·0
3068	" nut coke........	0	0	14·0	84·0	1·0	1·0
3069	" pea coke........	0	0	0·0	4·0	62·0	34·0
3032	Solvay (Buffalo) egg coke	0	60	33·0	5·0	0·5	1·5
3034	" (Detroit) nut coke.	0	0	11·0	83·0	4·5	1·5
3035	" " pea coke.	0	0	0·0	14·0	75·0	11·0
3590	Winnipeg stove coke.......	0	20	63·0	15·0	1·0	1·0
3591	" nut coke.........	0	0	0·0	70·5	27·0	2·5
2789	Ottawa gas coke—crushed	0	0	39·0	45·0	11·0	5·0
3893	" —large...	28·0	47	16·5	4·5	1·0	3·0

As will be noticed in the above table, there is a considerable variation in the screen test results of the different cokes with the same size designation.

COMPARISON OF STANDARD SIZES FOR ANTHRACITE AND COKE

As coke when used for household purposes is a substitute for anthracite, a comparison of the different coke sizes with those for anthracite is of interest and may be reviewed here. For anthracite a comparison of the sizes used in 1916 by the U.S. Bureau of Mines[1] with that according to the 1925 revision by the Anthracite Operators' Conference,[2] is as follows, to which is added the screen sizes adopted in 1920 by the Alberta Research Council[3] for their so-called domestic grades of coal.

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[1] U.S. Bureau of Mines, Bulletin 119, page 6.
[2] Coal Catalogue, Keystone Publishing Co., 1926, page 532.
[3] First Annual Report of the Advisory Council of Scientific and Industrial Research, Alberta, page 12.

Kind of screens	U.S. Bureau of Mines				Anthracite Operators		Alberta Research Council	
	Square mesh, inches		Round mesh, inches		Round mesh, inches		Perforated (round mesh), inches	
	Through	Over	Through	Over	Through	Over	Through	Over
Egg size............	$2\frac{3}{4}$	2	$3\frac{1}{4}$	$2\frac{1}{2}$	$3\frac{7}{16}$	$2\frac{1}{2}$	3	....
Stove size..........	2	$1\frac{3}{8}$	$2\frac{1}{2}$	$1\frac{1}{2}$	$2\frac{1}{2}$	$1\frac{9}{16}$	....	$1\frac{1}{2}$
Nut (chestnut) size	$1\frac{3}{8}$	$\frac{3}{4}$	$1\frac{1}{2}$	$\frac{7}{8}$	$1\frac{9}{16}$	$\frac{11}{16}$	$1\frac{1}{2}$	$\frac{3}{4}$
Pea size............	$\frac{3}{4}$	$\frac{1}{2}$	....	....	$\frac{11}{16}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{4}$

For coke, the "approximate sizes . . . . . . known to the trade" and those recommended by Landt [1] for Canada, using square mesh screens, are:—

	In general use by coke manufacturers	Recommended for Canada by Landt
Egg coke........	Through 3 or $3\frac{1}{2}$ inches over $1\frac{5}{8}$ inches....	Through $3\frac{1}{2}$ inches over $1\frac{5}{8}$ inches.
Stove "	Rather indefinite size between egg and nut.	
Nut "	Through $1\frac{5}{8}$ inches over $\frac{7}{8}$ inch...........	Through $1\frac{5}{8}$ or $1\frac{1}{2}$ inches over 1 inch.
Pea "	Through $\frac{7}{8}$ inch over $\frac{1}{2}$ inch...............	Through 1 inch over $\frac{1}{2}$ inch.

IMPORTANCE OF THE STOVE SIZE FOR COKE

As will be noticed in the coke sizes table just given, no recommendation is made for the "stove" size, it being described as a rather indefinite size between egg and nut. Taking into consideration the importance of this size in respect to anthracite, the omission of specifications for stove size coke is to be criticized. Certain cokes designated as egg size, sold recently in Canada, were found to be too large whereas others under the same name were much more suitable to the household furnaces. In general, however, for the furnaces as installed in houses of not larger than say eight rooms, the cokes designated as "stove" size have, according to information at hand in these laboratories, been found to be more satisfactory than the egg size, as is the case with these sizes of anthracite.

Although screen analyses were carried out on only a few of the egg and stove cokes as sent in, the results are worthy of comment. Samples Nos. 3047 and 3590 designated as stove coke showed 67 and 63 per cent respectively between $1\frac{1}{2}$-inch and 2-inch in size, as compared to 62 per cent of this size in Besco medium coke. The proportions of large and small sizes in these samples varied considerably, and in respect to general sizing as well as to name this stove size as marketed was not uniform. Sample No. 2945, viz., Hamilton egg coke, showed only 29 per cent above 2 inches with 58 per cent in the $1\frac{1}{2}$- to 2-inch size, showing that this sample designated as egg coke was more like the two samples of stove coke just mentioned than sample No. 3032, viz., Buffalo egg coke. The latter coke contained 60 per cent larger than 2 inches, and the large size of Ottawa gas coke,

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[1] "Coke as a Household Fuel in Central Canada," page 26 (Dominion Fuel Board, Ottawa). Mines Branch, Dept. of Mines, Canada, Rept. 630.

75 per cent. Here again the non-uniformity in respect to size and name is noticed, as is also evident in the cokes marketed as "small", nut and pea sizes. As Hamilton stove coke, Besco medium, Ottawa crushed coke, and the other cokes designated as stove size all contain a larger proportion of the 1½ to 2-inch size than they do the larger and smaller sizes, and since this size will give the best satisfaction in medium-size furnaces, inasmuch as it resembles stove anthracite in respect to size, it is, in the opinion of the writers, the most important size and should be more definitely specified in the coke manufacturing industry.

Just where to draw the line between the stove and egg sizes is debatable. That the stove size for coke should conform to the anthracite stove size is reasonable in that this is the size of anthracite in most demand, but taking into consideration the objection of the manufacturers to making two sizes, viz., egg and stove, where one size may do, this conformity need be approximate only. The dividing line between the egg and stove anthracite sizes according to that used in 1916 by the U.S. Bureau of Mines was 2 inches square mesh, which was apparently equal to 2¼ inches round mesh. A comparison of the 1916 and the 1925 revised specifications for the stove size anthracite shows that the 1925 upper and lower limits were widened out, the 1925 upper limit being ¼ inch larger and the lower limit being $\frac{1}{16}$ inch smaller. It will be noticed that the limits of the egg size for anthracite are narrow, so that for this standard household fuel we have fairly wide stove size limits with narrow egg size limits. This seems to be a suggestion worthy of following with coke, namely, provide a special more or less wide limit, stove size, instead of the wide limit egg size as now sold. The lower limits of the combined egg and stove size, viz., 1⅝ inches (or 1½) seem all right, but for the upper limit, either 2¼ or 2½ inches is to be recommended for a special stove size instead of 3 to 3½ inches as now in vogue for the egg sizes.

STANDARD LABORATORY SCREEN SIZES

The 2¼-inch would be for a square mesh screen at the producing plant, and in view of a certain general reduction in size by handling, the use of 2-inch screen at the testing laboratory, as used in the above comparative screen analyses, as the dividing line between the egg and stove sizes appears to be a suitable standard screen size. The use of a smaller mesh screen in the laboratory than is employed at the mine or manufacturing plant is permissible in view of the 15 per cent undersize allowed by the anthracite operators in the different domestic sizes. The use of a ¾-inch screen as standard in the laboratory as the dividing line between the nut and pea sizes instead of ⅞-inch screen as used at the plant also serves very well to take care of a probable slight reduction in size due to several handlings between producer and consumer. More attention will, however, be paid to this matter before definitely adopting standard screens for comparative screen analyses of cokes in these laboratories.

The use of the terms large, medium and small, to designate the different sizes as mentioned by Landt[1] is noteworthy, but instead of having these terms replace the egg, nut, and pea sizes as suggested, it would seem advisable to have the large size represent a new stove size of definite specifications as suggested above and then either leave the egg size as such or use the term "extra large."

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[1] Op cit.

Nut Coke. Nut coke, as per the above screen analyses table, showed 70, 83, and 84 per cent, respectively, through 1½ inch and on ¾ inch, which indicates that the smaller ¾-inch screen as the division between nut and pea as used here and as by the U.S. Bureau of Mines 1916 usage (for anthracite) serves, for examining the cokes on the market in respect to uniform sizes, better than the larger ⅞ screen known to the trade, as by the use of the latter screen the above percentage figures would be much lower. It will be noticed that the lower limit for nut anthracite, according to the 1925 revision, is 11/16 inch (round mesh) instead of the ⅞ inch as used in 1916; that is, the nut size is smaller than formerly. Ottawa gas coke designated as crushed, according to square screen sizes and names adopted above, contained 45 per cent nut size with 39 per cent of the larger stove size, with 16 per cent of smaller sizes, whereas the Besco "small" size coke showed 50 per cent nut size with only 8 per cent larger, but with 42 per cent smaller than the ¾ inch lower limit. In respect to the amount of unburned coke passing through the grates of medium-size furnaces in general use in central Canada, the opinion (formed as the result of actual trial) in these laboratories is that the latter small size Besco coke contained too large a proportion of the smaller sizes than ordinarily found in nut coal or coke, whereas the coke showing similar screen analysis to that designated as "crushed" was much more satisfactory. The sale of coke therefore containing a large proportion of sizes smaller than nut size, viz., smaller than ¾ inch, is not to be encouraged unless for smaller size furnaces containing more suitable grates or for the larger furnaces fitted with special grates for burning small-size fuel.

Pea Coke. The two samples of coke sold as pea size, viz., Nos. 3035 and 3069, showed 75 and 62 per cent respectively on the ½-inch screen used. The former contained 11 and the latter 34 per cent of the smaller sizes which it may be remarked does not show uniformity in respect to this size of coke, which non-uniformity, however, is in accordance with the variation from the ½-inch square mesh to the ½-inch round mesh in the 1920 and 1925 specifications for anthracite as noted above. The ½-inch square screen is however to be recommended for comparative purposes.

SHATTER TEST FOR FOUNDRY AND SMALLER SIZE COKES

An endeavour was made to utilize the shatter test, as used for foundry size coke, to determine the comparative handling qualities of the smaller size cokes, the results of which may be correlated with the apparent densities, to differentiate between the different kinds of cokes. The shatter test apparatus and method described in A.S.T.M. D. 141-23, is for coke, over 3 inches in size, to be used for metallurgical purposes. In brief, the method consists of dropping 50 pounds of coke four times through a distance of six feet on to an iron base and then passing over a 2-inch (square) screen. The percentage remaining on the screen is reported as the shatter test result for the coke tested. For the larger size domestic grades, that is the stove and egg sizes, the above specifications were altered as follows: The samples taken consisted of approximately 20 pounds of 1- to 2-inch lumps, that is, the coke remaining on a 1-inch square mesh screen after passing through a 2-inch screen. After dropping four times in the standard shatter test apparatus the coke was passed successively over ¾ and ½-inch square screens followed by a small 35-mesh screen. Two foundry cokes (3 inch), viz., samples Nos. 3497 and 3592, listed in Table I, were first tested according to the standard method for large-size metallurgical coke, and then lumps, 1 to 2 inches in size prepared from these samples, were tested according to the modified method just outlined. Several other gas and by-product domestic cokes were then examined with the following results:—

Lab. No.	Name of 3-inch coke tested	Shatter test result i.e. (per cent on 2-inch screen)
3592	Besco foundry coke..	67·5
3492	Hamilton foundry coke..	84·5

Lab. No.	Name and kind of coke (lumps, 1 to 2 inches, used)	Lumps on ¾-inch screen %	Smalls through ¾-inch on 35 mesh %	Fines and dust through 35 mesh %
3497	Hamilton by-product (foundry) coke...............	97·8	1·8	0·4
3067	" " stove coke..................	98·1	1·6	0·3
3590	Winnipeg by-product stove coke.....................	95·4	4·2	0·4
3592	Besco by-product (foundry) coke....................	94·8	4·8	0·4
3374	" " 2-inch coke.......................	97·1	2·6	0·3
2789	Ottawa gas (crushed) coke..........................	95·0	4·5	0·5
3065	" " "	95·0	4·4	0·6
3074	Montreal (vertical retort) coke......................	91·6	7·7	0·7
3073	" (D-shaped retort) coke...................	88·8	10·6	0·6

According to the above, 4 samples of gas coke varied from 88·8 to 95 per cent shatter test on ¾-inch screen with combined smalls, fines, and dust, ranging from 11·2 to 5·0 per cent. The corresponding shatter test for the 5 by-product cokes tested varied from 94·8 to 98·1 per cent on ¾-inch screen with 5·2 to 1·9 per cent smaller sizes. As with the apparent density results it will be noticed that certain gas cokes, viz., the Ottawa gas cokes showed up as well as the Besco by-product cokes and nearly as well as the Winnipeg coke tested. There is, however, a distinct difference in the general appearance of these cokes, as shown in Plates I and II (page 8) which difference is more noticeable when examined in bulk by the eye, the Besco coke having the typical by-product coke structure and the Ottawa gas coke appearing more irregular in shape and more porous. This difference in structure is better shown by the pebble mill tumbling method for comparative friabilities used in these laboratories. Results reported by Nicolls[1] on samples of these two cokes may be repeated here:—

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[1] Mines Branch, Dept. of Mines, Canada—Investigations of Fuels and Fuel Testing, 1924, page 32.

Sample No.	Kind and size of coke used	Lumps on ¾-inch screen %	Smalls through ¾-inch on 35 mesh %	Fines and dust through 35 mesh %
14	Ottawa gas coke, 1½-inch to 2-inch size	72·7	6·4	20·9
	" 1-inch to 1½-inch size	75·1	5·9	19·0
10	Besco by-product coke, 1½-inch to 2-inch size	82·5	3·3	14·2
	" " 1-inch to 1½-inch size	85·0	1·5	13·5
	Average for gas coke	73·9	6·1	20·0
	Average for by-product coke	83·8	2·4	13·8

From the above it is evident that the pebble-mill tumbling test does serve to differentiate between cokes having approximately the same apparent density and showing the same shatter test, but having different structural appearance. This is due, it would appear, to the double effect of the repeated tumbling from top to bottom of the 7-inch diameter pebble mill and the rubbing of one lump against the other for the given period of the test, whereas in the modified shatter test, the smalls are produced by the breakage when the sample tested falls four times through a distance of 6 feet onto an iron plate. Despite the probability that the proportion of smalls and fines produced in the shatter test is much larger than would result in actual handling from producer to consumer, the shatter test appears more applicable for determining comparative commercial crushing and handling qualities than is the pebble-mill tumbling test, in which test the production of fines and dust is generally increased. Besides being of use for showing the comparative friabilities, the shatter test may, therefore, be used to differentiate between widely separated types of coke. For distinguishing between cokes different in structure though having the same apparent density the use of the pebble-mill tumbling test in conjunction with the shatter test is to be recommended.

RELATION OF CALCULATED CALORIFIC VALUE TO DETERMINED VALUE

Two formulæ used for the calculation of the calorific value of coals from their ultimate analyses, expressing the result in calories per gramme, are:—

(*a*) 8080 carbon + 34460 (hydrogen − $\frac{1}{8}$ oxygen) + 2250 sulphur.

(*b*) 8080 (carbon − $\frac{1}{8}$ oxygen) + 34460 hydrogen + 2250 sulphur.

The figures used are the heats of combustions—to the nearest 10—reported by different authorities[1] for the combustible elements in the coal.

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[1] *See* Van Nostrand's Chemical Annual and Thermo-Chemistry by Thomsen (Burke's translation).

Equally reliable figures for the heat of combustion of carbon, hydrogen, and sulphur may be reviewed here:—

Element	Authority	Heat of combustion	
		Calories per gramme	B.T.U. per lb.
Carbon, amorphous	Berthelot	8,080	14,544
"	Favre & Silberman	8,137	14,647
Carbon, crystallized	Berthelot	7,859	14,146
Graphite	"	7,901	14,222
Hydrogen	Thomsen	34,180	61,524
"	Favre & Silberman	34,462	62,032
"	Berthelot	34,500	62,100
Sulphur, rhombic	Favre & Silberman	2,221	3,998
Sulphur, monoclinic	Thomsen	2,241	4,034

The value of 8,080 calories per gramme for carbon as used by Strahan and Pollard[1] according to formula *(a)* above, gave results that checked the determined value to within 53 calories per gramme, i.e. 99 B.T.U. per pound for 31 out of 47 samples of Welsh anthracite and bituminous coals. The use of this carbon value for coke, however, does not check average determined values to within 300 or more B.T.U. per pound, an explanation being that the carbon in these cokes is not in the same allotropic form as in coals and that it is more similar to crystallized carbon, especially graphite or graphitic carbon, than to amorphous carbon. In these low volatile matter cokes produced at high temperatures, hydrogen is not likely to be present in the form of H_2O in the dry coke, nor is the combination of oxygen with the carbon likely to be in an uncombustible form, and, as the oxygen figure is obtained by difference, the use of formulæ where the oxygen is not subtracted is to be recommended. Due, however, to possible errors in the determination of the moisture content, etc., the formulæ subtracting $\frac{1}{8}$ of the oxygen first from the hydrogen, and then from the carbon, were tried and the results compared with those from the same formula where no correction is made for the oxygen. Different heats of combustion values for carbon, hydrogen, and sulphur as in the above table were tried, the use of 14,220 B.T.U. for carbon, and the higher values, 62,100 for hydrogen and 4,000 for sulphur, being preferred. The three formulæ giving the more satisfactory results and a comparison of the results with the determined value using the ultimate analyses figures for the 16 cokes given in Table II are tabulated below, using the B.T.U. per pound values instead of the calories per gramme.

Calculated calorific value in B.T.U. per pound equals:—

(1) 14220 carbon + 62100 hydrogen + 4000 sulphur.
(2) 14220 carbon + 62100 $(H - \frac{1}{8} O)$ + 4000 sulphur.
(3) 14220 (carbon $- \frac{1}{8}$ O) + 62100 hydrogen + 4000 sulphur.

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[1] The Coals of South Wales—Memoirs of the Geological Survey, England and Wales.

Lab. No.	Calculated calorific value			Determined B.T.U. per pound (dry basis)	Difference between calculated and determined values		
	Formula (1)	Formula (2)	Formula (3)		Formula (1)	Formula (2)	Formula (3)
2385	13,080	13,027	13,068	13,142	− 62	−115	− 74
2624	12,902	12,792	12,868	12,895	+ 5	−103	− 27
2632	12,801	12,664	12,774	12,590	+211	+ 74	+180
2789	12,277	12,234	12,267	12,136	+141	+ 98	+131
2945	12,888	12,736	12,855	13,005	−117	−269	−150
3032	12,639	12,529	12,610	12,622	+ 17	− 93	− 12
3034	13,119	13,098	13,118	13,036	+ 83	+ 62	+ 82
3065	12,442	12,386	12,438	12,260	+182	+126	+178
3067	13,270	13,214	13,260	13,284	− 14	− 70	− 24
3069	13,377	13,321	13,362	13,417	− 40	− 96	− 55
3073	12,867	12,724	12,834	12,905	− 28	−181	− 71
3074	12,858	12,846	12,855	12,676	+182	+170	+179
3091	13,183	13,169	13,179	13,180	+ 3	− 11	− 1
3374	13,137	13,093	13,126	13,061	+ 76	+ 32	+ 65
3588	13,002	12,990	13,000	13,173	−171	−183	−173
3590	13,075	13,062	13,072	13,090	− 16	− 28	− 18
Number of samples—							
With minus calculated values					7	10	10
With plus " "					9	6	6
Difference—calculated and determined values—							
Average of minus differences					− 56	−115	− 60
" plus "					+100	+ 93	+136
Number of samples for which the calculated values checked the determined—							
Within 100 B.T.U.					10	9	10
" 50 B.T.U.					7	3	5

Although the above results are more or less confusing it is possible to indicate a preference among the three formulæ—formula (1), it will be noticed, gave the best in respect to the number of samples where the calculated calorific values checked the determined values to within 50 B.T.U., and also gave the lowest average difference, both minus and plus, between the calculated and determined values. In making the calorific value determinations trouble was experienced in obtaining complete combustion in the bomb, so that the general tendency was for the determined values to be low. In this respect the larger number of plus calculated values, as in formula (1), is in accordance with what was expected, but on the other hand the larger number of minus values, as in formulæ (2) and (3), may mean that the value used for the heat of combustion of carbon was too low. The observation that the calculated values varied from the determined, both minus and plus, to approximately the same extent indicates, however, that the heat of combustion value assumed for carbon, viz: 14,220 B.T.U. per pound, is approximately correct. Where the calculated values using this figure are consistently low, and where the use of 8,080 calories (14,540 B.T.U.) or higher for the heat of combustion of carbon gives results that check the determined values more closely, a formula may be applied to estimate the proportions of graphitic and amorphous carbon present. This should be kept in mind when examining low-temperature cokes where the carbonization process in respect to lowering of volatile matter content with consequent increase in fixed carbon has not been carried so far as with the high-temperature cokes.

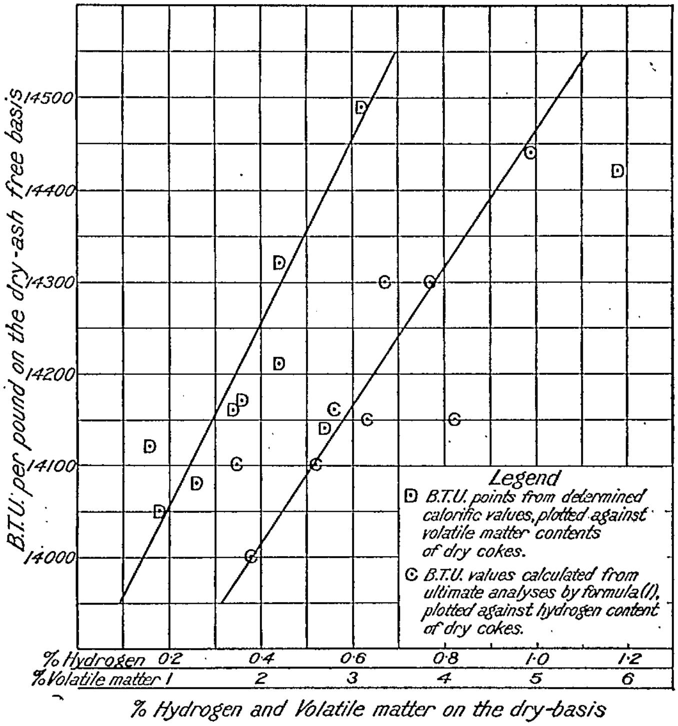

Figure 1. Diagram showing the relation between the calorific values and the hydrogen and volatile matter content of the cokes.

With the 10 samples for which the calculated calorific value according to formula (1) checked the determined value within 100 B.T.U. (seven of which checked within 50 B.T.U.), a comparison of values may be tabulated as follows:—

Lab. No.	Calorific value B.T.U. per pound (dry basis) calculated from		Ash and volatile matter contents (dry basis)		Dry, ash-free B.T.U. per pound		Hydrogen, dry basis %
	Calorimeter determination	Ultimate analysis formula (1)	Ash %	Vol. %	From determined value	From formula (1)	
3590	13,090	13,075	7·25	0·8	14,120	14,100	0·35
2385	13,142	13,080	6·43	0·9	14,050	13,980	0·38
3032	12,622	12,639	10·30	1·3	14,080	14,100	0·52
3091	13,180	13,183	6·92	1·7	14,160	14,160	0·56
3374	13,061	13,137	7·19	1·8	14,170	14,150	0·63
3034	13,036	13,119	8·28	2·2	14,210	14,300	0·67
3067	13,284	13,270	7·20	2·2	14,320	14,300	0·77
2624	12,895	12,902	8·83	2·7	14,140	14,150	0·82
3069	13,417	13,377	7·43	3·1	14,490	14,440	0·99
3073	12,905	12,867	10·54	5·9	14,420	14,390	1·53

The above results show that the calorific value on the dry, ash-free basis varied from slightly less than 14,000 to nearly 14,500 B.T.U. per pound so that the use of a constant dry, ash-free figure for calculating the heating value from the ash content on the dry basis will not give very accurate results. There is however as expected a definite, though somewhat irregular, relation between the dry, ash-free calorific values and the hydrogen content which in turn varied directly with the volatile matter content of the cokes. An attempt has been made to show these relations in Figure 1, the curves of which were derived from the above table being offered for what they are worth without further comment.

ASH DETERMINATION ERRORS

The ash content of the different cokes examined, as reported in Table I, was determined according to the A.S.T.M. method for coal, instead of according to the A.S.T.M. D 37-24 for cokes. It will be noticed the temperature specified for cokes is different from that for coal, being up to 950° C. for coke, as compared to 700° to 750° C. for coals. Just why the higher range is recommended, unless it is to ensure better burning of the (graphitic) carbon of the coke, is not apparent. A series of determinations were made at the lower and higher ranges, the results of which are of interest.

The electric muffle furnaces in which the cokes, as reported in Table I, were ashed, had previously been standardized within the specified range, viz., 700° to 750° C., but due to changes in voltages, variations in room atmosphere, and to changes in carrying capacity of the heating elements, it is difficult to keep the maximum temperature always within this range. In this respect it is not unlikely that the maximum temperature appreciably exceeds that desired, especially during the intervals when the muffles, or rather the rheostats, are standardized. In one instance with the muffle set for a maximum of 750° C., the temperature rose (over the noon hour) nearly 100 degrees (C), due apparently to change of voltage. This accounts for certain non-uniformity in all ash results on both coals and coke made at the lower temperature ranges. The higher range, viz., up to 950° C., is near the maximum operating temperature of the average electric furnace and consequently the variations in this range will not be so great as at the lower range.

The results of ashing 10 samples of coke, first at a maximum temperature in the neighbourhood of 750° C., and then at approximately 950° C., and a comparison of these results with those by ordinary proximate analyses, as reported in Table I, and with the ash results obtained in the ultimate analyses, are as follows:—

Coke sample Lab. No.	Per cent of ash at		Difference between average per cent ash at low and high ranges		Average per cent ash (dry basis)		Difference between ultimate and proximate results
	Low range up to 750° C.	High range up to 950° C.	As determined	On 10 per cent ash basis	Proximate analysis	Ultimate analysis	
	(As—received basis)						
3034	8·34 8·28	8·24 8·17	0·10	0·12	8·28	8·42	+0·16
3036	21·27 21·49	20·86 20·95	0·47	0·22	21·98	22·05	+0·07
3065	12·00 12·06	11·86 11·88	0·16	0·13	12·16	12·73	+0·57
3067	7·13 7·18	6·98 7·05	0·14	0·20	7·20	7·47	+0·27
3073	10·40 10·53	10·19 10·24	0·25	0·24	10·54	10·57	+0·03
3074	10·10 9·97	10·04 10·09	0·03	0·03	10·12	10·18	+0·06
3091	7·03 7·14	6·95 6·95	0·14	0·20	6·92	7·36	+0·44
3374	7·28 7·30	6·97 6·95	0·33	0·48	7·19	7·56	+0·37
3588	7·91 7·91	7·68 7·68	0·13	0·17	7·95	8·45	+0·50
3592	6·94 6·90	6·65 6·56	0·31	0·47	6·79	....	....

It will be observed from the above that the ash results, obtained at the higher range as commended by A.S.T.M. for coke, were consistently lower than at the lower range recommended for coals and as reported in Table I. It will also be noticed that ash results obtained in the ultimate analyses where the combustion takes place at a high (gas flame) temperature in a current of oxygen, were consistently higher than those obtained in the proximate analysis low-temperature range. An attempt was made to show just what caused these differences, but as yet no definite explanation is available. Examination, in a carbon and hydrogen combustion furnace, of the ash residue produced at the lower range failed to show the presence of unburned carbon, so that the lower result at the higher temperature range must be due to loss of weight of the inorganic constituents in the coal ash rather than to further combustion of carbon or other organic compounds. Therefore, in view of the consistent higher results in the ultimate analysis in an oxidizing atmosphere similar to that desired in actual burning, it is difficult to understand why the higher temperature range as recommended by the A.S.T.M. for cokes, should be used in preference to the lower range used for coals.

ERRORS IN VOLATILE MATTER DETERMINATIONS

The volatile matter determinations were carried out in platinum crucibles in Chaddock gas burners as described in a Mines Branch publication[1], which is similar to the A.S.T.M. alternative method using a Meker burner. The platinum crucibles used were the set-in lid type, and were 20 c.c. net capacity—A.S.T.M. says 10 or 20 c.c. Comparative tests carried out in these laboratories indicated, however, practically no difference in the results when using 15, 20, and 25 c.c. capacity crucibles. With cokes having low volatile matter contents a certain amount of oxidation, or rather combustion of the carbon, will take place unless a reducing atmosphere is present within the covered crucible, thus giving high results. The extent of this oxidation will depend on the size of the crucible used and will tend to be greater when heated in an electric furnace than when heated by gas with the reducing "flue" gas surrounding the crucible. An endeavour was made to determine the extent of oxidation and consequent error with the apparatus used. After allowing to cool in an evacuated dessicator, according to the usual practice after the regular seven-minute period of heating, the cokes were weighed and the results recorded. The weighed fixed carbon residue (containing the ash) was then returned to the gas burners and heated for a second period of seven minutes according to the usual practice for driving off the volatile matter. The tabulation of the net volatile matter contents by first heating and the loss during the second heating for 13 cokes is as follows:—

Laboratory Number	Loss by 1st heating (dry basis) %	Loss by 2nd heating		Net volatile matter content by 1st heating corrected for oxidation* loss.
		As per cent of residue from 1st heating	As per cent of original dry coal	
3032	1·29	0·67	0·66	0·63
3033	1·75	0·66	0·65	1·10
3034	2·18	0·78	0·76	1·42
3035	1·82	0·68	0·67	1·14
3039	1·93	0·64	0·63	1·30
3065	1·88	0·69	0·68	1·20
3066	1·93	0·68	0·67	1·26
3067	2·13	0·72	0·70	1·43
3068	2·18	0·77	0·75	1·43
3069	3·05	0·70	0·68	2·47
3073	5·91	0·78	0·73	5·18
3074	2·41	0·42	0·41	2·00
3091	1·66	0·83	0·82	0·84
Average	....	0·69	0·67	

*Oxidation loss indicated by loss shown by 2nd heating (per cent of dry coke).

The corrections used as above are based on the assumption that the loss during the second heating is due to combustion rather than to the evolution of volatile matter and on the assumption that combustion takes place to the same extent during the first heating. The first assumption seems reasonable in view of the fact that the temperature during the

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[1] Mines Branch, Dept. of Mines, Canada, Rept. 83, Vol. II, part IX, page 134.

second heating was practically the same as that during the first heating, but it does not rule out the possibility of part of the loss being due to further evolution of volatile matter during the extra time of heating. If, however, as indicated, combustion to the extent of 0·4 to 0·8 per cent of the original sample does take place, the results obtained in the volatile matter determinations conducted according to the usual practice may be considered high to the extent of these losses in weight during a second period of heating.

ERRORS CAUSED BY CHANGES IN MOISTURE CONTENT OF LABORATORY SAMPLE

As will be noticed in Table I, the moisture contents of twenty-seven of the thirty samples listed varied from 0·0 to 1·0 per cent which are to be considered low in comparison with the low moisture content coals. The moisture contents, of course, were determined on the pulverized cokes used for chemical analyses according to the usual practice, the different determinations being conducted soon after the laboratory samples were prepared. The moisture content of the pulverized cokes, though kept in ground-glass-stoppered bottles have been noticed to change considerably, due apparently to changes in the relative humidity of the room atmosphere, to the number of times and duration of time the bottles were unstoppered, and to the tightness of the stopper during storage. During a period varying from six months to a year moisture changes in a few cases of over 0·5 per cent of the original sample were found, at least this was the difference between the average of two determinations made on certain pulverized coke samples when first examined, and the average of two determinations six months or so later. Ten out of fourteen samples examined for moisture changes showed higher moisture contents after storage and four showed less moisture. The maximum plus change was 0·65 per cent, with an average of 0·31 per cent for the ten samples showing increased moisture contents. The maximum minus change was 0·48 per cent with an average of 0·25 per cent for the four samples showing decreased moisture contents. It may be noted that the permissible difference allowed by the A.S.T.M. for duplicate determinations by the same analyst is 0·2 per cent, and for different analysts in different laboratories 0·3 per cent. Although the average difference in the moisture content after storage is within these permissible experimental error limits, it is nevertheless important to keep a check on the moisture changes taking place on a given sample or series of samples. In this connexion moisture determinations should be made at approximately the same time as the volatile matter and calorific value determinations otherwise there may be considerable error when correcting for net volatile matter content and for calorific value on the dry basis.

ACKNOWLEDGMENTS

The courtesy and co-operation of the different coke manufacturers and distributors is herewith acknowledged, and it is hoped they may see fit to send in representative samples from year to year for comparative examination so that these laboratories may be of service in maintaining a high standard, thus encouraging the continued use of coke as a household fuel.

The active co-operation of J. H. H. Nicolls is hereby acknowledged. J. L. Bowlby assisted with the calorific value determinations, and the proximate analyses were made by G. E. LeWorthy.

SUMMARY

1. A total of thirty typical cokes comprising twenty samples of by-product coke, seven of gas coke, and three samples of foundry coke were examined for the main purpose of determining their comparative qualities as household fuels. In addition to the usual proximate analyses, special chemical analyses were made and attention paid to their comparative general characteristics.

2. Proximate analyses along with the determination of the calorific values were carried out on all the samples listed, followed by ultimate analyses on sixteen representative cokes. The fusibility of ash and apparent density determinations were made on most of the samples in addition to which their general characteristics in respect to appearance, size, apparent density, and comparative handling qualities were examined and reported, the latter tests being applied to differentiate between the gas cokes made in retort and the by-product cokes made in ovens.

3. The ash contents varied from 6½ to 13 per cent, the average of eighteen of the by-product cokes being roughly 7½ per cent, which in comparison with anthracite is not materially higher than the ash content of Welsh anthracite and only a little over half that of the higher ash Pennsylvania anthracites on the market

4. The calorific values of the cokes with one exception varied from slightly under 12,000 to nearly 13,500 B.T.U. per pound on the as-received basis, with an average of eighteen of the lower ash cokes of roughly 13,000 B.T.U. The calorific values on the dry, ash-free basis varied from slightly under 14,000 to nearly 14,500, the average being 14,200. From this latter value, knowing the dry-basis ash content, the calorific value of a given coke may be calculated to within plus or minus 200 B.T.U. or so.

5. The relation of the ash contents of the cokes examined to their respective calorific values, in comparison with this relation for anthracites is discussed. A coke must have 2 per cent less ash along with 2 per cent less moisture to equal the average Pennsylvania anthracite in respect to calorific value. In this connexion the cokes showed up to advantage in that the average ash of twenty-eight domestic cokes was 4½ per cent lower than the average ash for the anthracite just referred to.

6. In respect to ash fusibility, most of the cokes tested came in Class 2, viz: with ashes of medium fusibility—2,200 to 2,600° F. Four of the gas cokes and one by-product coke were in Class 1, i.e. above 2,600° F., in the same class as Pennsylvania anthracite, while four of the (Besco) by-product cokes were in Class 3, viz., below 2,200° F. The ash content of these latter cokes, however, was sufficiently low to assure non-clinkering burning qualities at ordinary rates of burning.

7. Screen analyses using standard laboratory screens showed considerable non-uniformity in the cokes with the same size designation. The importance of the stove size for coke to correspond roughly with that for anthracite was stressed and the selection of standard screen sizes most suitable in the laboratory for the dividing lines, between the egg, stove, nut, and pea sizes is discussed.

8. The results of chemical analyses failed to distinguish between the gas cokes and by-product cokes in general, and between the cokes of different structures and densities in these two classes. The use of a standard tumbling test method in conjunction with a modified shatter test did, however, serve to differentiate between a gas coke and a by-product coke having similar apparent densities.

9. For the shatter test on the domestic sizes, 20-pound samples of 1- to 2-inch lumps were dropped four times according to the usual practice for foundry coke, the amounts remaining on $\frac{3}{4}$-inch, $\frac{1}{2}$-inch, and 35-mesh screens indicating the comparative friability of the different cokes tested. This test is suggested for showing the comparative handling qualities of the different kinds of coke.

10. Three different formulæ for calculating the calorific value from the ultimate analyses were tried and a choice indicated. The use of 14,220 B.T.U. per pound, the heat of combustion of graphite (crystallized) carbon, instead of 14,540 for amorphous carbon, was found to give results that checked the determined calorific values quite closely. For seven samples where the calculated value checked the determined to within 50 B.T.U., the calorific values on the dry, ash-free basis varied from approximately 14,000 to nearly 14,500 B.T.U. per pound. This variation as was expected, was found to bear a definite relation to the hydrogen content in the dry coke, which in turn varied directly with the volatile matter. Knowing the volatile matter content of the dry coke, therefore, a dry, ash-free value may be assumed from which the calorific value of a given coke, the ash and moisture content of which is known, may be calculated to give values correct within practical limits

11. The use of the temperatures up to 950° C. for the ash determination of cokes, as recommended by the American Society for Testing Materials, in preference to 700° to 750° C., as recommended for coals is criticized. The ash results in the proximate analyses of ten representative cokes using a maximum temperature of 950° C. were consistently lower than those at 700° to 750° C., whereas the ash results in the ultimate analyses of the same cokes were consistently higher than at the proximate analyses lower range just mentioned. The possible errors in the volatile matter determinations due to oxidation or combustion of the (fixed) carbon, as well as moisture changes in the pulverized laboratory samples are also discussed.

II

TESTS OF VARIOUS FUELS MADE IN A DOMESTIC HOT-WATER BOILER AT THE FUEL TESTING STATION IN CO-OPERATION WITH THE DOMINION FUEL BOARD

E. S. Malloch and C. E. Baltzer

PURPOSE OF THE INVESTIGATION

The purpose of this investigation was to ascertain the relative value of various fuels for domestic heating. This was accomplished by comparing the behaviour of each fuel, when burned in a standard type of domestic heater, with that of a typical sample of American anthracite coal. American anthracite coal was used as a standard of comparison on account of its widespread use, in the central Provinces at least, for domestic heating purposes. The comparison of the different fuels was based chiefly on the efficiency of heat transference, though attention was also paid to such factors as the attendance which had to be given the fire; ease of controlling rate of combustion; cleanliness; and the handling and storage properties of the fuel. These factors are of importance, apart from the efficiency of heat transference, in judging the general suitability of a fuel for house-heating purposes. This paper, however, deals only with the comparison of the efficiencies of heat transference.

TYPE OF DOMESTIC HEATER USED DURING THE INVESTIGATION

Inasmuch as the conditions obtaining in actual practice had of necessity to be approximated in conducting these tests, the various types of domestic heaters in use were considered before deciding on the particular type to employ. Hot-water and hot-air furnaces are extensively used throughout Ontario and probably to an equal extent, and while it would have been desirable to have conducted tests concerning the burning qualities of fuels in both types, this was not feasible on account of the greater difficulty in obtaining reliable tests with the hot-air furnace. The hot-water heater was eventually chosen because of the ease with which it can be adapted to such an investigation, e.g. the transference of heat delivered by the burning fuel to the water, can be easily measured. Moreover, results obtained with the burning of the fuels in this type of heater are very similar to those which would have been obtained had other good types of heaters been selected. The hot-water heater used throughout the tests was of a size generally recommended for a house of eight or nine rooms.

METHOD OF TESTING FUELS

Inasmuch as it was decided to approximate, in this investigation, the methods of operating a heater in a private dwelling of moderate size, the continuous fire method of starting and stopping the tests was adopted.

The fire was first lit in the furnace 12 to 24 hours before the commencement of the test, to ensure that a proper fuel bed, containing the correct proportion of ash and unburned fuel, would be built up before the start of the test. Then at the beginning of a test, coal in sufficient quantity to last the requisite fire period, was charged. With the better grade fuels this period was from 12 to 8 hours, but as the quality of the fuel decreased or the rate of burning increased, the time was shortened, in the extreme case, to 3 hours. At the end of this period the fire was shaken, and when necessary, sliced, thus leaving the fuel bed in a condition similar to that at the beginning. This method of charging fuel was repeated for the succeeding fire periods.

The duration of each test varied from 40 to 120 hours, depending on the rate at which the heater was operated, and was so determined that approximately 1,000 pounds of fuel would be consumed. This quantity was, however, varied so that the time of ending would come at the end of a fire period, and preferably during the hours from 8 to 12 a.m. Unfortunately, limitations of staff necessitated a reduction in the time of the test in certain cases. In these cases the duration of the test was reduced to from 16 to 32 hours, in which approximately 250 pounds of coal was burned. The former were termed "long tests" and the latter "short tests."

The water contained in the heater was circulated by gravity through a system of wall radiators which were immersed in a tank of water. The tank, which is called a radiation tank, was thoroughly insulated from the cooling effect of the surrounding atmosphere. In order to measure the useful heat delivered by the furnace, a supply of cooling-water was employed which entered the tank at the bottom of one end and was discharged from the top of the other end. The cooling-water was accurately metered before entering and its temperatures at the inlet and outlet were carefully noted every half hour, at which time the water meter was also read. In this way the quantity of cooling-water and its rise in temperature were obtained, and the product of these two gave the useful heat transmitted by the furnace.

The heat losses from the furnace were measured in the usual way. The refuse removed from the ash-pit and from over the fire was carefully weighed, sampled, and analysed for combustible matter. The flue gases were continuously sampled and a portion taken for analysis every hour; and the temperature of the chimney gases at the offtake of the furnace was measured by means of a thermocouple placed in the flue pipe.

DESCRIPTION OF EXPERIMENTAL HEATING PLANT

The heating plant employed for this investigation consisted of: a round hot-water boiler; a radiation tank and cooling-water system; and the usual equipment of scales for weighing fuel and refuse; thermometers; pyrometers; draft gauges; gas sampling apparatus; gas analysis apparatus; and water-meter calibration apparatus, composed of tanks, weigh scales and piping. Figure 2 shows the general layout of the equipment, piping, etc.

The Furnace. The round hot-water boiler used in the investigation was of standard design, similar in all respects to those installed in an eight- or nine-room house. The boiler consisted of a number of separate castings set in cement and bolted together. The base casting, which

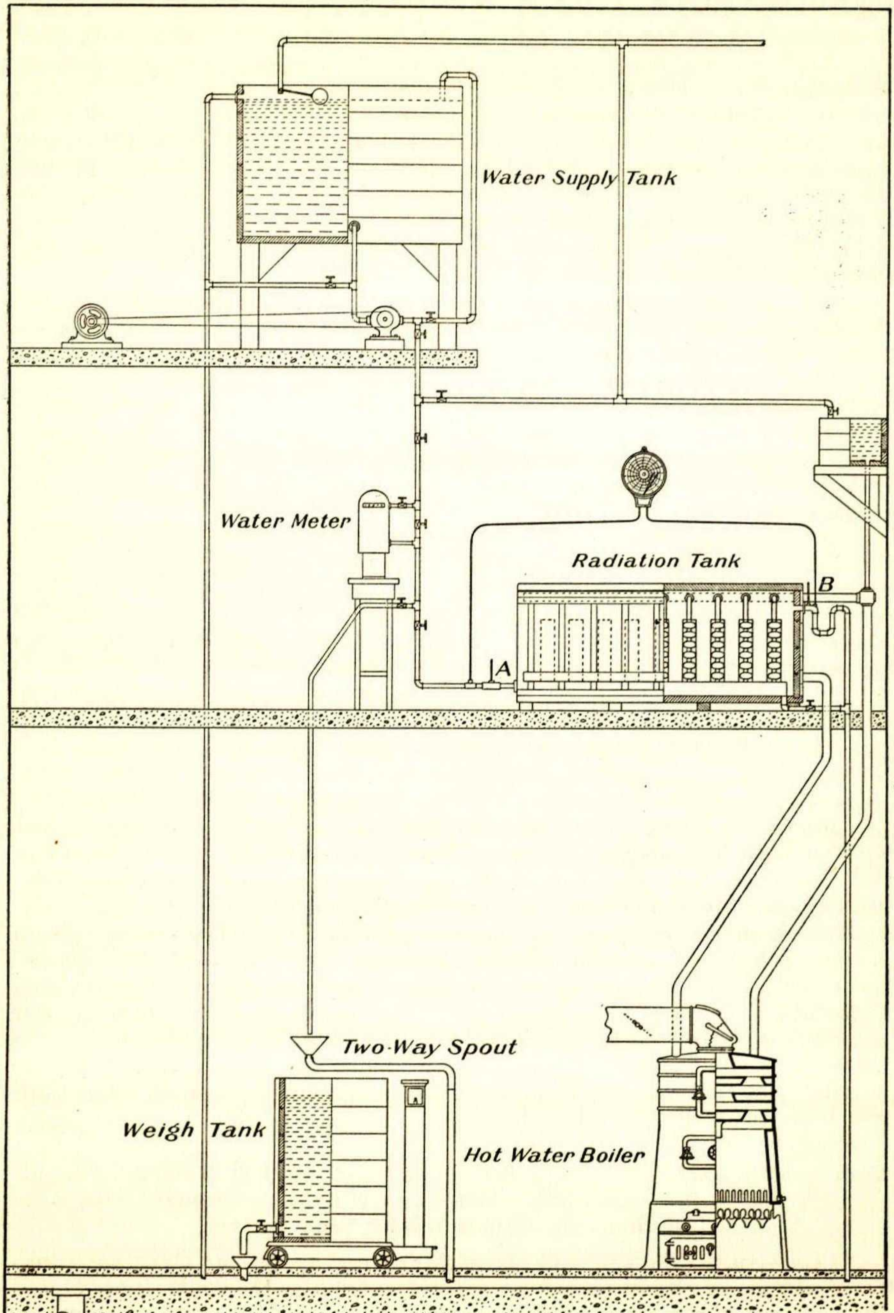

Figure 2. Elevation showing layout of apparatus used for domestic heater fuel tests.

formed the ash-pit of the furnace, was 15½ inches high and held 7 triangular-shaped, revolving grate bars. These bars were so geared together that the grate was shaken in three sections. The fire-pot casting, 21¾ inches high, rested on the base casting and was slightly smaller at the bottom than at the top. It was water-jacketed and the inner surface slightly overhung the grate. The fire-pot casting supported four water-section castings, each being approximately 2¾ inches thick, which were pierced by ports, arranged in such a manner that the products of combustion took a staggered path in passing from the fire-pot up through the ports to the flue. The top section, however, forming the cap of the furnace, had only one port, centrally located, to which a patented fixture was attached containing a check damper. This fixture served as the connexion between the flue pipe and the furnace. The flue pipe, which extended approximately 35 feet upward through the roof of the test room, formed the stack, and was made up of 8-inch galvanized iron pipe. The water sections and the water-jacketed portion of the fire-pot casting made up the heating surface of the furnace which totalled approximately 32·4 square feet. The nominal diameter of the grate was 25 inches, giving a nominal grate area of 3·4 square feet. The following are the main ratings and dimensions of the furnace:—

Size of boiler..................................	No. 4	
Net rating, feet of radiation....................	670	
Gross rating, feet of radiation....................	1,100	
Nominal diameter of grate......................	25	inches
Grate area....................................	3·4	square feet
Area of heating surface........................	32·4	“
Ratio of heating surface to grate area............	9·2	
Total volume of fuel and combustion space........	5·4	cubic feet
Diameter of smoke outlet........................	8	inches
Number of circulating water openings............	4	
Size of circulating water openings................	2	inches
Total approximate weight of castings.............	1,630	pounds

Radiation Tank. The radiation tank was a box 6½ feet long, 3 feet wide and 2½ feet deep, containing nine wall radiators, each of 9 square feet radiation. The radiators were connected to 2½-inch flow and return headers, one on either side and running the length of the tank. The headers were connected by 2-inch piping to the circulating-water system of the boiler, and both headers and piping were thoroughly insulated. Inside the tank the radiators were placed side by side and connected in parallel between these headers. The inlets from the flow header entered the top of the radiators and the outlets to the return header were taken off at the bottom. A valve was placed in the inlet to each radiator, in order that any one might be cut out of the circuit, as desired. The tank was built of 1½-inch lumber, lined with copper sheeting and thoroughly insulated on all sides. The insulation consisted of ¼-inch air space, ⅛-inch sheet asbestos, rigidly nailed on furring strips of ordinary lath, and over all a ½-inch thickness of sheet felt. The top of the tank was made removable to permit of inspection of the radiators from time to time.

Cooling-water System. The heat was carried away from the circulating-water system of the furnace by means of cooling-water which flowed past and between the radiators in the radiation tank. The cooling-water was admitted through a 1-inch pipe at the bottom of one end of the tank and left through a $1\frac{1}{2}$-inch pipe at the top of the other end. The inlet pipe was fitted with a short length of rubber tubing in which was inserted a mercury thermometer. The rubber tubing being a good non-conductor of heat, was used to prevent heat from passing from the hot water in the radiation tank along the iron inlet pipe to the bulb of the thermometer. The outlet pipe was so situated with respect to the height of the radiators that at all times they were completely immersed in the cooling-water. This pipe was trapped close to the tank to prevent siphoning and to immerse completely the bulb of another mercury thermometer similar to the one in the inlet pipe.

In order to ensure a steady and constant flow of cooling-water, a small rotary pump, electrically driven, was installed, which drew the water from a storage or supply tank and forced it through the meter and thence to the inlet pipe of the radiation tank. The supply tank, in which the water level was kept constant by means of a ball and cock valve on a pipe from the city water supply main, was placed on a floor, 7 feet above the radiation tank, and had a capacity of about 200 gallons.

Water Meter. An accurate measure of the quantity of cooling-water flowing through the radiation tank was absolutely essential in the method employed for measuring the heat given up by the furnace: to secure this a piston type meter was selected. A half-inch meter having a full flow capacity of 25 gallons per minute was installed, with the manufacturer's guarantee that the error would not be greater than 1 per cent for all water flows from a dribble to full capacity. The meter was calibrated in Imperial gallons and could be accurately read to within one gallon.

Water Meter Calibration System. To ensure accuracy in the measurement of the water, the meter was calibrated before and after each test; and to accomplish this, the cooling-water pipes were so arranged with valves that the radiation tank could be by-passed as desired. When this was done the cooling-water from the meter passed to a two-way movable spout and thence either directly to the drain or into a tank placed on scales; this tank had a capacity of 500 pounds of water. The first step taken in calibrating the meter was to by-pass the radiation tank and set the valve from the supply tank so that the same quantity of water per minute which was to be or had been used during the test, would pass through the meter, the two-way spout being thrown so that the water passed into the drain. The tare of the weigh tank was taken, and after a constant water flow was observed through the meter, the two-way spout was switched to throw the water into the weigh tank, and at the same instant the meter was read. After 50 gallons had passed through the meter the spout was again switched. The tank was then weighed, and in this manner the error in the meter was at once observed. These meter tests were continued until the error became constant. Throughout the investigation the error seldom exceeded 2 per cent and averaged a little over 1 per cent; the greatest errors were due to the wear in one of the valves which could be and was adjusted from time to time to take up this wear. The cooling-water system proved to be very satisfactory and very constant flows of water were maintained during the tests, with variations in flow of seldom more than 1 gallon from one half-hour period to another.

Other Miscellaneous Apparatus. The thermometers used to measure the temperature of the cooling-water were calibrated to one-tenth of 1 degree, in the Physical Laboratory, Topographic Survey, Department of the Interior. These thermometers were graduated in single degrees from 32° to 200° F. A double-pen recording thermograph gave a continuous record of the inlet and outlet temperatures of the cooling-water, the bulbs of which were placed in the cooling-water in close proximity to the mercury thermometers.

Two mercury thermometers, graduated for 2 degree readings, scale 32° to 220° F. were used to measure the temperatures in the circulating water of the furnace, the bulb of one being immersed in the flow side of the furnace and the other in the return side.

The temperature of the flue gases at the offtake from the furnace was measured by means of a pyrometer. The pyrometer was calibrated from time to time by means of the melting points of various metals.

The draft or pressure in the flue pipe was obtained by means of a draft gauge reading to within 1 one-hundredth of an inch of water.

The flue gas was sampled continuously, the sample being taken off at the end of each hour and analysed in a Hayes-Orsat apparatus.

PRELIMINARY DECISIONS AND DUPLICATION OF APPARATUS

At the outset of the investigation one preliminary test was made on each fuel, in order to ascertain the correct draft settings and lengths of fire period required for each particular fuel at three different rates of combustion. The three different rates of combustion were so regulated that approximately 66,000, 99,000, and 132,000 B.T.U. per hour were delivered by the furnace to the cooling-water.

In order to hasten the completion of the investigation the apparatus was duplicated. Another furnace, radiation tank, water meter, thermograph, etc., were set up and operated together with the first system. With the apparatus in duplicate, it was decided to operate the two furnaces together for two successive weeks on the same fuel. For the first week's tests they were operated each at the rate of approximately 99,000 B.T.U. per hour, and during the second week one furnace at the rate of approximately 132,000 B.T.U. per hour, and the other one at the rate of approximately 66,000 B.T.U. per hour. The duplication of plant enabled the investigators to check their work, and in addition, permitted a reduction in the time of the investigation to two-thirds of that required when a single furnace was employed.

METHOD OF CONDUCTING TESTS

Length of Fire Period

The fire periods varied in length from 12 to 3 hours, and were determined by the calorific value and bulkiness of the fuel. Upon the latter quality depended the quantity of fuel which could be conveniently charged into the furnace at one time. From the preliminary run and the known calorific value of the fuel, the weight of fuel to be charged was determined.

Method of Starting and Stopping Tests

The continuous fire method of starting and stopping the tests used throughout the investigation, was as follows:—

A fire was built in the furnace the evening before the start of the test and the furnace was operated overnight at that rate which would pertain during the test, thus ensuring, so far as possible, the thorough heating of the piping and radiation tank, and a fuel bed in an approximately stable condition, similar to that which would obtain at the end of the test. Just before the beginning of the test the fire was carefully shaken down and its level and general condition noted; then it was started by taking the initial readings. To terminate the test the fire was brought to approximately the condition which pertained at the beginning. The tests were continued until a sufficient quantity of fuel had been consumed to permit the error in judging the fire at the end of the test to be reduced so as not to be greater than 2 per cent. The error made in judging the fire, it was estimated, should not exceed 20 pounds of fuel; therefore, by continuing the test until 1,000 pounds of fuel were consumed this maximum was not exceeded.

Sampling of Fuel and Refuse

One sample of fuel was taken for each group of two tests when, as in the majority of cases, the two heaters were operated simultaneously upon the same fuel. In order to avoid too many handlings, the quantity required for the tests was shovelled directly from the storage bin onto a clean sampling floor, the sample was cut out by means of the alternate shovelling method, i.e. one shovelful in every four or five, according to the amount of fuel being sampled, was set aside in a separate pile. All of the lumps were then broken up into pieces no larger than four or five inches in diameter, and the sample was then coned and quartered down until approximately only 75 pounds were left. This quantity was sent directly to the chemical laboratory to be crushed, ground, and then riffled down for analysis. The remainder of the fuel left on the sampling floor was carried in sacks to the furnace room, as required, each sack containing a predetermined weight of fuel sufficient for one fire period. All the refuse, as it was removed from the furnace, either from the ash-pit or through the fire-door, was weighed, and stored in covered galvanized iron receptacles until the end of the test, when it was given to the chemical laboratory for sampling and analysis.

Analyses of Fuel and Refuse

All chemical analyses were made in the chemical laboratories of the Fuel Testing Division, by chemists who were continually employed on this class of work. In general, a screen and ultimate analyses were made on a sample collected by a member of the chemical staff, upon receipt of each different fuel as it was placed in storage, and a determination of the calorific value was made at the same time. Further, a proximate analysis was made upon each new sample of fuel as obtained, prior to each test, and the ultimate analysis and calorific value were then calculated for it from the previous analysis which had been made. A sample of the refuse, which contained both ash and clinker was analysed for combustible content only.

After the test the chemist in charge submitted a report to the observers which gave the proximate analysis, the calorific value, and ultimate analysis of the fuel as charged, as well as the combustible content of the refuse on a dry basis.

Methods of Firing the Fuels

The methods used in firing the fuels differed in such a manner as to suit the physical characteristics of three groups of fuels, viz., anthracites and cokes, semi-bituminous coals, and Alberta sub-bituminous and domestic coals.

Before charging the anthracites and cokes the fire was well shaken; the quantity of fuel required for the fire period was then charged into the fire-pot and spread over until the fuel bed was completely covered. When the fuel was bulky, such as coke, it was necessary to practically fill the whole combustion space, in order to charge the requisite quantity of fuel into the furnace. With the anthracites, however, it was only necessary to crown the fuel bed a little above the level of the bottom of the fire-door.

With the smokeless or semi-bituminous coals it was found to be advantageous to leave a part of the glowing fuel bed exposed, in order to ignite the volatile gases as they were given off by the freshly charged fuel, and to heap the fresh charge to either one side or other of the grate, or to heap fresh fuel around the circumference of the fire-pot and leave the centre of the hot fuel bed exposed to ignite the gases.

When testing Alberta domestic coals an endeavour was made to follow as closely as possible the method advocated by the Fuel Engineer of the Province of Alberta, viz., to pack the fresh fuel as closely as possible on one side of the fuel bed, placing the larger lumps at the bottom, to form a bridge wall across the fire-pot from the front to rear, and finally covering the charge with the fines. For the next fire period fuel was fired on the opposite side of the fuel bed. Each time glowing fuel was left on one half of the grate. The fire-pot and combustion space did not lend themselves very readily to the firing of the Alberta fuels, as the depth of the fire-pot was large in comparison with its diameter. To maintain the fire for at least six hours at a low rate of combustion, it was difficult to fire the requisite quantity of fuel on one side of the grate only.

Attendance Required

As the furnaces were to be operated as closely as possible under household conditions, the attendance to the fire after charging the fresh fuel, was reduced to a minimum. Neither the fuel bed nor the drafts were altered between firings, except when this was found to be absolutely necessary, in order to maintain the correct combustion rate. Such attendance is permissible and might be said to be in parallel with the operation in a house, for when the house is too cold the drafts are opened; when too hot the drafts are closed and the check draft is opened. Any attention the fire did receive, however, which might be considered as additional to what would be expected with an ordinary house heater, was given in accordance with the desire to have the tests fairly comparable upon a basis of efficiency of heat delivered, rather than to obtain the data of the attendance given the fire.

FUELS TESTED

Twenty-one fuels were tested, as shown in the list in Table III. Eight of the fuels were purchased from coal dealers in Ottawa. These comprised: three anthracites, two cokes, two smokeless semi-bituminous coals, and air-dried, machine peat. Nine were obtained from Alberta, and were selected by the late Dr. D. B. Dowling of the Geological Survey and Dominion Fuel Board, with the co-operation of the Scientific and Industrial Research Council of Alberta, as typically representative of Alberta coals. Two cokes were obtained from the Maritime Provinces, one coke from the United States, and Welsh briquettes from a Montreal firm.

TABLE III

List of Fuels Tested

No.	Fuel	Obtained from	Size	Date received
1	American anthracite	Ottawa coal dealer	Stove	1924
2	Welsh anthracite	Ottawa coal dealer	Re-screened	1924
3	Scotch semi-anthracite	Ottawa coal dealer	Re-screened	1924
4	Gas coke	A Canadian gas company; made from American coal	Crushed	1924
5	By-product coke No. 1	Imported from the United States	Egg	1924
6	By-product coke No. 2	A Canadian by-product coke oven; made from American coal	Stove	1925
7	By-product coke No. 3	A Canadian by-product coke oven; made from Canadian coal	Small	May, 1925
8	By-product coke No. 4	A Canadian by-product coke oven; made from Canadian coal	Medium	October, 1925
9	American smokeless, semi-bituminous No. 1	Ottawa coal dealer	Smokeless, forked lump	October 15, 1924
10	American smokeless, semi-bituminous No. 2	Ottawa coal dealer	Smokeless, egg	April 24, 1925
11	Alberta semi-bituminous	The mine	Smokeless	December 17, 1924
12	Alberta sub-bituminous No. 1	The mine	Egg	January 8, 1925
13	Alberta sub-bituminous No. 2	The mine	Stove	February 2, 1925
14	Alberta sub-bituminous No. 3	The mine	Stove	December 11, 1924
15	Alberta domestic No. 1	Alberta coal dealer	Stove and nut	December 11, 1924
16	Alberta domestic No. 2	The mine	Lump	June 4, 1924
17	Alberta domestic No. 3	The mine		May 19, 1924
18	Alberta domestic No. 4	Alberta coal dealer	Egg	May 22, 1924
19	Alberta domestic No. 5	The mine	Stove	May 21, 1924
20	Welsh briquettes	Montreal coal dealer	Ovoids	February, 1924
21	Air-dried, machine peat	Ottawa coal dealer	Lump	October 16, 1925

RESULTS OF TESTS

Table IV gives the results in detail of the 123 tests which were conducted on 21 different fuels. The table gives the proximate and ultimate analyses of each fuel, fuel fired, refuse removed, temperatures, draft, analysis of the flue gases, and economic results, as well as the heat balance for the majority of the tests. It will be noted that flue gas analyses were not made for the earlier tests; this was on account of the limited staff then available to act as observers.

Item 20, "fuel fired per therm (100,000 B.T.U.) delivered to the cooling-water," is the most important item on the table, as it is a measure of the pounds of fuel required per unit of useful heat delivered, and is used in comparing one fuel with another, in preference to the item giving the thermal efficiency.

Item 3, "duration of test," shows that the majority of tests were from 72 to 120 hours in length. These tests were the "long tests" in which approximately 1,000 pounds of fuel were burned. The remaining tests, having a duration of from 16 to 32 hours, were the "short tests" in which the total fuel fired was in the neighbourhood of 250 pounds.

In working up the results it became evident that the short tests did not yield the required accuracy. Accordingly, all short tests were discarded, except those on by-product cokes Nos. 3 and 4 and air-dried, machine peat, on which only short tests were made. Long tests which were found to be in gross error in one particular or another were also discarded. The discarded tests are marked with an asterisk (*) in Table IV, and were not used in the compilation of the other tables, charts, and diagrams.

TABLE IV

Detailed Data and Results of All Tests

Item No.	Item		American Anthracite			
1	Trial number		**G-17-A***	**G-20-A***	**G-58-A**	**G-77-A***
2	Date of trial		7–3–23	10–29–23	5–4–25	10–14–25
3	Duration of test	Hours	84	72	120	32
4	Intervals between firings	"	12	8	8	8
	Proximate analysis of fuel, as fired—					
5	Moisture	Per cent	1·8	4·0	3·9	3·5
6	Ash	"	13·6	14·8	14·4	11·6
7	Volatile matter	"	5·5	5·5	6·2	6·1
8	Fixed carbon (by difference)	"	79·1	75·7	75·5	78·8
9	Gross calorific value of fuel, as fired	B.T.U. per lb.	12530	12030	12090	12760
	Ultimate analysis of fuel, as fired—					
10	Carbon	Per cent	....	....	76·1	78·5
11	Hydrogen	"	....	....	3·1	2·9
12	Ash	"	....	....	14·4	11·6
13	Sulphur	"	0·8	0·8	0·9	0·9
14	Nitrogen	"	....	....	0·8	0·9
15	Oxygen (by difference)	"	....	....	4·7	5·2
	Fuel and refuse—					
16	Fuel fired, total	Lb.	669·5	622·0	932·75	261·5
17	Fuel charged per fire period, average	"	95·6	69·1	62·2	65·4
18	Fuel fired per hour	"	8·0	8·6	7·8	8·2
19	Fuel fired per sq. ft. grate surface per hour	"	2·3	2·5	2·3	2·4
20	Fuel fired per therm delivered to cooling-water	"	11·72	11·93	10·95	11·60
21	Refuse removed through fire-door	"	0·0	0·0	0·0	0·0
22	Refuse removed from ash-pit	"	118·5	126·75	159·5	52·0
23	Refuse removed, total	"	118·5	126·75	159·5	52·0
24	Refuse removed per ton of fuel fired	"	354·0	408·0	342·0	398·0
25	Total refuse as a percentage of the fuel fired	Per cent	17·7	20·4	17·1	19·9
26	Combustible matter in refuse	"	34·1	44·2	34·5	48·6
	Temperatures and drafts—					
27	Temperature of circulating water, flow	Deg. F.	151	133	127	132
28	Temperature of circulating water, return	"	122	101	99	103
29	Temperature of flue gases	"	315	280	300	250
30	Temperature of room	"	....	66	72	73
31	Draft in flue	Inch of water	0·017	0·017	0·010	0·025
	Analysis of flue gases by volume—					
32	Carbon dioxide	Per cent	....	....	12·4	12·7
33	Oxygen	"	....	....	7·6	7·2
34	Carbon monoxide	"	....	....	0·1	0·2
35	Nitrogen (by difference)	"	....	....	79·9	79·9
36	Weight dry flue gases per pound of fuel as fired	Lb.	....	....	13·9	13·4
37	Excess air	Per cent	....	....	55·7	51·3
	Rates and efficiencies—					
38	Heat delivered to cooling-water per hour	B.T.U.	67950	72410	70940	70450
39	Heat delivered to cooling-water per pound of fuel fired	"	8530	8380	9130	8620
40	Grate efficiency	Per cent	91·7	85·5	90·7	87·1
41	Overall thermal efficiency	"	68·1	69·7	75·5	67·6
	Heat account per pound of fuel, as fired—					
42	Gross calorific value per pound fuel, as fired	B.T.U.	12530	12030	12090	12760
43	Heat delivered to the cooling-water	B.T.U.	8530	8380	9130	8620
		Per cent	68·1	69·7	75·5	67·6
44	Loss due to total heat of steam formed from moisture in fuel and that formed by combustion of hydrogen	B.T.U.	....	....	320	290
		Per cent	....	....	2·6	2·3
45	Loss due to heat carried away in dry flue gases	B.T.U.	....	....	760	570
		Per cent	....	....	6·3	4·5
46	Loss due to unburned combustible matter in refuse	B.T.U.	1020	1700	1100	1590
		Per cent	8·1	14·1	9·1	12·5
47	Loss due to unburned carbon monoxide	B.T.U.	....	....	60	110
		Per cent	....	....	0·5	0·8
48	Balance of heat account; errors of observation, radiation, and that unaccounted for	B.T.U.	....	....	720	1580
		Per cent	....	....	6·0	12·3

Tests marked * have been discarded as not being representative of the fuel.

TABLE IV—Continued

Detailed Data and Results of All Tests—Continued

AMERICAN ANTHRACITE											ITEM No.
G-85-A*	**G-27-A***	**G-27-B***	**G-59-A**	**G-59-B**	**G-77-B***	**G-86-A***	**G-24-A***	**G-58-B**	**G-78-B***	**G-87-A***	1
1–25–26	7–21–24	7–21–24	5–11–25	5–11–25	10–14–25	1–27–26	2–10–24	5–4–25	10–21–25	1–29–26	2
32	96	96	96½	96	24½	24	120	73	16½	16	3
8	8	8	8	8	8	8	8	8	8	8	4
3·4	3·3	3·3	3·7	3·7	3·5	3·4	3·3	3·9	3·5	3·4	5
14·4	14·1	14·1	14·6	14·6	11·6	14·4	15·7	14·4	11·6	14·4	6
6·5	6·2	6·2	6·2	6·2	6·1	6·5	6·3	6·2	6·1	6·5	7
75·7	76·4	76·4	75·5	75·5	78·8	75·7	74·7	75·5	78·8	75·7	8
12300	12250	12250	12090	12090	12760	12300	11990	12090	12760	12300	9
76·9	....	....	76·1	76·1	78·5	76·9	....	76·1	78·5	76·9	10
2·4	....	....	3·1	3·1	2·9	2·4	....	3·1	2·9	2·4	11
14·4	....	....	14·6	14·6	11·6	14·4	....	14·4	11·6	14·4	12
1·0	0·7	0·7	0·9	0·9	0·9	1·0	0·7	0·9	0·9	1·0	13
0·8	....	....	0·8	0·8	0·9	0·8	....	0·8	0·9	0·8	14
4·5	....	....	4·5	4·5	5·2	4·5	....	4·7	5·2	4·5	15
260·0	1186·0	1132·0	1115·0	1029·75	285·0	260·25	1922·0	1130·5	246·0	249·5	16
65·0	98·8	94·3	92·8	85·8	95·0	86·7	128·1	125·6	123·0	124·8	17
8·1	12·6	11·8	11·6	10·8	11·6	10·8	16·0	15·5	14·9	15·6	18
2·4	3·6	3·5	3·4	3·2	3·4	3·2	4·7	4·6	4·4	4·6	19
12·06	12·38	12·06	11·44	10·80	10·65	10·58	12·97	12·36	10·50	11·14	20
0·0	0·0	0·0	0·0	0·0	0·0	2·25	22·5	19·5	0·0	7·25	21
54·25	261·25	239·25	224·25	191·5	45·75	49·0	438·0	188·5	30·75	40·0	22
54·25	261·25	239·25	224·25	191·5	45·75	51·25	460·5	208·0	30·75	47·25	23
417·0	441·0	423·0	402·0	372·0	321·0	394·0	479·0	368·0	250·0	379·0	24
20·9	22·0	21·2	20·1	18·6	16·1	19·7	24·0	18·4	12·5	18·9	25
45·6	43·4	41·6	40·6	35·2	46·1	32·2	35·1	37·0	45·0	31·5	26
115	156	169	141	145	155	132	146	155	164	148	27
86	121	121	106	109	117	95	103	112	122	104	28
295	450	375	375	385	315	400	425	510	385	560	29
63	77	77	74	74	74	67	....	73	72	57	30
0·020	0·025	0·024	0·019	0·031	0·085	0·034	0·078	0·094	0·150	0·063	31
11·3	....	....	12·5	12·1	12·2	13·8	....	11·4	12·7	14·0	32
8·8	....	....	7·5	7·8	7·9	6·4	....	8·5	7·4	5·9	33
0·1	....	....	0·1	0·1	0·2	0·1	....	0·1	0·2	0·1	34
79·8	....	....	79·9	80·0	79·7	79·7	....	80·0	79·7	80·0	35
14·5	....	....	13·4	14·2	14·1	12·9	....	14·9	13·7	12·7	36
70·9	....	....	54·6	57·9	59·5	43·3	....	66·6	53·7	38·4	37
67350	99840	97810	100980	99320	109290	102480	123480	125330	141820	139960	38
8290	8080	8290	8740	9260	9400	9450	7710	8090	9510	8980	39
85·3	86·9	87·8	87·8	90·3	88·3	91·7	89·5	89·6	88·8	92·0	40
67·4	66·0	67·6	72·3	76·6	73·7	76·8	64·3	66·9	74·5	73·0	41
12300	12250	12250	12090	12090	12760	12300	11990	12090	12760	12300	42
8290	8080	8290	8740	9260	9400	9450	7710	8090	9510	8980	43
67·4	66·0	67·6	72·3	76·6	73·7	76·8	64·3	66·9	74·5	73·0	
250	....	....	330	330	300	260	....	350	310	280	44
2·0	....	....	2·7	2·7	2·3	2·1	....	2·9	2·4	2·3	
810	....	....	970	1060	820	1030	....	1560	1030	1530	45
6·6	....	....	8·0	8·8	6·4	8·4	....	12·9	8·1	12·4	
1750	1570	1460	1440	1150	1440	990	1230	1230	1380	960	46
14·2	12·8	11·9	12·0	9·5	11·3	8·1	10·3	10·2	10·8	7·8	
60	....	....	50	60	110	50	....	60	110	50	47
0·5	....	....	0·4	0·5	0·9	0·4	....	0·5	0·9	0·4	
1140	....	....	560	230	690	520	....	800	420	500	48
9·3	....	....	4·6	1·9	5·4	4·2	....	6·6	3·3	4·1	

TABLE IV—Continued

Detailed Data and Results of All Tests—Continued

ITEM No.	WELSH ANTHRACITE						SCOTH SEMI-ANTHRACITE			
1	**G-19-A***	**G-28-A**	**G-28-B**	**G-35-A**	**G-35-B**	**G-21-A**	**G-43-A**	**G-41-A**	**G-41-B**	**G-43-B**
2	10–14–23	7–28–24	7–28–24	10–6–24	10–6–24	11–19–23	12–8–24	11–24–24	11–24–24	12–8–24
3	72	120	120	96	96	120	120	96	96	80
4	8	8	8	8	8	8	8	8	8	8
5	2·2	2·3	2·3	1·8	1·8	2·7	3·0	2·9	2·9	3·0
6	5·2	4·8	4·8	5·3	5·3	4·2	6·8	7·1	7·1	6·8
7	7·7	7·6	7·6	7·8	7·8	8·3	10·0	10·0	10·0	10·0
8	84·9	85·3	85·3	85·1	85·1	84·8	80·2	80·0	80·0	80·2
9	14260	13930	13930	14130	14130	14260	13780	13760	13760	13780
10	....	....	....	85·9	85·9	....	82·5	82·3	82·3	82·5
11	....	....	....	3·3	3·3	....	3·6	3·6	3·6	3·6
12	....	....	....	5·3	5·3	....	6·8	7·1	7·1	6·8
13	0·9	0·9	0·9	1·2	1·2	0·9	0·7	0·7	0·7	0·7
14	....	....	....	1·0	1·0	....	1·8	1·8	1·8	1·8
15	....	....	....	3·3	3·3	....	4·6	4·5	4·5	4·6
16	480·75	809·25	811·75	923·75	901·75	1547·5	754·5	925·75	946·25	1081·25
17	53·4	53·9	54·1	77·0	75·1	103·2	50·3	77·1	78·9	108·1
18	6·7	6·7	6·8	9·6	9·4	12·9	6·3	9·6	9·9	13·5
19	2·0	2·0	2·0	2·8	2·8	3·8	1·8	2·8	2·9	4·0
20	10·40	9·60	9·78	9·48	9·35	9·57	9·44	9·57	9·68	10·24
21	0·0	0·0	0·0	0·0	0·0	10·0	0·0	0·0	0·0	21·0
22	46·5	46·0	35·75	41·5	37·25	78·75	49·0	62·75	70·25	47·75
23	46·5	46·0	35·75	41·5	37·25	88·75	49·0	62·75	70·25	68·75
24	193·0	114·0	88·0	90·0	83·0	115·0	130·0	136·0	148·0	127·0
25	9·7	5·7	4·4	4·5	4·1	5·7	6·5	6·8	7·4	6·4
26	72·3	45·4	40·6	49·7	52·9	45·8	29·1	25·2	30·6	21·9
27	131	146	150	155	156	152	123	146	143	156
28	101	118	117	122	118	107	97	112	106	113
29	225	305	260	400	395	395	290	400	380	520
30	72	75	75	73	73	....	71	75	75	73
31	0·016	0·019	0·027	0·040	0·056	0·084	0·017	0·057	0·047	0·096
32	10·7	....	....	10·7	10·6	....	11·8	12·3	12·3	12·4
33	....	....	....	8·8	9·0	....	7·7	7·4	7·2	6·8
34	....	....	....	0·3	0·3	....	0·3	0·2	0·2	0·2
35	....	....	....	80·2	80·1	....	80·2	80·1	80·3	80·6
36	....	....	....	18·5	18·5	....	16·6	16·2	16·0	16·2
37	....	....	....	70·3	73·2	....	56·5	53·3	50·9	46·5
38	64260	70300	69190	101550	100430	134720	66570	100600	101830	132080
39	9620	10420	10230	10550	10690	10450	10590	10450	10330	9770
40	85·4	95·7	96·5	94·4	93·6	96·2	96·9	97·3	96·5	97·9
41	67·5	74·8	73·4	74·7	75·7	73·3	76·8	75·9	75·1	71·0
42	14260	13930	13930	14130	14130	14260	13780	13760	13760	13780
43	9620	10420	10230	10550	10690	10450	10590	10450	10330	9770
	67·5	74·8	73·4	74·7	75·7	73·3	76·8	75·9	75·1	71·0
44	....	....	....	360	360	....	370	390	380	410
	....	....	....	2·6	2·5	....	2·7	2·8	2·8	3·0
45	....	....	....	1450	1430	....	870	1260	1170	1740
	....	....	....	10·3	10·1	....	6·3	9·2	8·5	12·6
46	1970	580	480	760	860	510	410	350	450	280
	13·8	4·2	3·4	5·4	6·1	3·6	3·0	2·5	3·3	2·0
47	....	....	....	220	220	....	200	130	130	130
	....	....	....	1·6	1·6	....	1·4	0·9	0·9	0·9
48	....	....	....	790	570	....	1340	1180	1300	1450
	....	....	....	5·4	4·0	....	9·8	8·7	9·4	10·5

Tests marked * have been discarded as not being representative of the fuel.

TABLE IV—Continued

Detailed Data and Results of All Tests—Continued

GAS COKE								BY-PRODUCT COKE No. 1		ITEM No.
G-18-A*	**G-29-A**	**G-29-B**	**G-56-A**	**G-34-A**	**G-34-B**	**G-23-A**	**G-56-B**	**G-26-A***	**G-22-A***	1
10–2–23	8–11–24	8–11–24	4–20–25	9–29–24	9–29–24	12–15–23	4–20–25	3–16–24	12–1–23	2
72	96	96	120	96	96	120	66	120	120	3
8	8	8	8	6	6	6	6	8	6	4
9·4	0·6	0·6	0·2	1·0	1·0	0·8	0·2	0·1	0·6	5
11·7	13·0	13·0	12·1	11·3	11·3	13·1	12·1	13·4	12·6	6
1·6	1·9	1·9	1·9	1·9	1·9	1·9	1·9	1·8	1·6	7
77·3	84·5	84·5	85·8	85·8	85·8	84·2	85·8	84·7	85·2	8
10850	12060	12060	12230	12250	12250	11955	12230	11880	11980	9
....	83·2	83·2	84·4	84·5	84·5	....	84·4	....	....	10
....	0·6	0·6	0·6	0·6	0·6	....	0·6	....	....	11
....	13·0	13·0	12·1	11·3	11·3	....	12·1	....	....	12
0·8	1·0	1·0	1·0	1·1	1·1	1·0	1·0	1·9	1·9	13
....	1·1	1·1	1·1	1·1	1·1	....	1·1	....	....	14
....	1·1	1·1	0·8	1·4	1·4	....	0·8	....	....	15
541·0	748·0	761·25	902·0	1048·5	1037·25	1875·0	1007·5	978·75	1904·75	16
60·1	62·3	63·4	60·1	65·5	64·8	93·4	91·6	65·3	95·2	17
7·5	7·8	7·9	7·5	10·9	10·8	15·6	15·3	8·2	15·9	18
2·2	2·3	2·3	2·2	3·2	3·2	4·6	4·5	2·4	4·7	19
12·12	11·45	11·20	10·93	10·82	10·96	11·36	11·76	12·22	12·05	20
0·0	0·0	0·0	11·5	0·0	0·0	52·5	60·5	0·0	38·0	21
92·5	126·5	113·0	105·75	131·0	138·0	219·0	60·25	212·25	269·75	22
92·5	126·5	113·0	117·25	131·0	138·0	271·5	120·75	212·25	307·75	23
342·0	338·0	297·0	260·0	250·0	266·0	290·0	240·0	434·0	323·0	24
17·1	16·9	14·8	13·0	12·5	13·3	14·5	12·0	21·7	16·2	25
28·8	18·4	18·4	12·0	21·8	19·6	17·4	5·5	35·9	17·4	26
132	146	153	120	156	170	154	152	125	154	27
103	119	120	92	122	118	112	109	95	115	28
225	300	295	295	425	410	385	520	280	445	29
62	73	73	72	73	73	....	72	....	....	30
0·008	0·006	0·005	0·011	0·038	0·041	0·058	0·063	0·020	0·077	31
14·7	12·6	13·8	11·9	12·7	11·8	....	11·4	....	....	32
....	6·7	5·6	8·1	6·9	8·3	....	8·2	....	....	33
....	0·7	0·5	0·5	0·2	0·2	....	0·4	....	....	34
....	80·0	80·1	79·5	80·2	79·7	....	80·0	....	....	35
....	15·2	14·3	16·8	15·9	17·2	....	17·8	....	....	36
....	45·9	35·7	62·2	47·8	64·4	....	62·8	....	....	37
62020	68010	70830	68700	100870	98550	137480	129710	66680	131790	38
8250	8730	8930	9140	9240	9120	8800	8500	8180	8300	39
94·0	96·6	96·6	98·1	96·4	96·9	96·8	99·2	91·3	96·9	40
76·0	72·3	74·0	74·8	75·4	74·4	73·6	69·5	68·8	69·3	41
10850	12060	12060	12230	12250	12250	11955	12230	11880	11980	42
8250	8730	8930	9140	9240	9120	8800	8500	8180	8300	43
76·0	72·3	74·0	74·8	75·4	74·4	73·6	69·5	68·8	69·3	
....	60	60	60	70	70	....	70	....	....	44
....	0·5	0·5	0·5	0·6	0·6	....	0·6	....	....	
....	830	760	900	1350	1390	....	1910	....	....	45
....	6·9	6·3	7·4	11·0	11·3	....	15·6	....	....	
690	430	420	240	460	400	400	100	1090	380	46
6·4	3·6	3·5	2·0	3·8	3·3	3·3	0·8	9·2	8·2	
....	430	290	340	130	140	....	290	....	....	47
....	3·6	2·4	2·7	1·1	1·2	....	2·4	....	....	
....	1580	1600	1550	1000	1130	....	1360	....	....	48
....	13·1	13·3	12·6	8·1	9·2	....	11·1	....	....	

TABLE IV—Continued

Detailed Data and Results of All Tests—Continued

ITEM No.	BY-PRODUCT COKE NO. 2						BY-PRODUCT COKE NO. 3				
1	**G-44-A**	**G-75-A***	**G-42-A**	**G-42-B**	**G-15-B***	**G-44-B**	**G-62-A***	**G-72-A**	**G-61-A**	**G-61-B**	**G-62-B**
2	12-15-24	9-30-25	12-1-24	12-1-24	9-30-25	12-15-24	6-8-25	9-9-25	5-25-25	5-25-25	6-8-25
3	120	32	96	96	24	72	120½	32½	96	96	78½
4	8	8	8	8	8	6	8	8	8	8	6
5	0·9	0·6	0·5	0·5	0·6	0·9	0·8	0·5	0·6	0·6	0·8
6	7·4	7·5	8·5	8·5	7·5	7·4	8·2	7·3	6·9	6·9	8·2
7	1·7	2·1	1·7	1·7	2·1	1·7	1·6	1·4	1·7	1·7	1·6
8	90·0	89·8	89·3	89·3	89·8	90·0	89·4	90·8	90·8	90·8	89·4
9	13040	13040	12940	12940	13040	13040	12900	12940	13100	13100	12900
10	87·6	87·7	86·9	86·9	87·7	87·6	87·8	88·9	89·2	89·2	87·8
11	0·8	0·8	0·8	0·8	0·8	0·8	0·6	0·6	0·6	0·6	0·6
12	7·4	7·5	8·5	8·5	7·5	7·4	8·2	7·3	6·9	6·9	8·2
13	0·7	0·7	0·7	0·7	0·7	0·7	1·7	1·7	1·7	1·7	1·7
14	0·8	0·8	0·8	0·8	0·8	0·8	0·9	0·9	0·9	0·9	0·9
15	2·7	2·5	2·3	2·3	2·5	2·7	0·8	0·6	0·7	0·7	0·8
16	836·0	225·5	996·5	997·0	248·0	1030·75	889·0	227·0	1079·75	1063·25	1154·75
17	55·7	56·4	83·0	83·1	82·7	85·9	59·3	56·7	90·0	88·6	88·8
18	7·0	7·0	10·4	10·4	10·3	14·3	7·4	7·0	11·3	11·1	14·7
19	2·1	2·1	3·0	3·1	3·0	4·2	2·2	2·1	3·3	3·3	4·3
20	10·18	10·37	10·34	10·25	9·90	10·57	....	10·50	10·91	11·16	10·83
21	0·0	0·0	5·5	7·0	0·0	9·5	20·25	0·0	34·5	31·25	48·25
22	58·25	20·5	70·0	70·0	15·25	54·75	51·75	15·0	55·75	78·75	40·0
23	58·25	20·5	75·5	77·0	15·25	64·25	72·0	15·0	90·25	110·0	88·25
24	139·0	182·0	152·0	154·0	123·0	125·0	162·0	132·0	167·0	207·0	153·0
25	7·0	9·1	7·6	7·7	6·1	6·2	8·1	6·6	8·4	10·3	8·7
26	14·4	34·8	10·8	9·8	15·9	8·9	16·3	25·2	27·4	34·8	12·0
27	125	135	144	141	157	157	140	142	145	149	178
28	97	108	110	104	120	114	113	116	110	113	132
29	295	235	410	385	310	470	325	250	410	415	525
30	70	71	72	72	71	70	78	76	74	74	80
31	0·008	0·009	0·031	0·041	0·055	0·060	0·025	0·017	0·040	0·042	0·069
32	13·6	15·3	11·9	12·1	13·2	13·5	13·1	12·6	12·8	12·4	13·6
33	6·3	4·4	8·3	8·1	7·2	6·4	6·9	7·2	7·3	7·7	6·5
34	0·5	1·2	0·4	0·3	0·5	0·3	0·5	0·2	0·5	0·4	0·4
35	79·6	79·1	79·4	79·5	79·1	79·8	79·5	80·0	79·4	79·5	79·5
36	15·5	12·9	17·4	17·5	16·0	16·0	16·1	17·1	16·5	16·9	15·7
37	42·4	26·5	64·8	62·2	52·1	43·2	48·5	51·2	52·8	57·3	44·4
38	68400	68000	100300	101340	104350	135400	....	66530	102990	99300	135690
39	9820	9640	9670	9760	10100	9460	....	9520	9160	8960	9230
40	98·6	95·7	98·9	99·0	98·5	99·2	98·2	97·3	97·2	96·0	98·8
41	75·3	73·9	74·7	75·5	77·5	72·5	....	73·6	69·9	68·4	71·6
42	13040	13040	12940	12940	13040	13040	12900	12940	13100	13100	12900
43	9820	9640	9670	9760	10100	9460	....	9520	9160	8960	9230
	75·3	73·9	74·7	75·5	77·5	72·5	....	73·6	69·9	68·4	71·6
44	80	80	90	90	80	90	60	60	60	70	70
	0·6	0·6	0·7	0·7	0·6	0·7	0·5	0·5	0·5	0·5	0·6
45	840	510	1410	1310	920	1530	950	710	1330	1380	1680
	6·4	3·9	10·9	10·1	7·1	11·7	7·4	5·5	10·2	10·5	13·0
46	180	580	150	130	200	110	230	350	380	530	160
	1·4	4·5	1·2	1·0	1·5	0·8	1·8	2·7	2·9	4·1	1·3
47	310	620	280	210	320	190	320	140	330	270	250
	2·4	4·8	2·2	1·6	2·4	1·5	2·5	1·1	2·5	2·1	1·9
48	1810	1610	1340	1440	1420	1660	....	2160	1840	1890	1500
	13·9	12·3	10·3	11·1	10·9	12·8	....	16·6	14·0	14·4	11·6

Tests marked * have been discarded as not being representative of the fuel.

TABLE IV—Continued

Detailed Data and Results of All Tests—Continued

By-product Coke No. 4			American Smokeless, Semi-bituminous No. 1							Item No.
G-80-A	**G-80-B**	**G-81-B**	**G-45-A**	**G-76-A***	**G-82-A***	**G-40-A**	**G-40-B**	**G-76-B***	**G-82-B***	1
11–4–25	11–4–25	12–9–25	1–5–25	10–7–25	12–16–25	11–17–24	11–17–24	10–7–25	12–16–25	2
32	24	18½	120	32	32	96	96	24	24	3
8	8	6	8	8	8	8	8	8	8	4
0·8	0·8	0·5	0·8	1·3	1·0	0·8	0·8	1·3	1·0	5
7·1	7·1	6·8	8·1	8·3	8·7	9·0	9·0	8·3	8·7	6
1·8	1·8	1·1	19·8	20·0	20·1	19·7	19·7	20·0	20·1	7
90·3	90·3	91·6	71·3	70·4	70·2	70·5	70·5	70·4	70·2	8
12960	12960	13120	14060	14120	14180	13930	13930	14120	14180	9
88·6	88·6	89·1	81·0	80·0	80·3	80·1	80·1	80·0	80·3	10
0·7	0·7	0·7	4·5	4·5	4·5	4·5	4·5	4·5	4·5	11
7·1	7·1	6·8	8·1	8·3	8·7	9·0	9·0	8·3	8·7	12
1·5	1·5	1·6	2·8	3·2	2·7	2·7	2·7	3·2	2·7	13
....	....	....	1·4	1·3	1·3	1·3	1·3	1·3	1·3	14
....	....	....	2·2	2·7	2·5	2·4	2·4	2·7	2·5	15
240·0	257·75	287·5	878·75	280·5	244·75	981·0	960·5	287·0	290·25	16
60·0	86·0	95·8	58·6	70·1	61·2	81·7	80·0	95·7	96·8	17
7·5	10·7	15·5	7·3	8·8	7·6	10·2	10·0	11·9	12·1	18
2·2	3·2	4·6	2·1	2·6	2·3	3·0	2·9	3·5	3·5	19
10·83	10·23	11·38	10·79	12·75	11·27	10·91	10·72	12·0	....	20
0·0	0·0	3·75	6·75	0·0	0·0	6·75	11·5	0·0	2·5	21
21·5	15·25	20·75	66·25	45·75	24·25	65·25	60·75	28·25	17·25	22
21·5	15·25	24·5	73·0	45·75	24·25	72·0	72·25	28·25	19·75	23
179·0	118·0	170·0	166·0	326·0	198·0	147·0	150·0	197·0	136·0	24
9·0	5·9	8·5	8·3	16·3	9·9	7·3	7·5	9·8	6·8	25
39·1	27·3	29·3	26·5	58·8	39·4	20·3	13·6	43·4	20·6	26
124	146	152	127	133	114	140	136	152	137	27
94	109	108	99	105	87	107	101	116	97	28
290	290	410	400	325	330	465	440	420	435	29
73	73	76	76	71	75	74	74	71	76	30
0·001	0·058	0·140	0·041	0·034	0·034	0·088	0·063	0·128	0·154	31
14·3	11·8	13·4	9·3	11·5	9·5	9·2	9·7	10·6	10·2	32
5·5	8·3	7·2	10·1	7·9	10·2	10·4	9·5	8·7	9·5	33
0·5	0·5	0·2	0·2	0·0	0·1	0·2	0·3	0·1	0·1	34
79·7	79·4	79·2	80·4	80·6	80·2	80·2	80·5	80·6	80·2	35
14·5	17·6	16·1	20·6	15·2	19·6	20·7	19·7	17·4	19·0	36
35·1	64·8	52·0	89·6	58·4	91·7	95·2	79·8	68·3	80·4	37
69200	104960	136500	67860	68800	67820	93640	93330	99600	....	38
9230	9770	8790	9270	7850	8870	9160	9330	8330	....	39
95·1	97·1	97·0	96·8	86·9	93·8	97·5	98·4	93·0	97·5	40
71·2	75·4	67·0	65·9	55·6	62·6	65·8	67·0	59·0	....	41
12960	12960	13120	14060	14120	14180	13930	13930	14120	14180	42
9230	9770	8790	9270	7850	8870	9160	9330	8330	....	43
71·2	75·4	67·0	65·9	55·6	62·6	65·8	67·0	59·0	....	
70	70	80	480	470	470	500	490	490	490	44
0·5	0·5	0·6	3·4	3·3	3·3	3·6	3·5	3·5	3·5	
760	920	1290	1590	930	1200	1940	1730	1460	1640	45
5·9	7·1	9·8	11·3	6·6	8·5	13·9	12·4	10·3	11·6	
660	380	410	430	1720	820	330	210	920	330	46
5·1	2·9	3·1	3·1	12·2	5·8	2·4	1·5	6·5	2·3	
290	360	130	170	000	80	170	240	70	80	47
2·2	2·8	1·0	1·2	0·0	0·6	1·2	1·7	0·5	0·6	
1950	1460	2420	2120	3150	2740	1830	1930	2850	....	48
15·1	11·3	18·5	15·1	22·3	19·2	13·1	13·9	20·2	....	

TABLE IV—Continued

Detailed Data and Results of All Tests—Continued

Item No.	American Smokeless Semi-bituminous No. 1		American Smokeless, Semi-bituminous No. 2				Alberta Semi-bituminous			
1	**G-83-B***	**G-45-B**	**G-57-A**	**G-69-A**	**G-60-B**	**G-57-B**	**G-55-A**	**G-71-A***	**G-79-A***	**G-48-A**
2	12–29–25	1–5–25	4–27–25	5–18–25	5–18–25	4–27–25	3–30–25	9–2–25	10–28–25	2–2–25
3	24½	78	120	96½	97½	79	120	32	32	96
4	8	6	8	8	8	6	8	8	8	8
5	1·0	0·8	0·6	1·0	1·0	0·6	0·9	0·7	0·9	1·0
6	8·8	8·1	10·0	11·4	11·4	10·0	13·4	13·2	12·7	13·0
7	19·2	19·8	16·0	15·6	15·6	16·0	15·7	16·1	16·4	15·3
8	71·0	71·3	73·4	72·0	72·0	73·4	70·0	70·0	70·0	70·2
9	14130	14060	14020	13750	13750	14020	13300	13260	13310	13340
10	80·2	81·0	80·3	78·8	78·8	80·3	77·7	78·0	78·3	77·9
11	4·5	4·5	4·3	4·3	4·3	4·3	4·1	4·1	4·1	4·1
12	8·8	8·1	10·0	11·4	11·4	10·0	13·4	13·2	12·7	13·0
13	2·7	2·8	1·8	1·7	1·7	1·8	0·7	0·7	0·7	0·7
14	1·3	1·4	1·2	1·2	1·2	1·2	1·3	1·4	1·4	1·4
15	2·5	2·2	2·4	2·6	2·6	2·4	2·8	2·6	2·8	2·9
16	273·0	1041·0	863·25	1042·0	1037·5	1086·75	922·5	255·0	252·25	1088·0
17	91·0	80·1	57·5	86·8	86·5	83·6	61·5	63·7	63·1	90·7
18	11·1	13·3	7·2	10·9	10·6	13·8	7·7	8·0	7·9	11·3
19	3·3	3·9	2·1	3·2	3·1	4·1	2·3	2·3	2·3	3·3
20	11·70	11·30	10·55	11·20	11·03	11·25	11·18	12·00	12·28	11·34
21	2·0	22·5	4·25	0·0	7·75	35·75	16·75	9·5	0·0	55·0
22	23·5	58·75	105·25	128·75	111·25	70·75	150·75	27·75	28·0	82·25
23	25·5	81·25	109·5	128·75	119·0	106·5	167·5	37·25	28·0	137·25
24	187·0	156·0	254·0	247·0	229·0	196·0	363·0	292·0	222·0	252·0
25	9·3	7·8	12·7	12·3	11·5	9·8	18·2	14·7	11·1	12·6
26	20·9	16·4	24·9	25·5	17·3	9·4	49·3	45·8	54·8	30·9
27	130	146	124	140	146	151	117	143	121	146
28	93	107	96	107	111	110	88	117	94	111
29	410	605	380	490	500	600	350	295	285	525
30	69	76	73	73	73	73	72	73	71	75
31	0·132	0·117	0·063	0·107	0·113	0·139	0·031	0·060	0·067	0·049
32	9·6	9·0	8·8	8·9	10·2	11·3	9·7	9·6	8·7	10·6
33	10·2	10·2	10·8	11·1	9·4	8·0	9·8	10·5	11·3	9·0
34	0·1	0·2	0·1	0·1	0·1	0·1	0·1	0·0	0·2	0·0
35	80·1	80·6	80·3	79·9	80·3	80·6	80·4	79·9	79·8	80·4
36	20·1	21·5	21·6	20·8	18·6	17·5	16·8	17·6	18·0	17·1
37	92·0	90·9	102·3	109·4	78·7	59·6	84·7	97·7	114·0	72·7
38	95280	118160	68100	96400	96520	122320	68710	66300	64220	99960
39	8550	8850	9470	8930	9070	8890	8940	8320	8150	8820
40	97·4	98·3	96·3	95·6	97·3	98·8	84·8	87·0	82·2	93·2
41	60·5	63·0	67·5	64·9	65·9	63·4	67·2	62·7	61·2	66·1
42	14130	14060	14020	13750	13750	14020	13300	13260	13310	13340
43	8550	8850	9470	8930	9070	8890	8940	8320	8150	8820
	60·5	63·0	67·5	64·9	65·9	63·4	67·2	62·7	61·2	66·1
44	490	520	460	480	480	500	430	420	420	460
	3·5	3·7	3·3	3·5	3·5	3·6	3·2	3·2	3·2	3·4
45	1640	2730	1590	2060	1910	2210	1120	940	920	1850
	11·6	19·4	11·3	15·0	13·9	15·8	8·4	7·1	6·9	13·9
46	330	230	480	570	350	150	1890	1630	2220	850
	2·3	1·6	3·4	4·1	2·5	1·0	14·2	12·3	16·7	6·4
47	80	180	90	80	80	70	70	....	150	....
	0·6	1·3	0·6	0·6	0·6	0·5	0·6	....	1·1	....
48	3040	1550	1930	1630	1860	2200	850	1950	1450	1360
	21·5	11·0	13·9	11·9	13·6	15·7	6·4	14·7	10·9	10·2

Tests marked * have been discarded as not being representative of the fuel.

TABLE IV—Continued

Detailed Data and Results of All Tests—Continued

ALBERTA SEMI-BITUMINOUS					ALBERTA SUB-BITUMINOUS NO. 1						ITEM No.
G-48-B	**G-72-B***	**G-79-B***	**G-55-B**	**G-71-B***	**G-54-A**	**G-46-A**	**G-46-B**	**G-67-B***	**G-54-B**	**G-68-B***	1
2–2–25	9–9–25	10–28–25	3–30–25	9–2–25	3–23–25	1–19–25	1–19–25	8–5–25	3–23–25	8–12–25	2
96	24½	24	72	18½	104	78	78	24	52	16	3
8	8	8	6	6	8	6	6	6	4	4	4
1·0	1·0	0·9	0·9	0·7	9·0	9·7	9·7	8·2	9·0	8·0	5
13·0	9·1	12·7	13·4	13·2	7·7	8·0	8·0	6·9	7·7	7·0	6
15·8	15·9	16·4	15·7	16·1	32·6	32·2	32·2	34·6	32·6	33·7	7
70·2	74·0	70·0	70·0	70·0	50·7	50·1	50·1	50·3	50·7	51·3	8
13340	13940	13310	13300	13260	11240	11110	11110	11610	11240	11690	9
77·9	81·4	78·3	77·7	78·0	66·2	65·4	65·4	67·4	66·2	67·5	10
4·1	4·3	4·1	4·1	4·1	5·0	5·1	5·1	5·1	5·0	5·1	11
13·0	9·1	12·7	13·4	13·2	7·7	8·0	8·0	6·9	7·7	7·0	12
0·7	0·8	0·7	0·7	0·7	0·3	0·3	0·3	0·3	0·3	0·3	13
1·4	1·4	1·4	1·3	1·4	1·0	1·0	1·0	1·0	1·0	1·0	14
2·9	3·0	2·8	2·8	2·6	19·8	20·2	20·2	19·3	19·8	19·1	15
1071·75	270·75	271·25	1087·75	287·75	1003·0	1174·25	1181·75	334·5	1022·25	309·0	16
89·3	90·3	90·4	90·6	95·9	77·2	90·3	90·9	83·6	78·6	77·2	17
11·2	11·1	11·3	15·1	15·6	9·6	15·1	15·2	13·9	19·7	19·3	18
3·3	3·3	3·3	4·4	4·6	2·8	4·4	4·5	4·1	5·8	5·7	19
11·19	11·52	10·75	11·39	12·59	13·89	15·27	14·90	13·85	14·99	14·33	20
77·5	10·5	2·5	78·0	26·25	16·25	48·75	47·5	6·0	32·75	9·0	21
59·75	21·75	24·0	86·75	22·75	96·75	65·25	61·0	19·0	56·0	23·75	22
137·25	32·25	26·5	164·75	49·0	113·0	114·0	108·5	25·0	88·75	32·75	23
256·0	238·0	195·0	303·0	341·0	225·0	194·0	184·0	149·0	174·0	212·0	24
12·8	11·9	9·8	15·1	17·0	11·3	9·7	9·2	7·5	8·7	10·6	25
20·5	35·2	45·8	20·5	28·3	37·6	22·8	17·9	36·9	26·2	37·6	26
139	157	148	151	170	117	144	141	162	149	175	27
103	123	111	107	131	88	110	104	126	105	133	28
515	455	340	620	520	410	570	575	405	670	575	29
75	74	71	73	74	73	73	73	77	73	75	30
0·066	0·065	0·113	0·107	0·108	0·015	0·058	0·045	0·092	0·078	0·067	31
10·6	13·2	11·2	11·2	12·9	11·3	11·6	10·5	12·2	10·2	12·7	32
8·9	6·8	8·7	8·2	7·1	8·2	7·1	8·3	7·2	9·2	7·0	33
0·1	0·1	0·1	0·0	0·0	0·1	0·5	0·4	0·5	0·1	0·2	34
80·4	79·9	80·0	80·6	80·0	80·4	80·8	80·8	80·1	80·5	80·1	35
17·5	14·6	15·2	16·7	14·4	13·8	12·9	14·7	12·7	15·5	12·6	36
71·4	47·1	69·2	62·0	50·1	62·2	49·4	63·0	51·1	75·4	49·0	37
99850	95900	105000	132630	123570	69450	98560	101690	100600	131100	134800	38
8940	8680	9300	8780	7950	7200	6550	6710	7220	6670	6980	39
96·1	94·5	87·6	96·0	93·9	94·4	97·1	97·9	95·3	96·7	95·1	40
67·0	62·3	69·9	66·0	60·0	64·1	58·9	60·4	62·2	59·3	59·7	41
13340	13940	13310	13300	13260	11240	11110	11110	11610	11240	11690	42
8940	8680	9300	8780	7950	7200	6550	6710	7220	6670	6980	43
67·0	62·3	69·9	66·0	60·0	64·1	58·9	60·4	62·2	59·3	59·7	
460	470	430	480	460	540	590	590	550	600	590	44
3·4	3·4	3·2	3·6	3·5	4·8	5·3	5·3	4·7	5·3	5·0	
1850	1340	980	2190	1540	1120	1570	1770	1000	2220	1510	45
13·9	9·6	7·3	16·5	11·6	10·0	14·1	15·9	8·6	19·8	12·9	
490	720	1550	500	760	670	340	250	580	400	610	46
3·7	5·2	11·6	3·8	5·7	5·9	3·1	2·2	5·0	3·6	5·2	
70	60	60	....	....	60	270	240	260	60	100	47
0·5	0·4	0·5	....	....	0·5	2·4	2·2	2·3	0·5	0·9	
1530	2670	990	1350	2550	1650	1790	1550	2000	1290	1900	48
11·5	19·1	7·5	10·1	19·2	14·7	16·2	14·0	17·2	11·5	16·3	

TABLE IV—Continued

Detailed Data and Results of All Tests—Continued

ITEM No.	ALBERTA SUB-BITUMINOUS No. 2								
1	**G-53-A**	**G-73-A***	**G-81-A***	**G-49-A**	**G-49-B**	**G-65-B***	**G-66-B***	**G-73-B***	**G-53-B**
2	3-16-25	9-16-25	12-9-25	2-9-25	2-9-25	7-2-25	7-31-25	9-16-25	3-16-25
3	104	32	32	66	72½	24	24	24	52
4	8	8	8	6	6	6	6	6	4
5	8·8	7·3	7·9	8·9	8·9	8·0	7·9	7·3	8·8
6	10·3	9·7	10·0	9·3	9·3	9·8	9·9	9·7	10·3
7	34·1	35·7	34·3	34·5	34·5	34·7	34·8	35·7	34·1
8	46·8	47·3	47·8	47·3	47·3	47·5	47·4	47·3	46·8
9	10740	11100	11110	10860	10860	10910	11000	11100	10740
10	63·0	64·6	63·9	63·7	63·7	64·0	64·1	64·6	63·0
11	5·1	5·0	5·0	5·1	5·1	5·0	5·0	5·0	5·1
12	10·3	9·7	10·0	9·3	9·3	9·8	9·9	9·7	10·3
13	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2
14	0·8	0·8	0·8	0·8	0·8	0·8	0·8	0·8	0·8
15	20·6	19·7	20·1	20·9	20·9	20·2	20·0	19·7	20·6
16	1068·5	329·25	329·25	1011·0	1123·5	351·5	353·25	351·75	1094·5
17	82·2	82·3	82·3	91·9	93·6	87·9	88·3	87·9	84·2
18	10·3	10·3	10·3	15·3	15·5	14·6	14·7	14·6	21·1
19	3·0	3·0	3·0	4·5	4·6	4·3	4·3	4·3	6·2
20	15·04	15·15	14·35	15·18	15·82	14·95	14·84	15·0	16·16
21	28·0	4·0	4·5	45·75	63·75	5·25	9·75	14·75	60·5
22	124·75	29·5	38·5	67·0	83·5	32·75	34·25	21·75	83·0
23	152·75	33·5	43·0	112·75	147·25	38·0	44·0	36·5	143·5
24	286·0	203·0	261·0	223·0	262·0	216·0	249·0	208·0	262·0
25	14·3	10·2	13·1	11·1	13·1	10·8	12·5	10·4	13·1
26	35·5	38·3	34·1	20·6	18·2	40·3	40·3	24·1	29·7
27	116	139	119	146	139	155	159	157	149
28	86	113	89	111	102	119	123	122	104
29	410	350	340	595	515	425	420	475	630
30	73	71	74	76	76	73	71	70	74
31	0·014	0·013	0·011	0·058	0·090	0·084	0·073	0·026	0·086
32	10·7	12·3	13·3	12·6	11·1	11·8	12·6	10·9	11·1
33	8·8	7·6	6·3	6·6	8·6	6·4	....	8·6	8·1
34	0·1	0·4	0·2	0·1	0·1	0·6	....	0·2	0·2
35	80·4	79·7	80·2	80·7	80·2	81·2	....	80·3	80·6
36	13·6	11·9	11·2	12·3	13·9	11·9	....	14·1	13·2
37	70·0	55·9	41·9	44·4	67·6	42·1	....	67·5	60·8
38	68310	67870	71700	100870	97900	97990	99140	97670	130210
39	6650	6600	6970	6580	6320	6690	6740	6660	6190
40	93·0	92·8	93·7	97·0	97·5	91·9	91·9	96·3	94·6
41	61·9	59·5	62·7	60·6	58·2	61·3	61·3	60·0	57·6
42	10740	11100	11110	10860	10860	10910	11000	11100	10740
43	6650	6600	6970	6580	6320	6690	6740	6660	6190
	61·9	59·5	62·7	60·6	58·2	61·3	61·3	60·0	57·6
44	550	530	530	590	570	550	550	560	600
	5·1	4·8	4·8	5·4	5·2	5·0	5·0	5·0	5·6
45	1100	800	720	1530	1460	1010	....	1370	1760
	10·2	7·2	6·5	14·1	13·4	9·3	....	12·3	16·4
46	820	870	750	350	300	960	960	450	630
	7·6	7·8	6·7	3·2	2·8	8·8	8·7	4·1	5·9
47	60	190	90	50	60	290	....	110	110
	0·6	1·7	0·8	0·5	0·6	2·7	....	1·0	1·0
48	1560	2110	2050	1760	2150	1410	....	1950	1450
	14·6	19·0	18·5	16·2	19·8	12·9	....	17·6	13·5

Tests marked * have been discarded as not being representative of the fuel.

TABLE IV—Continued

Detailed Data and Results Of All Tests—Continued

ALBERTA SUB-BITUMINOUS NO. 3						ALBERTA DOMESTIC NO. 1				ITEM No.
G-52-A	**G-84-A***	**G-47-A**	**G-47-B**	**G-84-B***	**G-52-B**	**G-51-A**	**G-50-A**	**G-50-B**	**G-51-B**	1
3–9–25	1–14–26	1–26–25	1–26–25	1–13–26	3–9–25	3–2–25	2–16–25	2–16–25	3–2–25	2
104	32	78	78½	24	48	96	60	60	48	3
8	8	6	6	6	4	8	6	6	4	4
10·0	9·7	10·3	10·3	9·7	10·0	18·8	18·7	18·7	18·8	5
10·7	9·4	10·3	10·3	9·4	10·7	7·9	7·5	7·5	7·9	6
32·7	35·7	32·7	32·7	35·7	32·7	30·1	30·2	30·2	30·1	7
46·6	45·2	46·7	46·7	45·2	46·6	43·2	43·6	43·6	43·2	8
10820	11140	10840	10840	11140	10820	9390	9420	9420	9390	9
61·6	62·8	61·7	61·7	62·8	61·6	56·6	57·0	57·0	56·6	10
5·5	5·5	5·5	5·5	5·5	5·5	5·8	5·8	5·8	5·8	11
10·7	9·4	10·3	10·3	9·4	10·7	7·9	7·5	7·5	7·9	12
0·6	0·7	0·6	0·6	0·7	0·6	0·4	0·4	0·4	0·4	13
1·6	1·6	1·6	1·6	1·6	1·6	1·2	1·2	1·2	1·2	14
20·0	20·0	20·3	20·3	20·0	20·0	28·1	28·1	28·1	28·1	15
1021·75	330·75	1239·75	1268·0	351·0	1051·0	1070·0	1038·25	1038·0	1149·5	16
78·6	82·7	95·4	97·5	87·8	87·6	89·2	103·8	103·8	95·8	17
9·8	10·3	15·9	16·1	14·6	21·9	11·2	17·3	17·3	23·9	18
2·9	3·0	4·7	4·7	4·3	6·4	3·3	5·1	5·1	7·0	19
14·46	14·71	16·08	16·26	15·53	16·98	16·03	17·30	16·98	18·25	20
47·75	8·5	88·75	87·0	19·75	72·5	27·0	64·75	31·25	60·0	21
66·25	28·0	52·75	57·5	24·75	42·0	70·0	30·25	51·0	45·75	22
114·0	36·5	141·5	144·5	44·5	114·5	97·0	95·0	82·25	105·75	23
223·0	221·0	229·0	228·0	254·0	218·0	181·0	183·0	158·0	184·0	24
11·2	11·0	11·4	11·4	12·7	10·9	9·1	9·2	7·9	9·2	25
19·2	14·4	17·1	15·7	16·5	16·7	28·0	31·3	26·4	20·5	26
115	118	145	139	130	148	116	129	135	156	27
86	88	111	102	92	104	87	93	98	105	28
380	390	540	580	455	670	370	500	510	615	29
72	68	73	73	68	73	73	75	75	72	30
0·027	0·018	0·048	0·034	0·117	0·077	0·006	0·034	0·076	0·075	31
12·1	14·1	11·6	10·0	12·0	10·3	11·1	13·1	12·1	11·5	32
6·8	4·9	7·2	9·0	7·5	8·2	8·1	5·9	7·2	7·5	33
0·2	0·5	0·5	0·4	0·3	0·3	0·1	0·3	0·2	0·2	34
80·9	80·5	80·7	80·6	80·2	81·2	80·7	80·7	80·5	80·8	35
12·2	10·7	12·5	14·5	12·6	14·1	12·1	10·3	11·2	11·8	36
46·2	29·7	50·5	72·4	54·3	61·3	60·7	37·9	50·7	53·7	37
67920	70240	98820	99300	94110	129030	69510	100060	101840	131150	38
6910	6800	6220	6150	6440	5890	6240	5780	5890	5480	39
96·8	98·1	97·3	97·6	97·7	97·3	95·8	95·4	96·4	97·2	40
63·9	61·0	57·4	56·7	57·8	54·4	66·3	61·4	62·5	58·4	41
10820	11140	10840	10840	11140	10820	9390	9420	9420	9390	42
6910	6800	6220	6150	6440	5890	6240	5780	5890	5480	43
63·9	61·0	57·4	56·7	57·8	54·4	66·3	61·4	62·5	58·4	
590	590	630	640	610	660	620	650	650	680	44
5·5	5·3	5·8	5·9	5·5	6·1	6·6	6·9	6·9	7·2	
900	830	1400	1760	1170	2020	860	1050	1170	1540	45
8·3	7·5	12·9	16·2	10·5	18·7	9·2	11·1	12·4	16·4	
370	230	310	280	270	310	450	490	390	300	46
3·4	2·1	2·9	2·6	2·4	2·9	4·8	5·2	4·1	3·2	
100	210	250	240	150	170	50	120	90	100	47
0·9	1·9	2·3	2·2	1·4	1·6	0·5	1·3	1·0	1·1	
1950	2480	2030	1770	2500	1770	1170	1330	1230	1290	48
18·0	22·2	18·7	16·4	22·4	16·3	12·6	14·1	13·1	13·7	

TABLE IV—Continued

Detailed Data and Results of All Tests—Continued

ITEM No.	ALBERTA DOMESTIC No. 2						ALBERTA DOMESTIC No. 3		
1	**G-39-A**	**G-70-A***	**G-33-A**	**G-33-B**	**G-39-B**	**G-70-B***	**G-38-A**	**G-69-A***	**G-32-A**
2	11–3–24	8–26–25	9–15–24	9–15–24	11–3–24	8–26–25	10–27–24	8–19–25	9–8–24
3	96	30½	66	66	48	15	84	30	65½
4	6	6	5	5	3	3	6	6	5
5	13·2	13·0	12·5	12·5	13·2	13·0	16·7	16·4	16·1
6	12·3	12·7	12·7	12·7	12·3	12·7	7·2	8·0	8·8
7	31·8	33·2	31·9	31·9	31·8	33·2	31·4	31·6	30·9
8	42·7	41·1	42·9	42·9	42·7	41·1	44·7	44·0	44·2
9	9600	9720	9620	9620	9600	9720	9600	9740	9470
10	55·6	55·4	55·7	55·7	55·6	55·4	55·3	55·0	54·6
11	5·4	5·3	5·3	5·3	5·4	5·3	5·7	5·6	5·5
12	12·3	12·7	12·7	12·7	12·3	12·7	7·2	8·0	8·8
13	1·1	1·2	1·2	1·2	1·1	1·2	0·5	0·5	0·5
14	1·3	1·3	1·3	1·3	1·3	1·3	1·2	1·2	1·2
15	24·3	24·1	23·8	23·8	24·3	24·1	30·1	29·7	29·4
16	1047·25	347·75	1135·25	1113·5	1196·0	360·0	972·0	399·75	1127·25
17	65·4	69·6	87·3	85·7	74·8	72·0	69·4	79·9	86·7
18	10·9	11·4	17·2	16·9	24·9	24·0	11·6	13·3	17·2
19	3·2	3·3	5·1	5·00	7·3	7·1	3·4	3·9	5·1
20	16·34	16·35	17·51	17·18	18·76	18·78	16·56	16·41	16·81
21	34·0	7·5	70·0	83·75	104·25	23·75	34·0	11·75	37·5
22	127·75	39·5	107·0	65·25	75·25	21·75	64·75	21·75	52·5
23	161·75	47·0	177·0	149·0	179·5	45·5	98·75	33·5	90·0
24	309·0	270·0	312·0	268·0	300·0	253·0	203·0	168·0	160·0
25	15·4	13·5	15·6	13·4	15·0	12·6	10·2	8·4	8·0
26	24·1	27·5	24·4	16·7	17·1	22·3	30·4	13·6	19·2
27	132	147	155	155	165	172	137	158	159
28	104	120	120	121	120	132	109	129	123
29	360	370	445	405	610	570	340	370	450
30	74	72	74	74	75	76	75	80	71
31	0·024	0·017	0·081	0·043	0·131	0·098	0·018	0·008	0·025
32	9·3	12·4	11·0	10·0	9·1	12·4	9·6	14·5	12·1
33	10·2	7·0	8·0	9·3	10·4	7·3	9·7	4·7	7·0
34	0·2	0·3	0·2	0·3	0·2	0·2	0·3	0·4	0·2
35	80·3	80·3	80·8	80·4	80·3	80·1	80·4	80·4	80·7
36	13·8	10·3	11·8	13·0	14·4	10·5	13·3	9·2	10·9
37	91·6	48·8	59·4	77·0	95·0	52·2	83·1	28·2	48·4
38	66800	69760	98250	98180	132870	127800	69900	81190	102500
39	6120	6120	5710	5820	5330	5330	6040	6090	5950
40	94·8	93·5	94·5	96·6	96·6	95·1	95·9	98·3	97·2
41	63·8	63·0	59·4	60·5	55·5	54·8	63·0	62·5	62·9
42	9600	9720	9620	9620	9600	9720	9600	9740	9470
43	6120	6120	5710	5820	5330	5330	6040	6090	5950
	63·8	63·0	59·4	60·5	55·5	54·8	63·0	62·5	62·9
44	580	570	580	570	630	610	600	590	610
	6·0	5·9	6·0	5·9	6·6	6·3	6·2	6·1	6·4
45	950	740	1050	1030	1850	1250	850	640	990
	9·9	7·6	10·9	10·7	19·3	12·9	8·8	6·6	10·4
46	570	700	600	370	370	520	460	180	300
	5·9	7·2	6·2	3·8	3·9	5·3	4·8	1·8	3·2
47	110	120	100	160	120	80	160	150	90
	1·2	1·2	1·0	1·7	1·2	0·8	1·7	1·5	0·9
48	1270	1470	1580	1670	1300	1930	1490	2090	1520
	13·2	15·1	16·5	17·4	13·5	19·9	15·5	21·5	16·2

Tests marked * have been discarded as not being representative of the fuel.

TABLE IV—Continued

Detailed Data and Results of All Tests—Continued

Alberta Domestic No. 3				Alberta Domestic No. 4				Item No.
G-32-B	**G-74-B***	**G-38-B**	**G-69-B***	**G-37-A**	**G-31-A**	**G-31-B**	**G-37-B**	1
9–8–24	9–23–25	10–27–24	8–19–25	10–20–24	8–25–24	8–25–24	10–20–24	2
65	25	48	15	90	65	65	42	3
5	5	3	3	6	5	5	3	4
16·1	15·1	16·7	16·4	15·9	15·8	15·8	15·9	5
8·8	7·7	7·2	8·0	12·4	11·3	11·3	12·4	6
30·9	33·4	31·4	31·6	28·2	28·7	28·7	28·2	7
44·2	43·8	44·7	44·0	43·5	44·2	44·2	43·5	8
9470	9990	9600	9740	8960	9110	9110	8960	9
54·6	56·2	55·3	55·0	53·9	54·8	54·8	53·9	10
5·5	5·5	5·7	5·6	5·1	5·1	5·1	5·1	11
8·8	7·7	7·2	8·0	12·4	11·3	11·3	12·4	12
0·5	0·5	0·5	0·5	0·2	0·2	0·2	0·2	13
1·2	1·2	1·2	1·2	0·8	0·8	0·8	0·8	14
29·4	28·9	30·1	29·7	27·6	27·8	27·8	27·6	15
1118·0	417·0	1154·75	363·25	1034·75	1175·75	1168·5	1049·75	16
86·0	83·4	72·2	72·6	69·0	90·4	89·9	75·00	17
17·2	16·7	24·2	24·2	11·5	18·1	18·0	25·0	18
5·1	4·9	7·1	7·1	3·4	5·3	5·3	7·3	19
16·56	16·41	18·12	18·64	16·53	17·34	17·45	18·73	20
44·0	18·5	50·0	7·75	29·5	42·0	49·25	76·75	21
47·5	14·75	50·5	24·5	97·25	108·5	107·25	54·5	22
91·5	33·25	100·5	32·25	126·75	150·5	156·5	131·25	23
164·0	159·0	174·0	177·0	245·0	256·0	268·0	250·0	24
8·2	8·0	8·7	8·9	12·2	12·8	13·4	12·5	25
15·2	29·4	22·6	29·4	15·3	14·1	15·7	13·0	26
160	158	177	175	135	164	163	181	27
124	121	123	134	109	128	129	124	28
405	4 0	565	520	365	455	410	640	29
71	71	77	83	73	78	78	74	30
0·019	0·078	0·102	0·063	0·027	0·043	0·045	0·137	31
11·1	12·8	10·1	13·3	9·5	11·4	9·9	9·2	32
7·6	6·6	9 3	6·4	9·7	7·7	9·5	10·1	33
0·6	0·1	0·3	0·2	0·3	0·3	0·3	0·3	34
80·7	80·5	80·3	80·1	80·5	80·6	80·3	80·4	35
11·5	10·8	12·9	9·9	13·3	11·4	13·0	13·8	36
54·9	44·6	77·2	43·0	82·9	56·1	80·2	89·6	37
103900	101500	132770	129930	69580	104300	102920	133520	38
6040	6090	5520	5370	6050	5770	5730	5340	39
97·9	97·6	97·2	95·6	96·9	97·4	97·1	97·4	40
63·8	61·0	57·5	55·1	67·5	63·3	62·9	59·6	41
9470	9990	9600	9740	8960	9110	9110	8960	42
6040	6090	5520	5370	6050	5770	5730	5340	43
63·8	61·0	57·5	55·1	67·5	63·3	62·9	59·6	
600	600	650	630	540	560	550	600	44
6·3	6·0	6·8	6·5	6·0	6·1	6·0	6·7	
920	900	1510	1040	930	1030	1040	1870	45
9·7	9·0	15·7	10·7	10·4	11·3	11·4	20·9	
230	270	310	480	330	180	310	270	46
2·4	2·7	3·2	4·9	3·7	2·0	3·4	3·0	
280	40	160	80	160	140	160	170	47
3·0	0·4	1·7	0·8	1·8	1·5	1·8	1·9	
1400	2090	1450	2140	950	1430	1320	710	48
14·8	20·9	15·1	22·0	10·6	15·8	14·5	7·9	

TABLE IV—Continued

Detailed Data and Results of All Tests—Continued

Item No.	Alberta Domestic No. 5							Welsh Briquettes	Air-dried Machine peat	
1	**G-36-A**	**G-61-B***	**G-74-A***	**G-39-A**	**G-39-B**	**G-36-B**	**G-63-B***	**G-25-A***	**G-78-A***	**G-83-A**
2	10–13–24	6–22–25	9–23–25	8–18–24	8–18–24	10–13–24	6–17–25	2–25–24	10–21–25	12–29–25
3	90½	102½	18	66	65	39½	42	96	30	30
4	6	6	6	5	5	3	3	8	5	2½
5	19·6	19·3	17·3	19·1	19·1	19·6	18·8	1·3	32·0	25·1
6	9·1	7·9	9·7	8·4	8·4	9·1	8·5	10·2	4·3	4·4
7	31·5	32·2	32·1	32·1	32·1	31·5	32·1	12·4	43·1	47·0
8	39·8	40·6	40·9	40·4	40·4	39·8	40·6	76·1	20·6	23·5
9	8700	8880	9020	8840	8840	8700	8860	13380	6630	7350
10	51·6	52·7	52·8	52·5	52·5	51·6	52·6	....	38·7	42·8
11	5·7	5·7	5·5	5·7	5·7	5·7	5·6	....	7·4	7·0
12	9·1	7·9	9·7	8·4	8·4	9·1	8·5	....	4·3	4·4
13	0·2	0·3	0·2	0·3	0·3	0·2	0·3	1·0	0·1	0·2
14	1·0	1·0	1·0	1·0	1·0	1·0	1·0	....	1·1	1·2
15	32·4	32·4	30·8	32·1	32·1	32·4	32·0	....	48·4	44·4
16	1175·0	1340·75	218·0	1224·0	1203·0	1024·0	1059·75	840·0	601·5	592·5
17	78·0	78·9	72·7	87·5	92·5	78·8	75·7	64·6	100·2	49·4
18	13·0	13·1	12·1	17·5	18·5	25·9	25·2	8·8	20·0	19·7
19	3·8	3·9	3·5	5·1	5·4	7·6	7·4	2·6	5·9	5·8
20	18·73	19·69	18·07	18·90	19·19	19·42	21·65	12·18	29·43	25·00
21	12·5	17·25	0·0	32·0	30·25	34·25	28·0	....	0·0	0·0
22	114·5	178·75	16·0	112·5	100·75	56·0	119·25	157·25	25·5	23·5
23	127·0	196·0	16·0	144·5	131·0	90·25	147·25	157·25	25·5	23·5
24	216·0	292·0	147·0	236·0	218·0	176·0	278·0	374·0	85·0	79·0
25	10·8	14·6	7·3	11·8	10·9	8·8	13·9	18·7	4·2	4·0
26	32·4	47·0	43·7	30·6	30·3	21·4	43·2	49·3	23·4	16·7
27	139	142	136	158	160	178	163	126	126	123
28	112	113	109	123	122	128	121	95	97	92
29	375	350	320	450	400	600	525	290	330	325
30	73	71	72	73	73	74	73	....	72	68
31	0·026	0·033	0·052	0·057	0·051	0·098	0·100	0·036	0·039	0·037
32	8·9	11·4	9·3	12·1	12·3	10·5	10·9	....	6·5	10·9
33	9·9	8·0	11·2	7·0	6·9	8·5	8·5	....	14·1	8·9
34	0·4	0·3	0·1	0·3	0·4	0·4	0·5	....	0·1	0·2
35	80·8	80·3	79·4	80·6	80·4	80·6	80·1	....	79·3	80·0
36	13·0	10·2	12·6	10·1	9·9	11·4	10·5	....	14·2	9·6
37	85·6	59·9	113·0	48·5	47·7	65·8	66·4	....	202·0	72·0
38	69350	66440	67020	98120	96420	133500	116480	71870	68080	78980
39	5340	5080	5530	5290	5210	5150	4620	8210	3400	4000
40	93·9	90·4	89·7	94·9	95·0	96·5	91·1	88·8	97·9	98·8
41	61·4	57·2	61·3	59·8	58·9	59·2	52·1	61·4	51·3	54·4
42	8700	8880	9020	8840	8840	8700	8860	13380	6630	7350
43	5340	5080	5530	5290	5210	5150	4620	8210	3400	4000
	61·4	57·2	61·3	59·8	58·9	59·2	52·1	61·4	51·3	54·4
44	610	600	580	630	610	660	630	....	780	740
	7·0	6·8	6·4	7·1	6·9	7·6	7·1	....	11·8	10·1
45	940	680	750	910	780	1440	1140	....	880	590
	10·8	7·6	8·3	10·3	8·8	16·6	12·9	....	13·3	8·0
46	630	1020	1090	540	530	360	940	1440	190	130
	7·2	11·5	12·1	6·1	6·0	4·1	10·6	10·8	2·9	1·8
47	210	120	50	120	160	180	210	....	60	80
	2·4	1·4	0·6	1·4	1·8	2·1	2·4	....	0·9	1·1
48	970	1380	1020	1350	1550	910	1320	....	1320	1810
	11·2	15·5	11·3	15·3	17·6	10·4	14·9	....	19·8	24·6

Tests marked * have been discarded as not being representative of the fuel.

Figure 3 is a graph showing the relation between the quantity of fuel fired per therm delivered to the cooling-water, and the load on the boiler for the anthracites, cokes, and smokeless semi-bituminous coals. It would appear from this graph that it is more economical to operate this type of furnace with these fuels at low and intermediate loads than at high load. In general, little difference can be noted between low and intermediate loads, as some fuels show the operation at intermediate load to be more economical than at low load, and with the others, vice versa, but in no case is the operation of the furnace more economical at high load than at either of the other two.

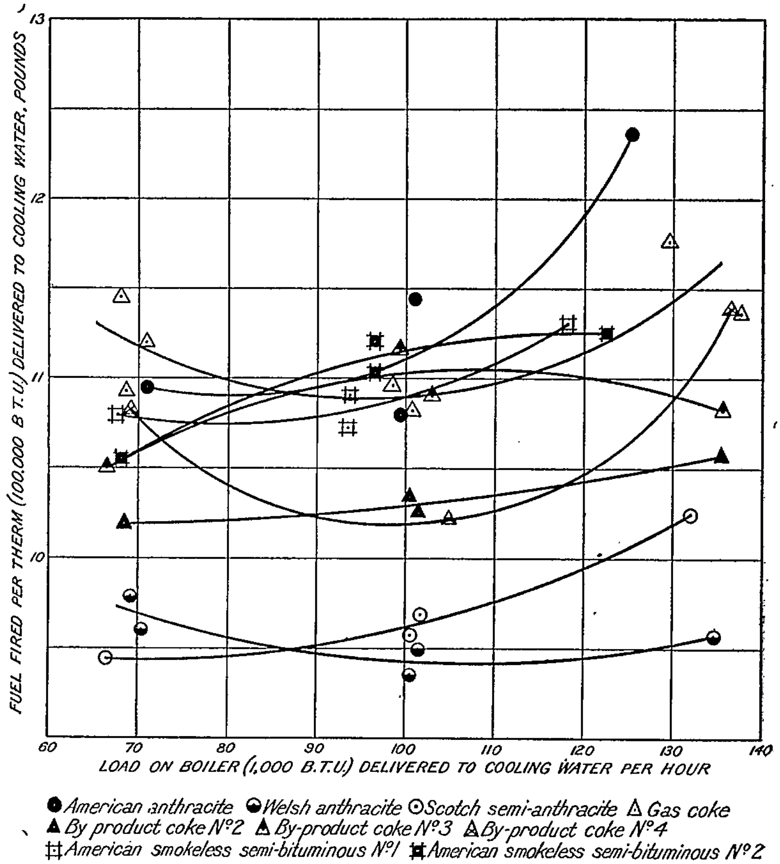

Figure 3. Diagram showing the relation between fuel fired per therm of heat delivered and load on boiler, for the anthracites, cokes, and American smokeless, semi-bituminous coals.

Figure 4 is a graph showing the relation between the quantity of fuel fired per therm delivered to the cooling-water, and the load on the boiler for American anthracite and all the Alberta fuels. It will be noted first that it takes from 25 to 65 per cent more fuel to deliver the same quantity of heat when burning any of the Alberta fuels, with the exception of Alberta semi-bituminous, than it does when burning American anthracite; and second, it is much more economical to operate the furnace at low load when burning Alberta fuels than at either intermediate or high load. This point is shown very clearly by the curves, which all slope up from left to right. From these curves it is seen that Alberta semi-bituminous coal is the equal of American anthracite, when compared on the basis of pounds of fuel fired per therm of heat delivered.

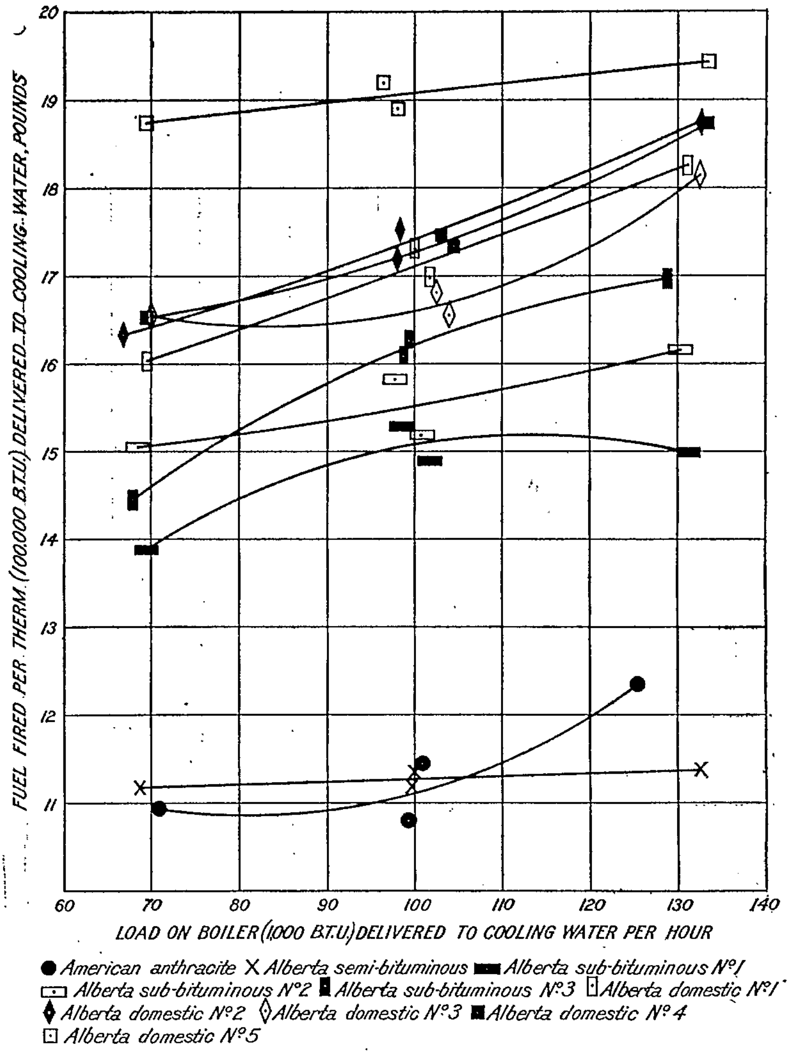

Figure 4. Diagram showing the relation between fuel fired per therm of heat delivered and load on boiler for all the Alberta coals and American anthracite.

Figure 5 is a graph showing the relation between the carbon dioxide content of the flue gas and the excess air. The effect of the dilution of the flue gases by the excess air is clearly shown, and the close proximity of all the points to the curve is, to a certain degree, a measure of the reliability of the flue gas analysis taken during this series of tests.

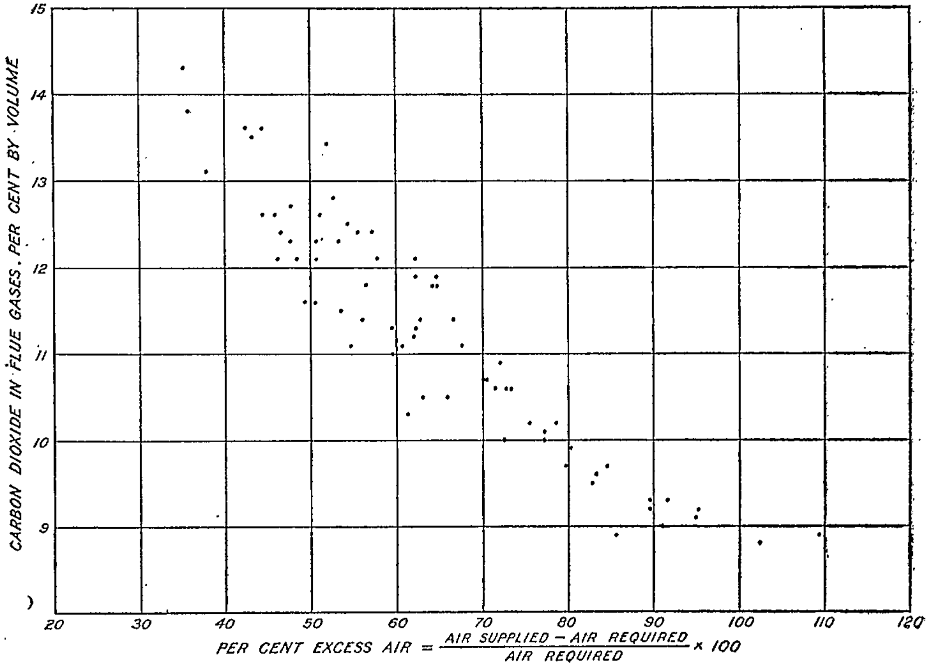

Figure 5. Diagram showing the relation between carbon dioxide content of the flue gas and per cent excess air.

Figure 6 shows the relation between the overall thermal efficiency and the volatile matter content of the fuel. The general slope of the curve is down from left to right, plainly showing that the furnace was much better suited for operation on the low-volatile fuels than on the high ones. The points lie in four approximate groups; one for the cokes, which have the lowest volatile matter content, and the rest in the following order: anthracites, the semi-bituminous coals, and high-volatile Alberta fuels. The irregular relationship of the points derived from the coke and anthracite tests, show in a general way that the furnace was better suited for burning anthracite than for burning coke, and further, the unsuitability of this type of furnace for burning the Alberta fuels is clearly demonstrated. The range of efficiency with the Alberta fuels was from 57½ to 67 per cent, whereas the efficiency with the anthracites ranged from 67 to 77 per cent.

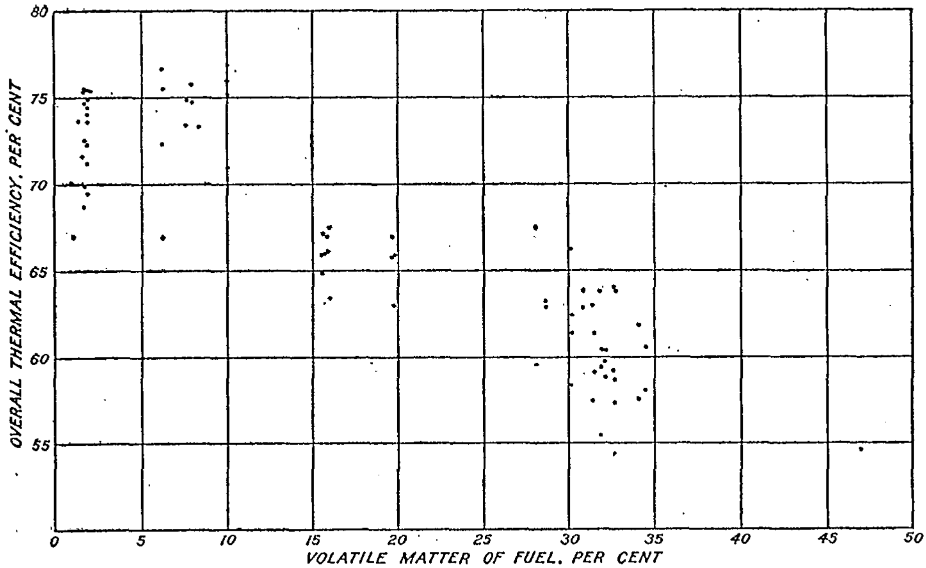

Figure 6. Diagram showing the relation between overall thermal efficiency and volatile matter of fuel.

RADIATION AND UNACCOUNTED FOR LOSS

The radiation and unaccounted for loss determined for the tests on all the fuels, except American anthracite, ranged from 10 to 27 per cent. That part of this loss due to radiation, it was estimated, was in the neighbourhood of 4 or 5 per cent. The remainder, the unknown part, was made up as follows:—

(1) Loss due to errors in judging the fuel bed, i.e. in not bringing the fuel bed at the end of the test to exactly the same condition as at the start.

(2) Loss due to unburned hydrocarbons in the flue gases, such as methane, ethylene, and hydrogen.

(3) Loss due to errors in measuring the temperature in the flue gases at the offtake of the furnace.

In order to determine, if possible, what loss might be expected from the first, a series of six short tests were made to compare the heat content of the fuel bed at the start of each of the tests, and the difference of this heat content between tests should give a measure of the loss due to errors in judging the fuel bed. The six tests were made on two fuels, viz., three on Alberta sub-bituminous coal No. 3, and three on American anthracite. Both furnaces were used and each test was conducted in the following manner:—

A fire was lit in each furnace at 8 o'clock in the evening with the fuel under test. It was replenished once during the night, and at 9 o'clock the following morning the fire was shaken down and brought to the condition that pertained at the start of the regular tests. The condition and depth of the fuel bed were carefully noted. The tests then proceeded as usual, with the exception that no further fuel was added and that readings of the temperatures and quantity of the cooling-water were recorded every 15 minutes until the outlet temperature dropped to within 3 degrees of the inlet temperature, at which time for all practical purposes the fuel bed was burned out. Each test lasted about 7½ hours. All the fuel bed was then shaken down into the ash-pit, the contents of which were carefully weighed, and after being quenched, were sent to the chemical laboratory to be analysed for the combustible matter content.

This procedure was followed with both fuels for the first test, and the procedure for the remaining two on each fuel was the same as that outlined above, with the exception that the test was started with the fuel bed in, as nearly as possible, the same condition as prevailed at the start of the first test.

In each test, the heat delivered to the cooling-water was calculated as usual, and the combustible matter in the refuse, it was estimated, was pure carbon, having a calorific value of 14,500 B.T.U. per pound. From the combustible content given by the chemical analysis, the total heat in the refuse was determined. The total heat of the fuel bed at the beginning of the test was then the sum of the heat transferred to the cooling-water and the heat content of the refuse, plus the following four heat losses: loss due to the sensible heat of the flue gases; loss due to the total heat of steam in the flue gases; loss due to unburned carbon monoxide; and loss due to radiation and unaccounted for. Probably the previous statement may be more clearly expressed in the form of the following equation:

$$\left.\begin{array}{l}\text{Heat content of}\\ \text{fuel bed at start}\\ \text{of test}\end{array}\right\} = \left\{\begin{array}{l}\text{Heat trans-}\\ \text{ferred to}\\ \text{cooling water}\end{array}\right\} + \left\{\begin{array}{l}\text{Heat content}\\ \text{of the refuse}\\ \text{as dumped}\end{array}\right\} + \left\{\begin{array}{l}\text{The four heat}\\ \text{losses men-}\\ \text{tioned}\end{array}\right.$$

Of the three parts constituting the right hand side of the above equation, the first two are determined by the test, and a value is obtained for each directly in B.T.U. in the manner before mentioned; the third will be assumed to be constant for the three tests on Alberta sub-bituminous coal No. 3 and constant for the three tests on American anthracite.

From the above the difference in original heat content of the fuel bed between any two tests of the three on each coal may be found; whence, knowing the calorific value of the fuel, the result was converted into the equivalent of pounds of coal.

The results of these tests show that in judging the fuel bed, in no case was the difference in weight between any two tests on American anthracite greater than 7·1 pounds, and in the case of Alberta sub-bituminous coal No. 3, 15·3 pounds. This difference in estimating the fuel bed would account for an error of not more than 0·7 per cent and 1·5 per cent respectively, provided 1,000 pounds of fuel were burned. The high unaccounted for loss in the majority of the tests must, therefore, be due to other causes.

However, Figure 7 clearly indicates that the radiation and unaccounted for loss is greater for the high-volatile fuels than for the cokes and anthracites. Although an attempt was made to analyse the flue gases for hydrogen, methane, and ethylene, no satisfactory results were obtained. It is the writers' opinion that possibly these high losses were due to faulty measurement of the temperature of the flue gases. The patented fixture at the offtake of the furnace may have caused eddy currents of cold air in the flue gases as they left the boiler, which would prevent the pyrometers from recording the true average temperature of these gases.

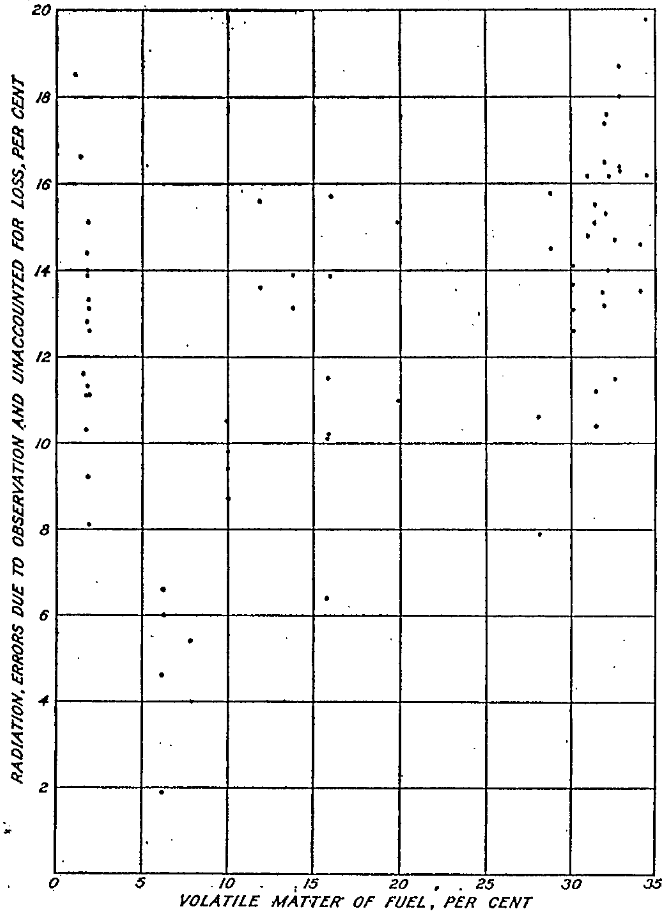

Figure 7. Diagram showing the relation between volatile matter of fuel and radiation, errors due to observation, and unaccounted for loss.

ECONOMIC RESULTS

Table V shows the relative values of the fuels tested, compared with American anthracite, based on quantity of fuel fired to deliver 100,000 B.T.U. to the cooling water of the system. The column headed "equivalent tonnage to 10 tons of American anthracite," is a comparison of all the fuels with American anthracite, on a basis of heat delivery only. This column shows that Welsh anthracite is the most economical fuel and that all the Alberta fuels, with the exception of Alberta semi-bituminous coal, require from 12·96 to 16·73 tons to equal 10 tons of American anthracite.

It must be remembered that this comparison is based on a single series of tests and might not apply to all types of furnaces, although it is safe to take the results of this series as a rough comparison of one fuel with another.

TABLE V

The Relative Values of Various Fuels tested, compared with American Anthracite and based on Pounds of Fuel fired per therm (100,000 B.T.U.) delivered to the Cooling-water of the System

No.	Fuel	Quantity of fuel fired per therm (100,000 B.T.U.) delivered to the cooling-water								Equivalent tonnage to 10 tons of American anthracite
		Values for each of the tests selected for charting and tabulation							Average value	
1	American anthracite	10·95	11·44	10·80	12·36	......	......	......	11·39	10·00
2	Welsh anthracite	9·60	9·78	9·48	9·35	9·57	......	......	9·56	8·39
3	Scotch semi-anthracite	9·44	9·57	9·68	10·24	......	......	......	9·73	8·54
4	Gas coke	11·45	11·20	10·93	10·82	10·96	11·36	11·76	11·21	9·84
6	By-product coke No. 2	10·18	10·34	10·25	10·57	......	......	......	10·33	9·07
7	By-product coke No. 3	*10·50	10·91	11·16	10·83	......	......	......	10·85	9·53
8	By-product coke No. 4	*10·83	*10·23	*11·38	......	......	......	......	10·81	9·49
9	American smokeless, semi-bituminous No. 1	10·97	10·91	10·72	11·30	......	......	......	10·97	9·63
10	American smokeless, semi-bituminous No. 2	10·55	11·20	11·03	11·25	......	......	......	11·01	9·67
11	Alberta semi-bituminous	11·18	11·34	11·19	11·39	......	......	......	11·27	9·89
12	Alberta sub-bituminous No. 1	13·89	15·27	14·90	14·99	......	......	......	14·76	12·96
13	Alberta sub-bituminous No. 2	15·04	15·18	15·82	16·16	......	......	......	15·55	13·65
14	Alberta sub-bituminous No. 3	14·46	16·08	16·26	16·98	......	......	......	15·94	13·99
15	Alberta domestic No. 1	16·03	17·30	16·98	18·25	......	......	......	17·14	15·05
16	Alberta domestic No. 2	16·34	17·51	17·18	16·76	......	......	......	17·45	15·32
17	Alberta domestic No. 3	16·56	16·81	16·56	18·12	......	......	......	17·01	14·93
18	Alberta domestic No. 4	16·53	17·34	17·45	18·73	......	......	......	17·51	15·37
19	Alberta domestic No. 5	18·73	18·90	19·19	19·42	......	......	......	19·06	16·73
21	Air-dried, machine peat	*25·00	......	......	......	......	......	......	25·00	21·95

*Denotes tests of short duration. *See* page 42, paragraphs 3 and 4, for explanation of short and long tests.

III

LOW-TEMPERATURE CARBONIZATION OF BITUMINOUS COALS

R. A. Strong

Investigations pertaining to the carbonization of Canadian coals, conducted in the Fuel Testing Laboratories prior to 1923, and reported in different Mines Branch publications,[1] were confined to the lower grade non-coking coals, namely, the brown lignites of Saskatchewan, and the black lignites and sub-bituminous coals of Alberta, and were carried out according to low-temperature carbonization methods. During 1923 and 1924 considerable attention was paid to the bituminous coking coals of Nova Scotia and New Brunswick, the results of a special investigation, by B. F. Haanel and R. E. Gilmore, being reported under the title of "Coking Experiments on Coals from the Maritime Provinces." [2] This investigation comprised coking experiments on a small-laboratory scale and large-scale tests on car lots in commercial by-product ovens, all of which were carried out according to the high-temperature method used in the city gas and coke industry. In view of the widespread interest in the development of low-temperature methods for the recovery of maximum yields of tar oils, and the production of a suitable coke, attention, during 1925, was paid to the examination of typical bituminous coals according to low-temperature carbonization principles. Only three coking coals (two Canadian and one foreign) have been examined to date, but in order to study the reactions taking place at different temperatures and under different conditions, a series of carbonization tests on each coal was conducted at maximum temperatures of 400°, 500°, and 600° C., according to the regular laboratory low-temperature method, and on one of the coals at several temperatures, first in the presence of steam, and then with recirculation of the uncondensed gases. The two Canadian coals used were "Minto" coal from New Brunswick, and "Sydney" coal from Nova Scotia. Tests were made, for the purposes of comparison, on a standard gas coal, namely "Westmoreland" coal from Pennsylvania.

Altogether, 32 carbonization tests were carried out, duplicate runs being made on the same coal at the same temperature, by the same method of carbonization. The results of these tests are given as a series of tables and are referred to in detail in the discussion.

DESCRIPTION OF COALS AND APPARATUS USED

The Westmoreland coal was obtained from the Ottawa Gas Co.; the sample consisting of several hundred pounds of lumps selected from the stock pile. The sample of Minto coal was taken from a shipment forwarded by the Public Works Department to the Fuel Testing Station for heating

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[1] Mines Branch Summary Reports for 1918 and 1919, and Mines Branch, Investigations of Fuels and Fuel Testing for 1921, 1922, and 1923.

[2] Mines Branch, Dept. of Mines, Canada—Investigations of Fuels and Fuel Testing, 1924.

PLATE III

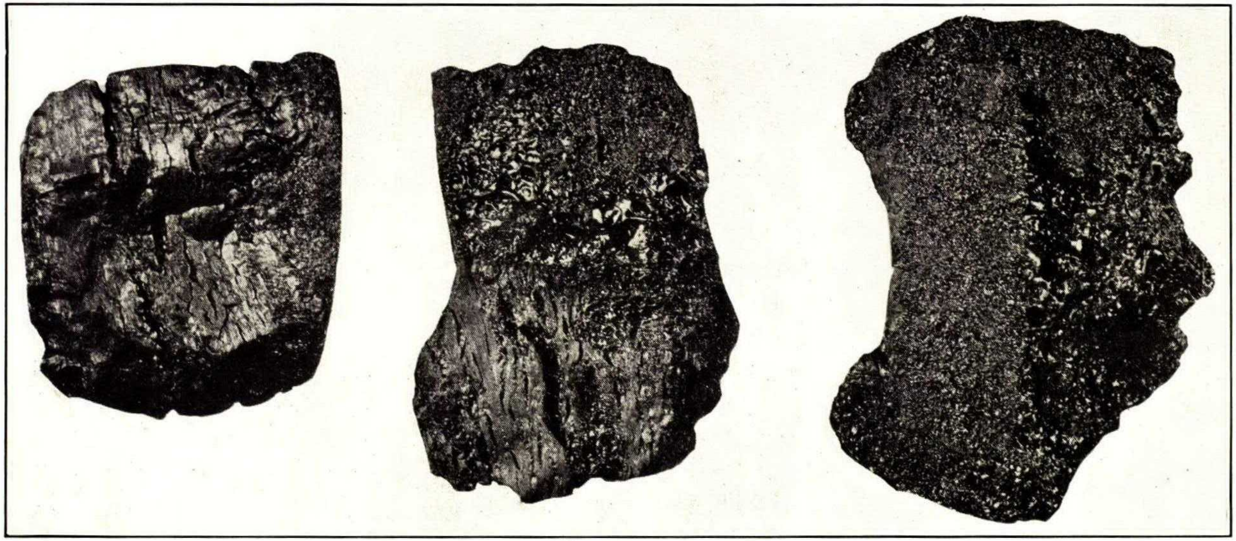

Fig. 1 Fig. 2 Fig. 3

Westmoreland cokes showing changes through which coal passes at carbonization temperatures of 350-370° C. The oil yield at these temperatures was only about a third of the maximum.

Plate IV

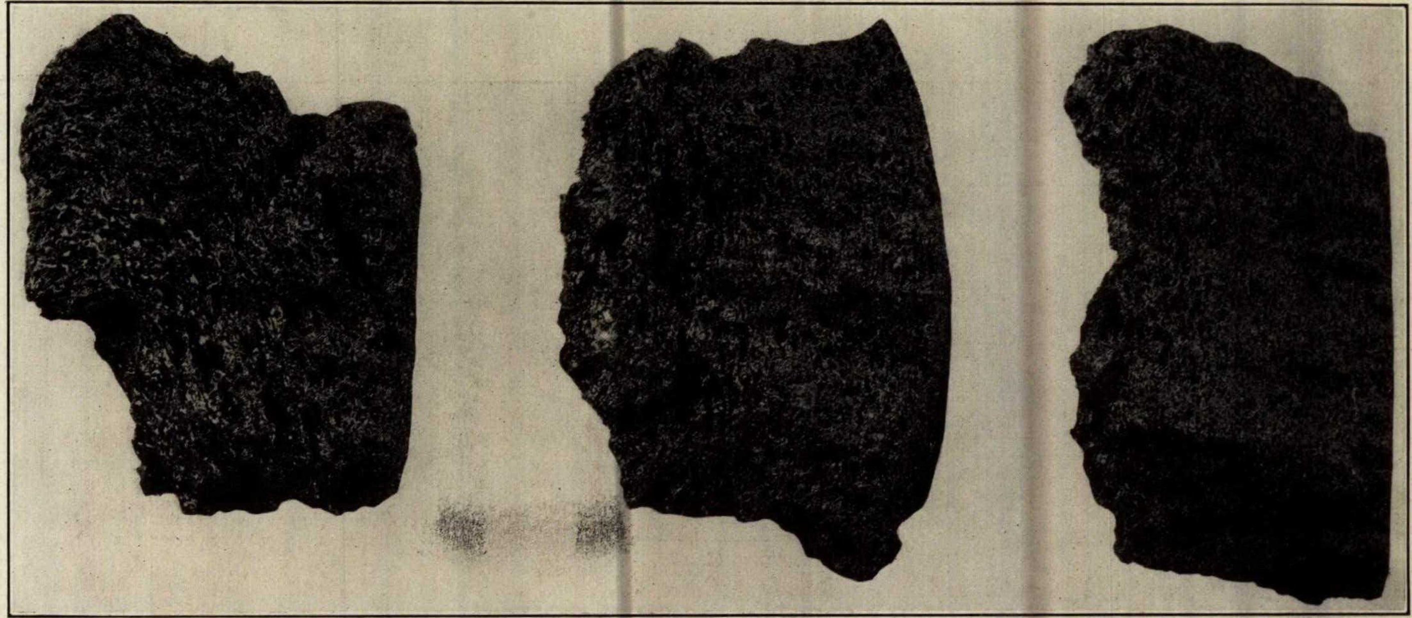

Fig. 1 Fig. 2 Fig. 3

Westmoreland cokes showing the difference in structure resulting from increase in temperature of carbonization. Figs. 1, 2, and 3 being at 400°, 500° and 600° C respectively; the rounded edges to the right having been in contact with the wall of the retort.

PLATE V

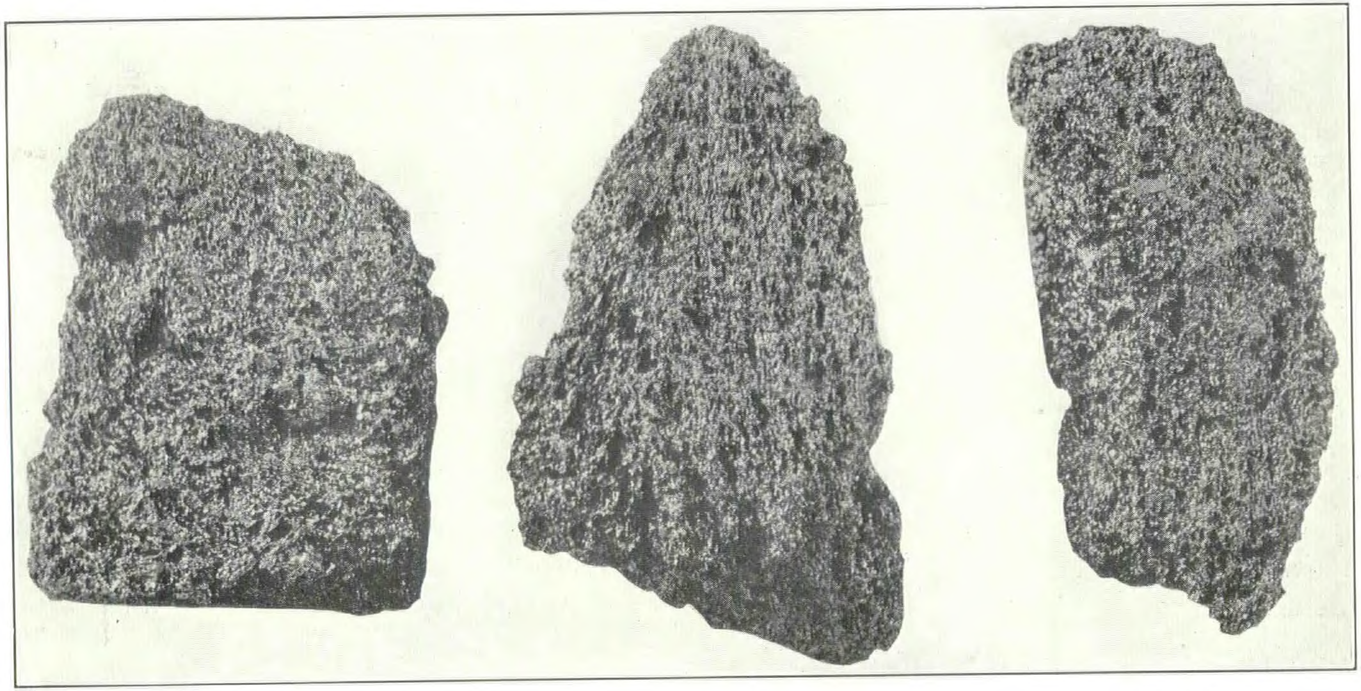

Fig. 1 Fig. 2 Fig. 3

Minto cokes showing the similarity of structure of different temperatures of carbonization; Figs. 1, 2, and 3 being at 400°, 500° and 600° C. respectively. Note that at 500° and 600° C. no appreciable sign of shrinking is evident as with the Westmoreland and Sydney cokes.

PLATE VI

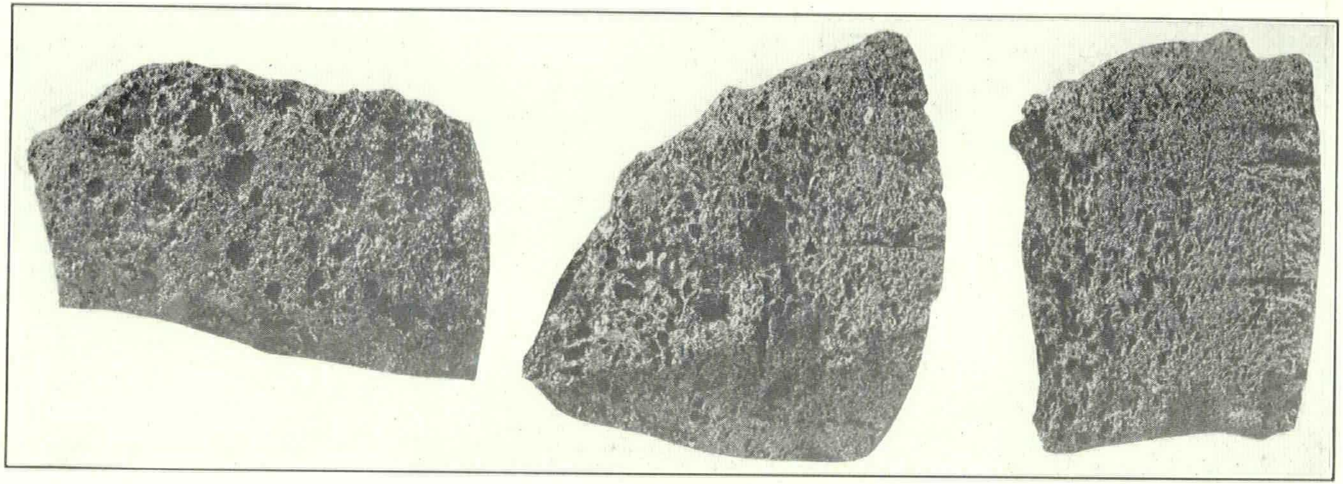

Fig. 1 Fig. 2 Fig. 3

Sydney cokes showing the difference in structure with increase in temperature of carbonization. Note the similarity to Westmoreland coke.

purposes. As a high ash content is characteristic of Minto coal, the sample was washed on a Wilfley table in the Ore Dressing Laboratories for ash reduction. The Sydney coal was shipped by the British Empire Steel Corporation from their washeries at Sydney and represents the coal used by them for the manufacture of metallurgical coke. The analyses of the coals are given in Table VI, page 85, which includes a proximate analysis, calorific value, and ultimate analysis.

The apparatus employed consisted of a circular retort, an electric (lead bath) furnace, an iron, circular condenser, a glass-bead scrubber, two glass condensers, a gas meter and holder, as illustrated in Figure 8.

The retort used for the distillation was circular in section, 6 inches in diameter and 10 inches long. It was provided with an iron flange at the upper end, to which a heavy cast-iron cover was bolted, an asbestos gasket being used to make the joint gas tight. The cover was provided with a gas off-take in which a thermometer could be inserted for obtaining the temperature of the gas on leaving the retort. In order to permit more rapid and uniform heating throughout the charge, a centre core made from a two-inch pipe was placed in the retort which reduced the thickness of the coal layer to two inches. An inlet was provided at the bottom of the retort for the introduction of steam or gas as desired. A piece of flexible steel tubing was connected to this steam inlet which was wound around the retort in the form of a coil. A perforated plate, which also formed the base of the core, acted as a screen to prevent the plugging of the inlet during carbonization.

The retort was heated by immersion in a bath of molten lead, the temperature of which was regulated by electric heaters provided with suitable rheostats, etc. The advantage of this method of heating is apparent inasmuch as the coal is never subjected to a higher temperature than that of the lead which can easily be maintained at the desired point; the coil being immersed in the lead regulates the heat of the circulating steam or gas, thus preventing a cooling of the charge.

OPERATION OF TEMPERATURE CONTROL APPARATUS

Previous to carrying out a carbonization run, the lead is heated to the desired temperature. The immersion of the retort cools the molten lead approximately 100 degrees from which temperature it is brought gradually to the maximum desired and held there as closely as possible until the completion of the run, temperature readings being taken at intervals by means of a pyrometer inserted in the lead.

The coal is first prepared by crushing down to about $\frac{1}{8}$ inch, and after setting aside a portion for analysis, 2,000 grammes are placed in the retort and uniformly distributed about the centre core. The retort is suspended above the bath of lead by means of four hanging rods, bolted to the angle iron frame. By means of a screw jack C. (Figure 8), the bath is raised until the retort A is completely immersed.

The gas leaving the retort A, passes down through the tubular condenser D, which serves to condense the heavy tar and some of the aqueous distillate which is collected in the receiver as shown. The lighter oils and gases pass on through the bead scrubber E, in which they meet a current

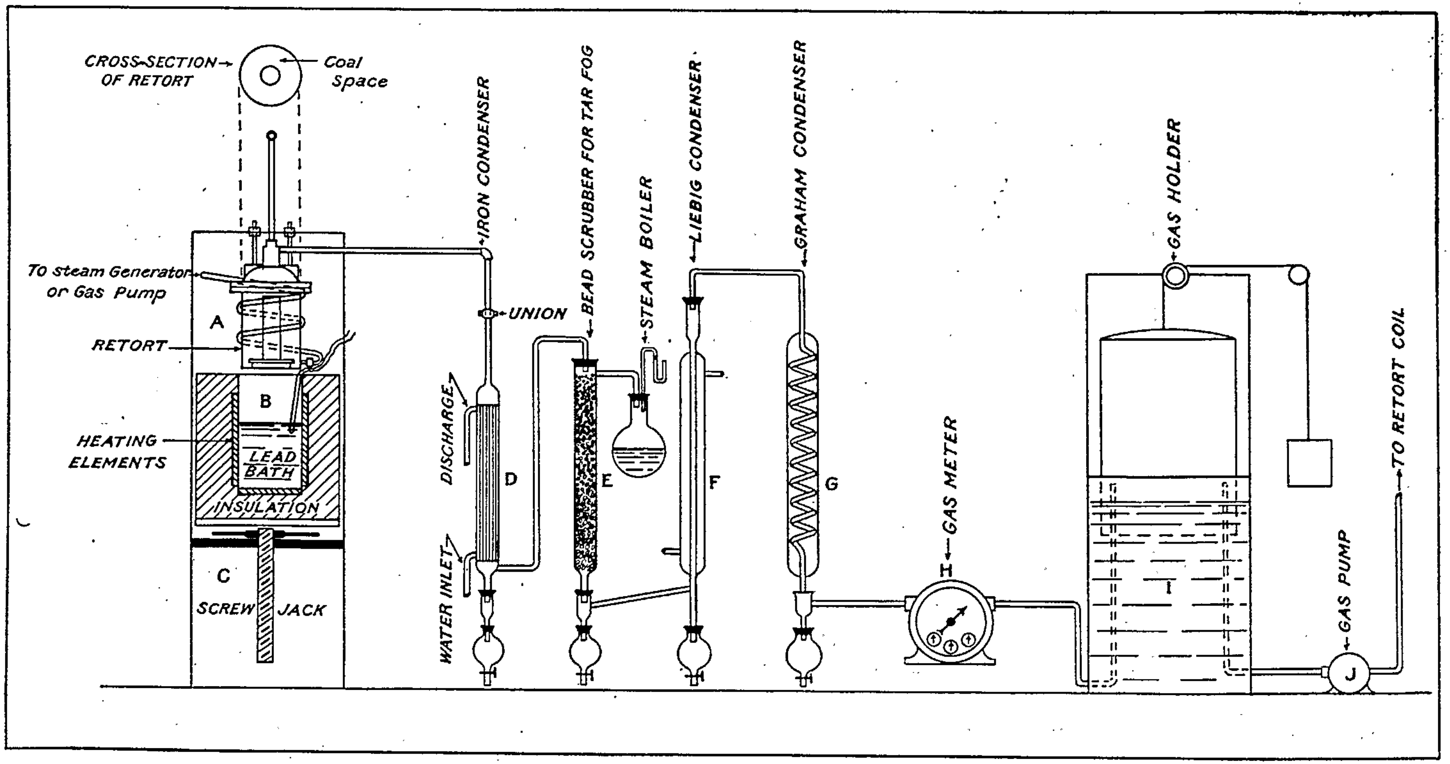

Figure 8. Apparatus for coal carbonization.

of steam which serves to assist in condensing the tar fog and also warms the scrubber causing the condensate to drop to the receiver immediately below. The uncondensed steam and gas passes on up the Liebig condenser F, and down the spiral condenser G, and thence through the meter H, to the holder I.

A data sheet of a typical run, which is inserted as a matter of interest, follows:—

Date—April 26, 1926 Run No.—C—7
Coal—Westmoreland
Conditions—Straight distillation.
Weight of charge—2,000 grammes.
Barometer—29·9 inches.

Time	Temperature		Meter reading	Temperature	Gas flow, cu. ft.
	Lead	Gas			
9.30	740°F	....	54194	....	....
10.00	750	111°C	54433	61°F	0·239
10.30	780	128	54471	62	0·038
11.00	845	192	54532	63	0·061
11.30	895	247	54870	64	0·338
12.00	930	273	54622	64	0·752
12·30	935	287	56625	64	1·003
1.00	940	292	57488	65	0·863
1.30	940	270	57942	66	0·454
2.00	940	257	58357	67	0·415
2.30	945	251	58572	68	0·215
3.00	940	242	58750	68	0·178
3.30	935	234	58868	69	0·118
4·00	935	230	59080	69	0·212
4.30	935	230	59187	69	0·107
5.00	930	228	59301	69	0·114
5.30	930	230	59398	69	0·097
6.00	940	228	59467	69	0·069
6.30	935	225	59514	68	0·047
7.00	940	225	59570	68	0·056
7.30	940	224	59626	68	0·056
8.00	945	224	59680	68	0·054
8.30	940	224	59730	67	0·050
9.00	940	224	59780	67	0·050

The tar and aqueous distillate was collected in four separate funnels as shown in Figure 8. The heavy distillate collected in the first receiver contained the major portion of the tar oils, the second receiver containing the steam condensate and the lighter oils. The distillate in the third receiver was mostly condensed steam with a thin film of very light oil. Practically no distillate was recovered in the fourth receiver, the spiral condenser serving merely to condense the remainder of the steam. The contents of the four glass receivers were placed in a single container and after separation had taken place by standing the aqueous distillate was drawn off. The condensers and scrubbers were washed out with ethyl ether after each run, and after the ether had been evaporated on a steam bath from the washings, the recovered oils were added to the wet tar which was then dehydrated by distillation. Figure 9 is a flow-sheet showing the products of carbonization and the method adopted for their examination.

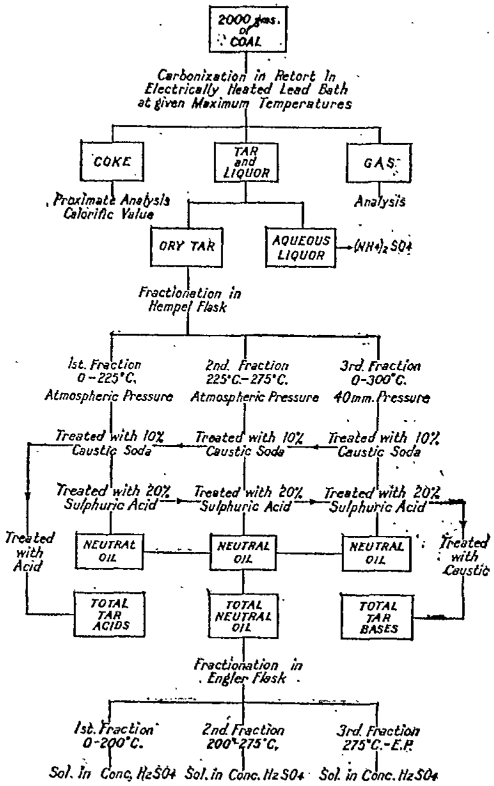

Figure 9. Flow-sheet of products from low-temperature carbonization.

DESCRIPTION OF SERIES OF TESTS CONDUCTED

As previously mentioned, the tests carried out included three series, namely, regular carbonization, carbonization in the presence of steam, and carbonization with the recirculation of the uncondensed gases.

Regular Carbonization

The term regular carbonization as used in this report implies carbonization of the coal according to the regular laboratory method of destructive distillation at atmospheric pressure without the use of steam or circulation of hot gases. After charging the retort with coal and after connecting the off-take to the condenser as shown in Figure 8, the hot lead bath is raised until the retort is completely immersed and the heating continued until the desired maximum temperature is reached. A slight suction is maintained on the system by the weights on the holder in order to better remove the gases as soon as possible after they are generated. Runs at 400°, 500°, and 600° C. were made by this method on the three coals.

Carbonization in the Presence of Steam

In this method the procedure was essentially as described above except that the inlet pipe, in the form of a coil surrounding the retort, was connected to a steam supply and a current of steam passed through the retort as soon as the retort was immersed in the bath of molten lead and generation of the gases had commenced. For the generation of steam a small flask was employed, the steam consumption being the difference between the weights of the flask before and after the experiment. The amount of steam used averaged 1,500 grammes per 2,000 grammes of coal carbonized. Runs at 350°, 400°, 420°, 500°, and 600° C. were conducted on the Westmoreland coal. It was intended to make the same tests on the two Canadian coals but lack of time prevented. The results, discussed below, indicate that the value of this method of procedure is problematical and little would have been gained by repeating the steam circulation tests on the Canadian coals. The reason for the selection of so low a temperature as 350° C. was that claims have been made by different inventors that bituminous coal can be treated at this temperature in the presence of circulating steam or gas to give commercial yields of tar oils and leave a coke residue only slightly altered in appearance from the original coal. For carbonization runs at this temperature lump coal was used.

Carbonization with Circulation of Hot Gases

Carbonization was made in the presence of the uncondensed gases after they have been passed through the condensing train. For experimental runs by this method the suction side of a vacuum pump was connected to the outlet of the gas holder, and the pressure side to the retort inlet previously used for the steam, a valve being used to regulate the quantity of gas circulated. The procedure was identical with that used for steam distillation, the retort being charged, immersed in lead and when a sufficient quantity of gas had been generated the pump was started and circulation continued until the end of the run. With Westmoreland coal, runs were made at 400° and 600° C. Owing to the similarity of the results with those obtained by carbonizing in the presence of steam, tests were run at these two temperatures only and the method was not used with the two Canadian coals.

Determination of Fusing Temperature

In view of the difference in appearance of the charge after carbonization at the various maximum temperatures it seemed advisable to determine the exact temperature at which the different coals became plastic or started to fuse. The temperature at which the tar first appears might give an indication of this, but in the method employed no accurate record of such appearance could be determined owing to the lead bath having been heated considerably above this point previous to the retort being immersed. In order to obtain this information a series of experiments were carried out with the different coals at various temperatures as follows:—

Samples of the three coals were crushed to 8 mesh and approximately 4 grammes placed in a pyrex test tube. A bath of lead was heated to the desired temperature and the test tube was gradually lowered into the molten lead until the coal was completely immersed. The temperature was recorded by a Leeds and Northrup potentiometer-type pyrometer which had been previously checked against a standard thermometer. Readings were taken at intervals during immersion which was continued for 30 minutes. Experiments were made varying the time factor to 1 hour without change of result.

The fusion temperature was taken to be that temperature at which the coal particles definitely adhered together and assumed the form of the tube, although the outline of the individual particles could still be distinguished; when the temperature was raised 10 or 15 degrees above this point, the coal assumed a porous coke-like structure in which the individual particles could not be distinguished. The fusion of the coal particles was unaccompanied by swelling until the coal mass had assumed the coke structure.

The following table contains the results of the experiments. It will be noted that Sydney coal fused at 380° C. or 20 degrees higher than Minto and Westmoreland, both of which fused at 360° C.

Coal	Temperature			
	350° C	360° C	370° C	380° C
Westmoreland........	Slightly sticky	Definitely fused		
Minto................	Slightly sticky	Definitely fused		
Sydney..............	No trace of fusion	No trace of fusion	Slightly sticky	Definitely fused

EXAMINATION OF PRODUCTS AND DISCUSSION OF RESULTS

The four products obtained by carbonization, viz.: coke, tar, aqueous distillate, and gas were examined separately as outlined in Figure 9. The cokes were carefully removed from the retort, weighed and, after retaining a sample for physical examination, were crushed for chemical analysis. The yield and analyses of the cokes are given in Tables VII, XVII and XXVII (pages 86, 93, 97). The tables also include the proximate analysis of the coal charged, the quantity of gas recovered, the amount of tar in Imperial gallons per ton, and the quantity of aqueous liquor and the ammonium sulphate obtainable therefrom. These results are again reviewed in the form of a weight balance, i.e. parts by weight per 100 parts of coal, in Tables VIII, XVIII, and XXVIII (pages 87, 93, 97).

The analysis of the tar, shown in Tables X, XX, and XXX (pages 88, 94, 98) includes boiling range, specific gravity, and calorific value. The results of treatment of the various fractions obtained from the Hempel distillation of the tar are given in Tables XII, XXII, and XXXII (pages 89, 95, 99), and the boiling ranges of the neutral oils are shown in Tables XIII, XXIII, and XXXIII (pages 90, 95, 99). The tar acids were recovered as shown in the flow-sheet and distilled, the boiling ranges being shown in Tables XIV, XXIV, and XXXIV (pages 90, 95, 100).

The gases were analysed and the results are shown in Tables XI, XXI, and XXXI (pages 89, 94, 99). The remaining tables show the thermal balance or the percentage of heat in the products as a percentage of the heat of the original coal and the commercial yields of products obtainable from the various low-temperature tars.

Nature of the Coke at Different Temperatures

It has been noted by certain investigators[1] that swelling of the charge presents one of the greatest difficulties in the applicability of low-temperature carbonization processes. The observations made by the writer confirm the above statement, although the three coals examined behaved somewhat differently and yielded decidedly different cokes, the difference being mainly in colour, lustre, and porosity.

Cokes from Westmoreland Coal. In the case of the Westmoreland coal carbonized in the presence of steam at 350° C., it was found on opening the retort that a few lumps on the top showed very little signs of having been affected, but the majority of the lumps had cracks along the cleavage planes. The larger part of the charge was fused to a solid mass of very porous swollen coke. The perforations in the bottom plate of the centre core were filled with globules of a black friable substance resembling carbonized tar. At the temperature of 400° C. the charge was found to be a solid mass, very much swollen. The coke adhered to the walls of the retort and it was necessary to break it up in order to empty the retort. The perforations in the bottom plate were again filled with needle-like formations of carbonized tar and a considerable amount of this substance was found on the bottom of the retort. The swelling represented about a 20 per cent expansion. At 500 ° C. a considerably different structure was noted. At this temperature the Westmoreland coal apparently begins to shrink, and the appearance of the charge indicated that the coal had first risen to the level noted at 400° C. and then had shrunk in the centre, leaving a deep crater-like depression converging from the outer walls to the centre core. The appearance of the coke was black and porous as in the previous experiments, the charge adhering to the walls of the retort. The coke from the carbonization test at 600° C. showed signs of considerable swelling, subsequent shrinking being apparent at the centre as described above. The appearance of the coke, however, was quite different, being greyish in colour and quite dense. It was hard and brittle and did not adhere to the walls of the retort. The coke mass exhibited a number of fractures forming triangular sections which converged at the centre. The structure was more porous at the centre core than at the outside. Distilling with steam or with recirculation of the gas gave cokes of practically the same nature as described above.

Cokes from Minto Coal. The Minto coal behaved quite differently from the Westmoreland. At 400° C. the charge gave evidence of shrinking and a shiny black layer, resembling carbonized tar, was present on top of the charge. The coke was not so porous as the Westmoreland coke made at the same temperature, but was quite soft, black in colour, but not so lustrous in appearance. At 500° C. the charge was considerably swollen and adhered to the walls of the retort. The coke was black and was not so porous as the Westmoreland coke. At 600° C. a very marked difference was noticed between the Minto and the Westmoreland cokes. In the case of the Minto, the charge was swollen to such an extent as to completely fill the retort and almost block the gas off-take. The coke was more porous than at 500° C. and was quite black in colour. It adhered strongly to the walls of the retort and had to be broken up in order to be removed.

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[1] Lewis: The Carbonization of Coal.
Wellington and Cooper: Low-Temperature Carbonization.

Cokes from Sydney Coal. The Sydney coal behaved quite differently from the Minto coal and resembled more closely the Westmoreland coal. At 400° C. there was no sign of swelling. The surface of the charge was level as with the Minto coal, and the structure was more porous, but not so much so as the coke from the Westmoreland coal. No evidence of stoppage in the holes in the bottom plate was noted. At 500° C. the charge was considerably swollen, but there was evidence of shrinking commencing to take place. The charge had risen in the retort, but a slight crater-like depression was seen at the centre. The coke was black and porous, and was lustrous in appearance. At 600° C. the charge was decidedly shrunken and the depression in the centre was very marked. The charge had also loosened from the walls of the retort. The appearance of the coke was very similar to the Westmoreland coke at the same temperature, being quite dense and greyish in appearance, more nearly resembling the metallurgical product.

It was quite evident that there was a vast difference in the behaviour of the three different coals at the temperatures employed, and the above observations indicate that from a standpoint of coke structure a Sydney coal is more suited to low-temperature treatment than is Minto coal. Plates III to VI show the structure of the various cokes obtained.

Coke Analyses

The analyses of the cokes are given in Tables VII, XVII, and XXVII (pages 86, 93, 97). In the case of the Westmoreland coal the samples were not at all uniform, as is evident from the variation in the ash content. The original sample, secured from the Ottawa Gas Co., consisted entirely of lumps and as it was desired to carbonize at the lower temperature in lump form, the entire sample was not crushed and thoroughly mixed as was the case with the Minto and Sydney coals.

Coke resulting from carbonization at 400° C. still contained considerable volatile matter, the average for the cokes at this temperature from the three coals being about 22 per cent. Carbonization at 500° C. reduced the volatile matter to between 10 and 11 per cent, and at 600° C. it had been lowered to 7 and 9 per cent. Davis and Berger,[1] working at 600° to 650° C., obtained cokes with volatile matter contents as low as ·2 and 3 per cent which indicates either that the volatile matter drops rapidly as the temperature of carbonization increases above 600° C. or that the temperature during carbonization was greater than indicated and reported. The writer is inclined to believe that the latter is the case, and in this connexion it would be of interest in future work to carry out carbonization runs say at 650° C., 700° C. and higher, in order to find out the volatile matter content of cokes at these temperatures.

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[1] Davis, J. D., and Berger, H. G.: "The Yield and Quality of the Gas, Oil and other By-products of the Constituents of the Freeport Coal Bed, Pennsylvania." Bull. 1, Carnegie Institute of Technology, 1922.

The following table gives the results of carbonization experiments with respect to volatile matter and shows the increase in fuel ratio of the coal and coke:—

Coal	Temperature of carbonization	Volatile matter, %		Fuel ratio	
		Coal	Coke	Coal	Coke
	°C.				
Westmoreland	400	34·9	22·0	1·6	3·1
	500	34·0	10·8	1·6	7·4
	600	34·7	7·1	1·7	11·9
Minto	400	34·5	22·3	1·6	3·1
	500	34·3	11·2	1·6	7·0
	600	34·0	8·7	1·7	9·2
Sydney	400	33·1	22·6	1·8	3·2
	500	33·1	11·6	1·8	7·2
	600	32·9	7·6	1·9	11·4

The high percentage of volatile matter shown in the cokes at 400° C. would indicate that they would not be entirely smokeless when burnt. This was borne out by both the colour of the flame and the presence of black smoke during the determination for volatile matter. The residue from the volatile determination was in the form of an agglomerate, indicating that at 400° C. the coke still had a tendency to further fuse and coke. This was still more pronounced with the residue from the experiments at 350° C., and would indicate that at these temperatures the coking properties of the coals tested were not destroyed. The cokes from the runs at 500° and 600° C. were in all cases free-burning and smokeless.

The following table shows the calorific value of the cokes obtained at the different maximum temperatures of carbonization as compared with that of the coal (on the dry basis) from which the cokes were made.

Coal	Temperature of carbonization	Calorific value—B.T.U.		Difference between coal and coke
		Coal	Coke	
	°C.			
Westmoreland	400	13,865	13,890	+ 25
	500	13,770	13,290	−480
	600	14,130	13,530	−600
Minto	400	13,875	13,760	−115
	500	13,846	13,250	−596
	600	13,855	13,240	−615
Sydney	400	14,180	14,375	+195
	500	14,300	14,125	−175
	600	14,215	14,045	−170

It will be noted by referring to the above table that the calorific value of the coke carbonized at 400° C. was practically the same as the coal from which it was made, but at the higher temperatures, the heating value of the coke was appreciably lower, the average difference at 500° and 600° C. for Westmoreland and Minto coals being 538 and 607 B.T.U. respectively.

As previously noted the cokes obtained from the carbonization experiments of all three coals at 400° C. and 500° C. were porous and friable; this was also true of the coke made from Minto coal carbonized at 600° C. In this respect they are quite different from the high-temperature cokes and would require a greater storage space if used as substitutes for anthracite coal. The following table shows the apparent density of the cokes from the various coals at different temperatures as compared to coke made from the same coal at high temperatures.

Coke	Westmoreland	Minto	Sydney
400°C.	0·77	0·73	0·67
500°C.	0·84	0·62	0·66
600°C.	0·80	0·76	0·70
Sydney by-product	....	....	0·83
Minto by-product (from unwashed coal)	....	1·09	
Ottawa gas (from Westmoreland coal)	0·86		

Examination of the Crude Tar Oils

The tar recovered from the distillation of the coals was first dehydrated and the weight of dry tar recorded. The gravity was then determined on a Westphal balance and a sample taken for a calorific value determination. The remainder of the tar was used for distillation and examination according to the flow-sheet shown in Figure 9.

Dehydration. The liquor and tar as previously mentioned was collected into a single separatory funnel in order to draw off the aqueous liquor. On standing only, a distinct separation was very difficult to obtain, but by the addition of a hot solution of sodium sulphate a distinct and rapid separation of tar and liquor could be made. By this method the water content of the crude tar oils was reduced to approximately 2 per cent, the tar being finally dehydrated, without excessive frothing, by distilling in an ordinary Engler flask. The tars obtained by steam distillation and by gas circulation invariably retained more water than those obtained by regular distillation and were more inclined to froth during dehydration, due apparently to their higher content of free carbon.

Yields of Tar Oils at Different Temperatures of Carbonization. The yields of dry tar recovered are shown in Tables VII, XVII, and XXVII (pages 86, 93, 97). In the case of the Westmoreland coal, the yield is progressively greater with the increase of temperature to 500° C. A further increase to 600° C. apparently gave no increased yield. Both at 400° and at 500° C., the use of steam seemed to increase the yield of tar, but at 600° C. the increase was not apparent. At 400° C. the recirculation of the gas gave a yield approximately equal to that of steam, but at 600° C. the yield had fallen off. However, it is more than likely that the decline is due to some other factor rather than to the method. The lower yields at 600° C. may be due to tar fog and light oils carried over with the gas, and not condensed, which loss would be greater in the gas circulation runs. Had the gases been scrubbed by activated charcoal or some other efficient means it is more than likely that the comparative oil yield would have been different. As it is, any light oil vapour carried over has the effect of giving a gas of higher calorific value than when the gases are specially scrubbed after ordinary condensing. The condensing train in the laboratory apparatus was, however, quite efficient and the comparative results reported can, in the opinion of the writer, be interpreted as applying directly to large-scale conditions.

In the case of Minto coal, the tar yield at 400° C. was about 50 per cent of that obtained at 500° C., at which temperature practically the same amount of tar was obtained as at 600° C. Sydney coal gave a distinctly different result. The yield at 400° C. was only 35 per cent of that obtained at 600° C., and at 500° C. only 60 per cent of the total was recovered. The difference in behaviour of these coals with regard to the coke and to the fusion temperature has been previously noted.

The following table summarizes the yields of tar and compares the yields by regular distillation with those obtained by steam and gas circulation. The results are given in parts by weight for 100 parts of coal.

Coal	Regular distillation			Steam distillation			Gas circulation	
	400°C.	500°C.	600°C.	400°C.	500°C.	600°C.	400°C.	600°C.
Westmoreland	5·7	11·2	12·8	6·7	12·7	12·7	6·1	11·4
Minto	4·8	10·0	10·4	....	....	....	....	....
Sydney	4·5	7·2	12·3	....	....	....	....	....

Density of Tar Oils. The specific gravities of the tars are shown in Tables X, XX, and XXX (pages 88, 94, 98). The lightest tar was obtained from Minto coal at 400° C., and the heaviest from Westmoreland coal at 600° C., with circulation of steam. The Minto coal yielded the lightest tar at the three different temperatures, and the Sydney was the heaviest. The Minto tars were all below 1·000 becoming progressively heavier with increase in the distillation temperature. In the case of the Sydney coal it will be noted that the tar from the 400° C. runs had approximately the same specific gravity as from the 500° C., but at 600° C. the tar became quite heavy. The Westmoreland tar occupied an intermediate position between the Minto and Sydney tar in respect to specific gravity when considering regular distillation only. The steam distillation and the recirculation of gas tended to produce a heavier tar.

The following table shows the gravity of the tars obtained by regular distillation of the coals at the various maximum temperatures employed and also shows the effect of steam and gas circulation on the gravity of tar from Westmoreland coal.

Coal	Regular distillation			Steam distillation			Gas circulation	
	400°C.	500°C.	600°C.	400°C.	500°C.	600°C.	400°C.	600°C
Westmoreland	0·957	1·004	1·009	0·987	1·022	1·033	0·985	1·037
Minto	0·928	0·968	0·985	....	....	....	....	....
Sydney	0·973	0·972	1·031	....	....	....	....	....

Examination of the Gas

The gas was collected in a holder and stored over water, from which a sample was drawn off for analysis. The apparatus used for the gas analyses was the Morehead, which was found to combine accuracy, rapidity, and ease of manipulation to the highest degree. No provision was made for determining the ethane content of the gas, but since completing the experiments, the apparatus has been modified in order to make this determination possible so that in future work it will be included.

Leaks in the gas pump prevented a correct measurement of the gas in gas circulation runs; gas analyses were, therefore, not made. The other results are given in Tables XI, XXI, and XXXI (pages 89, 94, 99). It will be noted that the hydrogen content was very small at both 400° and 500° C., but beyond these temperatures there was a decided increase. This is true in the case of both Westmoreland and Minto coals, but the Sydney coal shows a different result, the hydrogen content of the latter being practically equal at 400° and at 600° C., whereas at 500° C. a considerably lower result was obtained. No reason can be assigned for this variation.

The use of steam resulted in an increased gas yield and a lower calorific value both at 400° and 500° C. However, at 600° C. the yield of gas was the same as in the regular runs, but the calorific value was again lower. This is probably accounted for by the steam assisting in the more complete condensation of the tar fog. The yield of gas increased, as was expected, with the temperature, the amount varying from 900 to 1,000 cubic feet per ton at 400° C. to 3,500 to 4,000 cubic feet at 600° C. The yields, calorific value, density, etc., of the various gases are shown in Tables VII, XVII, and XXVII (pages 86, 93, 97). The following table compares the yields of gas in cubic feet per ton from the coals at the various temperatures used and also shows the hydrogen and methane content of the gas by regular distillation and by steam circulation.

Coal	Temperature of carbonization	Yield		Analysis			
				Regular		Steam	
		Regular	Steam	Hydrogen	Methane	Hydrogen	Methane
	°C						
Westmoreland........	400	1,067	1,125	0·0	68·6	0·3	52·8
	500	2,482	2,838	0·0	60·4	0·3	54·9
	600	4,058	4,059	18·2	60·3	14·3	52·8
Minto................	400	997	....	0·0	68·0	....	....
	500	2,583	....	1·6	69·1	....	....
	600	3,400	....	10·3	59·7	....	....
Sydney..............	400	900	....	11·3	56·4	....	....
	500	2,768	....	6·3	62·8	....	....
	600	3,527	....	10·5	54·6	....	....

Ammonia from the Aqueous Distillate

A definite amount of the aqueous distillate which had been separated from the tar was made alkaline with caustic soda, and the solution distilled into a measured volume of standard acid, the excess acid being determined by titration with a standard alkali. The yields of ammonium sulphate were extremely low which is to be expected from low-temperature distillation. Fischer[1] states that the bulk of the ammonia appears between temperatures of 600° and 800° C., which would seem to be borne out by the remarkably low results obtained as shown in the accompanying tables.

SPECIAL EXAMINATION OF LOW-TEMPERATURE TARS

Low-temperature tar more closely resembles crude petroleum than does high-temperature tar and the main incentive for low-temperature carbonization has been, to date, to recover a high yield of tar oils as a substitute for petroleum. In view of this, the main features of the method used for the examination of the oils by Davis and Parry, as published in Bulletin 8, Carnegie Institute of Technology, were adopted as follows:—

Dry Crude Tar Oils

1. Specific gravity.
2. Distillation in Hempel flask.
    - *(a)* Light and middle oil, 0° to 225° C.; specific gravity, tar acids, and boiling range.
    - *(b)* Heavy oil, 225° to 275° C.; specific gravity, tar acids, and boiling range
    - *(c)* Vacuum distillation at 40 mm. pressure, 0° to 300° C.; specific gravity, tar acids, boiling range.
    - *(d)* Pitch by weight.
3. Neutral oils from Hempel distillation fractions *a*, *b*, and *c*.
    - *(a)* Specific gravity.
    - *(b)* Distillation in Engler flask, 150 c.c. capacity.
        - (1). Light oil (gasoline) up to 150° C. Specific gravity, and insolubility in concentrated sulphuric acid.
        - (2). Medium oil (kerosene) 150° to 300° C. Specific gravity, and insolubility in concentrated sulphuric acid.
        - (3). Heavy oil (gas and lubricating oil) 300° C. to end point. Specific gravity and insolubility in concentrated sulphuric acid.
4. Tar acids from Hempel distillation fractions *a*, *b*, and *c*.
    - *(a)* Specific gravity.
    - *(b)* Boiling range.

The method of distillation of the dry crude tar in the Hempel flask as described in Bulletin 207 of the U.S. Bureau of Mines was strictly followed. The results of distillation of the various tars, according to this method, are shown in Tables X, XX, and XXX (pages 88, 94, 98). The table following is a comparison of the Hempel distillation results of the three coals investigated at the various temperatures employed.

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[1] Fischer, Dr. Franz: Conversion of Coal into Oils, p. 43.

Boiling range	Westmoreland		Minto		Sydney	
	Per cent	Sp. Gr.	Per cent	Sp. Gr.	Per cent	Sp. Gr.
Tar produced at 400°C.						
0° to 225°C....................	39·3	0·872	41·0	0·821	54·8	0·875
225°C. to 285°C...............	24·0	0·948	24·3	0·924	23·3	0·953
0° to 300°C. (40 mm. pressure)..	27·3	0·972	29·3	0·992	10·5	1·031
Pitch (by weight)............	6·9	....	6·1	....	7·1	....
Tar produced at 500°C.						
0° to 225°C....................	25·0	0·875	36·7	0·820	41·0	0·898
225° to 275°C..................	16·0	0·954	19·6	0·930	23·4	0·967
0° to 300°C. (40 mm. pressure)..	38·0	1·039	37·3	1·021	26·8	1·017
Pitch (by weight)............	24·6	....	6·7	....	5·4	....
Tar produced at 600°C.						
0° to 225°C....................	25·3	0·870	31·0	0·825	26·5	0·909
225° to 275°C..................	15·0	0·976	19·0	0·927	16·1	0·978
0° to 300°C. (40 mm. pressure)..	29·7	1·024	43·3	1·080	28·3	1·057
Pitch (by weight)............	34·6	....	5·6	....	25·5	....

It will be noted that the tars from the three coals produced quite different results when distilled. At 400° C. the Sydney tar had the highest percentage of oils boiling at 225° C., whereas the fraction 225° to 275° C. was equally distributed in the three tars. All the tars at 400° C. yielded practically the same quantity of pitch. At 500° C. the same difference existed, i.e. Sydney tar yielded a greater quantity of oils boiling at 225° C.; however, at this temperature the same difference existed with the 225° to 275° C. fraction, Sydney tar yielding a larger quantity than either the Minto or the Westmoreland tars. The percentage of pitch obtained at 500° C. showed considerable variation from the results at 400° C., Westmoreland tar yielding 24 per cent as compared to 6 per cent and 5 per cent for the Minto and Sydney tars respectively. At 600° C. a still different result was obtained. In this case the yield from Minto tar for both fractions was higher, the Westmoreland and Sydney being practically identical. The Minto tar was also very low in pitch yield, being only 5·6 per cent as compared to 34·6 per cent for Westmoreland and 25·5 per cent for the Sydney tar.

It will be noted that with the vacuum distillation the results with the Sydney tar were consistently lower at all three temperatures, the Westmoreland and Minto tars yielding practically identical results at both 400° and 500° C. At 600° C. the yield from the Minto tar increased over that from the Westmoreland tar, and as noted the percentage of pitch was correspondingly lower.

Effect of Steam and Gas Circulation on the Tar

As previously noted the effects of carbonization with steam and gas circulation were practically identical, both resulting in an increase of the specific gravity of the tar. It was found rather difficult to distil the steam and gas circulation tars under reduced pressure owing to their tendency to froth, which characteristic has been previously noted by Davis and Parry in their work with Pennsylvania coals. The following table shows the results of distillation of Westmoreland tar produced by steam and gas circulation as compared with the tar produced by straight carbonization.

Boiling range	Westmoreland, 400°C.						Westmoreland, 600°C.					
	Regular		Steam		Gas		Regular		Steam		Gas	
	%	Sp.Gr.	%	Sp.Gr.	%	Sp.Gr.	%	Sp.Gr.	%	Sp.Gr.	%	Sp.Gr.
0° to 225°C.	39·3	0·872	24·3	0·877	23·6	0·874	25·3	0·870	19·7	0·892	23·7	0·899
225° to 275°C.	24·0	0·948	17·7	0·954	16·8	0·949	15·0	0·976	14·3	0·957	14·0	0·974
0° to 300°C. (40 mm. pressure)	27·3	0·972	34·0	1·027	42·2	1·014	29·7	1·024	30·0	1·046	30·7	1·040
Pitch (by weight)	6·9	....	23·7	....	17·1	....	34·6	....	....	....	37·0	....

It will be noted by reference to the above table that at 400° C. the yields of the fractions 0° to 225° C. and 225° to 275° C. are both considerably lower with the tar by steam and gas circulation than with the tar from regular carbonization. The results of the vacuum distillation up to 300°C. indicate a higher oil yield with tar obtained by steam and gas circulation than with the tar obtained by regular carbonization This difference is not so pronounced at 600° C., the tar obtained by the three methods of carbonization giving practically the same results on distillation.

Examination of the Tar Acids

Each of the three fractions from the Hempel distillation was treated with a 10 per cent solution of caustic soda in a Barrett separatory funnel and the washings joined. The tar acids were recovered by acidifying with sulphuric acid, no attempt being made to make a separate analysis of the acids from each fraction owing to the small quantity. The tar acids were tested for gravity and distilled in an Engler flask of 150 c.c. capacity. The boiling ranges are given in Tables XIV, XXIV, and XXXIV (pages 90, 95, 100), and the yields, expressed in percentages of the original fractions, in Tables XII, XXII and XXXII, (pages 89, 95, 99).

A high percentage of tar acids is characteristic of low-temperature tar and in this respect the results were as expected. The Westmoreland tars were consistently lower in tar acids than either the Minto or the Sydney. The effect of steam and gas circulation apparently lowered the tar acid content at 400° C., but this was not noticeable at 600° C. The gravity of the tar acids was apparently increased by steam distillation and by gas circulation. Tar acids from Minto tar have a consistently higher gravity than those from either the Sydney or Westmoreland tars, the latter two being quite similar. The following table compares the yield of tar acids in the tars obtained by straight carbonization of the three coals at different temperatures.

Coal	400°C.	500°C.	600°C.
	Per cent	Per cent	Per cent
Westmoreland	22·0	21·0	19·3
Minto	21·0	23·0	24·3
Sydney	26·2	28·0	23·9

Figure 12 shows the distillation results of the tar acids from the three coals. Only the results of the regular 600° C. series were plotted and, as will be noted, the three coals yielded consistently uniform results.

Pyridine Bases

The bases were removed by the addition of 20 per cent sulphuric acid to the washed oil immediately after the removal of the tar acids. A Barrett separatory funnel was used for this purpose, the contraction due to the bases being read off directly. The bases were not recovered from the oil-acid solution owing to the small amounts present.The neutralization of the acid solution containing the bases, in a few cases, however, gave persistent odours of pyridine. The yields are shown in Tables XII, XXII, and XXXII (pages 89, 95, 99), also in Tables XVI, XXVI, and XXXVI (pages 92, 96, 100).

Examination of the Neutral Oils

The washed neutral oils from the three fractions after the extraction of the tar acids and bases were joined and distilled at atmospheric pressure in an Engler flask of 150 c.c. capacity, three cuts being made, i.e., 0° to 200° C., 200° to 275° C., and 275° C. to end point (E.P.). The three fractions obtained were treated with 95 per cent sulphuric acid to remove unsaturated compounds, the results of this test being shown in Tables XV, XXV and XXXV (pages 91, 96, 100), as "insolubility in concentrated sulphuric acid".

It will be noted that the neutral oils from Westmoreland tars contained a higher percentage of oils insoluble in concentrated sulphuric acid than either the Sydney or the Minto oils, the Minto neutral oil being slightly more favourable in this respect than the Sydney. The value of this test is questionable as the reagent does not give a true measure of the content of the so-called unsaturated compounds, but it was made to serve as an indication of the commercial results obtainable when refining with sulphuric acid. Owing to the small amounts of the refined fractions obtained, no further investigation of them was made. The following table compares the distillation results of the neutral oils from the three tars obtained at the various temperatures.

Neutral oils	Westmoreland		Minto		Sydney	
	%	Sp. Gr.	%	Sp. Gr.	%	Sp. Gr.
Regular carbonization at 400°C.—						
0° to 200°C. fraction	31·0	0·808	34·0	0·809	46·0	0·799
200° to 275°C. fraction	36·0	0·898	33·0	0·905	36·0	0·889
275° to End Point fraction	32·0	0·950	31·0	0·976	17·0	0·953
Regular carbonization at 500°C.—						
0° to 200°C. fraction	25·0	0·813	28·0	0·814	31·0	0·808
200° to 275°C. fraction	24·0	0·899	25·0	0·815	29·0	0·897
275°C. to End Point fraction	50·0	0·983	45·0	0·987	39·0	0·968
Regular carbonization at 600°C.—						
0° to 200°C. fraction	28·0	0·817	25·0	0·822	27·0	0·825
200° to 275°C fraction	27·0	0·904	22·0	0·908	24·0	0·906
275°C. to End Point fraction	44·0	0·978	51·0	0·994	47·0	0·990

It will be noted that considerable variation occurred in the yield of the various neutral oil fractions from the tars of the three coals investigated at 400° and 500° C. At 600° C. this variation is not so marked, the three coals showing very similar results in both yields of the three fractions as well as their respective specific gravities.

Figures 10, 11, and 12 show the distillation ranges of the neutral oils from the various coals tested and also show the effect of the temperature and the method of carbonization on the distillation range. Figure 10 compares the neutral oils from Westmoreland tar by regular carbonization and by carbonization with steam and gas circulation at 400° and at 600° C. It will be noted that at 400° C. the neutral oils of the regular carbonization series possess more of the lighter and less of the heavier compounds than do the neutral oils from the steam and gas circulation series. The latter two curves are quite uniform and follow each other consistently throughout the entire range. At 600° C. the oils from the three series are more nearly uniform, similar differences existing although not to so marked a degree. Figure 11 compares the neutral oils from Minto and Sydney tars and shows the effect of the carbonization temperature on the distillation range. Figure 12 shows the distillation results of the neutral oils from the regular carbonization series, comparing the oils from the three coals tested at the same temperature and by the same method of carbonization. It will be noted that the three coals gave neutral oils with quite uniform distillation ranges, the difference in the three curves being less than the usual difference noted with crude petroleum. This agrees with Neilson's claim[1] that all the neutral oils from bituminous coals are identical.

Primary Tar Tests

The term "low-temperature tar" is usually considered to mean a tar which has not been subjected to a temperature to produce secondary decomposition. According to Dr. Franz Fischer,[2] a primary or true low-temperature tar should satisfy the following conditions:—

1. It should be fluid at room temperature with possibly slight segregations of paraffin wax.
2. Its specific gravity at 25° C. should be 0·95 to 1·06.
3. In a thin layer it should be an oil of golden red or port wine colour.
4. Freshly made, it generally smells of hydrogen sulphide or ammonium sulphide; it should never smell of naphthalene.

Fischer contends that in order for a tar to be classed as primary, the retorting temperatures employed should not exceed 550° C. and in view of the maximum temperature of 600° C. having been reached in the lead bath carbonization runs, it was considered of interest to test the tars produced at 600° C. and also at 500° C. according to Fischer's method. In addition to the above physical characteristics, the tar must be free from naphthalene, as this compound, it is claimed, is formed by secondary decomposition at temperatures upwards of 750° C. The test for the absence (or presence) of naphthalene is as follows:—[3]

> ...."200 c.c. of tar are distilled in a flask of 1·5 litres capacity in a moderate current of steam at 100° C., the vapours being cooled in a very long Liebig condenser so that the distillate is perfectly cold. It is advisable to collect three separate fractions of about 250 c.c. each, which will all show a layer of oil on the water . . . . . . when subjected to steam distillation in this way; a primary tar will not show any crystalline deposit even after cooling in ice."

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[1] Neilson, Harold: Oils from Coal, Gas Journal, June 16, 1926.
[2] Fischer, Dr. Franz: Conversion of Coal into Oils, p. 30.
[3] Loc cit.

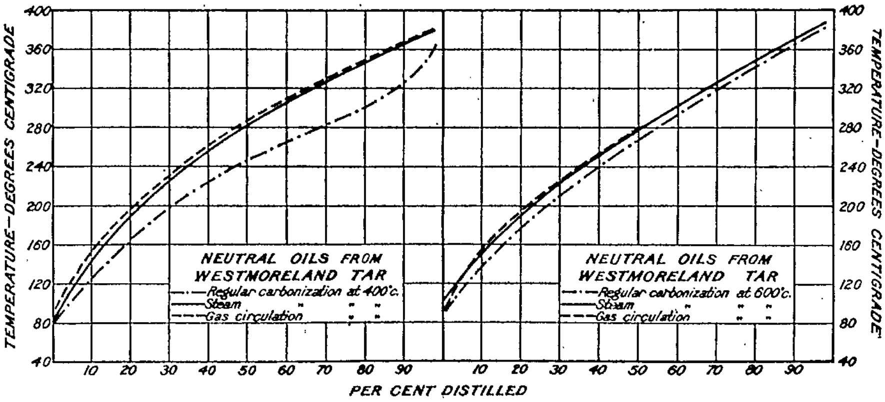

Figure 10. Diagram showing distillation range of neutral oils from crude tar obtained from Westmoreland coal carbonized at 400° and 600°C.

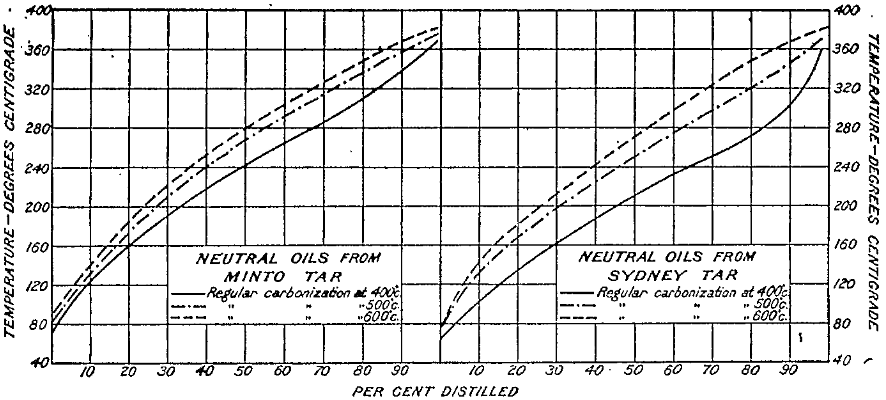

Figure 11. Diagram showing distillation range of neutral oils from crude tar obtained from Minto and Sydney coals carbonized at 400°, 500°, and 600°C.

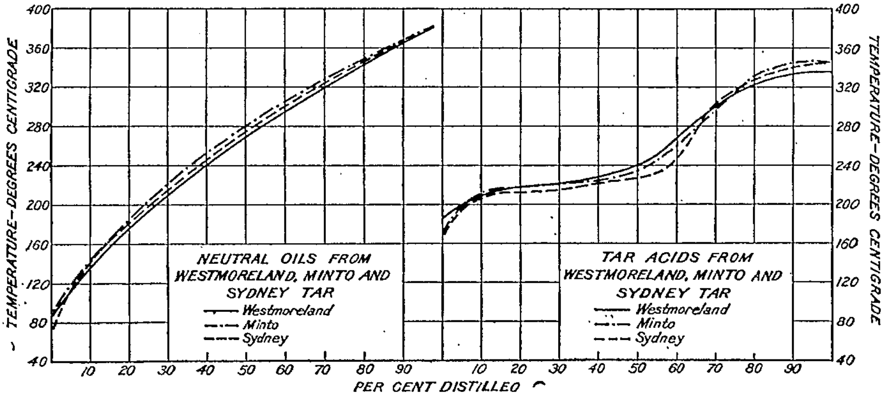

Figure 12. Diagram showing distillation range of neutral oils and tar acids from crude tar obtained from Westmoreland, Minto, and Sydney coals carbonized at 600 °C.

In order to further identify a true primary tar, it is necessary, according to Fischer, to determine the density of the neutral oils as follows:—The tar should be shaken with petroleum ether in order to precipitate pitch and asphaltic matter. The solution in petroleum ether is then freed of its acid constituents by means of alkali, and distilled up to 200° C. The oils coming over from 200° to 300° C. are collected separately and the specific gravities of the distillates and residues are determined. The specific gravity at 20° C. of the fraction from a primary tar, boiling from 200° to 300° C. is below 0·95. In the case of other tars it is close to 1·0 or higher. With a primary tar the residue boiling above 300° C. solidifies to a pasty consistency owing to segregation of paraffin wax; it is completely soluble in ethyl ether and petroleum ether and has at 50° C. a specific gravity below 1·0. (The corresponding residue from a superheated tar, although initially entirely soluble in petroleum ether is, after distilling off the fraction 200° to 300° C., only partially soluble in cold petroleum ether, leaving some solid matter undissolved. It is not completely soluble in ether and has at 50° C. a specific gravity above 1·0.)

A tar obtained by the carbonization of Westmoreland coal at 600° C. was selected for the above tests. The naphthalene test was negative; the results of the other tests being as follows:—

—	Specifications for primary tar	Westmoreland tar by regular carbonization at 600°C.
Specific gravity at 20°C. of fraction 200° to 300°C..........	below 0·95	0·900
" " 50°C. of residue above 300°C...........	" 1·00	0·988
Solubility of residue above 300°C. in ethyl ether..........	soluble	soluble
" " " petroleum ether......	soluble	not completely soluble

As just shown, the tar conforms to Fischer's specifications as to gravity, but the fraction above 300° C., although completely soluble in ethyl ether, is not completely soluble in petroleum ether. The fraction seemed soluble at first in petroleum ether but on standing a heavy dark precipitate was thrown down. The experiment was repeated with a similar result. It was considered that the bases soluble in dilute sulphuric acid might be the cause of this and a further test was made by treatment of the tar previous to distillation with 20 per cent sulphuric acid, but with a like result, the residue above 300° C. showing a dark precipitate on standing. It was noticed, however, that the amount of precipitate was greatly reduced by the acid treatment.

A similar tar from a 500° C. carbonization was then examined, such a tar coming well within Fischer's 550° C. limit. On this tar the naphthalene test was again negative, as was expected, the results of the other tests being:—

Specific gravity at 20°C. of fraction 200° to 300°C.........	0·898
" " 50°C. of residue above 300°C..........	0·989
Solubility of residue in ethyl ether.......................	soluble
" " petroleum ether...........	not completely soluble.

In respect to solubility of the residue in petroleum ether, the tar obtained when the maximum carbonization temperature used did not exceed 500° C. reacted similarly to that from the 600° C. tar. On first appearance it appeared soluble, but on standing a dark precipitate formed. The solvent used was labelled petroleum ether 30° to 90° C., and a determination of the distillation range showed the first drop at 30° C., 90 per cent over at 86° C. with the end point at 115° C. It is, therefore, quite evident from the above results that the tests as outlined by Fischer are not applicable in every particular to tar from all coals. Lack of time prevented a further investigation along these lines but it is proposed to carry out further experiments at a later date.

SUMMARY

Thirty-four low-temperature carbonization tests were carried out on three coals, i.e. Westmoreland, Minto, and Sydney coals. The maximum temperatures of individual runs varied from 350° to 600° C. Three methods of carbonization were used, i.e. regular carbonization, carbonization in the presence of steam, and carbonization with the recirculation of the condensed gases. The fusing (coking) point of the three coals used was determined and considerable variation found to exist which corresponded with the action of the coal in the retort during carbonization. The cokes were analysed and the results are shown in tabular form together with the analyses of samples of the coals from which the cokes were made. The densities of the cokes were determined and a comparison made with the corresponding high-temperature cokes. The gases at different temperatures of carbonization and by different methods were analysed and the results tabulated.

Examination of the tars was made by the standard Hempel distillation at atmospheric and reduced pressures. The fractions thus obtained were treated for removal of tar acids and bases and the remaining neutral oils were distilled in an Engler flask. Distillation ranges of both neutral oils and phenols were determined and the results are given as curves and are also shown in appended tables. Special examination of the tars was made to determine whether they came strictly within the definition of primary tar as outlined by Dr. Fischer, his tests being applied to both tars obtained at 500° and 600° C.

CONCLUSIONS

(1) The three coals tested yielded cokes of different quality. Minto coke obtained by carbonization at 600° C. could not be considered a commercial product owing to its porosity and friability. On the other hand, Westmoreland and Sydney coals yielded at 600° C. a dense coke which closely resembled the high-temperature product. Carbonization at 350° C. (of Westmoreland coal) did not produce the results which have been claimed. At this temperature the yield of products was negligible, the resulting coke being smoky and still possessing coking properties.

(2) The gas yield by low-temperature carbonization was low. At 400° C. the yield was approximately 1,000 cubic feet, at 500° C. the yield increased to approximately 2,600 cubic feet, and at 600° C. a yield of about 3,600 cubic feet was obtained.

(3) The plotted results of the distillation of the neutral oils from the three coals carbonized at 600° C. showed very uniform results which bears out the contention that neutral oils from bituminous coals are similar.

(4) Carbonization with steam and with the circulation of the condensed gases, yielded approximately similar tar oil results. The tars produced by these methods possessed a higher density and they contained a smaller percentage of the lighter oils with correspondingly higher quantities of the heavier fractions. At the lower temperatures the tar yield was apparently increased by steam and gas, but at 600° C. the yield was approximately the same.

(5) The tests as suggested by Fischer to determine whether a tar is a true primary product do not apply to tars from all coals, as the tar obtained from Westmoreland coal carbonized at 500° C., although soluble in ethyl ether, was not completely soluble in petroleum ether. This tar, as well as that obtained at 600° C., conformed, however, to the remainder of the tests as outlined by Fischer.

TABLE VI

Analyses of Coals—Low-Temperature Carbonization Tests

Name of coal		Westmoreland	Minto	Sydney
Proximate Analysis (as received)—				
Moisture	per cent	1·3	1·1	2·2
Volatile matter	"	33·1	34·1	32·7
Ash	"	7·1	8·6	4·4
Fixed carbon	"	58·5	56·2	60·7
Calorific Value—				
B.T.U. per pound		13,890	13,755	14,070
Proximate Analysis (dry basis)—				
Volatile matter	per cent	33·6	34·5	33·4
Fixed carbon	"	59·2	56·8	62·1
Ash	"	7·2	8·7	4·5
Calorific Value—				
B.T.U. per pound		14,070	13,910	14,390
Ultimate Analysis (dry basis)—				
Carbon	per cent	78·9	77·2	80·0
Hydrogen	"	5·1	5·1	5·3
Ash	"	7·1	8·6	4·4
Nitrogen	"	1·5	0·5	1·5
Sulphur	"	0·8	2·6	1·9
Oxygen (by difference)	"	6·6	6·0	6·9

TABLE VII

Westmoreland Coal—Summary of Low-Temperature Carbonization Tests

(Yield per 2,000 pounds of coal as charged)

Method of carbonization	Steam	Regular	Steam	Gas	Steam	Regular	Steam	Regular	Steam	Gas
Temperature	350°C.	400°C.	400°C.	400°C.	420°C.	500°C.	500°C.	600°C.	600°C.	600°C.
Coal—										
Proximate Analysis (as charged)										
Moisture................per cent..	1·4	1·5	1·4	1·9	1·5	1·9	1·4	1·4	1·5	1·5
Volatile matter......... " ..	35·2	34·9	34·2	35·0	34·8	34·0	35·3	34·7	35·1	33·7
Ash..................... " ..	7·8	8·1	10·0	4·7	6·7	8·2	5·4	6·3	6·6	8·6
Fixed carbon............ " ..	55·6	55·5	54·4	58·4	57·0	55·9	57·9	57·6	56·8	56·2
Sulphur................. " ..	0·92	0·78	1·38	0·78	0·92	1·21	0·80	1·03	0·96	0·77
Calorific Value—										
B.T.U. per pound................	13,920	13,865	13,310	14,380	14,070	13,770	14,380	14,130	14,070	13,640
Coke—										
Per cent of coal carbonized........	91·0	87·0	86·4	86·8	80·1	76·2	75·8	70·7	71·6	73·1
Proximate Analysis—										
Volatile matter..........per cent..	28·5	22·0	22·7	23·5	15·9	10·8	11·3	7·1	7·5	7·5
Ash..................... " ..	9·0	9·3	11·1	5·7	8·8	9·8	10·6	8·7	9·0	12·0
Fixed carbon............ " ..	62·5	68·7	66·2	60·8	75·3	79·4	78·1	84·2	83·5	80·5
Sulphur................. " ..	1·0	0·6	0·9	0·7	0·9	0·8	0·7	0·7	0·7	0·4
Calorific Value—										
B.T.U. per pound................	13,820	13,890	13,430	14,180	13,510	13,290	13,180	13,530	13,370	13,040
Gas—										
Cubic feet per ton................	....	1067	1125	....	1885	2482	2838	4058	4059	
B.T.U. per cubic foot (calculated)...	....	751	589	....	596	688	630	728	646	
Density (air=1)...................	....	0·71	0·78	....	0·78	0·76	0·78	0·66	0·65	
Tar (dry)—										
Imperial gallons per ton............	8·9	11·9	13·6	12·4	20·5	22·3	24·9	25·4	24·6	22·0
Specific gravity at 15·5°C...........	0·968	0·957	0·987	0·985	1·013	1·004	1·022	1·009	1·033	1·037
Liquor (aqueous)—										
Imperial gallons per ton............	32	68	62	66	70	112	66	114	114	116
Ammonium sulphate, pounds per ton	0·8	1·2	1·4	1·1	2·5	2·3	3·8	6·0	8·6	3·0

TABLE VIII

Westmoreland Coal—Weight Balance

(Parts by weight per 100 parts of coal charged)

Method of carbonization	Steam	Regular	Steam	Gas	Steam	Regular	Steam	Regular	Steam	Gas
Temperature	350°C.	400°C.	400°C.	400°C.	420°C.	500°C.	500°C.	600°C.	600°C.	600°C.
Coke........................per cent..	91·0	87·0	86·4	86·8	80·1	76·2	75·8	70·7	71·6	73·1
Tar........................ " ..	4·3	5·7	6·7	6·1	10·4	11·2	12·7	12·8	12·7	11·4
Liquor.................... " ..	1·6	3·4	3·1	3·3	3·5	5·6	3·3	5·7	5·7	5·8
Gas........................ " ..	....	2·9	3·2	....	5·6	7·1	8·4	10·2	10·2	
Loss....................... " ..	*3·1	−1·0	−0·6	*3·8	−0·4	+0·1	+0·2	−0·6	+0·2	*9·7

*Gas and loss by difference.

TABLE IX

Westmoreland Coal—Thermal Balance

(Thermal value of products as percentage of that in coal as charged)

Method of carbonization	Steam	Regular	Steam	Gas	Steam	Regular	Steam	Regular	Steam	Gas
Temperature	350°C.	400°C.	400°C.	400°C.	420°C.	500°C.	500°C.	600°C.	600°C.	600°C.
Coke........................per cent..	90·4	87·2	87·2	85·6	76·9	73·5	69·5	67·7	68·1	69·9
Tar........................ " ..	5·4	7·2	8·7	7·4	12·8	14·2	15·4	15·8	15·3	14·1
Gas........................ " ..	....	2·9	2·5	....	4·0	6·2	6·2	10·5	9·3	
Loss....................... " ..	4·2	2·7	1·6	7·0	6·3	6·1	8·9	6·0	7·3	16·0

TABLE X

Westmoreland Coal—Analyses of Tars from Low-Temperature Carbonization Tests

Method	Regular			Gas			Steam			Regular and steam			Regular			Gas			Steam		
Temperature	400°C.			400°C.			400°C.			500°C.			600°C.			600°C.			600°C.		
Tar (dry)— Specific gravity at 15·5°C..........	0·957			0·985			0·987			1·044—Regular 1·022—Steam			1·009			1·037			1·033		
B.T.U. per lb......	17,480			17,390			17,300			17,480			17,450			16,920			16,820		
	% vol.	Cum. % vol.	Sp. Gr. at 15·5°C.	% vol.	Cum. % vol.	Sp. Gr. at 15·5°C.	% vol.	Cum. % vol.	Sp. Gr. at 15·5°C.	% vol.	Cum. % vol.	Sp. Gr. at 15·5°C.	% vol.	Cum. % vol.	Sp. Gr. at 15·5°C.	% vol.	Cum. % vol.	Sp. Gr. at 15·5°C.	% vol.	Cum. % vol.	Sp. Gr. at 15·5°C.
Atmospheric distillation—	1st drop 46°C.			1st drop 55°C.			1st drop 57°C.			1st drop 53°C.			1st drop 48°C.			1st drop 56°C.			1st drop 65°C.		
75..............	2·7	2·7	......	0·7	0·7	......	1·3	1·3	......	1·3	1·3	......	1·3	1·3	......	0·7	0·7	......	0·3	0·3	......
100..............	1·3	4·0	......	3·3	4·0	......	1·0	2·3	......	1·0	2·3	......	2·0	3·3	......	2·3	3·0	......	1·7	2·0	......
125..............	4·0	8·0	......	0·4	4·4	......	2·0	4·3	......	1·7	4·0	......	0·7	4·0	......	0·7	3·7	......	0·7	2·7	......
150..............	5·0	13·0	......	1·4	5·8	......	3·7	8·0	......	4·0	8·0	......	4·0	8·0	......	2·3	6·0	......	2·3	5·0	
175..............	5·0	18·0	......	5·5	11·3	......	3·3	11·3	......	4·0	12·0	......	3·3	11·3	......	3·4	9·7	......	4·3	9·3	......
200..............	8·0	26·0	......	5·8	17·1	......	5·4	16·7	......	5·0	17·0	......	6·0	17·3	......	5·3	15·0	......	3·7	13·0	......
225..............	13·3	39·3	0·872	6·5	23·6	0·874	7·6	24·3	0·877	8·0	25·0	0·875	8·0	25·3	0·870	8·7	23·7	0·899	6·7	19·7	0·892
250..............	10·0	49·3	......	7·3	30·9	......	7·0	31·3	......	6·0	31·0	......	8·0	33·3	......	6·0	29·7	......	6·0	25·7	......
275..............	14·0	63·3	0·948	9·5	40·4	0·949	10·7	42·0	0·954	10·0	41·0	0·963	7·0	40·3	0·976	8·0	37·7	0·974	8·3	34·0	0·957
Vacuum distillation (40 mm. pressure)																					
175°C..............	......	......	......	......	......	......	......	......	......	......	......	......	0·7	0·7	......	......	......	......	1·7	1·7	
200..............	6·0	6·0	......	6·5	6·5	......	1·7	1·7	......	4·0	4·0	......	5·3	6·0	......	3·3	3·3	......	3·0	4·7	
225..............	3·3	9·3	......	9·5	16·0	......	7·6	9·3	......	6·7	10·7	......	7·0	13·0	......	5·0	8·3	......	8·0	12·7	
250..............	12·7	22·0	......	7·3	23·3	......	8·0	17·3	......	7·3	18·0	......	5·7	18·7	......	4·4	12·7	......	7·3	20·0	
275..............	2·7	24·7	......	8·7	32·0	......	10·0	27·3	......	10·0	28·0	......	11·0	29·7	......	4·0	16·7	......	7·3	27·3	
300..............	2·6	27·3	0·972	10·2	42·2	1·014	6·7	34·0	1·027	10·0	38·0	1·039	......	......	1·024	14·0	30·7	1·040	3·0	30·0	1·046
Pitch (by weight)...	6·9			17·1			23·7			24·6			34·6			37·0					

TABLE XI

Westmoreland Coal—Analyses of Gases

Method of Carbonization	Regular	Steam	Steam	Regular	Steam	Regular	Steam
Temperature	400°C.	400°C.	420°C.	500°C.	500°C.	600°C.	600°C.
Density (air=1)	0·71	0·78	0·78	0·76	0·78	0·66	0·65
Carbon dioxide per cent	2·4	4·0	5·5	5·1	4·6	3·2	2·9
Illuminants "	3·4	3·2	3·5	4·3	4·2	3·0	3·4
Oxygen "	5·0	5·4	6·0	5·3	5·6	2·8	3·5
Carbon monoxide "	3·4	2·8	2·3	4·8	4·4	5·8	5·6
Methane "	68·6	52·8	52·8	60·4	54·9	60·3	52·8
Hydrogen "	0·0	0·3	1·5	0·0	0·0	18·2	14·2
Nitrogen "	17·2	31·5	28·4	20·1	26·3	6·7	17·6
B.T.U. per cubic foot—							
Net	678	532	538	622	570	654	581
Gross	751	589	596	688	630	728	646

TABLE XII

Westmoreland Coal—Purification of Fractions from Distillation of Tars

Temperature	Method of carbonization	Fraction I: 0° to 225°C. (atmospheric pressure)			Fraction II: 225°—275°C. (atmospheric pressure)			Fraction III: 0° to 300°C. (40 mm. pressure)		
		Tar acids by caustic soda treatment	Pyridine bases by sulphuric acid treatment	Washed neutral oils	Tar acids by caustic soda treatment	Pyridine bases by sulphuric acid treatment	Washed neutral oils	Tar acids by caustic soda treatment	Pyridine bases by sulphuric acid treatment	Washed neutral oils
		%	%	%	%	%	%	%	%	%
400°C.	Regular	26·5	0·9	72·6	29·2	2·8	68·0	17·1	6·1	76·8
400°C.	Gas circulation	24·2	1·6	74·2	28·3	4·3	67·4	15·5	8·6	75·9
400°C.	Steam	27·4	1·4	71·2	18·9	3·8	77·3	18·6	4·9	76·5
500°C.	Regular and steam	28·4	1·4	70·2	31·2	4·2	64·6	23·7	7·0	69·3
600°C.	Regular	29·3	1·3	69·4	35·6	4·4	60·0	22·5	6·7	70·8
600°C.	Gas circulation	32·9	1·4	65·7	35·7	4·8	59·5	23·9	6·5	69·6
600°C.	Steam	32·8	1·7	65·5	34·9	4·7	60·4	24·4	7·8	67·8

TABLE XIII

Westmoreland Coal—Distillation Ranges of Neutral Oils

Method of carbonization	Regular	Gas	Steam	Regular and steam	Regular	Gas	Steam
Temperature	400°C.	400°C.	400°C.	500°C.	600°C.	600°C.	600°C.
Specific gravity at 15·5°C.	0·887	0·931	0·929	0·923	0·917	0·931	0·934
Distillation range—							
1st drop..........at	80°C.	89°C.	82°C.	85°C.	86°C.	88°C.	100°C.
10% vol.......... "	130	160	145	140	137	155	162
20% " .... "	163	193	187	177	170	190	188
30% " .... "	197	230	225	220	210	225	223
40%............. "	220	255	255	255	235	257	252
50% " .... "	247	282	285	280	262	278	280
60% " .... "	265	307	304	305	293	302	304
70% " .... "	282	327	325	330	322	325	325
80% " .... "	300	349	347	350	330	348	350
90% " .... "	325	365	365	368	367	367	373
End point......... "	365	380	380	390	380	390	390

TABLE XIV

Westmoreland Coal—Distillation Ranges of Tar Acids

Method of carbonization	Regular	Gas	Steam	Regular and steam	Regular	Gas	Steam
Temperature	400°C.	400°C.	400°C.	500°C.	600°C.	600°C.	600°C.
Specific gravity at 15·5°C.	1·050	1·073	1·078	1·084	1·073	1·089	1·083
Distillation range—							
1st drop..........at	180°C.	175°C.	170°C.	190°C.	185°C.	163°C.	180°C.
10% vol.......... "	206	214	205	215	209	213	211
20% " .... "	211	215	224	224	216	224	216
30% " .... "	218	217	231	228	221	228	228
40% " .... "	227	245	239	251	229	234	240
50% " .... "	233	267	275	283	234	264	252
60% " .... "	238	281	303	311	269	294	275
70% " .... "	257	309	317	338	303	320	299
80% " .... "	293	338	341	354	322	348	318
90% " .... "	307	348	353	368	334	352	320
100% " .... "	310	351	....	....	335	....	....
Specific gravity at 15·5°C. of distilled tar acids..........	1·039	1·051	1·066	1·074	1·060	1·068	1·049

TABLE XV

Westmoreland Coal—Yield, Specific Gravity, etc., of Neutral Oil Fractions

Method of carbonization	Regular	Gas	Steam	Regular and steam	Regular	Gas	Steam
Temperature	400°C.	400°C.	400°C.	500°C.	600°C.	600°C.	600°C.
Light oil (0°–200°C.) per cent............	31·0	23·0	25·0	25·0	28·0	24·0	24·0
Specific gravity at 15·5°C.............	0·808	0·820	0·816	0·813	0·817	0·817	0·829
Insoluble in conc. H_2SO_4...... per cent	81	80	76	74	74	74	80
Middle oil (kerosene 200°–275°C.) per cent	36·0	24·0	21·0	24·0	27·0	25·0	24·0
Specific gravity at 15·5°C.............	0·898	0·899	0·902	0·899	0·904	0·901	0·903
Insoluble in conc. H_2SO_4..... per cent	78	75	68	63	72	68	72
Heavy oil (275°C.–end point) . per cent	32·0	52·0	53·0	50·0	44·0	50·0	51·0
Specific gravity at 15·5°C.............	0·950	0·976	0·979	0·983	0·978	0·985	0·984
Insoluble in conc. H_2SO_4 ......per cent	62	50	50	48	52	50	50

NOTE.—Yields of the different fractions are given as percentages of washed neutral oils after alkali and acid treatment, and insolubilities in concentrated sulphuric acid are given as percentages of the individual fractions.

TABLE XVI

Westmoreland Coal—Yields of Crude Tar Oils and Fractions

Method of carbonization	Regular		Gas		Steam		Regular and steam		Regular		Gas		Steam	
Temperature	400°C.		400°C.		400°C.		500°C.		600°C.		600°C.		600°C.	
	Per cent of tar (vol.)	Imp. gals. per ton	Per cent of tar (vol.)	Imp. gals. per ton	Per cent of tar (vol.)	Imp. gals. per ton	Per cent of tar (vol.)	Imp. gals. per ton	Per cent of tar (vol.)	Imp. gals. per ton	Per cent of tar (vol.)	Imp. gals. per ton	Per cent of tar (vol.)	Imp. gals. per ton
Crude water-free tar oil	......	11·9	......	12·4	......	13·6	......	*23·6	......	25·4	......	22·0	......	24·6
Fraction I (0°—225°C.)	39·0	4·6	22·5	2·8	24·3	3·3	24·7	5·8	25·0	6·4	23·3	5·1	19·3	4·7
" II (225°—275°C.)	24·0	2·9	16·7	2·1	17·7	2·4	16·0	3·8	15·0	3·8	14·0	3·1	14·3	3·5
" III (0°—300°C. vacuum)	27·3	3·2	42·2	5·2	34·0	4·6	38·0	9·0	29·7	7·5	30·7	6·8	30·0	7·4
Neutral oil (fraction 0°—225°C.)	28·3	3·4	16·7	2·1	17·3	2·3	17·4	4·1	17·3	4·4	15·4	3·4	12·7	3·1
Neutral oil (fraction 225°–275°C.)	16·3	1·9	11·3	1·4	13·7	1·9	10·3	2·4	9·0	2·3	8·3	1·8	8·6	2·1
Neutral oil (fraction 0°—300°C. vacuum)	21·0	2·5	32·0	4·0	26·0	3·5	26·3	6·2	20·8	5·3	21·3	4·7	20·3	5·0
Tar acids from all three fractions	22·0	2·6	16·7	2·1	16·3	2·2	21·0	5·0	19·3	4·9	20·0	4·4	18·7	4·6
Tar acids (recovered)	20·0	2·4	16·4	2·0	16·3	2·2	19·0	4·5	18·0	4·6	16·3	3·6	17·0	4·2
Tar bases from all three fractions	2·7	0·3	4·7	0·5	2·7	0·4	3·7	0·9	3·3	0·8	3·0	0·7	3·3	0·8
Light neutral oil (0°—200°C.)	20·3	2·4	13·8	1·7	13·1	1·8	13·5	3·2	13·2	3·4	10·8	2·4	10·0	2·5
Middle neutral oil (200°—275°C.)	23·6	2·8	14·4	1·8	13·7	1·9	13·0	3·1	12·7	3·2	11·3	2·5	10·0	2·5
Heavy neutral oil (275°C.—end point)	21·0	2·5	31·2	3·9	29·6	4·0	27·0	6·4	20·7	5·3	22·5	5·0	21·2	5·2

*Average result from both methods of distillation.

TABLE XVII

Minto Coal—Summary of Low-Temperature Carbonization Tests

(Yields per 2,000 pounds of coal as charged)

Maximum temperature of carbonization as per lead bath pyrometer reading	400°C.	500°C.	600°C.
Coal—			
Proximate Analysis, as charged—			
Moisture per cent	1·2	1·1	1·1
Volatile matter "	34·5	34·3	34·0
Ash "	8·4	8·5	8·6
Fixed carbon "	55·9	56·1	56·3
Sulphur "	2·7	2·5	2·3
Calorific Value—			
B.T.U. per pound "	13,875	13,840	13,855
Coke—			
Per cent of coal carbonized	88·3	78·6	76·3
Proximate Analysis—			
Ash per cent	9·5	10·7	11·2
Volatile matter "	22·3	11·2	8·7
Fixed carbon "	68·2	78·1	80·1
Calorific Value—			
B.T.U. per pound	13,760	13,250	13,240
Gas—			
Cubic feet per ton	997	2,583	3,400
B.T.U. per cubic foot (calculated)	748	767	696
Density (air =1)	0·71	0·70	0·66
Tar (dry)—			
Imperial gallons per ton	10·3	20·7	21·1
Specific gravity at 15·5°C	0·928	0·968	0·985
Liquor (aqueous)—			
Imperial gallons per ton	66	86	90
Ammonium sulphate, pounds per ton	0·7	1·4	2·9

TABLE XVIII

Minto Coal—Weight Balance

(Parts by weight for 100 parts of coal charged)

Temperature of carbonization	400°C.	500°C.	600°C.
Coke per cent	88·3	78·6	76·3
Tar "	4·8	10·0	10·4
Liquor "	3·3	4·3	4·5
Gas "	2·7	6·9	8·6
Loss "	0·9	0·2	0·2

TABLE XIX

Minto Coal—Thermal Balance

(Thermal value of products as percentage of that in the coal as charged)

Temperature of carbonization	400°C.	500°C.	600°C.
Coke per cent	87·9	75·4	73·5
Tar "	5·9	12·3	12·9
Gas "	2·7	7·1	8·5
Loss "	3·5	5·2	5·1

TABLE XX

Minto Coal—Analyses of Tars from Low-Temperature Carbonization Tests

Temperature	400°C.			500°C.			600°C.		
Tar (dry)—									
Specific gravity at 15·5°C..............	0·928			0·968			0·985		
B.T.U. per pound......	17,220			17,190			17,240		
	Per cent vol.	Cum. % vol.	Sp. Gr. at 15·5°C.	Per cent vol.	Cum. % vol.	Sp. Gr. at 15·5°C.	Per cent vol.	Cum. % vol.	Sp. Gr. at 15·5°C.
Atmospheric distillation	1st drop 43°C			1st drop 40°C			1st drop 50°C		
75°C...............	3·6	3·6	....	3·3	3·3	....	2·0	2·0	....
100..................	3·0	6·6	....	5·3	8·6	....	2·0	4·0	....
125..................	5·4	12·0	....	1·0	9·6	....	1·7	5·7	....
150..................	3·0	15·0	....	5·4	14·0	....	4·0	9·7	....
175..................	5·0	20·0	....	4·7	18·7	....	4·6	14·3	....
200..................	10·7	30·7	....	8·6	27·3	....	7·0	21·3	....
225..................	10·3	41·0	0·821	9·4	36·7	0·820	9·7	31·0	0·825
250..................	12·0	53·0	....	8·0	44·7	....	9·7	40·7	....
275..................	12·3	65·3	0·924	11·6	56·3	0·930	9·3	50·0	0·927
Vacuum distillation— (40 mm. pressure)									
175°C...............	2·7	2·7	....	3·3	3·3	....	6·7	6·7	....
200..................	7·3	10·0	....	8·0	11·3	....	6·6	13·3	....
225..................	5·0	15·0	....	10·0	21·3	....	12·0	25·3	....
250..................	5·7	20·7	....	9·7	30·7	....	6·0	31·3	....
275..................	4·0	24·7	....	6·6	37·3	1·021	8·7	40·0	....
300..................	4·6	29·3	0·992	....	....	....	3·3	43·3	1·080
Pitch (by weight).......	6·1			6·7			5·6		

TABLE XXI

Minto Coal—Analyses of Gases

Temperature of carbonization		400°C.	500°C.	600°C.
Density (air=1)...		0·71	0·70	0·66
Carbon dioxide..................................	per cent	3·5	4·3	4·3
Illuminants.......................................	"	3·6	3·7	3·2
Oxygen...	"	2·8	2·7	2·8
Carbon monoxide...............................	"	3·2	3·6	4·6
Methane..	"	68·0	69·1	59·7
Hydrogen..	"	0·0	1·6	10·3
Nitrogen...	"	18·8	15·0	15·1
B.T.U. per cubic foot—				
Net..		674	691	627
Gross..		748	767	696

TABLE XXII

Minto Coal—Purification of Fractions from Distillation of Tars

Temp.	Loss on extraction as percentages by volume of orignal fractions				
			Fraction I 0°–225°C.	Fraction II 225° – 275°C.	Fraction III (40 mm. pressure) 0°–300°C.
400°C.	Tar acids (caustic soda)	Per cent	23·0	27·4	17·0
	Pyridine bases (sulphuric acid)	“	0·8	4·1	6·8
	Neutral oil—washed	“	76·2	68·5	76·2
500°C.	Tar acids (caustic soda)	Per cent	28·0	30·5	18·7
	Pyridine bases (sulphuric acid)	“	1·9	3·4	6·2
	Neutral oil—washed	“	70·1	66·1	75·1
600°C.	Tar acids (caustic soda)	Per cent	28·0	33·3	21·5
	Pyridine bases (sulphuric acid)	“	3·2	3·5	5·4
	Neutral oil—washed	“	68·8	63·2	73·1

TABLE XXIII

Minto Coal—Distillation Ranges of Neutral Oils from Low-Temperature Tars

Temperature of carbonization		400°C.	500°C.	600°C.
Specific gravity at 15·5°C		0·900	0·918	0·932
Distillation range				
1st drop	at	74°C.	80°C.	88°C.
10% vol.	“	127	127	140
20% “	“	160	165	185
30% “	“	193	210	220
40% “	“	220	247	250
50% “	“	247	268	280
60% “	“	265	290	307
70% “	“	280	315	325
80% “	“	313	335	350
90% “	“	357	353	370
End point		370	375	380

TABLE XXIV

Minto Coal—Distillation Ranges of Tar Acids from Low-Temperature Tars

Temperature of carbonization		400°C.	500°C.	600°C.
Specific gravity at 15·5°C		1·057	1·081	1·086
Distillation range—				
1st drop	at	125°C.	160°C.	165°C.
10% vol.	“	197	203	208
20% “	“	203	208	215
30% “	“	213	217	220
40% “	“	221	228	226
50% “	“	226	234	233
60% “	“	235	268	272
70% “	“	253	273	293
80% “	“	309	315	332
90% “	“	327	323	343
End point	“	330	335	345
Specific gravity at 15·5°C. of distilled tar acids		1·046	1·063	1·072

TABLE XXV

Minto Coal—Yield, Specific Gravity, etc., of Neutral Oil Fractions

Temperature of carbonization	400°C.	500°C.	600°C.
Light oil—(0° to 200°C.)...per cent	34·0	28·0	25·0
Specific gravity at 15·5°C.	0·809	0·814	0·822
Insoluble in concentrated H_2SO_4...per cent	74	70	72
Middle oil (kerosene—200°–275°C.)...per cent	33·0	25·0	22·0
Specific gravity at 15·5°C.	0·905	0·915	0·908
Insoluble in concentrated H_2SO_4...per cent	67	65	66
Heavy oil (275°C—end point)...per cent	31·0	45·0	51·0
Gravity at 15·5°C.	0·976	0·987	0·994
Insoluble in concentrated H_2SO_4...per cent	40	45	47

NOTE.—Yields of the different fractions are given as percentages of washed neutral oils after alkali and acid treatment, and insolubilities in concentrated sulphuric acid are given as percentages of the individual fractions.

TABLE XXVI

Minto Coal—Yields of Crude Tar Oils and Fractions

Temperature of carbonization	400°C.		500°C.		600°C.	
	Per cent of tar (vol.)	Imp. gal. per ton	Per cent of tar (vol.)	Imp. gal. per ton	Per cent of tar (vol.)	Imp. gal. per ton
Crude water-free tar oil	....	10·3	....	20·7	....	21·1
Fraction I (0°–225°C.)	40·7	4·2	35·7	7·4	31·0	6·5
Fraction II (225°–275°C.)	24·3	2·5	19·7	4·1	19·0	4·0
Fraction III (0°–300°C.vac.)	29·3	3·0	37·3	7·7	43·3	9·1
Neutral oil (fraction 0°–225°C.)	31·0	3·2	25·0	5·2	21·3	4·5
Neutral oil (fraction 225°–275°C.)	16·7	1·7	13·0	2·7	12·0	2·5
Neutral oil (fraction 0°–300°C.vac.)	22·3	2·3	28·0	5·8	31·7	6·7
Tar acids from all three fractions	21·0	2·2	23·0	4·8	24·3	5·1
Tar acids (recovered)	20·0	2·0	20·3	4·2	23·0	4·9
Tar bases from all three fractions	3·3	0·3	3·7	0·7	4·0	0·8
Light neutral oil (0°–200°C.)	23·8	2·5	18·5	3·8	16·3	3·4
Middle neutral oil (200°–275°C.)	23·1	2·4	16·5	3·4	14·3	3·0
Heavy neutral oil (275°C—end point)	21·7	2·2	29·7	4·1	33·1	7·0

TABLE XXVII

Sydney Coal—Summary of Low-Temperature Carbonization Tests

(Yields per 2,000 pounds of coal as charged)

Maximum temperature of carbonization as per lead bath pyrometer reading	400°C.	500°C.	600°C.
Coal:			
Proximate Analysis, as charged—			
Moisture per cent	2·6	2·1	2·2
Volatile matter "	33·1	33·1	32·9
Ash "	3·9	3·8	3·9
Fixed carbon "	60·4	61·0	61·0
Sulphur "	1·9	1·9	2·0
Calorific Value—			
B.T.U. per pound	14,180	14,300	14,215
Coke:			
Per cent of coal carbonized	88·7	79·8	71·4
Proximate Analysis—			
Ash per cent	4·4	4·8	5·4
Volatile matter "	22·5	11·6	7·6
Fixed carbon "	73·0	83·6	87·0
Calorific Value—			
B.T.U. per pound	14,375	14,125	14,045
Gas—			
Cubic feet per ton	900	2,768	3,527
B.T.U. per cubic foot (calculated)	660	710	642
Density (air=1)	0·65	0·68	0·69
Tar (dry)—			
Imperial gallons per ton	9·3	14·8	23·9
Specific gravity at 15·5°C.	0·973	0·972	1·031
Liquor (aqueous)—			
Imperial gallons per ton	90	108	132
Ammonium sulphate, pounds per ton	2·2	1·4	2·9

TABLE XXVIII

Sydney Coal—Weight Balance

(Parts by weight for 100 parts of coal charged)

Temperature of carbonization	400°C.	500°C.	600°C.
Coke per cent	88·7	79·8	71·4
Tar "	4·5	7·2	12·3
Liquor "	4·5	5·4	6·6
Gas "	2·2	7·2	9·3
Loss "	0·1	0·4	0·4

TABLE XXIX

Sydney Coal—Thermal Balance

(Thermal value of products as percentage of that in coal as charged)

Temperature of carbonization		400°C.	500°C.	600°C.
Coke	per cent	90·4	79·5	71·1
Tar	"	5·3	8·4	14·5
Gas	"	2·1	6·1	7·7
Loss	"	2·2	6·0	6·7

TABLE XXX

Sydney Coal—Analyses of Tars from Low-Temperature Carbonization Tests

Temperature	400°C.			500°C.			600°C.		
Tar (dry)— Specific gravity at 15·5°C. B.T.U. per pound	0·973 16,940			0·972 16,920			1·031 17,000		
	Per cent vol.	Cum. % vol.	Sp.Gr at 15·5°C	Per cent vol.	Cum. % vol.	Sp.Gr at 15·5°C	Per cent vol.	Cum. % vol.	Sp. Gr. at 15·5°C
Atmospheric distillation—	1st drop 32°C	......	......	1st drop 38°C	......	......	1st drop 38°C	......	....
75°C	8·6	8·6	......	3·6	3·6	......	2·0	2·0	....
100	1·9	10·5	......	1·0	4·6	......	0·6	2·6	....
125	3·8	14·3	......	3·4	8·0	......	1·7	4·3	....
150	6·6	20·9	......	4·6	12·6	......	3·1	7·4	....
175	6·2	27·1	......	6·6	18·0	......	2·6	10·0	....
200	15·3	42·4	......	9·6	27·6	......	6·5	16·5	....
225	12·4	54·8	0·875	13·4	41·0	0·898	10·0	26·5	0·909
250	12·0	66·8	......	11·5	52·5	......	5·7	32·2	....
275	11·3	78·1	0·953	11·9	64·4	0·907	10·4	42·6	0·978
Vacuum distillation (40 mm. pressure)—									
175°C	......	......	......	1·2	1·2	......	....	......	....
200	1·0	1·0	......	3·4	4·6	......	2·6	2·6	....
225	1·9	2·9	......	9·2	13·8	......	3·9	6·5	....
250	2·8	5·7	......	5·4	19·2	......	7·8	14·3	....
275	1·9	7·6	......	3·0	22·2	......	6·6	20·9	....
300	2·9	10·5	1·031	4·6	26·8	1·017	7·4	28·3	1·057
Pitch (by weight)	7·1			5·4			25·5		

TABLE XXXI

Sydney Coal—Analyses of Gases

Temperature of carbonization		400°C.	500°C.	600°C.
Density (air=1)		0·65	0·68	0·69
Carbon dioxide	per cent	5·4	3·8	6·8
Illuminants	"	2·6	3·0	2·6
Oxygen	"	2·6	3·6	2·8
Carbon monoxide	"	4·8	4·2	6·6
Methane	"	56·4	62·8	54·6
Hydrogen	"	11·3	6·3	10·5
Nitrogen	"	16·9	16·3	16·1
B.T.U. per cubic foot—				
Net		594	640	579
Gross		660	710	642

TABLE XXXII

Sydney Coal—Purification of Fractions from Distillation of Tars

Temperature	Loss on extraction as percentages by volume of original fractions		Fraction I 0°—225°C.	Fraction II 225°—275°C.	Fraction III (40 mm. pressure) 0°—300°C.
400°C.	Tar acids (caustic soda)	per cent	29·6	28·6	31·8
	Pyridine bases (sulphuric acid)	"	17·4	4·1	9·1
	Neutral oil—washed	"	53·0	67·3	59·1
500°C.	Tar acids (caustic soda)	per cent	35·5	34·4	20·0
	Pyridine bases (sulphuric acid)	"	2·0	3·3	5·7
	Neutral oil—washed	"	62·5	62·3	74·3
600°C.	Tar acids (caustic soda)	per cent	37·7	32·4	30·8
	Pyridine bases (sulphuric acid)	"	3·3	5·4	5·1
	Neutral oil—washed	"	59·0	62·2	63·1

TABLE XXXIII

Sydney Coal—Distillation Ranges of Neutral Oils from Low-Temperature Tars

Temperature of carbonization		400°C.	500°C.	600°C.
Specific gravity of oil at 15·5°C.		0·861	0·903	0·934
Distillation range—				
1st drop	at	65°C.	75°C.	71°C.
10% vol.	"	103	136	144
20 "	"	136	164	181
30 "	"	162	199	209
40 "	"	184	223	258
50 "	"	209	253	274
60 "	"	234	275	288
70 "	"	253	297	318
80 "	"	272	321	346
90 "	"	303	347	368
End point	"	360	370	380

TABLE XXXIV

Sydney Coal—Distillation Ranges of Tar Acids from Low-Temperature Tars

Temperature of carbonization		400°C.	500°C.	600°C.
Specific gravity of tar acids at 15·5°C.		1·038	1·055	1·075
Distillation range—				
1st drop	at	146°C.	163°C.	165°C.
10% vol.	"	200	198	206
20 "	"	206	209	212
30 "	"	214	214	215
40 "	"	216	219	223
50 "	"	220	225	227
60 "	"	229	232	249
70 "	"	235	246	305
80 "	"	259	283	324
90 "	"	297	318	342
End point	"	320	323	347
Specific gravity of distilled tar acids at 15·5°C.		1·032	1·044	1·062

TABLE XXXV

Sydney Coal—Yield, Specific Gravity, etc., of Neutral Oil Fractions

Temperature of carbonization		400°C.	500°C.	600°C.
Light oil (0°—200°C.)	per cent	46·0	31·0	27·0
Specific gravity at 15·5°C.		0·799	0·808	0·825
Insoluble in concentrated H_2SO_4	per cent	59	68	67
Middle oil (kerosene 200°—275°C.)	per cent	36·0	29·0	24·0
Specific gravity at 15·5°C.		0·889	0·897	0·906
Insoluble in concentrated H_2SO_4	per cent	57	62	59
Heavy oil (275°C.—end point)	per cent	17·0	39·0	47·0
Specific gravity at 15·5°C.		0·953	0·968	0·990
Insoluble in concentrated H_2SO_4	per cent	32	30	32

TABLE XXXVI

Sydney Coal—Yields of Crude Tar Oils and Fractions

Coal	400°C.		500°C.		600°C.	
	Per cent of tar (vol.)	Imp. gals. per ton	Per cent of tar (vol.)	Imp. gals. per ton	Per cent of tar (vol.)	Imp. gals. per ton
Crude water-free tar oil	....	9·3	....	14·8	....	23·9
Fraction I (0°—225°C.)	54·8	5·1	41·0	6·1	26·5	6·3
Fraction II (225°—275°C.)	23·3	2·2	23·4	3·5	16·1	3·8
Fraction III (0°—300°C. vacuum)	10·5	1·0	26·8	4·0	28·3	6·8
Neutral oil (fraction 0°—225°C.)	37·6	3·5	25·7	3·8	15·7	3·8
Neutral oil (fraction 225°—275°C.)	15·7	1·5	14·6	2·2	10·0	2·4
Neutral oil (fraction 0°—300°C. vacuum)	6·2	0·6	19·9	2·9	17·8	4·3
Tar acids from all three fractions	26·2	2·4	28·0	4·1	23·9	5·7
Tar acids (recovered)	22·8	2·1	25·3	3·7	21·3	5·1
Tar bases from all three fractions	2·9	0·3	3·1	0·5	3·5	0·8
Light neutral oil (0°—200°C.)	27·4	2·5	18·7	2·8	11·7	2·8
Middle neutral oil (200°—275°C.)	21·4	2·0	17·5	2·6	10·4	2·5
Heavy neutral oil ((275°C.-end point)	10·1	0·9	23·5	3·5	20·5	4·9

IV

EFFECTS OF CONTINUED WEATHERING UPON THE FRIABILITIES OF VARIOUS FUELS

J. H. H. Nicolls

A series of tumbling tests to determine the friabilities of various solid fuels obtainable in this country has been fully described in a previous report.[1] The present report, therefore, consists only of tables showing the results of a continuation of these tests upon fuels which have been subjected to open shed exposure, with some brief comments thereon. These are followed by a summary of the completed friability tests, particularly as regards the effects of weathering.

Disintegration or Breakage

The term "disintegration" is preferable to "breakage" in dealing with material coming away from the lumps of fuel during weathering, as distinguished from that broken off in the tumbling tests. However, since the latter was used in the previous report, both terms have been retained in referring to the figures shown in Table XXXVII.

As had been expected, the Scotch semi-anthracite disintegrated very little due to weathering. However, the semi-bituminous coals, especially that from Pennsylvania, broke up to a very considerable degree. It seems probable, therefore, that this disintegration is a characteristic of semi-bituminous coals, just as is their great friability.

Neither the sub-bituminous nor the higher grade lignite coals broke up to a large extent during exposure, but the Pembina and Cardiff coals did so to a considerable degree. Data are given in Table XXXVII for two consecutive exposures of four of the lignites, and it will be noted that most of the disintegration occurred during the first 4½ months' storage. In each of these tests the third line gives the total disintegration as a percentage of the coal originally exposed. It was indicated in the previous report that the friabilities of small samples of coal, of one size only, increased less than those of similar, though larger, samples of mixed sizes, so that it is possible that larger samples of the four lignites under consideration would have disintegrated to a greater extent during the second exposure. However, as will be shown below, there is not necessarily any definite relation between the amount of disintegration during storage and the increase in friability resulting from the same.

Changes in Friability

According to the tests, as shown in Table XXXVIII, the friability of the Scotch semi-anthracite decreased slightly during storage. This is in accord with a number of the results of the previous series of tests and it, therefore, seems quite within the bounds of possibility that the friabilities of anthracites and cokes may be actually decreased by open shed exposure.

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[1] Mines Branch, Dept. of Mines, Canada: Investigation of Fuels and Fuel Testing, 1924, pp. 20-35.

It is to be noted that the friabilities of the semi-bituminous coals remained practically unchanged. These coals broke up considerably during weathering, but this disintegration was apparently unaccompanied by an increase in friability.

During open shed exposure the sub-bituminous coals became more friable than the coal of that grade used for the previous tests. However, sub-bituminous coals as a class may still be considered as fair storage coals. The increases in friability were marked in all cases by the production not only of larger amounts of "smalls" and "fines" but also of greater quantities of "dust."

The effects of the open shed exposure upon the lignites differed from those produced in the sub-bituminous coals. In both cases the increases in friabilities were marked by a greater production of "smalls" and "fines", but in the case of the lignites they were generally notable for decreased productions of "dust." Lignites are, nevertheless, poor storage coals. However, in the series of tests under consideration, the increases in friability were proportionally far greater during the first 4½ months than during the succeeding 12 months of exposure. These may have been due in part to the smaller amounts of coal exposed during the second period (already referred to in the discussion under disintegration), but it does not seem likely that these decreases in amount would have brought about anything like the changes shown in the table.

GENERAL SUMMARY

The report describes a series of tumbling tests carried out upon eleven samples of solid fuel following exposure in an open shed; it also shows the amounts of disintegration of the fuels brought about during exposure. Although a considerable amount of disintegration is generally accompanied by increased friability this is not necessarily so, and the difference between the two should be clearly realized, particularly in considering such fuels as peat and semi-bituminous coals. The term "disintegration", as employed here, denotes the percentage of any fuel which breaks off from lumps during exposure, and which, after exposure, passes through the size of screen upon which the lumps were previously all retained; the term "friability" denotes the extent to which lumps of any fuel will break up when subjected to handling. The amount of a sample of any fuel passing through a certain screen will often be increased by as much as 2 or 3 per cent as the result of an immediate second screening of the lumps previously retained on the screen, and the probability of the occurrence of similar experimental errors should be borne in mind and allowed for during consideration of the results of disintegration.

The tests herein described complete a series of determinations of the friabilities both of unweathered fuels, and of the same after different kinds and different periods of exposure; they also show the amounts of disintegration brought about during exposure. The following paragraphs deal with the different types of fuel individually, and serve to correlate the results of the present tests with those previously obtained.

Cokes, particularly those made in by-product ovens, are very resistant to breakage. Their friabilities are only very slightly increased by open shed exposure, and not greatly affected by outdoor exposure.

Anthracites, as a general rule, are more resistant to breakage than any other class of coal. Their friabilities are not appreciably affected by open shed storage, though they are considerably increased by outdoor exposure. During 19 months' open shed exposure the sample of Pennsylvania anthracite used for the tests lost 5 per cent by weight due to disintegration, whereas the samples of Welsh anthracite lost an average of 10 per cent.

The sample of Scotch semi-anthracite used in the tests was more friable than the Pennsylvania anthracite and less so than the Welsh anthracites. Its friability was not materially affected by open shed exposure. During 15 months' exposure it lost 6 per cent by weight due to disintegration.

Semi-bituminous or "smokeless" coals are exceedingly friable and likely to produce excessive "fines" and "dust." Their friabilities are not increased by open shed exposure. However, during such exposure they disintegrate to a very considerable extent. The samples tested lost respectively 36 per cent during 15½ months' exposure and 10 per cent during 12 months' exposure due to disintegration.

The bituminous coals tested were somewhat more friable than the general class of anthracites. Their friabilities were not materially increased by open shed exposure, but they were considerably increased by outdoor exposure. During 18 months' open shed exposure they lost, on an average, 12 per cent by weight due to disintegration.

Sub-bituminous coals are almost as resistant to breakage as bituminous coals, and have, therefore, fair handling qualities. Their friabilities are increased by open shed exposure though not to a very great extent. Increases in friability are marked by the production of "smalls" rather than "fines" and "dust." The samples tested lost, on an average, 7 per cent due to disintegration during 12 months' open shed storage.

Alberta lignites when unweathered are only slightly more friable than the hardest anthracites. However, after only 4½ months' open shed exposure, their friabilities are very greatly increased. After a further 12 months' exposure the friabilities are still further increased, though to a much smaller degree than during the first storage period. These increases in friability are marked principally by a larger production of "smalls" and "fines," particularly the former, and it is to be noted that lignites seldom or never produce "dust." Lignites become excessively friable as the result of outdoor exposure. During 4½ months' open shed exposure the samples of Alberta lignite lost on an average 10 per cent (varying from 6 to 17) by weight due to disintegration, and this was gradually increased to 11 per cent during 16 months' exposure.

Alfred peat when unweathered is less friable than any of the other fuels herein enumerated. Its friability is only very slightly increased by open shed exposure, but greatly increased by outdoor exposure. However, during 17 months' open shed exposure the sample tested lost 27 per cent by weight due to disintegration.

TABLE XXXVII

Disintegration due to Open Shed Exposure

Sample No.	Fuel Used	Size	Weight, pounds	Time of weathering, months	Disintegration (breakage), per cent
8	Scotch semi-anthracite	1"-1½"	65	15	6
16	Pennsylvania semi-bituminous	1"-1½"	30	15½	36
17	Alberta, Canmore, semi-bituminous	1"-1½"	30	12	10
21	Alberta, Coalspur, sub-bituminous	1"-1½"	40	12	3
22	Alberta, Saunders, sub-bituminous	1"-1½"	55	12½	11
32	Alberta, Lethbridge, sub-bituminous	1"-1½"	45	12	8
24	Alberta, Taber, lignite	1"-2"	37	4½	6
24	Alberta, Taber, lignite, second exposure	1"-1½"	13	12	2
24	Alberta, Taber, lignite, total exposure	....	....	16½	7
25	Alberta, Drumheller, upper seam, lignite	1"-1½"	45	13½	10
27	Alberta, Drumheller, lower seam, lignite	1"-2"	43	4½	7
27	Alberta, Drumheller, lower seam, lignite, second exposure	1"-1½"	17	12	2
27	Alberta, Drumheller, lower seam, lignite, total exposure	....	....	16½	8
28	Alberta, Pembina, lignite	1"-2"	40	4½	11
28	Alberta, Pembina, lignite, second exposure	1"-1½"	14	12	2
28	Alberta, Pembina, lignite, total exposure	....	....	16½	12
29	Alberta, Cardiff, lignite	1"-2"	38	4½	17
29	Alberta, Cardiff, lignite, second exposure	1"-1½"	14	12	2
29	Alberta, Cardiff, lignite, total exposure	....	....	16½	18

TABLE XXXVIII

Changes in Friability due to Weathering

(All for 1″ to 1½″ coal)

Sample No.	Fuel	Kind of exposure	Time of exposure, months	Summary of screen analyses			
				"Lumps", on 0·742″ screen	"Smalls", through 0·742″ on 0·0164″ (35 mesh) screen	"Fines", through 0·0164″ on 0·0029″ (200 mesh) screen	"Dust", through 0·0029″ screen
				%	%	%	%
	Semi-anthracite—						
8	Scotch	unweathered	....	69·2	7·0	10·3	13·5
	"	open shed	15	74·1	5·3	7·2	13·4
	Semi-bituminous—						
16	Pennsylvania	unweathered	....	35·3	13·0	29·8	21·9
	"	open shed	15½	35·8	11·7	30·1	22·4
17	Alberta, Canmore	unweathered	....	49·4	9·9	20·4	20·3
	" "	open shed	12	49·0	10·3	19·8	20·9
	Sub-bituminous—						
21	Alberta, Coalspur	unweathered	....	67·1	10·9	12·2	9·8
	" "	open shed	12	61·2	13·5	13·0	12·3
22	Alberta, Saunders	unweathered	....	62·9	13·3	12·2	11·6
	" "	open shed	12½	52·7	21·8	13·1	12·4
32	Alberta, Lethbridge	unweathered	....	78·4	6·0	6·3	9·3
	" "	open shed	12	64·1	19·2	6·3	10·4
	Lignite—						
24	Alberta, Taber	unweathered	....	63·6	15·0	8·9	12·5
	" "	open shed	4½	41·7	35·8	11·2	11·3
	" "	"	16½	34·5	41·7	13·5	10·3
25	Alberta, Drumheller, upper seam	unweathered	....	73·5	13·5	4·8	8·2
	" "	open shed	13½	61·4	20·4	9·9	8·3
27	Alberta, Drumheller, lower seam	unweathered	....	74·6	11·3	6·7	7·4
	" "	open shed	4½	62·2	22·7	6·9	8·2
	" "	open shed	16½	56·1	21·4	14·5	8·0
28	Alberta, Pembina	unweathered	....	51·2	25·6	12·2	11·0
	" "	open shed	4½	44·2	31·6	14·4	9·8
	" "	"	16½	37·1	37·4	16·7	8·8
29	Alberta, Cardiff	unweathered	....	58·5	22·0	13·0	6·5
	" "	open shed	4½	52·2	30·6	9·7	7·5
	" "	"	16½	42·9	35·8	14·3	7·0

V

ANALYSES OF SOLID FUELS

Compiled by J. H. H. Nicolls

The solid fuel analyses compiled here are tabulated under the following three headings:—

(1) Solid fuels occurring in Canada.
(2) Coal samples submitted by the Department of Soldiers' Civil Re-establishment.
(3) Miscellaneous solid fuels.

The samples of the first group were largely either "mine" or "prospect" samples; the former term being applied to those procured from deposits already under development, the latter to those as yet undeveloped. Most of the "mine" and "prospect" samples were collected by technical officers of either the Federal or Provincial governments. However, a considerable number of the samples were collected by the mine operators at the request of the Fuel Testing Laboratories, and, when taken from underground seams and thoroughly described as such, the coals in question were termed "mine" samples. A few "commercial" samples occur in the first group of fuels; each of these is considered to be representative of the corresponding product as shipped from the mine.

The samples of the second group of fuels consisted entirely of bituminous coals purchased by the Department of Soldiers' Civil Re-establishment for use in the heating plants at their various hospitals. These include coals occurring in Canada and those mined in the United States. They are all "commercial" samples, and consist principally of "slack" coal. The samples were collected entirely by the engineers at the various heating plants, following instructions sent out by their headquarters after consultation with the staff of the Fuel Testing Division. According to the procedure employed in reporting these samples to the D.S.C.R., only the moisture content (which may vary with weather conditions) is shown on the "as-received" basis, the remainder of the analyses being reported on the "dry" basis, in order to simplify comparisons between the different coal samples.

The samples of the third group consisted chiefly of imported fuels, such as are sold by local dealers either for private residences or for public buildings. These are all "commercial" samples. In addition to these a few analyses of the products of some recent carbonization processes are given.

Wherever possible the exact date of sampling is given, or at least the month during which the sample was taken. However, in some few cases this information was not available, and the dates upon which the samples were received at the laboratory are shown.

The following notes explain abbreviations in the tables, and may be of assistance in studying them.

(a) Figures in columns "R" refer to fuels as received; in columns "AD" to air-dried fuels; and in columns "D" to those dried at 108° C. It may be generally accepted that the fuels were analysed as received, except in the instances where the "AD" column is included. In such cases the fuels were analysed following the standard air-drying procedure. A few analyses either of lignites or of high-moisture "slack" coals, do not include the "AD" column, although it is obvious that the fuels could not have been ground for analysis without previous drying. For such lignites the centre column has been omitted because the drying process was hurried, and quite different from the standard procedure, with the result that the figures obtained would be quite misleading. For the "slack" coals the analyses on the air-dried basis were not considered to be of any particular interest.

(b) In certain instances more than one sample number will be observed at the head (or foot) of a column. In such cases the analysis shown is the average of the analyses of the samples enumerated.

(c) The "coking properties" described were obtained by heating 1-gramme samples in closed platinum crucibles during the determination of volatile matter. They serve only as indications of the cokes to be expected from commercial ovens, and may occasionally be somewhat misleading. On the whole, however, they may be considered as useful guides in coking practice.

The analyses reported below were carried out under the direct supervision of the author, according to the general directions of the Superintendent of the Fuel Testing Laboratories and his senior officers. The samples were prepared for analysis by the laboratory attendants, the proximate analyses for moisture, ash, and volatile matter being made mostly by G. E. LeWorthy. The calorific value determinations were made by J. L. Bowlby and J. D. Johnston, with G. P. Connell assisting with the necessary sulphur determinations. The carbon and hydrogen determinations were made by C. B. Mohr, who also assisted in the checking of the results and the reporting of the same.

TABLE XXXIX

Analyses of Solid Fuels Occurring in Canada

—	Dominion Iron and Steel Co., Ltd. (Besco) Sydney, N.S.		Dredged from a 4-foot 8-inch seam near Salter's lumber wharf, North Sydney, N.S.		Cumberland Railway and Coal Co., Ltd. (Besco), Springhill, N.S.						McKinnon mine, Chignecto, N.S.				Victoria mine, River Hebert, N.S.		Maritime Coal, Railway and Power Co., Ltd., No. 7 mine, Joggins, N.S.		Peat from Portage, P.E.I.	
					No. 2 mine		No. 6 mine		No. 7 mine											
Sample number	3593		3120		3401		3402		3403		3405		3406		3600		3404		3108	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—																				
Moisture per cent	2·3	.....	4·0	.....	2·2	.....	3·5	.....	3·3	.....	2·5	.....	3·5	.....	6·2	.....	3·2	.....	24·5	...
Ash "	3·9	4·0	4·7	4·9	5·5	5·6	2·3	2·4	2·8	2·9	23·0	23·6	9·7	10·1	19·4	20·7	11·3	11·7	9·4	12·4
Volatile matter "	33·0	33·8	34·4	35·8	31·2	31·9	35·2	36·5	34·8	36·0	33·5	34·3	39·3	40·7	32·0	34·1	35·8	37·0	46·6	61·8
Fixed carbon "	60·8	62·2	56·9	59·3	61·1	62·5	59·0	61·1	59·1	61·1	41·0	42·1	47·5	49·2	42·4	45·2	49·7	51·3	19·5	25·8
Ultimate Analysis—																				
Sulphur per cent	1·9	2·0	3·9	4·0	1·0	1·0	0·9	0·9	0·7	0·8	11·2	11·5	7·6	7·9	5·3	5·7	7·3	7·6	....	.....
Calorific Value—																				
Calories per grm., gross	8,000	8,190	....	.....	7,880	8,060	7,830	8,120	7,780	8,050	5,570	5,710	6,780	7,020	5,900	6,280	6,670	6,890	3,530*	4,680
B.T.U. per lb., gross	14,400	14,740	....	.....	14,190	14,510	14,100	14,620	14,010	14,490	10,030	10,280	12,200	12,640	10,620	11,310	12,000	12,400	6,360	8,420
Fuel ratio	1·85		1·65		1·95		1·65		1·70		1·20		1·20		1·30		1·40		0·42	
Coking properties	....		Fair to good		Fair to good		Poor		Poor		Poor		Poor		Fair to good		Poor		....	
Kind of sample	Commercial		....		Mine....................................						Mine		Mine		....		Mine		....	
Designation of coal	Washed slack		....		....						Soft fall		Hard fall							
Taken by	Washery operators		Private individual		F. A. Kerr, Geological Survey..........						F. A. Kerr..............				Submitted by D.S.C.R.		F. A. Kerr		Private individual	
Date of sampling	September, 1925		June, 1925		Summer of 1924........................						Summer of 1924..........				February, 1926		Summer of 1924		Summer of 1925	

*Sulphur content assumed to be 0·35, the average determined value for former P.E.I. peat samples.

—	McPherson mine, Coal Creek, N.B.		Peat from Alfred, Ont.			Peat from west of Midland, Tay township, Ont.						"Anthraxolite" from Sudbury district, Ont.	
Sample number	3339		3354			3421		3420		3422		3619	
Moisture condition	R	D	R	AD	D	R	D	R	D	R	D	R	D
Proximate Analysis—													
Moisture per cent	1·1	....	32·0	16·9	....	6·9	....	6·1	....	6·8	....	1·9	....
Ash "	6·8	6·8	4·3	5·2	6·3	3·1	3·3	7·0	7·4	15·7	16·8	33·7	34·3
Volatile matter "	37·8	38·3	43·1	52·7	63·4	57·5	61·8	58·1	61·9	51·0	54·7	3·4	3·5
Fixed carbon "	54·3	54·9	20·6	25·2	30·3	32·5	34·9	28·8	30·7	26·5	28·5	61·0	62·2
Ultimate Analysis—													
Carbon per cent	....	....	38·7	47·4	56·9	....	....	....	..	....	....	....	....
Hydrogen "	....	....	7·4	6·5	5·6	....	....	....	....	....	....	....	....
Ash "	....	....	4·3	5·2	6·3	....	....	....	....	....	....	....	....
Sulphur "	4·4	4·5	0·1	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·9	0·9
Nitrogen "	....	....	1·1	1·3	1·6	....	....	....	....	....	....	....	....
Oxygen "	....	....	48·4	39·4	29·4	....	....	....	....	....	....	....	....
Calorific Value—													
Calories per grm., gross	7,940	8,030	3,680	4,500	5,410	5,170	5,560	5,150	5,490	4,540	4,870	4,830	4,920
B.T.U. per lb., gross	14,300	14,450	6,630	8,100	9,740	9,310	10,010	9,270	9,880	8,170	8,770	8,690	8,850
Fuel ratio	1·45			0·48		0·56		0·49		0·52		17·65	
Carbon-Hydrogen ratio	....	....	5·2	7·2	10·2	....	....	....	....	....	....	....	....
Coking properties	Poor to fair		....	....	....	....	....	....	....	....	....	Non-coking	
Kind of sample	....		Commercial, 1 ton			Top peat		Bottom peat		....		....	
Taken by	Private individual		Local dealer			Private individual						Private individual	
Date of sampling	October, 1925		September, 1925			December, 1925						Fall of 1925.	

TABLE XXXIX—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	D. Smith's mine, No. 881, Groton, Lucky Strike, Alberta, sec. 10, tp. 3, R. 11, W. 4 mer.			"Hollander" mine, No. 271, operated by Coghill & Hughes, Milk River, Alberta, sec. 26 tp. 2, R. 16, W. 4 mer.			Majestic Collieries, Ltd., No. 105, Taber, Alberta, sec. 31, tp. 9, R. 16, W. 4 mer.			Kleenbirn Collieries, Ltd., No. 226, Eyremore, Alberta, sec. 10, tp. 17, R. 17, W. 4 mer.		
Sample number		N 49			N 48			3232			N 12	
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—												
Moisture, per cent	20·0	16·7	....	13·3	11·3	....	13·0	12·4	....	17·3	14·1	....
Ash "	7·9	8·2	9·8	13·5	13·8	15·6	12·7	12·7	14·6	8·4	8·7	10·1
Volatile matter "	30·1	31·4	37·7	30·9	31·6	35·7	33·2	33·5	38·2	32·1	3·33	38·8
Fixed carbon "	42·0	43·7	52·5	42·3	43·3	48·7	41·1	41·4	47·2	42·2	43·9	51·1
Ultimate Analysis—												
Carbon, per cent	....	....	....	....	....	....	55·4	55·8	63·7	55·4	57·5	66·9
Hydrogen "	....	....	....	....	....	....	5·3	5·3	4·5	5·7	5·5	4·6
Ash "	....	....	....	....	....	....	12·7	12·7	14·6	8·4	8·7	10·1
Sulphur "	0·7	0·7	0·9	0·7	0·7	0·8	1·2	1·2	1·3	0·8	0·8	1·0
Nitrogen "	....	....	....	....	....	....	1·3	1·3	1·5	1·3	1·4	1·6
Oxygen "	....	....	....	....	....	....	24·1	23·7	14·4	28·4	26·1	15·8
Calorific Value—												
Calories per grm., gross	5,250	5,470	6,560	5,550	5,680	6,400	5,400	5,440	6,210	5,270	5,470	6,370
B.T.U. per lb., gross	9,450	9,840	11,810	10,000	10,230	11,530	9,720	9,790	11,170	9,480	9,850	11,460
Fuel ratio		1·40			1·35			1·25			1·30	
Carbon-Hydrogen ratio	....	....	....	....	....	....	10·4	10·6	14·3	9·7	10·4	14·6
Coking properties		Non-coking			Non-coking			Non-coking			Non-coking	
Location in mine	....						....			4-ft. 8-in. seam, 900 feet from mine entry at river bank.		
Kind of sample	Mine						Commercial; 6 tons			Mine.		
Designation of coal	....						Lump.					
Taken by	Provincial Mine Inspector						Mine operators			Mine operator.		
Date of sampling	May 5, 1926			May 4, 1926			May 31, 1924. Lab. sample, Aug. 23, 1925.			May, 1925.		

—	Castella Mine, No. 360, Standard, Alberta, sec. 2, tp. 25, R. 22, W. 4 mer.			N. F. Engstrom's mine, Rose Lynn, Alberta, secs. 34 and 35, tp. 28, R. 13, W. 4 mer.			Newcastle Junior Mining Co., Ltd., No. 816, Drumheller, Alberta, Upper or No. 5 Drumheller seam, sec. 3, tp. 29, R. 20, W. 4 mer.		Rose Deer Coal Mining Co., Ltd., No. 347, Wayne, Alberta, Lower or No. 1 Drumheller seam, sec. 7, tp. 28, R. 19, W. 4 mer.	
Sample number		N 3			3331		3041		3251	
Moisture condition	R	AD	D	R	AD	D	R	D	R	D
Proximate Analysis—										
Moisture per cent	15·7	13·0	....	18·8	16·0	....	18·7	....	15·1	....
Ash "	10·8	11·2	12·9	6·6	6·8	8·1	7·5	9·3	7·7	9·1
Volatile matter "	32·9	33·9	39·0	31·5	32·6	38·8	30·2	37·1	33·4	39·4
Fixed carbon "	40·6	41·9	48·1	43·1	44·6	53·1	43·6	53·6	43·8	51·5
Ultimate Analysis—										
Carbon per cent	55·1	56·8	65·3	....	....	....	57·0	70·0	56·2	66·1
Hydrogen "	5·6	5·4	4·5	....	....	....	5·8	4·6	5·5	4·5
Ash "	10·8	11·2	12·9	....	....	....	7·5	9·3	7·7	9·1
Sulphur "	0·4	0·4	0·5	0·5	0·6	0·7	0·4	0·5	0·5	0·6
Nitrogen "	1·1	1·1	1·3	....	....	....	1·2	1·5	1·2	1·4
Oxygen "	27·0	25·1	15·5	....	....	....	28·1	14·1	28·9	18·3
Calorific Value—										
Calories per grm., gross	5,180	5,340	6,140	5,310	5,510	6,550	5,230	6,430	5,550	6,530
B.T.U. per lb., gross	9,330	9,630	11,060	9,570	9,910	11,790	9,420	11,580	9,990	11,750
Fuel ratio		1·25			1·35		1·45		1·30	
Carbon-Hydrogen ratio	9·9	10·5	14·4	....	....	....	9·9	15·1	10·2	14·6
Coking properties	Non-coking			Non-coking			Non-coking		Non-coking	

Kind of sample			Commercial; 12 tons	Commercial; 6 tons.
Description of coal			Stove and nut	
Taken by	Mine operators	Mine operator	Northwestern Fuel Supply Co., Ltd. Drumheller.	Mine operators
Date of sampling	April, 1925	September, 1925	November 27, 1924 Lab. sample, Feb. 16, 1925	May 2, 1924. Lab. sample, Sept. 19, 1925.

TABLE XXXIX—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	North Star mine, operated by E. D. Bray, Heatburg, Alix, Alberta						Canadian Dinant Coal Co., Ltd., No. 374, Dinant, Alberta, sec. 12, tp. 48, R. 20, W. 4 mer.			Canadian Coal Co., Ltd., No. 32, Cardiff, Alberta, sec. 24, tp. 55, R. 25, W. 4 mer.					
Sample number	N5			N6			N4			3112		3119		3250	
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	D	R	D	R	D
Proximate Analysis—															
Moisture per cent	19·1	16·0	....	17·9	15·0	....	26·9	16·7	....	18·9	....	19·3	....	17·3	....
Ash "	7·0	7·3	8·7	13·0	13·5	15·8	3·3	3·8	4·6	8·5	10·5	7·9	9·8	9·7	11·7
Volatile matter "	28·6	29·7	35·3	27·6	28·5	33·6	29·8	33·9	40·7	32·1	39·6	32·2	39·9	32·1	38·8
Fixed carbon "	45·3	47·0	56·0	41·5	43·0	50·6	40·0	45·6	54·7	40·5	49·9	40·6	50·3	40·9	49·5
Ultimate Analysis—															
Carbon per cent	....	....	....	....	....	....	51·6	58·8	70·5	....	....	....	....	52·8	63·9
Hydrogen "	....	....	....	....	....	....	6·3	5·6	4·5	....	....	....	....	5·5	4·3
Ash "	....	....	....	....	....	....	3·3	3·8	4·6	....	....	....	....	9·7	11·7
Sulphur "	0·5	0·5	0·6	0·3	0·3	0·4	0·3	0·3	0·4	0·3	0·3	0·3	0·3	0·3	0·3
Nitrogen "	....	....	....	....	....	....	1·0	1·2	1·4	....	....	....	....	1·0	1·3
Oxygen "	....	....	....	....	....	....	37·5	30·3	18·6	....	....	....	....	30·7	18·5
Calorific Value—															
Calories per grm., gross	5,140	5,340	6,350	4,750	4,920	5,780	4,790	5,460	6,550	4,920	6,070	4,930	6,120	5,010	6,060
B.T.U. per lb., gross	9,260	9,610	11,440	8,550	8,850	10,410	8,620	9,820	11,790	8,860	10,920	8,880	11,010	9,020	10,910
Fuel ratio		1·60			1·50			1·35		1·25		1·25		1·30	
Carbon-Hydrogen ratio	....	....	....	....	....	....	8·2	10·5	15·8	....	....	....	....	9·6	14·8
Coking properties	Non-coking			Non-coking			Non-coking			Non-coking					
Location in mine	First seam			Second seam			From No. 8 pillar north, off main east entry.								
Kind of sample							Mine, taken equally from top and bottom sections of 6-ft. 6-in. seam, omitting 1-in. parting.			Commercial: 6 tons.					
Designation of coal	"Blackfalds" coal									Stove.					
Taken by	Mine operator						Mine operators			Mine operators.					
Date of samoling	May 7, 1925						May 6, 1925			May 6, 1924.					
										Lab. sample. June 15, 1925.		Lab. sample. June 22, 1925.		Lab. sample. Sept. 19, 1926.	

—	Alex. Noble's mine, No. 1009, Boundary Creek, Alberta, sec. 22, tp. 1, R. 26, W. 4 mer.			W. H. Vair's mine, No. 996, Boundary Creek, Cardston, Alberta, sec. 29, tp. 1, R. 26, W. 4 mer.			Evan Evans' mine, No. 316, Cardston, Alberta, sec. 26, tp. 2, R. 26, W. 4 mer.			Rozzolini & Fillestino, "Wall" mine, No. 1020, Magrath, Alberta, sec. 7, tp. 7, R. 21, W. 4, mer.			Benjamin Oliver's mine, No. 1086, Magrath, Alberta, sec. 8, tp. 7, R. 21, W. 4 mer.		
Sample number	N50			N38			N37			N42			N35		
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—															
Moisture per cent	6·6	5·6	....	8·0	5·6	....	6·4	4·6	....	11·8	9·6	....	10·1	7·8	....
Ash “	8·2	8·3	8·8	7·7	7·9	8·4	13·0	13·3	13·9	13·2	13·5	14·9	10·9	11·2	12·2
Volatile matter “	37·4	37·8	40·0	34·8	35·7	37·8	34·7	35·3	37·0	34·3	35·2	38·9	36·9	37·8	41·0
Fixed carbon “	47·8	48·3	51·2	49·5	50·8	53·8	45·9	46·8	49·1	40·7	41·7	46·2	42·1	43·2	46·8
Ultimate Analysis—															
Carbon per cent	....	....	....	68·1	69·9	74·0	64·5	65·7	68·9	....	....	....	62·0	63·5	68·9
Hydrogen “	....	....	....	5·1	5·0	4·6	5·2	5·0	4·8	....	....	....	5·5	5·3	4·8
Ash “	....	....	....	7·7	7·9	8·4	13·0	13·3	13·9	....	....	....	10·9	11·2	12·2
Sulphur “	1·4	1·5	1·6	0·7	0·7	0·7	0·7	0·8	0·8	1·6	1·6	1·8	0·8	0·8	0·9
Nitrogen “	....	....	....	1·7	1·7	1·9	1·6	1·6	1·7	....	....	....	1·5	1·6	1·7
Oxygen “	....	....	....	16·7	14·8	10·4	15·0	13·6	9·9	....	....	....	19·3	17·6	11·5
Calorific Value—															
Calories per grm., gross	6,740	6,810	7,220	6,630	6,810	7,210	6,410	6,530	6,840	5,740	5,880	6,500	6,100	6,250	6,780
B.T.U. per lb., gross	12,130	12,260	12,990	11,940	12,250	12,970	11,530	11,750	12,310	10,330	10,590	11,700	10,980	11,250	12,210
Fuel ratio	1·30			1·40			1·35			1·20			1·15		
Carbon-Hydrogen ratio	....	....	....	13·3	14·1	16·1	12·5	13·0	14·5	....	....	....	11·4	12·0	14·3
Coking properties	Poor coke			Agglomerates			Agglomerates			Agglomerates			Agglomerates		
Hoffmann potash test	....	....	....	7 to 6			6 to 7			5 to 6			5		
Kind of sample	All mine														
Taken by	All by Provincial Mine Inspector														
Date of sampling	May 18, 1926			Nov. 17, 1925			Nov. 16, 1925			Jan. 26, 1926			Nov. 19, 1925		

TABLE XXXIX—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	J. Rollingson's "Wall" mine, No. 981, Magrath, Alberta, sec. 8, tp. 7, R. 21, W. 4 mer.			Canadian Pacific Railway, Natural Resources Dept., Calgary, Galt No. 6 mine, Lethbridge, Alberta, sec. 18, tp. 9, R. 21, W. 4 mer.						Garrett Collieries, No. 76, Lundbreck, Alberta, sec. 23, tp. 7, R. 2, W. 5 mer.			John L. Patton's mine, No. 1096, Lundbreck, Alberta, sec. 26, tp. 7, R. 2, W. 5 mer.		
Sample number		N36			3028			3582			N2			N34	
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—															
Moisture, per cent	10·4	7·9	....	10·3	8·4	....	9·7	8·9	....	4·5	3·9	....	7·2	4·1	....
Ash, "	13·6	14·0	15·2	10·3	10·5	11·5	9·4	9·5	10·4	14·3	14·4	15·0	16·9	17·4	18·2
Volatile matter, "	35·8	36·8	39·9	32·7	33·4	38·8	35·7	36·0	39·6	35·6	35·8	37·2	33·6	34·7	36·2
Fixed carbon, "	40·2	41·3	44·9	46·7	47·7	49·7	45·2	45·6	50·0	45·6	45·9	47·8	42·3	43·8	45·6
Ultimate Analysis—															
Carbon, per cent	59·7	61·4	66·7	61·7	63·0	68·8	....	....	....	67·0	67·4	70·2	....	....	....
Hydrogen, "	5·4	5·2	4·7	5·5	5·4	4·8	....	....	....	5·2	5·2	4·9	....	....	....
Ash, "	13·6	14·0	15·2	10·3	10·5	11·5	....	....	....	14·3	14·4	15·0	....	....	....
Sulphur, "	0·6	0·6	0·7	0·6	0·6	0·7	0·6	0·6	0·7	1·0	1·0	1·0	0·9	0·9	1·0
Nitrogen, "	1·5	1·5	1·6	1·6	1·6	1·8	....	....	....	1·9	1·9	2·0	....	....	....
Oxygen, "	19·2	17·3	11·1	20·3	18·9	12·4	....	....	....	10·6	10·1	6·9	....	....	....
Calorific Value—															
Calories per grm, gross	5,820	5,990	6,500	6,020	6,140	6,710	6,190	6,250	6,850	6,670	6,710	6,990	6,230	6,440	6,720
B.T.U. per lb., gross	10,480	10,780	11,700	10,840	11,060	12,080	11,140	11,250	12,340	12,010	12,090	12,580	11,220	11,600	12,100
Fuel Ratio		1·10			1·45			1·25			1·30			1·25	
Carbon-Hydrogen ratio	11·0	11·7	14·1	11·3	11·7	14·2	....	....	....	12·8	13·0	14·2			
Coking properties	Barely agglomerates			Non-coking			Non-coking			Poor to fair			Poor to fair		
Hoffmann potash test		5									8				
Location in mine										No. 2 seam.			No. 2 seam; from face of main gangway; 120 ft. from surface or 260 ft. from slope bottom.		
Kind of sample	Mine.			Commercial, 10 tons									Mine. Partings left out.		
Designation of coal				Stove											
Taken by	Provincial Inspector			Mine operators						Mine operators			Provincial Inspector.		
Date of sampling	Nov. 19, 1925			Nov. 24, 1924						April, 1925			Nov. 24, 1925.		
				Lab sample, Jan. 24, 1925			Lab. sample Jan. 9, 1926								

—	R. E. Marlow's mine, No. 1132, Lundbreck, Alberta, sec 1, tp. 8, R. 2, W. 5 mer.			A. D. Salisbury's mine, No. 924, Longview, Alberta, sec. 8, tp. 18, R. 2, W. 5 mer.			L.F. Rathbun's No. 70, or "Riley mine," Longview, Alberta, sec. 9, tp. 18, R. 2, W. 5 mer.			Fish Creek Coal Co. Ltd., No. 361, Fish Creek, Priddis, Alberta, sec. 7, tp. 22, R. 3, W. 5 mer.			Wm. Oldham's mine, No. 1187, Bragg Creek, Alberta, sec. 28, tp. 22, R. 4, W. 5 mer.		
Sample number		N33			N40			N45			N41			N39	
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—															
Moisture per cent	6·6	4·7	....	8·9	4·3	....	7·5	5·0	....	6·9	5·1	....	6·6	3·7	....
Ash “	14·5	14·8	15·5	9·6	10·1	10·5	10·[illegible]	10·2	10·8	7·7	7·8	8·2	10·4	10·7	11·1
Volatile matter “	34·0	34·7	36·4	35·5	37·3	39·0	34·5	35·4	37·3	36·1	36·8	38·8	35·3	36·4	37·8
Fixed carbon “	44·9	45·8	48·1	46·0	48·3	50·5	48·0	49·4	51·9	49·3	50·3	53·0	47·7	49·2	51·1
Ultimate Analysis—															
Carbon per cent	64·4	65·6	68·9	66·2	69·6	72·7	....	....	....	....	....	....	68·3	70·4	73·1
Hydrogen “	5·1	5·0	4·7	5·6	5·3	5·0	....	....	....	....	....	....	5·4	5·3	5·0
Ash “	14·5	14·8	15·5	9·6	10·1	10·5	....	....	....	....	....	....	10·4	10·7	11·1
Sulphur “	0·5	0·6	0·6	0·6	0·6	0·7	0·7	0·7	0·7	0·5	0·5	0·6	0·7	0·7	0·7
Nitrogen “	1·6	1·6	1·7	1·7	1·8	1·9	....	....	....	....	....	....	1·8	1·8	1·9
Oxygen “	13·9	12·4	8·6	16·3	12·6	9·2	....	....	....	....	....	....	13·4	11·1	8·2
Calorific Value—															
Calories per grm., gross	6,410	6,530	6,860	6,610	6,940	7,250	6,600	6,780	7,140	6,900	7,030	7,420	6,870	7,090	7,360
B.T.U. per lb., gross	11,540	11,760	12,350	11,900	12,500	13,060	11,880	12,210	12,850	12,430	12,660	13,350	12,370	12,760	13,240
Fuel ratio		1·30			1·30			1·40			1·35			1·35	
Carbon-Hydrogen ratio	12·5	13·2	14·7	12·0	13·2	14·6	....	....	....	....	....	....	12·6	13·4	14·6
Coking properties		Poor to fair			Poor			Poor to fair			Poor			Poor to fair	
Hoffman potash test		8 to 7			8 to 7						8 to 7			9	
Location in mine	Lower 12 feet of No. 1 seam, from face of No. 1 level.			....			....			....			From face of main entry		
Kind of sample	Mine. Bands of clay left out according to mine practice.			Mine			Mine			Mine			Mine		
Taken by	Provincial Mine Inspector														
Date of sampling	Nov 24, 1925			Nov. 11, 1925			March 17, 1926			Jan. 13, 1926			Nov. 11, 1925		

TABLE XXXIX—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

	Bighorn & Saunders Creek Collieries Ltd., No. 388, or Saunders Creek mine, Saunders, Alberta, secs. 19 and 24, tp. 40, R. 12, W. 5 mer.			Foothills Collieries Ltd., No. 771. Foothills, Alberta, sec. 24, tp. 47, R. 20, W. 5 mer.								Coal Valley Mining Co. Ltd., No. 1002, Coal Valley, Alberta, sec. 25 tp. 47, R. 20 W. 5 mer.		Saunders Ridge Coal Co. Ltd., No. 846,. Mercoal, Alberta, sec. 25, tp. 48, R. 22, W. 5 mer.		
Sample number		3019		3038			3416			3581		3400			3399	
Moisture condition	R	AD	D	R	D	R	AD	D	R	AD	D	R	D	R	AD	D
Proximate Analysis—																
Moisture.....per cent	9·5	7·2	....	8·9	...	7·9	7·1	....	7·8	7·4	....	6·4	....	7·4	6·4	....
Ash..... "	7·8	8·0	8·6	9·3	10·2	10·0	10·1	10·8	6·2	6·3	6·7	10·9	11·6	8·0	8·1	8·6
Volatile matter..... "	32·3	33·2	35·7	34·5	37·9	34·3	34·6	37·3	35·6	35·7	38·6	34·6	37·0	35·8	36·2	38·7
Fixed carbon..... "	50·4	51·6	55·7	47·3	51·9	47·8	48·2	51·9	50·4	50·6	54·7	48·1	51·4	48·8	49·3	52·7
Ultimate Analysis—																
Carbon.....per cent	65·7	67·3	72·6	63·7	69·9	....	....	....	....	....	....	....	....	....	....	....
Hydrogen..... "	5·1	5·0	4·5	5·1	4·5	....	....	....	....	....	....	....	....	....	....	....
Ash..... "	7·8	8·0	8·6	9·3	10·2	....	....	....	....	....	....	....	....	....	....	....
Sulphur..... "	0·3	0·3	0·4	0·2	0·2	0·2	0·2	0·2	0·1	0·1	0·1	0·2	0·3	0·1	0·1	0·2
Nitrogen..... "	1·0	1·0	1·1	0·8	0·9	....	....	....	....	....	....	....	....	....	....	....
Oxygen..... "	20·1	18·4	12·8	20·9	14·3	....	....	....	....	....	....	....	....	....	....	....
Calorific Value—																
Calories per grm. gross.....	6,190	6,350	6,840	6,030	6,620	6,170	6,230	6,700	6,380	6,410	6,920	6,240	6,670	6,420	6,490	6,930
B.T.U. per lb., gross.....	11,150	11,430	12,320	10,860	11,920	11,110	11,210	12,070	11,490	11,530	12,460	11,240	12,010	11,550	11,680	12,470
Fuel ratio.....		1·55		1·35			1·40			1·40		1·40			1·35	
Carbon-Hydrogen ratio.....	12·8	13·6	16·2	12·4	15·4	....	....	....	....	....	....	....	....	....	....	....
Coking properties.....	Non-coking			Non-coking		Non-coking			Non-coking			Non-coking		Non-coking		
Kind of sample.....	Commercial; 10 tons....			Commercial; 7 tons.....					All mine.....							
Designation of coal.....	Egg.....			Stove.....												
Taken by.....	Mine operators.....			Mine operators.....					B. R. MacKay, Geological Survey.....							
Date of sampling.....	Dec. 22, 1924..... Lab. sample Jan. 9, 1925			Jan. 5, 1925..... Lab. sample Feb. 7, 1925.....		Lab. sample Dec. 5, 1925.....			Sept. 15, 1925.....					Summer of 1925.....		

	Hillcrest Collieries Limited, No. 40, Hillcrest, Alberta. sec. 18, tp. 7, R. 3, W. 5 mer.		West Canadian Collieries, Ltd., Blairmore, Alberta.							
			Bellevue mine, No. 87, Bellevue, Alberta, secs. 20 and 29 tp. 7, R. 3, W. 5 mer.		Greenhill mine, No. 396, Blairmore, Alberta, sec. 2, tp. 8, R. 4, W. 5 mer.					
Sample number	N1		N22		N23		N46		N47	
Moisture condition	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—										
Moisture per cent	1·3	....	1·3	....	1·1	....	0·9	....	0·9	....
Ash "	11·0	11·1	12·6	12·8	9·3	9·4	16·9	17·1	10·1	10·2
Volatile matter "	29·2	29·6	27·0	27·3	24·8	25·1	22·2	22·4	23·7	23·9
Fixed carbon "	58·5	59·3	59·1	59·9	64·8	65·5	60·0	60·5	65·3	65·9
Ultimate Analysis—										
Sulphur per cent	0·7	0·7	0·5	0·5	0·4	0·4	0·4	0·4	0·4	0·4
Calorific Value—										
Calories per grm., gross	7,500	7,600	7,280	7,370	7,740	7,820	7,020	7,090	7,740	7,800
B.T.U. per lb., gross	13,500	13,690	13,110	13,270	13,930	14,090	12,630	12,760	13,930	14,050
Fuel ratio	2·00		2·20		2·60		2·70		2·75	
Coking properties	Fair		Fair		Good		Fair		Fair to good	
Designation of coal	....		....		....		Coal as fed to dry-cleaning plant. Sizes up to 3½-in..		Coal coming from dry-cleaning plant. Sizes up to 3½ in.	
Taken by	All by mine operators........									
Date of sampling	April 1925..........		June 1925..........		June 1925..........		April 1926..........		April 1926.	

TABLE XXXIX—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

	International Coal & Coke Co., Ltd., Denison colliery, No. 88, Coleman, Alberta, sec.16, tp. 8, R. 4, W.5 mer.		McGillivray Creek Coal & Coke Co., Ltd., Carbondale, or No. 204 mine, Coleman, sec. 17, tp. 8, R. 4, W. 5 mer.		Canmore Coal Co., Ltd., No. 2 mine, Canmore, Alberta, sec. 29, tp. 24, R. 10, W. 5 mer.							
Sample number	N17		N21		3031		3238		3244		3363	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—												
Moisture per cent	1·1	....	1·1	....	1·0	....	0·7	....	1·0	....	0·9	....
Ash "	9·3	9·4	14·8	15·0	13·0	13·2	13·2	13·3	9·1	9·2	12·7	12·8
Volatile matter "	24·6	24·9	25·3	25·6	15·8	15·9	16·1	16·3	15·9	16·1	16·4	16·6
Fixed carbon "	65·0	65·7	58·8	59·4	70·2	70·9	70·0	70·4	74·0	74·7	70·0	70·6
Ultimate Analysis—												
Carbon per cent	....	....	....	....	78·2	79·0	....	....	....	....	....	....
Hydrogen "	....	....	....	....	4·1	4·0	....	....	....	....	....	....
Ash "	....	....	....	....	13·0	13·2	....	....	....	....	....	....
Sulphur "	0·5	0·5	0·6	0·6	0·7	0·7	0·7	0·7	0·8	0·8	0·7	0·7
Nitrogen "	....	....	....	....	1·4	1·4	....	....	....	....	....	....
Oxygen "	....	....	....	....	2·6	1·7	....	....	....	....	....	....
Calorific Value—												
Calories per grm., gross	7,520	7,600	7,010	7,080	7,410	7,490	7,370	7,420	7,750	7,830	7,390	7,460
B.T.U. per lb., gross	13,540	13,690	12,610	12,750	13,340	13,480	13,260	13,360	13,940	14,100	13,310	13,420
Fuel ratio	2·65		2·30		4·45		4·35		4·65		4·25	
Carbon-Hydrogen ratio	....	....	....	....	19·1	19·6	....	....	....	....	....	....
Coking properties	Poor		Fair to good		Agglomerates		....	....	....	....	....	....
Location in mine	....		....		From Stewart, Morris & Carey seams							
Kind of sample	....		....		Commercial: 10 tons							
Taken by	Mine operators		Mine operators		Mine operators							
Date of sampling	May 1925		May 1925		December 3, 1924 Lab. sample, Jan. 30, 1925		Lab. sample, Aug. 31, 1925		Lab. sample, Sept. 5, 1925		Lab. sample, Oct. 26, 1925	

	Brazeau Collieries, Ltd., No. 256, Nordegg, Alberta, sec. 22, tp. 40. R. 15, W. 5 mer.				British Collieries Ltd., No. 365, situated on upper Brazeau river, tp. 44, R. 20, W. 5 mer.		Medicine Lake Collieries, Ltd., near Mountain Park, Alberta, tp. 45, R. 26, W. 5 mer.				Luscar Collieries Ltd., from prospect 1 mile west of Luscar, Alberta, tp. 47, R. 24, W. 5 mer.	
Sample number	3397		3398		3423		3425		3426		3424	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—												
Moisture per cent	0·5	....	0·5	....	1·0	....	0·9	....	3·3	....	3·0	....
Ash "	9·0	9·0	9·6	9·6	28·2	28·5	21·0	21·2	11·1	11·5	12·7	13·1
Volatile matter "	16·5	16·6	16·3	16·4	20·0	20·2	19·5	19·6	31·6	32·7	20·7	21·4
Fixed carbon "	74·0	74·4	73·6	74·0	50·8	51·3	58·6	59·2	54·0	55·8	63·6	65·5
Ultimate Analysis—												
Sulphur per cent	0·5	0·5	0·4	0·4	0·2	0·2	0·5	0·6	0·4	0·4	0·2	0·2
Calorific Value—												
Calories per grm., gross	7,960	8,010	7,920	7,960	5,910	5,970	6,680	6,740	6,720	6,950	6,800	7,010
B.T.U. per lb., gross	14,330	14,410	14,260	14,340	10,640	10,750	12,020	12,130	12,100	12,510	12,240	12,620
Fuel ratio	4·50		4·50		2·55		3·00		1·70		3·05	
Coking properties	Poor		Poor		Poor		Poor		Barely agglomerates		Non-coking	
Location of mine	No. 2 mine, No. 2 room, No. 5 level.		No. 3 mine, No. 5 room, No. 9 level.		....		20-ft. seam in Medicine Lake claim.		7-ft. seam in Crooked Creek claim.		80-ft. seam in Mike Burke claim, near Camp creek.	
Kind of sample	All mine						All prospect					
Taken by	All by B. R. MacKay, Geological Survey											
Date of sampling	Sept. 12, 1925		Sept. 11, 1925		Aug. 7, 1925		Aug. 12, 1925		Oct. 23, 1925		Sept. 2, 1925	

TABLE XXXIX—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	Corbin Coals, Ltd., Corbin, B.C.				Crow's Nest Pass Coal Co., Ltd., Fernie, B.C.											
					Michel colliery				Coal Creek colliery							
Sample number	N44		N43		N31		N32		N27		N28		N29		N30	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—																
Moisture.........per cent	1·2	....	1·2	....	1·6	....	1·7	....	1·4	....	1·8	....	1·4	....	3·4	....
Ash "	20·0	20·3	12·5	12·7	7·2	7·3	6·6	6·7	7·3	7·4	6·8	6·9	6·4	6·5	5·1	5·3
Volatile matter "	25·7	26·0	22·4	22·7	23·3	23·7	23·7	24·1	25·0	25·4	26·4	26·9	22·9	23·2	24·4	25·2
Fixed carbon "	53·1	53·7	63·9	64·6	67·9	69·0	68·0	69·2	66·3	67·2	65·0	66·2	69·3	70·3	67·1	69·5
Ultimate Analysis—																
Sulphur.........per cent	0·2	0·2	0·3	0·3	0·4	0·4	0·5	0·5	0·3	0·3	0·4	0·4	0·7	0·7	0·5	0·5
Calorific value—																
Calories per grm., gross	6,280	6,350	7,340	7,430	8,030	8,170	8,110	8,250	8,080	8,200	8,060	8,210	8,110	8,230	8,050	8,340
B.T.U. per lb., gross	11,300	11,430	13,210	13,370	14,460	14,700	14,600	14,850	14,540	14,750	14,510	14,780	14,600	14,810	14,500	15,010
Fuel ratio	2·05		2·85		2·90		2·85		2·65		2·45		3·05		2·75	
Coking properties	Poor		Poor		Fair to good		Good		Good		Good		Good		Good	
Location in mine	....		....		No. 3 mine, No. 1 seam.		No. 3 mine, No. 2 seam.		No. 1 east mine, No. 1 seam; face of cross-cut off main level or entry.		No. 2 mine, No. 2 seam; from working face in No. 5 incline.		No. 3 mine, No. 3 seam; from No. 6 incline district.		No. 8 mine, No. 8 seam; from working face.	
Kind of sample	....		....		Mine; roof to floor; 9 feet of coal.		Mine; roof to floor; 5½ feet of coal.		Mine; 10-foot portion of 15 to 25-foot seam sampled as worked.		Mine; 8 feet of coal.		Mine; roof to floor; 10 feet of coal.		Mine; roof to floor; 13 feet of coal.	
Designation of coal	Unwashed......		Sizes 1 to 4 inches washed in Elmore jig.		....											
Taken by	Mine operators............				All by Provincial Senior Inspector of Mines............											
Date of sampling	March, 1926............				All during November, 1925............											

—	Coalmont Collieries, Ltd., Coalmont, B.C.			Keystone Coal Co., Ltd., Merritt, B.C.			Middlesboro Collieries, Ltd., Middlesboro, Merritt, B.C.								
Sample number		N26			N25			N 7			N 8			N24	
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—															
Moisture per cent	7·4	5·7	....	6·5	5·0	....	5·1	3·8	....	4·3	3·3	....	6·0	4·6	....
Ash "	9·8	10·0	10·6	18·6	18·9	19·9	8·1	8·2	8·5	6·6	6·6	6·9	19·5*	19·8	20·7
Volatile matter "	33·6	34·2	36·3	32·8	33·4	35·1	37·6	38·1	39·6	38·0	38·4	39·7	33·7	34·2	35·9
Fixed carbon "	49·2	50·1	53·1	42·1	42·7	45·0	49·2	49·9	51·9	51·1	51·7	53·4	40·8	41·4	43·4
Ultimate Analysis—															
Carbon per cent	66·9	68·1	72·2	58·8	59·7	62·8	69·8	70·7	73·6	72·4	73·2	75·7	....	....	....
Hydrogen "	5·1	5·0	4·7	4·8	4·7	4·4	5·5	5·4	5·2	5·6	5·5	5·3	....	....	....
Ash "	9·8	10·0	10·6	18·6	18·9	19·9	8·1	8·2	8·5	6·6	6·6	6·9	....	....	....
Sulphur "	0·3	0·3	0·4	0·5	0·6	0·6	0·8	0·8	0·8	0·6	0·6	0·6	0·6	0·6	0·6
Nitrogen "	1·2	1·2	1·3	1·1	1·1	1·2	1·3	1·4	1·4	1·7	1·8	1·8	....	....	....
Oxygen "	16·7	15·4	10·8	16·2	15·0	11·1	14·5	13·5	10·5	13·1	12·3	9·7	....	....	....
Calorific Value—															
Calories per grm., gross	6,530	6,650	7,050	5,750	5,840	6,150	6,920	7,010	7,290	7,190	7,270	7,520	5,950	6,040	6,330
B.T.U. per lb., gross	11,750	11,970	12,700	10,350	10,520	11,080	12,460	12,620	13,130	12,940	13,090	13,530	10,700	10,870	11,390
Fuel ratio		1·45			1·30			1·30			1·35			1·20	
Carbon-Hydrogen ratio	13·1	13·5	15·5	12·2	12·7	14·4	12·7	13·1	14·2	12·9	13·2	14·2	....	....	....
Coking properties		Poor			Poor			Poor to fair.			Poor to fair.			Poor	
Hoffmann potash test		7 to 6			6 to 7			8 to 7			....			....	
Location in mine	....			....			No. 1 seam............			No. 4 seam............			....		
Kind of sample	Commercial; grab sample from tipple.			Commerciel; grab sample from tipple.			....			....			Commercial; grab sample from tipple.		
Taken by	Provincial Inspector of Mines..................						Mine operators..................................						Provincial Inspector of Mines.		
Date of sampling	November, 1925..................................						May, 1925..................................						November, 1925.		

*Two subsequent coal samples from the same source contained respectively 13·6 and 6·2 per cent of ash.

TABLE XXXIX—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	Hat Creek Coal area, Clinton mining division, B.C. Samples from near Pavilion, principally from propertunder development by Hat Creek Coal Co.													
Sample number	3242		3265			3266			3267			3351		
Moisture condition	R	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—														
Moisture ... per cent	21·4	....	28·9	15·8	....	26·2	15·5	....	35·4	18·5	....	39·4	18·3	....
Ash ... "	9·0	11·4	16·9	20·0	23·8	19·2	22·0	26·0	6·1	7·7	9·4	3·2	4·3	5·3
Volatile matter ... "	34·8	44·3	25·9	30·7	36·4	27·0	30·9	36·6	25·8	32·5	39·9	24·7	33·3	40·7
Fixed carbon ... "	34·8	44·8	28·3	33·5	39·8	27·6	31·6	37·4	32·7	41·3	50·7	32·7	44·1	54·0
Ultimate Analysis—														
Carbon ... per cent	....	....	....	....	....	....	....	....	....	....	....	40·8	55·0	67·3
Hydrogen ... "	....	....	....	....	....	....	....	....	....	....	....	7·3	5·9	4·7
Ash ... "	....	....	....	....	....	....	....	....	....	....	....	3·2	4·3	5·3
Sulphur ... "	0·6	0·7	0·5	0·8	0·7	0·5	0·5	0·7	0·8	1·0	1·3	0·5	0·7	0·9
Nitrogen ... "	....	....	....	....	....	....	....	....	....	....	....	0·9	1·2	1·4
Oxygen ... "	....	....	....	....	....	....	....	....	....	....	....	47·3	32·9	20·4
Calorific Value—														
Calories per grm., gross	4,750	6,050	3,710	4,400	5,230	3,660	4,190	4,960	3,970	5,000	6,140	3,930	5,310	6,490
B.T.U. per lb., gross	8,550	10,890	6,680	7,920	9,410	6,590	7,550	8,930	7,140	9,000	11,050	7,080	9,600	11,690
Fuel ratio	1·00		1·10			1·00			1·25			1·30		
Carbon-Hydrogen ratio	....	......	....	....	....	....	....	....	....	....	....	5·6	9·3	14·2
Coking properties	Non-coking		Non-coking			Non-coking			Non-coking			Non-coking		
Hoffmann potash test	......		......			......			......			1		
Location in mine	......		Face of room off No. 1 (old) tunnel.			Along right rib of No. 1 tunnel.			Face of No. 1 tunnel.			Face of workings in No. 1 tunnel; 168 feet from mouth.		
Kind of sample	......		Mine			Mine			Mine			Mine		
Taken by	Submitted by J. D. Galloway, Provincial Mineralogist											B. R. MacKay, Geological Survey.		
Date of sampling	All during summer of 1925													

—	Hat Creek Coal area, Clinton mining division, B.C Samples from near Pavilion, principally from property under development by Hat Creek Coal Co.											
Sample number		3350			3352			3353			3268	
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—												
Moisture.....per cent	34·2	18·5	....	29·6	17·0	....	26·2	15·9	....	27·8	14·4	....
Ash "	10·9	13·5	16·6	15·5	18·3	22·1	21·3	24·3	28·9	22·0	25·9	30·2
Volatile matter "	24·2	30·0	36·8	26·5	31·2	37·6	26·2	29·8	35·5	26·5	31·2	36·4
Fixed carbon "	30·7	38·0	46·6	28·4	33·5	40·3	26·8	30·0	35·6	24·2	28·5	33·4
Ultimate Analysis—												
Sulphur.....per cent	0·9	1·1	1·4	0·4	0·5	0·6	0·5	0·6	0·7	0·9	1·1	1·3
Calorific Value—												
Calories per grm., gross	3,670	4,540	5,580	3,740	4,410	5,320	3,500	3,980	4,730	3,400	4,000	4,680
B.T.U. per lb., gross	6,600	8,180	10,040	6,730	7,940	9,570	6,290	7,170	8,520	6,120	7,200	8,420
Fuel ratio		1·25			1·05			1·00			0·92	
Coking properties		Non-coking			Non-coking			Non-coking			Non-coking	
Location in mine	Across 7-foot face of No. 1 (old) tunnel, 168 feet from mine mouth.			Across 9-foot face of 18-foot drift run in on N. side of No. 1 tunnel, 96 to 105 feet from mine mouth.			Along No. 1 tunnel from mouth to face 168 feet distant.			Along right rib of No. 2 (new) tunnel.		
Kind of sample	All mine											
Taken by	B. R. MacKay, Geological Survey									Submitted by J. D. Galloway, Provincial Mineralogist.		
Date of sampling	All during summer of 1925											
Sample number		3269			3270			3344			3345	
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—												
Moisture.....per cent	25·7	15·3	....	29·1	12·3	....	28·2	11·2	....	26·0	15·1	....
Ash "	18·2	20·7	24·5	31·5	38·9	44·3	33·6	41·5	46·7	21·9	25·2	29·7
Volatile matter "	28·3	32·3	38·1	21·1	26·1	29·8	20·7	25·6	28·8	27·3	31·3	36·8
Fixed carbon "	27·8	31·7	37·4	18·8	22·7	25·9	17·5	21·7	24·5	24·8	28·4	33·5
Ultimate Analysis—												
Sulphur.....per cent	0·7	0·7	0·9	0·8	1·0	1·1	0·7	0·9	1·0	0·8	0·9	1·0
Calorific Value—												
Calories per grm., gross	3,870	4,410	5,210	2,560	3,170	3,620	2,390	2,960	3,380	3,560	4,080	4,810
B.T.U. per lb., gross	6,970	7,950	9,380	4,610	5,710	6,510	4,300	5,330	6,000	6,400	7,350	8,650
Fuel ratio		0·98			0·87			0·85			0·91	
Coking properties		Non-coking			Non-coking			Non-coking			Non-coking	
Location in mine	Face of room off No. 2 (new) tunnel			Face of No. 2 tunnel .			Across 4-foot face at end of No. 2 tunnel			Across 7-foot face of 25-foot drift on N. side of No. 2 tunnel, 40 to 47 feet from mouth of mine		
Kind of sample	All mine											
Taken by	Submitted by J. D. Galloway, Provincial Mineralogist.						B. R. MacKay, Geological Survey					
Date of sampling	All during summer of 1925											

TABLE XXXIX—Continued.

Analyses of Solid Fuels Occurring in Canada—Continued.

—		Hat Creek Coal area, Clinton mining division, B.C. Samples from near Pavilion, principally from property under development by Hat Creek Coal Co.											
Sample number		3346			3347			3348			3349		
Moisture condition		R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—													
Moisture	per cent	30·4	13·1	....	29·5	13·9	....	24·7	16·2	....	26·1	17·2	....
Ash	"	22·8	28·5	32·8	20·1	24·6	28·5	15·8	17·6	21·0	10·6	11·9	14·3
Volatile matter	"	24·2	30·2	34·7	26·8	32·7	38·0	29·7	33·1	39·5	31·5	35·3	42·7
Fixed carbon	"	22·6	28·2	32·5	23·6	28·8	33·5	29·8	33·1	39·5	31·8	35·6	43·0
Ultimate Analysis—													
Carbon	per cent	....	....	....	....	....	....	....	....	....	45·6	51·1	61·7
Hydrogen	"	....	....	....	....	....	....	....	....	....	6·4	5·8	4·7
Ash	"	....	....	....	....	....	....	....	....	....	10·6	11·9	14·3
Sulphur	"	1·0	1·2	1·4	1·0	1·2	1·4	0·8	0·9	1·1	0·6	0·6	0·8
Nitrogen	"	....	....	....	....	....	....	....	....	....	1·0	1·1	1·4
Oxygen	"	....	....	....	....	....	....	....	....	....	35·8	29·5	17·1
Calorific Value—													
Calories per grm., gross		3,110	3,880	4,470	3,400	4,150	4,820	3,990	4,440	5,300	4,480	5,010	6,060
B.T.U. per lb., gross		5,600	6,990	8,050	6,120	7,470	8,670	7,180	7,990	9,540	8,060	9,020	10,910
Fuel ratio			0·95			0·88			1·00			1·00	
Carbon-Hydrogen ratio		....	....	....	....	....	....	....	....	....	7·2	8·8	13·2
Coking properties		Non-coking			Non-coking			Non-coking			Non-coking		
Hoffmann potash test		....	....	....	....	....	....	....	....	....	....	1	....
Location in mine		Across measures in No. 2 (new) tunnel, from centre of syncline 75 feet from tunnel mouth to end of tunnel 105 feet from mouth.			Across measures in No. 2 tunnel, from centre of syncline, 75 feet from tunnel mouth, to centre of anticline, 57 feet from tunnel mouth.			Across seam in No. 2 tunnel from centre of syncline 50 feet from mine mouth to base of measures at mouth.			From drift on N. side of No. 2 tunnel, 45 feet from mouth.		
Kind of sample		All mine											
Taken by		B. R. MacKay, Geological Survey											
Date of sampling		All during summer of 1925											

—		Telkwa Collieries Co., Ltd, mine situated on Goat creek, 6 miles from Telkwa, B.C.								Kathlyn Lake Coal Co., Lake Kathlyn, B.C.	
Sample number		3396		3505		3635		3636		3358	
Moisture condition		R	D	R	D	R	D	R	D	R	D
Proximate Analysis—											
Moisture	per cent	1·2	....	1·4	....	1·1	....	1·0	....	9·8	....
Ash	“	11·6	11·7	4·5	4·6	10·3	10·4	8·5	8·6	2·2	2·4
Volatile matter	“	31·6	32·0	32·2	32·7	32·1	32·4	32·2	32·6	6·5	7·2
Fixed carbon	“	55·6	56·3	61·9	62·7	56·5	57·2	58·3	58·8	81·5	90·4
Ultimate Analysis—											
Carbon	per cent	75·8	76·7	....	....	....	....	....	....	....	....
Hydrogen	“	4·5	4·5	....	....	....	....	....	....	....	....
Ash	“	11·6	11·7	....	....	....	....	....	....	....	....
Sulphur	“	0·7	0·7	....	....	2·1	2·1	2·2	2·2	0·1	0·1
Nitrogen	“	0·9	0·9	....	....	....	....	....	....	....	....
Oxygen	“	6·5	5·5	....	....	....	....	....	....	....	....
Calorific Value—											
Calories per grm, gross		7,430	7,530	....	....	7,600	7,680	7,770	7,850	6,720	7,440
B.T.U. per lb., gross		13,380	13,550	....	....	13,680	13,830	13,980	14,130	12,090	13,400
Fuel ratio		1·75		1·90		1·75		1·80		12·50	
Carbon-Hydrogen ratio		16·7	17·1	....	....	....	....	....	....	....	....
Coking properties		Poor		Fair		Poor to fair		Poor to fair		Non-coking	
Location in mine		Across 7- to 10-foot seam									
Kind of sample		Mine								Prospect.	
Taken by		B. R. MacKay Geological Survey.		Submitted by Commissioner of C.N. Railways.		Mine operators				G. Hanson, Geological Survey.	
Date of sampling		Summer of 1925		December, 1925		February, 1926				Summer of 1925.	

TABLE XXXIX—Concluded

Analyses of Solid Fuels Occurring in Canada—Concluded

—	Granby Consolidated Mining, Smelting and Power Co., Ltd., Cassidy, B.C.				Western Fuel Corporation of Canada, Ltd., Nanaimo, B.C.					
Sample number	N15		N16		N18		N19		N20	
Moisture condition	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—										
Moisture.....per cent	1·9	....	1·8	....	2·9	....	2·4	....	2·3	....
Ash.....“	19·5	19·9	14·6	14·8	11·0	11·3	7·3	7·4	8·1	8·3
Volatile matter.....“	34·7	35·4	36·5	37·2	42·5	43·8	40·4	41·4	41·2	42·2
Fixed carbon.....“	43·9	44·7	47·1	48·0	43·6	44·9	49·9	51·2	48·4	49·5
Ultimate Analysis—										
Carbon.....per cent	....	....	....	....	70·2	72·3	74·6	76·5	73·8	75·5
Hydrogen.....“	....	....	....	....	5·3	5·2	5·3	5·2	5·4	5·3
Ash.....“	....	....	....	....	11·0	11·3	7·3	7·4	8·1	8·3
Sulphur.....“	0·5	0·5	0·5	0·6	1·6	1·7	0·6	0·6	0·4	0·5
Nitrogen.....“	....	....	....	....	1·3	1·3	1·4	1·4	1·2	1·2
Oxygen.....“	....	....	....	....	10·6	8·2	10·8	8·9	11·1	9·2
Calorific Value—										
Calories per grm., gross	6,370	6,500	6,870	7,000	6,960	7,170	7,360	7,540	7,300	7,470
B.T.U. per lb., gross	11,470	11,700	12,370	12,600	12,530	12,900	13,250	13,580	13,130	13,450
Fuel ratio	1·25		1·30		1·05		1·25		1·20	
Carbon-Hydrogen ratio	....	....	....	....	13·2	14·0	13·9	14·7	13·7	14·4
Coking properties	Poor to fair.		Poor to fair.		Poor to fair.		Fair.		Poor to fair.	
Location in mine	.....		.....		No. 1 mine, Newcastle seam.		Reserve mine, Douglas seam.		Wakesiah mine, Wellington seam.	
Designation of coal	Raw feed to washery, through 2-inch mesh.		Washed pea and slack from Faust jig washery, through 1-inch mesh.		.....		.....		.....	
Taken by	All by mine operators.....				.....					
Date of sampling	April 28, 1925.....				April 30, 1925.....					

—	Canadian Collieries (Dunsmuir), Limited, Cumberland, B.C.									
	Wellington mines, Ladysmith				Comox mines, Union Bay					
Sample number	N13		N14		N9		N10		N11	
Moisture condition	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—										
Moisture per cent	2·3	....	1·9	....	1·7	....	1·4	....	0·6	....
Ash "	7·1	7·3	5·7	5·8	9·4	9·5	12·5	12·7	18·1	18·2
Volatile matter "	39·2	40·1	39·6	40·3	30·7	31·2	30·1	30·5	2·8	2·8
Fixed carbon "	51·4	52·6	52·8	53·9	58·2	59·3	56·0	56·8	78·5	79·0
Ultimate Analysis—										
Carbon per cent	....	....	....	....	76·2	77·5	....	....	....	....
Hydrogen "	....	....	....	....	5·1	5·0	....	....	....	....
Ash "	....	....	....	....	9·4	9·5	....	....	....	....
Sulphur "	0·5	0·5	0·5	0·5	1·0	1·0	1·1	1·1	1·9	1·9
Nitrogen "	....	....	....	....	1·1	1·1	....	....	....	....
Oxygen "	....	....	....	....	7·2	5·9	....	....	....	....
Calorific Value—										
Calories per grm., gross	7,390	7,560	7,580	7,730	7,450	7,580	7,250	7,350	6,140	6,180
B.T.U. per lb., gross	13,300	13,610	13,640	13,910	13,420	13,650	13,050	13,230	11,060	11,130
Fuel ratio	1·30		1·35		1·90		1·85			
Carbon-Hydrogen ratio	....	....	....	....	15·0	15·6	....	....	....	....
Coking properties	Poor to fair.		Poor to fair.		Good.		Good			
Location in mine	Douglas seam		Wellington seam		No. 4 mine		No. 4 mine			
Kind of sample					Commercial; from tipple.					
Designation of coal	South Wellington lump.		Extension lump		Crushed lump		Pea coal from modified Luhrig jig washery.		Coke made in beehive oven.	
Taken by	All by mine operators									
Date of sampling	May 13, 1925				May 8, 1925					

TABLE XL

Analyses of Coal Samples Submitted by Department of Soldiers' Civil Re-establishment

—	Delivered to Ste. Anne de Bellevue Hospital; described as "Dominion" or Glace Bay, Nova Scotia, coal.															
Sample number	3235	3236	3246	3254	3255	3260	3261	3321	3336	3359 3370	3360 3371	3376 3413	3377	3378	3407	3408
Moisture (as received)	4·7	4·4	3·2	6·9	4·7	4·7	4·2	5·0	4·5	5·1	4·6	7·7	3·7	2·8	5·7	5·9
Dry Basis—																
Ash ... per cent	16·1	9·8	13·6	11·2	11·7	9·4	8·9	12·7	10·5	8·7	8·6	9·1	7·8	7·7	10·2	10·0
Volatile matter ... "	31·9	33·3	32·3	32·6	33·8	34·9	34·6	33·4	34·4	33·7	33·9	33·6	34·6	34·3	32·4	32·5
Fixed carbon ... "	52·0	56·9	54·1	56·2	54·5	55·7	56·5	53·9	55·1	57·6	57·5	57·3	57·6	58·0	57·4	57·5
Sulphur ... "	1·9	2·5	2·5	2·5	2·3	2·9	3·0	2·0	2·2	2·9	2·9	2·7	2·3	2·4	2·8	3·1
Calories per grm., gross	6,940	7,620	7,260	7,490	7,430	7,630	7,670	7,340	7,480	7,740	7,730	7,680	7,850	7,860	7,630	7,620
B.T.U. per lb., gross	12,490	13,720	13,070	13,480	13,370	13,730	13,800	13,210	13,470	13,920	13,920	13,820	14,130	14,140	13,730	13,720
Number of tons represented by sample	103	85	208	122	140	104	89	289	322	258	304	232	193	266	167	193
Date of delivery	Aug. 15 to 20 1925	Aug. 25	Sept. 5	Sept. 17	Sept. 21	Sept. 25	Sept. 25	Oct. 5	Oct. 12	Oct. 17	Oct. 20	Oct. 24	Oct. 28	Oct. 31	Nov. 12 to 16	Nov. 18

—	Delivered to Ste. Anne de Bellevue Hospital; described as "Dominion" or Glace Bay, Nova Scotia, coal.							Delivered to Lancaster Hospital, St. John, N.B.; described as Minto, N.B., coal.			Delivered to Ste. Anne de Bellevue Hospital; described as Minto, N.B., coal.		Delivered to Deer Lodge Hospital, Winnipeg; described as "McGillivray," Coleman, Alberta, coal.			
Sample number	3414	3429	3430	3574	3575	3576	3642	3125–8	3427	3643	3117	3132 3225	3140 3330	3362	3431	3604
Moisture (as received)	3·9	3·7	4·7	5·8	6·0	5·8	6·1	2·3	1·9	1·6	4·2	4·1	4·9	4·3	2·7	4·9
Dry Basis—																
Ash ... per cent	8·6	7·8	8·3	9·2	9·1	9·3	10·0	16·2	19·9	18·0	22·9	20·4	20·5	18·8	20·2	18·9
Volatile matter ... "	33·7	34·6	33·9	33·0	33·4	33·4	33·1	32·3	30·5	30·8	30·1	31·6	28·0	27·1	26·1	26·4
Fixed carbon ... "	57·7	57·6	57·8	57·8	57·5	57·3	56·9	51·5	49·6	51·2	47·0	48·0	51·5	54·1	53·7	54·7
Sulphur ... "	2·8	2·9	3·0	3·2	3·3	3·2	3·2	7·4	8·1	6·4	6·4	5·4	0·6	0·7	0·9	1·0
Calories per grm., gross	7,730	7,820	7,810	7,710	7,690	7,690	7,670	6,970	6,680	7,000	6,450	6,720	6,450	6,740	6,700	6,790
B.T.U. per lb., gross	13,910	14,080	14,050	13,870	13,840	13,840	13,810	12,540	12,020	12,600	11,610	12,090	11,600	12,140	12,070	12,220
Number of tons represented by sample	200	237	186	210	222	213	203	....	125	110	97	145	25	31	49	52
Date of delivery	Nov. 23	Nov. 30	Dec. 5	Dec. 10	Dec. 18	Dec. 27	Dec. 31	....	July to Nov., 1925	Jan. 6 to Mar. 11, 1926	June 13, 1925	June 26 to 29, 1925	July 18, 1925	Oct. 15, 1925	Dec. 8, 1925	Jan. 2 to 30, 1926

—	Delivered to Christie St. Hospital, Toronto; described as coming from the Pittsburg, or No. 8 seam, in Belmont co., Ohio, U.S.; from the following mines: "Oco" at Lafferty, "Columbia" at Fairpoint, or "Lucy" at Stewartsville.															
Sample number	3220 3324	3241 3325	3247 3326	3275	3361	3383	3410	3411	3572	3573	3579	3596	3610	3611	3630	3634
Moisture (as received)	5·5	4·2	5·4	5·3	6·0	5·7	5·4	5·9	5·4	5·3	3·9	5·7	4·3	4·6	5·7	4·9
Dry Basis—																
Ash per cent	14·8	13·9	14·5	12·5	12·2	12·9	10·9	10·2	11·1	10·9	10·8	11·1	9·0	7·7	10·4	9·0
Volatile matter "	36·2	35·4	36·4	37·8	37·4	38·3	34·3	34·5	34·8	35·0	32·7	39·4	36·6	36·3	35·0	36·0
Fixed carbon "	49·0	50·7	49·1	49·7	50·4	48·8	54·8	55·3	54·1	54·1	56·5	49·5	54·4	56·0	54·6	55·0
Sulphur "	3·5	3·2	3·6	3·7	3·4	4·0	2·2	2·1	2·4	2·1	1·5	4·1	3·3	2·9	2·6	3·3
Calories per grm., gross	7,000	7,100	7,010	7,240	7,210	7,240	7,580	7,610	7,510	7,510	7,580	7,370	7,770	7,930	7,680	7,790
B.T.U. per lb., gross	12,600	12,780	12,620	13,030	12,980	13,030	13,640	13,700	13,520	13,520	13,640	13,270	13,990	14,270	13,830	14,020
Number of tons represented by sample	200	200	400	400	300	315	340	430	240	330	330	230	360	260	365	360
Date of delivery	July 10 to Aug. 1, 1925	Aug. 12 to 26	Sept. 2 to 10	Sept. 18 to 30	Oct. 8 to 20	Oct. 23 to Nov. 4	Nov. 13 to 18	Nov. 24	Dec. 9 to 12	Dec. 22	Dec. 30	Jan. 9 to 18, 1926	Jan. 28 to Feb. 10	Feb. 15	Feb. 27	Mar. 11

—	Delivered to Westminster Hospital, London, Ont.; described as coming from Logan co., West Virginia, U.S., from the following mines:—"Monitor" on the Draper seam at Monitor Mines or "Rossmore" on the Silent Creek seam at Rossman.															
Sample number	3233 3322	3245 3323	3262	3276	3343	3366	3375	3393	3412	3571	3595	3599	3608	3629	3637	....
Moisture (as received)	3·8	3·4	4·4	4·5	5·3	4·5	4·1	4·4	5·3	2·1	4·7	4·8	4·0	5·5	4·9	....
Dry Basis—																
Ash per cent	13·2	7·8	10·4	14·0	14·3	12·9	13·6	15·2	13·2	9·9	6·8	6·6	5·7	6·8	6·4	....
Volatile matter "	32·3	34·6	36·1	32·2	34·2	34·3	34·0	33·2	33·9	34·6	33·2	33·9	35·0	34·5	34·0	....
Fixed carbon "	54·5	57·6	53·5	53·8	51·5	52·8	52·4	51·6	52·9	55·5	60·0	59·5	59·3	58·7	59·6	....
Sulphur "	1·1	1·0	2·0	2·0	2·1	1·6	1·0	1·0	1·3	1·3	0·8	0·8	0·7	0·8	0·7	....
Calories per grm., gross	7,330	7,800	7,540	7,220	7,120	7,300	7,300	7,150	7,290	7,660	7,910	7,930	7,970	7,890	7,900	....
B.T.U. per lb., gross	13,190	14,040	13,570	12,990	12,810	13,150	13,140	12,870	13,130	13,790	14,230	14,270	14,350	14,210	14,230	....
Number of tons represented by sample	196	193	285	210	248	380	410	304	250	233	262	420	418	264	382	....
Date of delivery	Aug. 22, 1925	....	Sept. 1 to 23	Oct. 2	Oct. 12	Oct. 25	Oct. 31	Nov. 7	Nov. 20 to 26	Dec. 9 to 14	Dec. 30, 1925, to Jan. 15, 1926	Jan. 27	Feb. 9	Feb. 23	Mar. 1 to 15	

TABLE XLI

Analyses of Miscellaneous Solid Fuels

—	Welsh Anthracitic Coal											
Number of samples represented	2		1		2		2		1		1	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—												
Moisture per cent	1·9	....	3·6	....	2·3	....	2·4	....	2·3	....	1·8	....
Ash “	4·3	4·4	6·0	6·2	4·8	4·9	4·7	4·8	4·8	4·9	5·3	5·4
Volatile matter “	8·4	8·6	8·5	8·8	7·5	7·7	8·0	8·2	7·6	7·8	7·8	8·0
Fixed carbon “	85·4	87·0	81·9	85·0	85·4	87·4	84·9	87·0	85·3	87·3	85·1	86·6
Ultimate Analysis—												
Carbon per cent.	....	....	....	....	....	....	....	....	....	....	85·9	87·5
Hydrogen “	....	....	....	....	....	....	....	....	....	....	3·3	3·2
Ash “	....	....	....	....	....	....	....	....	....	....	5·3	5·4
Sulphur “	1·0	1·1	....	....	0·7	0·7	0·9	0·9	0·9	1·0	1·2	1·2
Nitrogen “	....	....	....	....	....	....	....	....	....	....	1·0	1·0
Oxygen “	....	....	....	....	....	....	....	....	....	....	3·3	1·7
Calorific Value—												
Calories per grm, gross	8,140	8,300	7,640*	7,930	7,930	8,120	7,920	8,120	7,740	7,920	7,850	7,990
B.T.U. per lb., gross	14,650	14,930	13,760	14,270	14,270	14,610	14,260	14,620	13,930	14,260	14,130	14,390
Fuel ratio	10·20		9·70		11·35		10·65		11·25		10·85	
Carbon-Hydrogen ratio	....	....	....	....	....	....	....	....	....	....	25·3	27·5
Designation of coal	....	....	"Swansea-Beth, Big Vein."		From Ponty Berem colliery.		....		....		....	
Date	Sept. 13, 1922				Nov. 29, 1922 and June 1923.		Oct. 19 and Nov. 20, 1923.		July 25, 1924.		Oct. 6, 1924.	
Numbers of samples	2071 and 2072		2073		2151 and Special		2522 and 2592		2777		2898	

Number of samples represented	2		2		2		2		3	
Moisture condition	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—										
Moisture per cent	2·0	....	9·3	....	3·6	....	0·9	....	1·5	....
Ash “	3·7	3·8	5·8	6·4	5·8	6·0	5·4	5·5	7·3	7·4
Volatile matter “	8·2	8·4	7·6	8·4	....	....	11·7	11·8	12·9	13·1
Fixed carbon “	86·1	87·8	77·3	85·2	....	....	82·0	82·7	78·3	79·5
Ultimate Analysis—										
Sulphur per cent	0·9	1·0	....	....	....	....	....	....	....	....
Calorific value—										
Calories per grm, gross	8,030	8,190	....	....	....	....	8,070*	8,140	....	....
B.T.U. per lb., gross	14,450	14,750	....	....	....	....	14,520	14,650	....	....
Fuel Ratio	10·50		10·10		....		7·00		6·05	
Designation of coal	....		Screenings		Screenings		Mixed sizes		'Anthracite cobbles'	
Date	Aug. 19 and Oct. 13, 1925		May 6 and 26, 1924		Oct. 13, 1924		Sept. 25 and Nov. 18, 1922		Oct. 13 and 14, 1925	
Numbers of samples	3229 and 3328		2726 and 2735		2906 and 2907		2078 and 2126		3327, 3332, and 3333	

*Calorific value corrected according to the sulphur content of representative Welsh anthracite.

——	Welsh Anthracitic Coal							
Number of samples represented	1		1		1		2	
Moisture condition	R	D	R	D	R	D	R	D
Proximate Analysis—								
Moisture ... per cent	1·4	....	4·3	....	0·8	....	2·9	....
Ash ... "	7·5	7·6	5·9	6·2	10·9	11·0	10·1	10·4
Volatile matter ... "	11·1	11·3	10·5	11·0	13·4	13·5	13·4	13·8
Fixed carbon ... "	80·0	81·1	79·3	82·8	74·9	75·5	73·6	75·8
Ultimate Analysis—								
Sulphur ... per cent	0·9	0·9	....	....	....	....	0·9	1·0
Calorific Value—								
Calories per grm, gross	7,810	7,920	7,720*	8,070	....	....	7,300	7,520
B.T.U. per lb., gross	14,070	14,260	13,900	4,530	....	....	13,140	13,530
Fuel ratio	7·20		7·60		5·60		5·50	
Designation of coal	"Big Vein"		"Welsh Boulets" (Briquettes).		"Stovoids" (Briquettes).		"Ovoids" (Briquettes).	
Date	Mar. 19, 1926		Aug. 15, 1922		Nov. 29, 1922		Feb. 19, 1924 and June 1923.	
Numbers of samples	3638		2056		2149		2627 and Special	

——	Scotch Semi-Anthracite							
Sample number	2271		2270		2269		2921	
Moisture condition	R	D	R	D	R	D	R	D
Proximate Analysis—								
Moisture ... per cent	1·9	....	1·5	....	1·3	....	2·3	....
Ash ... "	4·9	5·0	4·1	4·2	6·5	6·6	6·6	6·8
Volatile matter ... "	10·2	10·4	10·2	10·4	10·3	10·4	10·1	10·3
Fixed carbon ... "	83·0	84·6	84·2	85·4	81·9	83·0	81·0	82·9
Ultimate Analysis—								
Carbon ... per cent	....	....	....	....	....	....	83·2	85·2
Hydrogen ... "	....	....	....	....	....	....	3·6	3·4
Ash ... "	....	....	....	....	....	....	6·6	6·8
Sulphur ... "	0·8	0·8	0·8	0·9	0·8	0·8	0·7	0·7
Nitrogen ... "	....	....	....	....	....	....	1·8	1·9
Oxygen ... "	....	....	....	....	....	....	4·1	2·0
Calorific Value—								
Calories per grm., gross	7,890	8,040	8,020	8,140	7,870	7,970	7,730	7,910
B.T.U. per lb., gross	14,200	14,470	14,440	14,660	14,170	14,360	13,910	14,240
Fuel ratio	8·10		8·20		8·00		8·05	
Carbon-Hydrogen ratio	....	....	....	....	....	....	23·2	25·0
Designation of coal	Furnace		Stove		Nut		Chiefly stove, nut and pea sizes.	
Date	June 9, 1923						Oct. 31, 1924.	

*Calorific value corrected according to the sulphur content of representative Welsh anthracite.

TABLE XLI—Continued

Analyses of Miscellaneous Solid Fuels—Continued

—	Pennsylvania Anthracite													
Number of samples represented	1		1		1		1		1		1		1	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—														
Moisture per cent	2·9	....	2·2	....	2·6	....	2·6	....	2·8	....	2·9	....	2·6	....
Ash "	13·4	13·8	18·8	19·2	16·1	16·6	23·7	24·4	7·9	8·2	9·2	9·5	7·5	7·7
Volatile matter "	....	....	....	....	5·6	5·7	....	....	4·9	5·0	4·9	5·0	4·5	4·6
Fixed carbon "	....	....	....	....	75·7	77·7	....	....	84·4	86·8	83·0	85·5	85·4	87·7
Ultimate Analysis—														
Sulphur per cent	0·9	1·0	0·6	0·6	....	....	1·3	1·3	0·7	0·8	0·5	0·5	0·5	0·6
Calorific Value—														
Calories per grm., gross	6,950	7,160	6,520	6,670	....	....	5,890	6,040	7,410	7,620	7,320	7,530	7,500	7,710
B.T.U. per lb., gross	12,520	12,890	11,730	12,000	....	....	10,600	10,880	13,330	13,720	13,170	13,560	13,510	13,870
Fuel ratio	....		....		13·60		....	....	17·50		17·10		19·00	
Designation of coal	Nut		Egg		Egg		Nut		Egg		Stove		Nut	
Date	Nov. 15, 1918		Dec. 22, 1920		Feb. 25, 1921		June 14, 1921		Nov. 30, 1921		....		....	
Numbers of samples	1372		1727		1762		1816		1943		1944		1945	
Number of samples represented	3		1		1		2		2		1		2	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—														
Moisture per cent	3·9	....	4·7	....	3·3	....	2·9	....	3·2	....	2·7	....	3·3	....
Ash "	11·4	11·8	15·0	15·8	9·1	9·5	14·2	14·6	12·0	12·4	10·5	10·8	14·9	15·4
Volatile matter "	6·8	7·1	6·6	6·9	....	....	5·5	5·7	....	....	6·5	6·6	6·3	6·5
Fixed carbon "	77·9	81·1	73·7	77·3	....	....	77·4	79·7	....	....	80·3	82·6	75·5	78·1
Ultimate Analysis—														
Sulphur per cent	....	....	0·8	0·9	....	....	0·8	0·8	....	....	....	....	0·7	0·7
Calorific Value—														
Calories per grm., gross	7,090*	7,370	6,650	6,980	....	....	6,820	7,030	....	....	7,120*	7,320	6,730	6,970
B.T.U. per lb., gross	12,750	13,260	11,970	12,570	....	....	12,280	12,650	....	....	12,820	13,180	12,120	12,540
Fuel ratio	11·50		11·15		....	....	14·10		....	....	12·45		12·10	
Designation of coal	Stove		Pea		Furnace		Stove		Probably stove		Stove		Stove	
Date	June 20, and July 5, 1922		Aug. 24, 1922		Oct. 21, 1922		June 30, and Oct. 30, 1923		Nov. 20, 1923		Feb., 1924		Feb. 17, and July 23, 1924	
Numbers of samples	2018, 2019, 2022		2062		2090		2302, 2568		2588, 2589		2388		2620, 2775	

* Calorific value corrected according to the sulphur content of representative Pennsylvania anthracite.

—	Pennsylvania Anthracite											
Number of samples represented	1		1		1		1		7		1	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—												
Moisture per cent	3·9	....	3·6	....	3·5	....	3·4	....	3·4	....	1·6	....
Ash "	14·4	15·0	15·0	15·6	11·6	12·0	14·3	14·9	12·2	12·6	11·8	12·0
Volatile matter "	6·2	6·5	6·0	6·2	6·1	6·3	6·5	6·7	6·1	6·3	....	....
Fixed carbon "	75·5	78·5	75·4	78·2	78·8	81·7	75·8	78·4	78·3	81·1	....	....
Ultimate Analysis—												
Carbon per cent	76·1	79·2	....	....	78·5	81·4	77·0	79·6	....	....	....	....
Hydrogen "	3·2	2·8	....	....	2·9	2·6	2·4	2·1	....	....	....	....
Ash "	14·4	15·0	....	....	11·6	12·0	14·3	14·9	....	....	....	....
Sulphur "	0·9	1·0	0·9	1·0	0·9	1·0	1·0	1·0	....	....	....	....
Nitrogen "	0·8	0·8	....	....	0·9	0·9	0·8	0·8	....	....	....	....
Oxygen "	4·6	1·2	....	....	5·2	2·1	4·5	1·6	....	....	....	....
Calorific Value—												
Calories per grm., gross	6,720	6,990	6,630	6,880	7,090	7,340	6,830	7,070	....	....	....	....
B.T.U. per lb., gross	12,090	12,580	11,930	12,380	12,760	13,220	12,300	12,720	....	....	....	....
Fuel ratio	12·15		12·50		12·90		11·65		12·80		....	....
Carbon-Hydrogen ratio	24·2	28·1	....	....	27·0	31·2	32·2	38·3	....	....	....	....
Designation of coal	Stove		Stove		Stove		Stove		Egg and stove		Nut	
Date	May 4, 1925		June 6, 1925		Oct. 13, 1925		Jan. 18, 1926		Jan. 21, July 21 and Aug. 19, 1925, Feb. 23, 1926.		Feb. 23, 1926	
Numbers of samples	3072		3099		3329		3587		3024, 3137, 3230A, 3230B, 3230C, 3614 3614A		3615	

TABLE XLI—Continued

Analyses of Miscellaneous Solid Fuels—Continued

—	Pennsylvania anthracite						Pennsylvania, Connell, semi-anthracite			
Number of samples represented	1				3		1		1	
Moisture condition	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—										
Moisture per cent	0·9	....	4·1	....	4·2	....	1·7	....	1·8	....
Ash “	17·0	17·1	16·4	17·1	11·5	12·0	15·9	16·2	12·6	12·9
Volatile matter “	....	....	....	....	5·5	5·8	9·0	9·1	8·5	8·6
Fixed carbon “	....	....	....	....	78·8	82·2	73·4	74·7	77·1	78·5
Ultimate Analyses—										
Sulphur per cent	....	....	....	....	....	....	0·7	0·7	....	....
Calorific Value—										
Calories per grm., gross	....	....	....	....	....	....	6,950	7,070	....	....
B.T.U. per lb., gross	....	....	....	....	....	....	12,510	12,720	....	....
Fuel ratio	....	....	....	....	14·25		8·20		9·05	
Designation of coal	Pea		Buckwheat		Red ash		....		....	
Date	Feb. 23, 1926		Feb. 23, 1926		Jan. 21, Aug. 19, Aug. 20, 1925		June 6, 1925		Aug. 31, 1925	
Numbers of samples	3616		3613		3025, 3230D, 3231B		3100		3237	

—	Coke manufactured by Illingworth Carbonization Co., Pontypridd, Wales		Carbonized Saskatchewan lignite, manufactured by Heyes process, Toronto		Fuel briquettes, manufactured by Superfuel Corporation of New York City		Eichelberger, Broad Top, United States semi-bituminous or "smokeless" coal			
Sample number	3506		3040		3018		3495		3641	
Moisture condition	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—										
Moisture per cent	0·9	....	5·6	....	0·7	....	0·5	....	1·0	....
Ash “	9·5	9·5	15·5	16·5	8·9	9·0	14·6	14·6	11·4	11·5
Volatile matter “	8·7	8·8	12·7	13·4	6·4	6·4	15·9	16·0	....	....
Fixed carbon “	80·9	81·7	66·2	70·1	84·0	84·6	69·0	69·4	....	....
Ultimate Analysis—										
Sulphur per cent	....	....	0·5	0·6	0·9	0·9	2·1	2·1	....	....
Calorific Value—										
Calories per grm., gross	....	....	6,420	6,790	7,470	7,520	7,360	7,400	....	....
B.T.U. per lb., gross	....	....	11,550	12,230	13,440	13,540	13,250	13,320	....	....
Fuel ratio	9·30		5·20		13·10		4·35		....	....
Date	Dec. 21, 1925		Feb. 7, 1925		Jan. 8, 1925		Dec. 17, 1925		March 22, 1926	

—		United States Semi-Bituminous or "Smokeless" Coals											
		"Red Star" Pennsylvania		Clearfield district, near Johnstown, Pa.		"Lincoln"		"Raven"					
Sample number		1467		1468		2920		2393		3271		3509	
Moisture condition		R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—													
Moisture	per cent	1·2	....	2·0	....	1·1	....	1·6	....	1·3	....	1·0	....
Ash	"	8·5	8·6	15·0	15·3	7·0	7·1	9·1	9·2	8·3	8·4	8·8	8·9
Volatile matter	"	16·3	16·5	16·8	17·1	20·7	20·9	19·3	19·6	20·0	20·3	19·2	19·4
Fixed carbon	"	74·0	74·9	66·2	67·6	71·2	72·0	70·0	71·2	70·4	71·3	71·0	71·7
Ultimate Analysis—													
Carbon	per cent	....	....	....	....	....	....	....	....	80·0	81·0	....	....
Hydrogen	"	....	....	....	....	....	....	....	....	4·5	4·4	....	....
Ash	"	....	....	....	....	....	....	....	....	8·3	8·4	....	....
Sulphur	"	0·8	0·8	3·8	3·9	1·5	1·5	2·9	2·9	3·2	3·3	3·2	3·3
Nitrogen	"	....	....	....	....	....	....	....	....	1·3	1·3	....	....
Oxygen	"	....	....	....	....	....	....	....	....	2·7	1·6	....	....
Calorific Value—													
Calories per grm., gross		....	....	....	....	....	....	7,760	7,890	7,850	7,950	7,840	7,920
B.T.U. per lb., gross		....	....	....	....	....	....	13,980	14,200	14,120	14,310	14,120	14,260
Fuel ratio		4·55		3·95		3·45		3·65		3·50		3·70	
Carbon-Hydrogen ratio		....	....	....	....	....	....	....	....	17·9	18·4	....	....
Designation of coal		Smithy coal		Smithy coal		Smithy coal		....		....		....	
Date		Feb. 3, 1919		Jan. 31, 1919		Oct. 29, 1924		Aug. 28, 1923		Oct. 5, 1925		Dec. 24, 1925	
Remarks		....		....		....		....		Both these samples from same consignment of coal.			

TABLE XLI—Concluded

Analyses of Miscellaneous Solid Fuels—Concluded

—		United States Semi-Bituminous, or "Smokeless" Coals									
		Fulton seam, Broadtop field, Pa.		"Pennsylvania Scots' Run"		"Seese"		"Moshannan"		3rd seam Pocohontas	
Sample number		3070		3093		3223		3224		3409	
Moisture condition		R	D	R	D	R	D	R	D	R	D
Proximate Analysis—											
Moisture	per cent	0·6	....	0·6	....	1·7	....	1·8	....	0·7	....
Ash	"	10·0	10·0	13·0	13·1	12·6	12·8	13·1	13·4	7·8	7·9
Volatile matter	"	16·0	16·1	18·5	18·6	17·3	17·6	17·3	17·6	17·8	17·9
Fixed carbon	"	73·4	73·9	67·9	68·3	68·4	69·6	67·8	69·0	73·7	74·2
Ultimate Analysis—											
Carbon	per cent	80·3	80·8	....	....	....	....	....	....	....	....
Hydrogen	"	4·3	4·3	....	....	....	....	....	....	....	....
Ash	"	10·0	10·0	....	....	....	....	....	....	....	....
Sulphur	"	1·8	1·8	1·6	1·6	1·8	1·9	2·0	2·1	0·6	0·7
Nitrogen	"	1·2	1·3	....	....	....	....	....	....	....	....
Oxygen	"	2·4	1·8	....	....	....	....	....	....	....	....
Calorific Value—											
Calories per grm., gross		7,790	7,840	7,510	7,560	7,460	7,580	7,430	7,570	8,050	8,110
B.T.U. per lb., gross		14,020	14,110	13,510	13,600	13,420	13,650	13,380	13,630	14,490	14,600
Fuel ratio		4·60		3·65		3·95		3·90		4·15	
Carbon-Hydrogen ratio		18·7	19·0	....	....	....	....	....	....	....	....
Designation of coal				Slack, smithy coal							
Date		April 25, 1925		May 28, 1925		Aug. 13, 1925		Aug. 13, 1925		Nov. 24, 1925	

PART II

I

THE EXAMINATION OF LUBRICATING OILS AFTER USE IN AUTOMOBILE ENGINES

P. V. Rosewarne

INTRODUCTION

The marvellous development of the automotive industry during the past twenty years has brought with it many new and interesting problems. One of them deals with methods for the lubrication of that intricate mechanism known as the internal combustion engine, which problem may be left confidently in the hands of the mechanical engineers; another closely related one enters a field of chemistry that in the past has not been too closely studied, namely, the reactions of lubricating oils when used under service conditions in the engine.

Every automobile owner has been urged to change the oil in his car after an arbitrarily specified number of miles has been travelled. The natural conclusion in the popular mind was that the oil was "worn out" and its appearance when removed certainly differed from the oil which had been put into the crankcase originally. Some drivers of a more enquiring turn of mind may have found statements in the scientific press to the effect that the oil did not actually "wear out." If these statements were correct, why was one urged to discard the old oil and so waste a material extravagantly, which from every point of view should be conserved as much as possible? The reply that experience had proved it advisable was not entirely satisfactory and many investigators in various countries set out to discover a more comprehensive answer.

Some of the results of an investigation which began three years ago at the Fuel Testing Station of the Mines Branch, form the basis of this report. It deals with practical trials of several oils in automobile engines operated by their respective owners. The object of the investigation was to obtain, as a preliminary to further work, data on the changes that take place in several brands of automobile lubricating oil in general use and on the carbon deposit in an automobile engine under ordinary operating conditions. Some of the considerations which were kept in mind in undertaking the investigation were: *(a)* the almost universal use of the internal combustion engine, *(b)* the general lack of knowledge of the capabilities of oils for use in these engines, *(c)* the lack of specific data which could be used in interpreting the relation between analytical results and actual results in operation, and *(d)* the extravagant and conflicting claims made for some oils.

METHOD OF PROCEDURE

The general procedure adopted was to clean the carbon from the engine, drain the oil from the crankcase and fill it up with the selected brand of oil. The owner agreed: (1) to make careful note of the general operation of the car, such as power, acceleration, spark-plug fouling, overheating, etc.; (2) to buy, as far as possible, only one brand of gasoline; (3) to put into the engine only such oil as was supplied by the laboratory; and (4) to return the car at the end of the test in order that the carbon might be removed and the oil changed for another test.

Samples of the different oils used were examined before and after the test. The carbon samples obtained were set aside for further analysis, the results of which are not yet complete.

There were eight different makes of cars used in the series of tests, all of them in the popular price class. Sixteen owners co-operated in making the tests and seventeen cars were used. Over forty test runs were made as shown in Table XLII.

TABLE XLII

Data on Test Runs

Lab. No. of used oil	Lab. No. of engine	Name of make of car	Brand of oil used	Grade of oil	Name of owner
6—1	FA	Ford	Autolene	Heavy	R. E. Gilmore
2	FB	Ford	Mobiloil	"A"	L. L. Bolton
3	LA	McLaughlin	Veedol	Medium	A. W. Mantle
4	FA	Ford	Autolene	Medium	R. E. Gilmore
5	FB	Ford	Veedol	Medium	L. L. Bolton
6	GA	Gray Dort			
7	FF	Ford	Polarine	Medium	S. Holman
8	FA	Ford	Autolene	Medium	R. E. Gilmore
9	GB	Gray Dort			H. Kohl
10	DA	Dodge			W. Kritsch
11	FC	Ford	Polarine	Medium	L. MacMartin
12	OA	Overland			E. Cottingham
13	FB	Ford	Veedol	Medium	L. L. Bolton
14	FF	Ford	Polarine	Medium	J. Sugrue
15	MA	Maxwell			T. Flood
16	FA	Ford	Autolene	Medium	R. E. Gilmore
17	GC	Gray Dort			P. V. Rosewarne
18	FA	Ford	Autolene	Medium	R. E. Gilmore
19	GD	Gray Dort	Motorene	"A"	E. Chartrand
20	SA	Star	Mobiloil	"A"	S. Holman
21	RA	Durant			J. S. Godard
22	FD	Ford	Purol	Medium	J. Sugrue.
23	FC	Ford	Veedol	Medium	L. MacMartin
25	OA	Overland	Autolene	Medium	E. Cottingham
26	FA	Ford	Autolene	Medium	R. E. Gilmore
27	FB	Ford	Monogram	Medium	L. L. Bolton
28	CA	Chevrolet			R. Curran
29	SA	Star	Red Indian	Medium	S. Holman.
30	GC	Gray Dort	Enarco	Medium	P. V. Rosewarne
31	FB	Ford	Polarine	Medium	L. L. Bolton
32	FA	Ford	Autolene	Medium	R. E. Gilmore
33	FB	Ford	Enarco	Medium	L. L. Bolton
34	FA	Ford	Autolene	Heavy	R. E. Gilmore
35	FB	Ford	Veedol	Forzol	L. L. Bolton
36	FA	Ford	Autolene	Heavy	R. E. Gilmore
37	FA	Ford	Autolene	Heavy	R. E. Gilmore
38	FE	Ford	Enarco	Ex. Med	C. E. Baltzer
39	FA	Ford	Autolene	Heavy	R. A. Strong
40	FB	Ford	Red Indian	Medium	L. L. Bolton
41	GC	Gray Dort	Enarco	Heavy	P. V. Rosewarne
42	FG	Ford			R. E. Gilmore
44	GC	Gray Dort	Motorene	"A"	P. V. Rosewarne
45	GC	Gray Dort	Polarine	Heavy	P. V. Rosewarne
46	FH	Ford	New Process	Medium	F. Burstow
47	FH	Ford	Autolene	Medium	F. Burstow

METHODS USED FOR EXAMINATION

The oils were examined by approved laboratory methods. The characteristics determined were specific gravity, flash point, carbon residue, viscosity, and dilution. A few typical samples were further tested for acidity, oxidation, precipitation, free carbon, inorganic matter, and heavy metals.

The specific gravity was determined by means of the hydrometer or the Westphal balance at room temperature and corrected to 60° F. by reference to tables;[1] the flash point, by means of the Pensky-Marten's closed, flash-point tester manipulated according to procedure approved by the Institution of Petroleum Technologists and the American Society for Testing Materials;[2] the viscosity, by means of the Redwood viscometer according to procedure approved by Sir Boverton Redwood;[3] the carbon residue, by the Conradson method as specified by the Institution of Petroleum Technologists and the American Society for Testing Materials;[4] the dilution, by the method suggested by Sligh,[5] which was found to be quite satisfactory in so far as duplicate results from the same sample could be obtained readily and quickly with a variation of less than 0·5 per cent; the oxidation, by the method outlined by Waters;[6] and the precipitation, by the method approved by the Institution of Petroleum Technologists[7] and the American Society for Testing Materials. The free carbon was determined by igniting the dried precipitated material and calculating the loss in weight as free carbon. The method is obviously open to criticism since some resinous or asphaltic matter was also present, but it was believed that these constituents were present in only small amounts. The inorganic matter was the residue after ignition, and this in turn was tested qualitatively for the presence of heavy metals, such as lead, tin, iron, copper, etc.

RESULTS OF EXAMINATION

In Table XLIII are to be found the results of the examination of the samples before and after use. The laboratory numbers are shown in order that any sample mentioned may be referred back to this table for more complete information.

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[1] U.S. Bureau of Standards, Circular No. 57.

[2] "Standard Methods of Testing Petroleum and its Products," Method L. O. 7.
"American Society for Testing Materials," Method D93-22.

[3] Redwood: "A Treatise on Petroleums," Vol. 2, p. 275.

[4] "Standard Methods of Testing Petroleum and its Products," Method G. O. 9.
"American Society for Testing Materials," Method D189-24T.

[5] Journal of Society of Automotive Engineers, Vol. 16, No. 3, p. 355.

[6] U.S. Bureau of Standards, Scientific Papers 153 and 160; Technologic Papers 4 and 73; Circular 99.

[7] "Standard Methods for Testing Petroleum and its Products," Method F. O. 14a.
"American Society for Testing Materials," Method D96--24T

TABLE XLIII

Analyses of Used and Unused Oils

Lab. No.	Date taken	Eng. No.	Sp. Gr. at 60° F.		Viscosity at 100° F.		Flash point °F.		Carbon residue		Dilution % After
			Before	After	Before	After	Before	After	Before	After	
	1923										
1..........	June 12	FA	0·904	0·921	288	335	385	155	0·33	0·46	4·0
2..........	July 5	FB	0·932	0·927	569	430	345	175	0·40	0·85	5·5
3..........	July 7	LA	0·894	0·896	262	233	380	165	0·38	0·64	6·5
4..........	July 9	FA	0·906	0·901	370	564	355	160	....	1·15	5·0
5..........	July 27	FB	0·894	0·894	262	202	380	145	0·38	0·76	9·5
6..........	Aug. 11	GA	....	0·910	....	184	....	135	....	....	10·5
7..........	Aug. 14	FF	0·933	0·911	399	297	355	190	0·28	0·37	2·0
8..........	Aug. 14	FA	0·906	0·898	370	465	355	175	0·95	0·95	5·5
9..........	Aug. 18	GB	....	0·916	....	373	....	265	....	....	1·5
10..........	Aug. 20	DA	....	0·914	....	261	....	135	....	....	9·5
11..........	Aug. 21	FC	0·933	0·908	399	233	355	135	0·28	0·19	2·5
12..........	Aug. 23	OA	....	0·904	....	177	....	100	....	....	7·5
13..........	Aug. 27	FB	0·894	0·895	262	312	380	180	0·38	0·94	5·0
14..........	Aug. 27	FD	0·933	0·905	399	188	355	150	0·28	0·26	7·0
15..........	Aug. 29	MA	....	0·900	....	319	....	150	....	....	6·0
16..........	Aug. 31	FA	0·906	0·896	370	265	355	140	....	0·82	8·5
17..........	Sept. 1	GC	0·888	0·906	174	201	380	135	0·11	0·81	11·0
18..........	Oct. 3	FA	0·901	0·896	251	228	380	130	0·46	0·89	5·5
19..........	Oct. 8	GD	....	0·912	....	518	....	130	....	....	8·5
20..........	Oct. 11	SA	0·932	0·912	569	153	345	150	0·46	0·46	13·0
21..........	Oct. 12	RA	....	0·896	....	91	....	140	....	....	16·5
22..........	Oct. 18	FD	0·913	0·902	262	138	400	135	0·37	0·51	11·0
23..........	Oct. 19	FC	0·892	0·890	267	217	390	135	0·45	0·65	4·5
25..........	Oct. 29	OA	....	0·890	....	122	....	95	....	0·42	13·0
26..........	Oct. 31	FA	0·901	0·894	251	173	380	120	0·46	0·64	7·5
27..........	Nov. 2	FB	0·895	0·894	278	276	390	155	0·37	0·77	4·0
28..........	Dec. 18	CA	0·904	0·880	228	69	385	100	0·33	0·28	19·5
	1924										
29..........	May 15	SA	0·913	0·919	455	194	405	110	0·93	0·66	11·5
30..........	May 21	GC	0·888	0·874	174	....	380	110	0·11	....	15·5
31..........	May 30	FB	0·933	0·908	399	239	355	165	0·28	0·45	5·5
32..........	June 21	FA	0·902	0·898	259	214	390	150	....	0·60	4·0
33..........	July 15	FB	0·888	0·914	174	294	380	165	0·11	0·50	5·5
34..........	July 29	FA	0·928	0·921	461	366	310	145	0·15	0·37	3·5
35..........	Aug. 18	FB	0·895	0·891	251	196	385	160	0·39	0·64	7·5
36..........	Aug. 18	FA	0·928	0·903	461	202	310	135	0·15	0·71	5·0
37..........	Aug. 25	FA	0·928	0·920	461	303	310	150	0·15	0·39	6·0
38..........	Sept. 5	FE	0·899	0·906	293	305	375	190	0·42	0·68	0·5
39..........	Sept. 16	FA	0·930	0·921	447	304	325	140	0·12	0·23	4·5
40..........	Sept. 17	FB	0·913	0·901	502	213	420	150	0·83	1·23	12·0
41..........	Nov. 1	GC	0·899	0·891	293	107	375	110	0·42	0·75	17·5
42..........	Nov. 8	FG	0·895	0·893	292	137	395	115	0·42	0·76	10·5
	1925										
44..........	Aug. 31	GC	0·913	....	547	....	385	....	0·95	....	12·5
45..........	Nov. 12	GC	0·914	....	372	....	392	....	....	....	18·0
	1926										
46..........	May 5	FH	0·937	0·929	344	218	415	160	0·03	0·15	4·7
47..........	May 15	FH	0·937	0·926	344	197	415	160	0·03	0·20	6·8

DISCUSSION OF RESULTS

As stated before, the investigation was intended to collect data on the changes that take place in lubricating oils when used in automobile engines under normal operating conditions. It is believed that the tabulated results show with a fair degree of accuracy the conditions that will probably obtain in a car driven by the average owner in a reasonably careful manner. Large variations were expected and expectations were fully realized, but not always in the direction that had been anticipated. It should be kept in mind that the work was planned purely as a preliminary and makes no claim to be a finished investigation. The conclusions drawn are intended merely as tentative to be proved or disproved later with laboratory equipment designed especially to obtain results on that one particular phase of the problem.

Used Oil

The term "used oil" may be somewhat ambiguous without further explanation. For that reason it may be pointed out that in this paper "used oil" refers to the liquid found in the crankcase at the completion of the test run, and includes whatever colloidal matter and suspended material that may be present in the supernatant liquid after the sample has stood for some time in closed containers. The sample was allowed to stand in order that the water might separate out to a certain degree, since it interfered considerably in the distillation to determine the amount of dilution. It is undoubtedly true that some solid particles settled out also, but it was believed that these would have only a minor effect on the determinations made. The samples of used oil were examined in respect to specific gravity, flash point, carbon residue, viscosity, and dilution. A determination of the water content would probably have been of interest in reviewing the data, but its significance was not realized in time.

Sludge

After the oil had been drawn off in one of the tests, it was observed that the inner surfaces of the crankcase were coated with a brown jelly-like substance, often referred to as "sludge." This was analysed and found to consist approximately of the following materials:—

Water	20 per cent
Gasoline (boiling below 437° F.)	15 "
Lubricating oil	50 "
Sediment	15 "

The test from which this material was obtained was completed late in the fall, during which many short runs were made, and it is improbable that sludges or emulsions of this type would form during warm weather or even in cold weather if the car were driven sufficiently to heat up the oil thoroughly.

Specific Gravity

There are many variations of specific gravity shown in Table XLIII and, although it is expected that in the next part of the investigation the data may be valuable, it was not thought necessary to place undue emphasis upon it at the present time. The specific gravity has been suggested as an index of the amount of dilution[1], but in view of the erratic results obtained it is doubtful if it is of much value for that purpose.

Flash Point

The flash point is the temperature to which an oil has to be heated in order that enough vapour may be given off to form an inflammable mixture with the air which will "flash" or burn momentarily when exposed to a flame or spark. In order that concordant results may be obtained when an oil is tested in different laboratories by different operators, the design and dimensions of the apparatus, as well as the method of procedure, must be standardized. As stated above, the closed Pensky-Marten's apparatus was used for determining the flash points given in this paper.

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[1] Knoch, Crosby, and Matthews: Journal of Industrial and Engineering Chemistry, Vol. 16, No. 11, p. 1153 (1924).
Larson: Journal of Industrial and Engineering Chemistry, Vol. 17, No. 5, p. 476 (1925).

Flash Point and Dilution. It will be noted that in all cases the flash point was surprisingly low, even when as little as 0·5 per cent of dilution was present. Also that, generally, the greater the amount of dilution the lower was the flash point. The lowering of the flash point has been used as an indication of the amount of dilution.[1] In Table XLIV the eight samples which showed the highest flash point and the eight samples which showed the lowest flash point are shown with the amount of dilution found in each sample. It will be observed that while the general agreement is very good, the flash point cannot be depended upon for an accurate estimation of the amount of diluent. The controlling factor in determining the flash point is the vapour pressure of the diluent present and that would vary somewhat according to the fuel used.

TABLE XLIV

Flash Points of Used Oil and Dilution

Eight highest flash points			Eight lowest flash points		
Lab. No.	Flash point, °F	Dilution, per cent	Lab. No.	Flash point, °F.	Dilution, per cent
38	190	0·5	22	135	11·0
7	190	2·0	18	130	5·5
13	180	5·0	26	120	7·5
2	175	5·5	42	115	10·5
8	175	5·5	29	110	11·5
3	165	6·5	30	110	15·5
33	165	5·5	41	110	17·5
31	165	5·5	28	100	19·5

On referring to Table XLV it will be seen that the flash point returns practically to its former value when the diluent has been removed by vacuum distillation.

Flash Point and Lubrication. Wagner[2] has pointed out that the flash point of a lubricating oil is commonly held to indicate the ability of the oil to resist heat, and in so far as that impression is held it may give misleading results. As explained above, the flash point is a measure of the volatility of the most volatile fraction present. It does not necessarily represent the volatility of the entire mass of the oil. It seems likely, in the light of the results shown in Table XLIV, that too much emphasis has been placed on the flash point of automobile oils. Table L shows that the amount of dilution is practically the same after 200 miles' travel as after 1,000 or 1,500 miles' travel. Then it must be admitted that for the greater part of the time the engines in these tests were lubricated, and lubricated satisfactorily, with oil which had a flash point so low that no refiner would risk his reputation by offering it to the trade as long as it is generally believed that a high flash point is a characteristic of good oil.

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[1] Knoch, Crosby, and Matthews: *loc. cit.*

[2] Wagner: Journal of the Society of Automotive Engineers, Sept., 1925, p. 263.

Carbon Residues

The carbon residues may be considered as the coke-like residue that remains when the oil is vapourized and burned under stated conditions. The method of procedure is very like that adopted in the proximate analysis of coals to obtain the amount of volatile matter. As in coals, so in oils, the coke residue varies in appearance and amount with the origin of the sample under test. In this connexion Gill[1] states that oils showing more than 0·50 per cent of coke-like residue are not suitable for automobile engine work. The best of them contain 0·06 to 0·08 per cent; a large number contain 0·20 to 0·40 per cent and are entirely satisfactory. Steam-engine cylinder oils contain in the neighbourhood of 4·00 per cent and cannot be used. It should be noted that Gill did not use the Conradson method, but it is evident that the results obtained with the glass retort that he used are somewhat comparable to those obtained with the standardized Conradson apparatus. The recently published work of Livingstone, Marley, and Gruse[2] shows that an oil with a high-carbon residue value deposits a larger amount of carbon in the combustion chamber than an oil with a low-carbon residue value.

An examination of the results given in Table XLIII shows that in most cases the carbon residue value of the oil increased considerably after use, even when the diluent was present in the sample tested. Removal of the diluent increased the carbon residue values of the residual oil still more as shown in Table XLV.

Viscosity

The viscosity of any liquid refers to its internal resistance or its resistance to flow. This viscosity of an oil is usually measured by determining the time required for a given volume of oil at a specified temperature to flow through an opening of definite size. There are several different kinds of apparatus in general use to determine the viscosity of oils by this method. The Redwood viscometer is the instrument generally adopted in England, and was used to determine the viscosity of the oils described in this paper. The volume of oil to be measured from the Redwood under approved procedure is 50 c.c. In the tables given the time has been expressed in seconds.

Variations in Viscosity. It may be noted here that in some cases there was found to be considerable variation in viscosity for different samples of new oil of the same brand and grade. On the other hand, some brands showed a very uniform viscosity for different samples.

It was noted also that the terms "light," "medium," and "heavy" motor oil had little significance, since it was apparent that each manufacturer decided for himself what grading should be applied to his own product. It would appear, in spite of the interim report prepared by the sectional committee of the Canadian Engineering Standards Association,[3] that standard grades for motor lubricating oil could be established by co-operation among Canadian refiners, somewhat similar to the plan advocated by the Society of Automotive Engineers,[4] which would bring

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[1] Gill: "Oil Analysis," page 47.

[2] "Motor Carbon Deposits Formed under Controlled Conditions from Typical Automobile Oils," Journal of Industrial and Engineering Chemistry, Vol. 18, No. 5, p. 502 (1926).

[3] Canadian Engineering Standards Association, Bulletin No. D11 (1924), "Interim Report of the Sectional Committee on Gasoline and Lubricating Oil."

[4] Journal of the Society of Automotive Engineers, March, 1925, p. 266.

large returns in increased confidence, and would certainly be a material aid to the public in selecting oils for automobile use. Under the present system the buyer is mystified at the very beginning by the fact that oils of different brands which are obviously different in "body" or viscosity, are stated to be of the same grade.

Viscosity and Dilution. It is well known that dilution of an oil with a more volatile fraction decreases the viscosity of the oil, and that is what happens when oil is diluted in an automobile engine by the motor fuel. Since a decrease in viscosity lowers the pressure which can be maintained by the oil film, the question arises as to how much dilution may be permitted without incurring danger of a ruptured film and a burned-out bearing. The results are too few and the data too meagre to permit drawing any conclusions, but at least it is indicated that very heavy oils are not essential for the operation of the automobile engine. It may be, however, that some of the used oils were working perilously near the breaking point.

On the other hand, there were several samples which even with the diluent present showed a higher viscosity than the original oil. Usually the higher viscosity of the used oil was reflected in a higher specific gravity also, but in one or two cases the specific gravity increased or showed little change, whereas the viscosity dropped considerably. On referring to Table XLV, it will be observed that when the diluent is removed the specific gravity, the viscosity, the flash point, and the carbon residue values are all increased (with one exception in the case of the last named). It will be seen also that the specific gravity and the flash point return approximately to the values found for the unused oil, but that the viscosity value (with one exception) and the carbon residue value are higher than the values found for the original oil. Since the viscosity values are higher when the diluent is removed, it is logical to believe that the oil had undergone some change, and that the change which seems to have occurred in all cases, may have proceeded in some few instances to such an extent that the viscosity was increased sufficiently to more than offset the normal effect of dilution. From these results it would seem that the determination of the amount of dilution by the change in viscosity[1] could not be altogether depended upon.

TABLE XLV

Comparison of Unused, Used, and Reclaimed Oils

Lab. No.	Specific gravity at 60° F.			Viscosity at 100° F.			Flash point °F.			Carbon residue, per cent			Dilution, per cent
	New	Used	Recl'd.	New	Used	Recl'd.	New	Used	Recl'd.	New	Used	Recl'd.	Used
20	0·932	0·912	0·930	569	153	559	345	150	365	0·46	0·46	0·80	13·0
23	0·892	0·890	0·899	267	217	315	390	135	380	0·45	0·65	0·79	4·5
39	0·930	0·921	0·928	447	304	556	325	140	340	0·12	0·23	0·22	4·5
40	0·913	0·901	0·915	502	213	671	420	150	415	0·83	1·23	1·80	12·0

Viscosity and Decomposition. Such erratic behaviour is difficult to explain with the data given, but, as stated above, it seems evident that the oil had undergone some change, and not necessarily the same type of change in every case. For instance, some of the oil may have decomposed

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[1] Barnard: Journal of Industrial and Engineering Chemistry, Vol. 17, No. 3, p. 278 (1925).
Larson: Journal of Industrial and Engineering Chemistry, Vol. 17, No. 5, p. 476 (1925).

or "cracked"; it may have become oxidized; it may have reacted chemically with the metals present; a stable emulsion may have been formed; and finally it may have been caused by something else. The writer believes that the change is largely due to the first two, namely, decomposition and oxidation, and this view is supported by the results of the examination of the oil when the diluent is removed.

Since the decomposition of petroleum products is always accompanied by the deposition of free carbon,[1] the formation of carbon in the combustion chamber is very good evidence that the oil has partly broken down. It may be argued that the carbon can also come from the fuel and so it may, but the preponderance of evidence clearly indicates that by far the larger part comes from the oil. For instance, the oil before use is clear red or yellow, after use it becomes black and opaque. Moreover, photomicrographs have been prepared in which the carbon particles may be observed[2] in the oil. There is good reason, therefore, to believe that decomposition does take place and it only remains to show the relation between decomposition and viscosity. In the decomposition of petroleum there is produced, besides carbon, a heavy residual oil. This may be due to a selective reaction by which the lighter compounds are decomposed first.[3] In any case, the resultant is an oil higher in viscosity than the oil before treatment.

Viscosity and Oxidation. It is generally accepted now that lubricating oils can be oxidized to an appreciable extent by the action of sunlight and air.[4] In an ordinary automobile engine the oil is beaten to a fine mist by the rapidly moving parts and in such a fine state of subdivision is in the best possible condition to be ozidized by the air. Moreover, it is subjected to a higher temperature than normal, which condition is also conducive to oxidation. The used oils described in this paper were found to have a higher acidity and a higher carbon residue value than the new oil, both of which characteristics have been shown by Waters[5] to accompany oxidation. The thickening of other oils due to oxidation is well known and there is every reason to expect petroleum oils also to become thicker on that account.

Viscosity and Mileage. Since it is well known[6] that lubricating oils become more viscous through use it was to be expected that the oils used in these tests would become more viscous the greater the distance travelled. Such a result was indicated by the few results that were available at the time of writing, but it was believed that further work was necessary before the matter could be discussed satisfactorily. It has been stated[7] that heavy viscous oils deposit larger percentages of carbon in the combustion chamber than lighter oils do.

The possibility of the amount of change in viscosity through use being related to the lubricating value of the various oils was also suggested, but that too must be left over till a later date.

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[1] Wagner: Journal of the Society of Automotive Engineers, Sept., 1925, p. 266.
Hallock: Journal of the Society of Automotive Engineers, Jan., 1924, p. 57.

[2] Round: Journal of the Society of Automotive Engineers, Feb., 1925, p. 232.

[3] Battle: "Lubricating Engineers' Handbook," p. 295.

[4] Holde: "Examination of Hydrocarbon Oils," p. 150.
Van Brunt and Miller: Journal of Industrial and Engineering Chemistry, Vol. 17, No. 4, p. 416.
Wagner: Journal of the Society of Automotive Engineers, Sept., 1925, p. 265.

[5] Waters: U.S. Bureau of Standards, Technologic Paper 73.
Journal of Industrial and Engineering Chemistry, Vol. 13, No. 10, p. 901.

[6] Sligh: Journal of the Society of Automotive Engineers, March, 1925, p. 355.
Sparrow and Eisinger: Journal of Industrial and Engineering Chemistry, Vol. 18, No. 5, p. 482 (1926).

[7] Hallock: Journal of the Society of Automotive Engineers, Jan., 1924, p. 57.

DILUTION

When lubricating oil has been in use in an automobile engine it appears to have become thinner and to have lost some of its "body" or viscosity. Formerly, the oil was said to be "worn out," but it has become fairly well recognized now[1] that the greater part of the oil is still a valuable lubricant if the foreign matter present were removed. "Foreign matter" as used in the above case is intended to include road dust, metallic particles from the moving parts, free carbon from the fuel or from the oil itself, oxidized products from the oil, and light oils due to absorption of some of the fuel, or to decomposition of the oil. The presence of light oils tends to dilute or thin out the lubricant, thereby lowering its viscosity and it is to this effect that the term "dilution" is applied. It should be pointed out that all the other kinds of foreign matter referred to above tend to thicken lubricating oil or to increase its viscosity. Usually the effect of the thickening factors is more than counterbalanced by the amount of diluent present.

The Cause of Dilution

The two chief factors[2] in producing dilution have been accepted for some time as the low temperature of the cylinder walls, and the excessive use of the "choke" when a cold engine is started. Other factors mentioned are: engine load, fuel-air ratio, temperature of oil in the crankcase, temperature of the intake air, volatility of the fuel, and fit of pistons and rings. The dilution of the oil is believed to occur[3] through the condensation of some of the vaporized fuel, or through the absorption of some of the partly vaporized incoming fuel by the oil film on the cylinder walls, in which diluted state it gradually works past the piston rings and returns to the oil sump to dilute the whole body of oil. It is generally admitted[4] that a considerable portion of the fuel, even under normal operation, is not completely vaporized, but passes into the combustion chamber in a more or less finely-divided liquid phase. Research[5] has indicated that improved manifold design can do much toward better vaporization and distribution of the fuel which should assist in lowering the percentage of dilution.

Dilution and Atmospheric Conditions

A casual examination of Table XLIII shows that the percentage of dilution, irrespective of the make of engine, or of the brand of oil used, has a general tendency to increase during the cooler months. This agrees with tests reported by Warner.[6]

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[1] Wagner: Journal of the Society of Automotive Engineers, Sept., 1925, p. 263.
Flowers, McBerty and Reamer: Journal of Industrial and Engineering Chemistry, Vol. 17, No. 5, p. 481 (1925).
Hallock: Journal of the Society of Automotive Engineers, Jan., 1924, p. 57.

[2] Lee: Journal of the Society of Automotive Engineers, July, 1923, p. 12.
Hallock: Journal of the Society of Automotive Engineers, Jan., 1924, p. 57.
MacCoull: Journal of the Society of Automotive Engineers, July, 1924, p. 93.
Sparrow and Eisinger: Journal of Industrial and Engineering Chemistry, Vol. 18, No. 5, p. 482 (1926).

[3] Eisinger: Journal of the Society of Automotive Engineers, July, 1924, p. 69.
Schweitzer: Journal of the Society of Automotive Engineers, Jan., 1925, p. 92.
Clayden: Journal of the Society of Automotive Engineers, July, 1925, p. 58.

[4] Wagner: Journal of the Society of Automotive Engineers, Sept., 1925, p. 263.
Schweitzer: Journal of the Society of Automotive Engineers, Jan., 1925, p. 92.

[5] Asire: Journal of the Society of Automotive Engineers, April, 1924, p. 387.

[5] Warner: Journal of the Society of Automotive Engineers, Feb., 1924, p. 151.

The amount of dilution in the samples tested was found to vary from 0·5 per cent to almost 20 per cent. These were obtained under actual operating conditions and are believed to represent a fair average. However, the latter figure should not be considered the maximum that can occur. Instances have been brought to the writer's attention where the dilution amounted to almost 50 per cent, but such cases are believed to be due to an abnormal condition of the engine, or of its operation. Rhodes and Haon[1] report from 25 to 30 per cent under cold weather conditions, and other investigators[2] found somewhat similar amounts.

Table XLVI shows the percentage dilution obtained when the same brand of oil is used in the same engine by the same driver in successive tests, using the same brand of gasoline. It will be observed that the dilution varies from 3·5 to 8·5 per cent. From these results it would appear that a variation of at least 5 per cent may be expected from this type of engine when conditions are controlled as much as they can be during normal operation of the car.

TABLE XLVI

Results Obtained When the Same Brand of Oil is Used in the Same Engine by the Same Driver

Laboratory number	Date taken	Engine number	Brand of oil	Dilution, per cent
1	June 12	FA	10	4·0
4	July 9	FA	10	5·0
8	Aug. 14	FA	10	5·5
16	Aug. 31	FA	10	8·5
18	Oct. 5	FA	10	5·5
26	Oct. 31	FA	10	7·5
32	June 21	FA	10	4·0
34	July 29	FA	10	3·5
37	Aug. 25	FA	10	6·0

Dilution and Different Brands of Oil

In Table XLVII is shown the percentage of dilution obtained when six different brands of oil were used in the same engine by the same driver using the same brand of gasoline as fuel. The brands were selected so that they include oils made from paraffin, mixed, and napthene-base, crude petroleums. In this case the dilution varied from 4·0 to 7·5 per cent; a variation of 3·5 per cent. Therefore, it seems evident that under operating conditions the amount of dilution was not affected greatly by the different characteristics of the six brands used, since an equal or greater variation occurred when only one brand was used as shown in Table XLVI.

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[1] Rhodes and Haon: Journal of Industrial and Engineering Chemistry, Vol. 17, No. 1, p. 25 (1925).

[2] Flowers, McBerty, and Reamer: Journal of Industrial and Engineering Chemistry, Vol. 17, No. 5, p. 481 (1925).
Barnard: Journal of Industrial and Engineering Chemistry, Vol. 17, No. 3, p. 280 (1925).

TABLE XLVII

Results Obtained When Different Brands of Oil Are Used in the Same Engine by the same Driver

Laboratory number	Date taken	Engine number	Brand of oil	Dilution, per cent
2	July 5	FB	12	5·5
13	Aug. 27	FB	18	5·0
27	Nov. 2	FB	13	4·0
31	May 30	FB	15	5·5
33	July 15	FB	11	5·5
35	Aug. 18	FB	19	7·5

In Table XLVIII is shown the average results from different engines of the same make using the same brand of oil. The results were compiled in order to show the amount of dilution that may be expected to occur from this type of engine in the hands of different drivers. Eight different engines were used in making the tests. Ten different brands of oil were used and the number of tests on each brand varied from one to twelve. The amount of dilution varied from 4·0 to 12·0 per cent.

TABLE XLVIII

Average Results Obtained When Different Engines of the Same Make Use the Same Brand of Oil

Number of tests	Brand of oil	Average dilution, per cent
12	10	5·5
5	11	5·5
4	15	4·5
3	18	6·5
2	12	5·5
2	20	5·5
2	19	9·0
2	17	12·0
1	13	4·0
1	16	11·0

Dilution and Mechanical Wear

Table XLIX was compiled to show in a general way how the amount of wear in engines of the same make affected the amount of dilution. For this purpose the age of the engine was accepted as being more or less comparable to the amount of wear. The oldest engine in this class had been in use four years previous to the year of the test; the newest came directly from the dealers; the other engines varied between these extremes. The mechanical condition of the different engines was considered good, in view of their respective ages. The results were rather surprising inasmuch as the oldest one gave results below the average, the newest one, very high results, and the lowest result was obtained from an engine that had run three seasons previous to the test.

It is also to be noted in Table XLVI and Table XLVII, where successive tests on two engines covering two years' operation are shown, that there is no definite trend toward greater dilution in the second year than occurred in the first.

Another interesting result was obtained from an engine of a different make from the above. This engine was seven years old. The pistons were loose and gave a definite "piston slap" when running under load. Two cylinders were slightly scored. The amount of dilution under these conditions averaged 15·0 per cent for three tests. A new cylinder block, new pistons, new piston rings and pins were obtained from the factory, so that the engine might be considered a new one in so far as wear of the moving parts could affect dilution. The amount of dilution under the new conditions averaged 16·0 per cent for two tests.

These results indicate that the amount of wear has a minor influence on the amount of dilution and agrees with the observations reported by Sparrow and Eisinger[1] who used from one to three rings on the piston, and a measured amount of clearance between the piston and the cylinder wall. They found that a clearance up to $\frac{1}{32}$-inch or 0·031 inch seemed to have little effect on the amount of dilution. The clearance on a new engine is from 0·002 to 0·004 inch.

TABLE XLIX

Dilution in Relation to Age of Engine

Number of tests	Age of engine at time of tests	Number of engines tested	Average dilution per cent
1	new	1	10·5
10	1 year	2	6·0
11	2 years	3	5·9
5	3 years	3	6·7
2	4 years	1	3·5

Dilution and Mileage

In Table L is shown the results obtained when the same brand of oil was used in one engine for different mileages, and when different brands of oil were used in another engine of the same make for different mileages. In the latter case it was necessary to use a second engine to complete the series. It will be observed that practically the same amount of dilution was found in both cases for a little over 200 miles' travel as for 1,000 and 1,500 miles' travel. It would seem that some sort of an equilibrium of dilution was reached which agrees with observations made by other investigators.[2] MacCoull[3] shows that an important factor in maintaining equilibrium is the temperature of the oil in the crankcase, while Sparrow[4] states that ventilation of the crankcase is also of material aid.

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[1] Sparrow and Eisinger: Journal of Industrial and Engineering Chemistry, Vol. 18, No 5, p. 483 (1926).

[2] Eisinger: Journal of the Society of Automotive Engineers, July, 1924, p. 69.
Barnard: Journal of the Society of Automotive Engineers, March, 1925, p. 278.
Van Brunt and Miller: Industrial and Engineering Chemistry, Vol. 17, No. 4, p. 416 (1925).

[3] Journal of the Society of Automotive Engineers, July, 1924, p. 93.

[4] Journal of Industrial and Engineering Chemistry, Vol. 18, No. 5, p. 482 (1926).

Evidences of this have doubtless come under the observation of most motorists who make short runs about the city and find that the oil consumption of their car is very low, but who find that on long trips the engine suddenly develops an almost insatiable thirst for oil. The explanation is simply that, with the higher temperatures developed in the crankcase during the long run, a part of the previously accumulated dilution of the oil was driven off through the breather tube. Some may have also noticed the oily appearance of the motor and hood in consequence. Wilson and Wilkin[1] state that equilibrium is established in approximately the first 250 miles' travel. The above results agree in so far as equilibrium was reached before 250 miles were travelled.

TABLE L

Effects of Mileage on Oil Dilution When the Same Brand of Oil is Used and When Different Brands of Oil are Used

Same brand of oil				Different brands of oil			
Lab. No.	Eng. No.	Mileage	Dilution, per cent	Lab. No.	Eng. No.	Mileage	Dilution, per cent
8	FA	236	5·5	46	FH	200	5·0
39	FA	326	4·5	47	FH	510	6·5
16	FA	341	8·5	40	FB	559	12·0
18	FA	488	5·5	5	FB	574	9·5
26	FA	537	7·5	31	FB	1,016	5·5
4	FA	574	5·0	35	FB	1,040	7·5
34	FA	847	3·5	2	FB	1,067	5·5
32	FA	955	4·0	27	FB	1,108	4·0
1	FA	1,097	4·0	33	FB	1,113	5·5
37	FA	1,098	6·0	13	FB	1,559	5·0

Dilution and Viscosity

It will be observed from Table LI that the original viscosity of oil appeared to have little effect on the percentage of dilution. In other words, a high-viscosity oil was diluted just as much as a low-viscosity oil. This is probably true only for the rather narrow range of viscosities which obtain in automobile oils. There was one oil of rather high viscosity that gave a larger percentage of dilution than was expected but other oils of equal or greater viscosity did not show a similar tendency so that it was perforce concluded that the high result was due to some factor unrecognized at the time.

TABLE LI

Dilution in Relation to Viscosity of Oil Used

Lab. No.	Month of year	Eng. No.	Brand of oil	Viscosity (seconds)	Dilution, per cent
33	July	FB	11	174	5·5
1	June	FA	10	228	4·0
13	Aug.	FB	18	262	5·0
27	Nov.	FB	13	278	4·0
4	July	FA	10	370	5·0
31	May	FB	15	399	5·5
36	Aug.	FA	10	461	5·0
40	Sept.	FB	17	502	12·0
2	July	FB	12	569	5·5

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[1] Journal of Industrial and Engineering Chemistry, Vol. 18, No. 5, p. 486 (1926).

Dilution and Lubrication

Before the nature of used oils had been carefully studied, mechanics and service men were accustomed to say that an oil after use in an automobile engine was "worn out." The idea of the oil "wearing out" has been successfully combatted by lubrication engineers who have shown that the oil was merely diluted by the fuel. Then, in the popular mind, dilution became the cause of all lubrication troubles and ought to be eradicated at all costs. However, as Hallock[1] pointed out, dilution in itself is not an evil, since it has been customary during the entire life of the automobile industry to lubricate the cylinder walls of the two-cycle marine engine by adding one pint of oil to five gallons of fuel and feeding the mixture through the carburetor. If such procedure will lubricate that critical part of an internal combustion engine satisfactorily, and it does, then it would appear advisable to be cautious before deciding that dilution is the cause of trouble.

Barnard,[2] who investigated the ratio of wear in automobile engines, could not get conclusive evidence by road tests that increased wear was caused by ordinary amounts of dilution, although he observed a tendency in that direction at the higher dilutions, and, by dynamometer tests, obtained an increased rate of wear with dilution.

For the proper lubrication of an automobile engine as at present designed, it is necessary for one grade of oil to serve many purposes and keep on doing so over and over again. One of the prime requisites, and the most widely accepted criterion of quality, is a satisfactory viscosity. It has been suggested[3] that 180 seconds Saybolt at 100° F. (equivalent to 144 seconds Redwood) was perhaps the lower limit for safety. It would not be difficult to choose an oil of sufficient viscosity to permit an ordinary amount of dilution and still be above that minimum, but the disappointing feature of dilution is that it fluctuates[2] considerably under operating conditions.

If an oil of too low a viscosity is used the dilution may lower it to such an extent that the oil can no longer keep the moving parts separated and some of them will seize. None of the oils used in the tests gave any trouble due to seizure or to burned-out bearings.

If too viscous an oil is used some parts may not get a sufficient supply, especially during starting in cold weather. At first glance it would appear an advantage that the dilution is greater in cold weather and so helps to reduce the viscosity, but, as Sparrow[4] points out, the greater dilution develops only during operation at low temperatures and therefore its benefits are not available when the engine is started.

To change the oil, with the amount of dilution as the determining factor, is scarcely feasible, since, as shown above, it would be necessary to change about every 200 miles' travel, and so various methods to control the amount of dilution have been advocated. One of the most promising[5] is to increase the temperature of the jacket water and to increase the temperature of the crankcase oil. However, even this has some disadvantages.[6] Increasing the temperature of the jacket water may cause

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[1] Journal of the Society of Automotive Engineers, Jan., 1924, p. 57.

[2] Journal of Industrial and Engineering Chemistry, Vol. 17, No. 3, p. 280 (1925).

[3] Flowers, *et al:* Journal of Industrial and Engineering Chemistry, Vol. 17, No. 5, p. 481.

[4] Sparrow: Journal of Society of Automotive Engineers, Feb., 1925, p. 117.

[5] MacCoull: Journal of Society of Automotive Engineers, July, 1924, p. 93.

[6] Hallock: Journal of Society of Automotive Engineers, Jan., 1925, p. 57.

detonation trouble, and increasing the temperature of the crankcase oil would require the use of an oil which would be more viscous at ordinary temperatures, and so would make the engine more difficult to crank.

From the above discussion it is apparent that dilution is a very complex problem with the present type of lubricating system. Clayden[1] claims that it is the systems that are fundamentally at fault, and the writer is inclined to agree.

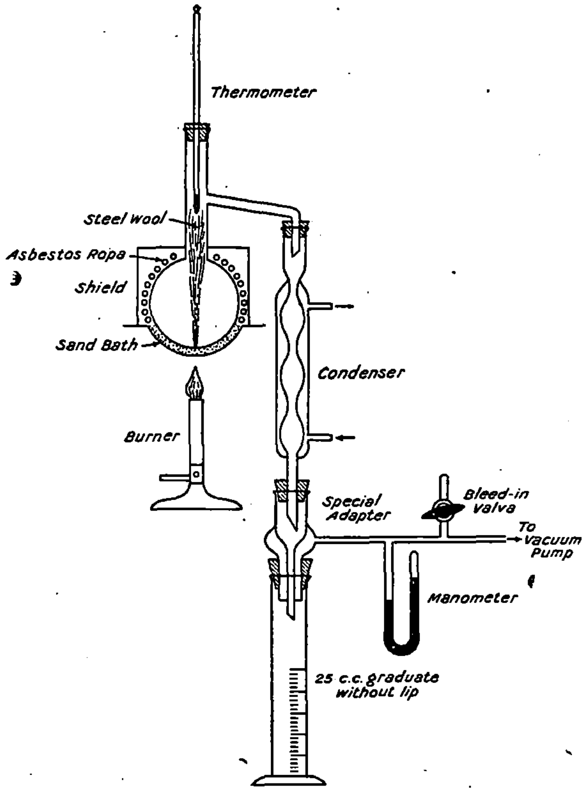

Figure 13. Apparatus for removing diluent at 40 mm. pressure.

THE DILUENT

The diluent as recovered from the used oil was light yellow in colour, and had a specific gravity of 0·793 at 60° F. On distillation about 3 per cent of heavy ends was left. The condensate on being distilled again yielded a product practically identical in boiling range with the first 30 per cent cut from commercial kerosene. Treatment with concentrated sulphuric acid and 10 per cent solution of sodium hydroxide rendered the product stable on prolonged exposure to light.

The distillation range of the diluent is shown in Table LII in comparison with the distillation ranges of representative samples of gasoline and of kerosene.

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[1] Journal of the Society of Automotive Engineers, July, 1925, p. 61.

TABLE LII

Distillation Ranges of the Diluent and of Some Other Distillates

Amount of distillate	Gasoline	Diluent	30 per cent fraction of kerosene	Kerosene
	°F	°F	°F	°F
1st drop	116	311	290	340
10 c.c.	174	342	340	370
20 c.c	199	351	348	383
30 c.c	219	360	356	394
40 c.c	237	369	362	405
50 c.c	258	378	374	414
60 c.c	277	388	384	424
70 c.c	299	399	398	437
80 c.c	322	414	416	453
90 c.c	359	435	432	478
Dry	412	496	498	523

EQUILIBRIUM OILS

Equilibrium oils may be described as those to which a light oil similar in character and quantity to the diluent found in used oils has been added. The preparation and use of such oils are being studied by the Standard Oil Company of Indiana and by others. The present consensus of opinion appears to be that the results on the whole have been encouraging, but that much remains to be done before the use of such oils can be generally satisfactory. The greatest difficulty is the fluctuation in the percentage of diluent present which varies with the weather conditions, with different makes of cars, with different drivers of the same make, and with different types of service. These variations in the amount of diluent present are difficult to control and make the proper servicing of the car correspondingly difficult for the service station.

TREATMENT OF USED OILS

The fact that oils do not entirely wear out but become more viscous after use, together with the probable cause of such thickening, namely, oxidation of some of the constituents, precipitation of carbon due to decomposition, chemical reactions, and suspended road dust and extraneous matter, naturally leads to the problem of purifying used oils If the relatively unstable compounds in the oil which have been decomposed, oxidized, or otherwise chemically combined, are not essential to the most efficient lubrication of the internal combustion engine, it follows that the inert residual oil, when separated from such compounds, should be a superior oil to new oil which still contains such active constituents.

Method of Treatment Adopted

Various methods have been proposed for the reclamation of used oils. They include filtration, sedimentation, centrifugation, etc.

All such methods appeared to the writer to be only partly effective in obtaining the desired result. Accordingly, he decided to try a redistillation of the oil under very low pressures and test out the resultant product.

The apparatus used is shown in Figure 14. The sample to be treated is run through apparatus at 40 mm. pressure, as shown in Figure 13, to remove water and diluent.

The residual oil is then transferred to apparatus, as shown in Figure 14, and the distillation continued, but at a pressure of approximately 5 mm. The percentage of distillate recovered from a typical used oil after being stripped of diluent is shown in Table LIII.

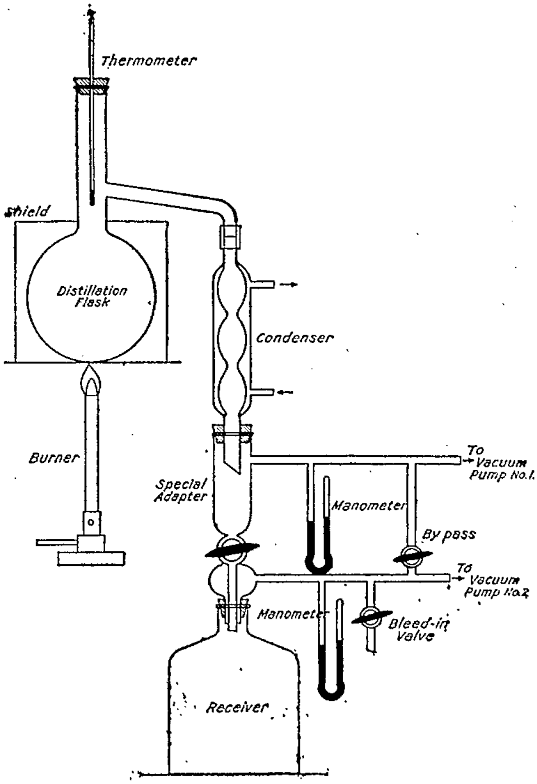

Figure 14. Apparatus for distilling used oils at low pressures.

TABLE LIII

Percentage of Distillate Recovered from Used Oil No. 648

Percentage distillate by volume	Temperature	Pressure
	°F.	mm.
Start	230	5
10	345	5
20	368	5
30	393	5
40	413	5
50	421	5
60	455	5
70	500	5

In the preliminary work five fractions were collected according to the temperature of the vapours. The first, up to 350° F.; the second, from 350° to 400° F.; the third, from 400° to 450° F.; the fourth, from 450° to 500° F.; the fifth, the residual oil left in the flask. The laboratory examination of the distillates showed characteristics as given in Table LIV.

TABLE LIV

Results of Examination of Four Fractions of Used Oil No. 648

—	Oil before use	Oil after use	Oil diluent removed	Cut No. 1	Cut No. 2	Cut No. 3	Cut No. 4
Specific gravity at 60°F	0·932	0·916	0·924	0·9026	0·9113	0·9180	0·9257
Viscosity (Redwood)—							
Secs. at 100° F	454	208	434	65	108	252	580
Secs. at 140°F	134	....	....	44	55	93	167
Secs. at 210°F	50	....	....	....	37	44	54
Carbon residue (Conradson), per cent	0·29	0·31	0·46	0·002	0·001	0·001	0·001
Acidity as oleic acid, per cent	....	....	0·28	0·42	0·40	0·31	0·23
Flash point, °F. (Pensky-Marten's, closed)	345	155	345	285	330	380	395
Fire point,° F. (Pensky-Marten's, open)	420	290	440	360	420	455	500

Two of the outstanding features of the treatment were the remarkably low carbon-residue values and the clear colour of the products. It will be observed that the acidity values were rather high. The samples tested had not been treated with acid or alkali. It is proposed to test exhaustively the oils represented by cuts Nos. 3 and 4 in order to determine their value as a lubricant for automobile engines.

CARBON DEPOSITS

The carbon deposits were removed from the combustion chambers of the test cars periodically and samples of the deposits were sent to the laboratory for analysis.

Methods of Examination

The moisture was removed by heating the sample in an atmosphere of carbon dioxide for 2 hours at a temperature of 105° C. It was found that longer drying was unnecessary as the sample came to constant weight within that time. The dried sample was then ignited in an electric muffle furnace and the percentage of ash determined. The oil content was determined by extracting the sample with petroleum ether in a Soxhlet apparatus until the solvent was clear. This usually required 12 to 16 hours' extraction. The sample was weighed by difference into a previously extracted, dried, and weighed paper thimble. The sample and thimble after extraction were again dried and weighed. The loss in weight of the sample was calculated and recorded as the oil content. It was found necessary to make all weighings, in which the paper extraction thimbles were involved, in glass-stoppered weighing bottles. The resins were determined by extraction of the oil-free sample with acetone till the solvent ran through without perceptible colour. The residue was dried and weighed as before. The carbon was calculated by difference.

Results of Examination

All determinations were made in duplicate and the average results, as far as they have been completed, are shown in Table LV. In Table LVI is given the distillation range and the specific gravity of the petroleum ether used for extraction of the oil.

TABLE LV

Analyses of Carbon Deposits

Lab. No.	Date taken	Moisture (C) %	Oil (A) %	Resin (B) %	Ash (D) %	Carbon (by diff.) %
	1923					
7-1	May 16	2·54	14·0	8·93	4·77	69·8
2	" 21	1·95	23·3	3·60	6·13	65·0
3	" 28	1·06	30·49	5·06	8·23	55·2
4	" 31	1·83	14·01	4·81	9·72	69·6
5	June 12	1·03	24·22	5·01	4·28	65·5
6	" 20	0·83	30·71	7·33	6·30	54·8
7	" 25	1·76	15·16	3·42	11·57	68·1
8	July 5	0·65	24·67	5·95	7·14	61·6
9	" 6	1·02	20·16	2·06	16·66	60·1
10	" 27	1·03	23·05	5·59	6·53	63·8
11	Aug. 14	1·16	19·46	8·34	4·28	66·8
12	" 17	1·25	....	....	6·14	....
13	" 20	2·27	....	....	5·15	....
14	" 21	1·37	17·53	4·47	5·29	71·34
15	" 23	2·57	....	....	4·20	....
16	" 27	0·85	23·06	3·56	6·97	65·6
17	" 27	1·50	14·46	....	6·08	....
18	" 29	1·48	....	....	1·83	....
19	" 31	1·11	27·39	....	6·47	....
20	Sept. 1	2·59	....	....	9·91	....
21	Oct. 8	1·04	....	....	21·20	....
22	" 11	2·55	22·95	....	7·06	....
23	" 12	2·19	....	....	6·37	....
24	" 18	1·08	25·62	....	2·22	....
25	" 19	1·23	....	....	4·79	....
26	" 29	1·42	....	....	6·71	....
27	Nov. 2	1·63	21·27	....	5·78	....
28	Dec. 12	0·97	26·96	....	2·82	....
29	" 18	2·30	....	....	12·37	....
	1924					
30	May 30	1·92	....	....	5·38	....
31	June 21	1·21	....	....	3·23	....
32	July 15	1·50	....	....	3·67	....
33	" 29	1·19	....	....	2·64	....
34	Aug. 18	1·09	....	....	2·92	....
35	" 18	1·37	....	....	13·66	....
36	Sept. 5	1·74	....	....	4·83	....
37	" 17	1·49	....	....	1·79	....
38	....	2·21	24·6	4·8	6·29	....

TABLE LVI

Analysis of Petrol Ether Solvent

Specific gravity at 60°F. 0·665
Distillation Range—

	°F.
1st drop	95
10 c.c.	113
20 c.c.	118
30 c.c.	124
40 c.c.	127
50 c.c.	135
60 c.c.	142
70 c.c.	151
80 c.c.	163
90 c.c.	187
Dry	235
Per cent recovered	96·5 c.c.

Discussion of Results

Discussion of the results may properly be left until the analyses are complete, but it may be permissible to draw attention to the wide variation in the amount of ash present in the different samples. Sample No. 21, for instance, had an ash content of over 21 per cent. It is interesting to note that during this test the car was driven over long stretches of very sandy country roads. When the cylinder head was removed there was observed a small concretion of greyish material at the centre of each piston head. One of these concretions, on being carefully removed and ashed in a crucible to bright red heat, lost only 0·5 per cent in weight. In several other cases of high-ash content it was known that the car had been driven over dirt roads to a considerable extent. This is important as it indicates that the composition of the deposit depends to a considerable extent on the character of the roads over which the car has been driven.

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II

GASOLINE SURVEY FOR 1925

P. V. Rosewarne[1] and H. McD. Chantler[2]

A survey of the gasoline sold in Canada was made by the Fuels and Fuel Testing Division of the Mines Branch in 1923 and in 1924.[3] This report covers a similar survey for 1925. During the early part of August, 73 samples were collected[4] from wholesalers or distributors in the following cities:—Halifax, St. John, Quebec, Montreal, Ottawa, Toronto, London, Winnipeg, Regina, Calgary, Edmonton, Vancouver, and Victoria. These samples were tested for distillation range, iodine value, and specific gravity. The distillation range was determined according to the method recommended by the United States Bureau of Mines.[5] From the results so obtained, a weighted index number was calculated after the method advocated by Gruse[6], with the exception that the index numbers were calculated from temperatures of the distillation range expressed in ° F. instead of from temperatures expressed in ° C. as was done by Gruse. The iodine value was determined by the Hanus method[7], and the specific gravity was obtained by the Westphal balance at room temperature and the results calculated at 60° F.

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[1] Chemist, Fuel Testing Laboratories, Mines Branch.

[2] Junior Chemist, Fuel Testing Laboratories, Mines Branch.

[3] Mines Branch, Dept. of Mines, Invest. of Fuels and Fuel Testing, 1924.

[4] The writers wish to acknowledge the hearty support and co-operation of the Department of Health in taking the samples.

[5] U.S. Bureau of Mines, Technical Paper 323A.

[6] Chemical and Metallurgical Engineering, Vol. 29, No. 22, p. 970.
Mines Branch, Dept. of Mines, Invest. of Fuels and Fuel Testing, 1924.

[7] Ellis and Meigs: "Gasoline and other Motor Fuels."

TABLE LVII

Results of Analyses

Lab. No.	Brand	1st drop °F.	Distillation Range					End point °F	Recovvery	Iodine value	Sp. Gr.	° Bé	Index number °F
			10% °F.	20% °F.	50% °F.	70% °F.	90% °F.						
	HALIFAX, N.S.												
3147	Premier (*a*).......	122	192	221	273	309	361	406	97·5	36	0·746	57·7	1762
3148	Red Seal (*b*)......	129	198	221	270	307	363	419	97·5	27	0·750	56·7	1778
3149	White Rose (*b*)...	108	163	203	280	315	369	410	95·3	30	0·736	60·2	1740
	Average........	120	184	215	274	310	364	412	96·8	31	0·744	58·2	1760
	ST. JOHN, N.B.												
3150	Fundy (*c*)........	113	163	187	237	273	331	392	97·6	4	0·724	63·4	1583
3151	Premier (*a*).......	118	192	219	273	311	365	417	97·5	30	0·751	56·4	1777
3152	White Rose (*b*)...	129	199	219	270	306	361	417	97·6	32	0·749	56·9	1772
	Average........	120	185	208	260	297	352	409	97·6	22	0·741	58·9	1711
	QUEBEC, QUE.												
3153	British Motor (*d*).	131	199	223	268	309	363	423	97·5	29	0·751	56·4	1785
3154	Peerless (*d*).......	115	167	181	219	252	309	385	97·0	1	0·718	65·0	1513
3155	Premier (*a*).......	127	196	221	273	309	365	419	97·3	29	0·750	56·7	1783
3156	Queen (*a*).........	111	165	196	261	295	358	408	96·7	23	0·741	58·9	1683
3157	Red Seal (*b*)......	153	241	277	365	433	523	572	96·3	17	0·784	48·6	2411
3158	White Rose (*b*)...	124	194	219	273	309	365	423	97·3	30	0·751	56·4	1783
	Average........	127	194	219	276	318	381	438	97·0	21	0·749	56·9	1826

MONTREAL, QUE.

3159	British Motor (*d*).	104	156	192	264	313	369	408	96·4	19	0·740	59·2	1702
3160	Crown (*e*).........	127	189	208	270	311	369	417	97·7	22	0·743	58·4	1764
3161	Empire (*f*)........	111	162	192	268	315	369	412	96·7	19	0·739	59·4	1718
3162	Peerless (*a*).......	109	154	176	219	252	320	378	96·9	2	0·718	55·0	1499
3163	Premier (*a*).......	113	176	203	266	313	363	406	96·9	22	0·739	59·4	1727
3164	Queen (*a*).........	104	163	187	234	277	338	392	96·7	25	0·730	61·8	1591
3165	Shell (*e*)..........	113	158	187	234	259	315	383	97·2	6	0·721	64·2	1536
3166	Sunoco H.T. (*g*)..	109	156	178	226	261	322	379	96·7	6	0·720	64·4	1522
	Average........	111	164	190	248	288	346	397	96·9	15	0·731	61·5	1633

OTTAWA, ONT.

3167	British Motor (*d*).	100	158	189	259	309	365	412	97·5	17	0·740	59·2	1692
3168	Crown (*e*).........	117	183	210	270	315	370	424	97·4	19	0·743	58·4	1772
3169	Marathon (*h*).....	118	172	196	253	300	367	441	97·6	3	0·736	60·2	1729
3170	Peerless (*d*).......	115	165	181	212	244	309	379	96·8	4	0·719	64·7	1490
3171	Premier (*a*).......	106	160	194	266	320	365	412	97·0	20	0·740	59·2	1717
3172	Queen (*a*).........	102	147	172	243	284	342	394	96·3	31	0·726	62·8	1582
3173	Red Seal (*b*)......	108	162	194	268	309	354	394	96·7	20	0·740	59·2	1681
3174	Shell (*e*)..........	111	156	178	226	262	322	383	96·8	6	0·721	64·2	1527
3175	Sunoco H.T. (*i*)...	111	165	185	235	273	347	423	97·3	5	0·722	63·9	1628
3176	Sunoco Navy (*l*)..	113	185	228	307	349	392	423	97·5	9	0·765	53·0	1884
3177	Supertest (*k*)......	109	169	192	262	300	369	414	96·7	16	0·739	59·4	1706
3178	White Rose (*b*)...	95	153	190	277	316	367	405	95·1	20	0·733	61·0	1708
	Average........	109	165	192	256	298	356	409	96·9	14	0·735	60·5	1676

TORONTO, ONT.

3179	British Motor (*d*).	118	183	205	268	316	385	433	96·4	27	0·744	58·2	1790
3180	Crown (*e*).........	106	176	205	270	320	387	435	96·8	5	0·743	58·4	1793
3181	Marathon (*h*).....	108	162	192	271	324	387	430	96·7	18	0·739	59·4	1766
3182	Peerless (*d*).......	126	165	181	221	255	318	390	97·5	3	0·725	63·1	1530
3183	Perfection (*l*).....	126	178	214	295	329	376	417	97·8	28	0·750	56·7	1809
3184	Premier (*a*).......	113	178	210	280	316	376	417	97·0	37	0·742	58·7	1777
3185	Shell (*a*)..........	108	153	176	225	257	318	383	96·7	1	0·721	64·2	1512
3186	Solv. Naptha (*a*)..	109	147	158	187	205	241	302	96·9	3	0·705	68·6	1240
	Average........	114	168	193	252	290	348	401	97·0	15	0·734	60·7	1652

TABLE LVII—Concluded

Result of Analyses—Concluded

Lab. No.	Brand	1st drop °F.	Distillation Range					End point °F.	Recov-ery	Iodine value	Sp. Gr.	°Bé	Index number °F.
			10% °F	20% °F.	50% °F.	70% °F.	90% °F.						
LONDON, ONT.													
3187	AmericanH.T.(*m*)	108	162	196	275	325	379	417	96·4	35	0·739	59·4	1754
3188	British Motor (*d*).	127	190	214	264	306	372	415	97·3	27	0·745	57·9	1761
3189	Crown (*e*).........	118	189	208	275	327	392	441	97·0	7	0·745	57·9	1832
3190	Marathon (*h*).....	115	163	183	225	279	370	412	96·6	6	0·727	62·6	1632
3191	Peerless (*d*).......	104	147	165	219	253	324	374	96·3	2	0·716	65·5	1482
3192	Premier (*a*).......	117	183	214	273	316	358	401	96·4	45	0·739	59·4	1745
3193	Shell (*e*)..........	108	160	176	208	246	306	367	96·8	1	0·716	65·5	1463
3194	White Rose (*b*)...	113	180	199	266	311	369	430	96·8	34	0·738	59·7	1755
	Average........	114	172	194	251	295	359	407	96·7	20	0·733	61·0	1678
WINNIPEG, MAN.													
3195	British Motor (*d*).	117	183	212	275	313	356	410	97·2	41	0·746	57·7	1749
3196	Peerless (*d*).......	113	158	180	228	262	331	396	97·3	6	0·724	63·4	1555
3197	Premier (*a*).......	113	169	192	262	304	367	412	97·1	44	0·738	59·7	1706
3198	Red Seal (*b*)......	118	187	214	273	313	369	419	97·3	36	0·746	57·7	1775
3199	Red Star (*n*)......	115	160	194	253	295	356	415	97·3	19	0·732	61·3	1673
3200	Royal (*n*).........	120	163	189	255	298	352	403	97·0	36	0·734	60·7	1660
	Average........	116	170	197	258	297	355	409	97·2	30	0·737	60·0	1686
REGINA, SASK.													
3201	Peerless (*d*).......	117	172	192	244	286	343	392	97·3	17	0·734	60·7	1629
3202	Premier (*a*).......	113	180	205	264	304	352	394	97·4	42	0·744	58·2	1699
3203	Royal (*n*).........	122	185	212	268	304	356	401	97·2	41	0·745	57·9	1726
3204	White Rose (*b*)...	126	189	214	261	302	370	433	97·0	31	0·742	58·7	1769
	Average........	119	182	206	259	299	355	405	97·2	33	0·741	58·9	1706

CALGARY, ALBERTA

3205	Premier (*a*).......	120	180	205	270	316	372	419	97·2	21	0·741	58·9	1762
3206	Red Seal (*b*)......	120	178	205	270	311	370	419	97·3	22	0·741	58·9	1753
3207	Royal (*n*).........	118	181	208	271	315	372	421	97·1	23	0·743	58·4	1768
3208	Sunshine (*o*)......	144	196	217	279	324	387	451	97·3	4	0·748	57·2	1854
	Average........	125	184	209	273	316	375	427	97·2	18	0·743	58·4	1784

EDMONTON, ALBERTA

3209	British Motor (*d*).	113	171	194	253	298	365	412	96·7	18	0·735	60·5	1693
3210	Premier (*a*).......	118	178	207	268	315	365	412	97·2	20	0·742	58·7	1745
3211	Royal (*n*).........	113	171	199	264	304	367	410	96·9	20	0·741	58·9	1715
3212	White Rose (*b*)...	118	181	208	270	315	370	421	97·7	19	0·741	58·9	1765
	Average........	115	175	202	264	308	367	414	97·1	19	0·740	59·2	1730

VANCOUVER, B.C.

3213	General (*p*).......	115	169	199	261	302	369	430	96·8	2	0·753	55·9	1730
3214	Premier (*a*).......	117	180	201	259	300	358	430	97·3	10	0·747	57·4	1728
3215	Shell (*e*)..........	115	176	196	264	315	387	432	96·7	3	0·754	55·7	1770
3216	Union (*q*).........	124	178	199	244	282	347	421	97·2	2	0·753	55·9	1671
	Average........	118	176	199	257	300	365	428	97·0	4	0·752	56·2	1725

VICTORIA, B.C.

3217	Premier (*a*).......	111	178	205	255	293	349	423	97·2	6	0·746	57·7	1703
3218	Shell (*e*)..........	106	160	194	264	316	387	432	96·6	3	0·753	55·9	1753
3219	Union (*q*).........	118	178	199	244	280	347	423	97·0	2	0·750	56·7	1671
	Average........	112	172	199	254	296	361	426	96·9	4	0·750	56·7	1709
	Average of all samples......	116	174	199	258	299	359	412	97·0	18	0·739	59·4	1701

(*a*) Imperial Oil Company, Limited. (*b*) Canadian Oil Companies, Limited. (*c*) Canadian Independent Oil, Limited. (*d*) British American Oil Company, Limited. (*e*) Shell Oil Company, Limited. (*f*) Tidioute Refining Co., Limited. (*g*) Sun Oil Company, Limited. (*h*) McColl Bros., Limited. (*i*) Capital City Oil Company, Limited. (*k*) Supertest of London, Limited. (*l*) Perfection Petroleum Company, Limited. (*m*) J. L. T. Hayes. (*n*) North Star Oil Company, Limited. (*o*) Alberta Refining Company, Limited. (*p*) General Oil Company, Limited. (*q*) Union Oil Company, Limited.

TABLE LVIII

Average Result of Analyses by Cities

District	Distillation range							Recovery	Iodine value	Specific gravity	Index number °F
	1st drop °F	10% °F	20% °F	50% °F	70% °F	90% °F	End point °F				
Halifax, N.S.	120	184	215	274	310	364	412	96·8	31	0·744	1769
St. John, N.B.	120	185	208	260	297	352	409	97·6	22	0·741	1711
Quebec, Que.	127	194	219	276	318	381	438	97·0	21	0·749	1826
Montreal, Que.	111	164	190	248	288	346	397	96·9	15	0·731	1633
Ottawa, Ont.	109	165	192	256	298	356	409	96·9	14	0·735	1676
Toronto, Ont.	114	168	193	252	290	348	401	97·0	15	0·734	1652
London, Ont.	114	172	194	251	295	359	407	96·7	20	0·733	1678
Winnipeg, Man.	116	170	197	258	297	355	409	97·2	30	0·737	1686
Regina, Sask.	119	182	206	259	299	355	405	97·2	33	0·741	1706
Calgary, Alberta	125	184	209	273	316	375	427	97·2	18	0·743	1784
Edmonton, Alberta	115	175	202	264	308	367	414	97·1	19	0·740	1730
Vancouver, B.C.	118	176	199	257	300	365	428	97·0	4	0·752	1725
Victoria, B.C.	112	172	199	254	296	361	426	96·9	4	0·750	1709
Average*	116	174	199	258	299	359	412	97·0	18	0·739	1701

*This is average value for all the samples tested.

COMPARISON OF RESULTS

It is interesting to compare the above figures with others obtained in somewhat the same way. Table LIX gives the average results of 88 samples collected in Canada, presumably in 1916, and reported by the laboratories of the Department of Inland Revenue[1]; the average of 48 samples collected throughout Canada during August, 1923[2]; the average of 59 samples collected in Canada during 1924[3]; the average of 73 samples collected in Canada during August, 1925; the average of 143 samples collected in United States during July, 1925, and reported by U.S. Bureau of Mines[4]; and the essential features of the specification of motor gasoline adopted by the Specification Board of United States[4] for use of the various departments and independent establishments of the United States Government.

It will be observed that the gasoline sold in Canada shows an average of distinctly good quality when judged by the distillation range which is the ordinarily accepted standard.

TABLE LIX

Average Results for Comparison

—	1st drop °F	Distillation Range					End point °F	Recovery %	Iodine value	Specific gravity	Index number °F
		10% °F	20% °F	50% °F	70% °F	90% °F					
Canada, 1916	125	170	192	237	270	330	380	....	17	0·732	1579
Canada, 1923	120	170	193	255	296	358	423	97·1	19	0·737	1695
Canada, 1924	113	173	195	249	288	347	410	97·4	18	0·736	1662
Canada, 1925	116	174	199	258	299	359	412	97·0	18	0·739	1701
United States, July, 1925	108	......	204	275	......	387	427	96·2	....	0·754	....
U.S. Federal Specification	131	......	221	284	......	392	437	....	....	....	....

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[1] Department of Inland Revenue, Canada, Bulletin 362, "Gasoline."

[2] Mines Branch, Dept. of Mines, Canada, Invest. of Fuels and Fuel Testing, 1923.

[3] Mines Branch, Dept. of Mines, Canada, Invest. of Fuels and Fuel Testing, 1924.

[4] U.S. Bureau of Mines, Report of Investigations, Serial No. 2703.

In order to estimate the variations in quality of the gasoline being sold, the average of the 10 per cent (7 samples) having the highest end point and the average of the 10 per cent having the lowest end point was obtained, as shown in Table LX.

Table LXI shows the difference between the average end points of the maximum 10 per cent and minimum 10 per cent of samples collected in Canada in 1916,[1] in 1923, in 1924, and in 1925, together with similar figures obtained by the Bureau of Mines[2] in the United States for the years 1923, 1924, and 1925.

The difference between the two averages, shown in Table LXI, may be accepted, for the purpose of comparison, as a measure of the variation in quality. It will be observed that in 1925 the variation in quality was less than that obtained in the survey of 1924.

TABLE LX

10 per cent of Samples Having Maximum End Points

Laboratory Number	Distillation range							Reco-very %	Iodine value	Specific gravity	Index number °F
	1st drop °F	10% °F	20% °F	50% °F	70% °F	90% °F	End point °F				
3157	153	241	277	365	433	523	572	96·3	17	0·784	2411
3208	144	196	217	279	324	387	451	97·3	4	0·748	1854
3169	118	172	196	253	300	367	441	97·6	3	0·736	1729
3189	118	189	208	275	327	392	441	97·0	7	0·745	1832
3180	106	176	205	270	320	387	435	96·8	5	0·743	1793
3179	118	183	205	268	316	385	433	96·4	27	0·744	1790
3204	126	189	214	261	302	370	433	97·0	31	0·742	1769
Average	126	192	217	282	332	402	458	96·9	13	0·749	1883

10 per cent of Samples Having Minimum End Points

Laboratory Number	1st drop °F	10% °F	20% °F	50% °F	70% °F	90% °F	End point °F	Reco-very %	Iodine value	Specific gravity	Index number °F
3185	108	153	176	225	257	318	383	96·7	1	0·721	1512
3166	109	156	178	226	261	322	379	96·7	6	0·720	1522
3170	115	165	181	212	244	309	379	96·8	4	0·719	1490
3162	109	154	176	219	252	320	378	96·9	2	0·718	1499
3191	104	147	165	219	253	324	374	96·3	2	0·716	1482
3193	108	160	176	208	246	306	367	96·8	1	0·716	1463
3186	109	147	158	187	205	241	302	96·9	3	0·705	1240
Average	109	154	173	214	245	306	366	96·7	3	0·716	1458

TABLE LXI

Difference Between Maximum and Minimum End Points

	Canada				United States		
	1916	August 1923	August 1924	August 1925	July 1923	July 1924	July 1925
	°F	°F	F	°F	°F	°F	°F
Maximum 10 per cent	432	446	459	458	471	457	458
Minimum 10 "	322	381	358	366	400	396	399
Difference	110	65	101	92	71	61	59

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[2] Mines Branch, Dept. of Mines, Canada, Invest. of Fuels and Fuel Testing, 1923.

[1] U.S. Bureau of Mines, Report of Investigations, Serial No. 2703.

SUMMARY

Seventy-three samples of gasoline were collected in August, 1925, from thirteen widely separated Canadian cities, and may be accepted, therefore, as representative of the gasoline sold in Canada at that time.

The analyses and detailed examination of these samples show that the average quality of the gasoline sold during 1925 was good although it was slightly inferior to that sold during 1924.

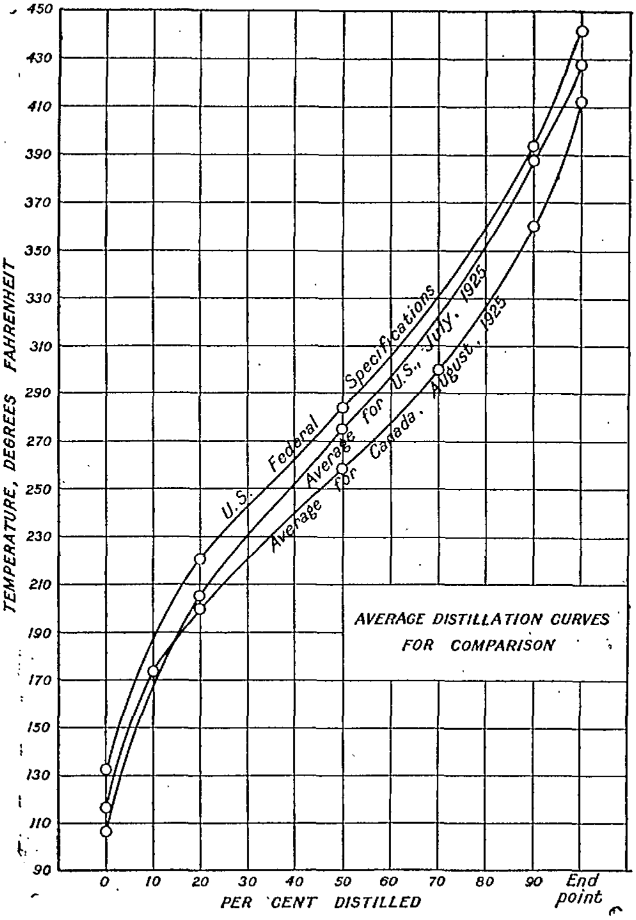

Figure 15. Average distillation curves.

The average distillation curves show that the gasoline sold in Canada during August, 1925, was superior to that sold in the United States during July, 1925, and superior to the United States Federal specifications for U.S. Government motor gasoline.

The variation in quality during 1925 was less than that during 1924.

III

ANALYSES OF OILS AND LIQUID FUELS

P. V. Rosewarne

This report contains the results obtained from the analyses of miscellaneous samples of oils and liquid fuels submitted to the Fuel Testing Laboratories for examination by various departments of the Government, by corporations, and by private individuals. Most of the analytical determinations were made by H. McD. Chantler with the assistance of laboratory attendants. The analyses were carried out under the direct supervision of the author and the general direction of the Superintendent of the Fuel Testing Laboratories. For the most part the samples were received during the year 1925, but in some few cases they were received previous to that time as noted in the context. The names of the kind of oil, the names of the localities in which the samples were obtained, and the trade names are those which were given to the laboratory, and are believed to be correct. For convenience of reference the petroleum products have been classified according to their suitability for use as crude petroleum, lubricating oils, gasolines, kerosenes, and fuel oils.

Section I

THE EXAMINATION OF SOME ARCTIC ANIMAL OILS

During the early part of the year 1925, an investigation relating to the economic possibilities of some Arctic animal oils was undertaken by the Fuel Testing Laboratories at the request of the North West Territories and Yukon Branch of the Department of the Interior. The oils examined were white seal oil, white porpoise oil, brown whale oil, and polar bear oil. It was desired to determine several of the more important characteristics and, if possible, the relative heating and illuminating values.

A survey of the literature revealed considerable information regarding seal oil, porpoise oil, and whale oil. A little was found regarding bear fat, but nothing was found about bear oil, unless the two terms may be regarded as synonymous, which from the results obtained does not appear warranted. It may be assumed that the sample examined was the oily matter separated from the fat by rendering and subsequent refrigeration. The material was obtained from the white polar bear, known zoologically as "Ursus (Thalassarctus) maritimus," and it is undoubtedly this species to which Lewkowitsch (and his many abstractors) refers when he speaks of the "Icebear." Lewkowitsch also refers to another bear, "Ursus arctus," which might be confused with the white polar bear on account of the name being similar to the habitat of the polar bear, but "Ursus arctus" is the proper name of the brown bear of Europe and Asia, and is quite distinct from the polar bear.

The characteristics reported in the literature for these oils have been brought together in the appended table. It should be noted that the maximum and minimum values recorded there are not necessarily those reported by the same authority.

Methods of Examination

The flash point of the samples examined in this laboratory was obtained with the closed Pensky-Marten's tester; the cloud, pour, and freezing points with the apparatus recommended by American Society for Testing Materials for testing petroleum products; the calorific value by means of the Emerson calorimeter; the illuminating value by specially arranged equipment; the tendency to gum by the method suggested by Holde[1]; and the sulphur by the calorimeter bomb method. All of the above determinations were made without difficulty with the exception of the illuminating value. An electric light with carbon filament of about 16 candle power, standardized by the Electrical Testing Laboratories, New York, was found to give too much illumination to be used directly against the oil lamps without involving a large experimental error in reading the position of the photometer. Standard candles were found to be somewhat unreliable, and finally a secondary standard was established by comparing the illuminating power of the standardized electric light referred to above, and a "17 c.p." automobile headlight bulb with tungsten filament, operated from a 6-volt storage battery. By carefully controlling the current to the bulb with an ammeter and a slide-wire rheostat, the arrangement gave very satisfactory results. Considerable difficulty was also experienced in obtaining a satisfactory lamp for burning the oils. The arrangement that gave the best results consisted of an ordinary 3-inch, glass crystallizing-dish and a common wick burner and chimney. The burner was suspended in the crystallizing-dish with stout wires and the oil level was kept close up to the burner. The method of procedure was as nearly as possible that outlined by Day.[2] The equipment used was a standard photometer bench with black cloth screen used in a dark room; the photometer was of the Lummer-Brodhun type, made by the Leeds and Northrup Company. Observations were made by two persons in both the regular and the reversed photometer position. Figure 16 shows the comparative results obtained for the first hour's burning.

Discussion of Results

The results of the examination of the four Arctic animal oils referred to above are as follows:—

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[1] Holde: "Examination of Hydrocarbon Oils," p. 150.

[2] Day: "Handbook of Petroleum Industry," Vol. I, p. 691.

Characteristics of Four Animal Oils Determined at the Fuel Testing Laboratories

	White seal oil	White porpoise oil	Brown whale oil	Polar bear oil
Laboratory number	2957	2958	2959	2960
Colour	Straw	Pale straw	Brownish amber	Very pale straw
Specific gravity at 60°F	0·925	0·922	0·919	0·923
Degrees Baumé at 60°F	21·4	21·8	22·3	21·7
Flash point, °F	310	440	370	435
Viscosity (Redwood) at 100°F	138	143	148	137
Cloud point, °F	3	9	21	10
Pour point, °F	1	5	16	9
Freezing point, °F	0	3	14	7
Sulphur, per cent	0·07	....	....	....
Calorific value, B.T.U. per pound	16960	16620	16740	17220
Average illuminating value for 1st hour in standard c.p	3·9	2·5	2·0	3·3
Gumming test	Very slight gum	No gum	No gum	No gum

It is to be noted that polar bear oil has a higher calorific value than any of the other three oils, and an illuminating value second only to white seal oil. However, the calorific value is considerably lower than ordinary commercial kerosene and probably has a higher economic value for some other purpose than as a source of heat. It is further reported[1] that polar bear oil is available in small quantities only.

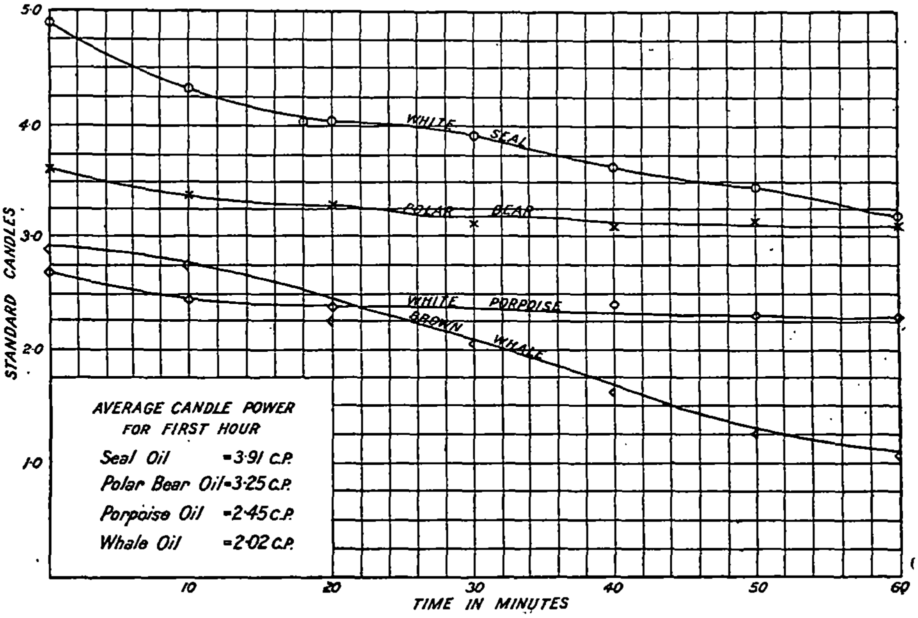

Figure 16. Diagram showing illuminating power of four animal oils.

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[1] Private communication to the writer.

White seal oil gave the highest illuminating value, the lowest flash point, and a calorific value slightly lower than polar bear oil. The comparatively low flash point is indicative of ease in lighting and yet is sufficiently high to be safe.

White porpoise oil and brown whale oil have considerably lower illuminating values than the other two oils referred to above, as well as slightly lower calorific values. Porpoise oil has probably far too high a value as a lubricant to be used to any extent for lighting and heating.

Section II

EXAMINATION OF CRUDE AND REFINED PETROLEUM OILS

Crude Petroleum. The analyses of crude petroleum shown below are the results obtained from several samples which have been received since the year 1921. Some fourteen samples received previous to that were reported in "Analyses of Canadian Fuels" by Stansfield and Nicolls.[1]

In this report the distillation results are shown as four fractions: first fraction, distillate up to 150° C.; second fraction, distillate between 150° and 300° C.; third fraction, distillate above 300° C.; and fourth, the coke residue remaining in the flask. The first three fractions are reported as percentage by volume and the fourth as percentage by weight. The continuous Engler method was used throughout. The first fraction may be termed "crude naphtha" since on being treated, re-run and blended, it would yield gasoline; the second fraction may similarly be termed "crude illuminants"; and the third, "crude lubricants." It is to be understood, of course, that the percentages shown do not represent the amount of finished product to be obtained from the various crudes, but serve as a basis for comparing the different oils. By modern methods of "cracking" on a commercial scale, the amount of the first fraction can be enormously increased and its characteristics almost completely controlled.

The distillation cuts were made from the samples after they had been dehydrated. This was necessary in order to obtain correct results, since the presence of water vapour would tend to increase the percentage of distillate at the lower temperatures. Where the water content of the sample was comparatively large the amount was estimated by direct measurement of the separated water, supplemented when necessary by a determination by the Dean and Stark method. When the amount was small the latter method was used exclusively on a representative portion taken from the sample.

The sulphonation residue represents the amount of the 300° to 350° C. fraction of the oil which did not react with concentrated sulphuric acid. It was obtained by a method similar to that outlined by Abraham.[2]

The sulphur content was determined by the bomb calorimeter method.

Lubricating Oils. The analyses of lubricating oil samples shown below are the results obtained from samples submitted to the laboratories for examination during the year 1925. The methods of examination were

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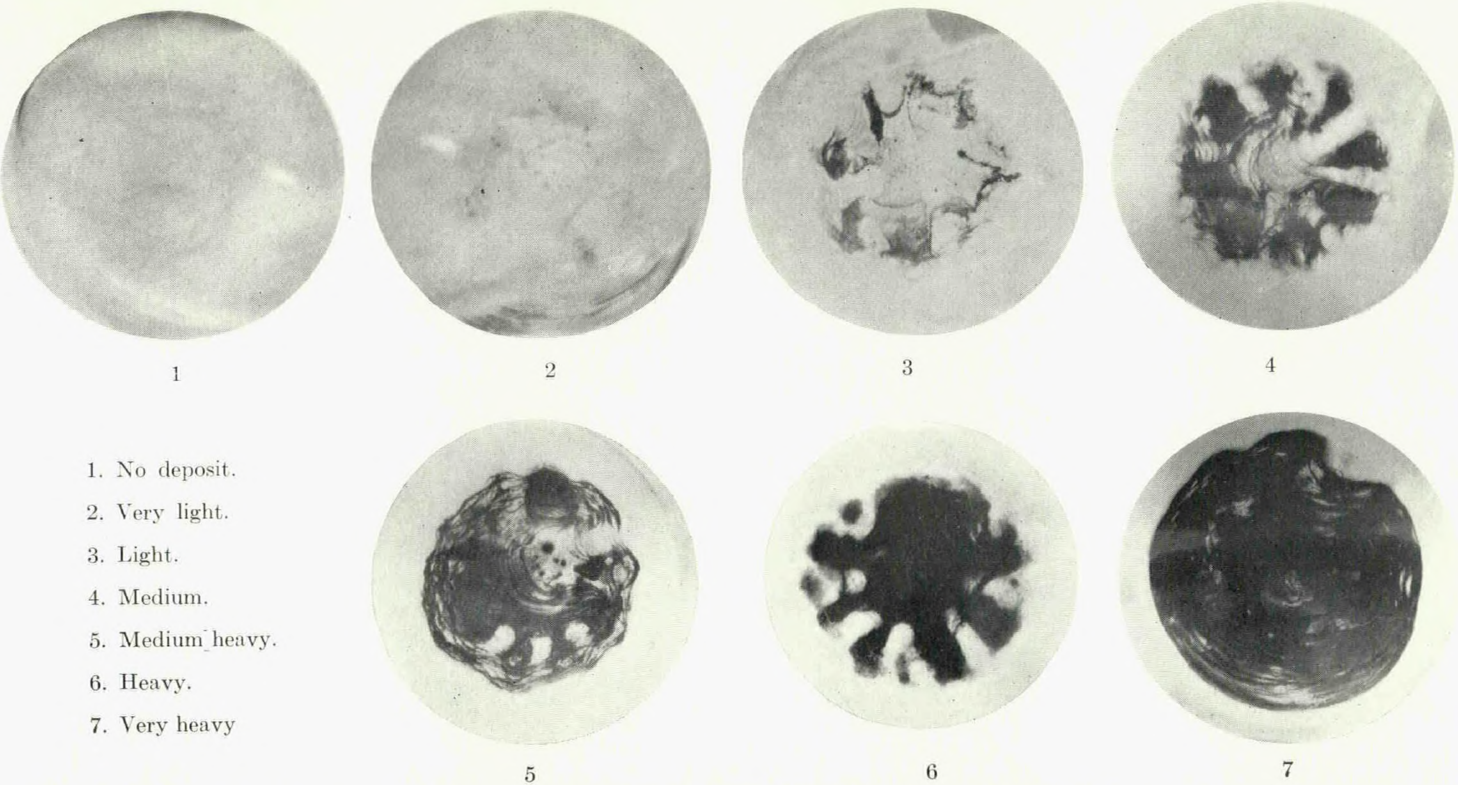
[1] Mines Branch, Dept. of Mines, Canada, Repts. Nos. 480, 482, 483.

[2] Abraham: "Asphalts and Allied Substances," p. 21.

Plate VII



1. No deposit.
2. Very light.
3. Light.
4. Medium.
5. Medium heavy.
6. Heavy.
7. Very heavy

Carbon formed from gasoline in bottom of distillation flask.

the same as used previously and were described in the Report of Investigations for 1924, with the exception that the freezing point was determined by the standardized method approved by the American Society for Testing Materials[1] and the Institution of Petroleum Technologists.[2]

Gasoline. The analyses of gasoline samples shown below were not included with the samples used for the gasoline survey. They were miscellaneous samples sent to the laboratory for examination from various sources and were taken at different times during the year 1925.

The methods used for examination of the samples were similar to those used for the gasoline survey, which methods have been described previously.[3] In addition there has been added a characteristic not previously reported but which has been observed and recorded for some time. It has been shown under the heading "Carbon deposit."

Some time ago there was observed on the bottom of the distillation flask after the completion of a distillation a carbon deposit. The deposit was characteristic of the sample and was duplicated in amount and appearance, as far as could be determined by inspection, every time a distillation was made from any particular sample. The amount and appearance varied widely for different samples, but remained fairly uniform for samples of the same brand. On Plate VII are shown photographic reproductions of seven representative deposits. They are graded as to amount and vary from "none" to "very heavy." The flasks containing these deposits were set aside and were used as standards in determining the amount of deposit given by the samples whose analyses are shown below. The terms adopted to describe the different grades were as follows: none, very light, light, medium, medium heavy, heavy, and very heavy. In many cases, of course, the deposit was intermediate between those grades used as standards, and the worker determined the proper grade. The general policy was to grade toward "light" unless the sample definitely approached the next heavier grade.

The writer has found no reference to this characteristic in current literature. It would appear possible that it is important in determining the quality of different samples of gasoline, although it bears no apparent relation to the iodine value, the specific gravity, the distillation range, or to the final end point.

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[1] "Standard Methods of Testing Petroleum and its Products," Method G.O. 11.
[2] American Society for Testing Materials, Method D. 97-22T.
[3] Mines Branch, Dept. of Mines, Canada, Invest. of Fuels and Fuel Testing, 1922, 1923, and 1924.

TABLE LXII

Characteristics of Some Animal Oils Reported in the Literature*

Name of oil	Seal oil	Porpoise oil		Whale oil	Bear fat	
		From body	From jaw		Ursus maritimus	Ursus arctus
Colour	White to brown			Pale yellow to dark brown		
Specific gravity at 60°F	0·924 to 0·934	0·925 to 0·937	0·926	0·926 to 0·927	0·9256	0·913 to 0·921
Flash point, °F				380 to 570		
Viscosity at 100°F				166 secs.†		
Refractive index at 60°F	1·4776			1·463 to 1·476		
Freezing point, °F	27 to 37	3		71 to 81		94 to 100
Melting point, °F						
Saponification value	178 to 196·2	195	253 to 272	160 to 194	187·9	194·8 to 203·4
Unsaponifiable, per cent	0·38 to 1·05	0·7 to 4·0	Up to 16·0	0·6 to 3·7		
Iodine value	127 to 193	88 to 119·4	21 to 77	89 to 146	147	80·4 to 107
Drying or non-drying	Poor drying			Slow drying	Drying	
Acid value				0·56 to 98·5		
Free fatty acid, as per cent oleic	0·2 to 19·95			Up to 35		
Volatile acids, per cent		23 to 40	47 to 65	Absent		
Reichert value (c.c. N/10 KOH)	0·08 to 0·22	23 to 65	47·77	0·7 to 2·04		1·15 to 1·66
Reichert—Meissl value	0·96 to 1·69					
Fatty acids, per cent	92·8 to 95·8			93·5		
Neutralization value	190·4 to 198					203
Freezing point, °F	55 to 63			73 to 75		97
Melting point, °F	57 to 91			57 to 81		87 to 107
Specific gravity at 60°F	0·9156 to 0·9172			0·8922‡		0·935
Iodine value	186·5 to 201·8			130·3 to 144·7		45·5 to 65
Vitamin A (fat-soluble)	Present			Rich		

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* Lewkowitsch: "Chemical Technology of Oils, Fats and Waxes."
Tressler: "Marine Products of Commerce," page 636, *et seq.*
Laucks: "Commercial Oils," page 20, *et seq.*
Marion White: "Fuels of the Household," p. 64.

† Equivalent to 133 seconds, Redwood.

‡ At 212° F. (water 212°=1).

TABLE LXIII

Analyses of Crude Petroleum

Locality from which sample was taken and year sample received	Lab. sample No.	Sp. Gr. at 60°F.	Degree Baumé at 60°F.	Fraction 0° to 150°C.		Fraction 150° to 300°C.		Fraction above 300°C.		Residue % by wt.	Sulphur content by wt.	Water content % by vol.	Cal. value B.T.U. per lb. gross	Sulphonation residue on fraction 300° to 350°C. %
				% by vol.	Sp. Gr. at 60°F.	% by vol.	Sp. Gr. at 60°F.	% by vol.	Sp. Gr. at 60°F.					
Gaspe, Que. (*a*)....................(1923)	2900	0·923	21·7	2·0	....	13·7	0·854	79·1	0·877	6·2	....	65·0	....	....
“ “ (*b*)....................(1923)	2901	0·881	28·9	none	....	23·4	0·828	73·2	0·869	3·0	....	40·0	....	....
“ “ (*c*)....................(1923)	2902	0·803	44·4	13·0	0·731	47·5	0·774	38·7	0·843	0·7	....	....	....	....
“ “ (*d*)....................(1923)	2903	0·790	47·2	23·2	0·714	41·8	0·777	34·0	0·844	1·0	....	....	....	....
Stoney Creek, N.B. (*e*)............(1925)	3264	0·833	38·1	11·0	0·695	24·0	0·779	64·0	0·834	3·3	0·09	....	....	....
Oil Springs, Ont...........................	3021	0·837	37·3	17·7	0·719	32·0	0·803	47·0	0·859	4·3	....	....	....	....
Camperdown, Ont..................(1921)	1822	....	....	none	....	43·0	....	52·0	0·822†	2·97	....	....	....	....
Manitoulin is., Ont. (*f*).............(1920)	1720	0·864	32·0	10·0	....	26·0	....	64·0*	....	....	0·2	....	19·080	....
“ “ (*g*).............(1920)	1721	0·877	29·6	none	....	30·0	....	70·0*	....	....	0·2	....	19·430	....
“ “ (h).............(1920)	1722	0·881	28·9	none	....	28·0	....	72·0*	....	....	0·2	....	19,440	....
Wainwright, Alberta (*j*)............(1923)	2596	0·878†	29·5	8·0	0·765	14·0	0·869	18·0	0·934	10·4	....	45·3	....	....
“ (*k*)...............(1923)	2609	0·882†	28·7	3·8	....	31·1	0·851	46·5	0·916	15·0	....	20·0	....	85·0
“ ....(1923)	2633	0·906†	24·5	0·9	....	24·9	0·954	62·4	0·918	10·6	....	15·0	....	....
“ ....(1923)	2634	0·901†	25·4	1·8	....	25·9	0·846	58·0	0·911	11·1	....	16·0	....	84·0
“ (*l*)...............(1924)	2940	0·973	13·9	none	....	12·9	0·870	68·2	0·897	14·1	1·98	7·4	....	....
“ (m)..............(1925)	3357	0·940	18·9	2·1	0·774	21·3	0·860	69·0	0·915	10·9	1·60	....	....	....
Black Diamond, Alta, (*n*).........(1923)	2594	0·765	53·0	52·5	0·723	35·3	0·790	10·0	0·864	....	0·26	....	....	....
McLeod dist., Alta. ....(1925)	3043	0·870	30·9	0·5	....	34·0	0·818	64·0	0·872	1·9	....	trace	....	....
Burnaby lake, B.C. (*o*)............(1921)	1817	0·974	13·7	none	....	1·0	....	81·0	....	....	6·0	....	....	....

* Per cent by difference. Coke residue not determined.
† Specific gravity of total distillate.
(*a*) Seepage oil.
(*b*) Composite sample from wells Nos. 7, 10, and 11.
(*c*) Well No. 20.
(*d*) Well No. 34.
(*e*) Composite sample from several wells.
(*f*) Sample from Green Bay.
(*g*) Sample from Assiginack.
(*h*) Sample from Gore Bay.
(*j*) Grattan No. 1 well of Imperial Oil Co.
(*k*) Well No. 2, of British Petroleum Limited.
(*l*) Well No. 4, of British Petroleum Limited.
(*m*) Well No. 3B.
(*n*) Well of Southern Alberta Oil Co. Field also known as Sheep River and as Turner Valley.
(*o*) Seepage oil.

TABLE LXIV

Analyses of Lubricating Oils

Lab. sample No.	Brand of oil	Grade of oil	Sp. Gr. at 60°F.	Degrees Baumé at 60°F.	Flash point		Fire point °F.	Viscosity (Redwood) in sec. at °F.			Freezing point °F		Emulsion test, per cent clear in 1 hr.		Carbon residue %	Acidity as oleic acid %	Refractive index at 66°F.
					(closed) °F.	(open) °F.		100	140	210	Oil flows	Does not flow	130°F.	180°F.			
3042	70 per cent Mobiloil "A" + 30 per cent Paraffin oil	....	0·878	29·4	....	....	....	174*a*	....	....	− 8	....	....	....	....	....	....
3063	....	....	0·910	23·9	....	325	455	....	....	50	....	....	25	....	....	....	....
3064	....	....	0·925	21·4	....	370	425	....	....	53	....	....	100	....	....	....	....
3092	Mobiloil "B"	Ex. h'vy.	0·895	26·4	445	....	540	1,042	333	88	48	43	....	100	1·20	....	1·495
3101	Enarco	Ex. h'vy.	0·915	23·0	380	....	545	....	490	105	69	64	....	75	1·92	....	1·510
3102	Sunoco	O. Special	0·939	19·1	385	....	470	....	222	59	31	26	....	03	0·59	....	1·518
3103	Sunoco	XX h'vy.	0·927	21·0	....	425	520	....	423	92	38	33	....	05	0·99	....	1·514
3104	Red Indian	Ex. h'vy.	0·913	23·3	440	....	560	....	505	108	33	28	....	85	2·00	....	1·509
3105	Motorene	"B"	0·916	22·8	390	....	525	....	323	82	28	23	....	100	1·70	....	1·510
3116	Enarco	Heavy	0·906	24·5	400	....	490	....	202	63	45	40	....	50	0·93	....	1·504
3118	Castrol	"R"	0·959	16·0	475	....	565	....	321	81	0	....	....	0	0·24	4·1	1·484
3129	Cities Service	....	0·907	24·4	400	....	475	330	122	49	32	27	....	100	0·48	....	....
3143	....	....	0·905	24·7	385	....	470	....	....	58	....	....	....	....	....	....	....
3373	Oak	Medium	0·915	23·0	345	375	415	171	72	40	5	1	0	....	0·13	0·3	....
3561	Marine cylinder oil	....	0·919	22·3	....	505	....	....	....	157*b*	....	50	....	....	....	0·13	....
3562	Marine cylinder oil	....	0·918	22·5	....	495	....	....	....	150*b*	....	50	....	....	....	0·07	....

a Viscosity at 60°F.
b Saybolt viscosity, not Redwood.

TABLE LXV

Analyses of Gasoline Samples

Lab. No.				Density at 60°F.		Distillation range							Recovery	Index number	Carbon deposit in distillation flask
				Sp. Gr.	Bé.	1st drop °F.	10% °F.	20% °F.	50% °F.	70% °F.	90% °F.	End point °F.	%	°F.	
3029	Beach No. 9..................	Ottawa,	Jan., 1925..	0·725	63·1	111	162	183	234	271	331	397	97·8	1578	Medium
3030	Beach No. 10..................	"	" 1925..	0·725	63·1	95	147	165	239	280	334	374	96·7	1539	Very heavy
3048	Supertest......................	"	Mar., 1925..	0·733	61·0	86	136	178	304	358	424	441	92·8	1841	Very light
3049	Supertest......................	"	" 1925..	0·726	62·8	93	145	172	255	315	381	430	95·3	1698	None
3077	Supertest No. 14..............	"	May, 1925..	0·725	63·1	93	138	169	252	297	347	383	96·4	1586	Very heavy
3082	British Motor..................	"	" 1925..	0·741	58·9	115	171	201	273	311	356	397	97·7	1709	Very heavy
3083	Peerless........................	"	" 1925..	0·712	66·6	104	160	167	203	235	297	376	97·2	1438	None
3084	Supertest......................	"	" 1925..	0·741	58·9	113	180	205	271	311	356	390	97·5	1713	Very heavy
3085	White Rose....................	"	" 1925..	0·739	59·4	109	171	201	259	300	361	433	97·3	1725	None
3086	Queen...........................	"	" 1925..	0·728	62·3	100	158	190	244	298	349	385	96·6	1624	Medium
3087	Premier.........................	"	" 1925..	0·742	58·7	113	187	212	273	311	356	392	97·6	1731	Very heavy
3088	Shell............................	"	" 1925..	0·715	65·8	97	142	163	208	246	311	381	97·0	1451	Medium
3089	Crown...........................	"	" 1925..	0·739	59·4	106	165	194	261	302	367	424	98·0	1713	Medium heavy
3090	Marathon.......................	"	" 1925..	0·724	63·4	104	154	174	235	282	361	430	96·5	1636	None
3109	British Motor..................	"	June, 1925..	0·741	58·9	95	180	201	270	309	360	392	97·0	1712	Very heavy
3110	Supertest......................	"	" 1925..	0·741	58·9	111	174	203	257	307	347	387	97·5	1675	Very heavy
3094	Taylor Bros....	Carleton Place, Ont.,	May, 1925..	0·732	61·3	97	160	189	280	336	435	475	94·2	1875	None
3111	"	" "	June, 1925..	0·724	63·4	99	145	172	259	323	383	430	96·6	1702	None
3239	"	" "	Sept., 1925..	0·721	64·2	118	162	184	232	268	340	412	97·5	1598	None
3563	Shell............................	Ottawa,	Dec., 1925..	0·718	85·0	103	151	173	221	254	313	379	97·5	1594	Light
3664	Queen...........................	"	" 1925..	0·731	61·5	99	147	174	247	289	346	397	97·0	1708	Medium
3665	Supertest Aero................	"	" 1925..	0·726	62·8	95	154	179	244	287	341	390	97·0	1690	None
3666	Peerless........................	"	" 1925..	0·719	64·7	108	159	177	221	253	310	374	97·5	1608	
3667	White Rose....................	"	" 1925..	0·736	60·2	138	184	204	248	282	342	432	97·7	1830	
3668	Super Quality..................	"	" 1925..	0·722	63·9	102	153	177	230	270	320	375	97·2	1632	Very light
3669	Super Quality..................	"	" 1925..	0·730	61·8	100	148	179	242	276	330	383	97·0	1660	Very light

PART III

I

DISTILLATION OF OIL SHALE WITH CIRCULATION OF UNCONDENSED GASES

A. A. Swinnerton

Several series of tests were made during 1924 on a (standard) sample of oil shale in different retorting apparatus, with and without steam, the results of which have been already reported.[1] In order to determine the comparative value of destructively distilling oil shale with the circulation of hot uncondensed gases, further tests have been conducted on the standard sample of oil shale on hand in the Fuel Testing Laboratories. Claims are made by certain promoters and investigators that a higher yield of crude oil is obtainable by the circulation of hot uncondensed gases than by ordinary or regular destructive distillation, and that the quality of the oil is superior. When the ratio of uncondensed gases to shale-oil vapour is large, the shale oil will tend to distil at lower temperatures than when the ratio is small, due to the greatly lowered partial pressure of the shale-oil vapour. This, it is argued, will give a larger yield of the primary shale oil resulting from the decomposition of the so-called "kerogen" oil-bearing constituents of the shale. Inasmuch as distillation with steam is equivalent to distillation at reduced pressure, the results obtained with the circulation of uncondensed gases should be compared with those by steam distillation and also with those by regular distillation at atmospheric pressure, at different rates in different sized retorts.

As pointed out in previous reports, the most important method is not the one that gives the highest yield of crude oil, but rather it is the method that gives the highest yield of finished products, or intermediate oils that can be refined with a high degree of efficiency and at a low cost. On the assumption that crude shale oil is more suitable and valuable as a raw material from which the lighter petroleum oil products may be obtained than it is for the production of lubricating stock, and that the comparative yields of light and heavy oils and coke residue by ordinary laboratory fractionation is a direct indication of its comparative value for refining by modern pressure-cracking methods, a direct comparison of the crude oil obtained by distillation of the shale with uncondensed gases, with that obtained by distillation with steam, and by regular destructive distillation is permissible. This report, therefore, contains the results of three distillation runs at different rates of gas circulation, as well as a comparison of these results with those obtained with, and without, steam in the small and large assay retorts.

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[1] Distillation of Oil Shale, *Comparison of Laboratory Methods*, Investigations of Fuels and Fuel Testing, 1924, and "The Development of a Standard Canadian Laboratory Distillation Method for the Examination of Oil Shale," by R. E. Gilmore and A. A. Swimmerton, Canadian Chemistry and Metallurgy, October and November, 1925.

DESCRIPTION OF APPARATUS AND METHOD

The apparatus employed, as shown in Figure 17, is a modification of that described in the Mines Branch Investigations of Fuels and Fuel Testing, 1924, page 72. The retort used was the two-pint capacity, large field-assay retort described in the reference just mentioned. As will be noticed it was the same as that used previously for the steam distillation runs, the retort being fitted with a coil of Shelby tubing, in which the circulating gases were preheated before entering the retort at the bottom. As shown in the sketch, the condensing train consisted of two spiral condensers, collecting flasks and cylinders of activated charcoal to scrub the gases free of light oil vapours, and a suction-pressure gas pump. A plug of glass wool was inserted at the top of the second condenser to trap as much dust as possible. The gas pump was placed between the exit of the charcoal container and the gas meter to suck the gas through the condensing train and pass it on to a storage tank which was maintained under slight pressure. From here the gas was drawn off and recirculated through ths retort and condensing system. A second charcoal absorption tube was connected to the exit pipe of the gas meter to ensure that the make-up gae was free of condensable light oils.

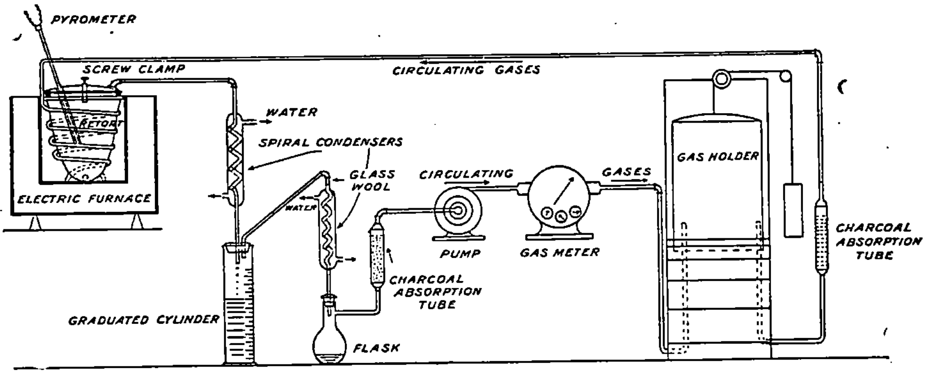

Figure 17. Large field-assay retort fitted for distillation with gas circulation.

To make a distillation test the retort is charged with 1,000 grammes of shale, the asbestos gasket inserted and the cover screwed down. After placing the retort in the electric crucible furnace the rate of heating is adjusted so that no tar fog comes past the condensers; the rate of gas circulation is adjusted by means of a valve on the pump. Practically all the oil is distilled off in two hours but the heating is continued for an extra half-hour, or so, to ensure maximum oil yield. When no further oil distillate is noticed the usual practice is to continue the run until the centre of the charge has reached 600° C., as indicated by the pyrometer.

The standard oil-shale sample used in this work was a sample from Albert Mines, N.B., (Lab. No. 1517) being known as a "30 gallon per ton" shale, the proximate analysis of which is:—

Moisture	0·7 per cent
Ash	65·8 "
Volatile matter	31·4 "
Calorific value	4,210 B.T.U. per pound

Four different distillation runs on the standard oil-shale sample were carried out, three by gas circulation, and one by regular distillation. In order to ascertain the effect of varying the rate of circulation, the amounts of gas circulated through the meter were 5·5 cubic feet for the slow rate, 21·7 cubic feet for the medium rate, and 81·0 cubic feet for the fast rate, while distilling 1,000 grammes of shale in each case. As the yield of gas obtainable, during the actual oil distillation period from this amount of shale by regular distillation at atmospheric pressure, varies from 1 to 1¼ cubic feet, the ratio of total gas circulated to gas produced was roughly 5 to 1, 20 to 1, and 75 to 1, for the slow, medium, and fast rates respectively.

TABLE LXVI

Main Details of Distillation Tests in Large Assay Retort

Method	Gas circulation			Regular distillation
Rate of gas circulated	Fast	Medium	Slow	
Sample taken (grammes)	1000	1000	1000	1000
Gas circulated (cubic feet)	81·0	21·7	5·5	(1·23)
Time of distillation	2 h. 20 m.	2 h. 20 m.	2 h. 15 m.	2 h. 45 m.
Products Obtained—				
Weight of condensed oil and water (grammes)	133·6	149·2	154·4	147·3
Specific gravity of condensed oil at 60°F.	0·935	0·924	0·911	0·883
Weight of water (grammes)	3·0	16·0	24·5	15·6
Naphtha scrubbed from gas (c.c.)	26·0	19·0	17·5	3·5
Specific gravity of naphtha at 60°F.	0·731	0·728	0·722	(0·72)
Weight of naphtha (grammes)	18·7	13·6	12·3	2·5
Total oil—condensed oil plus oil scrubbed from gas (grammes)	149·3	146·8	142·2	134·2
Total oil—Imperial gallons per ton	33·1	32·6	32·0	30·7
Spent shale obtained (grammes)	800·5	795·2	803·6	806·2
Analysis of condensed oil—				
Solids in the condensed oil (grammes)	0·843	0·891	0·171	0·241
Percentage volume of fractions—				
Up to 150°C	1·0	2·0	3·0	11·0
150° to 300°C	30·0	33·0	34·5	39·0
300°C. to end point	48·0	50·0	46·0	40·5
Pitch residue per cent (by weight)	23·2	12·7	16·4	10·3
Specific gravity of fractions at 60°F.—				
Up to 150°C	…………	…………	…………	0·750
150° to 300°C	0·840	0·840	0·830	0·835
300°C. to end point	0·908	0·930	0·912	0·928
Insolubility in concentrated H_2SO_4—				
As percentage of fractions up to 150°C	…………	…………	69	70
“ “ 150° to 300°C	60	62	66	66
“ “ 300°C. to end point	42	40	52	44
Analysis of spent shale—				
As percentage of original shale	80·0	79·5	80·4	80·6
Moisture	1·1	1·0	1·0	1·1
Ash	79·2	80·1	78·9	79·7
Volatile matter	18·1	16·4	17·9	16·2
Fixed carbon (by difference)	1·6	2·5	2·2	3·0

TABLE LXVII

Comparison of Yields of Light and Heavy Oils at Different Rates of Gas Circulation with those Obtained by Regular Distillation in Large and Small Assay Retorts

Method	Crude (water-free) oil, Imperial gallons per ton	Fractions obtained by distillation in Engler flask		
		Light oils (naphtha and illuminating) up to 300°C. including light oils scrubbed from gas, gallons per ton	Heavy (lubricating) oils 300°C. to end point, gallons per ton	Pitch, pounds per ton
Regular distillation in large assay retort	30·7	15·7	12·1	27·1
Gas circulation in large assay retort—				
Slow circulation	32·0	14·2	13·1	42·6
Medium circulation	32·6	13·9	14·4	33·9
Fast circulation	33·1	13·9	13·4	60·6
Steam distillation in large assay retort	31·5[a]	12·9[a]	11·7	19·5
Regular distillation in small assay retort	32·0[a]	14·4[a]	11·9	16·3

[a] Not including light oils scrubbed from the gas.

TABLE LXVIII

Rates of Oil Distillation from Shale by Different Methods

Method	Size of sample (grms.)	Average crude oil distillate c.c. per 15-minute period	Average yield of oil, c.c. per 1000 grms. of shale 15-minute period	Yield of light oils scrubbed from gas, Imp. gals. per ton	Total yield of oil, Imp. gals. per ton
Regular distillation in large assay retort	1000	20	20	0·7	30·7
Gas circulation in large assay retort—					
Slow circulation	1000	23	23	3·5	32·0
Medium circulation	1000	28	28	3·8	32·6
Fast circulation	1000	32	32	5·2	33·1
Regular distillation in small assay retort	350	12	34	....	32·0

A data sheet of a typical distillation run is as follows:—

Run No. 4 Date: July 31, 1926.
Weight of sample 1,000 grammes. Barometer 29·95 inch.

Time	Temperature of shale	Gas meter		Distillate
		Reading, cubic feet	Temperature °F.	
9.15	290°F.	27·65	60	
9.30	548	30·5	61	
10·00	660	35·1	62	30 c.c.
10.15	774	37·3	62	60
10.30	842	39·1	62	125
10.45	882	40·5	63	135
11.00	922	42·3	63	142
11.15	940	46·0	64	150
11.30	950	48·1	64	150
11.45	942	49·92	64	150

Weight of cylinder and oil...	684·25	grms.	Weight flask and oil...	263·70	grms. Water 16 c.c.
Weight of cylinder..........	543·40	"	Weight flask..........	255·35	"
Weight of oil..............	140·85	"	Weight of oil.........	8·35	"

Specific gravity of settled oil at 60° F. = 0·924.
Light oil recovered by charcoal = 19 c.c.; Specific gravity at 60° F. = 0·728
Weight of spent shale residue = 795·2 grms.

EXAMINATION OF PRODUCTS

The graduated cylinder and flask were weighed before and after the run, the difference being the weight of total distillate obtained. As much as possible of the water present was removed with a pipette from the bottom of the cylinder, the balance being removed by distillation of the settled oil in a glass flask, which aqueous distillate was added to the amount already obtained and the total measured. The specific gravity of the water-free oil was determined by the Westphal balance, and from this the yield in gallons per ton calculated. The amount of solids present was determined by diluting a 25 c.c. sample of the oil with ether and passing through an oil-free filter paper from which the oil had been previously extracted with ether. After washing and drying, the increase in weight of the filter paper gave the amount of solids in 25 c.c. from which result the total solids in the total volume of oil were calculated. The water-free oil was fractionated in a standard Engler distillation apparatus using 100 c.c. of oil. Cuts were made at 150° C., 300 °C., and end point (E.P.), and the amount of pitch weighed. Specific gravity determinations on each fraction were made and the percentage insoluble in concentrated sulphuric acid (1·84 sp. gr.) was determined by taking 5 c.c. of oil, adding 5 c.c. concentrated sulphuric acid, shaking in a 15 c.c. graduated centrifuge tube for 1 minute and then centrifuging until the oil and acid layers separated, the volume of oil left floating on top was read off and the amount insoluble in the acid calculated. The spent shale was examined according to the standard method for the proximate analyses of coals where moisture, ash, and volatile matter determinations were made and the percentage of fixed carbon obtained by difference. The amount of scrubber naphtha absorbed by the charcoal was determined by distilling the charcoal with 200 c.c. glycerine up to 250° C., according to the standard Burrell method, the naphtha obtained being collected and measured in a graduated receiver.

DISCUSSION OF RESULTS

Weight Balance. In these experiments, weight balances were not obtained owing to the fact that in all cases gas leaked out through the packing glands of the pump; city (coal) gas having to be added to the gas reservoir as "make-up" from time to time during the run.

Comparison of Oil Yields. It will be noticed that with gas circulation the total crude oil yields, including the light oils from the gas, were greater than by regular distillation, and that the increase varied with the amount of gas circulated. The amount of scrubber naphtha recovered varied directly with the rate of gas circulation. For instance, the naphtha absorbed by the charcoal was 17½, 19, and 26 c.c. for the slow, medium, and fast rates of gas circulation respectively, as compared with 3½ c.c. by regular distillation. The scrubber naphtha from four runs was combined for a distillation test, the results being as follows:—

First drop	35° C.	60 per cent	122° C.
10 per cent........	60° C.	70 "	139° C.
20 "	76° C.	80 "	159° C.
30 "	86° C.	90 "	205° C.
40 "	100° C.	Dry	242°C.
50 "	110° C.	Recovery	95 per cent
		Residue by weight	2·3 "

It will be seen from the above that practically all distilled below 200° C., 80 per cent coming over below 150° C. It will also be noticed that although the distillates from the runs giving the higher oil yields contained larger quantities of sediment than those giving lower yields, the maximum amount of such was less than 0·9 grammes in the crude oil from 1,000 grammes of shale.

As shown in Tables LXVI and LXVII, the total crude oil yield varied from 32·0 to 33·1 Imperial gallons per ton for the three gas circulation runs, in comparison with 30·7 and 32·0 gallons by regular distillation in the large and small assay retorts respectively, and with 31·5 and 32·0 gallons in the large and small retorts using steam. It should, however, be noted that the oil yields for the steam and regular distillation runs in the small retort do not include any naphtha recovered from the gases, which indicates that higher crude oil yields are not to be expected from the gas circulation method than by the use of steam or from regular distillation.

Comparison of Crude Oils Obtained by Gas Circulation, Steam, and Regular Distillation in Large Assay Retort

—	Gas circulation average 3 runs		Steam distillation		Regular distillation	
		gallons per ton		gallons per ton		gallons per ton
Specific gravity at 60° F........	0·921	....	0·899	....	0·883	
Fractions 0° to 150° C. (by vol.)..	2·0%	0·6a	9·0%	2·8a	11·0%	3·3a
150° to 300° C. (by vol.).......	32·5%	10·6	32·0%	10·1	29·0%	11·7
300° C. to end point (by vol.)..	48·0%	15·6	37·0%	11·7	40·0%	12·0
Pitch residue (by weight).......	17·4%	....	22·0% (by diff.)	....	10·3%	

a Does not include the scrubber naphtha.

This table shows the variation in the quality of the oils obtained by different methods of distillation[1], the most striking differences being in the first and third fractions. It was noted that the end point, that is the temperature at which cracking started, was always lower for the oils obtained by gas circulation than by regular distillation, the comparative figures being 360° and 395° C. respectively.

Relation of Rate of Distillation to Yield of Crude Oil. As shown in Table LXVI, the effect of increasing the gas circulation and also the rate of distillation was to give one or two more gallons of oil per ton. This relation of higher yields of crude oil for the faster rate of distillation from the shale was also apparent, as noted in the 1924 Investigations of Fuels and Fuel Testing (page 80) in comparison of the small and large assay retorts where the faster rate of distillation from the small retort gave appreciably higher crude oil yield than from the large retort at a slower rate.

Relation of Yield of Crude Oil to Light Oil Content. As shown in Table LXVII, the yields of light oils distilling below 300° C., for the gas circulation and regular runs varied inversely as the yield of crude oil, that is, the higher the yield of crude oil the less light oils it contained. This relation is emphasized in the regular distillation where the appreciably lower crude oil yield contained the highest percentage of light oils. This means that the higher yields obtained by gas circulation are not specially attractive on account of their comparatively low light-oil content. The light-oil yield by the regular distillation method is 15·7 gallons per ton as compared with an average of 14·0 gallons by gas circulation and 12·9 by steam distillation. Of the 14·0 gallons light oils (per ton) for the gas circulation runs, over 4 gallons were scrubbed from the gas as compared with less than 1 gallon for the regular distillation. It is therefore evident that to obtain maximum yields of both crude and light oils by the gas circulation method the gases would have to be efficiently scrubbed which would involve considerable extra expense.

The Effect of Gas Circulation. Gas circulation has the same effect as steam in reducing the percentage of fixed carbon in the spent shale although the reduction is not large. As shown in Table LXVI, the fixed carbon was 2·2, 2·5, and 1·6 per cent for the slow, medium, and fast rates of gas circulation as compared with the minimum of 0·4 per cent for steam and 3·0 per cent for regular distillation. The effect of gas circulation is also similar to that produced by steam in that the oil products are swept out of the retort rapidly and at a comparatively low temperature with the effect that the yield of "primary" crude oil is larger than that obtained by regular distillation. As noted above the light oil content varied inversely with the total (crude) oil yield and as was expected, the ratio of light oils scrubbed from the gas to the total yield of light oils varied directly with the rate of the gas circulation. This, coupled with the observation that the light oils obtained in the gas circulation runs were lighter than the similar light oils in the regular distillation runs, means that a certain amount of cracking of the heavier oils into lighter oils takes place by the gas circulation method, but such cracking is not objectionable if the objective is the production of light petroleum oil products. As shown in Table LXVII,

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[1] For further details of the steam and regular runs, the tables on page 77, Investigations of Fuels and Fuel Testing for 1924, should be consulted.

the yield of total light and heavy oils (that is the total crude oil obtained minus the pitch) for the three gas circulation runs averaged 27·6 gallons per ton, which was practically the same as the 27·8-gallon yield for the regular distillation in the same retort. The corresponding pitch yields were 45·7 pounds (per ton)—the average of the gas circulation runs—as compared with 27·1 pounds for regular distillation. It is, therefore, evident that the gas circulation method involving more elaborate and expensive gas-scrubbing equipment is not specially attractive for the production of "low-pitch content" crude oils suitable for refining by modern cracking processes into motor fuels, and light-gas and fuel oils.

SUMMARY

(1) Three runs at different rates of circulation were made on a standard oil-shale sample in a standard retorting apparatus previously used in the Fuel Testing Laboratories for the purpose of determining the comparative value of distilling oil shale with the circulation of hot uncondensed gases. As the desired effect of distilling in the presence of hot gases is to lower the partial vapour pressure of the shale oil, thus allowing the oil to distil over at lower temperatures than at atmospheric pressure, and as this effect is similar to that when distilling with steam, the results of the gas circulation runs have been compared with those obtained with steam and by regular distillation at atmospheric pressure. In the gas circulation runs the gases entering and leaving the retort were passed through activated charcoal tubes to ensure first, that the gases entering the retort were free from oils, and second, that all condensable light oils were scrubbed from the gases leaving the condensing system before going through the suction-pressure pump. The amounts of hot gas circulated in the slow, medium, and fast rates were roughly 5, 20, and 75 times the normal yield of shale gas.

(2) The yield of total shale oil obtained in the slow, medium, and fast gas circulation runs was equivalent to 32·0, 32·6, and 33·1 Imperial gallons per ton, as compared with 30·7 gallons by regular distillation in the same retort. The amounts of light oils (or scrubber naphtha) recovered from the gas was equivalent to 3·5, 3·8, and 5·2 gallons per ton of shale distilled as compared to 0·7 in the regular run. Previous yields of total oil from the standard sample of shale, distilled from the small retort at a comparatively fast rate with and without steam were the same, namely, 32·0 gallons, which yields did not include the naphtha from the gas. Allowing for the latter, it was observed that distillation in the presence of hot uncondensed gases did not give higher yields of crude oil than obtainable with steam or by regular distillation. In the gas circulation runs the yield of total oil varied directly with the rate of oil evolution; this agrees with the observation made in connexion with regular distillation in the large and small assay retorts.

(3) The amounts of light oils distilling below 300° C. (including the naphtha from the gas) varied inversely as the yield of total crude oil. The average light oil yield from the three gas circulation runs was equivalent to 14·0 gallons per ton as compared with 15·7 in the regular distillation. The corresponding yields of heavy oils distilling between 300° C. and end point was 13·6 gallons for the gas circulation runs and 12·1 for the regular.

(4) The effect of distilling shale in the presence of hot uncondensed gases in respect to yield and quality of the oil obtained was similar to that with steam. Both methods tended to increase the yield of crude oil giving lower proportions of light oils and higher yields of heavy oils as compared to regular distillation. The oils distilling below 300° C., including the naphtha scrubbed from the gas in the gas circulation runs, had a lower specific gravity and a boiling range than those from the regular run, which indicates that a certain amount of cracking of the heavier oils into lighter oils took place by the gas circulation method. The average yield of total light and heavy oils distilling below 300° C. from the three gas circulation runs was 27·6 gallons per ton, as compared with 27·8 by regular distillation, and the amounts of the pitch residue were roughly 46 and 27 pounds per ton for the gas circulation and regular runs, respectively. It may, therefore, be concluded that the distillation of oil shale with the recirculation of uncondensed gas is not superior to regular distillation for the production of low pitch content (crude) oils suitable for refining by modern cracking processes into motor fuels, etc., and this, coupled with the necessity of installing elaborate and costly equipment for the efficient preheating, condensing and scrubbing of the gases, does not make the gas circulation method attractive for the distillation of oil shale.