CANADA

DEPARTMENT OF MINES

HON. W. A. GORDON, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

MINES BRANCH

JOHN MCLEISH, DIRECTOR

INVESTIGATIONS
OF
FUELS AND FUEL TESTING

(Testing and Research Laboratories)

1930 and 1931

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PART I—SOLID FUELS

PART II—NATURAL GAS AND LIQUID FUELS

No. 725

OTTAWA
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Annual reports on Mines Branch investigations are now issued in four parts, as follows:—

Investigations of Mineral Resources and the Mining Industry.

Investigations in Ore Dressing and Metallurgy (Testing and Research Laboratories).

Investigations of Fuels and Fuel Testing (Testing and Research Laboratories).

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

Other reports on Special Investigations are issued as completed.

MINES BRANCH INVESTIGATIONS OF
FUELS AND FUEL TESTING, 1930 AND 1931

GENERAL REVIEW OF INVESTIGATIONS

B. F. Haanel, *Chief of Division of Fuels and Fuel Testing*
R. E. Gilmore, *Superintendent of Fuel Testing Laboratories*

During 1930 and 1931 both laboratory and field investigations were conducted as in former years. The field work comprised an investigation relating to the natural gas and naphtha in the Turner Valley, Alberta; the further sampling of oil-shale outcrops and the inspection of oil-shale developments in Nova Scotia and Quebec; and the observing of plant-scale coking tests on Canadian coals at Winnipeg and Montreal. Samples of natural gas, naphtha, oil shale, etc., taken in the field, were submitted to a detailed examination in the laboratory in Ottawa. The principal plant-scale investigations carried out in the Fuel Research Laboratories were tests in the experimental pulverized fuel fired boiler installation and in the two-ton by-product coke oven. Detailed results of these tests, which were confined to coals from British Columbia, Alberta, and Nova Scotia, and which extended over the period of two years covered by this report, have already been supplied to the parties especially interested, and will be published at a later date in separate bulletin form. The scope of the more important of these investigations and the results obtained are, however, reviewed here, in addition to a review of the different reports and papers which are presented as Investigations of Fuels and Fuel Testing for 1930 and 1931.

Acknowledgments. The carlot shipments of coals from Western Canada, on which the coking tests reviewed below were made, were supplied gratis by the coal mining companies producing the respective coals, and were transported free of charge by special arrangements with the two Canadian railway companies. To the colliery officials concerned, to Mr. J. M. Horn, Assistant Freight Agent, and H. A. Plow, General Freight Agent of the Canadian National and Canadian Pacific Railways at Winnipeg, respectively, grateful acknowledgment is herewith tendered on behalf of the Department of Mines, and also to Professor E. Stansfield, A. Millar, and the provincial Government mining inspectors, who co-operated in the selection and shipping of the Alberta coals. In respect to the testing of Onakawana lignite, special reference and appreciation is to be made to the co-operative arrangement between the Ontario Department of Mines for supplying the lignite. Thanks are also due to the officials of the Dominion Steel and Coal Corporation who supplied the carlot of Princess coal for the tests at Ottawa, and who specially prepared the coal for and witnessed the tests at Montreal, and to Mr. Donald Munro and Mr. J. D. Price, Manager and Superintendent, respectively, of the Montreal Coke and Manufacturing Company, who not only made possible the large-scale coking tests at their LaSalle plant, but co-operated to the fullest extent to make the combined coking and storage tests on Nova Scotia coal a complete success.

Coking, Washing, and Storage Tests on Canadian Coals. During 1930 and 1931, series of coking, washing, and storage tests on Canadian coals were carried out in the Fuel Research Laboratories at Ottawa, and at commercial plants, the objective of which was to show how the use of Canadian bituminous coals could be increased for the manufacture of city gas and by-product oven coke. The coke oven installation at the Fuel Research Laboratories employed for these tests was a horizontal by-product oven with vertical flues, equipped with a gas producer burning coke as fuel, charging hoppers mounted on tracks, an electrically driven coke discharging ram, and a Shallcross automatic signal pressure regulator. A suitable gas scrubbing train consisting of a steam driven exhauster, a tar extractor of the P & A type, a bubble washer, a naphtha scrubber, gas meters and Thomas recording calorimeter, completed the installation in the order as connected to the oven. The oven has a capacity of 4,500 pounds or slightly over two tons, and although small in comparison with most industrial by-product ovens, is in reality a unit of a battery of horizontal by-product ovens in commercial use, and was found to be capable of yielding coke, gas, and other products comparable in yield and quality to those from regular commercial ovens. The tests reviewed here were in the immediate charge of R. A. Strong, who was assisted by Messrs. E. J. Burrough, G. P. Connell, and E. Swartzman, and a staff of observers and operators.

Tests on British Columbia Coals at Ottawa during October and November, 1930. These tests were on a series of coals supplied by coal mining companies at the instigation of the British Columbia Department of Mines. Despite the fact that they were selected primarily for tests in the experimental pulverized fuel fired boiler installation, they were also submitted to tests in the two-ton by-product oven. The individual coals were first coked alone and then in admixture or blended with one another, the main objective being to determine their suitability for the production of metallurgical coke. Certain of the lower ash coals as mined in the eastern part of the province were specially examined as to their suitability for the production of city gas, as well as coke for the domestic fuel market in Winnipeg. The coals tested, listed according to area or district, were:

Crowsnest Pass area—Michel and Coal Creek coals.
Nicola area—Coalmont and Middlesboro coals.
Vancouver Island—Cassidy, Reserve, and Comox coals.
Inland (north)—Telkwa coal.

It was found that by blending Crowsnest Pass coals with Island coals, blast furnace cokes grading from suitable to good could be produced, and fair to good coke was produced in the Telkwa-Coal Creek mixture. Blends of Coal Creek coal from Fernie with Coalmont and Middlesboro coals from the Nicola area failed to produce a coke that could be graded better than poor to fair, while what may be termed a "suitable" coke resulted from a mixture of Middlesboro, Comox, and Coal Creek coals in equal proportions. Of the four coals coked alone, Comox coal produced a fair to good metallurgical coke, Coal Creek coal, good, and Michel an excellent grade of coke. Cassidy coal, although it failed to produce a satisfactory coke when coked alone, did, when blended with Michel coal, produce a coke that may be graded good for general metallurgical purposes. Michel coal proved to be the most suitable of all the British Columbia coals tested for blending purposes and also when coked alone for the production of blast furnace, foundry, or domestic coke.

Special Tests on Michel and Allison Coals. Experimental coking tests on these two coals were carried out in the coke oven at the Fuel Research Laboratories, and were followed by practical plant tests in the by-product coke ovens of the Winnipeg Electric Company, in December, 1930. The objective of these tests was to determine on a full-size plant scale the comparative merits of Michel and Allison coals for the production of city gas and domestic coke. The ovens employed at Winnipeg were typical Koppers horizontal by-product recovery coke ovens, each of seven-ton capacity, and were operated with a view to meeting the local gas demand; coke quality, although important, was of secondary significance. In the experimental runs on the two-ton oven at Ottawa, over 20 tons of each coal were coked, and in the tests at Winnipeg, the results from 1,000 tons of the Michel coal were compared with those from the regular Allison slack coal. The Michel coal was from B seam of the Michel mine of the Crow's Nest Pass Coal Company, British Columbia, and the Allison was Pittsburgh seam coal from the Allison mine, Fayette county, Pennsylvania. The analysis of the Michel coal on the dry basis was: 6·5 per cent ash, 26·9 per cent volatile matter, 0·7 per cent sulphur, and F.P.A. of 2,235° F. in comparison with 8·2 per cent ash, 33·8 per cent volatile matter, 1·3 per cent sulphur, and F.P.A. over 2,700° F. for the Allison coal. The coking period in the 14-inch ovens at Winnipeg varied from 20 to over 22 hours in comparison, or rather in contrast, with the 12-hour coking period in the 12-inch oven at Ottawa. The following is a summary of the yields of gas, coke, and other by-products.

—	Allison coal		Michel coal	
	2-ton oven at Ottawa	7-ton ovens at Winnipeg	2-ton oven at Ottawa	7-ton oven at Winnipeg
Gas, cubic feet, 510 B.T.U. gas per ton of coal as charged	12,565	11,940	12,535	11,775
H_2S in gas per 100 cubic feet (grs.)	382	433	140	158
Tar, Imperial gals. per ton	10·2	10·2	7·8	9·0
Coke, lb. per ton	1,420	1,410	1,500	1,600
Shatter index of wharf coke	45	53	57	66
Stove and nut sizes by crushing (lb.)	....	1,120	....	1,315
Breeze (per cent of total coke)	2·3	8·4	2·2	6·8

The coke yields shown above are not strictly comparable, in that the two-ton oven yields were on a dry coke to dry coal basis, whereas the other results were on a wet coke to coal as-charged basis. The tabulated results do, however, show that the yield of saleable stove and nut sizes of coke from Michel coal was appreciably higher than that from the Allison coal. The gas from the former coal, it will be observed, had only about one third as much hydrogen sulphide content, thus allowing of a considerably lower sulphur purifying cost. Also, Michel coal with 27 per cent volatile matter according to laboratory analysis, gave in terms of gas with equal B.T.U. per cubic foot, a commercial yield closely approaching that from Allison, with nearly 34 per cent volatile matter. This is significant and most remarkable. An explanation of this is that the tar and other volatile constituents in the two coals are different and are decomposed in one coal in a different manner than in the other, which shows the necessity of actual coking tests to determine comparative data on the quantity and quality of the gas to be expected. As for coke quality, the Michel coke was large and blocky with a straight fracture, indicating a low breeze yield when crushed, in comparison with the harder, more dense, triangular shaped coke from the Allison coal, which tended to produce more breeze on crushing. The average ash content for the sizes above one inch for the Michel coke was 8 per cent as compared with 12 per cent for the Allison coke and the respective fusion point of ash (F.P.A.) temperatures were 2,170° and 2,700° F. Burning tests conducted on sized Michel coke showed it to be a very satisfactory domestic household fuel. The net result of these comparative tests may, therefore, be summed up in remarking that, whereas the good features of Allison coal for coking alone in by-product ovens were confirmed, it was demonstrated that Michel coal had in several respects, as just outlined, superior merits.

Coking and Storage Tests on Nova Scotia Coal at Montreal. In July and August, 1930, commercial scale coking and storage tests were made on Nova Scotia coal at the LaSalle plant of the Montreal Coke and Manufacturing Company. The coal selected was "New Waterford" coal as supplied by the Dominion Steel and Coal Corporation, and the purpose of the tests was to determine in what proportion Nova Scotia coal could be used in the manufacture of domestic coke suitable for the Montreal market. The mixture of imported stock coals used at that time was 41·5 per cent high volatile "gas" coal from Pennsylvania, 47·5 per cent medium volatile bituminous coal from the same state, and 11 per cent semi-bituminous (Pocahontas type) coal from West Virginia. This, their regular blend, had been selected after many trial mixtures to produce a domestic coke having the physical and general burning qualities suitable for the Montreal market. A special requirement was that the fusion point of ash (F.P.A.) of the coke was to be not lower than 2,500° F., and the problem, therefore, was to determine to what extent either of the imported bituminous coals could be replaced by the Nova Scotia coal so as to produce a domestic coke as suitable in all respects as that produced from the regular blend.

The New Waterford (or Dominion coal, as it was termed) as supplied by the Dominion Coal Corporation, was slack coal freshly mined from their collieries No. 12 and No. 14. A total of 10,000 tons of this coal was shipped to the coke plant, of which 6,000 tons were used in the tests reviewed here, and the remaining 4,000 tons were put in the stock pile for observations on its storage properties. The average of several analyses of this coal was 3·9 per cent moisture, 6·8 per cent ash, 35·6 per cent volatile matter, 57·6 per cent fixed carbon, 2·67 per cent sulphur, and F.P.A. 2,025° F., all the results except the moisture being on the dry basis. Tests were made using the Dominion coal alone, that is, 100 per cent of Nova Scotia coal, and then for comparative purposes on 100 per cent of the medium volatile coal. These were followed by four coal mixes or blends in which portions of this medium volatile coal were displaced by the Nova Scotia coal, in which blends the respective contents of the Dominion coal were 20 per cent, 15 per cent, and 10 per cent. Tests on these blends were carried out in addition to test runs on their regular three-coal mix mentioned above. Special care was taken in sampling and analysing both the coal and coke and attention was also given to the examination of the physical properties as well as the chemical properties, the former mainly in respect to ash fusion temperature.

The blend in which 20 per cent of the Dominion coal was used produced egg, stove, and nut coke with ash fusion temperatures closely approaching 2,500° F., the limit specified, but the F.P.A. of the pea size and breeze fell appreciably below this figure. The ash fusion results of the coke from the 15 per cent Dominion blend, as well as from the 10 per cent blend, were satisfactorily above 2,500° F. for all coke sizes, so that it was decided that the maximum amount of the New Waterford coal allowable was 15 per cent. All the domestic coke sizes produced with the blends using the Nova Scotia coal—including the 20 per cent blend—contained less than 10 per cent ash as required, and as judged by the shatter index and breeze produced by crushing and sizing, the quality of the coke produced in both the 15 per cent and 10 per cent Dominion blends was not reduced below the standard set. The results of the storage test on the portion of the 10,000-ton shipment not used in the coking test were not satisfactory.

Washing, Coking, and Storage Tests on New Waterford and Princess Coals. The combined coking and storage tests on the freshly mined New Waterford slack coal may be briefly summed up in remarking that the results of the coking tests were encouragingly positive, whereas the results of the storage test were negative. On the theory that the heating of the Nova Scotia slack coal is largely due to fines contained in it, in which fines the percentage of natural mineral charcoal or "fusain," as it is termed, is high, washing and sizing were considered advisable to accomplish the double purpose of (1) improving storage properties and (2) reducing the ash content, in order to permit a larger proportion to be used in blends with imported coal and still comply with the ash fusion specification. With this in view, preliminary washing experiments were made at the Fuel Research Laboratories on a sample of New Waterford coal supplied by the Dominion Coal Corporation in May, 1931, and synthetic blends were made with the washed product and one of the high fusion point ash coals as used at Montreal. "Floats" with 2·6 per cent ash and a F.P.A. of 2,010° F. prepared from the sample of the new Waterford coal, were mixed in the laboratory in percentages of 20, 40, 60, and 80, respectively, with the standard high volatile Pennsylvania bituminous coal with a F.P.A. of 2,740° F. From a curve drawn after plotting ash fusion temperatures against percentages of coals used in the mixtures, it was evident that for the blends containing up to 40 per cent of the washed "float" coal the F.P.A. remained above 2,500° F. This indicated that by using washed Dominion coal with an ash content of 3 per cent or lower, percentages as high as 30 to 35 per cent could be employed at the Montreal coke plant, and still comply with the ash fusion specification.

At this stage of the investigation it was decided by the coal company to wash, size, and prepare for shipment one of their best coals for large-scale coking and storage tests. The coal selected and specially prepared was Victoria seam coal from their Princess colliery at Sydney Mines, and this was later used in quantity at Montreal. As indicated by washing experiments made at the Fuel Research Laboratories, the coal company found that this coal could be washed in commercial quantities to slightly less than 3 per cent ash with a substantial reduction in sulphur content, and accordingly, a carlot of the washed coal was shipped to Ottawa for coking tests there, as a preliminary to full-size tests on selected blends at Montreal.

The tests on washed Princess in the two-ton oven at Ottawa were made in September, 1931, in conjunction with tests on the Alberta coals reviewed below, and comprised a series of runs on blends of Princess coal with the standard medium and high volatile Pennsylvania coals and the standard Pocahontas as employed at that time by the coke company at Montreal. Twelve different blends were coked, in which the proportion of Princess coal varied from 30 to 60 per cent, in admixture with 55 to 30 per cent of either the medium or high volatile Pennsylvania coals, and with variations of 10 to 35 per cent Pocahontas. As a standard, and for the purpose of comparing the coke in respect to physical properties as produced in the two-ton oven with that in the commercial ovens, test runs were made on the blends used regularly at Montreal, which blended mixture was shipped direct from the coke plant. Charges of 100 per cent of the Pennsylvania gas coal were also coked and results recorded. Blends that showed good results were those in which the proportion of Princess varied between 30 and 35 per cent with 57 to 52 per cent of the medium volatile Pennsylvania coal and the remainder Pocahontas. Cokes made from coal blends in these proportions possessed physical properties which compared favourably with the standard "LaSalle" coke, and as shown by comparative burning tests in a standard domestic hot-water boiler, afforded in this respect equal satisfaction. The results of the coking test on Princess coal at Ottawa indicated it to be quite suitable for blending with the imported coals to produce a domestic coke satisfactory for the Montreal market.

In the subsequent tests conducted in November, 1931, at the LaSalle plant of the Montreal Coke & Manufacturing Company, 8,000 tons of the washed Princess coal was used, and an additional 35,000 tons was put in the stock pile for a storage test, as described below. The analysis of the Princess coal coked was 2·8 per cent ash, 40·3 per cent volatile matter and 1·25 per cent sulphur, all on the dry basis, the moisture content being 4·6 per cent and the F.P.A. 2,000° F. The blend selected was 35 per cent Princess, 50 per cent medium volatile Pennsylvania coal, and 15 per cent Pocahontas. It will be noticed that the high volatile Nova Scotia coal replaced the Pennsylvania "gas" coal instead of the cheaper, medium volatile imported coal as in the former tests on unwashed New Waterford coal. The run of oven coke produced had an F.P.A. of 2,400°F., but on account of the low-ash content, namely, 7 per cent, it showed up as well in the burning tests as the higher ash, 2,500° F. ash fusion temperature coke from the regular mix. In general, the results of the plant-scale tests were considered satisfactory, and although the maximum of the Princess allowable in order to maintain coke quality in respect to structure and ash fusion temperature would probably have to be slightly lowered, it was demonstrated that at least twice as much of washed Nova Scotia coal could be used as was permissible with the raw unwashed coal as mined.

The storage test on 35,000 tons of specially prepared washed Princess coal was conducted during and immediately after the coking tests outlined above, and lasted during the winter and following spring months. In the preparation of this coal at the washing plant of the Dominion Steel and Coal Company at Sydney, special care was taken to eliminate fines, which, with their high content of mineral charcoal or "fusain", were considered to be the main cause of spontaneous combustion. The coal used in the coking tests, containing nearly 70 per cent through a one-eighth screen, was found, on account of its moisture-holding capacity, to be not entirely suitable for blending purposes in that it was found mechanically difficult to maintain a uniform mixture. Hence, for the double purpose of eliminating blending difficulties and improving storage properties, it was decided to remove as large a portion of the fines that were likely to cause heating as was economically possible. The coal put into the storage pile contained approximately 5 per cent over one inch in size, 61 per cent through one inch and on one-half inch size, 32 per cent of sizes between one-half and one-eighth, and only 2 per cent through a one-eighth inch screen. The coal to be stored was put in a specially prepared location and piled to a height of 40 feet according to the standard practice at the plant. For the purpose of recording the temperatures at the bottom and throughout the pile, both vertically and horizontally, 20 1-inch pipes were placed vertically at regular intervals in which copper-constantan wires 40 feet long were placed. These wires served both as thermocouples and lead wire. Readings on a standardized, potentiometer-type, indicating pyrometer were made, starting November 6th and continuing to February 12, 1932. At no time nor place did these readings indicate temperatures above 88° F. and after December 1 the average for the whole pile ranged from 65° to 40° F. These results were remarkable in that it was the first time on record, according to the writers' knowledge, that so large a quantity of Nova Scotia coal piled so high at a coke plant showed so little tendency to heat and possessed such excellent storage properties.

Coking Tests on Alberta Coals. During September and October, 1931, coking tests on a series of six Alberta coals were carried out in the two-ton oven at Ottawa. These coals were coked alone and in admixture with one another, primarily for the purpose of judging their suitability for the production of domestic coke, rather than for blast furnace coke, as with the tests on British Columbia coals tested during 1930 and reviewed above. The Alberta coals tested, carlots of each of which were received, were:

Mountain Park area—Cadomin, Mountain Park, and Luscar coals.

Crowsnest Pass area—Greenhill, International, and McGillivray Creek coals.

Hillcrest coal was received too late to be included in the above series, hence the coking tests on this coal as published in Investigations of Fuels and Fuel Testing, 1927, may be accepted for purposes of comparison. The dry-basis volatile matter contents of the coals for the three Crowsnest Pass coals tested ranged from 24 to 25 per cent, with Cadomin at 26 per cent, and the two lots of Mountain Park coal from the Michelean and Kennedy seams roughly 28 and 29 per cent respectively. Hillcrest coal, just referred to, contains 29 to 30 per cent volatile matter, depending on the ash content, so that in this respect it resembles the coals from the Mountain Park area more closely than those of the Crowsnest

Pass area. For the purposes of blending, four other coals were tested in this series, namely, the high volatile Pennsylvania bituminous coal, the washed Princess coal from Nova Scotia, both as gas coals; the medium volatile content Michel coal from British Columbia and Luscar coal, the latter to serve as a low volatile semi-bituminous coal in place of Pocahontas. A fifth extra coal, an Alberta (non-coking) sub-bituminous, was used for blending purposes in order to determine if its use would increase the gas yield obtained normally from a medium volatile bituminous coal without seriously affecting coke quality.

The gas yield from the three coals from the Crowsnest Pass area, in terms of 510 B.T.U. per cubic foot gas, varied from 9,500 to 10,400 cubic feet per ton, with corresponding dry coke yields of 77 to 79 per cent of the (dry) coal charged. The yield of gas on the same basis from the coals from the Mountain Park area varied from 11,000 to 13,000 cubic feet per ton and the coke yield from 75 to 79 per cent. In accordance with the findings in the comparative tests on Michel and Allison coals reviewed above, these gas yields, based on equal heating value per cubic foot, did not bear a direct relation to the respective volatile matter contents. In respect to coke structure, all six of the Alberta coals tested appear to be suitable, in varying degrees, for blast furnace purposes, but for domestic (household) purposes only the cokes made from the Cadomin, Mountain Park, and Greenhill coals were judged satisfactory. The ash contents in the cokes from these coals, ranging from 13·5 to 15·5 per cent in the domestic coke sizes, were, however, excessive, and until a substantial reduction in ash content is effected by washing, their respective cokes, when coked alone, would have difficulty in competing on the market, e.g. in Winnipeg.

Luscar coal, with a volatile matter content of 20 per cent, proved to have the blending properties peculiar to the Pocahontas coal, despite the fact that it produced a coke of poor structure when coked alone. Blending washed Princess as the high volatile gas coal, Michel as a standard medium volatile bituminous, and Luscar as the low volatile semi-bituminous coal, in proportions of 40-40-20 respectively, produced a coke of high quality in respect to appearance and physical properties. Hence, this Luscar coal, especially after washing to reduce its ash content, can be recommended to the coking industry of Western Canada for blending purposes. The non-coking sub-bituminous coal from the Saunders area in Alberta, when coked first with 75 per cent Greenhill coal and then with 40 per cent Greenhill and 40 per cent Michel coals, failed to produce a favourable coke in respect to structure. In fact, in the proportions used it appeared to impair the appearance and structure of the cokes from the other strongly coking coals blended with it, consequently, the use of a non-coking, high volatile content, sub-bituminous coal (without pretreatment) cannot be recommended for blending purposes.

Blends of the six different Alberta coals with equal quantities of the standard Pennsylvania gas coal low in ash content, had in every case the double effect of improving the structure and general quality of the coke and of substantially increasing the gas yield. Still better results in respect to coke quality were obtained in each case by the blending of 40 per cent of the Alberta coal with 30 per cent of the Pennsylvania gas coal and 30 per cent of Michel coal from British Columbia. Michel coal, the ash content of which was comparatively low, had the effect when blended in equal proportions with the Alberta coals, of improving coke structure, but the ash in the cokes was not sufficiently low, and the respective gas yields were not so high as with the 40-30-30 mixtures using the standard gas coal. The use of two coal blends of Michel coal with certain of the higher volatile Alberta coals in which the ash content has been substantially reduced by washing, is, however, promising and indicates the possibility of using 100 per cent native coal for the manufacture of domestic coke and city gas.

The detailed results of coking tests on British Columbia and Alberta coals will appear in a separate Mines Branch bulletin now in the course of preparation, under the title "Coking Tests on Bituminous Coals from Western Canada." Likewise, the results of the coking, washing, and storage tests on Princess and New Waterford coals are to be published in separate bulletin form, under the title of "Investigations on Coals from Cape Breton, Nova Scotia." In this report it is planned to report somewhat in detail the results to date of the physical and chemical survey of the Phalen seam, as referred to in former Investigations of Fuels and Fuel Testing and annual reports of the Department of Mines.

not published

Carbonization and Briquetting Tests on Ontario Lignite. Carbonization tests on Onakawana lignite supplied by the Ontario Department of Mines were made in the two-ton coke oven during the cooling-down periods incident to the operation of the oven during the autumns of 1930 and 1931, and subsequent briquetting tests on the char produced were conducted. The lignite charged to the oven was that remaining from the first carlot shipment after the pulverized fuel and special boiler tests reviewed below were made, and did not represent the best grade of Onakawana lignite produced. The purpose of these tests was to indicate the amenability of this lignite to combined carbonization and briquetting treatment for the production of a domestic fuel rather than to demonstrate a suitable carbonization process. The lignite is non-coking and does not form a coherent mass when heated, hence, in order to carbonize it in this type of oven the discharge end of the oven was fitted with a small sliding cast iron door in the bricked-up wall used in the cooling-down period. Through this door, the lower edge of which was on the level of the oven floor, the hot carbonized residue or char, as it is called, was raked into the coke wharf and quenched. Char withdrawn at the end of six hours showed from 29 per cent volatile matter in the lumps larger than half-inch to as low as 20 per cent in the material through ⅛-inch screen, whereas the volatile matter in the char after remaining in the oven 72 hours, varied from 6 to 8 per cent. The calorific value of the char containing the lowest ash and volatile matter contents, was 11,500 B.T.U. per pound, showing that the effect of carbonizing was more than to double the calorific value of the wet, slightly air-dried lignite charged to the oven.

In the briquetting tests on the char three different binders were tried, namely: petroleum pitch, sulphite liquor, and a mixture of flour and petroleum pitch. In tests on fifty-pound lots of char using a small, steam-heated (bread) mixer and a four roll Mashek press with pillow-shaped pockets, satisfactory briquettes in respect to appearance and physical properties were made with all three binders. The last shipment of Onakawana lignite received at the Fuel Research Laboratories representing the better grade as available from the lower seam, contained 11 per cent ash on the dry basis, from which, by selective screening, lump material may be obtained averaging 7 to 9 per cent ash. On the assumption that it requires three tons of the lignite as mined or 1½ tons of the dry lignite to produce a ton of char, the ash content of such a char will not be less than say 11 to 13 per cent, the calorific value of which will range from 11,700 to 12,000 B.T.U. per pound. The use of petroleum pitch as a binder, approximately 12 per cent of which is required, would tend to enhance this dry basis heating value, due both to the relatively high calorific value of the pitch and to a reduction in ash content of the briquette, but after allowing three to five per cent moisture in the finished briquette, the calorific value range of the briquettes to be marketed would apparently not exceed the maximum 12,000 B.T.U. figure. Eight per cent asphalt pitch and 2 per cent flour produced a satisfactory briquette, the flour being added dry to the char, then steamed and followed by the melted pitch; and 12 per cent sulphite liquor solids were required to produce an equally satisfactory briquette. Noticeable reductions in the dry basis calorific value of the finished briquette were effected by the use of the flour-pitch mixture and more so with the sulphite liquor, as compared to that using asphalt pitch alone. The respective difference was 600 and 1,600 B.T.U. per pound. As for the general burning qualities, in respect to smokiness, the briquettes are to be graded with those made from sulphite liquor, first; flour and pitch, second; and asphalt pitch, third; but the waterproof grading is the reverse of this order.

The carbonization and briquetting tests conducted at the Fuel Research Laboratories on Onakawana lignite during 1930 and 1931 are, however, to be considered of a preliminary nature, and while the results obtained are by no means directly interpretable into commercial practice, they do indicate that the lignite from northern Ontario is amenable to the combined carbonization and briquetting treatments similar to that found suitable for Souris lignite from Saskatchewan. However, due to the different nature of the Ontario lignite, mainly in respect to the production of fines in the drying and carbonization process, the carbonization treatment on a large scale may involve considerable difficulties, mechanical and otherwise, as may also the selection of a suitable commercial carbonizer. The overall cost of the carbonization and briquetting treatment for this lignite, which contains up to 50 per cent moisture as mined, as compared with 33 to 35 per cent in the Saskatchewan lignite, is an important factor in its commercial development. Approximately a ton of the char produced in the coke oven is on hand, on which large-scale briquetting tests are planned. These tests will be in the immediate charge of R. A. Strong, who, with his assistants in the carbonization and briquetting section of these laboratories, conducted the tests on the Ontario lignite reviewed above.

Pulverized Fuel and Special Boiler Tests. Comprehensive tests in the pulverized fuel fired boiler installation at the Fuel Research Laboratories were conducted on the same series of carlot shipments of British Columbia and Alberta coals used in the coking tests. These tests were under the supervision of E. S. Malloch with C. E. Baltzer in immediate charge, assisted by J. R. Kirkconnell and a staff of observers and operators.

Twenty-seven coals were tested in the experimental pulverized fuel boiler, including 12 from British Columbia, 11 from Alberta, and three different lots of Onakawana lignite from northern Ontario. On each of the British Columbia coals three test runs were made at low, medium, and high rates of coal feed. The boiler had been previously standardized at three rates of feed on what has been termed the "operating coal" which was a standard low ash bituminous coal and which had both a high ash fusion temperature and high calorific value. A considerable quantity of this coal, which was readily available in Ottawa, was used in operating the boiler during the preliminary trial runs and in between the tests on the British Columbia coals and Ontario lignite, the supply of which coals was not sufficient for both the preheat period and actual tests at the different rates. In addition to obtaining comparative data on the different Canadian coals tested, the results of the individual coals were compared with those from the standard operating coal, hence, in the advance preliminary reports supplied to the different coal operators concerned, the results of the individual tests were compared with those from the operating coal. In the summary of the tests on British Columbia coals by E. S. Malloch, in addition to showing the comparison with the operating coal, Michel coal has been chosen more or less as a standard, and the other coals compared with it as well as with one another.

All the coals tested, it will be noticed, were found satisfactory for use as pulverized fuel, and in discussing the results, the adaptability in relation to existing power plant installations, as well as the general merits of each coal, is stressed. In order that a basis of comparison of the results obtained may be made with other methods of burning, for example in boilers equipped with mechanical stokers, an appendix—"Notes on Pulverized Fuel Fired Steam Generators, versus Other Types"—by B. F. Haanel, has been added. Advance publication of this combined report including the "Summary of Tests on British Columbia Coals When Used as Pulverized Fuel" with the appendix, has been made as Mines Branch Memorandum Series No. 56. The detailed results of the tests on British Columbia coals and on Ontario lignite will be published at a later date in a separate Mines Branch bulletin, in which the results of tests on the 11 Alberta coals, which were not completed until the end of the fiscal year ending March 31st, 1932, will be included. In addition to the three different carlot samples of Onakawana lignite from northern Ontario, the following is a complete list of the British Columbia and Alberta coals on which pulverized fuel fired boiler tests have been made:

British Columbia Coals

Pleasant Valley
Tulameen
Coalmont
Middlesboro
Michel
Corbin—"birdseye" and "washed steam" sizes
Cassidy
Reserve
Wellington
Comox
Telkwa

Alberta Coals

McGillivray Creek
International (Denison)
Greenhill (two lots)
Hillcrest
Canmore
Brazeau
Luscar
Mountain Park (Michelean)
" " (Kennedy)
Cadomin
Saunders

Steaming Tests on Ontario lignite, and on a series of miscellaneous fuels including Welsh buckwheat, Dominion slack coal from Nova Scotia, coke breeze and peat, were made in a forced draught boiler, temporarily installed, and equipped with patented grates. The boiler was also equipped with a mechanical stoker of the sprinkler type, so arranged that its operation could be discontinued in order to permit hand firing when desired. This permitted a comparison to be made of the general burning qualities of the fuels tested when hand fired and when stoker fired. From the tabulated results and the comments thereon, it is to be noted that the patented grates used did perform satisfactorily in permitting sufficient air to pass to maintain uniform combustion without allowing an undue amount of combustible matter to fall through into the ash pit. This indeed is a result worth while, since it shows that the Onakawana lignite and other fuels with a high percentage of fines can be successfully burned on this type of grate. Success also marked the attempts to burn the lignite with nearly 50 per cent moisture content, but of course the overall efficiency of the boiler was comparatively low. In comparison with an average of 8·0 pounds for the standard bituminous operating coal, an equivalent evaporation figure of 3·5 pounds was obtained for the lower seam lignite when air-dried to 34 per cent moisture content, and as high as 4·2 pounds for the mechanically dried lignite with 24 per cent moisture. Averages of the equivalent evaporation per pound of fuel fired for the other fuels tested were: 2·7 pounds for peat with 45 per cent moisture; 4·7 pounds for gas coke breeze with 10 per cent moisture and 13·6 per cent ash; 5·5 pounds for dry by-product coke breeze with 10·7 per cent ash; 8·1 pounds for the Welsh buckwheat; and 7·8 pounds for the Nova Scotia bituminous slack coal.

Coal Classification and Analyses. The contents of the paper by E. J. Burrough, E. Swartzman, and R. A. Strong, given in detail below, were announced and reviewed in Mines Branch Memorandum Series No. 55 (March, 1932) and do not require further extensive review here. As shown by the respective titles, the special feature of the classification scheme proposed is the use of what has been termed the "Specific Volatile Index" and it is a classification of coals primarily for "use in the by-product coking industry". The authors, however, have presented it in the hope that it will serve also as a classification for general scientific purposes. The specific volatile index is in reality the heat value expressed in B.T.U., per one per cent volatile matter content of the coal as determined in the laboratory. This volatile matter contains both the uncondensable gas and the tar oils, so that the heat units per unit volatile matter content is an index of the richness of the gas to be expected commercially when the coal is distilled destructively as in the coking industry. The classes or sections into which the whole range of coals, peat, and wood are arranged according to areas delimited by their respective percentage volatile matter contents and S.V.I. values (that is, their specific volatile indices) are:

	Volatile Matter Range Unit Coal Basis			
Non-coking lower rank coals—				
Section A—woods	Above 60	per cent	S.V.I.	under 50
" B—peats	45 to 75	"	"	50 to 82
" C—brown lignites (lignitic)	40 to 70	"	"	82 to 99
" D—black lignites (ortho-lignitious)	36 to 55	"	"	99 to 125
" E—sub-bituminous (meta-lignitious)	35 to 50	"	"	125 to 160
Coking bituminous coals—				
Section F—bituminous (para-bituminous)	28 to 45	"	"	160 to 175
" G— " (ortho-bituminous)	21 to 35	"	"	175 to 190
" H— " (meta-bituminous)	21 to 28	"	"	190 to 210
" I—semi- (or super-) bituminous	14 to 24	"	"	210 to 230
Non-coking high rank coals—				
Section J—semi- (or sub-) anthracite	9 to 16	"	"	230 to 255
" K—anthracites	3 to 10	"	"	255 to 300

A classification such as this is valuable, in that from the location of a coal or coals plotted on the chart, it is permissible to judge general chemical characteristics in respect to coking properties and to predict within certain limits the yield and quality of the coke and other products. It also serves to compare, or rather to differentiate between, those bituminous coals that show by the laboratory test different volatile matter contents, yet when coked in a by-product oven yield approximately the same number of therms in the gas. In other words, the special value of this classification scheme employing proximate analysis and calorific value is to evaluate coals in respect to their amenability for use in coke ovens, and may serve equally well to indicate the general coking properties of coals with varying volatile matter contents, and their blending capabilities.

Analyses of Coals and Other Solid Fuels—compiled by J. H. H. Nicolls and C. B. Mohr, is the fourth and last paper in Part I, and is similar to that included in Investigations of Fuels and Fuel Testing for 1925 and since. However, instead of containing the analyses for a single year, as formerly, it contains the analyses of coals and other solid fuels examined in the Fuel Research Laboratories during 1930 and 1931. The results of analyses are tabulated under three group headings, viz.:

(1) Coal, peat, etc., occurring in Canada.

(2) Coal samples submitted by Department of Pensions and National Health, incident to their coal purchasing according to penalty and bonus specifications.

(3) Miscellaneous coals, cokes, briquettes, etc., including imported anthracites, semi-bituminous and bituminous coal, and also foreign sub-bituminous and lignite coals.

Field Work on Natural Gas, Naphtha, and Oil Shales. The two reports by P. V. Rosewarne, in collaboration with R. J. Offord and W. P. Campbell, respectively, pertain mainly to field work on natural gas and naphtha in the Turner Valley field in Alberta during 1930 and 1931. The fractionation results obtained on the Turner Valley natural gas by the use of the Podbielniak apparatus are similar to, and confirm, generally, the results previously reported—see Investigations of Fuels and Fuel Testing, 1929, page 109. The methane plus content, that is, the methane, oxygen, nitrogen and helium, continued to remain in the range of 87 to 92 per cent by volume of the gas, and in several cases went as high as 98 to 99·8 per cent. With the exception of these high methane gases, the average composition of the Turner Valley gas was 88·5 per cent methane, 6·0 per cent ethane, 3·3 per cent propane, 1·5 per cent butane, and 0·7 per cent pentanes and higher. The analyses of five samples from Ontario and one sample each from Quebec and New Brunswick are included in the report. As for helium content, it will be noticed that none of the samples of gas from Alberta showed higher than 0·380 per cent helium, the average of the lower content gases represented by fifty samples out of a total of sixty-three examined being 0·017 per cent only. The two samples from Quebec and New Brunswick were likewise low in helium content, and the five Ontario samples showed only 0·1 to 0·226 per cent helium.

The tests on Turner Valley crude naphtha reported below by Messrs. Rosewarne and Campbell, represent the culmination of an investigation of the effect of weathering, started in 1929 and continued during 1930 and 1931. This weathering treatment to remove certain of the more volatile constituents is necessary in order that it may be more safely and economically handled as treated or "stabilized" naphtha. Separators are used to separate the naphtha from the gas as it comes from the well, and the separated naphtha is also known as crude condensate. This crude condensate is the raw product to be stabilized and since its composition varies considerably at wells in different parts of the field, it is to be expected that the loss by weathering will also vary considerably. In the weathering process sufficient of the more volatile constituents are removed by boiling or fractionation, so that the residue will not have a vapour pressure of more than 10 pounds per square inch at 100° F. Generally speaking, the greater the proportion of the lower boiling point (more volatile) fractions in the condensate, and the lower the vapour pressure of the stabilized product, the greater will be the total reduction. In the 1931 field work a separator was specially equipped at a certain well to make the tests, in which separator measurements of naphtha before and after weathering down to the required vapour pressure were made directly. Analyses of samples of crude condensate and stabilized naphtha were also made, from the results of which it was found that the loss in the weathering operation could be calculated, and that the calculated result agreed closely with that determined by actual measurement. This indeed is most significant, in that from the results of analyses of crude condensate and stabilized naphtha from different parts of the field, it is possible to calculate with a fair degree of accuracy the loss due to weathering. The losses by weathering two lots of condensate, in which the results obtained by actual measurement were checked closely by calculation, were 12·0 and 12·4 respectively. Based on the analyses of a number of samples of crude condensate, however, the calculated results indicated that the weathering loss for naphthas in different parts of the field ranged as high as 35 per cent. The composition of the gas given off and lost in the weathering treatment will vary considerably according to the variations in the crude condensate and to variations in operating conditions. The content of pentanes and higher hydrocarbons, which are liquid at ordinary temperatures, in the gas lost by weathering, amounted to about 8 per cent where rectifying columns were used, to as high as 17·5 per cent where the weathering process was conducted in tanks. The corresponding butane content figures did not show such a wide variation, being slightly over 15 per cent in the stabilizer gas and 23 per cent in the gas from the tanks, and according to the average for several analyses a similar ratio existed for the propane content. By improvement in the efficiency of the stabilizing equipment, the loss of the pentanes could no doubt be materially cut down, but to what extent this could be economically accomplished the writers cannot say. On the assumption that all the hydrocarbons with boiling points of the pentanes and higher could be completely recovered, Mr. Rosewarne estimates that two to four per cent of the total production could be recovered. On the basis of a million barrels yearly production, this amounts to an increase in output of from twenty to forty thousand barrels per year. Similar recoveries of butanes and pentanes may be made, but their recovery has not been seriously considered since more elaborate equipment is required and a market must first be established for them in the form of compressed gas in cylinders before it would be commercially profitable.

Oil-shale Investigations. The results of oil-shale field work conducted in 1929 in Pictou county, Nova Scotia, and a new outcrop sampling program in the same year in Bonaventure county, Port Daniel district, Quebec, are given in detail below in the report by A. A. Swinnerton. As summarized on the first page of his report, three of the six beds examined in Pictou county, which vary in thickness from 4½ to 5 feet, showed average crude shale oil contents for the whole bed of over 20 Imperial gallons, and one of which averaged over 25, and another over 30. The results from the Port Daniel shales were negative, since only traces of oil were found and therefore, the shale of this district is to be classified as non-oil bearing. In Mr. Swinnerton's report the results of the examination of six drill core samples of oil shales from the New Glasgow area are given and short descriptions of the experimental plants of the Torbanite Products, Limited, and of the Canadian Torbanite and Oil Products, Limited, both near New Glasgow, are included.

Hydrogenation Experiments on Alberta Bitumen. The third and last papers of Part II comprise the results of hydrogenation experiments and of gasoline analyses surveys conducted during 1930 and 1931. The paper entitled "Experiments on the Hydrogenation of Alberta Bitumen," etc., by T. E. Warren, contains, it will be noticed, a preface in which is reviewed the salient results obtained and the history of previous pressure-cracking and hydrogenation experiments on Alberta bitumen. Yields ranging from 30 to 40 per cent by weight of gasoline by ordinary cracking processes, without the use of hydrogen, had been reported, but the results of further experiments indicated that yields of 65 to 75 per cent by weight, equal to 90 to 100 per cent by volume, are possible by continuous recycling hydrogenation treatment. The second section of Dr. Warren's paper reports the results of his experiments on the effect of pressure on the pyrolysis of methane. Contrary to what was hoped, it was proved that for natural gas consisting wholly of methane, high pressure is not serviceable for the production therefrom of motor fuel or other liquid products.

Gasoline Surveys. The makeup of the "Gasoline Surveys for 1930 and 1931" by H. McD. Chantler, is different from previous surveys, in that it contains the results for two years instead of one, and comprises the summarized results or averages for the different cities rather than the analyses of individual samples. The analytical data for each sample collected are given in survey reports published in the Mines Branch Memorandum Series. Beginning with the 1931 survey report, a radical change was made by omitting the trade names of the separate samples, thus making comparative quality the main feature of the survey, as reported, rather than affording comparisons or contrasts of the gasolines as marketed under the different trade names. The main conclusions of the combined 1930 and 1931 surveys were: (1) that while the variation in quality during 1930 was greater than in the four previous years, that for 1931 was less than in any previous year, thus indicating a tendency towards a uniform grade of gasoline; and (2) that during the last five years the number of artificially coloured gasolines had progressively increased. As indicated by distillation range and other criteria, the gasoline sold during the two years under review was uniformly good, and knock ratings of the samples collected in the city of Ottawa showed relatively high anti-knock values. This determination of the knock ratings in a standard knock testing engine and the reporting of the results in terms of Octane numbers is a new feature of the annual gasoline surveys, and for the 1932 survey will be extended to gasolines from all the cities. The hearty co-operation of the officials and inspectors of the Department of Pensions and National Health, in the collection of the samples, is again acknowledged.

DEPARTMENT OF MINES

MINES BRANCH—FUEL RESEARCH LABORATORIES, OTTAWA, CANADA

DETAILED DATA AND RESULTS OF HAND AND STOKER FIRED BOILER TRIALS MADE WITH VARIOUS FUELS ON A PATENTED GRATE

FUEL Name	Standard Operating Coal				Ontario Lignite											Domestic Peat		Gas Coke Breeze			Byproduct Coke Breeze			Welsh Buckwheat Mixed No. 162			Eastern Canada Bituminous Slack	
FUEL No.	9–31	9–31	9–31	9–31	10–31	10–31	10–31	10–31	1–31	1–31	1–31	1–31	11–30	14 & 15–30	14 &15–30	8–31	8–31	4–31	4–31	4 & 5–31	6–31	6–31	6–31	7–31	7–31	7–31	5–31	5–31
Method of Firing (Hand or Stoker)	Stoker	Stoker	Hand	Hand	Hand	Stoker	Stoker	Stoker	Stoker	Stoker	Hand	Hand	Stoker	Stoker	Hand	Stoker	Hand	Stoker	Hand	Stoker	S & H††	Stoker	Hand	S & H††	Stoker	Hand	Stoker	Hand
Preheated Air (Yes or No)	Yes	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	No	No	No	No	No	No
1. Trial number	PG 21	PG 19	PG 20	PG 18	PG 26	PG 27	PG 29	PG 28	PG 1	PG 2	PG 12	PG 15	PG 3	PG 5	PG 6	PG 7	PG 9	PG 4	PG 8	PG 22	PG 10	PG 23	PG 17	PG 11	PG 24	PG 16	PG 14	PG 25
2. Date conducted	19/6/31	17/6/31	18/6/31	16/6/31	4/8/31	5/8/31	7/8/31	6/8/31	6/5/31	7/5/31	3/6/31	10/6/31	8/5/31	15/5/31	26/5/31	27/5/31	29/5/31	14/5/31	28/5/31	23/6/31	1/6/31	7/7/31	15/6/31	2/6/31	8/7/31	11/6/31	5/6/31	9/7/31
3. Time of starting trial	8·31 A.M.	8·49 A.M.	8·46 A.M.	9·00 A.M.	8·47 A.M.	8·46 A.M.	8·51 A.M.	8·50 A.M.	9·03 A.M.	9·05 A.M.	8·38 A.M.	8·49 A.M.	8·59 A.M.	9·09 A.M.	9·11 A.M.	8·58 A.M.	9·08 A.M.	9·53 A.M.	9·44 A.M.	10·38A.M.	9·32 A.M.	9·15 A.M.	8·50 A.M.	8·49 A.M.	8·40 A.M.	8·40 A.M.	9·10 A.M.	8·41 A.M.
4. Time of stopping trial	6·13 P.M.	4·50 P.M.	4·46 P.M.	5·02 P.M.	4·47 P.M.	4·46 P.M.	4·51 P.M.	4·47 P.M.	4·56 P.M.	5·09 P.M.	4·36 P.M.	4·49 P.M.	4·57 P.M.	5·09 P.M.	5·11 P.M.	4·59 P.M.	5·05 P.M.	5·53 P.M.	5·45 P.M.	4·41 P.M.	5·30 P.M.	5·13 P.M.	4·50 P.M.	4·45 P.M.	4·40 P.M.	4·40 P.M.	5·08 P.M.	4·41 P.M.
5. Duration of trial in hours	9·70	8·02	8·00	8·03	8·00	8·00	8·00	7·95	7·88	8·07	7·97	8·00	7·97	8·00	8·00	8·02	7·95	8·00	8·02	6·05	7·97	7·97	8·00	7·93	8·00	8·00	7·97	8·00
Raw Fuel as Fired																												
6. Screen analysis (a) retained on ¾" sq. mesh sieve %	4·4	4·4	5·6	4·8	11·6	17·1	23·8	27·6	10·0	11·7	12·1	37·3	18·4	11·9	7·5	17·0	16·0	3·0	1·3	1·8	0·0	0·0	0·0	0·0	0·0	0·0	13·4	11·3
(b) Passing ¾" " ½" " %	10·8	11·0	13·2	12·4	17·0	17·5	13·3	14·6	12·5	16·4	9·4	6·0	11·4	14·6	9·7	27·9	25·9	3·4	1·8	1·8	0·0	0·4	0·0	0·0	0·6	0·4	23·7	21·9
(c) ½" " ¼" " %	23·5	24·2	25·8	26·2	27·2	24·1	19·3	19·8	26·2	30·8	25·7	13·7	22·7	29·3	29·8	29·0	27·3	38·6	18·5	13·2	4·3	4·1	5·5	45·0	37·2	38·9	40·8	45·6
(d) ¼" " ⅛" " %	19·9	20·1	19·0	18·6	16·3	14·4	13·3	13·0	16·3	24·0	18·9	11·0	12·7	19·5	21·0	11·2	11·9	29·4	16·3	17·4	15·6	17·1	18·8	42·5	44·5	45·0	15·9	15·6
(e) ⅛" sq. mesh sieve %	41·4	40·3	36·4	38·0	27·9	26·9	30·3	25·0	35·0	17·1	33·9	32·0	34·8	24·7	32·0	14·9	18·9	25·6	62·1	65·8	80·1	78·4	75·7	12·5	17·7	15·7	6·2	5·6
7. Proximate analysis (a) Moisture %	2·8	3·1	2·7	1·9	35·4	35·6	33·2	35·0	48·1	48·6	45·9	32·5	43·8	24·4	23·9	45·8	44·8	11·0	9·8	9·0	0·7	0·7	1·0	3·9	3·0	4·4	1·9	1·9
(b) Ash %	6·2	6·1	6·1	6·2	7·9	7·9	7·9	8·8	8·6	9·8	9·8	9·1	9·0	8·8	9·1	2·9	2·9	14·5	13·6	12·8	10·7	10·6	10·9	5·5	5·3	5·4	6·2	6·1
(c) Volatile matter %	32·8	33·1	33·2	33·7	27·8	27·7	28·8	26·8	20·5	19·3	20·2	27·3	23·4	33·1	32·5	34·0	34·4	2·2	2·9	6·1	1·6	1·6	1·2	7·6	6·9	8·4	34·5	33·5
(d) Fixed carbon (by difference) %	58·2	57·7	58·0	58·2	28·9	28·8	30·1	29·4	22·8	22·3	24·1	30·5	23·8	33·7	34·5	17·3	17·9	72·3	73·7	72·1	87·0	87·1	86·9	83·0	84·8	81·8	57·4	58·5
8. Ultimate Analysis (a) Carbon %	78·6	78·4	78·7	79·3	40·1	40·1	41·8	39·7	31·7	30·7	32·6	42·4	34·3	47·4	47·4	30·8	31·4	70·7	73·2	73·6	86·1	86·3	85·6	81·5	82·6	81·2	77·4	77·5
(b) Hydrogen %	5·7	5·7	5·7	5·6	6·7	6·7	6·5	6·6	7·4	7·3	7·2	6·3	7·1	5·6	5·6	8·1	8·1	2·1	2·0	2·3	0·9	0·9	0·9	3·9	3·8	3·9	5·5	5·5
(c) Ash %	6·2	6·1	6·1	6·2	7·9	7·9	7·9	8·8	8·6	9·8	9·8	9·7	9·7	8·8	9·1	2·9	2·9	14·5	13·6	12·8	10·7	10·6	10·9	5·5	5·3	5·4	6·2	6·1
(d) Sulphur %	0·8	0·9	0·9	0·9	0·9	0·8	0·8	1·0	0·7	0·5	0·5	0·9	1·1	0·9	1·1	0·1	0·1	0·9	1·1	1·3	0·9	0·8	0·9	0·9	0·9	0·9	2·9	3·0
(e) Nitrogen %	1·6	1·6	1·6	1·6	0·4	0·4	0·4	0·4	0·3	0·3	0·3	0·4	0·3	0·5	0·6	1·2	1·2	1·1	1·0	1·1	0·8	0·8	0·8	1·2	1·2	1·2	1·4	1·4
(f) Oxygen (by difference) %	7·1	7·3	7·0	6·4	44·0	44·1	42·6	43·5	51·3	51·4	49·6	40·3	48·2	36·8	36·2	56·9	56·3	10·8	9·1	8·9	0·6	0·6	0·9	7·0	6·2	7·4	6·6	6·5
9. Calorific value (a) As fired, gross value B.T.U./LB.	13,960	13,880	13,970	14,130	6,710	6,660	6,850	6,540	5,190	4,830	5,150	6,930	5,590	7,690	7,700	5,240	5,330	10,490	10,890	11,210	12,350	12,370	12,410	13,770	14,170	13,810	14,060	14,060
(b) As fired, net value B.T.U./LB.	13,419	13,339	13,429	13,598	6,074	6,024	6,233	5,913	4,487	4,137	4,466	6,332	4,916	7,158	7,168	4,471	4,561	10,291	10,700	10,992	11,495	12,285	12,325	13,400	13,809	13,440	13,538	13,538
(c) Dry, gross value B.T.U./LB.	14,362	14,324	14,358	14,404	10,387	10,342	10,254	10,062	10,000	9,397	9,519	10,267	9,947	10,172	10,118	9,668	9,656	11,787	12,073	12,319	12,437	12,457	12,535	14,329	14,608	14,446	14,332	14,332
(d) Combustible, gross value B.T.U./LB.	15,341	15,286	15,318	15,375	11,834	11,788	11,630	11,637	11,937	11,611	11,625	11,866	11,843	11,512	11,493	10,214	10,191	14,081	14,217	14,335	13,939	13,946	14,086	15,199	15,453	15,310	15,229	15,283
10. Fuel ratio, fixed carbon, volatile matter	1·80	1·75	1·75	1·70	1·05	1·05	1·05	1·10	1·10	1·15	1·20	1·10	1·00	1·00	1·05	0·51	0·52	....	....	....	....	....	....	10·9	12·25	9·80	1·65	1·75
11. Carbon-hydrogen ratio	13·9	13·8	13·9	14·1	6·0	6·0	6·4	6·0	4·3	4·2	4·5	6·7	4·9	8·4	8·4	3·8	3·9	....	....	....	....	....	....	21·2	21·8	20·9	14·1	14·2
12. Coking properties	Good	Good	Good	Good	Non-coking	Non-coking	Non-coking	Non-coking	Non-coking	Non-coking	Non-coking	Non-coking	Non-coking	Non-coking	Non-coking	Non-coking	Non-coking	....	....	....	....	....	....	Non-coking	Non-coking	Non-coking	Good	Good
13. Ash fusibility (a) Initial deformation temperature °F	2,485	2,395	2,440	2,415	2,030†	2,030†	2,030†	2,030†	2,035	2,030	2,025	2,110	2,050	2,115	2,045	2,340	2,380	2,180	2,140	2,050	2,130†	2,130†	2,190	2,275	2,275	2,210	1,970	1,970
(b) Softening point or fusion temperature °F	2,730	2,670	2,720	2,750	2,210†	2,210†	2,210†	2,210†	2,100	2,090	2,060	2,170	2,125	2,215	2,155	2,375	2,430	2,500	2,430	2,460	2,550†	2,550†	2,560	2,410	2,405	2,445	2,020	2,020
(c) Fluid temperature or melting point °F	2,775+	2800+	2,775+	2,800+	2,235†	2,235†	2,235†	2,235†	2,140	2,220	2,135	2,210	2,150	2,280	2,230	2,390	2,470	2,730	2,590	2,595	2,735†	2,735†	2,775+	2,715	2,715	2.770+	2,200	2,200
14. Apparent specific gravity	1·23†	1·23†	1·23†	1·23†	1·04†	1·04†	1·04†	1·04†	1·19†	1·19†	1·19†	1·19†	....	....	....	....	....	....	1·28†	....	1·28†	1·28†	1·28†	1·36†	1·36†	1·36†	1·26†	1·26†
15. Weight per cubic foot LB.	52·2†	52·2†	52·2†	52·2†	41·1†	41·1†	41·1†	41·1†	48·6†	48·6†	48·6†	48·6†	....	....	....	....	....	....	33·8†	....	44·1†	44·1†	44·1†	48·0†	48·0†	48·0†	44·4†	44·4†
16. Volume per ton of 2,000 pounds CU.FT	38·3†	38·3†	38·3†	38·3†	48·7†	48·7†	48·7†	48·7†	41·2†	41·2†	41·2†	41·2†	....	....	....	....	....	....	59·2†	....	45·3†	45·3†	45·3†	41·7†	41·7†	41·7†	45·0†	45·0†
17. Temperature same as average temperature of boiler room °F	101	92	92	90	95	102	95	110	85	80	92	87	81	76	86	93	101	75	98	84	87	93	88	89	97	97	88	97
18. Weight fired (a) Total for trial LB.	1,636	1,559	1,201	1,332	2,557	2,859	3,594	6,047	6,109	5,809	4,256	3,043	5,026	2,348	2,358	3,498	4,112	2,395	1,920	2,617	1,607	2,738	1,550	1,369	1,295	1,274	1,468	1,594
(b) Per hour LB.	169	194	150	166	320	357	449	761	775	720	534	380	631	294	295	436	517	299	239	433	202	344	194	173	162	159	184	199
(c) Per sq. ft. of live grate area per hour LB.	16·7	19·2	14·9	16·4	31·7	35·3	44·5	75·3	76·7	71·3	52·9	37·6	62·5	29·1	29·2	43·2	51·2	29·6	23·7	42·9	20·0	34·1	19·2	17·1	16·0	15·7	18·2	19·7
(d) Per 1,000 lbs. of equivalent evaporation LB.	122	124	124	129	282	272	270	353	457	427	407	318	376	238	261	367	389	202	203	232	172	216	166	123	129	121	120	138
19. Heat liberated per cu. ft. furnace volume per hour B.T.U.	23,831	27,199	21,167	23,693	21,689	24,016	31,067	50,272	40,629	35,127	27,779	26,600	35,629	22,837	22,944	23,077	27,834	31,682	26,290	49,030	25,199	42,983	24,319	24,063	23,187	22,180	26,132	28,262
22. Temperature (a) Air in ash pit °F	389	272	389	286	285	341	396+	345	180	253	370	337	288	360	286	366	380	244	353	157	323	148	212	357	316	363+	301	320
(b) Preheated air at fan blast gate °F	265	85	264	80	261	267	263	247	82	253	257	264	252	258	256	265	270	76	256	76	256	88	79	79	88	91	77	86
24. **Power Used by Auxiliaries (Fan and Stoker)**																												
(e) Total power used during trial KWH.	4·7	4·2	1·5	1·7	1·5	4·8	4·5	4·7	4·1	4·1	1·6	1·3	4·6	3·2	1·5	3·0	1·3	5·5	1·7	3·9	2·9	5·5	1·9	4·0	4·4	1·6	4·3	1·7
(f) Power used per hour KWH.	0·48	0·52	0·19	0·21	0·19	0·60	0·56	0·59	0·51	0·51	0·20	0·16	0·58	0·40	0·18	0·37	0·16	0·69	0·21	0·64	0·36	0·69	0·24	0·50	0·55	0·20	0·54	0·21
(g) Power used per ton of fuel fired KWH.	5·7	5·4	2·5	2·6	1·2	3·4	2·5	1·6	1·3	1·4	0·8	1·1	1·8	2·7	1·2	1·7	0·6	4·6	1·8	3·0	3·6	4·0	2·5	5·8	6·8	2·5	5·9	2·1
Refuse, Ash and Carbon*																												
25. Dry refuse from over fire (a) Total weight removed* LB.	70	48	47	0	43	73	50	147	151	241	192	109	20	27	50	0	0	71	248	32	96	151	73	10	34	7	27	13
(b) Ash content* %	68·1	81·9	78·8	0	99·3	93·7	99·3	87·5	99·0	98·3	93·2	96·4	97·7	87·0	84·3	0	0	72·5	59·0	55·8	63·1	62·9	90·0	73·5	75·6	73·2	80·6	33·3
(c) " * LB.	48	39	37	0	43	68	50	129	149	237	179	105	20	26	42	0	0	51	146	18	61	95	66	7	26	5	22	4
(d) Combustible content* %	31·9	18·1	21·2	0	0·9	6·3	0·7	12·5	1·0	1·7	6·8	3·6	2·3	3·0	15·7	0	0	27·5	41·0	44·2	36·9	37·1	10·0	26·5	24·4	26·8	19·4	66·7
(e) " * LB.	22	9	10	0	0	5	0	18	2	4	13	4	0	1	8	0	0	20	102	14	35	56	7	3	8	2	5	9
(f) Calorific value (estimated)* B.T.U./LB.	4,589	2,738	3,106	0	0	1,000	0	1,788	193	242	989	536	0	541	2,336	0	0	4,113	6,005	6,388	5,323	5,415	1,400	4,380	3,435	4,171	2,704	10,108
26. Dry refuse from under fire (a) Total weight removed* LB.	5	6	5	64	33	10	77	48	106	87	33	59	158	122	98	57	57	408	60	187	95	28	33	108	12	68	5	56
(b) Ash content* %	67·9	71·7	87·0	78·6	82·6	64·8	76·7	82·5	79·5	83·3	81·8	74·6	88·4	63·9	77·7	79·5	87·6	47·4	32·6	61·4	36·9	61·0	48·1	17·8	11·6	34·1	64·0	81·8
(c) " * LB.	3	4	4	50	27	6	59	40	84	72	27	44	140	78	76	45	50	193	20	115	35	17	16	19	1	23	3	46
(d) Combustible content* %	32·1	28·3	13·0	21·4	17·4	35·2	23·3	17·5	20·5	16·7	18·2	25·4	11·6	36·1	22·3	20·5	12·4	52·6	67·4	38·6	63·1	39·0	51·9	82·2	88·4	65·9	36·0	18·2
(e) " " * LB.	2	2	1	14	6	4	18	8	22	15	6	15	18	44	22	12	7	215	40	72	60	11	17	89	11	45	2	10
(f) Calorific value (estimated) * B.T.U./LB.	5,840	4,867	2,920	3,194	2,655	5,840	3,413	2,433	3,030	2,517	2,655	3,712	1,663	5,266	3,278	3,074	1,793	7,694	9,733	5,633	9,221	5,736	7,521	12,031	13,383	9.662	5,840	2,607
27. Dry refuse from smoke box (a) Total weight removed* LB.	46	43	5	16	21	54	65	133	164	116	61	24	96	16	34	9	8	121	233	283	232	459	203	47	7	19	9	6
(b) Ash content* %	17·4	17·3	34·2	25·0	74·8	65·7	46·1	35·9	44·2	51·2	60·0	57·7	50·0	49·5	40·7	80·7	67·4	18·8	15·5	11·8	14·1	13·5	15·2	9·8	31·0	19·7	29·8	48·2
(c) " * LB.	8	7	2	4	16	22	30	48	72	59	37	14	48	8	14	7	5	23	36	33	33	62	31	5	2	4	3	3
(d) Combustible content* %	82·6	82·7	65·8	75·0	25·2	34·3	53·9	64·1	55·8	48·8	40·0	42·3	50·0	50·5	59·3	19·3	32·6	81·2	84·5	88·2	85·9	86·5	84·8	90·2	69·0	80·3	70·2	51·8
(e) " * LB.	38	36	3	12	5	12	35	85	92	57	24	10	48	8	20	2	3	98	197	250	199	397	172	42	5	15	6	3
(f) Calorific value (estimated) B.T.U./LB.	12,061	12,223	8,760	10,950	3,476	5,153	7,862	9,331	8,190	7,174	5,744	6,083	7,300	7,300	8,588	3,244	5,475	11,825	12,344	12,898	12,523	12,628	12,370	13,047	10,429	11,526	9,733	7,300
28. Dry refuse from base of chimney (a) Total weight removed LB.	7	10	1	9	10	9	12	93	60	52	20	2	41	2	2	6	6	34	27	135	3	23	3	2	13	1	3	24
(b) Ash content* %	27·0	24·6	32·3	22·6	38·5	52·9	48·7	36·8	67·7	66·3	39·2	42·2	47·7	35·8	34·8	54·3	33·4	20·7	20·8	13·9	22·6	13·8	23·3	17·6	17·4	46·0	24·2	16·1
(c) " * LB.	2	2	0	2	4	5	6	34	41	34	8	1	20	1	1	3	2	7	6	19	1	3	1	0	2	0	1	4
(d) Combustible content* %	73·0	75·4	67·7	77·4	61·5	47·1	51·3	63·2	32·3	33·7	60·8	57·8	52·3	64·2	65·2	45·7	66·6	79·3	79·2	86·1	77·4	86·2	76·7	82·4	82·6	54·0	75·8	83·9
(e) " * LB.	5	8	1	7	6	4	6	59	19	18	12	1	21	1	1	3	4	27	21	116	2	20	2	2	11	1	2	20
(f) Calorific value B.T.U./LB. (estimated)*	10,429	11,680	14,600	11,356	8,760	6,489	7,300	9,262	4,623	5,054	8,760	7,300	7,478	7,300	7,300	7,300	9,733	11,594	11,356	12,545	9,733	12,696	9,733	14,600	12,354	14,600	9,733	12,167
29. Total weight of ash in fuel fired (calculated) LB.	101	95	73	83	202	226	284	532	525	569	417	277	452	207	215	101	119	347	261	335	172	290	169	75	69	69	91	97
30. Total ash accounted for* LB.	61	52	43	56	90	101	145	251	346	402	251	164	228	113	133	55	57	274	208	185	130	177	114	31	31	32	29	57
31. Total ash unaccounted for* LB.	40	43	30	27	112	125	139	281	179	167	166	113	224	94	82	46	62	73	53	150	42	113	55	44	38	37	62	40
32. Distribution of ash as a percentage of ash in fuel fired—																												
(a) From over fire* %	47·5	41·1	50·6	0·0	21·3	30·1	17·6	24·2	28·4	41·7	42·9	37·9	4·4	12·6	19·5	0	0	14·7	55·9	5·4	35·5	32·8	39·1	9·3	37·7	7·2	24·2	4·1
(b) From under fire* %	3·0	4·2	5·5	60·2	13·4	2·7	20·8	7·5	16·0	12·7	6·5	15·9	31·0	37·7	35·3	44·6	42·0	55·6	7·7	34·3	20·3	5·9	9·5	25·3	1·4	33·3	3·3	47·4
(c) From smoke box* %	7·9	7·4	2·7	4·8	7·9	9·7	10·6	9·0	13·7	10·4	8·9	5·1	10·6	3·9	6·5	6·9	4·2	6·6	13·8	9·9	19·2	21·4	18·3	6·7	2·9	5·8	3·3	3·1
(d) From base of chimney* %	2·0	2·1	0·0	2·4	2·0	2·2	2·1	6·4	7·8	6·0	1·9	0·4	4·4	0·5	0·5	3·0	1·7	2·0	2·3	5·7	0·6	1·0	0·6	0·0	2·9	0·0	1·1	4·1
(e) Unaccounted for* %	39·6	45·2	41·2	32·6	55·4	55·3	48·9	52·9	34·1	29·2	39·8	40·7	49·6	45·3	38·2	45·5	52·1	21·1	20·3	44·7	24·4	38·9	32·5	58·7	55·1	53·7	68·1	41·3
33. Total refuse accounted for* LB.	128	107	58	89	107	126	204	421	481	496	306	194	315	167	184	72	71	634	568	637	426	661	312	167	66	95	44	99

Inasmuch as difficulty was experienced in removing the true quantities of refuse chargeable to any test, as noted under items 25, 26, 27 and 28, it was practically impossible to obtain true samples and consequently true analyses of these quantities. Therefore values for items under the heading "Refuse Ash and Carbon", which are marked with *an asterisk* may be below or above the true value and should therefore be used with discretion as should also values for items marked with a *double asterisk*, which for absolute accuracy are dependent on a true value being obtained for "Unburned Carbon". Although not strictly correct this value was arrived at by neglecting unburned carbon in the unaccounted for refuse as this procedure was found to give the most consistent and comparable results.

FUEL No.	PG 21	PG 19	PG 20	PG 18	PG 26	PG 27	PG 29	PG 28	PG 1	PG 2	PG 12	PG 15	PG 3	PG 5	PG 6	PG 7	PG 9	PG 4	PG 8	PG 22	PG 10	PG 23	PG 17	PG 11	PG 24	PG 16	PG 14	PG 25
34. Combustible in unaccounted for refuse (assumed) %																												
35. " " " " LB.																												
36. Total refuse unaccounted for LB.																												
37. Calculated total refuse LB.																												
38. Total weight of carbon fired LB.	1,286	1,222	945	1,056	1,025	1,146	1,502	2,401	1,937	1,783	1,387	1,290	1,724	1,113	1,118	1,077	1,291	1,693	1,405	1,926	1,384	2,363	1,327	1,116	1,070	1,034	1,136	1,235
39. Calculated total unburned carbon* LB.	67	55	15	33	17	25	59	170	135	94	55	30	87	54	51	17	14	360	360	452	296	484	198	136	35	63	15	42
40. Total weight of carbon consumed** LB.	1,219	1,167	930	1,023	1,008	1,121	1,443	2,231	1,802	1,689	1,332	1,260	1,637	1,059	1,067	1,060	1,277	1,333	1,045	1,474	1,088	1,879	1,129	980	1,035	971	1,121	1,193
41. Carbon consumed per lb. of fuel fired** LB.	0·745	0·749	0·774	0·768	0·394	0·392	0·402	0·369	0·295	0·291	0·313	0·414	0·326	0·451	0·453	0·303	0·311	0·557	0·544	0·563	0·677	0·686	0·728	0·716	0·779	0·762	0·764	0·748
42. " " carbon fired** LB.	0·948	0·955	0·984	0·969	0·983	0·978	0·961	0·929	0·930	0·947	0·960	0·977	0·950	0·951	0·954	0·984	0·989	0·787	0·744	0·765	0·786	0·795	0·851	0·878	0·967	0·939	0·987	0·966
Feed Water and Steam																												
43. Average temperature of feed water in feed tank °F	120	119	118	126	128	126	123	127	127	123	125	128	123	123	127	125	126	123	124	123	125	125	118	126	125	126	127	129
44. Water fed to boiler (a) Total for trial LB.	11,980	11,200	8,610	9,270	8,150	9,420	11,870	16,230	11,980	12,100	9,350	8,590	11,870	8,800	8,100	8,520	9,470	10,530	8,430	10,090	8,370	11,300	8,280	9,980	8,970	9,445	10,980	10,410
(b) Per hour LB.	1,235	1,397	1,076	1,154	1,019	1,178	1,484	2,042	1,520	1,499	1,173	1,074	1,489	1,100	1,013	1,062	1,191	1,316	1,051	1,668	1,050	1,418	1,035	1,259	1,121	1,181	1,378	1,301
(c) Per pound of fuel as fired LB.	7·32	7·18	7·17	6·96	3·19	3·29	3·30	2·68	1·96	2·08	2·20	2·82	2·36	3·75	3·44	2·44	2·30	4·40	4·39	3·86	5·21	4·13	5·34	7·29	6·93	7·41	7·48	6·53
45. Barometric pressure (a) Average IN. HG	29·67	29·80	29·90	29·86	29·81	29·84	29·95	29·72	29·82	29·86	29·96	29·94	29·78	29·56	29·86	30·07	29·82	29·59	29·98	29·99	29·84	29·83	29·83	29·92	29·85	30·01	29·72	30·00
(b) LB./SQ. IN.	14·5	14·6	14·7	14·6	14·6	14·6	14·7	14·6	14·6	14·6	14·7	14·7	14·6	14·5	14·6	14·7	14·6	14·5	14·7	14·7	14·6	14·6	14·6	14·7	14·6	14·7	14·6	14·7
46. Boiler steam pressure (a) Average by gauge LB./SQ. IN.	100·0	102·4	101·4	103·2	100·7	101·1	101·3	99·8	93·4	98·0	101·4	102·4	96·8	98·9	95·3	98·7	101·0	97·5	98·6	94·7	98·1	101·3	103·7	100·0	101·9	104·8	97·4	101·3
(b) Absolute LB./SQ. IN.	114·5	117·0	116·0	117·8	115·3	115·7	116·0	114·4	108·0	112·6	116·1	117·1	111·4	113·4	109·9	113·4	115·6	112·0	113·3	109·4	112·7	115·9	118·3	114·7	116·5	119·5	112·0	116·0
47. Calorimeter steam pressure (a) Average by gauge IN. HG.	3·1	3·2	3·0	3·3	3·3	3·3	3·2	3·1	2·9	3·1	3·3	3·4	3·0	3·0	2·9	3·2	3·4	3·1	3·3	2·9	3·2	3·3	3·4	3·3	3·3	3·5	3·1	3·2
(b) Absolute LB./SQ. IN.	16·0	16·2	16·2	16·2	16·2	16·2	16·3	16·1	16·0	16·1	16·3	16·4	16·1	16·0	16·1	16·3	16·3	16·0	16·3	16·1	16·2	16·2	16·3	16·3	16·2	16·4	16·1	16·3
48. Calorimeter steam temperature average °F	271	273	272	270	267	270	273	277	278	278	275	269	278	275	273	273	274	278	275	270	275	274	273	275	270	271	271	271
49. Average temperature of steam in main steam line °F	330	332	332	332	331	331	332	330	326	330	331	332	329	329	327	329	331	328	329	327	329	331	333	330	332	333	329	332
50. Moisture content of steam %	1·3	1·2	1·3	1·4	1·5	1·3	1·2	0·9	0·8	0·9	1·1	1·4	0·8	1·0	1·1	1·1	1·1	0·8	1·1	1·2	1·0	1·1	1·2	1·1	1·4	1·4	1·2	1·3
51. Factor of correction for quality of steam	0·990	0·990	0·990	0·989	0·988	0·990	0·990	0·993	0·994	0·993	0·991	0·989	0·994	0·992	0·991	0·991	0·991	0·994	0·991	0·990	0·992	0·991	0·990	0·991	0·989	0·989	0·990	0·990
52. Water evaporated corrected for quality of steam—																												
(a) Total LB.	11,860	11,088	8,524	9,168	8,052	9,326	11,751	16,116	11,908	12,015	9,266	8,496	11,799	8,730	8,027	8,443	9,385	10,467	8,354	9,989	8,303	11,198	8,197	9,890	8,871	9,341	10,870	10,306
(b) Per hour LB.	1,223	1,383	1,066	1,142	1,007	1,166	1,469	2,027	1,511	1,489	1,163	1,062	1,480	1,091	1,003	1,053	1,181	1,308	1,042	1,651	1,042	1,503	1,025	1,247	1,109	1,168	1,364	1,288
(c) Per pound of fuel as fired LB.	7·25	7·11	7·10	6·88	3·15	3·26	3·27	2·67	1·95	2·07	2·18	2·79	2·35	3·72	3·40	2·41	2·28	4·37	4·35	3·82	5·17	4·09	5·29	7·22	6·85	7·33	7·40	6·47
53. Factor of evaporation	1·134	1·136	1·137	1·129	1·129	1·128	1·131	1·127	1·126	1·131	1·129	1·126	1·131	1·131	1·126	1·129	1·128	1·131	1·130	1·130	1·129	1·129	1·137	1·128	1·130	1·129	1·127	1·125
54. Equivalent evaporation (a) Total for trial LB.	13,449	12,596	9,692	10,351	9,067	10,520	13,290	18,163	13,408	13,589	10,461	9,566	13,345	9,874	9,041	9,532	10,586	11,838	9,440	11,288	9,374	12,643	9,320	11,156	10,024	10,546	12,250	11,594
(b) Per hour LB.	1,386	1,571	1,212	1,289	1,133	1,315	1,661	2,285	1,702	1,684	1,313	1,196	1,674	1,234	1,130	1,189	1,332	1,480	1,177	1,866	1,176	1,586	1,165	1,407	1,253	1,318	1,537	1,449
(c) Per sq. ft. heating surface per hour LB.	3·97	4·50	3·47	3·69	3·25	3·77	4·76	6·55	4·88	4·83	3·76	3·43	4·80	3·54	3·24	3·41	3·82	4·24	3·37	5·35	3·37	4·54	3·34	4·03	3·59	3·78	4·40	4·15
(d) Per lb. of fuel as fired LB.	8·22	8·08	8·07	7·77	3·55	3·68	3·70	3·00	2·19	2·34	2·46	3·14	2·66	4·21	3·83	2·72	2·57	4·94	4·92	4·31	5·83	4·62	6·01	8·15	7·74	8·28	8·34	7·27
(e) Per lb. of dry fuel fired LB.	8·46	8·34	8·29	7·92	5·49	5·71	5·54	4·62	4·23	4·55	4·54	4·66	4·72	5·56	5·04	5·03	4·66	5·55	5·45	4·74	5·87	4·65	6·07	8·48	7·98	8·66	8·51	7·41
(f) Per lb. of combustible fired LB.	9·03	8·90	8·85	8·46	6·25	6·51	6·28	5·35	5·07	5·62	5·55	5·38	5·63	6·30	5·72	5·31	4·92	6·64	6·42	5·52	6·58	5·21	6·82	9·00	8·44	9·18	9·08	7·91
(g) Per lb. of carbon consumed** LB.	11·03	10·79	10·42	10·12	9·00	9·38	9·21	8·14	7·44	80·5	7·85	7·59	8·15	9·32	8·47	8·99	8·29	8·88	9·03	7·66	8·62	6·73	8·26	11·38	9·69	10·86	10·93	9·72
Miscellaneous Temperature and Pressures																												
55. Average air temperature (a) Outside boiler room °F	87	75	73	72	80	84	73	88	77	69	68	69	70	61	66	73	83	68	80	66	64	81	69	69	85	73	66	79
(b) Boiler room near fan °F	101	92	92	90	95	102	95	110	85	80	92	87	81	76	86	93	101	75	98	84	87	93	88	89	97	90	88	97
56. Air humidity (a) Relative of boiler room at pulverizer %	52	41	54	45	37	40	36	36	39	60	45	67	63	34	35	33	47	44	35	44	32	53	61	31	53	63	61	40
(b) Water vapour per 1,000 cu. ft. of air LB.	1·53	0·93	1·23	0·96	0·92	1·21	0·89	1·36	0·72	0·95	1·02	1·31	1·03	0·48	0·67	0·77	1·38	0·59	0·95	0·79	0·63	1·24	1·23	1·64	1·40	1·35	1·23	1·05
(c) Water vapour per lb. of air LB.	0·02316	0·01366	0·01799	0·01399	0·01355	0·01841	0·01318	0·02135	0·01027	0·01336	0·01499	0·01892	0·01454	0·00620	0·00955	0·01135	0·02093	0·00826	0·01416	0·01123	0·00904	0·01824	0·01781	0·00934	0·02075	0·01959	0·01781	0·01566
58. Furnace temperature (a) Start of trial °F	2,130	2,040	1,810	2,290	1,730	1,610	1,660	1,500	1,610	1,720	1,720	1,860	1,570	1,790	1,820	1,860	1,840	1,890	1,970	1,850	1,750	1,610	1,780	1,730	1,790	1,790	2,120	2,080
(b) Midway " °F	2,030	2,080	2,020	2,080	1,740	1,660	1,880	1,780	1,630	1,650	1,790	1,830	1,680	1,810	1,760	1,790	1,910	1,820	2,040	1,960	1,970	1,730	1,870	1,730	1,830	1,890	2,020	2,150
(c) End " °F	2,190	2,130	2,060	1,990	1,760	1,720	1,840	1,730	1,660	1,670	1,740	1,770	1,810	1,760	1,800	1,800	1,910	1,740	1,870	2,040	2,010	2,180	2,010	2,070	2,050	1,940	1,830	2,110
60. Draught (a) Under fire IN W.G.	0·105	0·172	0·128	0·127	0·268	0·286	0·237	0·481	0·396	0·394	0·333	0·284	0·229	0·271	0·294	0·143	0·196	0·351	0·352	0·464	0·579	0·482	0·424	0·722	0·473	0·400	0·361	0·325
(b) Over fire IN W.G.	0·095	0·049	0·019	0·033	0·034	0·037	0·019	0·045	0·029	0·021	0·011	0·011	0·038	0·043	0·013	0·050	0·022	0·026	0·024	0·040	0·015	0·007	0·002	0·012	0·012	0·008	0·028	0·066
Air and Products of Combustion																												
61. Air supplied per lb. of fuel as fired** LB.	16·24	14·80	15·65	16·76	8·28	6·94	6·22	5·72	4·47	4·89	5·39	6·18	5·41	8·30	8·50	5·82	4·84	11·10	13·64	10·91	11·97	14·90	12·70	12·07	15·02	13·02	14·20	19·63
62. Air theoretically required per lb. of fuel as fired LB.	10·73	10·70	10·75	10·81	5·06	5·05	5·25	4·96	4·01	3·85	4·11	5·35	4·36	5·83	5·87	3·88	3·98	8·42	8·76	8·93	10·22	10·24	10·15	10·45	10·58	10·40	10·63	10·66
63. Ratio of air supplied to air theoretically required**	1·51	1·38	1·46	1·55	1·64	1·37	1·18	1·15	1·11	1·27	1·31	1·16	1·24	1·42	1·45	1·50	1·22	1·32	1·56	1·22	1·17	1·46	1·25	1·16	1·42	1·25	1·34	1·84
64. Excess air** %	51	38	46	55	64	37	18	15	11	27	31	16	24	42	45	50	22	32	56	22	17	46	25	16	42	25	34	84
65. Temperature of products of combustion at boiler outlet °F	649	695	649	682	671	656	695	829	709	670	627	687	694	606	665	650	654	628	630	739	587	720	591	592	604	629	643	730
66. Volumetric analysis of dry flue gases at boiler outlet—																												
(a) CO_2 %	11·2	12·4	12·1	11·2	11·5	13·6	15·3	14·8	15·8	14·3	14·1	16·1	14·5	13·2	13·0	12·7	15·6	12·2	9·7	12·5	13·7	11·1	13·8	14·5	12·6	14·3	13·2	9·3
(b) O_2 %	8·3	6·8	7·2	8·2	8·8	6·3	4·2	4·0	4·0	5·8	5·1	3·5	5·5	6·7	6·5	6·8	3·7	7·6	10·1	7·6	6·4	9·4	6·8	4·9	7·3	5·1	5·9	10·2
(c) CO %	0·0	0·0	0·0	0·0	0·0	0·1	0·4	0·9	0·2	0·1	0·1	0·2	0·1	0·0	0·0	0·0	0·1	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
(d) N_2 (By Difference) %	80·5	80·8	80·7	80·6	79·7	80·0	80·1	80·3	80·0	79·8	80·7	80·2	79·9	80·1	80·5	80·5	80·6	80·2	80·2	79·9	79·9	79·5	79·4	80·6	80·1	80·6	80·9	80·5
67. Steam (a) From moisture in coal per lb. of fuel as fired LB.	0·028	0·031	0·027	0·019	0·354	0·356	0·332	0·350	0·481	0·486	0·459	0·325	0·438	0·244	0·239	0·458	0·448	0·110	0·098	0·090	0·007	0·007	0·010	0·039	0·030	0·044	0·019	0·019
(b) " H_2 in dry " " " LB.	0·485	0·482	0·486	0·485	0·249	0·247	0·253	0·244	0·185	0·171	0·189	0·242	0·201	0·260	0·265	0·271	0·281	0·079	0·082	0·117	0·074	0·074	0·071	0·312	0·312	0·307	0·476	0·476
(c) " moisture in air " " ** LB.	0·376	0·202	0·282	0·234	0·112	0·128	0·082	0·122	0·46	0·065	0·081	0·117	0·079	0·051	0·081	0·066	0·101	0·092	0·193	0·123	0·108	0·272	0·226	0·113	0·312	0·255	0·253	0·307
68. Dry flue gases (a) Per lb. of carbon LB.	22·4	20·3	20·8	22·4	21·9	18·5	16·3	16·2	16·0	17·7	17·9	15·7	17·4	19·2	19·4	19·9	16·3	20·7	25·7	20·2	18·5	22·6	18·4	17·5	20·0	17·8	19·2	26·8
(b) Per lb. of fuel as fired** LB.	16·7	15·2	16·1	17·2	8·6	7·3	6·6	6·0	4·7	5·2	5·6	6·5	5·7	8·7	8·8	6·0	5·1	11·5	14·0	11·4	12·5	15·5	13·4	12·5	15·6	13·6	14·7	20·0
Capacities and Efficiencies																												
69. Rated boiler horse-power BL. HP.	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
70. Rated capacity per hour, equivalent evaporation LB.	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208
71. Equivalent evaporation per hour LB.	1,386	1,571	1,212	1,289	1,133	1,315	1,661	2,285	1,702	1,684	1,313	1,196	1,674	1,234	1,130	1,189	1,332	1,480	1,177	1,866	1,176	1,586	1,165	1,407	1,253	1,318	1,537	1,449
72. Boiler horse-power developed BL. HP.	40·2	45·5	35·1	37·4	32·8	38·1	48·1	66·2	49·3	48·8	38·1	34·7	48·5	35·8	32·8	34·5	38·6	42·9	34·1	54·1	34·1	46·0	33·8	40·8	36·3	38·2	44·6	42·0
73. Percentage of rated capacity developed %	115	130	100	107	94	109	137	189	141	139	109	99	139	102	94	99	110	123	97	155	97	131	97	117	104	109	127	120
74. Efficiency of boiler and furnace—																												
(a) Based on gross calorific value fuel as fired %	57·1	56·5	56·1	53·4	51·3	53·6	52·4	44·5	40·9	47·0	46·4	44·0	46·2	53·1	48·3	50·4	46·8	45·7	43·8	37·3	45·8	36·2	47·0	57·4	53·0	58·2	57·6	50·2
(b) Based on net calorific value fuel as fired %	59·4	58·8	58·3	55·4	56·7	59·3	57·6	49·2	47·4	54·9	53·5	48·1	52·5	57·1	51·9	59·0	54·7	46·6	44·6	38·0	49·2	36·5	47·3	59·0	54·4	59·8	59·8	52·1
Heat Balance in B. T. U. and Per Cent																												
75. Heat absorbed by the boiler B.T.U.	7,977	7,841	7,831	7,540	3,445	3,571	3,590	2,911	2,125	2,271	2,387	3,047	2,581	4,085	3,717	2,639	2,494	4,794	4,774	4,182	5,657	4,483	5,832	7,909	7,511	8,035	8,093	7,055
76. Loss due to steam formed—																												
(a) From moisture in fuel B.T.U.	36	41	35	25	461	459	436	477	640	640	590	429	582	315	313	593	578	143	126	121	9	9	13	50	38	57	25	25
(b) By burning H_2 in dry fuel B.T.U.	624	635	630	637	324	318	333	332	246	225	243	319	267	336	347	351	362	103	105	157	94	98	90	397	396	396	617	633
(c) From moisture entering with air** B.T.U.	97	57	74	65	30	33	23	41	13	18	20	33	23	13	22	17	26	24	48	38	25	80	53	27	74	65	66	91
77. Loss due to heat carried away in dry flue gases** B.T.U.	2,196	2,200	2,152	2,444	1,189	971	950	1,035	707	736	719	936	834	1,106	1,223	802	677	1,526	1,788	1,792	1,500	2,332	1,618	1,509	1,898	1,759	1,958	3,038
78. Loss due to unburned carbon monoxide** B.T.U.	0	0	0	0	0	29	104	215	37	21	22	52	23	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0
79. Loss due to carbon in refuse and flue dust** B.T.U.	598	515	182	362	97	128	240	410	323	236	189	144	253	336	316	71	50	2,195	2,738	2,522	2,689	2,581	1,865	1,450	395	722	149	385
80. Loss due to radiation errors and unaccounted for** B.T.U.	2,432	2,591	3,066	3,057	1,164	1,151	1,174	1,119	1,099	683	980	1,970	1,027	1,499	1,762	767	1,123	1,705	1,311	2,398	2,376	2,787	2,939	2,428	3,858	2,776	3,152	2,833
81. Total calorific value of 1 lb. of fuel as fired, gross value. B.T.U.	13,960	13,880	13,970	14,130	6,710	6,660	6,850	6,540	5,190	4,830	5,150	6,930	5,590	7,690	7,700	5,240	5,330	10,490	10,890	11,210	12,350	12,370	12,410	13,770	14,170	13,810	14,060	14,060
82. Heat absorbed by the boiler (thermal efficiency) %	57·1	56·5	56·1	53·4	51·3	53·6	52·4	44·5	40·9	47·0	46·4	44·0	46·2	53·1	48·3	50·4	46·8	45·7	43·8	37·3	45·8	36·2	47·0	57·4	53·0	58·2	57·6	50·2
83. Loss due to steam formed—																												
(a) From moisture in fuel %	0·3	0·3	0·3	0·2	6·9	6·9	6·4	7·3	12·4	13·3	11·4	6·2	10·4	4·1	4·1	11·3	10·8	1·4	1·2	1·1	0·1	0·1	0·1	0·4	0·3	0·4	0·2	0·2
(b) By burning H_2 in dry fuel %	4·5	4·6	4·5	4·5	4·8	4·8	4·9	5·1	4·7	4·7	4·7	4·6	4·8	4·4	4·5	6·7	6·8	1·0	1·0	1·4	0·7	0·8	0·7	2·9	2·8	2·9	4·4	4·5
(c) From moisture entering with air** %	0·7	0·4	0·5	0·5	0·4	0·5	0·3	0·6	0·3	0·4	0·4	0·5	0·4	0·2	0·3	0·3	0·5	0·2	0·4	0·3	0·2	0·6	0·4	0·2	0·5	0·5	0·5	0·7
84. Loss due to heat carried away in dry flue gases** %	15·7	15·8	15·4	17·3	17·7	14·6	13·9	15·8	13·6	15·2	14·0	13·5	14·9	14·4	15·9	15·3	12·7	14·5	16·4	16·0	12·2	18·9	13·1	11·0	13·4	12·7	13·9	21·6
85. Loss due to unburned carbon monoxide** %	0·0	0·0	0·0	0·0	0·0	0·4	1·5	3·3	0·7	0·4	0·4	0·7	0·4	0·0	0·0	0·0	0·4	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
86. Loss due to carbon in refuse and flue dust** %	4·3	3·7	1·3	2·5	1·4	1·9	3·5	6·3	6·2	4·9	3·7	2·1	4·5	4·3	4·0	1·4	0·9	20·9	25·1	22·5	21·8	20·9	15·0	10·5	2·8	5·2	1·0	2·7
87. Loss due to radiation, errors and unaccounted for** %	17·4	18·7	21·9	21·6	17·5	17·3	17·1	17·1	21·2	14·1	19·0	28·4	18·4	19·5	22·9	14·6	21·1	16·3	12·1	21·4	19·2	22·5	23·7	17·6	27·2	20·1	22·4	20·1
88. Percentage, equivalent to total calorific value of 1 lb. of fuel as fired, gross value	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0

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†Values for items 13, 14, 15 and 16, so marked (†) were obtained on the bulk sample of this particular fuel as it was received in storage and not on the sample taken from the actual quantity of fuel used for this particular trial.

††Trials No. P.G. 10 and 11 are designated as being both stoker and hand fired because the belt on Reeves variable speed drive failed 6½ and 7½ hours respectively after trials were started and as spare belt was not available these trials were finished by hand firing.

Part I: Solid Fuels

I

SUMMARY OF TESTS ON BRITISH COLUMBIA COALS WHEN USED AS PULVERIZED FUEL

E. S. Malloch

During 1930, 1931, and 1932, a series of tests was made in the Fuel Research Laboratories of the Department of Mines at Ottawa on twelve coals from British Columbia, with a view to obtaining data concerning these coals when burned in the pulverized state for the generation of steam and also with a view to correlating them one with another and with a so-called operating coal.

The investigation was made at the request of the British Columbia Government, the officials of which selected the coals to be tested. These were as follows: Pleasant Valley, Tulameen, Coalmont, Middlesboro, Wellington, Reserve, Comox, Cassidy, Telkwa, Michel, Corbin "Birdseye", and Corbin "Washed Steam". Three complete tests were made on each of the above coals, as well as three on the operating coal—one test at high rate, one at medium rate, and one at low rate of coal feed, approximating to 20, 40, and 60 per cent of the rated capacity of the pulverizer, in order to gather sufficient and reliable data necessary to the making of a fair comparison with each other and with the operating coal. This operating coal was selected as being a high grade of bituminous coal eminently suited for this method of burning in this type of equipment. The test boiler consists of a B. & W. marine type, water-tube boiler mounted over a solid refractory wall furnace having a hollow air-cooled floor. The pulverizer was an Aero size B, high-speed, paddle-type mill rated at 1,000 pounds per hour which prepares and mixes the fuel with the primary air and transmits the air-floated coal to the furnace.

Full reports of the tests have been prepared; these are very comprehensive and comprise 84 items of information regarding each test of each coal, as well as numerous notes and comments. These reports have been sent to the coal operators who supplied the coal samples. The detailed results of the tests will be published at a later date in a separate Mines Branch bulletin, in which will be included results on coals from Alberta and on Ontario lignite.

Table I, which follows, shows the more salient results of the tests on each fuel at the high rate of coal feed. It will be noted that at this rate of coal feed the pulverizer was operated at approximately 60 per cent of its rated capacity.

The first four items of the table refer to the fuel as it is delivered to the pulverizer and give an indication of its inherent qualities. The next three items show: first, the fineness to which the coal was ground in the pulverizer, second, the power required to attain that degree of fineness; these two items together may be taken as a measure of the so-called grindability of the fuel; and, third, the rate of grinding in per cent of rated capacity. The next two items following set forth the economic possibilities of the fuel when burned in this manner; the first of the two, viz. water evaporated per pound of fuel fired, is, perhaps, of more interest to the operating engineers, and the second, viz. fuel fired per 1,000 pounds of steam generated, to the power plant owner. The last two items in the table deal solely with the performance of the boiler and the rated boiler capacity developed.

The following is a brief résumé of results of the tests for each coal.

Michel Coal

This coal was the best coal tested in the series. It had the lowest moisture content, the lowest ash content, and the highest calorific value—(*see* items 7a, 7b, and 9a). Besides these merits it was the most economical fuel when burned under the B. & W. boiler at the Fuel Research Laboratories, Ottawa, for the high rate of coal feed. This is shown by items 54d, 18d, and 82. Although the percentage of fines passing through a 200-mesh sieve, after pulverizing, was greater for Michel coal than for any of the other fuels tested, with the exception of the Corbin coals, slightly more power was required, and no difficulty was experienced in maintaining a high rated load on the boiler. Item 73 shows that the average load carried was 222 per cent of its rated capacity. The one demerit of Michel coal as tested in this series was the low temperature at which the ash fused (*see* item 13b). This fault is offset, partly or wholly, by the low ash content of the coal, as is shown by the fact that no trouble was experienced from this characteristic during the tests.

Operating Coal

This coal was entirely satisfactory and might be listed in this series second to Michel. It has low moisture and ash contents, a high calorific value, and a very high ash fusion temperature. The grindability of this fuel was very low; a fairly large quantity passed through a 200-mesh sieve, and the power required was low. The evaporation per pound of coal was high, and the average load developed during the test was 223 per cent of the rated capacity of the boiler.

Cassidy Coal

Cassidy coal was distinctly of lower class than either of the two coals described above. It contained, as fired, nearly twice as much moisture, considerably more ash, and the calorific value was about 9½ per cent lower than that of Michel coal. Also, the ash fusion temperature was slightly lower than the average for the fuels tested in this series. The fineness of this coal after pulverization was very satisfactory, and the power required to pulverize it was lower than the average for these fuels. From an economic viewpoint, Cassidy was an excellent coal, and this is shown by items 54d and 18d, both of which are better than the average. A load of 209 per cent of the rated capacity of the boiler was carried without difficulty and it may be stated that the Cassidy coal, as tested, is a very satisfactory fuel to burn in the pulverized state for steam raising.

TABLE I

	Item Number	7a	7b	9a	13b	20f	24g	24i	54d	18d	73	82
Fuel Number	Name of Item	Moisture in fuel as fired, %	Ash in fuel as fired, %	Calorific value of fuel as fired B.T.U. (gross)	Fusion temperature of ash (° F.)	Pulverized fuel passed through 200 mesh, %	K.W.H. required to pulverize 1 ton fuel	Rate of grinding per cent of rated capacity	Water evaporated per lb. of fuel fired, lb.	Fuel fired per 1,000 lb. of steam generated, lb.	Per cent of rated boiler capacity developed	Thermal efficiency of boiler, %
5–29	Pleasant Valley	22·9	13·3	8,110	2093	41·9	32·7	59·8	5·34	187·3	137	63·9
4–29	Tulameen	19·7	9·5	9,360	2118	40·4	33·4	59·5	6·29	159·0	160	65·2
8–30	Coalmont	7·9	10·3	11,450	2239	53·0	33·3	59·6	7·60	131·6	194	64·4
6–29	Middlesboro	9·3	11·3	11,230	2588	54·3	32·3	59·5	7·48	133·7	191	64·6
10–30	Wellington	5·3	17·2	11,330	2145	67·9	34·2	59·7	7·51	133·2	192	64·3
9–30	Reserve	3·9	13·5	12,140	2223	61·6	31·7	59·9	7·96	125·6	204	63·6
19–30	Comox	3·9	14·6	12,250	2459	65·0	30·8	59·8	8·05	124·1	206	63·8
17–30	Cassidy	3·0	11·6	12,630	2307	67·1	31·5	59·5	8·21	121·8	209	63·1
13–30	Telkwa	3·2	12·8	12,820	2170	66·1	32·4	59·5	8·49	117·8	216	64·3
20–30	Michel	1·7	7·7	13,950	2032	78·6	31·6	54·8	9·46	105·7	222	65·8
3–31	Corbin Birdseye	4·9	16·9	11,680	2700	78·7	48·7	58·8	7·99	125·2	201	66·4
2–31	Corbin Washed Steam	3·9	12·7	12,540	2490	80·9	46·1	60·0	8·54	117·1	219	66·1
7–30	Operating Coal	1·8	8·3	13,700	2593	69·5	30·9	59·8	8·69	115·1	223	61·6

Telkwa Coal

This coal was very similar to Cassidy coal. It was a little higher in both moisture and ash, and on the other hand its calorific value was slightly higher, but the ash fusion temperature was lower by 130° F. The grindability was rather poor in comparison with Cassidy coal—one per cent less passed through a 200-mesh sieve, after pulverization, and the power required was higher. Items 54d and 18d in the table show the economic value of this fuel to be above the average for the series. No difficulty was experienced in carrying a load of 216 per cent of the rated boiler capacity. From the above it may be noted that this coal is an excellent fuel when prepared and burned in this manner.

Comox Coal

Comox coal, although low in moisture, was high in ash. However, this was offset by the high ash fusion temperature, and in consequence, the ash did not slag on the walls and bottom of the furnace. The calorific value was well above the average for the thirteen coals tested. This coal was easily ground, the power requirements were the lowest for the series, and the percentage passing through a 200-mesh sieve was just a little above the average. Its so-called economic value was very good in comparison with the other fuels (*see* items 54d and 18d). The average load carried by the boiler for this test was 206 per cent of its rated capacity and was easily maintained. Comox coal proved itself to be a good fuel for this method of steam raising, and was particularly economical as regards the power required for pulverization.

Middlesboro Coal

This coal was high in moisture; the ash content was moderate, being a little lower than the average for all the coals in this series of tests; and the calorific value was a little lower than the average. When burning this coal in the pulverized state no troubles should arise due to the ash fusing, as the ash fusion temperature was high, higher than for any of the other fuels, with the exception of the "operating coal" and Corbin Birdseye. Items 20f and 24g show that only 54·3 per cent of the pulverized coal would pass through a 200-mesh sieve, which is below the average, while 32·3 k.w. hours were required to pulverize one ton of coal—this figure is a little lower than the average for the fuels in the series when tested at the high rate of coal feed. The figure given in the table for pounds of steam per pound of fuel is low, while the thermal efficiency of the boiler when fired with this coal was good, being just a little higher than the average at this rate of coal feed. Although this coal was of a distinctly lower grade than the average, no difficulty was encountered in operating at 191 per cent of the rated boiler capacity.

Coalmont Coal

Coalmont coal had a slightly higher moisture content than the average. The ash content was quite low—2 per cent lower than the average—the calorific value was also low, and the ash fusion temperature was a little lower than the average for this series of coals. This coal did not pulverize easily: only 53 per cent of the coal, as fired, passed through a 200-mesh sieve, and the power required was a little lower than the average. The economic values—(items 54d and 18d)—for Coalmont were not quite up to the average for the series at high rate of coal feed. The load carried on the boiler was 194 per cent of the rated boiler capacity. After considering all the points noted above, Coalmont coal may be classed as a fairly satisfactory fuel to burn under a steam boiler in the pulverized state.

Reserve Coal

This coal was low in moisture and high in ash—3·8 and 13·5 per cent respectively. While the calorific value was quite high, the ash fusion temperature was slightly lower than the average value for the series of tests. This latter factor, coupled with the high ash content, caused a little trouble in the removal of the refuse from the bottom and walls of the furnace. On the other hand, the grindability was very good and more than an average amount of coal passed through a 200-mesh sieve after pulverization, and the power required was low. The pounds of steam per pound of fuel was fairly high, and the average load carried by the boiler was 204 per cent of its rated capacity. This coal proved itself to be an excellent fuel for this purpose, even when its comparatively high ash content is considered.

Wellington Coal

The moisture content of this fuel was nearly 2 per cent lower than the average for the coals in the series, but the ash content was very high and the calorific value, as well as the ash fusion temperature, was lower than the average. After pulverization, 67·9 per cent passed through a 200-mesh sieve, which is high for these fuels, but the power required was high—34·2 k.w.h. Item 54d, viz. (7·51 lb. of water per lb. of fuel) is a little below the average. Although the refuse was hard to remove at this rate of coal feed, no apparent difficulty was found in maintaining 192 per cent of the rated capacity of the boiler.

Tulameen Coal

Tulameen fuel, as supplied for these tests, was very high in moisture, 19·7 per cent and low in ash, 9·5 per cent; the average values for these two items were 7 per cent and 12·3 per cent respectively. The calorific value was very low, as was also the ash fusion temperature. The grindability was poor, only 40·4 per cent passed through a 200-mesh sieve, after pulverization, and the power required was 33·4 k.w.h. per ton. This coal, when fired under the boiler used for these tests, only evaporated 6·29 pounds of water per pound of fuel, which figure is much lower than the average for the series. Although the efficiency of the boiler was high, only 160 per cent of the rated capacity of the boiler developed. This coal is undoubtedly of low grade in comparison with the other fuels in the series. However, no difficulties were encountered in burning this fuel in the installation used, and on one especially designed for Tulameen coal it might prove to be an admirable fuel.

Pleasant Valley Coal

This fuel was of a markedly lower grade than the other coals tested in the series. The moisture content and the ash content were 22·9 per cent and 13·3 per cent respectively, the former being exceedingly high.

The calorific value was only 8,110 B.T.U. per pound, whereas the average for the series was 11,950 B.T.U. per pound. The ash fusion temperature was very low also, but, fortunately, this characteristic caused no trouble in the furnace. The grindability was poor, only 41·9 per cent passed through a 200-mesh sieve after pulverization, and the power required was 32·9 k.w. hours per ton of fuel ground. From an economic consideration, disregarding fuel costs, Pleasant Valley coal, as tested, was of a very low grade in comparison with the other fuels tested, as indicated by item 54d, which shows that only 5·34 pounds of water was evaporated per pound of fuel fired, whereas 9·46 pounds were evaporated per pound of the highest grade of coal tested in the series. Providing Pleasant Valley coal could be purchased at a low price it may in certain installations prove to be an economic fuel to use.

Corbin Birdseye Coal

This coal sample was one of two sent by the Corbin Collieries, Limited, and upon test proved to be a fairly good fuel when burned in the pulverized state. The moisture was lower and the ash content higher than the averages for this series of fuels. The ash fusion temperature was higher than for any other coal in the series and in consequence even with the high ash content no slagging of the ash was observed in the furnace. A higher degree of pulverization was obtained than any other of the fuels, with the exception of Corbin Washed Steam coal, but at a cost of the highest power consumption per ton of coal pulverized for the series. The economic features of this coal as shown by items 54d and 18d class it as being just a little above the average; while the thermal efficiency of the boiler when testing it was the highest of the series. After considering all the items in the table, Corbin Birdseye coal may be said to be a fairly good fuel to burn in the pulverized state in any equipment similar to that installed at the Fuel Research Laboratories at Ottawa.

Corbin Washed Steam Coal

This sample of coal from the Corbin Collieries was decidedly better than the other sample shipped at the same time, viz.: Corbin Birdseye. It was 1 per cent lower in moisture; 4·2 per cent lower in ash and its calorific value was higher. When compared with other coals of the series Corbin Washed Steam ranked as being the second best of the British Columbia coals and third best when the operating coal is included. It had a high ash fusion temperature, thus, even with a fairly high ash content, no trouble was experienced due to ash slagging in the furnace. The highest degree of pulverization was obtained with this coal but the power required was very great. Item 54d gives the water evaporated per pound of fuel fired and for this fuel is 8·54 pounds, a figure which is well above the average for this series of coals. No trouble was experienced in developing 219 per cent of the rated boiler capacity. The thermal efficiency of the boiler when burning this coal sample was 66·1 per cent, the highest efficiency for the series of British Columbia coals with the single exception of the other coal sample shipped from the Corbin Collieries, Ltd. From the tests made at the Fuel Research Laboratories on Corbin washed steam it may be said that it is a very good fuel when utilized in the pulverized state and in such equipment as is installed in those laboratories.

NOTES ON PULVERIZED FUEL FIRED STEAM GENERATORS VS. OTHER TYPES

B. F. Haanel

The results obtained in the tests on British Columbia Coals and summarized by E. S. Malloch under the title "Tests on British Columbia Coals When Used as Pulverized Fuel," are largely comparative and will enable the steam engineer to evaluate the different coals for burning in the pulverized state in a steam boiler. The factors determined do not afford a basis of comparison of this method of burning coal with other methods. For such a comparison, results of the burning of all the coals in a boiler or boilers equipped with mechanical stokers of different types would have been required.

In making such comparisons the fact that the cost of generating steam depends on size of boiler plant, heat-saving appliances, and other factors, in addition to quality and cost of coal used, must be kept in mind, and also that the ultimate consideration in the generation of steam is the cost of the steam which is sold for industrial, power, or heating purposes—consequently, the method selected for burning coal, and the coal itself, will be so chosen that the lowest cost of steam will result.

The Pulverized Fuel Fired Steam Generator has made spectacular progress in the last decade, especially in the field of very large central station plants, and also for marine purposes. The tendency to-day, when electrical energy is generated in a steam turbine electric generator plant, is to construct the steam generators and steam turbines on an almost gigantic scale in order that the fullest advantage of the economies made possible through the most efficient use of the fuel, reduction in heat losses, and reduced cost per unit of power installed, may be realized.

A single steam generator unit supplying an 80,000 k.w. steam turbine is not uncommon to-day, and it is possible to design and install even larger units. For units of this character the pulverized fuel fired generator appears to possess distinct advantages over other types. When high peak loads must be provided for, a steam generator which will rapidly respond to increased steam demand and operate without difficulty over long periods at high ratings, will naturally be given serious consideration when the design and installation of a steam power plant is contemplated, and a boiler installation which is capable of burning the largest possible quantity of coal per cubic foot of combustion space, or per square foot of grate area, will naturally be selected on account of the lower capital cost and smaller floor space required for generator and prime mover.

The marked success achieved by a pulverized fuel fired steam plant in the United States in 1920, proved to be the turning point for this type of plant. From 1920 to 1924 several plants were designed and erection begun, and in 1928 most of these new plants were placed in operation. But from that time to the present new installations have fallen off, principally on account of the marked improvements in mechanical stokers by manufacturers of this type of plant who were stimulated to action by the success of the pulverized fuel fired boiler, which resulted in a decrease in the sales of their product. As a consequence of the activity displayed by the manufacturers of mechanical stokers, manufacturers of boiler plants are in a position to offer either type. Mechanical stokers for the efficient burning of almost every rank and grade of coal are now available and many of the largest central station power plants are equipped with this type of stoker, and the efficiencies obtained are not inferior to those which can be obtained with the former method. It is not possible to refer to either of the two methods for burning coal under boilers as being superior; each has its special advantages and the choice of plant will depend on local conditions, class and cost of fuel available, its suitability for the particular purpose for which it must be used, and character of load. The attendance required to operate either of the plants is practically the same but the cost of pulverizing plant and the cost of operating and maintaining it in repair must not be disregarded, since this represents an item of capital expenditure, upkeep and cost of operation, which is not present in the mechanical stoker plant.

Insofar as the application of pulverized fuel firing to locomotive boilers is concerned, the progress made to date is not sufficient to warrant special consideration. It is doubtful whether this special application of pulverized fuel firing has passed the experimental stage, although reports are issued from time to time in the technical press which would lead one to believe that this method of burning a solid fuel in a locomotive boiler has been developed to a point commensurate with that achieved in marine steam plants.

The application of pulverized fuel firing to marine plants is not in a similar position. Ships equipped with this type of boiler plant are regularly making long voyages without mishap, and it appears that the reduced fuel costs, together with the higher speeds made possible, have justified the introduction of such installations in certain ships, but nevertheless, its application to marine service is as yet very limited.

Size of Steam Plants

According to opinions of prominent combustion engineers, the minimum size pulverized boiler unit which can be economically and efficiently operated is 1,000 h.p., although there are others who hold the opinion that smaller units can be operated to advantage. Pulverized fuel fired boiler installations, however, show to the greatest advantage when the individual units are of large capacity and the steam load demand is several times the normal boiler rating. This, of course, applies also to properly designed mechanical stoker plants equipped with a type of stoker suited for burning the fuel it is found most economical to use, but in the case of the mechanical stoker plant smaller boiler units can be economically operated than obtains in the case of the pulverized fuel fired plant.

Fuels

Al ranks and grades of coals can be efficiently burned in a modern pulverized fuel fired boiler plant, but the grade which can be most economically burned depends not only on the relative costs per one million B.T.U. of high- and low-grade coals, but also on the per cent of the boiler rating at which the plant is to be operated and on the rank and grade of coal the plant is designed to burn. For example, if a steam plant is designed to operate at 300 per cent rating when burning a high-grade coal, such a rating cannot be maintained if the grade of coal is seriously lowered by high ash content. In order to produce the desired quantity of steam in this case, certain of the dimensions of the boiler, pulverizer, and coal and ash handling plant would have to be increased. This also applies to a mechanically stokered plant. It is evident, therefore, that given a steam plant of a definite capacity, when operating at high ratings and burning a high-grade coal, a low-grade coal cannot be economically burned, even though its cost per unit of heat energy is considerably less than that of the high-grade coal, since additional boiler capacity would have to be installed to maintain the steam load.

Power Situation in Canada

Unlike Great Britain and the European continent, Canada is endowed with great waterpower resources, located in industrial and more thickly populated areas, and during the past two decades many of these have been developed on an extensive scale. Industrial centres are, consequently, served with hydro-electric energy instead of steam-generated electrical energy, as obtains in Great Britain, parts of Europe, and to a very large extent in the United States, even though that country is possessed of very large waterpower resources. Since these hydro-electric developments are capable of supplying most of the requirements for power, Canada does not possess super-steam electric central stations. The largest industrial user of steam in Canada is the pulp and paper industry, and it is in this field that the pulverized fuel fired steam boiler has found its widest application.

II

RESULTS OF TWENTY-EIGHT HAND AND STOKER FIRED BOILER TRIALS MADE WITH VARIOUS FUELS ON A PATENTED GRATE

E. S. Malloch and C. E. Baltzer

The object of this investigation was to determine the efficacy of a patented grate and a mechanical stoker of the sprinkler type when burning several different fuels, and also to secure information regarding the economic value of these fuels for steam raising in comparison with a good grade of bituminous steam coal. The fuels tested were as follows: A bituminous-steam coal designated as "standard operating coal"; Ontario lignite; domestic peat; gas coke breeze; by-product coke breeze; Welsh buckwheat; and an Eastern Canada bituminous slack coal. All of these fuels with the exception of the lignite and peat may be readily obtained in the Ontario market. The tests were made in co-operation with a Canadian engineering equipment company. The Onakawana lignite used in the tests was supplied by the Ontario Department of Mines.

The appended table which is the basis of this report gives the detailed "Data and Results" of the tests. It will be noted that 28 trials were made, in all, on 7 different fuels. Several tests were made on each fuel, more or less approximating the same boiler rating, but with varying conditions of firing in respect to hand or stoker operation with and without preheated air, details of which will be found at the head of the main table appended. In making a comparison for any one test on any one fuel with the "standard operating coal" the reader is requested to make the comparison between the two tests with similar operating characteristics; that is, if for instance a test on lignite, stoker fired with preheated air is under consideration it should logically be compared with the test on the standard operating coal fired under similar conditions.

Certain data, respecting the fuels themselves, appearing in the main table with this sign—†—appended, were not obtained on the actual quantity of fuel used for each individual trial but were obtained on the bulk sample of that fuel as it was received in storage to be used for all the tests on that particular fuel.

COALS TESTED

The following gives detailed data on each of the 7 coals tested and the tests run on each:

1. *(a)* Fuel name: "Standard operating coal".
   (b) Shipment or receiving No.: 9-31.
   (c) Date shipped: May 23, 1931. Date received in storage:—June 3, 1931.
   (d) Procured from or supplied by: Mines Branch Fuel Research Laboratories.
   (e) Preparation at the mine: 4-inch mechanically cleaned run-of-mine.

(f) Approximate size as received: (square mesh screens)—

on 2 inch	4·5 per cent
on 1½ “	12·0 “
on 1 “	7·6 “
on ¾ “	10·0 “
on ½ “	8·5 “
on ¼ “	14·8 “
on ⅛ “	16·0 “
through ⅛ inch	26·6 “

(g) Number of tests made: 4, viz.: PG-21, stoker fired with preheated air; PG-19 stoker fired without preheated air; PG-20 hand fired with preheated air; and PG-18 hand fired without preheated air.

2. Lignite—4 shipments designated respectively as A, B, C, and D.

A. *(a)* Fuel name: Lignite.—Lower seam—Shaft W.

(b) Shipment or receiving No.: 10-31 viz.: fourth and last shipment July, 1931.

(c) Date shipped: July 22, 1931. Date received in storage:—July 29, 1931.

(d) Procured from or supplied by: Ontario Department of Mines.

(e) Preparation: Run-of-mine lignite shipped directly from the development. Noticeably dry and dusty as it had been stored in the open during dry hot weather for a considerable period before shipment and tended to heat in storage.

(f) Approximate size as received: (square mesh screens)—

on 3 inch	20·2 per cent
on 2 “	8·8 “
on 1½ “	8·0 “
on 1 “	7·4 “
on ¾ “	7·4 “
on ½ “	5·9 “
on ¼ “	12·5 “
on ⅛ “	9·4 “
through ⅛ inch	20·4 “

(g) Number of tests made: 4, viz.: PG-26 hand fired with preheated air; PG-27 stoker fired with preheated air; PG-29 stoker fired with preheated air; and PG-28 stoker fired with preheated air. These tests are arranged in the order of increasing capacity.

B. *(a)* Fuel name: Lignite.—Upper seam—Shaft W.

(b) Shipment or receiving No.: 1-31 viz.: third shipment of April 1931.

(c) Date shipped: April 1, 1931. Date received in storage:—April 11, 1931.

(d) Procured from or supplied by: Ontario Department of Mines.

(e) Preparation: Run-of-mine lignite shipped directly from the development. Noticeably very wet as received in a frozen condition.

(f) Approximate size as received—(square mesh screens)—

on 1 inch	23·2 per cent
on ½ "	20·7 "
on ¼ "	17·4 "
on ⅛ "	12·3 "
through ⅛ inch	26·4 "

(g) Number of tests made: 4, viz.: PG-1 stoker fired without preheated air; PG-2 stoker fired with preheated air; PG-12 hand fired with preheated air; and PG-15 hand fired with preheated air. The first 3 tests were made on the fuel as it was drawn from storage while the last test was made on fuel which had been air-dried under covered storage for 5 weeks.

C. *(a)* Fuel name: Lignite.—Shaft No. 1.

(b) Shipment or receiving No.: 11-30 viz.: first shipment of March 1930.

(c) Date shipped: March 1, 1930. Date received in storage: March 8, 1930.

(d) Procured from or supplied by: Ontario Department of Mines.

(e) Preparation: Run-of-mine lignite shipped directly from the development. Noticeably wet as received in a semi-frozen condition.

(f) Approximate size as received: 60 per cent lumps up to 12-inch diameter; 40 per cent slack.

(g) No. of tests made: one, viz.: PG-3 stoker fired with preheated air. This test was made on fuel which had been in covered storage for 14 months.

D. *(a)* Fuel name: Mechanically dried lignite.

(b) Shipment or receiving No.: 14 and 15-30, viz.: second shipment of April, 1930.

(c) Date shipped: April 25, 1930. Date received in storage:—April 30, 1930.

(d) Procured from or supplied by: Ontario Department of Mines.

(e) Preparation: A carload of wet run-of-mine lignite was shipped directly from the development as mined to an experimental coal dryer plant located in eastern Ontario where the fuel was mechanically dried in a "Harmour dryer" in two lots, viz.: lot No. 14-30 passed through the dryer once and lot No. 15-30 passed through the dryer twice. The dried fuel was then shipped to the Fuel Research Laboratories and on receipt was noticeably very dry and dusty, and tended to heat in storage. The once dried lignite, viz.: No. 14-30 contained 33·7 per cent moisture as received and the twice dried lignite, viz.: No. 15-30 contained 25·9 per cent moisture.

(*f*) Approximate size as received: 50 per cent lumps up to 6-inch diameter; 50 per cent slack.

(*g*) Number of tests made: 2, viz: PG-5 stoker fired with preheated air; and PG-6 hand fired with preheated air. Both tests were made on a mixture of equal parts of the once and twice dried lignites.

3. (*a*) Fuel name: Air-dried machine peat.

(*b*) Shipment or receiving No.: 8-31.

(*c*) Date shipped: Date received in storage: December, 1929.

(*d*) Procured from or supplied by: Department of Mines—Alfred peat plant.

(*e*) Approximate size as received: mostly fairly uniformly sized, in brick form, with some breakage.

(*f*) Number of tests made: 2, viz: PG-7 stoker fired with preheated air; and PG-9 hand fired with preheated air. These tests were made on fuel which had been in open exposed storage for about 17 months and consequently had disintegrated to small sized lumps.

4. (*a*) Fuel name: Gas coke breeze.

(*b*) Shipment or receiving No.: 4-31.

(*c*) Date shipped: Date received in storage: May 11, 1931.

(*d*) Procured from or supplied by: The Ottawa Gas Company, Ottawa, Ontario.

(*e*) Rank or trade name of fuel: Gas coke breeze.

(*f*) Preparation: wet as supplied from a large exposed storage pile. Refuse product under ½-inch screen size resulting from coke manufacture for the domestic market.

(*g*) Approximate size as received: (square mesh screens)—

on 1 inch	0·4 per cent
on ¾ "	0·9 "
on ½ "	1·8 "
on ¼ "	18·5 "
on ⅛ "	16·3 "
through ⅛ inch	62·1 "

(*h*) Number of tests made: 3, viz.: PG-4 stoker fired without preheated air; PG-8 hand fired with preheated air; and PG-22 stoker fired without preheated air. The first of these tests was made on screened fuel, i.e. fuel which remained on a ⅛-inch screen. Due, however, to the wet condition of the fuel the screening was only about 50 per cent effective. The second test was made on fuel as received and the third test was made on a mixture of 90 per cent of this fuel as received and 10 per cent of Eastern Canada bituminous slack coal.

5. (*a*) Fuel name: By-product coke breeze.

(*b*) Shipment or receiving No.: 6-31.

(*c*) Date shipped: May 13, 1931. Date received in storage: May 16, 1931.

(*d*) Procured from or supplied by: Montreal Coke & Manufacturing Company, Montreal, Quebec.

(e) Rank or trade name of fuel: "La Salle" by-product coke breeze.

(f) Preparation: dry and dusty—refuse product under ¼-inch screen size resulting from coke manufacture for the domestic market.

(g) Approximate size as received: (square mesh screens)—

on ½ inch	0·4 per cent
on ¼ "	4·1 "
on ⅛ "	17·1 "
through ⅛ inch	78·4 "

(h) Number of tests made: 3, viz.: PG-10, 6½ hours stoker and 1½ hours hand fired with preheated air; PG-23 stoker fired without preheated air; and PG-17 hand fired without preheated air. The first test was started as a stoker fired trial but was finished by hand firing because the belt on Reeves variable speed drive failed after 6½ hours of test.

6. *(a)* Fuel name: Welsh buckwheat mixed Nos. 1 and 2.

(b) Shipment or receiving No.: 7-31.

(c) Date shipped: Date received in storage: May 21, 1931

(d) Procured or supplied by: an Ottawa fuel dealer.

(e) Rank or trade name of fuel: Welsh anthracite buckwheat.

(f) Preparation: Rescreened screenings obtained from preparation of larger sizes of Welsh anthracite for the domestic market.

(g) Approximate size as received: (square mesh screens)—

on ½ inch	0·4 per cent
on ¼ "	38·9 "
on ⅛ "	45·0 "
through ⅛ inch	15·7 "

(h) Number of tests made: 3, viz.: PG-11, 7½ hours stoker and ½ hour hand fired without preheated air; PG-24 stoker fired without preheated air; and PG-16 hand fired without preheated air. The first test was started as a stoker fired trial but was finished by hand firing because the belt on Reeves variable speed drive failed after 7½ hours of test.

7. *(a)* Fuel name: Eastern Canada bituminous slack coal.

(b) Shipment or receiving No.: 5-31.

(c) Date shipped: Date received in storage: May 14, 1931.

(d) Rank or trade name of fuel: Bituminous steam coal.

(e) Preparation: screened slack.

(f) Approximate size as received: (square mesh screens)—

on 1 inch	0·6 per cent
on ¾ "	10·7 "
on ½ "	21·9 "
on ¼ "	45·6 "
on ⅛ "	15·6 "
through ⅛ inch	5·6 "

(g) Number of tests made: 2, viz.: PG-14 stoker fired without preheated air; PG-25 hand fired without preheated air.

The special equipment required for this investigation was installed by the co-operating engineering equipment company previously mentioned whose representative also witnessed the tests. A detailed description of the equipment used for these tests follows:—

The installation in which these tests were made consisted of a small stationary boiler of the horizontal locomotive type rated at 35 boiler h.p. and mounted over a brick combustion chamber containing 10 sq. ft. of a patented grate and 3 sq. ft. of dead plate. A special furnace front containing fire- and ash-pit clean out doors on which was mounted an electrically driven mechanical coal feeder—(sprinkler type stoker)—permitted either hand or stoker firing of the fuel. Under grate air—(forced draught)—was supplied to the ash-pit of the furnace by the conventional type of electrically driven blower supplied with this type of grate. A steam heated unit heater was mounted on the blower inlet so that either cool—(room temperature)—or preheated air could be used as desired. Sufficient over-fire air for ordinary operation was obtained by leakage through the furnace front but when more was required it was supplied by means of an air duct leading from the ash-pit of the furnace to a 4-inch perforated pipe lying across the back wall of the combustion chamber in such a way as to spray air down on and over the fire. The main damper was automatically manipulated by means of a patented damper regulator which was controlled by the over-fire draught. Steam jets from a small perforated pipe, lying across the top of the fire-door opening more or less successfully kept the fine fuel which fell from the mechanical coal feeder, off the dead plate. General information and dimensional data regarding the equipment are as follows:

1. Boiler:
    - *(a)* type—horizontal, through tube, locomotive type.
    - *(b)* manufacturer's rating—35 boiler horse-power.
    - *(c)* water heating surface on tubes—(50-3″ tubes 7′ 6½″ long)—275 sq. ft.
    - *(d)* total water heating surface—349 sq. ft.
    - *(e)* minimum draught area—(50 tubes-3″ dia.)—297 sq. in.

2. Furnace:
    - *(a)* kind—combination built-up brick and internally fired type.
    - *(b)* volume between grate and heating surface (crown sheet)—99 cu. ft.
    - *(c)* volume per sq. ft. of heating surface—0·284 cu. ft.
    - *(d)* volume per rated boiler horse-power—2·83 sq. ft.

3. Grates:
    - *(a)* type—patented—hand dumping.
    - *(b)* size—(live grate surface)—width 31″, length 47″, area 10·1 sq. ft.
    - *(c)* size—(total grate exclusive of dead plate)—width 36″, length 48″, area 12·0 sq. ft.
    - *(d)* size—(dead plate)—average width 30″, length 14″, area 2·9 sq. ft.

(e) percentage of area of air opening to live grate surface—30 per cent.
(f) ratio total heating surface to live grate surface—34·5 to 1.
(g) ratio minimum draught area to live grate surface—29·4 to 1.
(h) vertical distance centre of grate to nearest heating surface—(crown sheet) 7 ft. 11 in.

4. Stoker:
   (a) make, size and type—patented—20-inch—mechanical coal feeder —(sprinkler type stoker).
   (b) drive—electrically driven by ½ h.p. motor, addition speed control by Reeves drive.
5. Air Preheater:
   (a) type—steam heated unit heater.
   (b) location—on inlet to forced draught fan.
6. Draught:
   (a) fan—No. 2 blower capacity 1,660 c.f.m. 1½″ S.P. electrically driven by ¾ h.p. motor.
   (b) damper regulator—patented controlling over-fire draught.
   (c) breeching and chimney—24″ diameter steel plate breeching connected to a 28 x 28 inch brick chimney 35 feet high.

Plate I gives a general view of the experimental installation as used for these tests. The instrument and control panel will be noted at the extreme left of the photograph. The water weighing tanks, forced draught, air preheater, draught regulator and flue gas sampling and Orsat analysing equipment are in the rear—(not showing).

TEST CONDITIONS AND METHODS OF MEASUREMENT

(a) Condition of boiler plant unit at time of trial—in good order for all 28 trials except for minor trouble during two tests, viz.: PG-10 and 11 when belt on Reeves variable speed drive failed towards end of these tests necessitating their completion by hand firing.
(b) Trials made at an average output of 1,259 lb. of water evaporated per hour, 1,419 lb. of equivalent evaporation per hour, or 118 per cent of normal rating.
(c) Nature of load—steady exhausting direct to atmosphere.
(d) Average rate of coal feed—348 lb. per hour.
(e) Average boiler pressure—99·8 lb. gauge.
(f) Method of measuring feed water and coal consumption—by weighing on standard platform scales.
(g) Method of sampling and analysing fuel and refuse—Standard Fuel Research Laboratory Methods.
(h) Method of sampling and analysing flue gases—Standard Fuel Research Laboratory Methods.
(i) Method of measuring temperatures—thermometers and pyrometers, calibrations checked.
(j) Method of measuring draught and pressures—inclined water gauges.
(k) Method of measuring steam and power taken by auxiliaries—the electric power taken by draught fan and stoker was measured by means of an integrating kilowatt hour meter.

It should be particularly noted that the installation used for these tests was of a temporary nature only, therefore, no effort was made to insulate the boiler and furnace, in consequence the radiation losses were much higher than they otherwise would be. This, however, should not detract from the value of these trials as all tests were made in the same installation in identically the same way so that the results should be relative for the various fuels used.

The tests were conducted under the direct supervision of C. E. Baltzer who, in addition, with the assistance of J. R. Kirkconnell and a staff of three observers made the calculations and compiled the data and results for this report.

A few of the important items, from the appended table, representative of the more salient results for seven of the stoker fired tests, one on each of the seven fuels tested, are summarized in Table I. It will be noted that these tests were all made without the use of preheated air, with the exception of those on domestic peat and lignite.

From Table I it may be noted that although the water evaporated per pound of fuel fired (item 54d) was low for the lignite and peat, the overall efficiencies (item 82) were not unduly so when the moisture content (item 7a) of these fuels is considered in comparison with the "standard operating coal". In contrast to the above the values for item 54d for both gas and by-product breeze were higher than for both the lignite and peat, but still considerably lower than for the operating coal, whereas, the overall efficiencies (item 82) for the coke breeze were the lowest of any of the fuels tested. The low efficiency values for both gas and by-product breeze are accounted for by the high "carbon loss" (item 86, also see items 25 to 28 inclusive) associated with these two fuels because of their fineness—(see screen analysis items 6a to 6e inclusive, appended table). The relative efficacy of the patented grate may be judged from items 25 and 26 (a) and (d). The values for these items definitely indicate that the grates were well suited for efficiently burning all seven of the fuels tested and were especially efficient on operating coal, peat, Welsh buckwheat, and Eastern Canada bituminous slack and to a lesser degree on the finer gas and by-product breeze and lignite. In explanation of the lower grate efficiency with gas and by-product breeze it may be said that for any fuel high in ash (item 7b) the ash-pit loss (items 26 (a) and (d)) is, generally speaking, higher than for lower ash fuels and more especially so because of the many fines, especially in the breeze fuels.

Welsh buckwheat was the highest rank of fuel tested—low in moisture (item 7a)—low in ash (item 7b) and high in calorific value (item 9a). It was an anthracite and, when burned under a boiler in a setting designed to utilize a flaming fuel, very high thermal efficiencies could not be obtained.

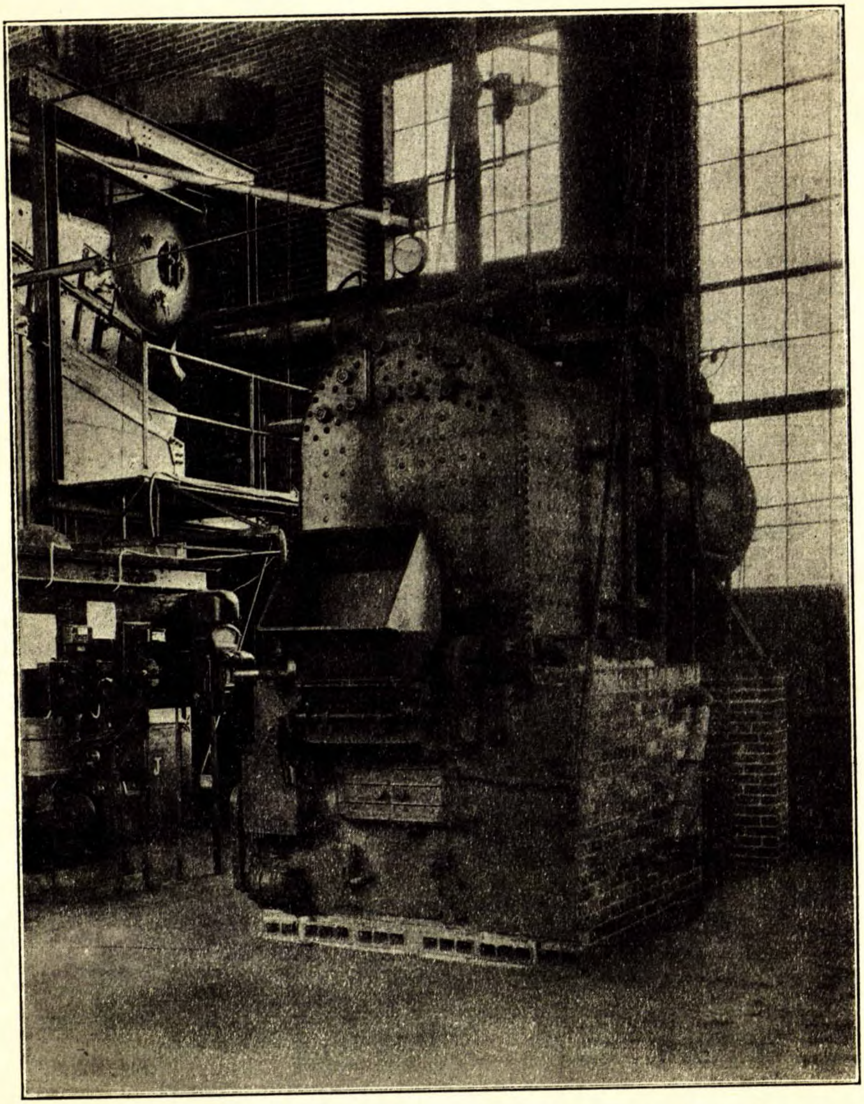
TABLE I

Summary of the More Salient Results for Seven of the Stoker Fired Tests

No.	Item	Name of Fuel						
		Standard operating coal	Domestic peat	Ontario lignite	Gas coke breeze	By-product coke breeze	Welsh buck-wheat mixed Nos. 1 and 2	Eastern Canada bitu-minous slack
1	Trial number	PG–19	PG–7	PG– 29	PG–4	PG–23	PG–24	PG–14
7 (a)	Moisture in fuel as fired %	3·1	45·8	33·2	11·0	0·7	3·0	1·9
7 (b)	Ash in fuel as fired %	6·1	2·9	7·9	14·5	10·6	5·3	6·2
9 (a)	Calorific value—fuel as fired, gross value B.T.U./lb.	13,880	5,240	6,850	10,490	12,370	14,170	14,060
18 (d)	Weight of fuel fired per 1,000 lb. of equiv. evap. lb.	124	367	270	202	216	129	120
25	Dry refuse hooked out fire-door (a) weight lb.	48	0	50	71	151	34	27
	(d) combustible content %	18·1	0	0·7	27·5	37·1	24·4	19·4
26	Dry refuse removed from ash pit (a) weight lb.	6	57	77	408	28	12	5
	(d) combustible content %	28·3	20·5	23·3	52·6	39·0	88·4	36·0
27	Dry refuse removed from smokebox—							
	(a) weight lb.	43	9	65	121	459	7	9
	(d) combustile content %	82·7	19·3	53·9	81·2	86·5	69·0	70·2
28	Dry refuse removed from chimney base—							
	(a) weight lb.	10	6	12	34	23	13	3
	(d) combustible content %	75·4	45·7	51·3	79·3	86·2	82·6	75·8
54 (d)	Equivalent evaporation per lb. of fuel as fired lb.	8·08	2·72	3·70	4·94	4·62	7·74	8·34
65	Temperature of products of combustion at boiler outlet °F	695	650	695	628	720	604	643
82	Heat absorbed by the boiler (thermal efficiency) %	56·5	50·4	52·4	45·7	36·2	53·0	57·6
84	Loss due to heat carried away in dry flue gases %	15·8	15·3	13·9	14·5	18·9	13·4	13·9
86	Loss due to carbon in refuse and flue dust %	3·7	1·4	3·5	20·9	20·9	2·8	1·0
87	Loss due to radiation, errors, and unaccounted for %	18·7	14·6	17·1	16·3	22·5	27·2	22·4

NOTE:—The item numbers correspond with similar numbering of appended table which gives the data and results of all twenty-eight trials in detail. Trials P.G. 7 and 29 were made with preheated air whereas all the other trials reported above were without preheated air. Trial P.G. 29 was on Onakawana lignite from the lower seam after air-drying to 33% moisture content. The results of other tests on Ontario lignite and the conditions under which they were made are shown on appended table opposite page 34.

PLATE I



General view of experimental locomotive type boiler installation fitted with enlarged solid refractory wall furnace, forced draught and air preheater equipment, sprinkler type stoker and pyramid grates for special test of peat, low-grade lignite, and coal screenings.

III

CLASSIFICATION OF COALS USING SPECIFIC VOLATILE INDEX*

E. J. Burrough, E. Swartzman, and R. A. Strong

Classification of coal both for scientific and for use purposes has occupied the attention of coal technologists since coal first came into common use. During the last few years interest in the subject in Canada and the United States has increased owing to the activities of the Sectional Committee on the Classification of Coal under the sponsorship of the American Society for Testing Materials, and also due to the activities of the Canadian Associate Committee on Coal Classification and Analysis. Having become interested in the subject from a practical viewpoint, the authors wish to present a scheme or method of classifying coals using what is termed the "Specific Volatile Index." This method, although designed for coals for use in the by-product coking industry and originally considered applicable only to bituminous coals, appears to offer a means of classifying all coals, and may therefore be employed as a basis for a general scientific classification.

During 1930 and 1931, a large number of coking tests on coals varying widely in nature were made in an experimental by-product coke oven of two-ton capacity at the Fuel Research Laboratories of the Department of Mines at Ottawa. In this oven, which is a duplicate of certain commercial units used in the industry, the different bituminous coals tested were coked alone and in admixture with one another, standard imported coals being used for blending purposes. On certain individual coals and coal mixtures, subsequent tests were made in commercial plants and the comparative results recorded. A study of the data thus obtained led to an attempt to classify bituminous coals using by-product data. The resultant graph is shown in Chart 1. In this graph the intention was to classify coals from their behaviour on carbonization, and it was prepared by plotting the tar yield in gallons per ton against a calculated value termed Specific Value Index.[1] This value represents the B.T.U's in the gas per pound of coal, per one per cent of volatile matter, the latter being determined in the laboratory or plant by subtracting the dry coke yield from 100. The resultant grouping of the coals appeared to be a satisfactory method of classifying bituminous coals, as they arranged themselves in an order conforming with the accepted rank of the coals, according to methods of classification based on ultimate analyses. As the volatile matter obtained by proximate analysis has always been considered to be an index of the gas-making properties of a coal, it would appear that coals may be classified from the data obtained by a simple proximate analysis, together with calorific value. Several methods have been proposed on this basis, the best known being that of Parr[2] in which the volatile matter

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*This paper is the full account of the development and details of the coal classification scheme announced in Mines Branch Memorandum Series No. 55, March, 1932, namely: "A classification of coals for use in the by-product coking industry" as proposed by E. J. Burrough and E. Swartzman, and reviewed by R. E. Gilmore.

and calorific value on a unit-coal basis are plotted on a two dimensional diagram. Rose[3], in making use of Parr's proposed classification, finds that it agrees remarkably well with that using ultimate analysis on a triaxial graph as proposed by Ralston,[4] but he concludes that insofar as the classification of coking coals is concerned, both methods fail to differentiate distinctly between the various classes of these coals, overlapping being quite marked.

PROPOSED CLASSIFICATION

It is a well established fact that coals of the same volatile matter content may have the most widely divergent calorific values. Assuming that the fixed carbon of coal has a constant calorific value, the conclusion must be that the calorific value of the volatile material will vary, and on a 1 per cent volatile matter basis will serve as an index of comparison for coals. This index may be referred to as the Specific Volatile Index, which is the special feature of the coal classification scheme presented herewith, and for sake of brevity this term is hereafter referred to as the S. V. I. In order to develop a formula for the calculation of this index it is first necessary to select a calorific value for "Fixed Carbon." As this material is neither wholly graphitic nor amorphous it is safe to assume that its heat value will fall between the accepted values of the two, hence the figure of 14,500 B.T.U. per pound was chosen after several analyses of this type of carbon, which is the residue from the standard volatile matter determination. If this value for carbon is used as a basis for determining the heat value of the fixed carbon in a given coal, and the resultant subtracted from the determined calorific value of the coal, the difference will be the heat value of the volatile material, which if divided by the percentage of volatile matter in the coal will give the specific volatile index. This calculation may be expressed by the following formula:—

$$\frac{\text{Determined B.T.U. in coal} - (14{,}500 \times \text{weight of F.C.})}{\text{Per cent of Volatile Matter}} = \text{S.V.I.}$$

An example of the application of the above formula is as follows:—

B.T.U. in coal = 15,100 (dry ash-free basis)
Volatile Matter = 37·6 per cent (dry ash-free basis)
Fixed Carbon = 62·4 per cent (dry ash-free basis)

$$\text{S.V.I. is } \frac{15{,}100 - (14{,}500 \times \cdot 624)}{37\cdot 6} = 160\cdot 9$$

This index arranges coals in *increasing value* from peats to anthracites, according to their rank, and when the index is plotted against the volatile matter or fixed carbon of the coal, a continuous band of varying width is obtained. The straightening out of the band of plotted coals avoids the difficulty of overlapping in the whole bituminous series which is present in certain other proposed methods that use calorific value for the horizontal axis. This fact, in the opinion of the authors, is the justification for the present attempt to establish a classification of coals from their proximate analysis and calorific value.

APPLICATION OF THE SPECIFIC VOLATILE INDEX FOR USE CLASSIFICATION

It is generally accepted that the classification of coals for any particular use is necessarily limited owing to factors which are independent of the coal material proper. Some of these factors are the relative quantity of ash and its fusion temperature, the sulphur content, and the competitive price. It must be recognized, however, that, with respect to these factors, different standards exist under varying market conditions, and they should therefore be neglected in a general classification scheme applied to any one industry.

The application of the proposed classification scheme to the by-product coke industry is presented in Chart 2. The data used in the compilation of this chart shown in Table II, were obtained from analyses and tests of coals of diversified origin, compiled by the Fuel Research Laboratories of the Department of Mines and from such other publications as were available, all data being converted to the dry ash-free basis. Further refinements in ash correction were not considered necessary, although the correction due to hydrated silicates, carbonates, and sulphur compounds, was found from previous work to approximate very closely to a constant value of 1/10 of the determined ash for coals of normal ash and sulphur content. The advisability of making such a correction is under consideration by the Technical Committee of Scientific Classification of North American coals, and, as Fieldner[5] intimates, there are the "practical difficulties of getting commercial laboratories to adopt the more complicated procedures." In a later paper by Fieldner and Selvig[6] on the same subject, they conclude that "it is a question whether any classification can be devised which will draw such fine distinctions as to require a corrected ash value." However, the authors found this refinement necessary for high-sulphur (over 2 per cent) and high-ash coals, and present it in Chart 3 which is referred to later.

For the construction of Chart 2 the Specific Volatile Index is plotted on the horizontal axis, while the volatile matter is plotted on the vertical axis. The vertical line at the Index of 154 appears to be the natural division between coking and non-coking coals, on the low-rank side, insofar as standard by-product coking practice is concerned; whereas the Index of 215 is the division on the high-rank side. The path of the plotted coals is a band of varying width passing through the lettered sections.

These sections, with the average carbonization yields, which are described below, have been defined to indicate the natural divisions into which the various types of coals should fall, and also to give a fair indication of their value to the by-product carbonization industry. Index limits have been indicated for the various ranks of coal, and as these are in close agreement with the well-known classification of Seyler[7] the major divisions have been designated, with slight departures, by the terminology of his classification for purposes of comparison. The modifications in terminology are in the cases of semi-bituminous and semi-anthracite or "carbonaceous" coals where the nomenclature suggested by David White[8], i.e. super-bituminous and sub-anthracite, is also used.

Section A—with S.V.I. limits of 100 to 120—comprises the low-rank, lignite coals that produce chars rather than coke, with fairly large yields of gas, high in carbon dioxide, and low in calorific value. The volatile matter range indicated for this group is above 40 per cent on the dry ash-free basis.

Section B—with S.V.I. limits of 120 to 145—includes the non-agglomerating sub-bituminous* coals that also produce a char rather than a coke but show an improvement in gas quality over those of Section A. The volatile matter content of coals in this group ranges from 37 to 60 per cent on the dry ash-free basis.

Section C—with S.V.I. limits of 145 to 154, and with the same volatile-matter range as immediately above—comprises a relatively small group of "sub-bituminous" coals which slightly agglomerate or show incipient caking or coking. Although these coals are not highly desirable for standard by-product use, the researches of Parr[9, 11, 12] on medium-temperature carbonization have shown, that they are satisfactory in this type of process, making a coke with 4 to 5 per cent of volatile matter, which is a very desirable domestic fuel, being smokeless, having a low ignition temperature and high physical strength. Parr's process is a quick carbonization in the mid-temperature range, the coal being preheated to about 300°C, and charged hot into the coke oven with a temperature range from 750° to 900°C. Fieldner[13] and his associates in their study of the gas, coke and by-product making properties of American coals show that cokes made at carbonization temperatures ranging from 500° to 900° C. are considerably stronger than those made at higher temperatures. The gas yields from coals of this class when carbonized at high temperatures are approximately the same as from those in Section B, but their tar yield is appreciably higher.

Section D—with S.V.I. limits of 154 to 160—contains the so-called "pseudo" gas coals, the volatile matter range of which is from 35 to 45 per cent. These are the high-oxygen coking coals of the para-bituminous rank. When these coals are carbonized they tend to give a porous, friable, fingery coke, the structure of which is greatly improved when blended with coals in Sections F to I inclusive. The tar yield is roughly the same as from those coals in Section C, and, although the yield of gas on the dry ash-free basis is slightly lower, there is a noticeable increase of therms.

Section E—with S.V.I. limits of 160 to 170 and volatile matter content on the dry ash-free basis ranging from 30 to 43 per cent—comprises the *true* gas coals of the para-bituminous rank, having high yields of rich gas preferred for use in gas retorts. They are also suitable for use in by-product coke ovens where they are used, either alone or blended with a low volatile coal, to improve coke quality.

Section F—with S.V.I. limits of 170 to 185 and with volatile matter contents on the dry ash-free basis ranging from 30 to 36 per cent—contains the medium volatile coking coals of the higher volatile ortho-bituminous class. These coals are seemingly most suitable for by-product oven coking and for this reason they are termed "natural by-product coking coals." Although the gas from these coals is slightly lower in therms than the gas from those in Section E, they produce, when coked alone, a high quality coke with respect to structure.

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*This nomenclature has been preferred to that of lignitous, as used by Seyler.

Section G—with S.V.I. limits of 170 to 185 which are the same as in Section F, but with a lower volatile matter range, namely 23 to 30 per cent on the dry ash-free basis—contains the lower volatile ortho-bituminous coals belonging to the medium volatile coking type. When coked alone these coals exhibit noticeably non-shrinking or even slightly expanding properties that, under certain operating conditions, make it difficult to push the coke from the oven. The coke is much harder and denser than that from coals in Section F, but the gas is appreciably lower in therms.

Section H—with S.V.I. limits of 185 to 200—contains coals that resemble Seyler's "meta-bituminous" class. Although in the same volatile matter range and somewhat similar to the coals in Section G, they are higher in rank and are considered more suitable for blending purposes.

Section I—with S.V.I. limits of 200 to 215, and a volatile matter range of 14 to 25 per cent—contains the semi- or "super-" bituminous coals, of which the well-known Pocahontas coal is typical. These coals are most serviceable for blending with high volatile (gas) coals for improving coke quality. They are quite unsuited for coking alone, as it is practically impossible to push their coke from the oven due to swelling. The therms in the gas and the tar yield are both appreciably lower than from coals in Sections G and H.

Section J—with S.V.I. limits from 215 to 230 and volatile matter contents ranging from approximately 9 to 16 per cent on the dry ash-free basis—contains the semi- or "sub-" anthracites.

Section K—with S.V.I. limits from 230 to 250 and volatile matter less than 10 per cent on the dry ash-free basis—contains the true anthracites.

It is well known that the rank of a coal has considerable bearing on its characteristic reactions in high-temperature carbonization. Therefore, on fixing the rank and volatile limits, predictions as to yields and behaviour may be made with fair accuracy, using only proximate analysis and the chart described above. The practical application of this classification for the by-product coke industry is best seen when new types of coals are to be investigated, new blends prepared, or one coal substituted for another of the same type. It is suggested that a satisfactory blend of coals should fall in Section F, and the best proportions of coals for a blend may be found from plotting the individual coals and calculating their proportions from their relative positions on the chart, the ideal by-product coal or blend falling in the ortho-bituminous class with volatile matter ranging from 30 to 35 per cent on the dry ash-free basis. This is in agreement with the later work of Seyler[10], who on plotting the softening points of a series of coals on his classification chart, came to the following conclusions:—"It will be seen that my three bituminous species (para, ortho, and meta) contain only commercially coking coals with one or two borderline exceptions. A few are found in the semi-bituminous species but the non-coking coals are otherwise outside the bituminous groups. Further, it is possible to draw approximately, lines of equal softening points, which may be provisionally called isotectic lines. *They centre around the ortho-bituminous species,* which forms a eutectic area of minimum softening point".

As the chart is traversed from left to right, certain outstanding characteristics may be noted, namely:

1. The coke yield increases, and a decided improvement in quality is noted which is indicated by a higher shatter index and a greater density;

2. The quality of the gas, as indicated by the therms, $\frac{\text{B.T.U.} \times \text{cubic feet of gas)}}{100{,}000}$, increases to a maximum at the para-bituminous gas coals (Section E on the chart) then decreases with a further increase in coke yield; and

3. The ammonium sulphate, carbon dioxide and water of decomposition decrease. It may also be noted that weathering of a coal depresses its rank, this being shown by an increase in the ammonium sulphate, carbon dioxide, and water of decomposition.

APPLICATION OF SPECIFIC VOLATILE INDEX FOR SCIENTIFIC CLASSIFICATION

As previously stated, this method of classification lends itself to the scientific classification of all carbonaceous material from wood to anthracites, but for this purpose it is advisable to reduce the substance to its pure form as recommended by Parr[11] and referred to as the "Unit Coal" basis. This correction is obtained by the following formulae:

$$\text{Unit Coal} = 1{\cdot}00 - (1{\cdot}08 \text{ ash} + 22/40 \text{ S})$$

$$\text{Unit Coal B.T.U.} = \frac{\text{Indicated B.T.U.} - 5000 \text{ S})}{1{\cdot}00 - (1{\cdot}08 \text{ Ash} + 22/400 \text{ S})}$$

$$\text{Unit Coal Fixed Carbon} = \frac{\text{Per cent of Fixed Carbon}}{1{\cdot}00 - (1{\cdot}08 \text{ Ash} + 22/40 \text{ S})}$$

$$\text{Unit Volatile Matter} = 100 - \text{Unit Coal Fixed Carbon}$$

In Chart 3, on which has been plotted a series of coals from the data shown in Table I, these corrections have been applied. The advisability of correcting to the Unit Coal basis is indicated by these data which contain the S.V.I. calculated to both the ash-free basis and the unit coal basis. It will be noted that very little difference exists in these values except where the ash and sulphur are excessive.

In comparing this system of classification with that of the Seyler classification by ultimate analysis, they are found to be in remarkably close agreement. It was, therefore, considered desirable to use the terminology, and be guided by the limiting values for the groups, as prepared by Seyler. This is shown in Table III which presents the relationships of the Specific Volatile Index limits to the carbon limits as used by Seyler; it also shows Parr's terminology and the calorific value limits as suggested by him for each group. From these tables a comparison may be made of the basis of each method of classification. In the case of plotting volatile matter and calorific value as proposed by Parr, it is evident that overlapping will occur on both axes, and very little effective delimiting can be made in the important groups of the subdivisions of the bituminous coals. When the calculated value for the Specific Volatile Index is used, however, a uniform progression is maintained parallelling that of the total carbon content by ultimate analysis. Plotting this value against volatile matter gives overlapping on one axis only, thereby presenting no difficulty in grouping coals in a manner comparable with that of ultimate analysis classifications.

It will be noted that the distinctive type of coals known as cannels plotted on Chart 3, occur in the same position as allotted to them by ultimate analysis, i.e. immediately above the ortho- and meta-bituminous groups. These have been indicated under two divisions using Parr's terminology, namely:

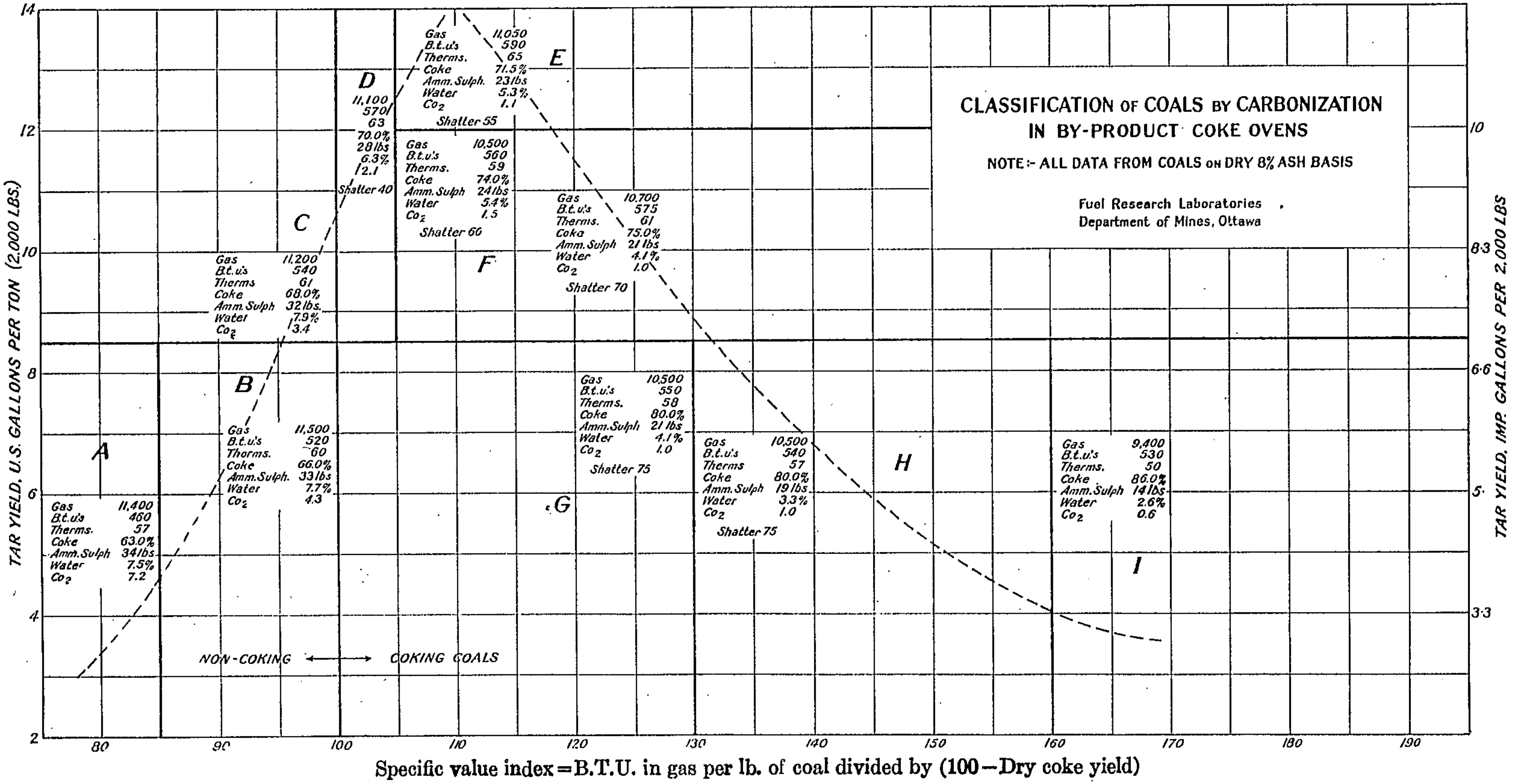
1. *Sub-Cannels*—with a volatile matter content of over 40 per cent on the unit coal basis, which fall immediately above the para-bituminous coals, and which in Seyler's classification are termed per-para-bituminous; and
2. *Cannels*—with a volatile matter content of 35 per cent on the unit coal basis, which fall above the ortho-bituminous coals, and which in Seyler's classification are called per-ortho-bituminous.

While only two classes of cannels have been indicated, owing to a lack of data for this type of carbonaceous material, in all probability each class of common coal will be found to have its respective cannel counterpart.

GENERAL DISCUSSION

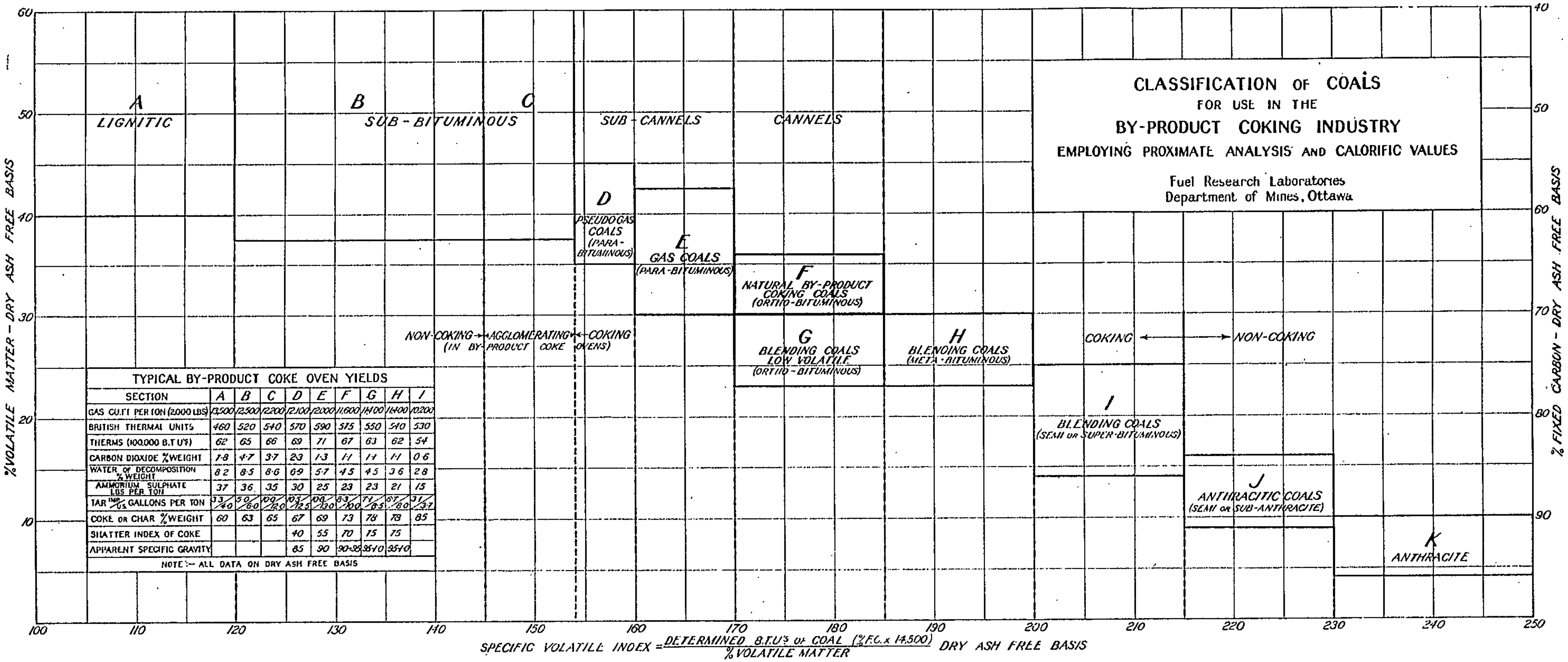
In the classification scheme proposed and outlined above, a distinct demarcation is indicated between the coking and non-coking coals. The coking coals when plotted on the unit coal basis have a specific volatile index range of 160 to 230. The justification for these limits may be seen on Chart 4, which shows that the rate of increase in the richness of the volatile matter is not uniform, and by plotting the Specific Volatile Index against S.V.I. divided by the Volatile Matter $\frac{\text{(S.V.I.)}}{\text{V.M.}}$ or against the B.T.U. in the Volatile Matter divided by the Volatile Matter squared $\frac{\text{(B.T.U. in V.M.)}}{\text{V.M.}^2}$, it will be noted that, at the index values 160 and 230 there are sharp changes which indicate a natural separation of the coking from the non-coking coals and show a rate of change in the calorific value of the volatile matter in this class of coal differing from that of the other types.

In the section below the Index value of 160 which delimits the lower rank coals, the curve has been extrapolated to the zero point, passing through the values obtainable for peats, wood and other low rank carbonaceous materials. The zero point indicates a material which would on distillation yield only products of no calorific value, such as water, carbon dioxide, and nitrogen, giving a Specific Volatile Index of zero. The index values for anthracite (above 230) show a very rapid increase of calorific value per unit of volatile, and for practical purposes a maximum Index value of approximately 290 may be considered the upper limit for anthracites exclusive of super anthracites, graphites, etc. This graph indicates that these types of coals will give increasing index values for increases in rank, which is measured by the increase of calorific value of the volatile matter, although the quantity of the volatile matter decreases. The fact that the volatile material of coals of different ranks



CLASSIFICATION OF COALS BY CARBONIZATION IN BY-PRODUCT COKE OVENS
NOTE:- ALL DATA FROM COALS ON DRY 8% ASH BASIS
Fuel Research Laboratories
Department of Mines, Ottawa
TAR YIELD, U.S. GALLONS PER TON (2,000 LBS.)
TAR YIELD, IMP. GALLONS PER 2,000 LBS
14
12
10
8
6
4
2
10
8·3
6·6
5·
3·3
80
90
100
110
120
130
140
150
160
170
180
190
Specific value index=B.T.U. in gas per lb. of coal divided by (100−Dry coke yield)
NON-COKING ⟷ COKING COALS
A
Gas 11,400
B.t.u's 460
Therms. 57
Coke 63.0%
Amm.Sulph 34 lbs.
Water 7.5%
Co2 7.2
B
Gas 11,500
B.t.u's 520
Therms. 60
Coke 66.0%
Amm.Sulph. 33 lbs
Water 7.7%
Co2 4.3
C
Gas 11,200
B.t.u's 540
Therms 61
Coke 68.0%
Amm.Sulph 32 lbs.
Water 7.9%
Co2 3.4
D
11,100
570
63
70.0%
28 lbs
6.3%
2.1
Shatter 40
Gas 11,050
B.t.u's 590
Therms. 65
Coke 71.5%
Amm.Sulph. 23 lbs
Water 5.3%
Co2 1.1
Shatter 55
E
Gas 10,500
B.t.u's 560
Therms. 59
Coke 74.0%
Amm.Sulph 24 lbs
Water 5.4%
Co2 1.5
Shatter 60
F
Gas 10,700
B.t.u's 575
Therms. 61
Coke 75.0%
Amm.Sulph 21 lbs
Water 4.1%
Co2 1.0
Shatter 70
Gas 10,500
B.t.u's 550
Therms. 58
Coke 80.0%
Amm.Sulph 21 lbs
Water 4.1%
Co2 1.0
Shatter 75
G
Gas 10,500
B.t.u's 540
Therms 57
Coke 80.0%
Amm.Sulph 19 lbs
Water 3.3%
Co2 1.0
Shatter 75
H
Gas 9,400
B.t.u's 530
Therms. 50
Coke 86.0%
Amm.Sulph 14 lbs
Water 2.6%
Co2 0.6
I

Chart 1



TYPICAL BY-PRODUCT COKE OVEN YIELDS

SECTION	A	B	C	D	E	F	G	H	I
GAS CU. FT PER TON (2,000 LBS)	13,500	12,500	12,200	12,100	12,000	11,600	11,400	11,400	10,200
BRITISH THERMAL UNITS	460	520	540	570	590	575	550	540	530
THERMS (100,000 B.T.U'S)	62	65	66	69	71	67	63	62	54
CARBON DIOXIDE % WEIGHT	7·8	4·7	3·7	2·3	1·3	1·1	1·1	1·1	0·6
WATER OF DECOMPOSITION % WEIGHT	8·2	8·5	8·6	6·9	5·7	4·5	4·5	3·6	2·8
AMMONIUM SULPHATE LBS PER TON	37	36	35	30	25	23	23	21	15
TAR IMP./U.S. GALLONS PER TON	3·3/4·0	5·0/6·0	10·0/12·0	10·5/12·5	10·8/13·0	8·3/10·0	7·1/8·5	6·7/8·0	3·1/3·7
COKE OR CHAR % WEIGHT	60	63	65	67	69	73	78	78	85
SHATTER INDEX OF COKE				40	55	70	75	75	
APPARENT SPECIFIC GRAVITY				85	90	90-95	95-1·0	95-1·0	

NOTE:— ALL DATA ON DRY ASH FREE BASIS

Chart 2

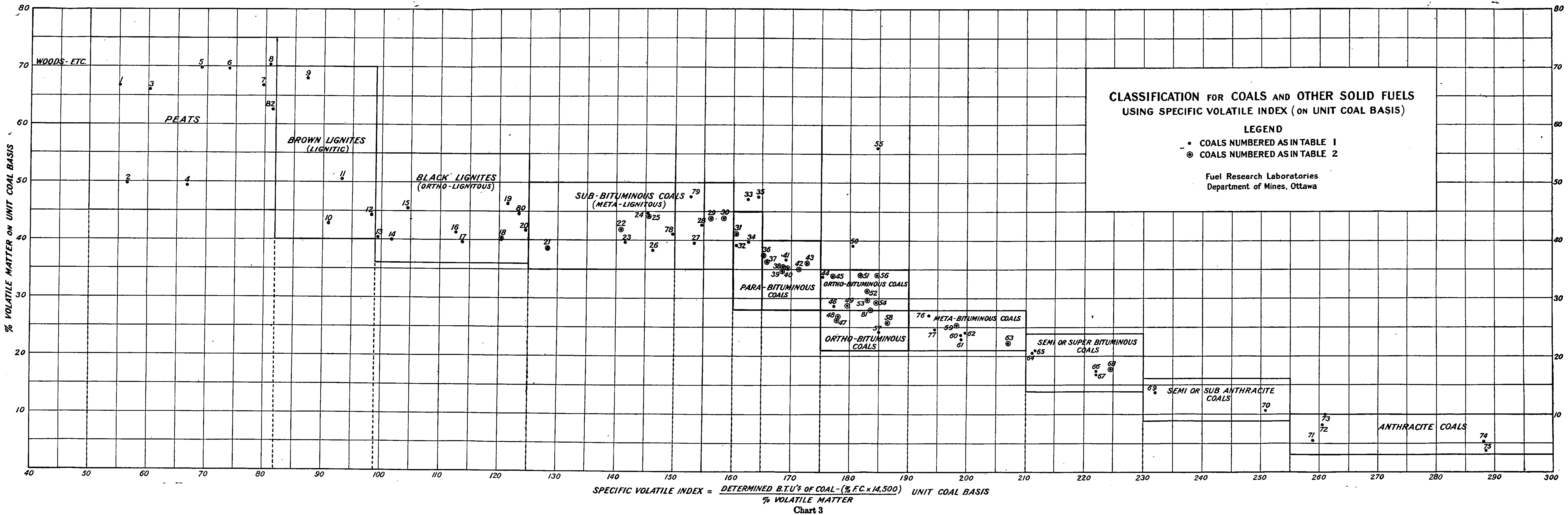

CLASSIFICATION FOR COALS AND OTHER SOLID FUELS
USING SPECIFIC VOLATILE INDEX (ON UNIT COAL BASIS)
LEGEND
• COALS NUMBERED AS IN TABLE 1
◉ COALS NUMBERED AS IN TABLE 2
Fuel Research Laboratories
Department of Mines, Ottawa
WOODS - ETC.
PEATS
BROWN LIGNITES (LIGNITIC)
BLACK LIGNITES (ORTHO-LIGNITOUS)
SUB-BITUMINOUS COALS (META-LIGNITOUS)
PARA-BITUMINOUS COALS
ORTHO-BITUMINOUS COALS
META-BITUMINOUS COALS
ORTHO-BITUMINOUS COALS
SEMI OR SUPER BITUMINOUS COALS
SEMI OR SUB ANTHRACITE COALS
ANTHRACITE COALS
% VOLATILE MATTER ON UNIT COAL BASIS
80
70
60
50
40
30
20
10
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
SPECIFIC VOLATILE INDEX = DETERMINED B.T.U's OF COAL - (% F.C. x 14,500) / % VOLATILE MATTER UNIT COAL BASIS

Chart 3

differs so widely in calorific value points to the impossibility of calculating calorific value by a simple formula from proximate analysis.

While it appears that there is a distinct division between the coking and non-coking coals, no such claim can be made for the subdivisions of the other types of coals and the lines drawn are somewhat arbitrary.

The section limits for peats have been indicated with due regard to other classifications, although opinions are divergent in this grouping as also in that of lignites and very little agreement can be claimed. In the meta-lignitous or sub-bituminous coals, a subdivision has been indicated for those coals which agglomerate and under certain favourable conditions may be coked. The para-bituminous class has also been subdivided for the purpose of grouping these coals into two classes, namely, gas coals and "pseudo" gas coals. It was also considered of interest to divide the coals of the ortho-bituminous class into those of high and low volatile matter, considering the high volatile matter group the preferred by-product coking coals.

Discussion of the merits of the classification proposed, as outlined above, must consider the reliability of the volatile matter determination on which the specific volatile index is based. The apparatus for making the volatile matter determination of the many coals on which this proposed classification is based, consists of either a Chaddock gas burner or a Fieldner electric furnace. This furnace and its method of operation are in accordance with the A.S.T.M. D.271-30, viz., "Standard Methods of Laboratory Sampling and Analysis of Coal and Coke." Many tests on coals differing widely in rank were made in platinum crucibles of two different sizes, first in the Chaddock burner by the alternative gas burner method as in D271-30, and then by the electric furnace method. These comparative tests indicate that for practical purposes the results by these two methods agree quite closely. Care, of course, is taken to see that the temperature during the determination is maintained as near as possible to the 950° C. specified, and those coals (mainly the non-coking low rank coals) that are liable to spark, are given a short preheating before the final period as specified. In general, it is considered that with reasonable care duplicate and consistent results are obtainable by the employment of the standard volatile matter determination as outlined above. This has been confirmed by the exchange of standard samples between different government laboratories in Canada and the United States. It is to be noted that for purposes of plotting coals on the S.V.I. chart (No. 2), changes of plus or minus 0·5 per cent in volatile matter cause variations in the S.V.I. figures ranging from zero for the low rank lignites, to as high as 5 to 7 for the anthracites. The variation for a typical bituminous coal near the intersection of F,G, and H, is less than 1, and a change in the volatile matter percentage of plus or minus one, along the line suggested by A. C. Fieldner for borderline coals, would double this variation.

SUMMARY

The charts and the classification illustrated are equally serviceable when either the volatile matter or the fixed carbon is used as the ordinate, since on the dry ash-free and "unit coal" bases the one is the reciprocal of the other. The value of 14,500 B.T.U. per pound as the calorific value of ash-free fixed carbon was chosen after finding it to be the average of a large number of actual determinations.

While similar to Parr's two-dimensional diagram, where calorific values are plotted against volatile matter, the S.V.I. classification scheme avoids overlapping of classes along the main axis.

The classification herewith presented has the feature of simplicity, requiring only the generally available data of proximate analysis and calorific value of the coal or coals under consideration, and while comparable to other systems of classification based on ultimate analysis, avoids the necessity of this costly and difficult determination.

By plotting a coal on the chart according to its S.V.I. and volatile matter, and noting its position, it is seemingly possible to predict with a fair degree of accuracy, the characteristics of that coal with respect to its behaviour in a by-product oven, and the approximate yield of by-products to be expected.

The chart is also serviceable for determining what mixtures or blends of coals may be suitable for obtaining certain yields of coke, gas, and other products, and for indicating the physical quality of the coke. Certain tests, such as can be conducted in the laboratory, are, however, desirable, and in some cases necessary, to ensure that these predictions are correct. A small-scale coke button test has been developed in the Fuel Research Laboratories, and by the use of this method large-scale tests of an experimental nature may be avoided.

The classification scheme employing the Specific Volatile Index plotted against either the volatile matter or fixed carbon on a two-dimension chart, may serve either for a purely scientific classification of coals or for a "use" classification, especially for the carbonization industry. For this purpose, that is, as a scientific classification, the calculation of all values to the Unit Coal basis before plotting is recommended.

TABLE I

Analyses of Coals Plotted on Chart 3

Coal No.	Proximate Analysis (dry ash-free basis)				Volatile matter	Calorific value (B.T.U.)	Specific volatile index		Ultimate analysis (dry ash and sulphur free)				
	Volatile matter	Fixed carbon	Calorific values (B.T.U.)	Sulphur	"Unit coal" basis	"Unit coal" basis	Dry and ash-free basis	"Unit coal" basis	Carbon	Hydrogen	Oxygen	Nitrogen	
1	67·4	32·6	8,320	0·5	66·8	8,490	53·4	55·0					Peats; C under 70·0
2	50·5	49·5	9,995	0·7	49·8	10,090	55·6	56·5	64·0	4·2	30·5	1·3	
3	66·7	33·3	8,810	0·6	66·1	8,920	59·7	60·5					
4	49·9	50·1	10,562	0·6	49·4	10,630	64·5	66·6	66·8	4·1	27·7	1·4	
5	70·0	30·0	9,180	0·3	69·9	9,200	69·0	69·1					
6	70·0	30·0	9,430	0·5	69·6	9,540	72·5	73·8					
7	66·8	33·2	10,090	0·2	66·7	10,150	79·0	79·8	59·5	5·6	32·6	2·3	
8	70·4	29·6	9,980	0·2	70·2	10,000	80·8	80·9	57·2	5·5	36·0	1·3	
82	64·0	36·0	10,330	4·8	62·6	10,520	79·9	81·4	63·9	5·4	29·3	2·4	
9	68·5	31·5	10,390	0·8	68·0	10,580	84·9	87·2					C=70·0 to 75·0 Lignitic (brown lignites)
10	43·8	56·2	12,030	0·6	42·9	12,180	88·6	90·9	72·2	4·4	22·1	1·3	
11	51·3	48·7	11,734	1·0	50·5	11,880	91·1	93·1					
12	45·1	54·9	12,130	0·8	44·3	12,430	96·4	98·2	73·2	4·9	20·1	1·8	
13	40·9	59·1	12,550	0·7	40·3	12,650	97·8	99·2	75·0	4·6	19·0	1·4	C=75·0 to 80·0 Ortho-lignitous (black lignites)
14	40·7	59·3	12,680	0·6	40·0	12,780	100·0	101·7	76·2	4·9	17·3	1·6	
15	46·7	53·3	12,500	0·6	45·5	12,660	102·1	104·5					
16	42·0	58·0	13,070	0·6	41·4	13,170	111·0	112·7	77·5	5·2	15·8	1·5	
17	40·4	59·6	13,130	1·0	39·6	13,270	111·0	113·8					
83	53·2	46·8	12,520	4·1	56·7	12,870	107·8	116·2					
18	41·1	58·9	13,350	0·5	40·3	13,500	117·1	120·4	77·5	5·2	15·1	2·2	
19	46·6	53·4	13,347	0·7	46·2	13,410	120·4	121·3	77·0	5·2	16·3	1·5	
80	50·2	49·8	13,340	1·7	49·5	13,430	121·8	123·2	76·8	5·4	16·5	1·3	
20	42·1	57·9	13,570	0·7	41·6	13,650	123·0	124·5	77·7	5·4	15·2	1·7	

TABLE I—Concluded

Analyses of Coals, Plotted on Chart 3—Concluded

Coal No.	Proximate Analysis (dry ash-free basis)				Volatile matter	Calorific value (B.T.U.)	Specific volatile index		Ultimate analysis (dry ash and sulphur free)				
	Volatile matter	Fixed carbon	Calorific values (B.T.U.)	Sulphur	"Unit coal" basis	"Unit coal" basis	Dry and ash-free basis	"Unit coal" basis	Carbon	Hydrogen	Oxygen	Nitrogen	
21	39·3	60·7	13,720	....	38·6	13,850	125·1	128·3					C=80·0 to 84·0 Meta-lignitous (sub-bituminous)
22	42·8	57·2	14,120	0·4	41·9	14,320	135·8	140·7	80·5	5·5	12·4	1·6	
23	40·3	59·7	14,230	0·5	39·7	14,360	138·2	141·5					
25	45·2	54·8	14,300	0·7	44·4	14,490	140·3	145·5	80·7	6·0	11·1	2·2	
24	48·5	51·5	14,415	0·8	44·6	14,520	143·2	145·3	81·0	5·7	11·6	1·7	
26	38·5	61·5	14,360	1·15	37·4	14,550	141·0	146·3	82·5	5·2	10·5	1·8	
27	40·9	59·1	14,540	1·1	39·6	14,830	145·9	153·4					
28	43·5	56·5	14,710	1·2	42·6	14,920	150·0	154·6	83·5	6·2	8·4	1·9	
29	45·0	55·0	14,760	1·1	43·9	14,980	150·7	156·0	83·4	6·0	9·0	1·6	
30	45·2	54·8	14,790	1·2	43·9	15,080	153·6	158·2	83·4	5·6	9·3	1·7	
78	41·9	58·1	14,528	1·3	41·0	14,700	145·8	149·8	82·9	5·5	9·9	1·7	
79	49·2	50·8	14,610	3·8	47·6	14,880	....	152·8	83·5	5·9	9·0	1·6	
31	41·9	58·1	14,900	0·7	41·0	15,120	154·2	160·2	84·3	6·0	7·9	1·8	C= 84·0 to 87·0 Para-bituminous
32	40·2	59·8	14,950	2·0	39·1	15,100	156·1	160·3	84·9	5·5	7·9	1·7	
33	47·7	52·3	15,190	0·7	47·1	15,330	159·5	162·5					
34	40·5	59·5	15,090	1·2	39·8	15,200	159·5	162·5	85·0	5·8	7·4	1·8	
35	48·1	51·9	15,280	0·8	47·5	15,420	161·2	164·3	84·5	6·2	7·5	1·8	
36	37·8	62·2	15,200	0·6	37·4	15,250	163·5	165·0	86·0	5·4	7·0	1·6	
37	37·6	62·4	15,100	2·3	36·3	15,260	160·9	165·8	86·5	5·8	6·2	1·5	
38	35·7	64·3	15,200	0·5	35·1	15,320	164·5	168·7					
39	35·2	64·8	15,250	0·7	34·8	15,310	166·0	168·4					
40	36·4	63·6	15,120	1·3	35·1	15,340	162·0	169·2	86·5	5·5	6·9	1·1	
41	37·3	62·7	15,290	1·0	36·6	15,400	166·0	169·0	85·2	6·1	6·9	1·8	
42	36·6	63·4	15,130	1·8	35·0	15,420	162·0	171·2	85·8	5·9	6·9	1·4	
43	37·2	62·8	15,320	1·3	36·2	15,500	167·0	172·6	86·5	5·8	6·3	1·4	

44	34·2	65·8	15,410	0·7	33·6	15,520	171·6	175·2	88·8	5·2	4·3	1·7	C=87·0 to 89·0 Ortho-bituminous
45	34·5	65·5	15,550	0·6	33·9	15,600	174·0	177·1					
46	30·0	70·0	15,190	0·5	28·7	15,430	168·0	177·4	87·4	5·1	6·5	1·0	
47	27·2	72·8	15,210	0·6	26·2	15,360	171·5	177·8	88·0	5·4	4·8	1·8	
48	27·4	72·6	15,210	0·2	26·4	15,370	171·0	178·5					
49	30·0	70·0	15,250	0·7	28·8	15,490	170·0	179·5	87·4	5·2	6·1	1·3	
50	40·6	59·4	15,550	0·8	39·1	15,880	171·0	180·3					
51	37·6	62·4	15,270	7·3	34·0	15,750	165·4	181·7	89·2	6·2	3·6	1·0	
52	31·9	68·1	15,610	0·7	31·4	15,700	179·5	183·0					
53	30·3	69·7	15,500	0·7	29·6	15,620	178·6	183·0	88·1	5·3	5·2	1·4	
81	29·8	70·2	15,300	0·9	28·0	15,570	173·0	183·5					
54	30·4	69·6	15,450	0·3	29·3	15,660	175·8	184·5					
55	56·8	43·2	16,480	0·8	56·1	16,730	179·6	184·6	87·2	7·5	4·0	1·3	
56	31·4	68·6	15,570	1·1	30·4	15,720	179·3	184·8					
57	27·0	73·0	15,460	4·3	24·2	15,470	180·6	185·0					
58	27·3	72·7	15,280	0·6	25·7	15,550	173·6	186·5					
76	29·2	70·8	15,530	4·3	27·0	15,800	179·7	193·4	90·2	5·1	3·0	1·7	C=89·0 to 91·2 Meta-bituminous
77	26·5	73·5	15,480	2·4	24·8	15,730	182·0	194·6	89·6	5·3	3·5	1·6	
59	26·4	73·6	15,680	0·7	25·3	15,850	189·8	198·4					
60	24·3	75·7	15,720	0·6	23·7	15,780	195·0	199·0	90·4	4·9	3·5	1·2	
61	23·5	76·5	15,660	0·5	23·0	15,750	194·0	199·0	90·7	4·8	3·2	1·3	
62	25·0	75·0	15,678	1·3	24·0	15,810	192·0	199·6	89·6	5·2	3·8	1·4	
63	23·4	76·6	15,720	0·4	22·3	15,880	197·4	207·0					
64	23·5	76·5	15,480	4·0	20·6	15,850	186·5	211·0	91·7	4·9	1·9	1·5	C=91·2 to 93·3 Semi- (or per-) bituminous
65	21·7	78·5	15,800	1·0	21·0	15,890	204·7	211·5	91·8	4·8	2·2	1·2	
66	18·1	81·9	15,690	0·6	17·3	15,830	211·0	222·0	92·9	4·3	1·5	1·3	
67	18·9	81·1	15,538	2·0	16·9	15,800	200·0	222·0	91·2	4·6	2·5	1·7	
68	18·5	81·5	15,770	0·9	17·6	15,900	214·0	224·5					
69	14·2	85·8	15,600	0·8	13·6	15,680	222·0	232·0					C over 93·3; semi-(or sub-) anthracite
70	12·0	88·0	15,450	1·8	10·6	15,620	222·5	251·0	93·7	4·4	0·7	1·2	
71	6·2	93·8	15,044	0·6	5·4	15,100	234·0	259·0	94·6	2·7	1·7	1·0	C over 93·3; H under 4·2; anthracite
72	9·4	90·6	15,350	1·0	8·1	15,440	235·0	260·5					
73	10·85	89·15	15,585	1·0	10·0	15,680	243·8	261·0	93·3	3·8	1·9	1·0	
74	6·5	93·5	15,080	1·0	5·1	15,230	234·0	288·0					
75	4·6	95·4	14,920	1·5	3·6	15,010	237·0	288·5					

TABLE II

By-product Yields, per 2,000 pounds of Dry, Ash-free Coal, for 28 Typical Coals Plotted on Chart 3

Classification, designation and coal number		Volatile* matter in coal	Specific volatile index* of coal	Gas			Carbon dioxide % wt.	Water of decomposition, % wt.	Ammonium sulphate, pounds per ton	Tar		Coke	Shatter index	Apparent specific gravity
Section letter	Sample number			C.F. per ton	B.T.U. per C.F.	Therms per ton				Gallons per ton Imp.	Gallons per ton U.S.	(or char) % wt.		
A	18	41·1	117·1	13,500	460	62·0	7·8	8·2	37·0	3·3	4·0	60·0	....	....
B	21	39·3	125·1	12,100	460	55·9	5·4	8·7	36·0	1·9	2·3	66·2	....	....
	22	42·8	135·8	12,400	540	67·0	4·6	8·8	33·0	5·3	6·4	64·1	....	....
	25	45·2	140·3	12,800	560	71·7	4·1	8·9	38·0	6·9	8·3	62·4	....	....
C	29	45·0	150·7	12,630	562	71·0	3·7	8·9	34·9	9·8	11·8	62·0	....	....
	30	45·2	153·6	12,900	570	73·5	3·8	8·2	34·6	10·2	12·3	61·5	....	....
D	31	41·9	154·2	12,150	575	69·9	2·6	7·6	33·4	11·3	13·6	65·0	30·0	0·85
E	36	37·8	163·5	11,150	630	70·2	1·3	7·0	24·1	10·6	12·6	67·2	....	....
	37	37·6	160·9	11,780	565	66·6	1·9	6·6	26·0	10·2	12·2	67·3	53·0	0·90
	38	35·7	164·5	11,720	597	70·0	1·1	5·0	23·3	10·8	12·9	70·0	....	....
	39	35·2	166·0	11,120	635	70·6	0·87	5·4	22·3	10·8	12·9	70·0	....	....
	40	36·4	162·0	11,180	556	68·2	2·5	6·3	18·8	10·2	12·2	69·2	....	....
	42	36·6	162·0	12,100	567	68·6	2·1	7·0	21·7	9·8	11·7	68·0	63·0	0·95
	43	37·2	167·0	11,740	584	68·6	1·2	5·8	27·0	11·3	13·5	67·8	52·0	1·00
F	45	34·5	174·0	11,750	585	68·7	1·2	4·7	23·1	9·5	11·4	70·7	70·0	0·94
	49	30·0	170·0	11,200	555	62·1	1·4	5·3	33·0	10·2	12·3	71·1	71·0	1·00
	51	37·6	[1]165·4	11,730	588	69·0	1·2	5·1	18·7	9·8	11·8	67·6	....	....
	52	31·9	179·5	10,950	609	66·7	0·8	4·7	22·6	9·1	10·9	72·4	....	....
	53	30·3	178·6	11,400	556	63·4	2·3	3·9	22·4	8·0	9·6	75·0	70·0	0·93
	54	30·4	175·8	11,270	558	62·9	1·5	4·5	22·3	6·2	7·4	73·8	....	....
	56	31·4	179·3	11,250	563	63·3	0·8	4·9	21·0	9·4	11·3	72·7	63·0	0·92
G	47	27·2	171·5	10,590	550	58·2	1·0	4·2	26·1	6·9	8·2	77·3	76·0	1·08
	48	27·4	171·0	11,160	524	58·5	1·7	4·3	26·3	6·6	7·8	76·0	68·0	1·05
	58	27·3	173·6	11,070	540	59·6	1·5	4·7	25·6	7·7	9·2	74·9	77·0	1·10
	81	29·8	173·0	11,710	529	61·9	1·5	4·8	24·9	7·8	9·3	74·6	73·0	1·12
H	59	26·4	189·8	11,400	560	63·7	1·2	3·6	21·2	6·7	7·9	77·5	67·0	0·95
	63	23·4	197·4	11,110	522	58·0	1·1	2·9	21·5	5·0	6·0	80·6	80·0	1·04
I	66	18·1	211·0	9,970	535	53·3	0·6	2·8	15·3	3·1	3·7	84·8	....	....

*Volatile matter and specific volatile index are on the dry and ash-free basis as on Chart 2.

[1] This index is low, because of high ash and sulphur. On the "Unit Coal" basis the index is 181·7 and places the coal in its correct position.

TABLE III

Specific Volatile Index Classification on the "Unit Coal" Basis

Section	Name of predominating group*	S.V.I. limits	Volatile matter range	Carbon range	Calorific value limits; B.T.U. per pound	Parr's terminology of predominating class
A	Woods	Under 50	60 and above	Below 50	Up to 9,000	
B	Peats	50—82	45—75%	50—70%	8,500—11,000	Peat
C	Brown lignites (lignitic)	82—99	40—70	70—75	10,500—12,700	Lignites
D	Black lignites (ortho-lignitous)	99—125	36—55	75—80	12,500—14,000	Bituminous D
E	Sub-bituminous (meta-lignitous)	125—160	35—50	80—84	13,800—15,100	Bituminous C
F	Bituminous (para-bituminous)	160—175	28—45	84—87	15,000—15,600	Bituminous B
G	Bituminous (ortho-bituminous)	175—190	21—35	87—89	15,300—15,800	Bituminous B
H	Bituminous (meta-bituminous)	190—210	21—28	89—91	15,700—16,000	Bituminous B
I	Semi- or "super" bituminous	210—230	14—24	91—93·3	15,700—16,000	Bituminous A
J	Semi- or "sub-" anthracite	230—255	9—16	Over 93·3	15,500—15,800	Semi-anthracite
K	Anthracites	255—300	3—10	Over 93·3	15,000—15,700	Anthracite

*The nomenclature in brackets in this column are those of Seyler.

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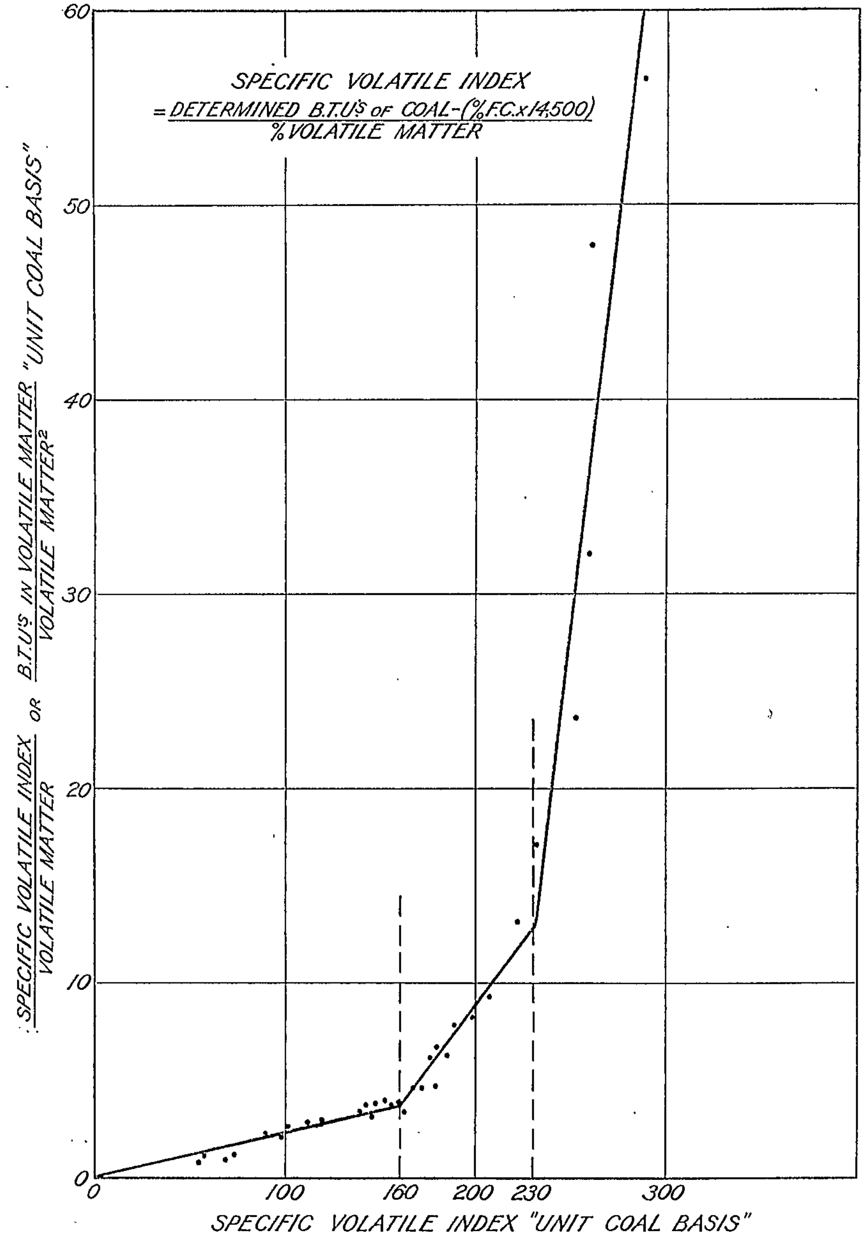
SPECIFIC VOLATILE INDEX
= DETERMINED B.T.U'S OF COAL-(%F.C.x14,500) / %VOLATILE MATTER
SPECIFIC VOLATILE INDEX / VOLATILE MATTER OR B.T.U'S. IN VOLATILE MATTER / VOLATILE MATTER² "UNIT COAL BASIS"
0
10
20
30
40
50
60
0
100
160
200
230
300
SPECIFIC VOLATILE INDEX "UNIT COAL BASIS"

Chart 4.

IV

ANALYSES OF SOLID FUELS

Compiled by

J. H. H. Nicolls and C. B. Mohr

The solid fuel analyses compiled here are those of samples of general interest received during the past two years, and in most cases only such data as were requested by the person submitting the sample are shown. They are tabulated under the three following group headings:—

(1) Solid fuels occurring in Canada.

(2) Coal samples submitted by the Department of Pensions and National Health.

(3) Miscellaneous solid fuels.

The first group of fuels (Table I) contains a number of "mine" or "prospect" samples, collected largely by technical officers of either the Federal or Provincial governments. The "mine" samples were procured from deposits already under development; the "prospect" samples from deposits as yet undeveloped. A number of "commercial" samples occurs in the first group; each of these is considered to be indicative of the corresponding product as shipped from the mine.

As a general rule "mine" and "prospect" samples contain less ash and have higher calorific values than would the corresponding "commercial" samples. This is due to the fact that, in ordinary mining practice, it is very difficult to exclude impurities as thoroughly as would be done in collecting the small "mine" samples. Therefore, in using the tables following in connexion with the sale or purchase of coal, care should be taken to note whether the samples are "mine" or "commercial" (which latter term includes "slack", "run-of-mine", and the various sizes of screened coal), and to judge therefrom whether any particular coal as shipped from the mine could reasonably be expected to have as good an analysis as that given in the table. It should also be realized that, generally speaking, "slack" coal will contain more moisture and ash and have a lower calorific value than the corresponding screened coal, and that "run-of-mine" coal will be intermediate between the two.

The second group of fuels (Table II) consists entirely of bituminous coals purchased by the Department of Pensions and National Health for use in the heating plants of their various hospitals. These include both Canadian and United States coals. 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 Research Laboratories. According to the procedure employed in reporting these samples to the Department of Pensions and National Health, only the moisture contents (which may vary with weather conditions) are 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 third group of fuels (Table III) consists of imported coals, such as are sold by local dealers for heating either private residences or public buildings, or for various industrial purposes. In addition, it includes a number of cokes recently obtained from manufacturers and dealers, all of which were made in Canada, though largely with coals from the United States. These are all "commercial" samples. Finally, the third group contains some processed fuels, a sample of hardwood charcoal such as is used for kindling and samples of fuel from Jamaica and Germany.

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" columns are included. In such cases the fuels were analysed following air-drying in the standard apparatus.[1] The analyses of the high-moisture "slack" coals do not include the "AD" column, since this information was not considered to be of any particular interest, although it is obvious that the fuels could not have been ground for analyses without previous drying.

(b) In certain cases more than one sample number will be observed at the head 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 one-gramme samples in closed platinum crucibles during the determination of volatile matter. The terms "non-coking", "poor", "fair", or "good" are used to indicate general coking properties, and serve to differentiate between the non-coking or poorly coking coals, and those that will produce coke in an oven that will grade as fair or better. They do not necessarily predict correctly the grade of coke that can be produced commercially.

---

[1] Report of Scientific and Industrial Research Council of Alberta, 1923, p. 39.

TABLE I

Analyses of Solid Fuels Occurring in Canada

—	Dominion Steel and Coal Corporation, Limited, Montreal Coal samples from the Sydney area, Nova Scotia, Supplied to Fuel Research Laboratories															
	By the Coal Company		Through the Department of Public Works													
Sample No.	7634		7107		9982		10049		10529		6775		6823		6961	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—																
Moisture...per cent	3·5	......	3·5	......	3·2	......	3·1	......	3·8	......	6·9	......	6·5	......	8·9	......
Ash "	7·3	7·6	13·2	13·7	10·4	10·7	8·4	8·7	8·9	9·2	8·4	9·0	8·9	9·6	8·3	9·1
Volatile matter "	32·6	33·8	32·2	33·4	32·5	33·6	34·7	35·8	34·6	36·0	30·1	32·3	30·3	32·3	30·9	33·9
Fixed carbon "	56·6	58·6	51·1	52·9	53·9	55·7	53·8	55·5	52·7	54·8	54·6	58·7	54·3	58·1	51·9	57·0
Ultimate Analysis—																
Sulphur...per cent	2·6	2·7	3·1	3·2	2·2	2·3	2·6	2·7	2·8	2·9	2·6	2·8	2·7	2·9	2·6	2·9
Nitrogen "	1·4	1·4	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Calorific Value—																
Calories per gramme, gross	7,470	7,740	6,885	7,135	7,385	7,635	7,515	7,755	7,280	7,565	7,115	7,645	7,035	7,520	6,645	7,305
B.T.U. per pound, gross	13,450	13,930	12,390	12,840	13,295	13,740	13,530	13,960	13,100	13,620	12,810	13,760	12,660	13,540	11,960	13,150
Fuel ratio	1·75		1·60		1·65		1·55		1·50		1·80		1·80		1·70	
Coking properties	Good		Good		Good		Good		Good		Good		Good		Good	
Softening temperature of ash....°F.	1945		......		......		......		......		......		......		......	
Designation of coal	Screened coal...		Run-of-mine....		......		......		......		Slack......		......		......	
Kind of sample	All commercial.															
Taken by	......		W. Kritsch, laboratory assistant, Fuel Research Laboratories......													
Date of sampling	Supplied to F.R.L. storage at the end of 1929, and sampled during October, 1930		During May, 1930		During November, 1931		During December, 1931		During February, 1932		During March, 1930		During April, 1930		About May 1, 1930	

TABLE I—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	Dominion Steel and Coal Corporation, Limited, Montreal Coal samples from the Sydney area, Nova Scotia																			
	Supplied to the Fuel Research Laboratories through the Department of Public Works																Supplied to the Fuel Research Laboratories by the Coal Company		Supplied to an industrial plant at Cornwall, Ont.	
Sample No.	8045		8107		8202		8493		8588		8961		10443		10612		9095		9984	
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 p.c.	2·9	....	4·3	....	6·6	....	8·0	....	6·6	....	6·3	....	7·9	....	6·9	....	1·9	....	1·7	....
Ash "	8·0	8·2	7·3	7·6	8·6	9·2	7·4	8·1	7·4	7·9	8·0	8·5	8·0	8·7	7·8	8·4	6·3	6·4	7·5	7·7
Volatile matter "	32·4	33·4	31·9	33·4	30·7	32·9	30·0	32·6	31·4	33·6	31·3	33·4	29·9	32·5	30·2	32·4	34·4	35·1	33·9	34·5
Fixed carbon "	56·7	58·4	56·5	59·0	54·1	57·9	54·6	59·3	54·6	58·5	54·4	58·1	54·2	58·8	55·1	59·2	57·4	58·5	56·9	57·8
Ultimate Analysis—																				
Carbon "	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	77·4	78·9	....	....
Hydrogen "	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	5·5	5·3	....	....
Ash "	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	6·3	6·4	....	....
Sulphur "	2·9	3·0	2·8	2·9	2·6	2·8	2·5	2·7	2·4	2·6	2·4	2·6	2·8	3·0	2·7	2·9	2·9	3·0	3·1	3·1
Nitrogen "	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1·4	1·5	....	....
Oxygen "	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	6·5	4·9	....	....
Calorific Value—																				
Calories per gramme, gross	7,495	7,720	7,495	7,830	7,020	7,520	7,050	7,665	7,145	7,650	7,125	7,605	7,025	7,620	7,225	7,760	7,810	7,965	7,600	7,730
B.T.U. per lb., gross	13,490	13,890	13,490	14,090	12,640	13,540	12,690	13,800	12,860	13,770	12,830	13,690	12,640	13,720	13,010	13,970	14,060	14,340	13,680	13,910
Fuel ratio	1·75		1·75		1·75		1·80		1·75		1·75		1·80		1·85		1·65		1·70	
Carbon-hydrogen ratio	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	14·1	14·8	....	....
Coking properties	Good		Good		Good		Good		Good		Fair		Good		Good		Good		Good	
Softening temperature of ash °F.	......		......		......		......		......		......		......		......		2020		......	
Screen analysis (square screen openings) p.c.	......		......		......		......		......		......		......		......		On 1″=0·8, 1″ to ¾″=12·6, ¾″ to ½″=23·7, ½″ to ¼″=40·8, ¼″ to ⅛″=15·9, Per ⅛″=6·2			
Designation of coal	All slack																......		......	
Kind of sample	All commercial																......		......	
Taken by	W. Kristch, laboratory assistant, Fuel Research Laboratories																Lab. sample by F.R.L. staff		Purchaser of coal	
Date of sampling	During November, 1930		During December, 1930		During January, 1931		During February, 1931		During March, 1931		During April, 1931		During January, 1932		During March, 1932		June 6, 1931		November, 1931	

TABLE I—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	Dominion Steel and Coal Corporation, Limited, Montreal Selected samples from coal pillars taken in the Phalen seam in the Glace Bay district, Nova Scotia															
	Bright coal								Dull coal							
Sample No.	7448		7449		7597		9852		7450		7451		7598		9853	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—																
Moisture per cent	2·4	....	2·2	....	3·1	....	2·7	....	1·8	....	1·3	....	2·2	....	2·1	....
Ash "	3·0	3·0	0·7	0·7	1·9	2·0	4·1	4·2	6·0	6·1	4·2	4·3	5·1	5·2	7·2	7·3
Volatile matter "	32·2	33·0	31·3	32·0	31·0	32·0	29·3	30·1	34·0	34·6	38·3	38·8	34·0	34·8	32·6	33·3
Fixed carbon "	62·4	64·0	65·8	67·3	64·0	66·0	63·9	65·7	58·2	59·3	56·2	56·9	58·7	60·0	58·1	59·4
Ultimate Analysis—																
Carbon "	....	....	....	....	80·3	82·9	80·0	82·3	....	....	....	....	75·7	77·4	76·1	77·8
Hydrogen "	....	....	....	....	5·4	5·2	5·0	4·8	....	....	....	....	5·2	5·0	5·1	5·0
Ash "	....	....	....	....	1·9	2·0	4·1	4·2	....	....	....	....	5·1	5·2	7·2	7·3
Sulphur "	1·3	1·4	0·7	0·8	1·3	1·3	1·3	1·3	0·8	0·8	5·0	5·1	3·5	3·6	2·3	2·3
Nitrogen "	....	....	....	....	1·4	1·4	1·4	1·4	....	....	....	....	1·3	1·3	1·5	1·6
Oxygen "	....	....	....	....	9·7	7·2	8·2	6·0	....	....	....	....	9·2	7·5	7·8	6·0
Calorific Value—																
Calories per gramme, gross	....	....	....	....	7,975	8,230	7,860	8,080	....	....	....	....	7,680	7,850	7,560	7,725
B.T.U. per lb., gross	....	....	....	....	14,360	14,810	14,150	14,550	....	....	....	....	13,830	14,130	13,610	13,910
Fuel ratio	1·95		2·10		2·05		2·20		1·70		1·45		1·75		1·80	
Carbon-hydrogen ratio	....	....	....	....	14·9	15·9	16·0	17·0	....	....	....	....	14·7	15·4	14·9	15·7
Coking properties	Good		Good		Good		Fair		Good		Good		Good		Fair	
Softening temperature of ash, °F.	....	....	....	....	2145		2009		....	....	....	....	2020		2115	
Specific gravity (apparent), lumps.	....	....	....	....	....	....	1·27		....	....	....	....	....	....	1·42	
Specific gravity (apparent), fines and dust	....	....	....	....	....	....	1·26		....	....	....	....	....	....	1·23	
Taken by	W. Nemerovsky, Geological Survey															
Date of sampling	Pillars taken during the summer and autumn of 1928															

TABLE I—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	Dominion Steel and Coal Corporation, Limited, Montreal										Coal samples believed to come from the Drummond colliery, Intercolonial Coal Co., Ltd., Westville, Nova Scotia			
	Selected samples of Fusain from pillars taken in the Phalen seam in the Glace Bay district, Nova Scotia								Coal from Princess colliery of Nova Scotia Steel and Coal Company, Ltd., Main seam, Sydney Mines, Nova Scotia					
Sample No.	7452		7453		7599		9854		9292		9045		9046	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—														
Moisture per cent	2·1	....	2·5	....	2·7	....	1·3	....	7·0	....	2·9	....	3·0	....
Ash "	10·8	11·0	11·3	11·6	19·9	20·4	17·2	17·4	3·1	3·3	12·5	12·9	13·0	13·4
Volatile matter "	20·7	21·1	18·4	18·9	23·4	24·1	22·5	22·8	36·3	39·0	27·1	27·9	27·0	27·8
Fixed carbon "	66·4	67·9	67·8	69·5	54·0	55·5	59·0	59·8	53·6	57·7	57·5	59·2	57·0	58·8
Ultimate Analysis—														
Carbon per cent	....	....	....	....	65·8	67·7	69·7	70·7	76·0	81·8	....	....	....	....
Hydrogen "	....	....	....	....	3·2	3·0	3·0	2·9	5·8	5·3	....	....	....	....
Ash "	....	....	....	....	19·9	20·4	17·2	17·4	3·1	3·3	....	....	....	....
Sulphur "	5·9	6·0	1·0	1·0	1·3	1·3	1·1	1·1	1·2	1·3	0·7	0·8	0·8	0·8
Nitrogen "	....	....	....	....	0·5	0·5	0·5	0·5	1·6	1·7	....	....	....	....
Oxygen "	....	....	....	....	9·3	7·1	8·5	7·4	12·3	6·6	....	....	....	....
Calorific Value—														
Calories per gramme, gross	....	....	....	....	5,995	6,155	6.205	6,290	7,610	8,185	7,120	7,330	7.000	7,215
B.T.U., per lb., gross	....	....	....	....	10,790	11,080	11,170	11,320	13,700	14,730	12,810	13,190	12,600	12,990
Fuel ratio	3·20		3·70		2·30		2·60		1·50		2·10		2·10	
Carbon-hydrogen ratio	....	....	....	....	20·4	22·5	23·1	24·3	13·2	15·3	....	....	....	....
Coking properties	Non-coking		Non-coking		Non-coking		Non-coking		Good		Poor		Poor	
Softening temperature of ash °F	....	....	....	....	2505		2680		1995		....	....	....	....
Specific gravity (apparent) lumps	....	....	....	....	....	....	1·48		....	....	....	....	....	....
Specific gravity (apparent) fines and dust	....	....	....	....	....	....	1·29		....	....	....	....	....	....
Screen analysis (square screen openings) per cent	....	....	....	....	....	....	....	....	On 1″–0·4, 1″ to ¾″=1·9, ¾″ to ½″=2·2, ½″ to ¼″=10·6, ¼″ to ⅛″=19·7, per ⅛″=65·2		....	....	....	....
Designation of coal	....								Specially washed slack		Drummond coal, ¾-inch bituminous		....	
Kind of sample	Mine								Commercial, 43 tons		Commercial			
Taken by	W. Nemerovsky, Geological Survey								Lab. sample by F.R.L. staff		Department of National Defence			
Date of sampling	Pillars taken during the summer and autumn of 1928								August 12, 1931		May, 1931			

TABLE I—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	Samples from a location 2 miles from Digby, Nova Scotia.				Sample from claims 287 to 289 and 331 to 336 in Coal Creek district near Chipman, New Brunswick.		Sample from north part of block 44, 4 miles S.W. of Chipman.		Avon Coal Co., Ltd., Minto, New Brunswick.					W. Benton Evans, Rothwell mine, Minto.		Minto Coal Co., Ltd., Minto. Probably from northern holdings of the company.	
									Winterport coal.		New Zion coal.						
Sample No.	9775a		9775b		10171		9354		7040		7039			7038		7037	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	AD	D	R	D	R	D
Proximate Analysis—																	
Moisture per cent	4·3	....	4·0	....	1·1	....	2·1	....	1·5	....	2·6	1·0	....	1·1	....	1·0	....
Ash "	7·8	8·1	14·6	15·2	15·2	15·4	8·3	8·5	16·9	17·1	14·5	14·7	14·9	12·9	13·1	13·1	13·2
Volatile matter "	6·3	6·6	28·1	29·3	34·2	34·5	31·9	32·5	31·1	31·6	29·9	30·4	30·7	33·1	33·4	32·8	33·2
Fixed carbon "	81·6	85·3	53·3	55·5	49·5	50·1	57·7	59·0	50·5	51·3	53·0	53·9	54·4	52·9	53·5	53·1	53·6
Ultimate Analysis—																	
Carbon per cent	....	....	....	....	....	....	....	....	....	....	71·9	73·1	73·8	71·8	72·6	....	....
Hydrogen "	....	....	....	....	....	....	....	....	....	....	4·8	4·7	4·6	4·8	4·7	....	....
Ash "	....	....	....	....	....	....	....	....	....	....	14·5	14·7	14·9	12·9	13·1	....	....
Sulphur "	....	....	....	....	8·4	8·5	2·5	2·6	7·1	7·2	5·7	5·8	5·8	5·9	6·0	6·2	6·3
Nitrogen "	....	....	....	....	....	....	....	....	....	....	0·7	0·7	0·8	1·0	1·0	....	....
Oxygen "	....	....	....	....	....	....	....	....	....	....	2·4	1·0	0·1	3·6	2·6	....	....
Calorific Value—																	
Calories per gramme, gross	....	....	....	....	7,035	7,110	7,445	7,600	6,760	6,865	6,945	7,060	7,135	7,270	7,350	7,285	7,355
B.T.U. per lb., gross	....	....	....	....	12,660	12,800	13,400	13,680	12,170	12,360	12,500	12,710	12,840	13,090	13,230	13,110	13,240
Fuel ratio	13·00		1·90		1·45		1·80		1·65		1·75			1·60		1·60	
Carbon-hydrogen ratio	....	....	....	....	....	....	....	....	....	....	15·0	15·6	15·9	14·8	15·2	....	....
Coking properties	Non-coking		Non-coking		Good		Good		Fair		Fair			Fair		Fair	
Softening temperature of ash °F.	....		....		....		....		1975		1980			1975		1950	
Kind of sample	Prospect								....								
Taken by	Submitted by official of Canadian Pacific Railway.				Private individuals				Mine operators								
Date of sampling	Summer of 1931				January, 1932		Summer of 1931		May, 1930								

TABLE I—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	Samples from Clones Settlement, about 14 miles north of Welsford, New Brunswick.				Samples reported to come from the island of Orleans, in the St. Lawrence river near Quebec, Quebec, believed to be "Anthraxolite".					Peat from Government bog, Alfred, Ontario; dug in 1929, and stored out-of-doors at the Fuel Research Laboratories.		Sample sent in from Sudbury, Ontario, and believed to be "Anthraxolite".	
Sample No.	7346		7589		10034			10042		9047		7633	
Moisture condition	R	D	R	D	R	AD	D	R	D	R	D	R	D
Proximate Analysis—													
Moisture ... per cent	1·4	....	1·1	....	6·9	3·4	....	4·1	....	45·8	....	3·3	....
Ash ... "	11·5	11·7	9·3	9·4	16·8	17·4	18·0	1·6	1·6	2·9	5·3	12·2	12·6
Volatile matter ... "	31·0	31·4	31·3	31·6	20·1	20·9	21·6	22·6	23·6	34·0	62·7	9·7	10·0
Fixed carbon ... "	56·1	56·9	58·3	59·0	56·2	58·3	60·4	71·7	74·8	17·3	32·0	74·8	77·4
Ultimate Analysis—													
Carbon ... per cent	....	....	....	....	....	....	....	....	....	30·8	56·8	....	....
Hydrogen ... "	....	....	....	....	....	....	....	....	....	8·1	5·6	....	....
Ash ... "	....	....	....	....	....	....	....	....	....	2·9	5·3	....	....
Sulphur ... "	0·3	0·4	6·3	6·4	0·5	0·5	0·5	0·6	0·7	0·1	0·2	0·9	0·9
Nitrogen ... "	....	....	....	....	....	....	....	....	....	1·2	2·2	....	....
Oxygen ... "	....	....	....	....	....	....	....	....	....	56·9	29·9	....	....
Calorific Value—													
Calories per gramme, gross	....	....	7,690	7,780	6,575	6,820	7,060	8,150	8,500	2,910	5,360	6,800	7,040
B.T.U. per lb., gross	....	....	13,850	14,000	11,840	12,270	12,700	14,670	15,300	5,240	9,650	12,250	12,670
Fuel ratio	1·80		1·85		2·80			3·15		0·51		7·75	
Carbon-hydrogen ratio	....	....	....	....	....	....	....	....	....	3·8	10·2	....	....
Coking properties	Good		Good		Non-coking			Non-coking		Non-coking		....	
Softening temperature of ash ... °F.	....		....		2220			....		2375		....	
Screen analysis (square screen openings) ... per cent	....		....		....			....		On 1″=0·7, 1″ to ¾″=16·3, ¾″ to ½″=27·9, ½″ to ¼″=29·0, ¼″ to ⅛″=11·2, per ⅛″=14·9.		....	
Designation of fuel	....				As sent to Fuel Research Laboratories.			Washed at F.R.L.		Domestic size.		....	
Kind of sample	Prospect				....			....		Commercial—2 carloads.		....	
Taken by	Submitted by official of Canadian Pacific Railway.				Private individual			....		Lab. sample by staff of F.R.L.		Private individual.	
Date of sampling	July, 1930		September, 1930		Autumn of 1931			December 30, 1931.		May 28, 1931		October, 1930	

TABLE I—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

	Onakawana lignite from the neighbourhood of the Abitibi river, Moose River basin, northern Ontario; from shaft No. 1—Lower seam.																				
Sample No.	6983			6984			6985			6986			6987			6988			6989		
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—																					
Moisture.....per cent	51·8	19·2	....	51·3	20·1	....	51·7	18·6	....	52·8	19·7	....	41·4	18·4	....	41·9	19·3	....	45·2	20·2	....
Ash.......... "	5·3	8·9	11·0	4·8	7·9	9·9	5·6	9·5	11·7	3·6	6·0	7·5	9·4	13·1	16·1	6·6	9·2	11·4	4·8	7·0	8·8
Volatile matter "	19·9	33·3	41·2	20·3	33·3	41·6	20·5	34·5	42·4	20·7	35·3	43·9	22·8	31·7	38·9	23·5	32·7	40·5	22·4	32·6	40·8
Fixed carbon. "	23·0	38·6	47·8	23·6	38·7	48·5	22·2	37·4	45·9	22·9	39·0	48·6	26·4	36·8	45·0	28·0	38·8	48·1	27·6	40·2	50·4
Ultimate Analysis—																					
Carbon.......per cent	....	....	....	....	....	....	30·4	51·2	62·9	30·4	51·8	64·5	34·4	47·9	58·7	35·8	49·8	61·6	34·8	50·7	63·5
Hydrogen.... "	....	....	....	....	....	....	7·8	5·5	4·2	8·0	5·8	4·5	6·9	5·3	4·0	7·0	5·4	4·0	7·2	5·5	4·0
Ash.......... "	....	....	....	....	....	....	5·6	9·5	11·7	3·6	6·0	7·5	9·4	13·1	16·1	6·6	9·2	11·4	4·8	7·0	8·8
Sulphur...... "	0·5	0·8	1·0	0·4	0·7	0·9	1·0	1·6	2·0	0·3	0·5	0·6	0·2	0·3	0·4	0·3	0·5	0·6	0·2	0·3	0·4
Nitrogen..... "	....	....	....	....	....	....	0·2	0·4	0·5	0·2	0·4	0·5	0·3	0·4	0·4	0·4	0·5	0·7	0·4	0·5	0·6
Oxygen....... "	....	....	....	....	....	....	55·0	31·8	18·7	57·5	35·5	22·4	48·8	33·0	20·4	49·9	34·6	21·7	52·6	36·0	22·7
Calorific Value—																					
Calories per gramme, gross..............	....	....	....	....	....	....	2,775	4,675	5,750	2,800	4,770	5,940	3,110	4,330	5,310	3,245	4,510	5,585	3,135	4,565	5,720
B.T.U. per lb., gross.	....	....	....	....	....	....	5,000	8,420	10,350	5,040	8,580	10,690	5,600	7,700	9,560	5,840	8,120	10,050	5,640	8,210	10,290
Fuel ratio..............	1·15			1·15			1·10			1·10			1·15			1·20			1·25		
Carbon-hydrogen ratio.	....	....	....	....	....	....	3·9	9·3	14·9	3·8	8·9	14·4	5·0	9·1	14·8	5·1	9·2	15·3	4·8	9·2	15·7
Coking properties.......	Non-coking			Non-coking			Non-coking			Non-coking			Non-coking			Non-coking			Non-coking		
Kind of sample.........	All mine..																				
Location in mine.......	2 feet along drift No. 1a; 0 to 2 ft. depth.			4 feet along drift No. 1a; 2 to 4 ft. depth.			2 feet along drift No. 1a; 4 to 6 ft. depth.			4 feet along drift No. 1a; 6 to 7 ft. depth.			Main shaft, 3 to 4 ft. depth.			4 to 5 ft. depth.....			5 to 6 ft. depth.		
Taken by..............	Ontario Department of Mines..																				
Date of sampling.......	Spring of 1930..																				

TABLE I—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	Onakawana lignite from the neighbourhood of the Abitibi river, Moose River basin, northern Ontario; from shaft No. 1—Lower seam.																				
Sample No.	6990			6991			6992			6994			6995			6996			6997		
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—																					
Moisture.....per cent	43·4	19·3	....	37·6	17·7	....	43·5	18·1	....	39·1	19·0	....	37·8	18·9	....	38·5	19·8	....	36·7	19·6	....
Ash "	6·4	9·1	11·3	7·0	9·2	11·2	4·3	6·2	7·5	5·9	7·8	9·6	6·7	8·7	10·7	5·6	7·4	9·2	7·1	9·1	11·3
Volatile matter "	23·3	33·2	41·1	27·2	35·9	43·6	26·9	39·0	47·7	26·0	34·7	42·8	26·2	34·2	42·2	25·9	33·7	42·1	26·8	34·0	42·3
Fixed carbon. "	26·9	38·4	47·6	28·2	37·2	45·2	25·3	36·7	44·8	29·0	38·5	47·6	29·3	38·2	47·1	30·0	39·1	48·7	29·4	37·3	46·4
Ultimate Analysis—																					
Carbon.......per cent	....	....	....	....	....	....	....	....	....	....	....	....	39·8	52·0	64·1	....	....	....	....	....	....
Hydrogen..... "	....	....	....	....	....	....	....	....	....	....	....	....	6·9	5·6	4·3	....	....	....	....	....	....
Ash......... "	....	....	....	....	....	....	....	....	....	....	....	....	6·7	8·7	10·7	....	....	....	....	....	....
Sulphur...... "	0·2	0·3	0·4	0·4	0·6	0·7	0·2	0·3	0·4	0·6	0·9	1·1	0·4	0·5	0·7	0·4	0·6	0·7	0·8	1·0	1·3
Nitrogen..... "	....	....	....	....	....	....	....	....	....	....	....	....	0·4	0·5	0·6	....	....	....	....	....	....
Oxygen....... "	....	....	....	....	....	....	....	....	....	....	....	....	45·8	32·7	19·6	....	....	....	....	....	....
Calorific Value—																					
Calories per gramme, gross	....	....	....	....	....	....	....	....	....	....	....	....	3,640	4,750	5,850	....	....	....	....	....	....
B.T.U. per lb., gross.	....	....	....	....	....	....	....	....	....	....	....	....	6,550	8,450	10,530	....	....	....	....	....	....
Fuel ratio	1·15			1·05			0·94			1·10			1·10			1·15			1·10		
Carbon-hydrogen ratio.	....	....	....	....	....	....	....	....	....	....	....	....	5·8	9·3	14·9	....	....	....	....	....	....
Coking properties	Non-coking			Non-coking			Non-coking			Non-coking			Non-coking			Non-coking			Non-coking		
Kind of sample	All mine																				
Location in mine	6 to 7 ft. depth			7 to 8 ft. depth			8 to 9 ft. depth			10 to 11 ft. depth			11 to 12 ft. depth			12 to 13 ft. depth			13 to 14 ft. depth		
Taken by	Ontario Department of Mines																				
Date of sampling	Spring of 1930																				

TABLE I—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	Onakawana lignite from the neighbourhood of the Abitibi river, Moose River basin, northern Ontario; from shaft No. 1—Lower seam																				
Sample No.	6998			6999			7000			7001			7002			7003			7004		
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—																					
Moisture......per cent	37·7	19·4	....	37·6	20·6	....	41·5	18·5	....	43·2	19·7	....	41·0	19·0	....	38·0	18·8	....	36·4	18·9	....
Ash "	5·7	7·4	9·1	6·1	7·8	9·8	6·2	8·7	10·7	6·2	8·8	10·9	5·4	7·4	9·1	9·1	11·9	14·7	8·1	10·3	12·7
Volatile matter "	27·9	36·1	44·9	27·7	35·2	44·4	25·7	35·8	43·9	23·4	33·1	41·3	25·8	35·5	43·8	25·8	33·8	41·6	26·6	34·0	41·9
Fixed carbon... "	28·7	37·1	46·0	28·6	36·4	45·8	26·6	37·0	45·4	27·2	38·4	47·8	27·8	38·1	47·1	27·1	35·5	43·7	28·9	36·8	45·4
Ultimate Analysis—																					
Carbon.......per cent	....	....	....	....	....	....	....	....	....	....	....	....	38·1	52·3	64·5	37·5	49·1	60·5	....	....	....
Hydrogen...... "	....	....	....	....	....	....	....	....	....	....	....	....	7·3	5·9	4·7	6·7	5·3	4·0	....	....	....
Ash............ "	....	....	....	....	....	....	....	....	....	....	....	....	5·4	7·4	9·1	9·1	11·9	14·7	....	....	....
Sulphur........ "	0·9	1·2	1·5	1·0	1·3	1·6	2·0	2·8	3·4	0·9	1·2	1·5	0·4	0·6	0·7	1·6	2·2	2·6	0·5	0·6	0·7
Nitrogen....... "	....	....	....	....	....	....	....	....	....	....	....	....	0·3	0·4	0·5	0·4	0·5	0·6	....	....	....
Oxygen......... "	....	....	....	....	....	....	....	....	....	....	....	....	48·5	33·4	20·5	44·7	31·0	17·6	....	....	....
Calorific Value—																					
Calories per gramme, gross......	....	....	....	....	....	....	....	....	....	....	....	....	3,535	4,855	5,990	3,440	4,505	5,545	....	....	....
B.T.U. per lb., gross.	....	....	....	....	....	....	....	....	....	....	....	....	6,360	8,740	10,780	6,190	8,110	9,980	....	....	....
Fuel ratio.............	1·05			1·05			1·05			1·15			1·10			1·05			1·10		
Carbon-hydrogen ratio.	....	....	....	....	....	....	....	....	....	....	....	....	5·2	8·9	13·9	5·6	9·3	15·3	....	....	....
Coking properties......	Non-coking			Non-coking			Non-coking			Non-coking			Non-coking			Non-coking			Non-coking		
Kind of sample.........	All mine																				
Location in mine.......	14 to 15 ft. depth			15 to 16 ft. depth			16 to 17 ft. depth			17 to 18 ft. depth			18 to 19 ft. depth			19 to 20 ft. depth			20 to 21 ft. depth		
Taken by.............	Ontario Department of Mines																				
Date of sampling.......	Spring of 1930																				

TABLE I—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	Onakawana lignite from the neighbourhood of the Abitibi river, Moose River basin, northern Ontario; from deposit worked by the Ontario Department of Mines													
	—								Samples selected from carlot 9235					
									Tree trunk —woody	Twigs —woody	Bark	Hard peaty	Soft peaty	Fusain
Sample No.	6751			8843			9235		10004	10005	10006	10007	10008	10009
Moisture condition	R	AD	D	R	AD	D	R	D	D	D	D	D	D	D
Proximate Analysis—														
Moisture . . . . per cent	51·8	18·3	....	55·8	18·1	....	36·3	....	....	....	....	....	....	....
Ash "	6·9	11·7	14·3	8·3	15·4	18·8	7·0	11·1	5·6	5·1	10·4	6·9	9·8	11·2
Volatile matter "	19·6	33·2	40·7	16·6	30·8	37·6	27·1	42·5	46·1	47·8	43·1	45·6	41·9	35·5
Fixed carbon "	21·7	36·8	45·0	19·3	35·7	43·6	29·6	46·4	48·3	47·1	46·5	47·5	48·3	53·3
Ultimate Analysis—														
Carbon . . . . per cent	30·0	50·8	62·1	26·4	48·8	59·7	40·2	63·2	66·2	66·0	64·1	64·1	66·3	65·7
Hydrogen "	7·7	5·4	4·1	7·9	5·1	3·8	6·8	4·3	4·7	4·6	4·1	4·4	4·1	3·5
Ash "	6·9	11·7	14·3	8·3	15·4	18·8	7·0	11·1	5·6	5·1	10·4	6·9	9·8	11·2
Sulphur "	1·0	1·7	2·1	0·5	0·9	1·0	0·8	1·2	0·7	0·4	1·8	0·6	1·1	3·6
Nitrogen "	0·3	0·5	0·6	0·3	0·5	0·6	0·4	0·6	0·4	0·5	0·7	0·7	0·6	0·5
Oxygen "	54·1	29·9	16·8	56·6	29·3	16·1	44·8	19·6	22·4	23·4	18·9	23·3	18·1	15·5
Calorific Value—														
Calories per gramme, gross	2,790	4,725	5,785	2,355	4,365	5,335	3,685	5,785	6,115	6,170	5,865	5,950	5,905	5,935
B.T.U. per lb., gross	5,020	8,510	10,410	4,240	7,860	9,600	6,630	10,420	11,010	11,110	10,560	10,710	10,630	10,680
Fuel ratio	1·10			1·15			1·10		1·05	1·00	1·10	1·05	1·15	1·50
Carbon-hydrogen ratio	3·9	9·4	15·2	3·3	9·6	15·8	5·9	14·8	14·0	14·3	15·6	14·4	16·3	18·7
Coking properties	Non-coking			Non-coking			Non-coking		Non-coking	Non-coking	Non-coking	Non-coking	Non-coking	Non-coking
Softening temperature of ash . . . . °F.	1975			2065			2210		2200	2350	2270	2360	2260	2125
Designation of fuel	Run-of-mine													
Kind of sample	Carload			Carload: 30 tons			Carload: 30 tons							
Taken by	Ontario Department of Mines								Staff of Fuel Research Laboratories					
Date of sampling	April, 1930			April, 1931			July, 1931		Autumn of 1931					

Carload shipments as represented by sample numbers 6751, 8843 and 9235 are the Onakawana lignites on which boiler trials were made, as listed on pages 27 and 28 and reported in appended table opposite page 35. The last carload, namely, 9235, which was the better grade lower seam lignite, was somewhat air-dried when received, whereas samples 6751 and 8843 were noticeably lower grade coal from the upper seam, and were received in the wet frozen condition. The as-received moisture figures of these two lots are, therefore, abnormally high and should be corrected for superficial moisture. Recent tests indicate that the actual (inherent) moisture content of the freshly mined Onakawana lignite is not in excess of 50 per cent and this is subject to a further loss by air drying during handling.

TABLE I—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	Deloraine Coal Mines, Ltd., south of Deloraine, Manitoba; N.W. ¼ sec. 11, tp. 2, R. 23 W. prin. mer.	E. J. Sinclair's mine, Roche Percée, Saskatchewan; L.S. 16, sec. 29, tp. 1, R. 6 W. 2 mer.			James Marshall's mine, Big Muddy, Saskatchewan; L.S. 6, sec. 6, tp. 1, R. 21 W. 2 mer.			E. E. Byers' mine, No. 28, Bengough, Saskatchewan; L.S. 7, sec. 34, tp. 4, R. 23 W. 2 mer.			C. H. Waldon's mine, Harptree, Saskatchewan L.S. 13, sec. 34, tp. 3, R. 26 W. 2 mer.					
Sample No.	10172	7966			7961			7962			7759			9094		
Moisture condition	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—																
Moisture........per cent	....	33·3	25·0	....	38·9	22·1	....	37·2	22·3	....	38·3	22·4	....	45·7	21·9	....
Ash "	15·5	6·8	7·7	10·2	10·0	12·8	16·4	6·8	8·4	10·9	10·2	12·9	16·6	8·7	12·5	16·0
Volatile matter "	38·4	27·9	31·3	41·8	26·0	33·2	42·6	25·6	31·7	40·8	22·8	28·6	36·9	20·5	29·4	37·7
Fixed carbon "	46·1	32·0	36·0	48·0	25·1	31·9	41·0	30·4	37·6	48·3	28·7	36·1	46·5	25·1	36·2	46·3
Ultimate Analysis—																
Sulphur.........per cent	0·6	0·7	0·7	1·0	0·3	0·4	0·5	0·5	0·7	0·9	0·7	0·8	1·1	0·6	0·9	1·1
Calorific Value—																
Calories per gramme, gross	5,725	4,265	4,800	6,395	3,250	4,145	5,320	3,640	4,505	5,800	3,305	4,155	5,355	2,960	4,260	5,450
B.T.U. per lb, gross	10,300	7,680	8,640	11,510	5,850	7,460	9,570	6,550	8,110	10,440	5,950	7,480	9,640	5,330	7,660	9,810
Fuel ratio	1·20	1·15			0·96			1·20			1·25			1·25		
Coking properties	Non-coking	Non-coking			Non-coking			Non-coking			Non-coking			Non-coking		
Softening temperature of ash °F.	2050	....			....			....			....			....		
Kind of sample	....	Mine												....		
Location of mine	....	Main entry; 5 ft. of coal overlain by ½-inch clay band			Face of main entry; 6 ft. of coal.			Room No. 4; upper 4 ft. coal, 8 inches clay, lower 1 ft. coal			Face of main entry; 7-ft. 6-inch seam with 4-in. clay parting 14 in. from floor.			....		
Taken by	Submitted by C. H. Freeman, Mines Branch	Mining Inspector, Federal Department of Interior												Submitted by Provincial Deputy Minister; probably taken by mine operator		
Date of sampling	Autumn of 1931	Nov. 13, 1930			Nov. 10, 1930			Nov. 10, 1930			Oct. 20, 1930			Spring of 1931		

TABLE I—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	William Johnson's mine, Harptree, Saskatchewan; L.S. 15, sec. 29, tp. 3, R. 26 W. 2 mer.			Henry Vanden Heuval's mine, Hart, Saskatchewan; L.S. 16, sec. 24, tp. 4, R. 27 W.2 mer.			William Meeker's mine, Gye, Saskatchewan; L.S. 10, sec. 34, tp. 4, R. 27 W. 2 mer.			Charles Sjodin's mine, No. 81, Verwood, Saskatchewan; L.S. 14, S. ½ sec. 29, tp. 6, R. 27 W. 2 mer.			R. O. Birchard's mine, Verwood; L.S. 10, sec. 32, tp. 6, R. 27 W. 2 mer.			From seam 3 miles from Readlyn, Saskatchewan; sec. 28, tp. 7, R. 27 W. 2 mer.		
Sample No.	7762			7963			7763			8001			7764			10478		
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—																		
Moisture, per cent	39·1	23·2	....	43·4	21·9	....	41·0	23·1	....	41·2	19·4	....	40·1	25·0	....	41·6	18·7	....
Ash "	9·7	12·2	15·9	9·1	12·6	16·1	9·4	12·2	15·9	5·6	7·7	9·5	10·0	12·5	16·6	7·6	10·6	13·0
Volatile matter "	25·0	31·5	41·0	21·7	30·0	38·4	22·6	29·5	38·3	26·3	36·0	44·7	24·1	30·2	40·2	24·9	34·7	42·7
Fixed carbon "	26·2	33·1	43·1	25·8	35·5	45·5	27·0	35·2	45·8	26·9	36·9	45·8	25·8	32·3	43·2	25·9	36·0	44·3
Ultimate Analysis—																		
Sulphur, per cent	1·2	1·5	2·0	2·3	3·1	4·0	2·2	2·8	3·6	1·4	1·5	1·9	1·4	1·7	2·3	1·0	1·4	1·7
Calorific Value—																		
Calories per gramme, gross	3,395	4,290	5,580	3,120	4,310	5,510	3,315	4,315	5,615	3,470	4,755	5,905	3,355	4,200	5,600	3,430	4,765	5,865
B.T.U. per lb., gross	6,110	7,720	10,050	5,620	7,750	9,920	5,970	7,770	10,110	6,250	8,560	10,630	6,040	7,560	10,080	6,170	8,580	10,560
Fuel ratio	1·05			1·20			1·20			1·05			1·05			1·05		
Coking properties	Non-coking			Non-coking			Non-coking			Non-coking			Non-coking			Non-coking		
Softening temperature of ash. °F.	....			....			....			....			....			2250		
Kind of sample	Mine															Prospect		
Location of mine	Face of main entry; across 7½-ft. seam with 4 in. of "black-jack" 14 in. from floor			Face of main entry; across 6-ft. seam			8-ft seam			New opening			Room No. 1; across 3-ft 8-in. seam, with 4-in. clay parting 4 in. from roof.			....		
Taken by	Mining Inspector, Federal Department of Interior									Mine operator			Mining Inspector			Private individual		
Date of sampling	Oct. 21, 1930			Nov. 11, 1930			Oct. 22, 1930			Autumn of 1930			Oct. 22, 1930			February, 1932		

TABLE I—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	From seams 3 miles from Readlyn, Saskatchewan; sec. 28, tp. 7, R. 27 W. 2 mer.									Joe Paulhus' mine, Willow Bunch, Saskatchewan; L.S. 15, sec. 13, tp. 5, R. 28 W. 2 mer.			M. B. Midland's mine, between Willow Bunch and Verwood; L.S. 3, sec. 12, tp. 6, R. 28 W. 2 mer.			Edwin Lund's mine, Willows, Saskatchewan; L.S. 2, sec. 24, tp. 7, R. 29 W. 2 mer.		
Sample No.	10479			10480			10481			7761			7760			7965		
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—																		
Moisture, per cent	41·3	18·7	....	40·0	16·6	....	40·4	18·2	....	39·7	22·1	....	40·1	22·3	....	42·3	22·9	....
Ash “	5·4	7·5	9·2	7·4	10·3	12·3	5·8	8·0	9·8	8·2	10·6	13·7	7·4	9·6	12·4	5·9	7·8	10·1
Volatile matter “	25·6	35·4	43·6	23·5	32·7	39·2	25·5	34·9	42·7	25·1	32·5	41·6	24·9	32·3	41·6	25·4	34·0	44·1
Fixed carbon “	27·7	38·4	47·2	29·1	40·4	48·5	28·3	38·9	47·5	27·0	34·8	44·7	27·6	35·8	46·0	26·4	35·3	45·8
Ultimate Analysis—																		
Sulphur, per cent	0·4	0·5	0·6	1·5	2·1	2·5	0·5	0·7	0·9	0·7	0·9	1·2	0·3	0·4	0·5	0·5	0·7	0·9
Calorific Value—																		
Calories per gramme, gross	3,555	4,920	6,055	3,570	4,965	5,950	3,565	4,900	5,985	3,340	4,315	5,540	3,410	4,425	5,690	3,500	4,675	6,065
B.T.U. per lb, gross	6,400	8,860	10,900	6,430	8,940	10,710	6,420	8,820	10,770	6,010	7,770	9,970	6,130	7,960	10,240	6,300	8,420	10,920
Fuel ratio	1·10			1·25			1·10			1·05			1·10			1·05		
Coking properties	Non-coking			Non-coking			Non-coking			Non-coking			Non-coking			Non-coking		
Softening temperature of ash.°F.	2300			2280			2275			......			......			......		
Kind of sample	Prospect									Mine								
Location in mine	......									Face of main entry; across 16½-ft. seam			Face of No. 2 entry; across 6½-foot seam.			First room; 16-in. coal, 4-in. clay, 26-in. coal.		
Taken by	Private individual									Mining Inspector, Federal Department of Interior								
Date of sampling	February, 1932									October, 1930			October 20, 1930			November 12, 1930.		

TABLE I—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	Blackfoot Indian Reserve mine, No. 72, near Gleichen, Alberta; sec. 5, tp. 21, R. 20 W. 4 mer.			Bighorn and Saunders Creek Collieries, Ltd., No. 388, Saunders, Alberta; secs. 19 and 24, tp. 40, R. 12 W. 5 mer.		Alberta Mountain Collieries, Ltd., Hinton, Prairie Creek area, Alberta; sec. 10, tp. 51, R. 25 W. 5 mer.		Mohawk Bituminous Mines, Ltd., Maple Leaf mine No. 133, Bellevue, Alberta; W. half of sec. 28, tp. 7, R. 3 W. 5 mer.		West Canadian Collieries, Ltd., Blairmore, Alberta, No. 87, Bellevue; secs. 20 and 29, tp. 7, R. 3 W. 5 mer.		Hillcrest Collieries, Ltd., Hillcrest, Alberta							
												From S.W. side of main basin on section line between 6 and 7				Mine No. 40, secs. 18 and 19, tp. 7, R. 3 W. 5 mer.			
Sample No.	10461			8019		6690		9886		8465		9888		9890		9887		10052	
Moisture condition	R	AD	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—																			
Moisture . . . per cent	17·7	15·7	....	9·8	....	6·0	....	2·2	....	0·9	....	13·3	....	20·1	....	1·4	....	1·2	....
Ash "	7·7	7·9	9·3	9·0	10·0	16·3	17·3	20·3	20·7	10·1	10·2	6·7	7·8	13·3	16·6	19·1	19·4	16·1	16·3
Volatile matter "	30·5	31·2	37·1	31·9	35·4	34·4	36·6	24·1	24·7	29·3	29·5	28·0	32·2	25·8	32·3	27·0	27·4	28·5	28·8
Fixed carbon "	44·1	45·2	53·6	49·3	54·6	43·3	46·1	53·4	54·6	59·7	60·3	52·0	60·0	40·8	51·1	52·5	53·2	54·2	54·9
Ultimate Analysis—																			
Carbon . . . per cent	55·6	57·0	67·7	64·5	71·5	....	....	66·6	68·1	....	....	....	....	....	....	68·9	69·9	71·6	72·5
Hydrogen "	5·7	5·6	4·5	5·3	4·6	....	....	4·2	4·0	....	....	....	....	....	....	4·5	4·4	4·5	4·4
Ash "	7·7	7·9	9·3	9·0	10·0	....	....	20·3	20·7	....	....	....	....	....	....	19·1	19·4	16·1	16·3
Sulphur "	0·4	0·4	0·5	0·3	0·4	0·3	0·4	0·6	0·6	0·6	0·6	0·5	0·6	0·3	0·4	0·5	0·5	0·9	0·9
Nitrogen "	1·3	1·3	1·5	0·9	1·0	....	....	1·0	1·0	....	....	....	....	....	....	1·1	1·1	1·1	1·1
Oxygen "	29·3	27·8	16·5	20·0	12·5	....	....	7·3	5·6	....	....	....	....	....	....	5·9	4·7	5·8	4·8
Calorific Value—																			
Calories per gramme, gross	5,280	5,405	6.410	6,190	6,870	6,235	6,630	6,405	6,550	7,615	7,685	5,615	6,475	4,600	5,755	6,670	6,765	6,990	7,080
B.T.U. per lb, gross	9,500	9,730	11,540	11,150	12,360	11,220	11,930	11,530	11,790	13,710	13,830	10,110	11,650	8,280	10,360	12,010	12,180	12,580	12,740
Fuel ratio	1·45			1·55		1·25		2·20		2·05		1·85		1·60		1·95		1·90	
Carbon-hydrogen ratio	9·7	10·2	14·9	12·3	15·4	....	....	15·9	16·9	....	....	....	....	....	....	15·4	15·9	15·8	16·3
Coking properties	Non-coking			Non-coking		Poor		Poor		Good		Non-coking		Non-coking		Fair		Fair	
Softening temperature of ash . . . °F.	2330			2210		....		2700+		....		....		....		2700+		2635	
Specific gravity (apparent)	....			....		....		....		....		....		....		....		1·342	
Weight per cubic foot . . . lb.	....			....		....		....		....		....		....		....		57	

Screen analysis (square screen openings), per cent.	....	On 3/4"=9·7, 3/4" to 1/2"=20·5, 1/2" to 1/4"=34·4, 1/4" to 1/8"=19·4, per 1/8"=16·0	....	....	....	....	....	....	On 2"=1·3, 2" to 1 1/2"=6·0, 1 1/2" to 1"=6·6, 1" to 3/4"=9·3, 3/4" to 1/2"=9·9, 1/2" to 1/4"=26·2, 1/4" to 1/8"=14·5, per 1/8"=26·2
Designation of coal									Run-of-mine.
Kind of sample	Mine	Commercial—5 tons.		Mine		Prospect		Mine	Commercial—40 tons.
Location in mine	Face of main entry		From dump	No. 2 seam; No. 13 cross-pitch, No. 34 chute.		No. 1 seam	No. 3 seam	No. 1 seam; face of workings off 860-ft. level, 3rd room from end of workings; 170 ft. from fault zone.	
Taken by	Mining Inspector, Federal Department of Interior.	Mine operators	Mine operators	B. R. Mackay, Geological Survey.	Mine operators	B. R. Mackay			Mine operators
Date of sampling	Jan. 28, 1932	November, 1930	January, 1930.	Aug. 27, 1931.	Dec. 10, 1931.	Aug. 19, 1931		Aug. 21, 1931.	December, 1931

TABLE I—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	West Canadian Collieries, Ltd., Greenhill mine, No. 396, Blairmore, Alberta; sec. 2, tp. 8, R. 4 W. 5 mer.				International Coal and Coke Co., Ltd., Denison, No. 88, mine, Coleman, Alberta; tps. 7 and 8, R. 4 W. 5 mer.				McGillivray Creek Coal and Coke Co., Ltd., Carbondale, No. 104, mine, Coleman; sec. 17, tp. 8, R. 4 W. 5 mer.		Canadian American Collieries, Sentinel, Alberta				
Sample No.	7967		9586		9618		9617		9619		9795			9891	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	AD	D	R	D
Proximate Analysis—															
Moisture.....per cent	2·4	....	1·3	....	1·3	....	1·4	....	1·7	....	5·0	3·3	....	3·7	....
Ash "	16·5	16·9	10·9	11·0	13·1	13·3	13·3	13·5	13·3	13·5	16·8	17·1	17·7	26·9	28·0
Volatile matter "	21·4	22·0	23·5	23·8	24·4	24·7	24·8	25·2	23·9	24·3	32·5	33·1	34·2	31·9	33·1
Fixed carbon "	59·7	61·1	64·3	65·2	61·2	62·0	60·5	61·3	61·1	62·2	45·7	46·5	48·1	37·5	38·9
Ultimate Analysis—															
Carbon.....per cent	....	....	77·6	78·6	73·9	74·9	....	....	73·5	74·8	65·2	66·3	68·6	....	....
Hydrogen "	....	....	4·5	4·4	4·3	4·2	....	....	4·4	4·3	4·9	4·7	4·5	....	....
Ash "	....	....	10·9	11·0	13·1	13·3	....	....	13·3	13·5	16·8	17·1	17·7	....	....
Sulphur "	0·4	0·4	0·4	0·5	0·6	0·6	0·7	0·7	0·5	0·5	1·1	1·1	1·2	2·3	2·4
Nitrogen "	1·0	1·1	1·2	1·2	1·1	1·1	1·1	1·1	1·2	1·2	2·2	2·3	2·3	....	....
Oxygen "	....	....	5·4	4·3	7·0	5·9	....	....	7·1	5·7	9·8	8·5	5·7	....	....
Calorific Value—															
Calories per gramme, gross	6,880	7,050	7,505	7,605	7,150	7,245	7,220	7,330	7,110	7,230	6,410	6,515	6,740	5,595	5,800
B.T.U. per lb., gross	12,390	12,690	13,510	13,690	12,870	13,040	13,000	13,190	12,800	13,010	11,540	11,730	12,130	10,060	10,440
Fuel ratio	2·80		2·75		2·50		2·45		2·55		1·40			1·15	
Carbon-hydrogen ratio	....	....	17·2	17·8	17·2	17·7	17·1	17·8	16·7	17·5	13·5	14·0	15·2	....	....
Coking properties	Fair		Good		Fair		Fair		Poor		Fair			Poor	
Softening temperature of ash °F.	2740+		2700+		2700+		2700+		2700+		2400			......	
Weight per cubic foot.....lb.	......		53⅜		58		58		59		46			......	
Screen analysis (square screen openings).....per cent	On 2"=2·8, 2" to 1½"=3·4, 1½" to 1"=3·4, 1" to ¾"=5·1, ¾" to ½"=4·7, per ½" 80·6.		On 1½"=0·7, 1½" to 1"=3·6, 1" to ¾"=11·1, ¾" to ½"=12·5, ½" to ¼"=32·8, ¼" to "=17·5, per ⅛"=21·8.		On 1½" = 0·6, 1½" to 1"=2·1, 1" to ¾"=4·0, ¾" to ½"=3·8, ½" to ¼"=13·4, ¼" to ⅛"=17·2, per ⅛"=58·9.		On 1½"=0·9, 1½" to 1"=2·1, 1" to ¾"=5·2, ¾" to ½"=5·6, ½" to ¼"=15·4, ¼" to ⅛"=18·0, per ⅛"=52·8.		On 1½"=2·3, 1½" to 1"=4·7, 1" to ¾"=9·0, ¾" to ½"=8·5, ½" to ¼"=20·0, ¼" to ⅛"=17·0, per ⅛"=38·5.		....			....	

Designation of coal	Steam coal	Slack, 2" to ⅛"; screened into 4 sizes, each of which was dry-cleaned separately and then remixed with other sizes	Slack, through 2⅛-inch screen; screened into 6 sizes, dry-cleaned and remixed, as with No. 9586.		Slack, through 2-inch screen; screened into 4 sizes, dry-cleaned and re-mixed as with No. 9586.		
Kind of sample	Commercial: 33 tons	Commercial: 20 tons	Commercial: 23 tons in each case		Commercial: 44 tons	Mine	
Location in mine			No. 2 seam; north and south sides of mine.	No. 2 seam; north side of mine.	No. 4 seam, No. 8 level.	Room on east side near bottom, left cross-cut, 400 ft. from mouth of slope.	
						Whole of 5-ft. 5.-in seam	5-in. canneloid bench from 5-ft. 5-in. seam.
Taken by	Mine operators					B. R. Mackay, Geological Survey	
Date of sampling	November, 1930	Sept. 2, 1931	Aug. 29, 1931		Aug. 26, 1931	Aug. 8th, 1931	

TABLE I—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	Canmore Coal Co., Ltd., No. 2, Canmore, Alberta; secs. 21 and 22, tp. 24, R. 10 W. 5 mer.		Brazeau Collieries, Ltd., No. 256, Nordegg, Alberta; sec. 22, tp. 40, R. 15 W. 5 mer.		Mountain Park Collieries, No. 282, Mountain Park, Alberta; sec. 33, tp. 45, R. 23 W. 5 mer.					Cadomin Coal Co., Ltd., No. 693, Cadomin, Alberta; sec. 12, tp. 47, R. 23 W. 5 mer.		Luscar Collieries, Ltd., No. 905, Luscar, Alberta; sec. 23, tp. 47, R. 24 W. 5 mer.	
Sample No.	9990		9800		9614			9601		9602		9834	
Moisture condition	R	D	R	D	R	AD	D	R	D	R	D	R	D
Proximate Analysis—													
Moisture ... per cent	2·7	....	2·1	....	6·6	1·1	....	1·9	....	1·1	....	1·9	....
Ash ... "	11·4	11·7	12·3	12·6	11·0	11·7	11·8	13·3	13·6	12·1	12·2	14·2	14·5
Volatile matter ... "	13·9	14·3	15·2	15·5	26·5	28·1	28·4	28·6	29·2	25·8	26·1	20·1	20·5
Fixed carbon ... "	72·0	74·0	70·4	71·9	55·9	59·1	59·8	56·2	57·2	61·0	61·7	63·8	65·0
Ultimate Analysis—													
Carbon ... per cent	77·1	79·3	78·0	79·6	72·2	76·4	77·3	74·0	75·4	76·4	77·3	75·1	76·5
Hydrogen ... "	4·1	3·9	4·2	4·1	5·1	4·7	4·6	4·8	4·7	4·6	4·5	4·3	4·2
Ash ... "	11·4	11·7	12·3	12·6	11·0	11·7	11·8	13·3	13·6	12·1	12·2	14·2	14·5
Sulphur ... "	0·7	0·7	0·5	0·5	0·3	0·3	0·4	0·6	0·6	0·3	0·3	0·3	0·3
Nitrogen ... "	1·6	1·7	1·2	1·2	1·1	1·2	1·2	1·2	1·2	1·1	1·1	1·1	1·1
Oxygen ... "	5·1	2·7	3·8	2·0	10·3	5·7	4·7	6·1	4·5	5·5	4·6	5·0	3·4
Calorific Value—													
Calories per gramme, gross	7,355	7,560	7,465	7,625	7,095	7,515	7,600	7,325	7,465	7,500	7,580	7,290	7,420
B.T.U. per lb., gross	13,240	13,610	13,440	13,730	12,770	13,530	13,680	13,190	13,440	13,500	13,650	13,120	13,360
Fuel ratio	5·20		4·60		2·10			1·95		2·35		3·20	
Carbon-hydrogen ratio	18·8	20·3	18·5	19·5	14·2	16·2	16·7	15·4	16·1	16·7	17·1	17·4	18·3
Coking properties	Poor		Fair		Good			Good		Good		Good	
Softening temperature of ash ... °F.	2440		2700+		2380			2420		2460		2600	
Weight per cubic foot ... lb.	53		57⅓		48½			52½		57		55½	

Screen analysis (square screen openings)....................per cent.	On 1″ =0·8, 1″ to ¾″ =3·0, ¾″ to ½″ = 6·7, ½″ to ¼″ =7·4, ¼″ to ⅛″ =21·6, per ⅛″ =60·5.	On 2″ =1·4, 2″ to 1½″ =2·3, 1½″ to 1″ =2·3, 1″ to ¾″ = 3·4, ¾″ to ½″ =4·3 ½″ to ¼″ =13·7, ¼″ to ⅛″ =16·8, per ⅛″ =55·8.	On 3″ =2·2, 3″ to 2″ =1·6, 2″ to 1½″ =4·6, 1½″ to 1″ = 4·0, 1″ to ¾″ =6·9, ¾″ to ½″ =7·3, ½″ to ¼″ =19·2, ¼″ to ⅛″ =19·3, per ⅛″ =34·9.	On 2″ =0·9, 2″ to 1½″ =0·9, 1½″ to 1″ =0·9, 1″ to ½″ = 5·5, ½″ to ¼″ = 20·5, ¼″ to ⅛″ = 20·5, per ⅛″ =50.8	On 3″ =4·8, 3″ to 2″ =6·2, 2″ to 1½″ = 5·0, 1½″ to 1″ = 3·9, 1″ to ½″ =8·9, ½″ to ¼″ =20·7, ¼″ to ⅛″ =15·7, per ⅛″ =34·8.	On 2″ =3·2, 2″ to 1½″ =2·8, 1½″ to 1″ =3·8, 1″ to ¾″ =5·7, ¾″ to ½″ =5·4, ½″ to ¼″ = 15·2, ¼″ to ⅛″ = 16·5, per ⅛″ = =47·4.
Designation of coal..................	½-inch slack.....	Steam coal......	Run-of mine; sizes over 2-inch removed, hand-picked, and re-mixed with smaller sizes.		Run-of-mine; treated as with No. 9614.	Run-of-mine....
Kind of sample......................	Commercial; 33 tons.	Commercial; 33 tons.	Commercial; 28 tons....	Commercial; 20 tons.	Commercial; 34 tons.	Commercial; 34 tons.
Location in mine....................	....	....	Michelean seam, Nos. 1 and 2 slopes.	Kennedy seam .	No. 4 panel, south half of sec. 12.	
Taken by...........................	All mine operators..					
Date of sampling....................	November, 1931	September, 1931	Sept. 1, 1931..............................		Sept. 4, 1931....	October, 1931...

TABLE I—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	Corbin Collieries, Ltd., Corbin, British Columbia																	
	No. 4 Mine				No. 6 Mine						Nos. 4 and 6 Mines		—					
Sample No.	7766		8150		7767		8152		9796		7765		8149		8148		8919	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—																		
Moisture per cent	2·1	....	1·2	....	4·9	....	3·1	....	1·5	....	2·7	....	2·2	....	1·3	....	4·5	....
Ash "	14·2	14·5	16·0	16·2	15·7	16·5	18·5	19·1	21·3	21·6	16·0	16·5	12·7	13·0	11·6	11·8	12·8	13·4
Volatile matter "	23·3	23·8	25·8	26·1	21·9	23·0	22·5	23·3	20·9	21·2	22·7	23·3	23·5	24·0	24·0	24·3	23·0	24·1
Fixed carbon "	60·4	61·7	57·0	57·7	57·5	60·5	55·9	57·6	56·3	57·2	58·6	60·2	61·6	63·0	63·1	63·9	59·7	62·5
Ultimate Analysis—																		
Carbon per cent	....	....	....	....	....	....	....	....	67·7	68·7	....	....	....	....	....	....	72·4	75·8
Hydrogen "	....	....	....	....	....	....	....	....	4·0	3·9	....	....	....	....	....	....	4·5	4·2
Ash "	....	....	....	....	....	....	....	....	21·3	21·6	....	....	....	....	....	....	12·8	13·4
Sulphur "	0·2	0·2	0·2	0·2	0·3	0·3	0·2	0·2	0·2	0·3	0·2	0·3	0·2	0·2	0·2	0·3	0·3	0·3
Nitrogen "	....	....	....	....	....	....	....	....	1·0	1·0	....	....	....	....	....	....	1·0	1·1
Oxygen "	....	....	....	....	....	....	....	....	5·8	4·5	....	....	....	....	....	....	9·0	5·2
Calorific Value—																		
Calories per gramme, gross	7,000	7,150	6,840	6,920	6,600	6,945	6,330	6,535	6,440	6,540	6,790	6,980	7,035	7,195	7,250	7,345	7,020	7,350
B.T.U. per lb., gross	12,600	12,870	12,310	12,460	11,880	12,500	11,390	11,760	11,590	11,770	12,220	12,570	12,660	12,950	13,060	13,220	12,640	13,230
Fuel ratio	2·60		2·20		2·65		2·50		2·70		2·60		2·65		2·65		2·60	
Carbon-hydrogen ratio	....	....	....	....	....	....	....	....	17·0	17·8	....	....	....	....	....	....	16·0	18·0
Coking properties	Poor		Poor		Poor		Poor		Poor		Poor		Poor		Poor		Poor	
Softening temperature of ash °F.									2700+								2485	
Screen analysis (square screen openings) per cent.																	On 1"=1·5, 1" to $\frac{3}{4}$"=10·8, $\frac{3}{4}$" to $\frac{1}{2}$"=14·8, $\frac{1}{2}$" to $\frac{1}{4}$"=40·4, $\frac{1}{4}$ to $\frac{1}{8}$"=16·3, per $\frac{1}{8}$"= 16·2	

Designation of coal						Average of day's run.	Air-cleaned coal.	Washed coal	Washed steam
Kind of sample	Mine		Mine		Mine	Tipple			Commercial; 15 tons.
Location in mine	Across coal seams, omitting shale bands.		Across 138-ft. seam at Jordan stripping; omitting shale over 1/10-inch thick.		Mammoth; seam; A level, from Nos. 1 and 2 south, and through the crosscut.				
Taken by	B. R. MacKay, Geological Survey.	Mine operators	B. R. MacKay	Mine operators	B. R. MacKay		Mine operators		
Date of sampling	Aug. 29, 1930.	Dec. 31, 1930.	Aug. 27, 1930.	Dec. 31, 1930.	August, 1931.	Aug. 15, 1930.	Dec. 31, 1930.		April, 1931.

TABLE I—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	Corbin Collieries, Ltd., Corbin, British Columbia				Crow's Nest Pass Coal Co., Ltd., Fernie, British Columbia													
					Michel colliery										Coal Creek colliery			
Sample No.	8147		8920		9797		9798		7222		8338		9342		9799		7596	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—																		
Moisture ... per cent	3·3	....	5·0	....	1·3	....	3·3	....	1·9	....	1·1	....	1·0	....	2·7	....	1·3	....
Ash "	17·2	17·8	16·8	17·7	7·1	7·2	7·9	8·2	6·1	6·2	6·9	7·0	5·3	5·3	5·7	5·9	10·8	10·9
Volatile matter "	23·0	23·8	21·4	22·5	22·1	22·4	20·8	21·5	27·9	28·4	26·4	26·7	27·3	27·6	22·4	23·0	23·3	23·6
Fixed carbon "	56·5	58·4	56·8	59·8	69·5	70·4	68·0	70·3	64·1	65·4	65·6	66·3	66·4	67·1	69·2	71·1	64·6	65·5
Ultimate Analysis—																		
Carbon ... per cent	....	....	....	....	....	....	....	....	80·5	82·1	....	....	81·8	82·7	....	....	78·8	79·8
Hydrogen "	....	....	....	....	....	....	....	....	5·1	5·0	....	....	4·9	4·9	....	....	4·8	4·8
Ash "	....	....	....	....	....	....	....	....	6·1	6·2	....	....	5·3	5·3	....	....	10·8	10·9
Sulphur "	0·2	0·3	0·3	0·3	0·8	0·8	0·8	0·9	0·7	0·7	0·6	0·7	0·6	0·6	0·5	0·6	0·5	0·5
Nitrogen "	....	....	1·0	1·0	1·4	1·5	1·4	1·4	1·3	1·3	....	....	1·5	1·5	1·2	1·2	1·1	1·1
Oxygen "	....	....	....	....	....	....	....	....	6·3	4·7	....	....	5·9	5·0	....	....	4·0	2·9
Calorific Value—																		
Calories per gramme, gross	6,530	6,755	6,480	6,820	7,900	8.010	7,705	7,965	7.925	8,080	....	....	8.050	8,140	8,010	8,235	7,670	7,770
B.T.U. per lb., gross	11,760	12,160	11,660	12,270	14,220	14,410	13,870	14,340	14,260	14,540	....	....	14,490	14,650	14,420	14,820	13.810	13,990
Fuel ratio	2·45		2·65		3·15		3·30		2·30		2·50		2·45		3·10		2·75	
Carbon-hydrogen ratio	....	....	....	....	....	....	....	....	15·7	16·4	....	....	16·6	17·1	....	....	16·2	16·7
Coking properties	Poor		Poor		Good		Good		Good		Good		Good		Good		Good	
Softening temperature of ash ... °F.	....		2700+		2700+		2650		2030		....		2060		2205		....	
Screen analysis (square screen openings) ... per cent	....		On ½"=0·3, ½" to ¼"=3·9, ¼" to ⅛"=24·5, per ⅛"=71·3.		....		....		....		....		On 3"=14·8, 3" to 2"=13·6, 2" to 1½"=13·3, 1½" to 1"=8·1, 1" to ¾"=8·5, ¾" to ½"=4·8, ½" to ¼"=9·6, ¼" to ⅛"=7·0, per ⅛"=20·3.		....		On 1" = 0·9, 1" to ¾"=4·3, ¾" to ½"=7·9, per ½"=86·9.	

Designation of coal	Birdseye coal, ¼ in. slack	Birdseye	.....		Run-of-mine			.....	Slack
Kind of sample	.....	Commercial; 15 tons.	Mine		Commercial; 30 tons.	Commercial; 20 cars.	Commercial; 41 tons.	Mine	Commercial; 33 tons.
Location in mine	.....	.....	No. 3 mine; No. 3 seam.. Face off counter level; east side of fault, main west.	No. 12 incline north; west side of fault.	B-seam	.....	B-seam	No. 3 mine; No. 2 seam, No. 8 slope, No. 2 room to left.	.....
Taken by	Mine operators		B. R. MacKay, Geological Survey.		Mineoperators	Delivered to, and sampled by Winnipeg plant.	Mineoperators	B. R MacKay	Mine operator
Date of sampling	Dec. 31, 1930.	April, 1931	August 20, 1931		June, 1930	January, 1931.	August, 1931	Aug. 5, 1931	September, 1930.

TABLE I—Continued

Analyses of Solid Fuels Occurring in Canada—Continued

—	Crow's Nest Pass Coal Co., Ltd., Fernie, British Columbia												Blue Flame Collieries, Ltd., No. 1., or Lynden, mine, near Princeton, British Columbia					
	Coal Creek colliery																	
Sample No.	8069		8070		8071		10031		10032		10033		10505			10564		
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D	R	AD	D	R	AD	D
Proximate Analysis—																		
Moisture...per cent	0·9	....	1·4	....	1·5	....	1·1	....	1·2	....	1·2	....	15·4	14·7	....	20·4	14·7	....
Ash "	9·2	9·3	10·1	10·3	11·3	11·5	10·3	10·4	8·5	8·6	10·6	10·7	5·0	5·1	5·9	7·2	7·8	9·1
Volatile matter "	24·2	24·4	23·9	24·2	23·8	24·1	23·9	24·2	23·8	24·1	24·1	24·4	32·5	32·8	38·4	29·7	31·8	37·3
Fixed carbon "	65·7	66·3	64·6	65·5	63·4	64·4	64·7	65·4	66·5	67·3	64·1	64·9	47·1	47·4	55·7	42·7	45·7	53·6
Ultimate Analysis—																		
Carbon...per cent	....	....	....	....	....	....	....	....	....	....	....	....	60·8	61·2	71·8	....	....	....
Hydrogen "	....	....	....	....	....	....	....	....	....	....	....	....	5·7	5·7	4·8	....	....	....
Ash "	....	....	....	....	....	....	....	....	....	....	....	....	5·0	5·1	5·9	....	....	....
Sulphur "	....	....	....	....	....	....	....	....	....	....	....	....	0·8	0·8	0·9	0·8	0·9	1·1
Nitrogen "	....	....	....	....	....	....	....	....	....	....	....	....	1·9	1·9	2·2	....	....	....
Oxygen "	....	....	....	....	....	....	....	....	....	....	....	....	25·8	25·3	14·4	....	....	..
Calorific Value—																		
Calories per gramme, gross	7,855*	7,930	7,735*	7,825	7,615*	7,730		....	....	....	....	....	5,995	6,040	7,085	5,400	5,780	6,780
B.T.U. per lb., gross	14,140	14,280	13,920	14,120	13,710	13,920	....	....	....	....	....	....	10,790	10,870	12,750	9,720	10,410	12,210
Fuel ratio	2·70		2·70		2·65		2·70		2·80		2·65		1·45			1·45		
Carbon-hydrogen-ratio	....	....	....	....	....	....	....	....	....	....	....	....	10·6	10·8	15·2	....	....	....
Coking properties	Good		Good		Good		Good		Good		Good		Non-coking			Non-coking		
Softening temperature of ash °F.													1950					
Designation of coal	Fernie slack						1-inch slack		2-inch slack									
Kind of sample	Commercial						Commercial—carload in each case									Mine		
Location in mine																Face of first right level off main slope.		
Taken by	Delivered in Winnipeg						Mine operators									Provincial mine inspector.		
Date of sampling	December, 1930						December, 1931						February, 1932			Feb. 27, 1932		

*Calorific value corrected according to the sulphur content of representative Coal Creek coal.

TABLE I—Concluded

Analyses of Solid Fuels Occurring in Canada—Concluded

—	Blue Flame Collieries, Ltd., No. 1, or Lynden, mine, near Princeton, British Columbia.									Granby Consolidated Mining, Smelting and Power Co., Ltd., Cassidy, British Columbia.			Canadian Collieries (Dunsmuir), Ltd., Comox colliery, Cumberland, British Columbia.			Telkwa Collieries, Ltd., operated by Broughton and McNeil, Telkwa, British Columbia.		
Sample No.	10565			10566			10567			7042			7122			6768		
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—																		
Moisture per cent	19·1	14·5	....	17·9	13·8	....	17·8	13·7	....	4·9	1·8	....	5·3	1·4	....	5·4	1·1	....
Ash “	6·3	6·7	7·8	8·0	8·4	9·8	7·2	7·5	8·7	12·3	12·7	12·9	14·2	14·7	15·0	12·4	13·0	13·1
Volatile matter “	29·4	31·0	36·3	30·1	31·6	36·6	31·7	33·3	38·6	36·3	37·5	38·2	29·5	30·7	31·1	29·9	31·2	31·6
Fixed carbon “	45·2	47·8	55·9	44·0	46·2	53·6	43·3	45·5	52·7	46·5	48·0	48·9	51·0	53·2	53·9	52·3	54·7	55·3
Ultimate Analysis—																		
Carbon per cent	....	....	....	....	....	....	....	....	....	69·2	71·5	72·8	67·8	70·7	71·6	70·2	73·3	74·2
Hydrogen “	....	....	....	....	....	....	....	....	....	5·5	5·3	5·2	5·3	5·0	4·9	5·0	4·8	4·7
Ash “	....	....	....	....	....	....	....	....	....	12·3	12·7	12·9	14·2	14·7	15·0	12·4	13·0	13·1
Sulphur “	0·7	0·7	0·9	0·9	1·0	1·1	1·1	1·2	1·4	0·5	0·6	0·6	1·4	1·5	1·5	1·1	1·1	1·1
Nitrogen “	....	....	....	....	....	....	....	....	....	1·5	1·5	1·6	0·9	0·9	0·9	0·9	0·9	0·9
Oxygen “	...	....	....	....	....	....	....	....	....	11·0	8·4	6·9	10·4	7·2	6·1	10·4	6·9	6·0
Calorific Value—																		
Calories per gramme, gross	5,580	5,900	6,900	5,520	5,800	6,720	5,605	5,890	6,820	6,855	7,080	7,210	6,765	7,045	7,145	6,910	7,220	7,300
B.T.U. per lb., gross	10,040	10,620	12,420	9,940	10,440	12,100	10,090	10,600	12,280	12,340	12,740	12,980	12,180	12,680	12,860	12,440	13,000	13,140
Fuel ratio	1·55			1·45			1·35			1·30			1·75			1·75		
Carbon-hydrogen ratio	....	....	....	....	....	....	....	....	....	12·6	13·4	14·0	12·9	14·1	14·6	13·9	15·4	15·8
Coking properties	Non-coking			Non-coking			Non-coking			Fair			Good			Good		
Softening temperature of ash. °F.	....			....			....			2310			2460			2170		
Designation of coal	....									Washed slack			Washed pea			Lump		
Kind of sample	Mine									Commercial; 46 tons.			Commercial; 43 tons.			Commercial; 30 tons.		
Location in mine	Main entry; pillar section of mine.			Face of first north level off new slope.			First south off new slope.			....			....			....		
Taken by	Provincial mine inspector									Mine operators								
Date of sampling	February 27, 1932									April, 1930			May, 1930			March, 1930		

TABLE II

Analyses of Coal Samples Submitted by Department of Pensions and National Health

—	Described as "Dominion" or Glace Bay, Nova Scotia, slack coal; delivered to Camp Hill Hospital, Halifax																	
Sample No.	6743	6789	7026	7166	7274	7833	8145	8126	8258	8516	8593	9738	9939	10001	10059	10468	10548	10610
Moisture (as received) per cent	3·9	3·6	4·5	4·6	3·9	5·9	5·3	5·0	4·5	3·8	3·5	6·3	4·5	6·3	5·1	8·6	4·3	4·9
Dry Basis—																		
Ash per cent	8·0	8·2	8·8	9·3	9·5	8·6	9·9	9·3	9·1	9·8	8·9	5·3	6·2	7·7	6·7	8·5	7·6	7·2
Volatile matter "	33·4	33·2	33·1	33·2	34·0	32·6	32·8	32·9	32·7	32·6	33·5	35·9	35·2	33·4	34·7	33·6	35·2	34·5
Fixed carbon "	58·6	58·6	58·1	57·5	56·5	58·8	57·3	57·8	58·2	57·6	57·6	58·8	58·6	58·9	58·6	57·9	57·2	58·3
Sulphur "	2·8	2·9	2·8	2·8	2·7	2·7	2·6	2·7	3·1	3·1	3·2	1·9	2·2	2·4	2·7	2·3	2·6	2·4
Calories per gramme, gross	7,780	7,750	7,625	7,570	7,645	7,700	7,595	7,660	7,695	7,625	7,710	8,035	7,860	7,720	7,860	7,685	7,785	7,835
B.T.U. per lb., gross	14,000	13,950	13,720	13,620	13,760	13,860	13,670	13,790	13,850	13,720	13,880	14,460	14,150	13,890	14,150	13,830	14,010	14,100
Number of tons represented by sample	124	182	173	88	31	119	172	196	225	162	88	38	101	152	200	187	199	163
Date of delivery	Feb. 1 to 22, 1930	Mar. 1 to 31	April 1 to 30	May 6 to 21	June 14 to 28	During Oct.	Nov. 4 to 27	During Dec.	Jan. 3 to 27, 1931	Feb. 2 to 22	Mar. 1 to 16	Sept. 30	Oct. 8 to 27	Nov. 8 to 28	Dec. 11 to 31	Jan. 5 to 28, 1932	Feb. 12 to 27	Mar. 1 to 21

—	Described as "Dominion" or Glace Bay, Nova Scotia, slack coal; delivered to Ste. Anne de Bellevue Hospital																
Sample No.	7167	7168	7169	7170	7332	7333	7429	7430	7431	7432	7994	7908	7909	7631	7632	7812	7813
Moisture (as received) per cent	3·8	3·5	3·5	3·5	3·5	4·5	5·2	3·9	6·9	3·1	4·5	3·2	4·2	4·0	3·7	4·0	4·0
Dry Basis—																	
Ash per cent	8·6	8·7	8·9	8·6	9·4	9·3	12·1	11·4	12·1	11·6	11·4	9·5	10·0	9·7	9·3	8·9	9·3
Volatile matter "	33·0	32·8	33·2	32·9	32·2	32·5	30·5	30·1	31·3	31·3	30·3	32·4	32·3	32·1	32·4	32·8	32·9
Fixed carbon "	58·4	58·5	57·9	58·5	58·4	58·2	57·4	58·5	56·6	57·1	58·3	58·1	57·7	58·2	58·3	58·3	57·8
Sulphur "	3·2	3·2	3·0	3·0	2·9	2·8	3·1	3·1	2·9	3·0	3·0	3·0	2·9	3·2	3·1	2·9	2·8
Calories per gramme, gross	7,720	7,685	7,690	7,750	7,565	7,615	7,300	7,425	7,330	7,400	7,385	7,700	7,605	7,640	7,650	7,700	7,710
B.T.U. per lb., gross	13,890	13,830	13,840	13,950	13,620	13,710	13,140	13,370	13,190	13,320	13,290	13,860	13,690	13,750	13,770	13,860	13,880
Number of tons represented by sample	198	227	183	202	246	178	180	204	213	209	196	222	221	220	216	201	206
Date of delivery	May 7 to 12, 1930	May 14 to 17	May 22 to 28	May 28 to June 6	July 5 to 15	July 16 to 24	July 25 to 31	Aug. 1 to 8	Aug. 9 to 16	Aug. 26 to 31	Sept. 1 to 6	Sept. 15 to 18	Sept. 20 to 27	Oct. 1 to 5	Oct. 6 to 11	Oct. 20 to 25	Oct. 27 to Nov. 1

TABLE II—Continued

Analyses of Coal Samples Submitted by Department of Pensions and National Health—Continued

—	Described as "Dominion" or Glace Bay, Nova Scotia, slack coal; delivered to Ste. Anne de Bellevue Hospital.														
Sample No.	7958	7959	8017	8018	8200	8201	8156	8157	9082	9083	9084	9206	9207	9208	9232
Moisture (as received) per cent	2·7	3·1	3·7	3·6	2·9	5·4	6·2	4·5	2·9	2·9	2·8	4·7	4·2	4·5	3·7
Dry Basis—															
Ash per cent	9·2	8·6	9·9	8·9	9·5	9·6	9·3	8·7	9·4	10·0	9·0	9·7	9·7	9·7	10·1
Volatile matter "	32·8	33·0	32·5	32·7	32·7	31·9	32·2	32·4	32·0	32·0	32·5	34·1	33·8	34·0	32·3
Fixed carbon "	58·0	58·4	57·6	58·4	57·8	58·5	58·5	58·9	58·6	58·0	58·5	56·2	56·5	56·3	57·6
Sulphur "	3·0	3·2	3·2	3·1	2·9	3·1	2·8	2·8	3·3	3·3	3·0	1·8	2·0	1·9	3·3
Calories per gramme, gross	7,650	7,705	7,565	7,665	7,640	7,510	7,655	7,570	7,655	7,610	7,690	7.480	7 565	7,450	7.625
B.T.U. per lb., gross	13,790	13,870	13,620	13,800	13,750	13,520	13,780	13,630	13,780	13,700	13,840	13,460	13,620	13,410	13,730
Number of tons represented by sample	191	193	192	196	191	135	204	196	203	153	228	229	193	197	194
Date of delivery	Nov. 1 to 8, 1930	Nov. 6 to 12	Nov. 15 to 21	Nov. 24 to 30	Dec. 12 to 18	Dec. 20 to 30	Dec. 20 to 27	Dec. 30, 1930 to Jan. 7, 1931	May 16, 1931	May 21	May 28	June 15 to 18	June 21 to 24	June 26 to July 3	July 5 to 15

Sample No.	9233	9234	9501	9571	9585	9652	9848	9849	9858	9885	9895	9935	9974	9975	9983	10482	10483	10484
Moisture (as received) per cent	3·6	4·0	3·9	4·7	4·6	5·0	6·9	6·5	6·4	3·7	3·7	4·2	5·4	5·5	5·4	5·5	5·6	5·8
Dry Basis—																		
Ash per cent	10·0	10·4	10·1	6·9	8·0	8·3	11·8	10·5	10·3	9·1	9·1	9·6	8·7	9·1	8·6	8·9	8·6	8·7
Volatile matter "	32·2	31·4	32·0	33·2	33·5	33·1	33·9	34·2	34·5	33·1	33·0	32·5	33·4	33·0	31·9	32·5	32·1	32·7
Fixed carbon "	57·8	58·2	57·9	59·9	58·5	58·6	54·3	55·3	55·2	57·8	57·9	57·9	57·9	57·9	59·5	58·6	59·3	58·6
Sulphur "	3·4	3·5	3·3	3·1	3·2	3·2	2·4	2·4	2·4	2·6	2·6	2·7	3·2	3·2	3·1	3·0	3·0	3·0
Calories per gramme, gross	7,625	7,615	7,605	7,790	7,780	7,795	7,265	7,410	7,425	7,610	7,615	7,570	7,725	7,675	7,680	7,610	7,600	7,555
B.T.U. per lb., gross	13,730	13,710	13,690	14,020	14,010	14,030	13,080	13,340	13,370	13,700	13,710	13,630	13,900	13,810	13,820	13,700	13,680	13,600
Number of tons represented by sample	203	235	210	192	192	184	211	237	226	231	241	231	239	235	246	238	232	238
Date of delivery	July 15 to 22 1931	July 22 to 25	Aug. 18 to 22	Sept. 1 to 8	Sept. 8 to 11	Sept. 7 to 13	Sept. 30 to Oct. 6	Oct. 7 to 12	Oct. 11 to 15	Oct. 16 to 21	Oct. 22 to 26	Oct. 26 to 30	Nov. 9 to 14	Nov. 14 to 17	Nov. 17 to 21	Dec. 5 to 12	Dec. 12 to 15	Dec. 16 to 19

TABLE II—Continued

Analyses of Coal Samples Submitted by Department of Pensions and National Health—Continued

—	Described as "Bras d'Or " slack from Sydney Mines district, Nova Scotia							Described as run-of-mine coal from W. Benton Evans' "Rothwell" mine, Minto, New Brunswick						Described as run-of-mine coal from Welton and Henderson, Ltd., Minto			
	Delivered to Camp Hill Hospital, Halifax							Delivered to Lancaster Hospital, St. John									
Sample No.	7412	8592	8995	9114	9193	9242	9737	9267	9896	10477	10260	10489	10609	6822	7334	7692	8047
Moisture (as received)........per cent	7·6	7·1	5·8	6·9	6·1	7·7	7·6	2·4	2·3	2·6	1·9	2·8	3·4	1·7	2·2	1·7	1·9
Dry Basis—																	
Ash "	10·9	15·3	14·6	14·3	11·4	13·9	11·7	14·2	13·5	20·7	13·3	17·0	19·5	18·8	20·6	19·6	17·8
Volatile matter "	34·4	35·4	33·2	34·9	34·7	34·1	33·4	33·2	33·4	31·3	33·8	31·9	31·1	31·2	30·7	31·8	31·8
Fixed carbon "	54·7	49·3	52·2	50·8	53·9	52·0	54·9	52·6	53·1	48·0	52·9	51·1	49·4	50·0	48·7	48·6	50·4
Sulphur "	5·7	6·5	7·4	5·9	6·2	6·8	6·4	6·6	6·4	7·0	6·5	7·5	7·6	5·8	5·8	5·8	6·1
Calories per gramme, gross	7,110	6,615	6,860	6,815	7,165	6,790	7,015	7,240	7,245	6,565	7,255	6,955	6,695	6,860	6,710	6,830	6,920
B.T.U. per lb., gross	12,800	11,910	12,350	12,270	12,900	12,220	12,630	13,030	13,040	11,820	13,060	12,520	12,050	12,350	12,080	12,300	12,460
Number of tons represented by sample	30	101	171	120	28	42	46	43	45	44	43	44	43	47	46	47	34
Date of delivery	Aug.11 to 22, 1930	Mar. 18 to 28, 1931	April 1 to 24	May 17 to 28	June 10 to 22	July 24 to 28	Sept. 1 to 17	Aug.4, 1931	Oct. 27	Dec. 9	Jan.20, 1932	Feb .9	Mar. 19	April 22, 1930	July 28	Oct. 21	Dec. 6

—	Described as run-of-mine coal from Welton and Henderson, Ltd., Minto; delivered to Lancaster Hospital, St. John			Described as coal from International Coal and Coke Co., Ltd., Coleman, Alberta													
				Run-of-mine								Slack					
				Delivered to Vetcraft shops, Winnipeg		Delivered to Deer Lodge Hospital, Winnipeg											
Sample No.	8127	8259	8572	6750	7025	6788	7024	8232	8557	9241	9340	7625	8049	8463	9936	10259	10519
Moisture (as received)........per cent	3·2	2·9	3·0	2·3	2·5	2·8	1·6	4·1	2·3	2·0	1·1	1·6	4·2	2·6	3·3	1·4	1·8
Dry Basis—																	
Ash "	18·2	17·8	20·0	15·6	15·4	17·0	18·4	14·7	11·1	16·6	12·7	16·6	15·9	15·8	13·0	13·6	13·4
Volatile matter "	32·1	31·9	31·7	23·9	25·7	24·8	25·0	25·9	25·8	25·7	25·4	24·5	24·5	25·2	25·6	25·6	24·5
Fixed carbon "	49·7	50·3	48·3	60·5	58·9	58·2	56·6	59·4	63·1	57·7	61·9	58·9	59·6	59·0	61·4	60·8	62·1
Sulphur "	6·0	6·5	6·0	0·4	0·5	0·5	0·5	0·6	0·5	0·4	0·8	0·5	0·4	0·5	0·7	0·7	0·5
Calories per gramme, gross	6,930	6,920	6,685	7,105	7,045	6,970	6,790	7,175	7,560	7,005	7,345	6,970	7,085	7,120	7,350	7,330	7,295
B.T.U. per lb., gross	12,480	12,450	12,030	12,790	12,680	12,550	12,220	12,910	13,610	12,610	13,220	12,540	12,750	12,810	13,230	13,190	13,130
Number of tons represented by sample	48	49	46	16	5	163	134	34	131	56	100	183	35	98	195	191	47
Date of delivery	Jan. 8, 1931	Feb. 4	Mar. 26	Feb. 1 to 28, 1930	April 1 to 30,	Feb. 1 to Mar. 31 1930	April 1 to 30	Jan. 1 to 15, 1931	Mar. 9 to 17	Mar. 17 to June 30	Aug. 3 to 6	Sept. 1 to 30, 1930	Nov. 1 to 30	Jan. 19 to Feb. 16, 1931	Oct. 1 to 31	Jan. 1 to 16, 1932	Feb. 1 to 20

TABLE II—Continued

Analyses of Coal Samples Submitted by Department of Pensions and National Health—Continued

—	Described as slack from Freeport seam in Westmoreland county, Pennsylvania; from "Kinloch" mine at Parnassus; delivered to Westminster Hospital, London									
Sample No.	9343	9358	9739	9850	9868	9963	9969	9988	10012	10184
Moisture (as received)...per cent	1·8	4·1	3·1	2·9	4·1	4·3	4·3	4·1	4·3	3·9
Dry Basis—										
Ash "	11·4	12·4	10·8	11·7	11·9	8·9	8·8	8·2	9·1	11·8
Volatile matter "	32·8	32·0	32·3	31·7	31·1	33·8	33·8	34·4	34·2	33·1
Fixed carbon "	55·8	55·6	56·9	56·6	57·0	57·3	57·4	57·4	56·7	55·1
Sulphur "	1·9	2·0	1·9	2·0	2·0	2·3	2 ·8	3·0	3·1	2·
Calories per gramme, gross	7,460	7,305	7,505	7,380	7,345	7,745	7,700	7,775	7,700	7,520
B.T.U. per lb., gross	13,430	13,150	13,510	13,280	13,220	13,940	13,860	13,990	13,860	13,530
Number of tons represented by sample	323	338	491	476	278	480	486	463	631	329
Date of delivery	Aug. 12 to 17, 1931	Aug. 18 to 22	Sept. 25 to 30	Oct. 1 to 8	Oct. 9 to 17	Nov. 7 to 14	Nov. 17 to 25	Nov. 24 to 30	Dec. 1 to 8	Dec. 10, 1931 to Jan. 21, 1932

—	Described as "Yatesboro," Pennsylvania, slack; delivered to Christie St. Hospital, Toronto									
Sample No.	9813	9937 9938	9979	10037	10057	10152	10455	10469	10518	10590
Moisture (as received)...per cent	4·2	4·1	3·8	3·0	3·3	7·3	10·5	10·7	8·4	7·2
Dry Basis—										
Ash "	9·3	9·8	9·0	9·3	8·5	8·6	8·8	8·8	8·1	8·1
Volatile matter "	31·1	30·1	31·1	31·3	32·2	32·3	31·3	31·6	29·5	31·1
Fixed carbon "	59·6	60·1	59·9	59·4	59·3	59·1	59·9	59·6	62·4	60·8
Sulphur "	2·5	2·8	2·5	2·3	2·1	2·4	8·1	2·1	1·8	2·1
Calories per gramme, gross	7,640	7,510	7,665	7,675	7,725	7,695	7,765	7,775	7,800	7,715
B.T.U. per lb., gross	13,760	13,520	13,800	13,820	13,900	13,850	13,980	14,000	14,040	13,890
Number of tons represented by sample	160	405	275	480	210	433	240	220	275	475
Date of delivery	Sept. 28 to 29, 1931	Oct. 5 to 21	Nov. 10	Dec. 4	Dec. 22	Jan. 7, 1932	Jan. 29	Feb. 3	Feb. 22 and 23	Mar. 10

TABLE II—Concluded

Analyses of Coal Samples Submitted by Department of Pensions and National Health—Concluded

—	Described as slack from Alleghany county, Pennsylvania; from "Wildwood" mine at Wildwood; delivered to Christie St. Hospital, Toronto																
Sample No.	6727	6744	6755	6780	7214	7286 7314	7695	7907	7957	7996	8050	8117	8176	8266	8496 8497	8541	8571
Moisture (as received) per cent	6·9	10·4	8·7	8·8	5·8	4·3	4·8	6·6	6·0	4·4	6·6	6·9	8·3	7·5	5·9	3·7	5·4
Dry Basis—																	
Ash per cent	11·1	13·0	10·8	14·3	11·1	12·2	9·8	9·4	8·5	7·2	8·6	8·5	7·4	8·7	8·8	8·5	6·9
Volatile matter "	34·4	31·1	33·2	31·4	33·4	33·2	35·3	35·3	34·7	35·2	34·6	34·8	34·8	34·0	34·1	34·4	35·9
Fixed carbon "	54·5	55·9	56·0	54·3	55·5	54·6	54·9	55·3	56·8	57·6	56·8	56·7	57·8	57·3	57·1	57·1	57·2
Sulphur "	2·7	2·4	2·2	2·4	1·4	1·8	1·4	1·4	1·3	1·2	1·4	1·3	1·1	1·1	1·0	1·1	1·1
Calories per gramme, gross	7,500	7,280	7,485	7,230	7,490	7,380	7,565	7,530	7,625	7,730	7,575	7,600	7,740	7,595	7,610	7,615	7,790
B.T.U. per lb., gross	13,500	13,100	13,480	13,080	13,490	13,290	13,620	13,550	13,730	13,920	13,630	13,690	13,930	13,670	13,690	13,710	14,020
Number of tons represented by sample	230	200	250	400	200	470	230	350	330	320	350	250	300	280	700	220	238
Date of delivery	Feb. 1 to 24, 1930	Feb. 27 to 28	Mar. 5 to 8	Mar. 19 to 27	June 13 to 26	June 30 to July 9	Oct. 10 to 17	Oct. 27 to Nov. 7	Nov. 8 to 16	Nov. 21 to 27	Dec. 2 to 9	Dec. 22 to 29	Jan. 5 to 16, 1931	Jan. 26 to 31	Feb. 6 to 28	Mar. 3 to 12	Mar. 16 to 23

—	Described as slack from Alleghany county, Pennsylvania; from "Wildwood" mine at Wildwood														
	Delivered to Christie St. Hospital, Toronto					Delivered to Westminster Hospital, London									
Sample No.	8656	8880	8976	9113	9188	7382	7626	7906	7910	8016	8104	8146	8454	8498	8558
Moisture (as received) per cent	7·3	7·1	6·6	7·1	7·9	4·7	4·8	5·1	5·8	4·3	5·7	7·1	4·5	5·9	4·5
Dry Basis—															
Ash "	8·8	7·0	7·1	8·1	9·4	12·4	9·2	6·9	9·6	8·4	8·7	9·7	9·5	9·7	9·1
Volatile matter "	34·5	35·5	35·1	34·9	34·4	32·2	35·1	33·7	31·5	33·5	32·9	32·0	32·1	31·8	33·1
Fixed carbon "	56·7	57·5	57·8	57·0	56·2	55·4	55·7	59·4	58·9	58·1	58·4	58·3	58·4	58·5	57·8
Sulphur "	1·1	1·0	1·1	1·0	1·2	2·1	1·4	0·7	1·1	1·1	1·1	1·1	1·1	1·1	1·2
Calories per gramme, gross	7,530	7,700	7,780	7,640	7,555	7,225	7,565	7,875	7,500	7,635	7,625	7,505	7,445	7,425	7,520
B.T.U. per lb., gross	13,550	13,990	14,000	13,750	13,580	13,010	13,620	14,170	13,500	13,750	13,730	13,510	13,400	13,370	13,540
Number of tons represented by sample	400	320	250	300	350	396	383	746	600	344	315	454	450	452	273
Date of delivery	Apr. 1 to 9, 1931	April 17 to 20	April 23 to 25	June 1 to 4	June 10 to 20	July 1 to Aug. 13, 1930	Sept. 18 to Oct. 4	Oct. 27 to Nov. 14	Nov. 15 to 19	Nov. 20 to 24	Dec. 17 to 24	Dec. 13, 1930, to Jan. 14, 1931	Jan. 22 to Feb. 5	Feb. 12 to 25	Mar. 4 to 11

TABLE III

Analyses of Miscellaneous Solid Fuels

—	Welsh anthracitic buckwheat coal																					
Sample No.	8163		8164		8165		9070		9781		9857		9957		9981		9991		10024		10508	
Moisture condition	R	D	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	....	1·6	....	0·9	....	3·9	....	2·5	....	2·7	....	1·3	....	0·6	....	2·1	....	1·5	....	1·2	....
Ash............ "	5·1	5·2	5·4	5·4	4·5	4·5	5·5	5·8	7·0	7·2	4·5	4·6	5·9	5·9	6·3	6·3	6·5	6·6	6·7	6·8	5·8	5·9
Volatile matter.. "	7·6	7·8	7·6	7·7	7·7	7·8	7·6	7·9	7·0	7·1	7·9	8·1	9·2	9·3	8·4	8·5	8·2	8·4	7·4	7·6	7·8	7·9
Fixed carbon.... "	85·0	87·0	85·4	86·9	86·9	87·7	83·0	86·3	83·5	85·7	84·9	87·3	83·6	84·8	84·7	85·2	83·2	85·0	84·4	85·6	85·2	86·2
Ultimate Analysis—																						
Carbon........per cent	....	....	....	....	....	....	81·5	84·8	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Hydrogen....... "	....	....	....	....	....	....	3·9	3·6	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ash............ "	....	....	....	....	....	....	5·5	5·8	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Sulphur......... "	....	....	....	....	....	....	0·9	0·9	....	....	....	....	....	....	....	....	....	....	....	....	1·1	1·1
Nitrogen........ "	....	....	....	....	....	....	1·2	1·2	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Oxygen.......... "	....	....	....	....	....	....	7·0	3·7	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Calorific Value—																						
Calories per gr. gross..	....	....	....	....	....	....	7,650	7,960	....	....	....	....	....	....	....	....	....	....	....	....	7,935	8,030
B.T.U. per lb., gross...	....	....	....	....	....	....	13,770	14,330	....	....	....	....	....	....	....	....	....	....	....	....	14,280	14,450
Fuel ratio	11·15		11·30		11·30		10·90		11·95		10·75		9·10		10·05		10·20		11·35		10·90	
Carbon-hydrogen ratio...	....	....	....	....	....	....	21·2	23·9	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Softening temperature of ash.................°F.	....		2395		....		2405		2395		2295		2445		2400		2355		2500		2350	
Screen analysis (square screen openings) per cent	On ½"=2·3, ½" to ¼"=37·2, ¼" to ⅛" =51·2, per ⅛"=9·3.		On ½"=2·3, ½" to ¼"=38·6, ¼" to ⅛"=43·2, per ⅛"=15·9.		On ¼"=26·2, ¼" to ⅛"= =61·9, per ⅛"=11·9.		On ¼"=45·0, ¼" to ⅛"=42·5, per ⅛" = 12·5.		....		....		On ·371= 2·0, ·371 to ·263=10·0, ·263 to ·131 =45·2, ·131, to ·065= 21·1, per ·065=21·7.		....		....		On ·525= 0·2, ·525 to ·371 = 10·0, ·371to·263= 23·0, ·263 to ·131=49·8, ·131 to ·065 =10·4, per ·065=6·6.		On ·525=5·0, ·525 to ·371= 17·9, ·371 to ·263=24·2, ·263 to ·131= 43·8, ·131 to ·065=7·3, per per ·065=1·8.	
Designation of coal	Nos. 1 and 2..										....		Nos. 1 and 2		No. 1.......		....				Nos. 1 and 2.	
Kind of sample	Delivered in Ottawa................						Delivered to Fuel Research Laboratories.		Delivered in Ottawa.		Dealer's stock.		Delivered in Ottawa.		Dealer's stock.		Delivered in Ottawa.....				Delivered at NewLiskeard, Ontario.	
Date	January, 1931........................						June, 1931....		Oct. 8, 1931.		Oct. 21, 1931		Nov. 17, 1931		Nov. 30, 1931		December, 1931		Dec. 14, 1931		Feb. 20, 1932.	

TABLE III—Continued

Analyses of Miscellaneous Solid Fuels—Continued

—	Anthracite Coals													
	From Westphalia, Germany		From Russia						From Pennsylvania, United States					
											Jeddo-Highland		"Blue Coal"	
Sample No.	9723		7624		8518		8586		7381		8166		9494	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—														
Moisture per cent	1·4	....	6·0	....	2·4	....	4·7	....	3·7	....	4·1	....	2·7	....
Ash "	5·3	5·4	5·7	6·1	3·4	3·5	4·9	5·1	15·2	15·8	9·0	9·4	9·1	9·3
Volatile matter "	7·5	7·6	4·5	4·8	3·6	3·7	4·0	4·2	5·4	5·6	4·2	4·4	5·4	5·6
Fixed carbon "	85·8	87·0	83·8	89·1	90·6	92·8	86·4	90·7	75·7	78·6	82·7	86·2	82·8	85·1
Ultimate Analysis—														
Sulphur per cent	1·2	1·2	1·3	1·4	1·3	1·3	1·2	1·3	0·6	0·7	0·7	0·7	0·8	0·9
Calorific Value—														
Calories per gramme, gross	7,940	8,055	7,200	7,650	....	....	7,395	7,755	6,660	6,915	7,110	7,415	7,355	7,560
B.T.U. per lb., gross	14,290	14,500	12,960	13,770	....	....	13,310	13,960	11,990	12,450	12,800	13,350	13,240	13,610
Fuel ratio	11·40		18·55		25·00		21·80		13·95		19·50		15·30	
Softening temperature of ash °F	2260		2050		....	....	....	....	2750+		....	....	....	....
Screen analysis (square screen openings) per cent	....	....	On ⅛"=58·6, per ⅛"=41·4		....	....	On ½"=8·7, ½" to ¼"=43·3, ¼" to ⅛"=23·2, per ⅛"=24·8		....	....	....	....	....	....
Designation of coal	No. 1 buckwheat		Screenings		Buckwheat		"Coarse screenings"		....		Stove		....	
Kind of sample	Dealer's supply		Delivered in Ottawa				Dealer's supply		Delivered at Camp Borden, Ontario		Delivered at Cooksville, Ontario		Delivered in Montreal	
Date	Oct. 3, 1931		Oct. 6, 1930		March, 1931		April 1, 1931		August, 1930		January, 1931		August, 1931	

TABLE III—Continued

Analyses of Miscellaneous Solid Fuels—Continued

—	Semi-bituminous or smokeless coals																	
	Designated as "Pocahontas"										"Portage No. 2" from Upper Kittanning seam, Portage, Cambria county, Pennsylvania						"Faux Logan" mine, Lloydell, Cambria county	
Sample No.	7349		7426		7709		7710		7723		9335		9336		9670		9037	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—																		
Moisture.....per cent	1·2	......	1·1	......	1·0	......	1·1	......	1·2	......	1·0	......	1·6	......	1·8	......	2·9	......
Ash "	10·9	11·1	10·2	10·3	10·6	10·8	10·1	10·2	9·9	10·0	8·2	8·3	8·5	8·6	8·9	9·0	6·5	6·7
Volatile matter "	21·4	21·6	22·3	22·5	22·0	22·2	22·0	22·2	22·9	23·2	17·8	17·9	17·3	17·6	17·5	17·8	17·2	17·7
Fixed carbon "	66·5	67·3	66·4	67·2	66·4	67·0	66·8	67·6	66·0	66·8	73·0	73·8	72·6	73·8	71·8	73·2	73·4	75·6
Ultimate Analysis—																		
Sulphur "	0·9	0·9	1·1	1·2	1·4	1·4	1·1	1·2	1·0	1·0	0·8	0·8	0·8	0·8	0·8	0·8	0·7	0·7
Calorific Value—																		
Calories per gramme, gross	7,625	7,710	7,715	7,800	7,710	7,790	7,730	7,820	7,750	7,845	7,880	7,960	7,800	7,930	7,775	7,915	......	......
B.T.U. per lb., gross	13,720	13,880	13,880	14,050	13,880	14,020	13,920	14,080	13,950	14,120	14,180	14,330	14,040	14,270	13,990	14,250	......	......
Fuel ratio	3·10		3·00		3·00		3·05		2·90		4·10		4·20		4·10		4·25	
Coking properties	Good		Good		Good		Good		Poor		Good		Good		Good		Good	
Designation of coal	......										Run-of-mine......						......	
Kind of sample	Delivered to Ottawa Public Schools......																Dealer's supply	
Date	Summer and autumn of 1930......										Summer and autumn of 1931......						May, 1931.....	

TABLE III—Continued

Analyses of Miscellaneous Solid Fuels—Continued

—	Bituminous coals													
	"Priestman," West Durham, England		Blend of Scotch gas coals		"National No. 1" mine, Morgantown, Monongalia county, West Virginia				"Provins" mine, Sewickley seam, Masontown, Fayette county, Pennsylvania				Connelsville coal	
Sample No.	10569		10570		7628		8158		9778		9940		7019	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—														
Moisture per cent	4·0	....	5·1	....	1·8	....	1·9	....	1·7	....	1·3	....	1·5	....
Ash "	6·0	6·3	4·7	4·9	7·7	7·9	8·3	8·5	12·5	12·7	13·3	13·5	7·9	8·0
Volatile matter "	27·7	28·8	30·5	32·2	34·8	35·4	34·2	34·9	33·9	34·5	33·2	33·6	36·0	36·6
Fixed carbon "	62·3	64·9	59·7	62·9	55·7	56·7	55·6	56·6	51·9	52·8	52·2	52·9	54·6	55·4
Ultimate Analysis—														
Carbon per cent	79·4	82·7	77·9	82·1	....	....	....	....	....	....	....	....	....	....
Hydrogen "	5·3	5·1	5·5	5·2	....	....	....	....	....	....	....	....	....	....
Ash "	6·0	6·3	4·7	4·9	....	....	....	....	....	....	....	....	....	....
Sulphur "	0·9	0·9	0·7	0·7	2·3	2·3	2·3	2·4	2·7	2·8	3·0	3·0	2·9	2·9
Nitrogen "	1·5	1·5	1·5	1·6	....	....	....	....	....	....	....	....	....	....
Oxygen "	6·9	3·5	9·7	5·5	....	....	....	....	....	....	....	....	....	....
Calorific Value—														
Calories per gramme, gross	7,800	8,120	7,650	8,065	7,650	7,790	7,590	7,740	7,210	7,340	7,160	7,260	7,690	7,810
B.T.U. per lb., gross	14,040	14,610	13,770	14,520	13,770	14,020	13,660	13,930	12,980	13,210	12,890	13,070	13,840	14,050
Fuel ratio	2·25		1·95		1·60		1·65		1·55		1·55		1·50	
Carbon-hydrogen ratio	14·9	16·3	14·3	16·0	....	....	....	....	....	....	....	....	....	....
Coking properties	Good		Good		Good		Good		Good		Good		Good	
Softening temperature of ash °F	2700+		2700+		....	....	....	....	....	....	....	....	....	....
Designation of coal	Unscreened		Contains "Plean", partially screened, "Kinneil", partially screened, "Gartshore", 2″ to ¼″ and "Polk Emmet", screened		....				1¼″ lump				Nut	
Kind of sample	Delivered in Montreal				Delivered to Ottawa Public Schools.				Delivered at Camp Borden, Ontario.				Delivered at Arnprior, Ontario.	
Date	February, 1932				Autumn and winter, 1930-31				October, 1931		Nov. 6, 1931		May, 1930	

TABLE III—Continued

Analyses of Miscellaneous Solid Fuels—Continued

	Bituminous coals—*Continued*															
—	"Royal" mine, Pittsburgh seam, Chestnut Ridge, Fayette county, Pennsylvania								"Allison" mine, Pittsburgh seam, Allison, Fayette county				"Banning" mine, Pittsburgh seam, Fayette or Westmoreland county		"Cornish" mine, Pittsburgh seam, Fayette county	
Sample No.	6756		7070		7121		7330		7434		8339		9111		10261	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—																
Moisture..........per cent	4·7	....	4·9	....	3·0	....	3·0	....	3·1	....	4·4	....	3·2	....	1·5	....
Ash ""	8·1	8·5	8·3	8·7	7·9	8·2	8·4	8·7	9·4	9·7	7·6	7·9	6·1	6·3	7·9	8·0
Volatile matter ""	31·1	32·6	31·0	32·6	31·0	31·9	32·1	33·1	32·6	33·6	30·3	31·7	32·7	33·8	37·7	38·3
Fixed carbon ""	56·1	58·9	55·8	58·7	58·1	59·9	56·5	58·2	54·9	56·7	57·7	60·4	58·0	59·9	52·9	53·7
Ultimate Analysis—																
Carbon..........per cent	75·2	78·9	74·5	78·3	76·1	78·5	76·2	78·6	75·2	77·5	....	....	78·4	80·9	....	....
Hydrogen ""	5·4	5·1	5·4	5·1	5·4	5·2	5·2	5·0	5·3	5·2	....	....	5·7	5·5	....	....
Ash ""	8·1	8·5	8·3	8·7	7·9	8·2	8·4	8·7	9·4	9·7	....	....	6·1	6·3	....	....
Sulphur ""	1·1	1·2	1·1	1·2	1·2	1·2	1·3	1·3	1·1	1·2	....	....	0·8	0·9	2·6	2·6
Nitrogen ""	1·6	1·7	1·6	1·7	1·3	1·3	1·5	1·5	1·3	1·3	....	....	1·6	1·6	....	....
Oxygen ""	8·6	4·6	9·1	5·0	8·1	5·6	7·4	4·9	7·7	5·1	....	....	7·4	4·8	....	....
Calorific Value—																
Calories per gramme, gross	7,420	7,790	7,365	7,745	7,575	7,810	7,555	7,785	7,445	7,685	....	....	7,800	7,060	7,710	7,835
B.T.U. per lb., gross	13,350	14,020	13,260	13,940	13,640	14,060	13,600	14,010	13,400	13,830	....	....	14,040	14,500	13,880	14,110
Fuel ratio	1·80		1·80		1·85		1·75		1·70		1·90		1·75		1·40	
Carbon-hydrogen ratio	13·9	15·4	13·7	15·3	14·2	15·2	14·8	15·9	14·1	15·0	....	....	13·7	14·7	....	....
Coking properties	Good		Good		Good		Good		Good		Good		Good		Fair	
Softening temperature of ash...°F.	About 2550		2595		2605		2610		....		....		2720		....	
Screen analysis (square screen openings)..........per cent	....		On ¼″=27·8, ¼″ to ⅛″=25·5, per ⅛″=46·7.		....		....		On 3″=17·8, 3″ to 2″=18·4, 2″ to 1½″=16·4, 1½″ to 1″=10·2, 1″ to ¾″=8·9, ¾″ to ½″=6·4, per ½″=21·9.		....		On 2″=4·5, 2″ to 1½″=12·0, 1½″ to 1″=7·6, 1″ to ¾″=10·0. ¾″ to ½″=8·5, ½″ to ¼″=14·8, ¼″ to ⅛″=16·0, per ⅛″=26·6.		....	
Designation of coal	Slack..........								Run-of-mine..........				4-inch mechanically cleaned run-of-mine.		"Morgan," probably run-of-mine.	
Kind of sample	Delivered to Fuel Research Laboratories by carloads..........										Delivered in Winnipeg.		Carload delivered to F.R.L		Delivered to Ottawa Public School	
Date	Mar. 15, 1930...		May 21, 1930....		June 10, 1930....		July 30, 1930....		Sept. 18, 1930...		January, 1931...		June 2, 1931.....		January, 1932.	

TABLE III—Continued

Analyses of Miscellaneous Solid Fuels—Continued

—	Bituminous coals—*Concluded*															
	"Wilpen" coal from Pittsburgh seam, Westmoreland county, Pennsylvania		"Yukon" coal from Pennsylvania				"Standard Smokeless" mine, lower Kittanning, or B, seam, Indiana, Indiana county, Pennsylvania.				"Bell's Mill" coal from lower Kittanning seam, Josephine, Indiana county		"Adrian" mine, Pennsylvania		Pittsburgh "Scot's Run"	
Sample No.	7923		9671		9989		8136		10043		9239		10185		7997	
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	....	2·7	....	1·6	....	2·7	....	1·2	....	1·1	....	1·4	....	1·5	....
Ash "	11·9	12·0	12·2	12·5	14·1	14·4	10·6	10·9	6·9	7·0	10·6	10·7	5·1	5·1	11·2	11·3
Volatile matter "	24·0	24·3	32·5	33·4	32·6	33·1	22·2	22·8	29·0	29·3	24·5	24·8	30·1	30·6	34·6	35·1
Fixed carbon "	62·9	63·7	52·6	54·1	51·7	52·5	64·5	66·3	62·9	63·7	63·8	64·5	63·4	64·3	52·7	53·6
Ultimate Analysis—																
Sulphur "	2·0	2·0	2·1	2·2	1·5	1·6	4·1	4·3	1·5	1·5	3·6	3·6	1·4	1·4	3·0	3·1
Calorific Value—																
Calories per gramme, gross	7,520	7,610	7,135	7,320	7,060	7,175	7,520	7,725	7,965	8,060	7,635	7,725	8,110	8,230	7,235	7,345
B.T.U. per lb., gross	13,540	13,700	12,840	13,180	12,710	12,920	13,530	13,900	14,340	14,510	13,740	13,900	14,600	14,810	13,020	13,220
Fuel ratio	2·60		1·60		1·60		2·90		2·15		2·60		2·10		1·50	
Coking properties	Good		Good		Good		Good		Good		Good		Good		Good	
Designation of coal	"Smokeless"		Run-of-mine								"Smokeless" 1¼-inch lump"		1¼-inch bituminous smokeless lump"		Slack	
Kind of sample	Delivered in Ottawa		Delivered to Ottawa Public Schools				Delivered in S. W. Ontario				Delivered in Toronto		Delivered at Niagara Falls		Delivered in Kingston	
Date	November, 1930		Autumn of 1931				January, 1931		December, 1931		July, 1931		January, 1932		November, 1930	

TABLE III—Continued

Analyses of Miscellaneous Solid Fuels—Continued

—	Bellingham coal mines, Bellingham, Washington, United States									Lignite from Thornton Works in north of parish of Malvern, Jamaica, British West Indies		Brown coal from Leopold mine, Edderitz, Germany			Brown coal from Westeregeln, near Magdeburg, Germany		
Sample No.	8648			8649			8650			10053		8002			8003		
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	D	R	AD	D	R	AD	D
Proximate Analysis—																	
Moisture per cent	6·9	6·0	....	7·5	6·6	....	7·5	6·8	....	14·0*	....	48·5	16·0	....	23·2	17·3	....
Ash "	17·8	17·9	19·1	19·5	19·7	21·1	11·7	11·8	12·7	28·9	33·6	6·8	11·1	13·2	10·9	11·8	14·2
Volatile matter "	37·7	38·1	40·5	36·9	37·3	39·9	38·8	39·1	41·9	33·1	38·5	29·5	48·1	57·3	38·4	41·3	50·0
Fixed carbon "	37·6	38·0	40·4	36·1	36·4	39·0	42·0	42·3	45·4	24·0	27·9	15·2	24·8	29·5	27·5	29·6	35·8
Ultimate Analysis—																	
Carbon "	....	....	....	....	....	....	....	....	....	....	....	32·2	52·5	62·4	47·7	51·4	62·2
Hydrogen "	....	....	....	....	....	....	....	....	....	....	....	8·3	6·4	5·5	6·3	5·9	4·8
Ash "	....	....	....	....	....	....	....	....	....	....	....	6·8	11·1	13·2	10·9	11·8	14·2
Sulphur "	0·5	0·5	0·5	0·3	0·3	0·3	0·2	0·3	0·3	7·4	8·6	2·3	3·8	4·5	2·7	2·9	3·5
Nitrogen "	....	....	....	....	....	....	....	....	....	....	....	0·2	0·4	0·5	....	....	....
Oxygen "	....	....	....	....	....	....	....	....	....	....	....	50·2	25·8	13·9	....	....	....
Calorific Value—																	
Calories per gramme, gross	5,800	5,860	6,135	5,510	5,565	5,960	6,145	6,195	6,645	4,305	5,010	3,225	5,255	6,255	4,575	4,935	5,965
B.T.U. per lb., gross	10,440	10,550	11,040	9,920	10,020	10,720	11,060	11,150	11,960	7,750	9,020	5,810	9,460	11,260	8,240	8,880	10,740
Fuel ratio	1·00			0·98			1·10			0·72		0·51			0·70		
Carbon-hydrogen ratio	....	....	....	....	....	....	....	....	....	....	....	3·9	8·2	11·3	7·6	8·8	13·1
Coking properties	Agglomerates			Agglomerates			Agglomerates			Non-coking		Non-coking			Non-coking		
Softening temperature of ash °F.	....			....			....			2135		....			....		
Designation of fuel	Lignite nut			Lignite lump						....		....					
Kind of sample	Imported into British Columbia									Prospect		....					
Date	March 19, 1931			March 24, 1931						December, 1931		December, 1930					

*This fuel was dried and disintegrated when received.

TABLE III—Continued

Analyses of Miscellaneous Solid Fuels—Continued

—	By-product coke made in Koppers ovens by Montreal Coke and Manufacturing Company, Ville La Salle, Quebec																	
	From normal blend of coals from the United States								From blends containing "Dominion," Nova Scotia, coal									
									No. 12, New Waterford, Victoria seam coal								35 per cent "Princess," Sydney Mines, Main seam coal, washed	
									10 per cent		15 per cent		20 per cent					
Sample No.	9570		9946		9065		8061		8062		8063		8064		8065		10151	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—																		
Moisture.....per cent	0·3	....	0·1	....	0·7	....	0·2	....	0·2	....	0·1	....	0·2	....	0·2	....	0·1	....
Ash....."	8·7	8·7	7·9	7·9	10·7	10·7	9·5	9·5	9·6	9·6	9·4	9·4	9·8	9·8	9·6	9·6	7·6	7·6
Volatile matter....."	1·0	1·0	1·0	1·0	1·6	1·6	1·1	1·2	1·2	1·2	1·2	1·2	1·2	1·2	1·0	1·0	1·0	1·0
Fixed carbon....."	90·0	90·3	91·0	91·1	87·0	87·7	89·2	89·3	89·0	89·2	89·3	89·4	88·8	89·0	89·2	89·4	91·3	91·4
Ultimate Analysis—																		
Carbon....."	....	....	....	....	86·1	86·8	....	....	....	....	....	....	....	....	....	....	......	....
Hydrogen....."	....	....	....	....	0·9	0·8	....	....	....	....	....	....	....	....	....	....	....	....
Ash....."	....	....	....	....	10·7	10·7	....	....	....	....	....	....	....	....	....	....	....	....
Sulphur....."	0·7	0·7	0·8	0·8	0·9	0·9	0·8	0·8	0·8	0·9	0·9	0·9	0·9	0·9	0·9	0·9	0·8	0·8
Nitrogen....."	....	....	....	....	0·8	0·8	....	....	....	....	....	....	....	....	....	....	....	....
Oxygen....."	....	....	....	....	0·6	0·0	....	....	....	....	....	....	....	....	....	....	....	....
Calorific Value—																		
Calories per gramme, gross.....	7,230	7,250	6,895	6,900	6,860	6,910	7,060	7,075	7,050	7,060	7,075	7,085	7,020	7,035	7,010	7,020	7,060	7,070
B.T.U. per lb., gross.....	13,010	13,050	12,410	12,420	12,350	12,440	12,710	12,740	12,690	12,710	12,740	12,750	12,640	12,660	12,620	12,640	12,710	12,720
Softening temperature of ash.....°F	2615		2490		2555		2660		2600		2455		2545		2455		2320	
Specific gravity (apparent).....	0·86		0·895		....	....	....	....	....	....	....	....	....	....	....	....	0·875	
Weight per cubic foot.....lb.	....	....	27·5		....	....	....	....	....	....	....	....	....	....	....	....	28·25	
Screen analysis (square screen openings).....per cent	....	....	On 2"=6·9, 2" to 1½"=83.1 1½" to 1" = 8·3, per 1"= 1·7		On ¼"=4·3, ¼" to ⅛"=15·6, per ⅛"=80·1		....	....	....	....	....	....	....	....	....	....	On 2"=16·0, 2" to 1½"=80·0, 1½" to 1"= 3·1, 1" to ¾"=0·1, ¾" to ½"=0·1, per ½"=0·7	
Designation of fuel.....	Stove.....				Breeze.....		Stove.....		Mixed.....		Stove.....		Mixed.....		Stove.....		....	
Kind of sample.....	Delivered to Fuel Research Laboratories.....																	
Date.....	September, 1931.....				May, 1931.....		During July and August, 1930.....										Nov. 13 to 22, 1931	

TABLE III—Concluded

Analyses of Miscellaneous Solid Fuels—Concluded

—	Gas coke made in Glover West retorts by Ottawa Gas Company, Ottawa, Ontario										"Canthracite" briquettes, made from carbonized bituminous coal		Wood charcoal		"Peat coal" briquettes prepared by Rudeman's process, by Kentol Syndicate, Ltd., London, England		Char from German brown coal from Geissen (K.V.G.) retort, Gölzau	
	From normal blend of coals from the United States								From Pittsburgh, 1½-inch, Crescent mine coal									
Sample No.	7901		9943		9944		9052		8887		10144		7960		7345		8004	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—																		
Moisture per cent	0·9	....	0·2	....	0·2	....	9·8	....	4·7	....	1·9	....	2·9	....	11·3	....	0·3	....
Ash "	9·9	10·0	10·4	10·4	10·2	10·2	13·6	15·0	9·1	9·5	9·7	9·9	1·6	1·6	2·5	2·8	24·0	24·1
Volatile matter "	1·2	1·2	2·0	2·0	2·2	2·2	2·9	3·2	1·8	1·9	6·6	6·7	21·0	21·6	54·8	61·8	16·6	16·6
Fixed carbon "	88·0	88·8	87·4	87·6	87·4	87·6	73·7	81·8	84·4	88·6	81·8	83·4	74·5	76·8	31·4	35·4	59·1	59·3
Ultimate Analysis—																		
Carbon "	....	....	....	....	....	....	73·1	81·1	....	....	....	....	....	....	....	....	....	....
Hydrogen "	....	....	....	....	....	....	2·0	1·0	....	....	....	....	....	....	....	....	....	....
Ash "	....	....	....	....	....	....	13·6	15·0	....	....	....	....	....	....	....	....	....	....
Sulphur "	0·8	0·8	0·9	0·9	1·0	1·0	1·1	1·2	0·8	0·9	2·2	2·3	....	....	1·9	2·1	2·9	2·9
Nitrogen "	....	....	....	....	....	....	1·1	1·2	....	....	....	....	....	....	....	....	....	....
Oxygen "	....	....	....	....	....	....	9·1	0·5	....	....	....	....	....	....	....	....	....	....
Calorific Value—																		
Calories per gramme, gross	7,015	7,075	6,735	6,750	6,870	6,885	6,055	6,710	6,935	7,275	7,130	7,270	....	....	5,280	5,955	6,195	6,210
B.T.U. per lb., gross	12,620	12,740	12,120	12,150	12,370	12,400	10,900	12,080	12,490	13,090	12,840	13,090	....	....	9,500	10,720	11,150	11,180
Softening temperature of ash °F	2745		2700+		2700+		2430		....	....	....	....	....	....	....	....	....	....
Specific gravity (apparent)	....	....	0·835		0·925		....	....	....	....	....	....	....	....	....	....	....	....
Weight per cubic foot lb.	....	....	25·75		27·0		....	....	....	....	....	....	....	....	....	....	....	....
Screen analysis (square screen openings) per cent	On 2″=9·5, 2″ to 1½″=57·2, 1½″ to ¾″=31·2, per ¾″=2·1		On 1″=23·9, 1″ to ¾″=45·9, ¾″ to ½″=28·6, per ½″=1·6		On 2″=29·7, 2″ to 1½″=54·0, 1½″ to 1″=13·9, 1″ to ¾″=0·7, ¾″ to ½″=0·5, per ½″=1·2		On ¾″=1·3, ¾″ to ½″=1·8, ½″ to ¼″=18·5, ¼″ to ⅛″=16·3, per ⅛″=62·1		....	....	....	....	....	....	....	....	....	....
Designation of fuel	Crushed				Nut		Breeze		....				....		....		....	
Kind of sample	Delivered to Fuel Research Laboratories												As sold in Ottawa		....		....	
Date	November, 1930		Nov. 13, 1931				May, 1931		April 25, 1931		Jan. 13, 1932		November, 1930		Summer of 1930		December, 1930	

Part II: Natural Gas and Liquid Fuels

ANALYSES OF NATURAL GAS DURING 1930-31

P. V. Rosewarne and R. J. Offord

During the last few years the Division of Fuels and Fuel Testing has conducted an analysis survey of Canada's natural gas resources, in conjunction with a special investigation of Turner Valley naphtha and "waste" gas. It is obvious that as a preliminary to such investigations the composition of the gas must be known as exactly as possible, and since this information was not available, samples were obtained from the principal producing fields in Canada, and subjected to careful and detailed examination. The analyses of several samples from the Turner Valley field have been reported[1] previously and the results are included in this report for convenient reference.

Valuable assistance was received from the various oil and gas companies operating in the field and from individuals who submitted samples for examination. Much assistance in the collection of the samples was received from: R. B. Harkness, Commissioner of Natural Gas for Ontario; Wm. Calder, Director of Petroleum and Natural Gas for Alberta; C. W. Dingman, Petroleum Engineer at Calgary; G. R. Elliott, Petroleum Engineer at Lethbridge; C. C. Ross, Supervisory Mining Engineer of the Department of the Interior at Ottawa, and F. M. Steel, Petroleum Engineer of the Department of the Interior at Calgary. The Royalite Oil Company at Turner Valley and the Provincial Institute of Technology at Calgary assisted greatly by providing laboratory accommodation in the field. To all the foregoing grateful acknowledgment is made for their hearty co-operation at all times.

APPARATUS AND METHODS OF ANALYSIS USED

The samples were analysed by fractional distillation in a Podbielniak column to determine the relative amounts of methane, ethane, propane, butane, pentane, and higher hydrocarbons that were present. A representative portion of each sample was retained and tested to show the specific gravity and the percentage of helium, carbon dioxide, oxygen, and nitrogen present. The sulphur present in the gas is the subject of a special investigation, the results of which will be reported separately. The apparatus used for the determination of carbon dioxide, oxygen, and nitrogen, was a type of Orsat apparatus usually referred to as the Burrell, or the United States Bureau of Mines type. This apparatus gave excellent results in the analyses of gases containing a large proportion of methane, but for those gases which contain an appreciable quantity of the higher hydrocarbons, the results obtained by calculating the products of combustion as methane and ethane only, are in error, somewhat in proportion to the amount of the higher hydrocarbons that are present. This is shown

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[1] "Analysis of Natural Gas from the Turner Valley Field in Alberta," Mines Branch No. 721, pp. 109-128, also Mines Branch Memorandum Series No. 43.

in different places in Table I where the nitrogen content appears to be a negative quantity. Repeated check analyses verified these erratic results.

The specific gravity was determined by direct weighing of the sample in a glass balloon, and the apparatus used for the determination of helium was similar to that described by Dr. R. T. Elworthy in Mines Branch Rept. No. 679, "Helium in Canada".

DISCUSSION OF RESULTS

The results of the analyses are shown in tabular form in Table I. The samples were all taken by ordinary water displacement from the pipeline near the well. In the case of the samples from Turner Valley the gas had already passed through the "separators". The separators are cylindrical units used for removing crude naphtha from the gas prior to its being purified for use as city gas, or going to waste as surplus gas. The results are those obtained from the analysis of a single sample, and where more than one sample was taken from any particular well the results obtained from the analyses of all the samples taken are shown. It will be observed that in these cases the results obtained agree very closely with one another. The values shown in the tables are based on percentage by volume in all cases. That shown for methane includes the percentages of all other gases present whose boiling point is near or below that of methane. That shown for pentanes includes all hydrocarbons whose boiling points are higher than that of pentane. The date on which the samples were taken is also shown.

CHANGES IN COMPOSITION OF THE GAS

The results obtained indicate that some changes in the composition of the Turner Valley gas may have occurred during the past two years. In 1930, these samples of gas were taken from Royalite No. 19 at intervals of a week or ten days. In 1931, four samples were taken from the same well at about the same time of year and at about the same interval. If the average of the sum of the butane and pentane fractions, which are the two commercially important constituents present, be taken from these two series, the average for 1930 will be found to be 2·07 per cent and the average for 1931 will be 2·48 per cent. This amount represents a difference in recoverable naphtha of 0·018 Imperial gallons per 1,000 cubic feet of gas processed. On the basis of 15,000,000 cubic feet of gas being produced per day from a well, this difference would amount to 270 gallons of crude condensate. On account of the low boiling point of the butanes and of the pentanes the weathering losses would probably be excessive. Even if only half of it could be retained, 135 gallons, or approximately 4 barrels per day would be recovered in addition to the present production. This is equivalent to an increased return of $12.00 per day, if the market value of the naphtha may be assumed to be $3.00 per barrel. It is proposed to obtain a series of samples from this same well during 1932 in order to have additional data on the subject.

IMPROVEMENTS IN THE APPARATUS

At different times during the operation of the Podbielniak fractionating column, difficulty has been experienced in maintaining a low temperature during the admission of the gas to the apparatus. Recently, a similar occurrence took place in which it was very definitely proven that this difficulty was due to carbon dioxide in the liquid air used in the cooling chamber. When a fresh supply of liquid air containing no carbon dioxide was obtained, the operation of the column became normal again. Several results in Table I are probably affected by a similar occurrence, in such a way that the methane content appears to be too high and the ethane content appears to be too low. The error affects the relative proportions of methane and ethane only. The sum of the two should be substantially correct. In the writer's opinion, those samples which show a lower ethane than propane content, are the ones chiefly affected.

With the exception of the difficulty described above, the Podbielniak type fractionating column has continued to give every satisfaction. Moreover, the designer has made certain improvements recently that greatly increase the efficiency of the column. The improved column is known as the Precision type, and with it much sharper separations of the various fractions can be made in slightly less time. With the older type, a separation of the isobutane and normal butane fractions was not clear cut and distinct. With the Precision type column the separation is quite good, and there appears evidence that, in addition to the two butanes, there is often present in natural gas, at least one other hydrocarbon, the boiling point of which is between minus 12° C. and plus 1° C.

A quantity of gas from Foothills well No. 1 in Turner Valley was available at the Fuel Research Laboratories, and several samples of this gas were fractionated, and selected portions of the fractions were retained. This selected portion, containing a large proportion of the fraction between minus 12° C. and plus 1° C., was refractionated. The result is shown graphically in Figure 1. An attempt was made to isolate the components other than isobutane and normal butane, but, unfortunately, the sample was lost in the later stages and the work must be repeated.

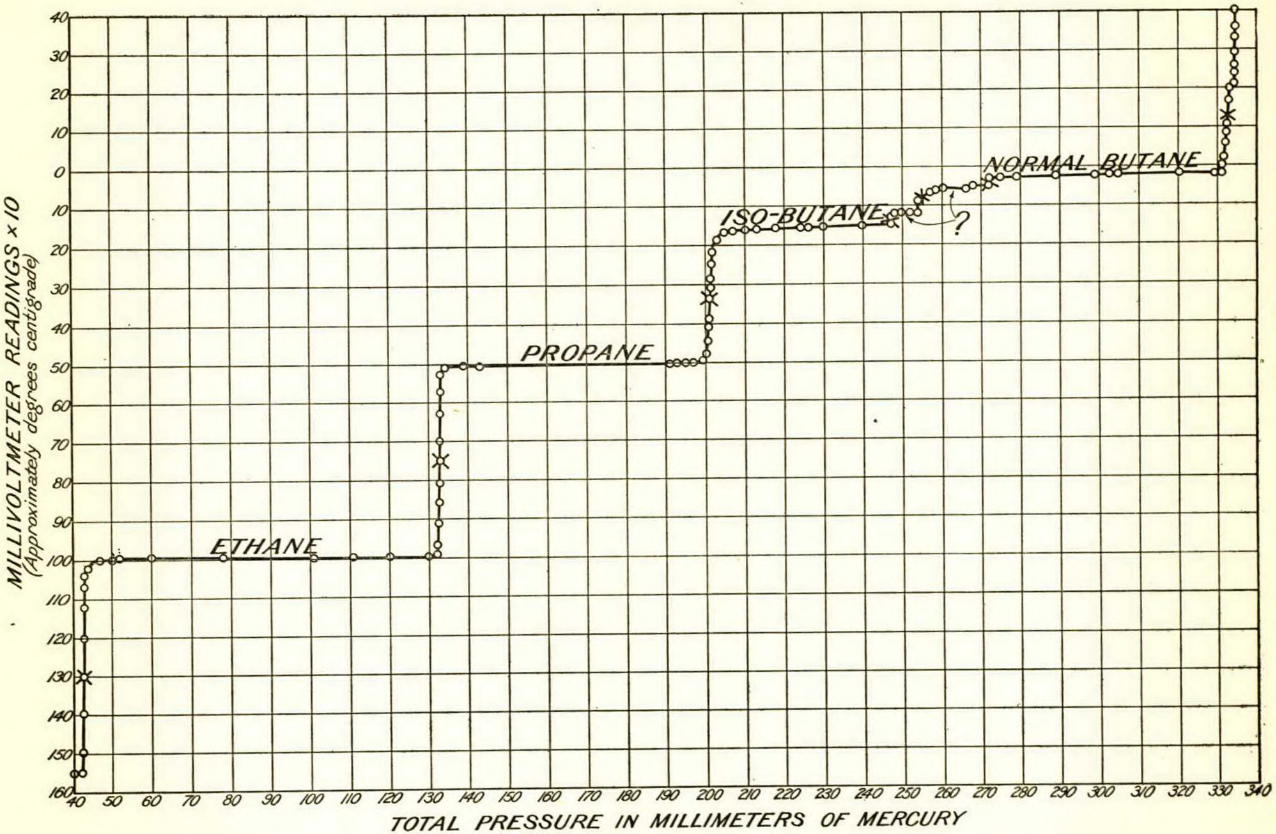

Figure 1. Fractionation curve for Sample No. 27, Foothills No. 1 well, in Turner Valley.

TABLE I

Results of Analyses of Natural Gas in 1930 and 1931

Sample No.	Name of well	Date sampled	Methane plus[1]	Ethane	Propane	Butane	Pentanes plus[2]	Total[3] hydro-carbons	Carbon dioxide	Oxygen	Nitro-gen	Helium	Specific gravity (air=1)	Sample No.
			%	%	%	%	%	%	%	%	%	%		
	New Brunswick													
1	New Brunswick Gas & Oil Co. No. 35................	14/ 8/31	91·0	4·5	3·2	1·0	0·37	98·82	0·29	0·29	0·58	0·024	0·683	1
	Quebec													
2	Lanoraie No. 1..............	22/10/31	99·5	0·5	....	....	....	97·29	0·14	0·69	1·87	0·010	0·605	2
	Ontario													
3	Charlton No. 233............	28/10/31	95·1	1·4	2·2	1·0	0·38	97·29	0·26	....	2·35	0·098	0·619	3
4	Coneybeare No. 5...........	29/10/31	95·3	1·4	2·1	1·0	0·30	94·75	....	0·56	4·49	0·200	0·677	4
5	De Clute No. 13............	29/10/31	98·1	0·3	0·5	0·7	0·30	89·65	0·57	0·28	9·30	0·199	0·664	5
6	Olga No. 1..................	28/10/31	95·5	1·4	2·0	0·8	0·30	94·72	....	....	5·05	0·226	0·647	6
7	Smith No. 2.................	4/11/31	92·3	5·0	1·9	0·6	0·23	94·50	....	....	5·40	0·122	0·716	7
	Alberta													
	Aldersyde field													
8	Ranchmen's No. 1...........	16/10/31	99·4	0·5	0·1	....	....	....	....	....	....	0·235	....	8
	Barnwell field													
9	Barnwell No. 4..............	15/9/31	99·2	0·4	0·2	0·2	....	90·33	....	0·52	8·77	0·380	0·607	9
10	" No. 7..............	15/9/31	98·0	0·7	0·5	0·4	0·37	91·93	....	0·34	7·73	0·372	0·683	10
	Border field													
11	Mayland Southern...........	3/9/31	98·2	1·2	0·2	0·1	0·32	96·57	0·38	....	2·97	0·077	0·602	11
12	Range No. 1................. (Formerly Rogers Imperial)	3/9/31	99·1	0·4	0·3	0·32	....	97·48	0·37	0·37	1·72	0·065	0·588	12
	Bow Island field													
13	Bow Island No. 13...........	3/9/31	99·1	0·6	0·1	0·2	0·14	96·84	0·27	0·27	2·33	0·291	0·598	13
14	" No. 14...........	3/9/31	99·4	0·2	0·1	0·2	0·14	89·98	....	0·24	9·43	0·348	0·602	14
15	" No. 22...........	3/9/31	99·4	0·2	0·1	0·2	0·20	94·91	0·29	0·29	4·16	0·347	0·599	15

	Brooks field													
16	Bro[illegible] 1	18/9/31	99·5	0·1	0·1	0·1	0·22	95·90	......	0·29	3·73	0·075	0·576	16
17	" No. 3	18/9/31	99·8	0·1	0·1	......	......	98·71	......	0·31	0·90	0·077	0·576	17
	Foremost field													
18	Foremost No. 1	16/9/31	99·2	0·5	0·2	......	......	93·41	0·31	......	6·08	0·200	0·592	18
19	" No. 4	27/8/31	99·2	0·5	0·3	......	......	96·69	......	0·45	2·66	0·204	0·589	19
20	" No. 5	16/9/31	99·1	0·7	0·2	......	......	97·67	......	0·40	1·73	0·204	0·590	20
21	United Gas No. 3	16/9/31	99·7	0·3	......	......	......	93·01	0·16	0·32	6·31	0·200	0·599	21
	Lacombe field													
22	Cannon	3/31	......	......	......	......	......	......	1·14	0·22	98·61	......	0·972	22
	Medicine Hat field													
23	Medicine Hat No. 55	17/9/31	99·6	0·1	......	0·2	0·16	99·03	0·22	......	0·65	0·101	0·580	23
	Oyen field													
24	Fuego No. 1	12/30	99·2	0·6	0·3	......	......	98·15	0·55	0·41	0·87	0·020	0·592	24
	Pincher Creek field													
25	Weymarn No. 2 (Formerly Mount Royal.)	17/9/31	90·2	5·5	2·5	1·1	0·70	87·43	0·61	0·15	11·73	0·082	0·688	25
	Redcliff field													
26	Dominion Glass No. 1	17/9/31	99·8	0·2	......	......	......	96·35	......	0·37	3·28	0·119	0·579	26
	Red Coulee field													
27	Vanalta No. 1	8/11/30	90·6	3·4	3·9	1·5	0·77	96·26	1·28	0·26	2·16	0·041	0·688	27
28	" No. 1	5/9/31	94·1	1·0	2·6	1·6	0·74	96·50	0·69	0·52	2·25	0·040	0·685	28
	Turner Valley field													
29	Advance No. 5A	4/9/30	87·2	6·6	3·7	1·7	0·8	[4]99·07	1·12	0·29	......	0·008	0·691	29
30	Associated No. 1	8/9/30	88·4	6·4	3·4	1·3	0·5	[4]99·10	1·07	0·27	......	0·007	0·671	30
31	Baltac No. 1	27/8/31	85·1	7·4	4·1	2·3	1·11	96·57	1·05	0·26	2·12	0·005	0·715	31
32	Brit. Dominion No. 3	10/30	90·0	4·2	3·5	1·6	0·76	97·98	0·75	0·30	0·96	0·008	0·682	32
33	Calmont No. 2	17/9/30	88·2	6·0	3·4	1·7	0· 7	96·02	1·09	0·27	2·61	0·008	0·687	33
34	Commonwealth No. 1	28/8/31	86·7	8·7	3·1	1·1	0·31	98·46	0·35	......	1·19	0·008	0·662	34
35	Dalhousie No. 5	6/9/30	85·0	7·4	3·8	2·1	1· 7	98·47	0·59	1·05	0·88	0·009	0·721	35
36	" No. 7	20/8/30	87·4	6·6	3·6	1·4	1· 1	95·27	0·99	0·14	3·59	0·010	0·678	36
37	East Crest No. 2A and No. 3	23/8/31	87·0	8·1	3·1	1·4	0·46	[4]101·93	0·64	0·32	......	0·007	0·675	37
38	Foothills No. 1	16/8/30	88·7	5·7	3·3	1·5	0· 9	[4]103·99	0·63	0·32	......	Trace	[5]0·687	38
39	" No. 1	16/8/30	87·0	7·5	3·2	1·5	0·81	......	......	......	......	......	......	39
40	" No. 3	17/8/30	89·0	4·8	3·6	1·8	0· 8	[4]100·92	0·59	0·44	......	0·009	[5]0·688	40
41	Freehold No. 2	23/8/31	87·6	6·8	3·5	1·4	0·71	[4]100·81	......	0·16	......	0·008	0·683	41
42	Freeman-Lundy	27/8/31	87·5	6·0	3·7	1·8	1·05	98·36	......	0·89	0·74	0·008	0·690	42

TABLE I—Concluded

Results of Analyses of Natural Gas in 1930 and 1931—Concluded

Sample No.	Name of well	Date sampled	Methane plus[1]	Ethane	Propane	Butane	Pentanes plus[2]	Total[3] hydrocarbons	Carbon dioxide	Oxygen	Nitrogen	Helium	Specific gravity (air=1)	Sample No.
			%	%	%	%	%	%	%	%	%	%		
43	Home No. 1	30/9/29	91·0	4·3	3·1	0·8	0·8	....	....	....	....	....	....	43
44	" No. 1	11/8/30	88·9	6·3	3·2	1·2	0·5	....	....	....	....	....	....	44
45	" No. 3	9/30	87·6	6·8	3·3	1·6	0·7	98·16	1·07	0·29	0·47	0·008	0·683	45
46	Homestead No. 1	26/8/31	88·1	6·4	3·3	1·5	0·69	....	....	....	....	0·061	....	46
47	Lowry No. 1	22/8/30	88·3	5·4	4·0	1·6	0·7	94·00	0·33	0·33	5·33	0·008	0·680	47
48	Mayland No. 1	2/9/30	87·0	7·0	3·5	1·7	0·9	97·70	0·30	0·60	1·39	0·010	0·684	48
49	" No. 6	26/8/31	90·3	5·0	3·1	1·3	0·31	97·45	0·80	0·27	1·47	0·010	0·671	49
50	McDougal-Segur No. 2	27/8/30	87·2	7·3	3·4	1·4	0·7	99·13	....	0·63	0·23	0·007	0·675	50
51	" No. 4	9/9/30	87·7	6·6	3·5	1·6	0·6	98·22	1·27	....	0·50	0·007	0·682	51
52	McLeod No. 4	9/9/30	90·0	4·5	3·4	1·6	0·71	[4]98·40	1·53	0·42	....	0·014	0·688	52
53	Mercury No. 3	11/9/30	89·0	5·2	3·7	1·5	0·6	98·21	0·80	0·27	0·71	0·010	0·678	53
54	Merland No. 1	16/10/31	92·6	4·1	2·5	0·7	0·13	....	....	....	....	0·011	....	54
55	Midfield No. 1	27/8/31	86·9	7·3	3·4	1·6	0·75	99·80	0·32	0·48	0·19	0·009	0·676	55
56	Miracle No. 1	24/8/31	85·6	8·6	3·6	1·6	0·64	99·09	0·47	....	0·44	0·006	0·683	56
57	Model No. 1	10/30	91·0	3·4	3·4	1·5	0·68	97·94	1·47	0·44	0·14	0·008	0·682	57
58	" No. 1	2/11/31	89·1	5·3	3·5	1·5	0·69	98·63	1·25	0·39	....	0·007	0·691	58
59	Okalta No. 1	26/8/31	94·9	1·0	1·3	1·8	0·96	96·30	1·02	0·68	2·00	0·004	0·694	59
60	Regent No. 1	9/9/30	88·3	5·9	3·5	1·6	0·6	96·38	0·52	0·27	2·82	0·010	0·683	60
61	Richfield No. 2	27/8/31	86·6	7·4	3·5	1·6	0·84	97·38	0·80	0·48	1·33	0·008	0·695	61
62	Royalite No. 4	27/9/29	92·2	4·1	2·5	0·5	0·7	....	....	....	....	....	....	62
63	" No. 6	25/8/30	88·5	6·5	3·3	1·3	0·5	[4]107·09	0·36	0·55	....	0·008	0·694	63
64	" No. 17	27/9/29	89·9	5·0	3·2	1·7	0·18	....	....	....	....	....	....	64
65	" No. 17	11/8/30	88·3	6·2	3·4	1·5	0·64	81·42	0·76	0·76	17·76	Trace	[5]0·706	65
66	" No. 18	13/8/30	89·8	4·7	3·3	1·7	0·59	85·91	0·64	0·64	12·80	0·007	[5]0·690	66
67	" No. 19	26/8/30	88·2	6·4	3·4	1·4	0·62	98·96	1·03	0·15	0·86	....	0·687	67
68	" No. 19	3/9/30	88·1	6·5	3·4	1·5	0·63	98·64	1·08	0·13	1·14	0·007	0·682	68
69	" No. 19	12/9/30	88·0	6·5	3·4	1·6	0·54	99·10	0·13	0·54	0·22	0·009	0·682	69
70	" No. 19	26/8/31	88·2	5·9	3·2	1·9	0·79	....	....	....	....	....	....	70
71	" No. 19	2/9/31	89·8	4·8	3·1	1·6	0·69	....	....	....	....	....	....	71
72	" No. 19	10/9/31	89·1	5·2	3·4	1·7	0·59	....	....	....	....	....	....	72
73	" No. 19	23/9/31	88·2	5·9	3·2	1·9	0·79	....	....	....	....	....	....	73
74	" No. 23	27/9/30	87·6	6·4	3·4	1·7	0·86	[4]99·79	0·52	0·52	....	0·009	0·678	74
75	" No. 25	26/8/31	86·2	8·0	3·4	1·6	0·83	98·94	0·45	0·30	0·30	0·011	0·679	75
76	Southern Lowry	16/10/31	86·7	8·2	3·4	1·4	0·39	....	....	....	....	0·008	....	76
77	Spooner No. 1	9/9/30	87·4	6·6	3·7	1·6	0·66	91·71	0·63	0·95	6·70	0·007	0·699	77
78	" No. 44	27/8/31	87·0	7·2	3·4	1·6	0·83	97·62	1·18	0·34	0·85	0·007	0·685	78
79	Sterling-Pacific No. 1	7/9/30	86·8	7·0	3·6	1·8	0·88	[4]99·14	0·94	0·43	....	0·007	0·691	79
80	Structure No. 1	26/8/31	96·1	1·4	0·9	1·0	0·59	97·40	....	0·44	2·15	0·009	0·677	80
81	Wellington No. 1	23/8/31	86·9	7·2	3·5	1·6	0·82	[4]101·00	....	0·33	....	0·006	....	81

	Twin River field													
82	Parco-Nordon No. 1.........	5/9/31	99·4	0·5	0·1	....	....	95·34	0·32	0·32	3·67	0·347	0·590	82
	Warner field													
83	Gas P. & T. Co.[6] No. 1......	16/9/31	99·7	0·3	....	....	....	....	....	....	....	....	....	83

[1] The percentage given for "methane" includes other gases noncondensible at the temperatures used, e.g., oxygen, nitrogen and helium.

[2] The percentage given for "pentane" includes whatever higher hydrocarbons that are present.

Total hydrocarbons were obtained by calculating results of combustion in Burrell apparatus as methane and ethane only.

Constituents obtained from analysis in Burrell apparatus total over 100 without nitrogen.

Calculated value.

Gas Production and Transport Company.

II

WEATHERING OF CRUDE NAPHTHA IN TURNER VALLEY

P. V. Rosewarne and W. P. Campbell

During an investigation of natural gas in Turner valley in Alberta, conducted by the Mines Branch in 1929 and 1930, the process of weathering the crude naphtha was studied. This "weathering," as it is called, is necessary in order to reduce the volatility of the naphtha so that it can be more safely and economically handled as treated or "stabilized" naphtha. The apparent reduction in the volume of crude condensate by the weathering process was further investigated during the summer of 1931, and this report is an account of the measurements taken, the observations made, and the conclusions drawn from them.

The investigation was conducted principally in Turner valley. The writers had placed at their disposal by the Supervisory Mining Engineer of the Department of the Interior, laboratory accommodation and equipment, both at Calgary and at Turner Valley, and it is desired to acknowledge herewith on behalf of the Mines Branch, indebtedness to the officers of the Department of the Interior for their courtesy and co-operation in this respect. Grateful acknowledgment is also made to the Lowry Petroleum Company for placing one of their wells at the disposal of the writers, and to the staff and officers of the Imperial Oil Company and of the Royalite Oil Company for a great deal of assistance in manufacturing and assembling special equipment, and for otherwise co-operating in the work in a very hearty manner.

GENERAL CONSIDERATIONS

As is well known, the gas from this field comes from the producing zone under great pressure carrying with it a certain amount of the heavier hydrocarbon in the liquid phase, which when it is collected forms the crude naphtha referred to above. The equipment that is in general use in the field for the separation and collection of the naphtha is called a separator. The separator is operated at various pressures which have an effect upon the product obtained. Under conditions of high pressure large quantities of gases and volatile vapours which would ordinarily be classed as gases are held in solution in the liquid condensate.[1] When the pressure is released the greater part of these gases passes off, but a certain portion is still held, and would remain in solution for some time if it were left undisturbed. The presence of gases and these very volatile vapours is most undesirable in naphtha which has to be held in storage, and is a source of both trouble and danger if it is to be transported. In the field when storage is limited and the stock must be kept moving, the rapid elimination of the gases becomes essential as in most cases the refiner will not accept it unless they are removed. The common field practice is to warm the naphtha up to a definite temperature considerably above 32° F. by means of steam coils. When the naphtha is to be transported by a common carrier legislative requirements demand that the vapour

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[1] In this paper the term "condensate" is used to denote the product collected by the separator as distinguished from "naphtha" or "crude naphtha," which refers to the same product after it has been weathered.

pressure under certain stated conditions shall not be greater than ten pounds per square inch. Some steaming tanks are fitted with pop-valves in order to give some measure of control, others simply have an opening in the cover of the tank. Unfortunately, during this steaming of the tanks the volatile vapours carry off with them a considerable quantity of marketable naphtha. The object of this investigation was to determine the amount of naphtha lost by the weathering process.

The most modern equipment for treating this class of material consists of a fractionating tower capable of being operated under pressure. This method of obtaining the desired products is very efficient, but it requires a heavy outlay for equipment, and in the field requires rather elaborate gathering lines, in order to transfer the condensate from the well to the central plant. It is of course obvious that it would be impracticable to set up fractionating equipment at each well.

The problem of determining the losses due to weathering may be approached from several angles; first, by considering the composition and quantity of gases given off from a definite volume of condensate; second, by determining the composition of the gases given off and that of the condensate before and after weathering; third, by the direct measurement of the shrinkage in volume of a known quantity of condensate. It was decided after consideration, that a combination of the second and the third methods of approach would present fewer practical difficulties than the first method, although it was not the most direct line of attack. The combined second and third method presented no special difficulties except at one point, namely, that of obtaining an average sample of the vapours given off in order to determine the proportion of pentanes and higher hydrocarbons that would be carried off with the lighter fractions. As already pointed out the lighter fractions in solution tend to raise the vapour pressure of the mixture and an appreciable amount of the pentanes and higher hydrocarbons passes off along with the lighter fractions. This means that the pentanes and higher hydrocarbons content of the weathered naphtha as determined by analysis is lower by the amount so lost. However, certain data were already available which would give close approximations to the amount that would be lost in this way. The third method was quite simple; it merely required that a conveniently large volume of condensate be measured at separator pressures and temperatures and then be weathered down to a vapour pressure of ten pounds per square inch at 100° F.

The equipment required for the method that was chosen consisted of a large high-pressure container which would hold pressures in excess of 300 pounds per square inch, have convenient means of measuring the initial and final volume of the condensate, and be fitted with suitable gauges and valves for charging or withdrawing samples of condensate during the course of the test. In addition, there were required several steel cylinders capable of withstanding high pressures, a vapour pressure bomb, and the use of a Podbielniak fractionating apparatus for the analysis of samples.

THE FIELD TESTS

In order to carry out the tests satisfactorily it was necessary to secure the co-operation of one of the companies operating in the field. As has been stated before, the Royalite Oil Company was approached and readily agreed to give the writers all possible assistance. After considering different possibilities it was finally decided to use a separator similar to those in general use in the field, instead of having a large high-pressure container specially constructed for the work. It happened that two separators had been installed at No 1 well of the Lowry Petroleum Company, and since only one of them was required for ordinary operation of the well, the other was placed at the disposal of the writers. A few changes were necessary in the fittings so that pressure could be built up in the test separator beforehand and then the condensate could be transferred from the producing separator without much change in pressure. No information was available regarding the exact volume of the separator. Accordingly it was necessary to determine its volume accurately, or the volume of that part of it that was to be used in the tests. This was done in two ways, namely, by direct measurement of the separator, and by filling it with water and weighing the water run off between two fixed points on the gauge glass. The two methods checked reasonably closely but the latter being the more accurate the calibration obtained by it was used in the tests. The volume so calibrated would take care of three barrels of condensate. A considerable part of the separator volume lay below the bottom of the gauge glass and as there was no convenient way of measuring this it was decided to fill it with water up to a suitable point on the glass, as shown in Figure 2. The condensate would float on the top of the water when transferred to the separator and would occupy the calibrated portion of the separator. With a definite volume of condensate charged to the separator any diminution in volume could be observed and measured on the gauge glass. A thermometer well and a convenient valve for drawing off naphtha for vapour pressure tests were also installed.

A high-pressure gauge was used at the beginning of each test. This was replaced later by a low-pressure gauge when the pressure had dropped to about 50 pounds per square inch. The gases and vapours from the separator were vented by hand through a small valve. When the pressure had dropped to about ten pounds per square inch, vapour pressure determinations were made periodically until a vapour pressure of less than 10 pounds per square inch was obtained by approved methods. No provision was made for collecting the vented vapour as the volume was too large to handle unless an expensive gas-holder were built for the purpose. Moreover, the gas was contaminated, at the beginning of the test at least, with the stripped gas used to build up pressure prior to the transfer of the condensate. A sample of crude condensate from the producing separator was taken at separator pressure in each test immediately before the transfer of the condensate to the test separator. At the conclusion of each test a sample of the weathered naphtha was also collected directly from the separator for analysis.

Operating Data

At the time of the tests the pressure on the well was kept at approximately 800 pounds per square inch, and the pressure on the separator at approximately 300 pounds per square inch. Water was run into the test separator until its level stood well above the bottom of the gauge glass. Gas was then admitted from the producing separator until the pressures were equal in the two separators. The blowdown valve of the producing separator was then opened and, by increasing the pressure on this separator slightly, the condensate was transferred to the test separator. When the desired quantity of condensate had been transferred, the valve was closed and the volume of condensate as shown by the height of liquid in the gauge glass was recorded. The temperature of the condensate and other pertinent information was also noted. The pressure in the test separator was then slowly reduced by venting the gases and vapours to the atmosphere until the pressure, as indicated by the gauge was 10 pounds per square inch. From this stage on, the pressure was released at intervals. After each release the naphtha was allowed to stand for a time so that the dissolved gases and volatile fractions could

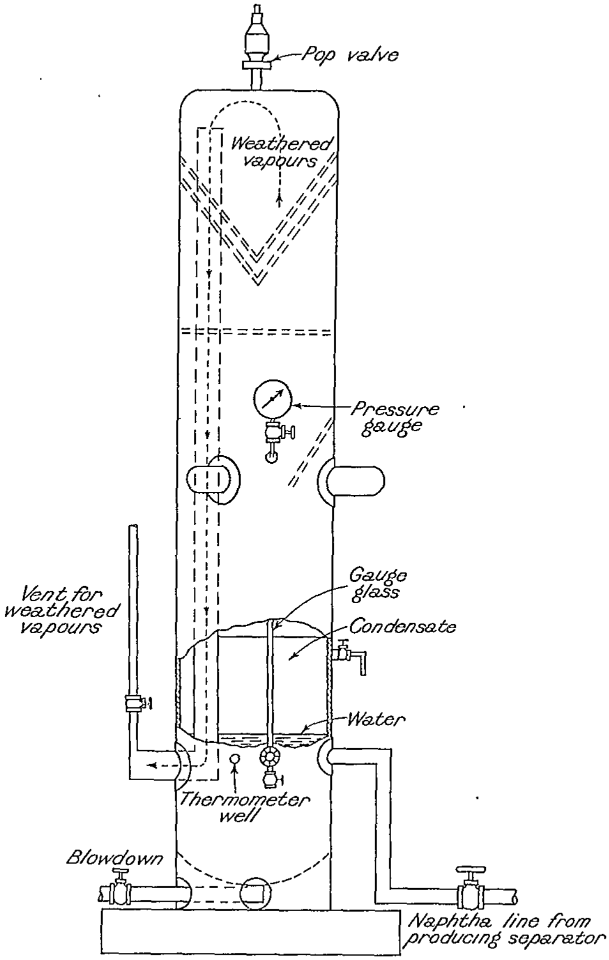

Figure 2. Diagrammatic sketch of test separator.

accumulate above the liquid. Vapour pressure tests were made and if the naphtha showed pressure greater than 10 pounds per square inch, it was again vented and allowed to stand. This was repeated until the required vapour pressure was reached.

DISCUSSION OF RESULTS

Three weathering tests were made. The results obtained and a summary of the analyses of the condensate before and after weathering are shown in Tables I, II, and III.

Test No. 1 was used as a preliminary in order to demonstrate that the apparatus was in satisfactory working order, and the results obtained from it were not as complete as could be desired because several minor difficulties were encountered. First, when the valve was opened to admit the crude condensate some of the water, used to bring the lower level of the condensate being tested up to a point that could be observed in the gauge glass, was forced back into the line, with the result that the quantity of condensate being treated could not be measured accurately. An estimation of the volume was made and is thought to be a reasonably close one. In succeeding tests the water was brought to a higher level at the beginning

TABLE I

Loss of Volume from Weathering

Test	Corrected gauge reading		Difference	Loss of volume, per cent	Specific gravity at 60° F.	
	Inches start	Inches finish			Start	Finish
1	35·63?	23·68?	11·95?	33·5?	0·685	0·693
2	18·38	16·18	2·20	11·97	0·686	0·6875
3	19·31	16·91	2·40	12·40	0·678	0·680

TABLE II

Fractional Analyses by Podbielniak Apparatus Showing Percentage by Volume

Condensate before Weathering

Sample No.	1A	2A	3A	Average
Methane +	....	2·1	1·6	1·8
Ethane	....	2·9	3·2	3·0
Propane	....	6·3	6·9	6·6
Butanes	....	13·2	16·6	14·9
Pentanes +	....	75·7	71·7	73·7
Specific gravity calculated	....	0·659	0·6505	

Condensate after Weathering

Sample No.	1B	2B	$3B_1$	$3B_2$	Average (2B & $3B_1$)
Methane +	....	0·2	0·1	0·1	0·2
Ethane	....	0·5	0·3	0·2	0·4
Propane	1·6	4·3	4·6	5·1	4·4
Butanes	10·6	12·1	15·6	14·0	13·8
Pentanes +	87·8	83·1	79·4	80·5	81·2
Specific gravity calculated	0·688	0·6793	0·6858	0·6834	

TABLE III

Summary of Analysis by Fractional Distillation of Crude and Weathered Condensate from Weathering Test in Turner Valley, 1931

Sample No.	2A	3A	1B	2B	$3B_1$	$3B_2$
Description	Condensate	Condensate	Weathered Condensate	Weathered Condensate	Weathered Condensate	Weathered Condensate
Name of well	Lowry Pet.	Lowry Pet.	Lowry Pet.	Lowry Pet.	Lowry Pet.	Lowry Pet.
Number of well	1	1	1	1	1	1
Taken from	Separator	Separator	Separator	Separator	Separator	Separator
Date taken	Aug. 25	Sept. 10	Aug. 24	Sept. 5	Sept. 25	Sept. 25
Time taken	....	....	....	....	....	....
Taken by	W.P.C.	W.P.C.	W.P.C.	W.P.C.	W.P.C.	W.P.C.
Average pressure in pounds per sq. in.						
On well	800±	800±	....	....	....	....
On separator	300±	300±	....	....	....	....
Temperature, °F. of sample	40±	32	73	69	59	59
Vapour pressure	....	....	8·0	10·0	10·6	10·6
Hydrocarbon by Volume—						
Methane+	2·1	1·6	....	0·2	0·1	0·1
Ethane	2·9	3·2	....	0·5	0·3	0·2
Propane	6·3	6·9	1·6	4·3	4·6	5·1
Butanes	13·2	16·6	10·6	12·1	15·6	14·0
Pentanes and higher	75·7	71·7	87·8	83·1	79·4	80·5
Specific gravity observed	0·686	0·678	0·693	0·6875	0·680	0·680
Specific gravity calculated	0·659	0·6505	0·688	0·6793	0·6858	0·6834
Date tested	Sept. 18	Sept. 22	Sept. 22	Sept. 12	Sept. 25	Sept. 26
Tested by	W.P.C.	W.P.C.	P.V.R.	W.P.C.	W.P.C.	W.P.C.

and no further trouble from this cause occurred. Second, the separator was vented frequently on a very warm day with the result that the vapour pressure of the weathered naphtha was reduced to 8·0 pounds before a sample was tested. On Tests No. 2 and No. 3, care was taken that the separator was not vented unless the atmospheric temperature was less than 70° F. This procedure prolonged the tests considerably but good results were secured thereby. Third, considerable difficulty was encountered in fractionating the crude condensate due to the presence of moisture and practically all of sample No. 1A was used up in efforts to overcome the difficulty. Samples from Test No. 2 and No. 3 were dehydrated under pressure by calcium chloride in a specially designed bomb before fractionation and gave no trouble.

The results obtained in Tests No. 2 and No. 3 indicated that the reduction in volume of crude condensate of the character tested, when weathered until the vapour pressure is 10 pounds per square inch would be about 12 per cent. The actual values obtained were 12 per cent and 12·4 per cent respectively, which were considered to be in satisfactory agreement. In regard to Test No. 1, the analysis of the crude condensate is not available, but a comparison of the specific gravities leads to the belief that the composition of sample No. 1A was similar to that of sample No. 2A. The analysis of sample No. 1B rather corroborates this conclusion. On account of the vapour pressure being reduced to 8 pounds instead of to ten pounds only, it is obvious that the reduction in volume would be greater in this than in the other two cases. Therefore, the figure obtained should be considered as an approximation only.

It is well to bear in mind when considering this problem of weathering crude condensate that a wide variation in gravity is encountered in naphthas from Turner Valley, as much as eighteen degrees A.P.I.[1] frequently occurring between samples from diffierent wells. This variation is probably due to a difference in operating conditions at the wellhead, or to different conditions at the producing horizon. When such widely different condensates are weathered to the same vapour pressure it is obvious that different changes in volume will also be found.

The Practical Value of Analyses

Having obtained by direct measurement a value for the reduction of volume of naphtha due to weathering, the question arises whether the analysis may be used to calculate the probable reduction.

In order to do that it is necessary to know the composition of the vapours given off during the weathering process. As was stated above the vapours given off were not collected nor analysed. However, several samples of similar vapours were analysed during 1929 and 1930 and the results obtained then can be utilized in order to indicate whether such a calculation is feasible.

ANALYSES OF VAPOURS MADE IN 1929 AND 1930

Four samples of stabilizer gas that were fractionated in a Podbielniak column during 1929 and 1930 yielded the results shown in Tables IV and V. The figures shown there indicate that the composition of this gas will vary greatly due to variations in the composition of the condensate being treated at the time and to variations in operating conditions. A great deal of work will be necessary in order to determine the actual effect of each one of the possible factors. In addition to the above, two samples of the gases given off from tanks being heated to drive off the more volatile fractions were analysed and the results are shown in Tables VI and VII. These two samples were obtained from the gas being given off from two different tanks on two different days when condensate from the same well was being treated.

TABLE IV

Hydrocarbons in Stabilizer Gas by Volume

Sample Nos.	6608	307	T2*	T4*	Average
Methane +	25·3	36·3	73·0	61·5	49·0
Ethane	13·6	20·7	3·1	8·2	11·4
Propane	29·4	15·7	8·9	11·6	16·4
Butanes	23·3	16·9	9·5	11·5	15·3
Pentanes and higher	8·4	10·4	5·5	7·2	7·9

*Analysis by H. Stevens-Guille, Royalite Oil Company, Turner Valley, Alberta.

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[1] Degrees A.P.I. refer to the Baumé scale adopted by the American Petroleum Institute.

TABLE V

Hydrocarbons in Average Stabilizer Gas Calculated to Equivalent Liquid Volume

Name of Hydrocarbon	Average per cent Gas vol.	Cubic feet per Imp. gal.	Imperial gallons liquid	Per cent liquid volume
Methane +	49·0	48·0	1·02	45
Ethane	11·4	50·4	0·23	10
Propane	16·4	43·9	0·37	16
Butanes	15·3	36·9	0·41	18
Pentanes and higher	7·9	31·0	0·25	11
	100·0	....	2·28	100

TABLE VI

Hydrocarbons in Vapours from Weathering Tanks

Sample Nos.	T3*	T6*	Average
Methane +	25·0	21·7	23·5
Ethane	14·1	15·2	14·6
Propane	19·9	22·2	21·0
Butanes	22·0	24·7	23·3
Pentanes and higher	19·0	16·2	17·6

TABLE VII

Hydrocarbons in Average Vapours from Weathering Tanks Calculated to Equivalent Liquid Volume

Name of Hydrocarbon	Average per cent Gas vol.	Cubic feet per Imp. gal.	Imperial gallons liquid	Per cent liquid volume
Methane +	23·5	48·0	0·49	20
Ethane	14·6	50·4	0·29	12
Propane	21·0	43·9	0·48	19
Butanes	23·3	36·9	0·63	26
Pentanes and higher	17·6	31·0	0·56	23

*Analysis by H. Stevens-Guille, Royalite Oil Company, Turner Valley, Alberta.

The general agreement in the composition of these two samples of gas is worthy of note, and indicates a very satisfactory degree of uniformity. As is to be expected, the percentage of pentanes and higher hydrocarbons was higher in these samples than was found in the gas from the stabilizer. The averages for the two series of samples tabulated above show that the stabilizers have reduced the loss of pentanes and higher hydrocarbons from 23 per cent to 11 per cent by equivalent liquid volume. It should be noted that the stabilizer used was of the low pressure type and the throughput was not sufficiently large to operate it continuously at its greatest efficiency. Therefore, the results given in this paper should not be compared in point of yield with those obtainable from modern high-pressure equipment operated at maximum efficiency.

In view of the foregoing discussion it would seem permissible to use the average results shown in the tables for pentanes and higher hydrocarbons as a basis for calculations.

ANALYSES OF LIQUIDS MADE IN 1929 AND 1930

In addition to the analyses of vapours that have been discussed, a number of samples of liquid were fractionated during 1929 and 1930. Three of these samples may be considered as representing the condensate recovered in the Smith separators that are in general use in the Turner Valley field. The results obtained are shown in Table VIII. The other five samples may be considered as belonging to the class of "weathered" naphthas. Three of them were composite samples from several wells. The results obtained are shown in Table IX.

TABLE VIII

Hydrocarbons in Condensate by Volume

Sample Nos.	3003	3004	3005	Average
Methane +	4·2	3·0	5·1	4·1
Ethane	4·6	4·8	4·8	4·7
Propane	9·7	9·7	10·8	10·1
Butanes	17·3	20·3	17·9	18·5
Pentanes and higher	64·2	62·2	61·4	62·6

TABLE IX

Hydrocarbons in Weathered Naphtha by Volume

Sample Nos.	6589	6609	3006	3007	3008	Average
Propane and lower	2·3	2·0	2·0	0·7	1·8	1·8
Butanes	10·1	8·8	7·7	9·6	5·1	8·2
Pentanes and higher	87·6	89·2	90·3	89·7	93·1	90·0

TABLE X

Pentanes and Higher Hydrocarbon Content of Various Samples

Name of Product	From Table No.	Liquid volume in per cent		Average for 1929 and 1930
		Test No. 2	Test No. 3	
Condensate before weathering	II & VIII	75·7	71·7	62·6
Condensate after weathering	II & IX	83·1	79·4	90·0
Gas from stabilizer tower	V	....	....	11·0
Gas from steaming tanks	VII	....	....	23·0

For convenience the figures that relate to the pentanes and higher hydrocarbons are brought together and arranged in Table X. The pentanes and higher hydrocarbons have been selected for discussion because they represent a product which, if recovered, is commercially valuable. The butanes and propanes might be dealt with in the same manner, but since a ready market is not yet available their commercial value is more indefinite.

CALCULATIONS BASED ON ANALYSIS

It has been shown that for Test No. 2 the pentanes and higher hydrocarbons in crude condensate were 75·7 per cent; that the pentanes and higher hydrocarbons in weathered naphtha were 83·1 per cent; and if it be assumed that pentanes and higher hydrocarbons in vapours evolved during this test were 23 per cent;* then, let X equal the total reduction of liquid in gallons from 100 gallons of crude condensate.

$$\begin{aligned} \text{and } \frac{83\cdot 1}{100}(100-X)+\frac{23}{100}X &= 75\cdot 7 \text{ gallons.}\\ \text{or, } 0\cdot 601\,X &= 7\cdot 40 \quad \text{``}\\ \text{and, } X &= 12\cdot 3 \quad \text{``}\\ &= 12\cdot 3 \text{ per cent.}\end{aligned}$$

The reduction found by measurement was 12·0 per cent.

In like manner an equation as shown below is obtained when data from Test No. 3 is used:

$$\begin{aligned} \frac{79\cdot 4}{100}(100-X)+\frac{23}{100}X &= 71\cdot 7 \text{ gallons.}\\ \text{or, } 0\cdot 564\ X &= 7\cdot 7 \quad \text{``}\\ \text{and } X &= 13\cdot 7 \quad \text{``}\\ &= 13\cdot 7 \text{ per cent.}\end{aligned}$$

The reduction found by measurement was 12·4 per cent.

It will be apparent from the above calculations that the analysis of the crude condensate and of the weathered naphthas may be used to estimate, with reasonable accuracy, the total reduction in volume of the crude condensate when weathered.

A comparison of the data shown in Table X is of interest since certain relations are brought out that must have a very definite bearing on the reduction in volume due to weathering. It can be seen from a scrutiny of Tables II, VIII, and IX, that the condensate samples collected during 1929 and 1930 had a lower pentane and higher hydrocarbons content than those collected in 1931, and also that the weathered naphtha has a higher pentanes and higher hydrocarbons content than those in the second case. In other words the condensate collected in previous years had a higher volatile fraction content than those collected during 1931. Consequently it is reasonable to believe that in 1929-1930 a large volume of gases and vapours was given off in the weathering process, since the weathered naphtha has a higher pentane and higher hydrocarbons content as shown by the analyses. A comparison of the specific gravities of the various samples also points to the same conclusion. It is probable that vapour pressure determinations on the weathered naphtha in 1929 and 1930 would have shown a lower vapour pressure than was found in 1931. It would appear, therefore, that when discussing the process of weathering, the fact must be kept in mind that the crude condensate produced is not a

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*This figure was used because it more nearly agreed with the conditions under which the test was run, since the vapours were vented to the atmosphere without passing through any fractionating equipment such as is used in stabilizers.

definite mixture of hydrocarbons, but varies greatly in composition in different parts of the field, partly due to different operating conditions at the wellhead, or to different conditions underground.

The general conclusion to be drawn from the above is that the greater the proportion of lighter fractions in the condensate, and the lower the vapour pressure of the weathered product, the greater will be the total reduction in volume, and vice versa.

The total reduction in volume by weathering during 1929 and 1930 can be estimated from the data shown in Table X by using an equation similar to that shown above. If it be assumed that the average percentage of pentanes and higher hydrocarbons in the vapours given off during weathering in 1929 and 1930 be as low as 11 per cent, and X represents the total reduction in volume of the condensate, then from 100 gallons of condensate, the following equation would be obtained:—

$$\begin{aligned} \frac{90}{100}(100 - X) + \frac{11}{100}X &= 62\cdot 6 \text{ gallons} \\ \text{or } 0\cdot 79\,X &= 27\cdot 4 \quad \text{``} \\ X &= 34\cdot 7 \quad \text{``} \\ &= 34\cdot 7 \text{ per cent.} \end{aligned}$$

If it be assumed that the average percentage of pentanes and higher hydrocarbons in the vapours be greater than 11 per cent, the total reduction in volume would be greater. If the weathering were not carried so far and a vapour pressure close to 10 pounds per square inch was maintained for the product, the reduction in volume would be less.

As a general conclusion it would appear that the total reduction in volume during weathering in 1929 and 1930 was of the order of 35 per cent. During the tests in 1931 considerable care was taken to operate the separator in such a way as to cause a minimum reduction of volume. Therefore, there appears to be good reason for expecting the reduction to be somewhat larger than 12 per cent under ordinary oil field conditions.

PROBABLE LOSS IN THE FIELD

If controlled stablization by modern equipment were generally used the reduction in volume would be substantially lessened. Assuming the yearly production to be one million barrels, and the reduction when this product is subjected to open weathering to be 35 per cent, and that the reduction in volume when treated in stabilizers be 12 per cent, then, if the pentanes and higher hydrocarbons of the stabilizer gas were recovered the yield would be 11 per cent (Table V) of 35 per cent and 11 per cent of 12 per cent, respectively. This would mean a saving of from 4 per cent to 2 per cent of the total production which is equivalent to between forty thousand and twenty thousand barrels of pentanes and higher hydrocarbons per year. The data upon which these results are based do not admit of a closer approximation. In the discussion above it is to be remembered that in those cases when total reduction in volume is mentioned that a large proportion of this is due to dissolved methane and ethane, which are not recoverable and have no greater value than the surplus gas being burned at the present time. The amount of dissolved methane is greater than it otherwise would be on account of the high pressure used in the separators.

In order to make possible the saving of pentanes and higher hydrocarbons shown above, a large capital expenditure would be necessary to provide suitable gathering lines from the field to a central stabilizing plant. The cost of the installation, the operation of it, the depreciation charges, and the problematical life of the field itself, are factors, that must be carefully considered before coming to a conclusion as to whether or not the increased yields would make the undertaking commercially profitable.

RECOVERY OF BUTANES AND PROPANE

No discussion has been given to the possible recovery of butanes and propane because it was felt that before these products had a commercial value a market for them would have to built up. Such a market when available would of course increase materially the profits arising from the operation of a stabilizer plant. An estimation of the amounts of these components that might be recovered can be made by a method similar to that used above in the discussion of pentane and higher hydrocarbons.

SUMMARY AND CONCLUSIONS

1. A measurement of the reduction in volume of crude condensate produced by one well in Turner Valley was made by a direct method.

2. The reduction in volume for the condensate treated was approximately 12 per cent.

3. A method for calculating the weathering loss from the analysis of the products has been worked out, the results of which agree reasonably well with those obtained by direct measurement.

4. The method has been applied to crude condensate from other wells which had been examined previously.

5. The additional amount of marketable product that might be obtained under ideal conditions of stabilizing has been estimated at between twenty and forty thousand barrels of naphtha per year.

6. A method is indicated by which the recoverable butanes and propane can be estimated.

7. The crude condensate produced in Turner Valley evidently varies considerably, partly due to operating conditions above ground and partly, perhaps, due to conditions at, or near the producing horizon. The composition of the condensate, the method of weathering, and the final vapour pressure, are all factors which must be taken into consideration when dealing with the weathering of Turner Valley condensate.

8. It is evident that a great deal more work could be done with advantage on this problem. However, the work which has been done indicates the order of the reduction in volume which may be expected.

III

EXPERIMENTS ON THE HYDROGENATION OF ALBERTA BITUMEN, AND ON THE EFFECT OF PRESSURE ON THE PYROLYSIS OF METHANE

PREFACE

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Prior to 1929 investigational work in Canada on bitumen from the bituminous sands of Alberta was concerned with its use as road-paving material and its amenability to refining into petroleum products by ordinary fire-still and pressure-cracking processes, the results thus obtained being compared with other results arising from crude petroleum and asphalt materials. Since that date, however, considerable attention has been paid to the value of this bitumen for hydrogenation treatment as compared with coal, coal tar, and petroleum residues.

Considerable pioneer work has been carried out by S. C. Ells of the Mines Branch, concerning its value for road and other similar purposes and methods for the economic separation of the bitumen, and this has been continued up to the present. Research work of a similar nature, but with special reference to the separation of the bitumen from the sands, and its comparative value for refining into petroleum products, has been conducted during the last decade by Dr. K. A. Clark of the Research Council of Alberta. Other investigators in Great Britain and the United States have been active in the study of Alberta bitumen, and their results are referred to in the comprehensive reports of both Ells and Clark, and in the technical literature. The work of the Division of Fuels and Fuel Testing, concerning laboratory methods for assaying both the raw bituminous sands and the extracted bitumen may be mentioned next. The results of this work are published in the annual Investigations of Fuels and Fuel Testing for 1926, where also are to be found the results of pressure-cracking tests by the Cross process. The hydrogenation experimental work conducted by E. H. Boomer at Edmonton, and by T. E. Warren at Ottawa, brings this chronological sketch of investigational work on Alberta bitumen up to date.

The accompanying report presents the results of experimental hydrogenation and pressure-cracking work on Alberta bitumen at the Fuel Research Laboratories, Ottawa, during 1930 and part of 1931. While the main portion of the experimental work involved the high-pressure hydrogenation treatment of separated bitumen, results obtained with ordinary pressure cracking, without the use of hydrogen, have been included in order to show the relative merits of the two methods. The latter results were obtained by tests made in a bomb supplied by the Kansas

City Testing Laboratory of the Cross Company, under the pressure and temperature conditions obtaining with the Cross process. In these tests the standard sample of dehydrated topped bitumen on hand in the Fuel Research Laboratories was used. The results obtained checked quite closely with those reported on the same sample by the Kansas City Testing Laboratory of the Cross Company, which firm is the sponsor and promoter of the Cross process.[1]

In his hydrogenation experiments without the use of catalysts, Dr. Warren studied the effect of different variable factors, one at a time, namely: temperature, pressure, and duration of reaction. In brief, the results were that gasoline formation and the tendency to form coke were both increased by higher temperatures and longer times of reaction, and that while the higher pressures decreased coke formation, the gasoline yield and corresponding kerosene yield were independent of pressure—at least within the pressure range used. Other observations were that the amount of hydrogen absorbed, while independent of temperature, increased with both longer duration and higher pressure, and that high pressure and long duration favoured the removal of sulphur as hydrogen sulphide, whereas high temperature did not.

Attention is to be drawn to the method of reporting the results obtained, or rather to the criteria used in expressing the results of the different experiments in respect to the conversion of the raw bitumen into products of lighter specific gravity and higher boiling points. The yields of motor fuel expressed in terms of unrefined gasoline with a boiling point up to 410° F. and of the kerosene fraction are shown, instead of merely indicating the degree of cracking with and without hydrogen, by stating the yield of total cracked product irrespective of the end products to be derived therefrom, as is the custom in stating the many hydrogenation results found in the literature. It is interesting to note that of the several catalysts experimented with, nickel carbonate proved the most efficient in respect to depressing carbon formation, but this and other catalysts did not greatly increase the yield of gasoline in comparison with experiments under similar conditions without the use of catalysts. It was found, however, that certain reagents, e.g. calcium or iron oxide, were effective after preheating with hydrogen, in reducing carbon formation. This permits larger quantities of intermediate liquid product to be recirculated in a continuous hydrogenation process, resulting in a higher gasoline yield as the main product.

Slightly higher yields of unrefined gasoline were obtained by pressure cracking than by the batch hydrogenation treatment, but the refining loss may be expected to be greater. Ordinary cracking also produced more coke. In comparison with a possible yield of 30 to 40 per cent by weight of gasoline by recycling in ordinary cracking processes without the use of hydrogen, yields of 65 to 75 per cent by weight, equal to 90 to 100 per cent by volume, are considered possible by continuous recycling hydrogenation treatment. Work on a larger scale, together with a more intensive study of the economics of the situation, is advisable and necessary before attempting to form an opinion regarding which process—hydrogenation or pressure cracking without hydrogen—is the more suitable for treating Alberta bitumen for the production of motor fuels.

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[1] Investigations of Fuels and Fuel Testing 1926, p. 121.

The accompanying report is in two parts: the first part, as summarized above, is confined to hydrogenation and pressure-cracking experiments on Alberta bitumen for the production of motor fuel; the second part, the effect of pressure on the pyrolysis of methane, presents the results of some experiments made on a sample of natural gas consisting almost entirely of methane. The feature of this investigation is the use of a silica tube for conducting experiments under conditions of high temperature as well as high pressure, which is not allowable with steel reaction chambers. Pyrolysis experiments were made at temperatures ranging from 900° to over 1100° C. and through a pressure range of slightly less than 0·5 up to 104 atmospheres. It was shown that the yields of condensation products were not, as was hoped, increased by the use of high pressure but were on the contrary, decreased; further, the higher pressures tended to lower the yield of hydrogen. Observations as to the effect of temperature and rate of flow on the yields of both hydrogen and unsaturated hydrocarbons are in accordance with the conclusions of other investigators. While the results of this investigation in respect to their commercial interpretation are not positive, in that it has been shown that high pressure is not serviceable for the production of condensed products from methane or natural gas having a high methane content, they may, however, be considered of value from an academic viewpoint.

REPORT OF HYDROGENATION AND PRESSURE-CRACKING EXPERIMENTS ON ALBERTA BITUMEN FOR THE PRODUCTION OF MOTOR FUEL

T. E. Warren

Two different samples of bitumen were experimented on, both of which were barrel-lot samples supplied by Dr. K. A. Clark of the Research Council of Alberta. The first sample, No. 3355, was raw separated bitumen which was dehydrated after reaching Ottawa, and the second, No. 7295, was dehydrated before shipment. On these two samples, some of the characteristics of which are shown in Table I, comparative fire-still, pressure-cracking, and hydrogenation tests were made. In the hydrogenation experimental work, considerable attention was paid to the effect of varying, one at a time, such factors as temperature, duration of reaction, and pressure; after which the effect of adding different catalysts was studied. All the results obtained are shown in tabular and graphical form. A review of previous and contemporary bitumen hydrogenation and pressure-cracking work is given, and the possible application to commercial conditions indicated.

The occurrence, extent, characteristics, and methods of mining of Alberta bituminous sand, from which the bitumen used in the present experiments was extracted, are reported by S. C. Ells[1]. The bitumen was separated from the sand by Clark's process[2], by which the bituminous sand is washed with hot water containing sodium silicate and sodium chloride.

TABLE I

Characteristics of Bitumen Samples Used

No.	3355	7295
Specific gravity	1·061	1·030
Viscosity, Saybolt—		
Furol, seconds at 210° F.	995	820
" " 250° F.	282	236
Ash, per cent	3·41	2·53
Sulphur, per cent	5·25	-
Distillate in Hempel apparatus at 760 mm. up to 200° C. (392° F.), per cent	3·5	2·8

PRESSURE-CRACKING EXPERIMENTS

It is apparent from the distillation yield shown that any treatment which produces gasoline in commercial quantities cannot be based on the separation of the small amount already existing in the bitumen, but must produce it by molecular change. The division of the large molecules of which the semi-solid bitumen is composed, into the smaller ones which make up gasoline may be accomplished by heat treatment, and is called cracking.

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[1] S. C. Ells, Bituminous Sands of Northern Alberta, Report No. 632, Mines Branch, Department of Mines, Ottawa (1926).

[2] K. A. Clark and D. S. Pasternack, Research Council of Alberta, Report No. 26, page 41 (1931).

FIRE-STILL DISTILLATION

A large proportion of the bitumen has such a low volatility that the temperature at which cracking begins (about 350° C.) is lower than the boiling point. Consequently, when it is distilled at atmospheric pressure, part of the vapour is the product of cracking taking place in the liquid phase. Therefore one method of cracking the bitumen is, to distil it at atmospheric pressure from an externally heated iron still such as the so-called "fire still" used in petroleum refining.

Both samples of bitumen were distilled until the residue was reduced to coke, by means of an electrically heated iron still of about four litres capacity. Two litres of the bitumen was charged, and the time required for the distillation was about seven hours. The top of the still was heated so that there was no reflux. The results are tabulated below.

	Weight, per cent	
No.	3355	7295
Charge of bitumen	100	100
Coke residue obtained	26·8	27·7
Liquid product obtained	61·6	56·9
Gas and loss	11·6	15·4
Liquid boiling up to 410° F. (gasoline)	12·1	12·9

Although the fire-still distillation described above is theoretically a cracking process, the term "pressure cracking" is usually applied to heat treatment at a pressure greater than atmospheric. Two well known pressure-cracking processes are those of Cross and Dubbs.

DUBBS PROCESS

In 1926, samples of bitumen were sent by K. A. Clark to the Universal Oil Products Laboratory for a test according to the conditions of the Dubbs process. The bitumen was charged to the cracking apparatus without preliminary treatment, and heated at 750° F. under a pressure of 90 pounds per square inch. The yield of gasoline was 27 per cent by weight of the charge and there was a coke residue of 28 per cent. The gasoline was found to have a good knock rating (benzol equivalent, 33·2)[1].

CROSS PROCESS

At about the same time (1926), part of sample No. 3355 was sent from the Fuel Research Laboratories to the Kansas City Testing Laboratory of the Cross Company for a cracking test. The bitumen was distilled to coke in a fire still, and the distillate cracked in small-scale equipment under the conditions described below. The yield of unrefined gasoline obtained by this treatment was 20·3 per cent of the weight charged to the fire still. A larger yield of gasoline may be obtained by recycling the higher boiling residue from the cracking apparatus.[2]

The experiments reported by the Kansas City Testing Laboratory were repeated at the Fuel Research Laboratories in 1930 using, as far as possible, the same kind of apparatus and the same procedure. The fire-still was the same as previously described. The cracking apparatus,

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[1] Egloff and Morrell, Canadian Chem. & Met. XI, page 33 (1927).

[2] R. E. Gilmore, P. V. Rosewarne, and A. A. Swinnerton, Investigations of Fuels & Fuel Testing 1926, page 121.

which was purchased from the Cross Company, is a steel cylinder of about 1·5 litres capacity tested to 3,000 pounds per square inch. It is equipped with a pressure gauge and outlet valve at one end, and a thermometer well at the other. It is heated from below by ten gas burners. The Cross experimental cracking bomb is shown assembled in Plate III A.

The procedure is to introduce 500 c.c. of the oil to be tested and heat it until the pressure has reached 810 pounds per square inch at 400° C. The heating rate should be such that the time required is between 55 and 70 minutes. After the correct temperature and pressure have been reached, the bomb is allowed to cool and the product removed at room temperature.

A series of pressure-cracking tests conducted in this bomb at the Fuel Research Laboratories gave a complete verification of the results obtained at the Kansas City Testing Laboratory. The yields of unrefined gasoline from the cracking experiments are shown below.

		Yield unrefined gasoline; weight, per cent
Kansas City Testing Lab. on No. 3355		20·3
Fuel Research Labs. on No. 3355	(1)	20·5
Fuel Research Labs. on No. 3355	(2)	20·1
Fuel Research Labs. on No. 7295	(1)	21·2
Fuel Research Labs. on No. 7295	(2)	20·8

Little hard carbon was formed in cracking, but the yield in the preliminary fire-still distillation was large.

The deposition of coke in both cracking processes is a serious objection to their use for it not only wastes a considerable amount of raw material but, also, it is a hindrance to continuous operation.

HYDROGENATION EXPERIMENTS

REVIEW OF OTHER HYDROGENATION TESTS ON ALBERTA BITUMEN

Results of Bergius

In 1922 a small quantity of bituminous sand was sent to Bergius' laboratory at Rheinau, and in 1926 a report of the test was given to the Fuel Research Laboratories. No operating details are given. The yields are incompletely reported as follows:—

	Per cent by weight of bitumen charged
Motor spirit (up to 392° F.)	30
Creosoting oil	5
Diesel oil	25
Pitch	25
Total	85

The nature of the 15 per cent not accounted for is not stated.

Results of Boomer and Saddington

During the past three years, experiments on the hydrogenation of bitumen have been conducted at the laboratories of the Research Council of Alberta by E. H. Boomer and A. W. Saddington, who have published two papers on the subject. The first[1] describes experiments with an apparatus similar to that used at the Fuel Research Laboratories. The second[2] describes further experiments using a rocking autoclave of 1·8 litres capacity. Of these two series of experiments, the part most interesting in connexion with this paper is that dealing with the hydrogenation of the residues from previous hydrogenation products after the more volatile fractions have been distilled off. It was found that the bitumen contained 15 per cent of a material which was not easily cracked at temperatures as high as 500° C., but that the rest was capable of conversion to oil, gas, and coke in proportions which depended on the conditions of the experiment.

HYDROGENATION EXPERIMENTS AT THE FUEL RESEARCH LABORATORIES

Apparatus

The equipment required for discontinuous experiments on hydrogenation comprises a reaction chamber, a means of heating it, of applying a high pressure of hydrogen to the charge in it, and of measuring the temperature and pressure of the charge. It is desirable also to have a stirring device, a means of cooling the reaction chamber quickly, and to have inlet and outlet tubes so placed that either liquid or gas can be added or removed during an experiment.

The reaction chamber employed in these experiments is shown in Plate III B. The bomb proper and the head and stirring equipment are to be seen at the left of Plate II. The chamber is made of chrome-nickel (18-8) steel, with an internal diameter of $3\frac{3}{16}$ inches and a wall thickness of $\frac{5}{8}$ inch. Its capacity with the head in place is 920 c.c. The stirring paddle is rotated from the outside by a shaft running through a water-cooled packing gland at the rate of 23·6 revolutions per minute. Temperature is measured by a thermocouple in a well beside the stirring shaft at about 2 inches from the bottom of the bomb. The bomb may be cooled by blowing air from a $\frac{1}{4}$-inch compressed air line against the bottom inside the heater.

To compress the hydrogen to the desired pressure it is allowed to pass from the shipping cylinder, where its pressure is less than 2,000 pounds per square inch, to a thick-walled cylinder of about one-gallon capacity. Water is pumped into this cylinder until the hydrogen is at the required pressure. The hydraulic pump and pressure cylinder may be used at pressures up to 10,000 pounds per square inch.

For protection in case of failure of the high-pressure apparatus, a wall of $\frac{3}{16}$-inch sheet steel was built around it, as shown in Plate II. Valves, gauges, switches, ammeter, rheostats, and pyrometer are mounted outside the wall. Inside it a fan and air duct prevent the accumulation of any gas leaking from the bomb or connexions.

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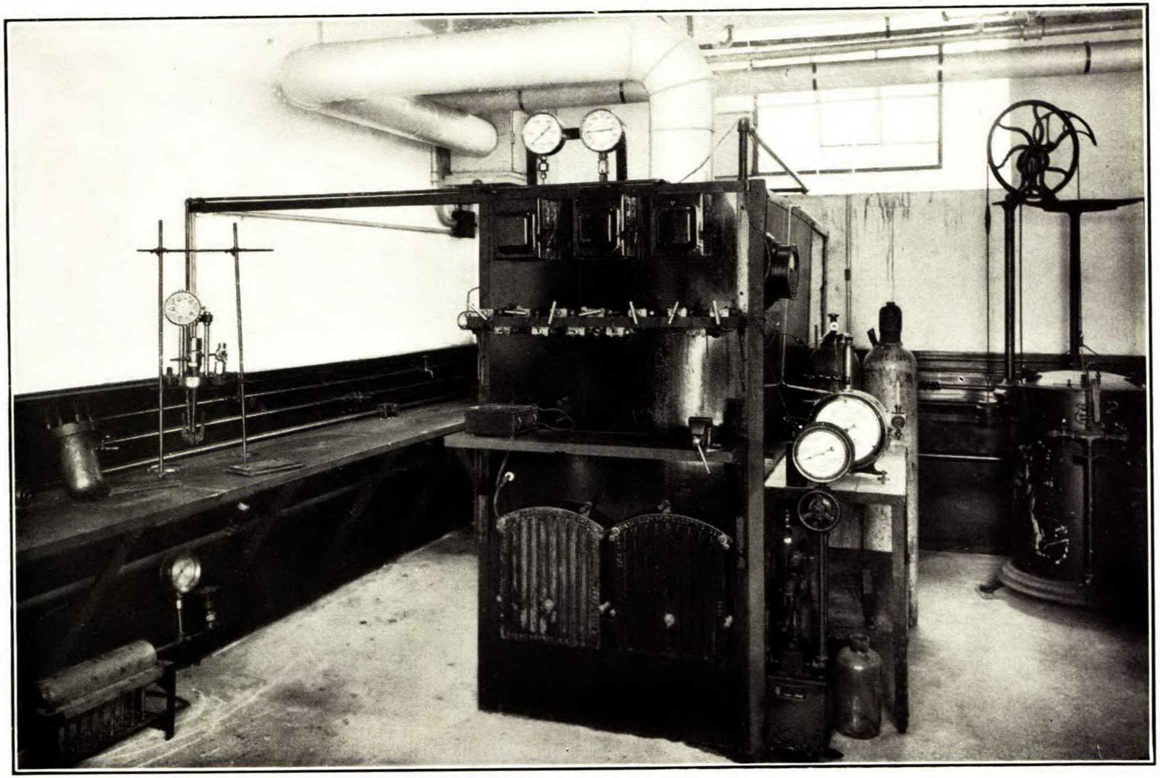
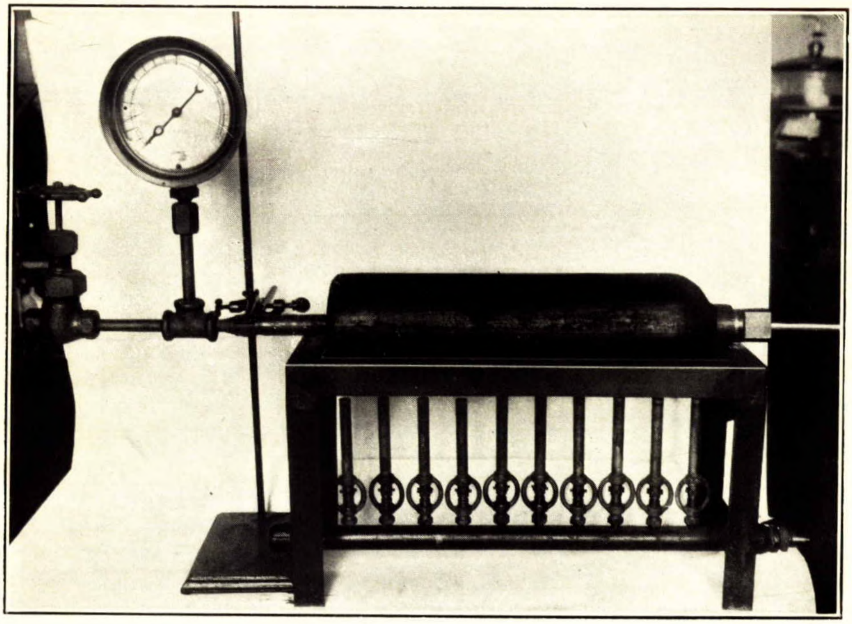
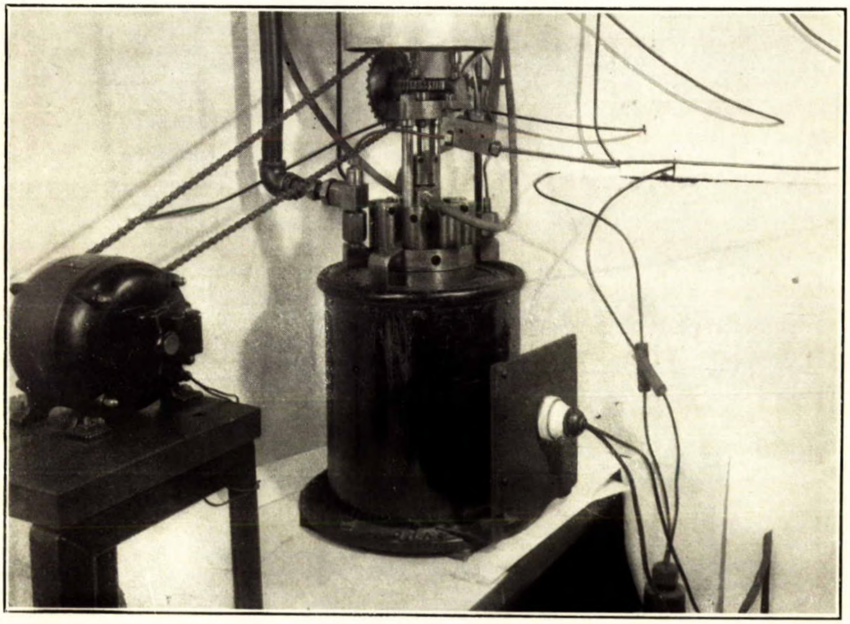
[1] Boomer and Saddington, Can. Jour. of Research, 2, 376 (1930).
[2] Boomer and Saddington, Can. Jour. of Research, 4, 517 (1931).



Hydrogenation apparatus as installed in the Fuel Research Laboratories.



A. The Cross experimental cracking bomb.



B. Hydrogenation bomb assembled with heater.

Procedure

The amount of bitumen charged was 200 grammes. A smaller amount did not yield sufficient product for a satisfactory analysis, but it was found that the charge had to be kept as small as possible in order to maintain the gas composition and pressure at nearly constant values. In introducing the charge, the bomb was weighed on a balance sensitive to 0·5 gramme, the melted bitumen poured into it to approximately 200 grammes, and the quantity determined exactly by difference in weight. The catalyst, when employed, was then added and the apparatus assembled. Hydrogen was introduced at the desired pressure and the apparatus examined for leaks and allowed to stand for an hour. If the pressure had not decreased during that time, the heating current was turned on. When the temperature, indicated by the pyrometer in the charge, was 50° C., stirring, which increases the rate of heating, was begun. When the desired temperature had been reached the heating current was suitably reduced and the air blast used, if necessary, to check the rate of heating. The temperature was maintained as nearly constant as possible with the air blast and rheostats for the desired duration. The heating current was then turned off and the air blast turned on until the temperature was 350° C. at which point the stirrer and air blast were turned off. The rate of cracking at temperatures lower than 350° C. is not appreciable, so that it is not necessary to cool the charge rapidly below this point. The apparatus was allowed to cool, usually over night, and the gas released through a meter. Two samples of gas were collected at atmospheric pressure before passing the meter. The head of the bomb was removed and the liquid product separated from the coke and catalyst by pouring through a screen. The bomb was weighed after the removal of gas, liquid, and solid respectively, and the amount of each determined by difference.

The samples of gas were analysed in a Burrell apparatus for hydrogen sulphide, unsaturates, hydrogen, methane and higher hydrocarbons. The reagents used were potassium hydroxide, fuming sulphuric acid, and copper oxide. Combustion on a platinum spiral was used to estimate the carbon-hydrogen ratio.

An Engler (A.S.T.M.) distillation of the liquid product was made. The specific gravities of the liquid product and of the gasoline and kerosene fractions (up to 410° F. and 410° to 572° F. respectively) of the distillation were determined. Twenty of the gasoline samples were given a refining test in which the volume losses on treatment with 80 per cent sulphuric acid and 10 per cent caustic soda were determined, and the samples so purified were given a "doctor" test for sulphur.

The solid product, as removed from the bomb, was extracted in a Soxhlet apparatus with petroleum ether for five hours. It was then dried, weighed, and pulverized. Proximate analyses on the dry powder were then made by the standard method for coal, to show ash, volatile matter, and fixed carbon contents. The Eschka method was used for the determination of sulphur in the dry pulverized residue.

Definitions

Before discussing the results of the hydrogenation experiments, it is thought advisable to define certain terms to be used.

Gasoline, unless otherwise stated, is that part of the product recovered as distillate up to 410° F. in a standard A.S.T.M. Engler distillation.

Kerosene is that part of the product recovered as distillate between 410° and 572° F. in a standard A.S.T.M. Engler distillation.

Coke is that part of the solid product remaining after extraction with petroleum ether.

Temperature, used in the sense of temperature of experiment, is the average temperature between the heating and cooling periods, i.e. over the "duration." [1]It is measured at the bottom of the pyrometer well, which is near the centre of the charge.

Pressure is read on a Bourdon gauge connected to the top of the bomb at room temperature before the experiment is begun. It is approximately half the maximum pressure after full temperature is reached.

Duration is the length of time between the heating and cooling periods.

Hydrogen used is the hydrogen disappearing during an experiment based on the known volume and pressure before an experiment and the volume, pressure, and analysis of the gas after the experiment.

Results

The variables examined in the present work were temperature, pressure, time, and catalytic action. Other conditions were as nearly constant as possible.

Temperature Variable. The study of the temperature variable was made by conducting a series of experiments at different temperatures between 400° and 470° C. No catalyst was used; the duration and initial pressure were 30 minutes and 1,470 pounds per square inch respectively.

The yields of gasoline and coke in weight per cent of the charge at the various temperatures, are given below in tabular form, and shown graphically in Figures 3 and 4.

Temperature, °C.	Gasoline (as weight per cent of charge)	Coke (as weight per cent of charge)
399	7·9	1·0
403	14·5	13·9
420	17·5	19·1
434	22·6	26·8
449	20·4	31·1
470	22·6	28·7

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[1] See page 110 for method of heating.

Over the entire temperature range, the yield of kerosene remained nearly constant at 11 per cent. The amount of hydrogen used was also approximately constant at 1·1 per cent by weight of the bitumen charged. The amount of sulphur removed in the gas decreased with the rising temperature from 11 per cent of the total sulphur in the bitumen to 5 per cent at 400° and 470° C. respectively.

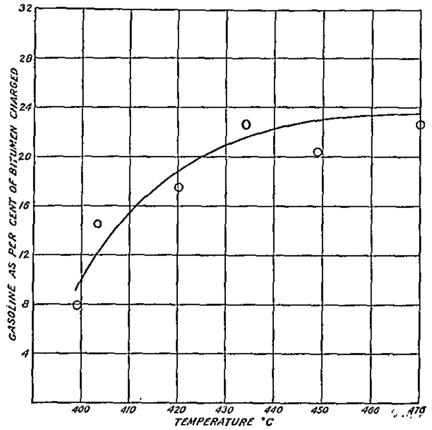

Figure 3 With duration and pressure constant the yield of gasoline is plotted against temperature.

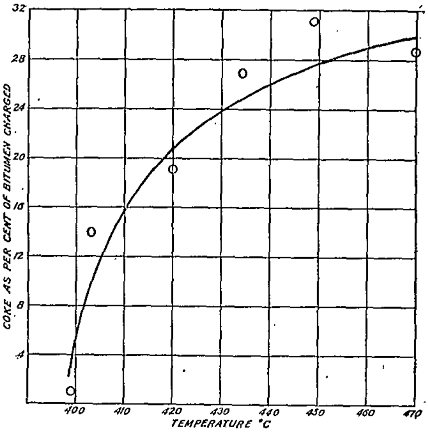

Figure 4 With duration and pressure constant the yield of coke is plotted against temperature.

Duration Variable. The study of the duration variable was made by conducting a series of experiments at different durations between 12 and 90 minutes. In all of the experiments the temperature was 410° C., at which temperature there were sufficient amounts of gasoline and carbon for convenient study. The initial pressure, as before, was 1,470 pounds per square inch. The yields of gasoline and coke are given below, and are shown graphically in Figures 5 and 6.

Duration (in minutes)	Gasoline (as weight per cent of charge)	Coke (as weight per cent of charge)
12	5·8	None
18	11·9	9·6
33	14·5	13·9
69	19·6	19·5
90	22·8	23·7

The yield of kerosene increased from 8 to 11 per cent between 12 and 33 minutes, but remained practically constant at the longer durations. The amount of sulphur in the gaseous product increased with increasing durations until, at the end of 90 minutes, 12 per cent of the sulphur in the original charge was present in the gas. The amount of hydrogen used increased from 0·9 per cent to 1·15 per cent over the range of duration studied.

Pressure Variable. The study of the pressure variable was made by conducting a series of experiments at different initial pressures between zero and 3,000 pounds per square inch. In all of the experiments the temperature was 410° C. and the duration 30 minutes. The yields of gasoline and coke are given below, and shown graphically in Figures 7 and 8.

Pressure (initial in pounds per square inch)	Gasoline (as weight per cent of charge)	Coke (as weight per cent of charge)
0	12·5	31·5
750	11·6	20·4
1,500	14·5	13·9
2,250	13·6	16·9
3,000	12·9	9·4

The yield of kerosene was nearly constant at 11 per cent. The amount of sulphur in the gaseous product increased rapidly with increase in pressure up to 20 per cent at 3,000 pounds per square inch. The amount of hydrogen used increased in direct proportion to the pressure. At an initial pressure of 3,000 pounds per square inch, the weight of hydrogen used was 2·0 per cent of that of the original bitumen.

Conditions for Maximum Gasoline with Low Carbon Yield. Two further experiments were made in an attempt to obtain simultaneously a high yield of gasoline and a low yield of carbon. The conditions and yields are as follows:

—	Experiment 45	Experiment 46
Temperature, °C	422	405
Duration (minutes)	32	186
Pressure (initial, pounds)	3,000	2,985
Gasoline (% by weight of bitumen charged)	24·0	26·2
Coke (% by weight of bitumen charged)	26·0	19·5

It is apparent that the pressure, which at the maximum was 6,000 pounds per square inch, was not sufficiently effective in suppressing carbon formation in either of the conditions under which high gasoline yields are to be obtained, namely, high temperature and long duration.

Catalysts. Throughout the program on varying catalytic materials added to the bitumen, the temperature was 410° C., the duration 30 minutes, and the initial pressure 1,470 pounds per square inch. The catalysts in inverse order of carbon formation with the corresponding yields of gasoline and coke, were:

Catalyst	Amount catalyst (in weight per cent of charge)	Gasoline (as weight per cent of charge)	Coke (as weight per cent of charge)
Nickel carbonate	3·6	17·3	12·7
Copper oxide	2·9	15·7	15·4
Ammonium molybdate	3·3	17·2	15·6
Tin	3·4	15·1	16·2
Zinc oxide	3·0	22·3	26·4
Chromic oxide	5·0	23·5	28·4
Iron oxide	5·0	14·1	37·7

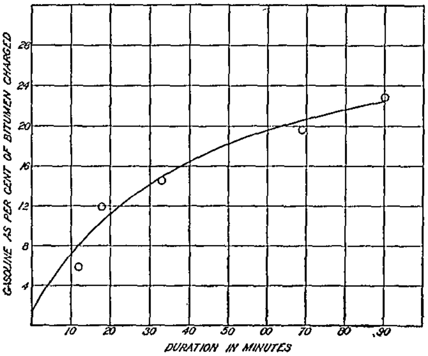

Figure 5 With temperature and pressure constant the yield of gasoline is plotted against duration.

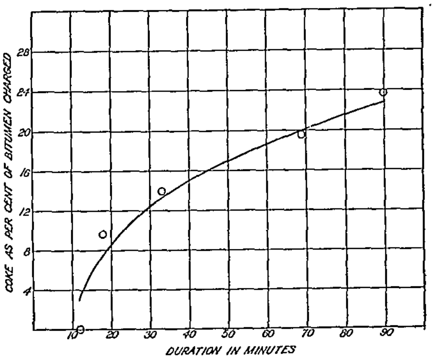

Figure 6 With temperature and pressure constant the yield of coke is plotted against duration.

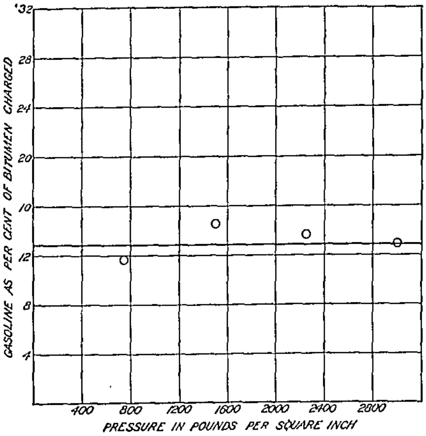

Figure 7 With temperature and duration constant the yield of gasoline is plotted against the pressure.

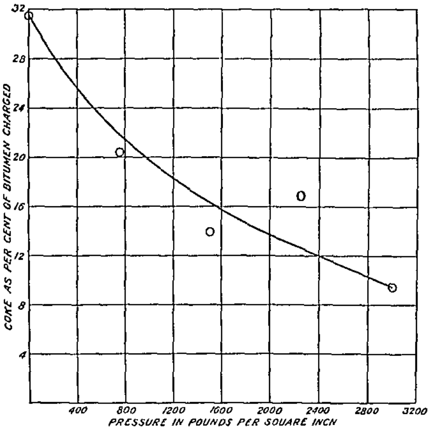

Figure 8 With temperature and duration constant the yield of coke is plotted against pressure.

It is to be noticed that under the conditions of the experiments most of the catalysts had the effect of forming carbon rather than preventing its formation. Nickel carbonate was the only catalytic material giving a lower yield of carbon than that which would have attended the corresponding yield of gasoline had no catalyst been present.

In an attempt to remove sulphur, bitumen was treated with hydrogen at temperatures between 300° and 350° C. in the presence of ferric oxide and calcium oxide. On being further hydrogenated at 410° C. it gave the usual yield of gasoline, but without the formation of *any* carbon. This effect was at first ascribed to the removal of sulphur, but it was found that the sulphur in the bitumen combined with the catalyst to an appreciable extent only at the higher temperature. Further, if the catalyst were removed between the first hydrogenation (at 330° C.) and the second (at 410° C.) carbon was formed as usual in the second period. It was found that when ferric oxide or calcium oxide were hydrogenated for two hours at 330° C. and added to a charge of bitumen which was then run under the usual conditions (410° C., 30 minutes, 1,470 pounds per square inch) no carbon was formed. The effect was, therefore, credited to prehydrogenation of the catalyst. Ferric oxide (Fe_2O_3) was found to be converted to a large extent to the magnetic oxide (Fe_3O_4) by the pretreatment. By combined pretreatment and second stage hydrogenation, 5 and 25 per cent of iron oxide removed 56 and 100 per cent respectively of the sulphur present in the bitumen.

Further study of these catalysts has been postponed until another apparatus, now under construction, has been completed, when it will be possible to investigate their behaviour in prolonged, continuous use.

Refining Tests: The refining tests to be described were made on the gasoline fractions distilled from the liquid product. These fractions were too small to permit any preliminary study of refining methods so that the following procedure was arbitrarily adopted:

1. As large a sample as was available (usually 15 to 40 c.c.) was shaken for 15 minutes with an equal volume of 80 per cent sulphuric acid. The gasoline was poured off, washed with water, the colour observed and the specific gravity and volume decrease measured.

2. The remaining gasoline was shaken for 15 minutes with an equal volume of 10 per cent sodium hydroxide solution, and the colour, specific gravity, and decrease in volume again observed.

3. The sample remaining after the acid and caustic refining was shaken with sodium plumbite according to the procedure of the doctor test for sulphur, and recorded as "sour" (+) or "sweet" (−).

The results of the refining tests are given in Table II.

TABLE II

Sample No. 15-F.T.-D	Temp. °C.	Pressure, pounds per square inch	Duration, minutes	Catalyst and remark	Before treatment		After treatment with 80 per cent sulphuric acid			After treatment with 10 per cent caustic soda			Total volume decrease	Doctor test
					Sp. Gr.	Colour	Sp. Gr.	Colour	Volume decrease	Sp. Gr.	Colour	Volume decrease		
									%			%	%	
12	410	1·470	62	None	0·772	Deep orange	0·774	Light yellow.	6·0	0·776	Light yellow.	2·0	8·0	−
13	410	1,470	90	None	0·757	Reddish	0·762	Light orange.	8·8	0·766	Light yellow.	8·7	17·5	−
35	....	....	....	Gasoline from fire-still distillation.	0·812	Deep amber	0·830	Deep yellow	16·7	0·829	Deep yellow	10·0	26·7	+
47	410	1,470	30	Fe_2O_3, 5 per cent	0·758	Reddish	0·761	Light pink	8·0	0·763	Almost colourless.	4·0	12·0	−
48	410	1,470	30	$(NH_4)_2MoO_4$, 3·3 per cent.	0·762	Red	0·764	Light pink	7·5	0·765	Light yellow.	2·5	10·0	+
50	410	1,470	30	ZnO, 3·0 per cent	0·767	Brown	0·767	Light pink	6·7	0·767	Light yellow.	0·0	6·7	−
51	410	1,470	30	Sn, 3·4	0·783	Deep orange	0·782	Light yellow.	6·7	0·781	Yellow	0·0	6·7	−
52	410	1,470	30	CuO, 2·9	0·778	Light brown	0·777	Straw	6·7	0·770	Straw	0·0	6·7	−
53	410	1,470	30	$NiCO_3$, 3·6	0·765	Brown	0·765	Orange	5·0	0·765	Yellow	0·0	5·0	+
54	410	1,470	30	None, Sample No. 7295	0·780	Reddish	0·777	Pink	7·5	0·778	Light yellow.	0·0	7·5	−
55	410	1,470	30	None, bomb copper-lined	0·757	Medium brown.	0·761	Pink	10·0	0·764	Very light yellow.	3·3	13·3	+
56	410	1,470	30	None, pre-run	0·753	Very dark red	0·757	Light pink	8·0	0·758	Light yellow.	0·0	8·0	+
57	410	1,470	30	Fe_2O_3, 5·0 per cent pre-run.	0·763	Reddish brown.	0·763	Pink	13·3	0·764	Yellow	3·3	16·6	+
58	440	1,470	30	Fe_2O_3, 5·0 per cent pre-run.	0·758	Very deep red	0·761	Pink	7·5	0·763	Light yellow.	1·3	8·8	+
59	415	1,470	30	Fe_2O_3, 15·0 per cent pre-run.	0·759	Brown	0·761	Light pink	10·0	0·764	Light yellow.	0·0	10·0	−
60	430	1,470	30	Fe_2O_3, 25·0 per cent pre-run.	0·765	Deep orange	0·766	Light yellow.	5·0	0·767	Light yellow.	0·0	5·0	−
62	420	1,470	60	CaO, 10·0 per cent pre-run.	0·764	Deep orange	0·764	Light yellow.	5·0	0·766	Light yellow.	0·0	5·0	−
65	410	1,470	30	$(NH_4)_2MoO_4$, 3·5 per-cent pre-run.	0·757	Orange	0·760	Light yellow.	6·7	0·761	Light yellow.	0·0	6·7	−
66	405	1,470	30	CaO, 10·0 per cent catalyst pre-run.	0·757	Brown	0·760	Pink	6·7	0·762	Yellow	0·0	6·7	+
67	410	1,470	30	Fe_2O_3, 10·0 per cent catalyst pre-run.	0·760	Brown	0·763	Very light yellow.	10·0	0·765	Yellow	3·3	13·3	+

Summary and Discussion of Results

The results obtained in the different series of experiments have been given above in tabular and graphical form. They may be further discussed and summarized in sections as follows:

Effect of Varying Temperature, Duration, and Pressure. The results of the three series of experiments to determine the effect of varying, in turn, the temperature, duration, and pressure on the products obtainable from the bitumen hydrogenated in the absence of catalysts, are: first, that coke formation is increased by high temperature, long duration, and low pressure; second, that gasoline formation is increased by high temperature and long duration and is independent of pressure; third, that the removal of sulphur as hydrogen sulphide is increased by low temperature, long duration, and high pressure; fourth, that the kerosene yield is not influenced by temperature or pressure and only slightly with increasing duration; and fifth, that the amount of hydrogen absorbed is independent of the temperature, increases slightly with increasing duration, and is directly proportional to the pressure. It should be borne in mind that these conclusions are not necessarily valid in ranges other than those studied, or in the presence of catalysts, or in different types of apparatus, although it is probable that they can be applied under conditions which might be used commercially.

Effect of Catalysts. The catalysts studied did not greatly increase the yield of gasoline, nor did they cause the removal of sulphur as hydrogen sulphide. It was found, however, that sulphur can be completely eliminated from the charge by combination with iron oxide or calcium oxide, and that if preheated with hydrogen, these materials are effective in reducing carbon formation. As shown on page 122, carbon formation varied greatly with the different catalysts used, that is, in the absence of hydrogen pretreatment. Iron oxide produced the greatest amount of carbon, and nickel carbonate the least, with chromic oxide, zinc oxide, tin, ammonium molybdate, and copper oxide showing decreasing carbon formation in the order stated.

Refining. It is to be noted that the refining loss is of a magnitude which makes it one of the most important variables, and that by changing the conditions of experiment it can be varied greatly. The conditions which reduce the refining loss are also those which eliminate sulphur from the liquid product, rather than those which reduce carbon formation. For example, in experiment 35, in which the refining loss was the greatest, no sulphur was eliminated by hydrogenation or combination with a metallic catalyst. In experiments 60 and 62, in which the refining loss was least, the sulphur in the charge had been removed by the iron and calcium oxides.

SIGNIFICANCE OF RESULTS IN RELATION TO THEIR COMMERCIAL APPLICATION

In commercial hydrogenation plants at present in use, the material to be hydrogenated is heated in a continuous stream of high-pressure hydrogen which carries with it the more volatile products formed by the process. The liquid feed is continuously introduced, and the less volatile product containing solid material continuously removed. After the process has been running some time the concentration of each material at any given point in the apparatus reaches a constant value. The conditions of the experiments described in this paper differ fundamentally from commercial practice in that the concentrations of the constituents of both gas and liquid are always changing. While this procedure has obvious faults, it possesses the advantages that the duration is known, and the effect of the pressure variable on hydrogenation can be studied without taking into account its effect on the distillation of the product. Complete data on ultimate yields can be obtained only in a continuous apparatus.

Considering only the experiments herewith reported, certain observations concerning the hydrogenation of Alberta bitumen are to be made, namely, the bitumen in question can be hydrogenated without the formation of solid carbon to give a crude oil yield of 95·4 per cent by volume (90·5 per cent by weight) of the charge, the yield of unrefined gasoline being 24·9 per cent by volume (18·2 per cent by weight) of the original bitumen; catalysts which can be used to give the results just mentioned are ferric oxide or calcium oxide pretreated with hydrogen at 2,500 pounds per square inch pressure and 330° C. for two hours; the duration of the actual bitumen hydrogenation test, neglecting heating and cooling periods, is 30 minutes, the temperature 410° C., and the initial pressure 1,470 pounds per square inch; sulphur, which has been shown to be an important factor in the refining loss, can be completely removed by ferric oxide or calcium oxide under hydrogenating conditions.

Considering the work done elsewhere, observations concerning the status of bitumen hydrogenation in general may be extended as follows. As shown by Boomer and Saddington, the residual oil after the removal of the gasoline product can be hydrogenated in the same way as the original bitumen, although a small portion (15 per cent) is resistant to thermal treatment below 500° C.

It is reported that refined gasoline can be produced from coal at a total cost of 14 cents per Imperial gallon[1], of which 4 cents represents the cost of the coal. On the assumptions that bitumen is more amenable to hydrogenation than coal, and that the difference in price between bitumen and coal is not too great there is a possibility that gasoline can be produced from Alberta bitumen at a price lower than that stated above. Such a prediction, however, is subject to confirmation by larger scale tests and by a complete study of the economics of the situation.

CONCLUSIONS

1. The results of small-scale cracking experiments reported by the Kansas City Testing Laboratory have been verified experimentally. Slightly larger yields of unrefined gasoline are obtained by the cracking process than by a batch hydrogenation process in which no coke is produced.

2. The advantage of the cracking process stated in (1) is offset by the fact that much of the charging stock is degraded to coke. The ultimate yield of unrefined gasoline, on recycling through the cracking process,

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[1] Imperial Chemical Industries Limited, Fuel, X, 481 (1931).

would probably be 40 to 50 per cent by volume (30 to 40 per cent by weight), while by recycling through the hydrogenation process the ultimate yields would probably be 90 to 100 per cent by volume (65 to 75 per cent by weight). Further, the refining loss is much smaller in hydrogenation than in cracking.

3. While there is a balance in favour of hydrogenation from a technical point of view, the fixed charges on equipment are higher than in cracking, due to the higher pressures, the additional apparatus necessary for the production of hydrogen, and the slower passage of material through apparatus of given volume. The cost of raw material for the production of hydrogen is another charge absent in cracking. It is impossible to conclude at present which type of process would be better for the treatment of Alberta bitumen, or if either is commercially possible.

THE EFFECT OF PRESSURE ON THE PYROLYSIS OF METHANE

T. E. Warren

This paper is a report of experiments on the influence of pressure on the rate of formation of hydrogen and unsaturated hydrocarbons from methane. Although the pyrolysis of methane has been the subject of numerous researches, among which the effect of pressure on the equilibrium has been studied, the influence of high pressure on the rate of formation of products has not, to the writer's knowledge, received special attention as in this investigation.

The literature is so voluminous that only brief mention can be made herein of the more important papers. A general review of the subject is given by C. D. Hurd (1). On the equilibrium $C + 2H_2 \rightleftarrows CH_4$ many studies have been made. *See* references (2) to (8) inclusive, of which those of Pring and Fairlie are of especial interest. Calculations from the data given in the literature show that even at the highest pressure, and assuming the presence of amorphous carbon, equilibrium was not approached in the experiments conducted by the writer. Accordingly, it is not necessary to discuss the references in detail.

At pressures lower than atmospheric some experimental studies have been made. Jones (9) obtained the following data using as a reaction chamber a quartz tube of one millimetre internal diameter, heated over 80 centimetres of length at 1000° C.

Pressure in cm. of mercury	10	20	30	40	50	60	70
Olefines, per cent, at rate of flow of 100 cm./sec.	0·13	0·78	1·25	1·55	1·75	1·61	0·84
per cent, at rate of flow of 200 cm./sec.	trace	0·27	0·49	0·38	0·16	0·15	trace

Schwab and Pietsch (10) have measured the rate of the reaction $CH_4 \rightarrow C + 2H_2$ at pressures of 0·04 to 0·06 millimetre and conclude that the rate of formation of hydrogen is proportional to the pressure of methane, i.e. that the reaction is unimolecular. Pressures less than atmospheric have also been used by Frölich, White, and Dayton (11). Valuable work concerning the effect of temperature, rate of flow, and contact surface on the formation of various products has been done by Fischer (12), Stanley and Nash (13), Bone and Coward (14), and Wheeler and Wood (15).

EXPERIMENTS AT FUEL RESEARCH LABORATORIES

Material

The methane used in all experiments was from natural gas well No. 1 of the Lanoraie Oil and Gas Syndicate, Limited, of Lanoraie, Que., collected on October 22, 1930. The analysis of this sample given by the

Oils and Natural Gas Section of the Fuel Research Laboratories, based on low-temperature distillation supplemented by an absorption analysis in a Burrell apparatus, is as follows:—

	Per Cent
Carbon dioxide	0·1
Methane	96·8
Oxygen	0·7
Ethane and higher hydrocarbons	0·5
Nitrogen (by difference)	1·9
Helium	0·015

After having been stored over water, under pressure in the supply cylinder and passed through the pyrolysis apparatus at room temperature the analysis obtained in a Burrell apparatus was:—

	Per Cent
Carbon dioxide	0·10
Oxygen	0·42
Unsaturates	0·21
Hydrogen	0·63
Carbon monoxide	0.21
Methane	88·45
Nitrogen	9·98

Apparatus and Procedure

The conditions under which the reactions were to be studied imposed limitations on the nature of the apparatus. Since temperatures up to 1122° C. and pressures up to 104 atmospheres were used, steel reaction chambers would not have been strong enough. Further, it has been found (15) that silica is the best contact surface for the pyrolysis of methane because it does not strongly catalyse the reactions producing carbon and hydrogen. Accordingly, the reaction chamber was made of vitreous silica (17). After preliminary tests it was found that a wall thickness of 3 mm. was sufficient for a tube of 4 mm. internal diameter. Similar tubes were tested under pressures as high as 229 atmospheres with water. The pressure and manner of failure varied greatly. The silica-to-metal joints were made with deKhotinsky's cement and were water-cooled. In experiments 1 to 4, a tube 30·5 cm. long was used as the reaction chamber. In subsequent experiments a tube 45·8 cm. in length was used. Heat was supplied by an electric heater, 20·3 cm. long and 2·5 cm. in internal diameter. Temperatures were measured by a platinum platinum-rhodium thermocouple in contact with the outside of the reaction tube at the centre of the heater. Temperatures measured by the thermocouple in contact with the reaction tube and at various positions along the longitudinal axis of the heater are shown in Figure 9. Pressure was measured in experiments 3 to 5 by Bourdon gauges of appropriate range on the inlet line; in experiments 6 to 7 by a mercury manometer on the inlet line. Rate of flow was controlled by adjustment of a needle valve and measured by observing the length of time required to fill the receiving vessel.

In experiments 1 and 2 the exit valve was open, the rate of flow controlled by the inlet valve, the sample of gas collected over sodium sulphate solution and stored until analysed in glass-stoppered tubes out of contact with the solution. In experiments 3, 4, and 5 the pressure was brought to the desired value by pumping water into the bottom of the supply cylinder. The inlet valve was open and the rate controlled by the exit valve. In experiments 6 and 7 the inlet gas was stored in a 6-litre bottle at the pressure to be used in the experiment and the supply replenished from the high-pressure supply cylinder. The gas was collected in an evacuated bottle of 5,720 c.c. capacity and transferred from it by sodium sulphate solution to the sample bottles. The inlet valve was open and the rate controlled by the exit valve. In experiments 1 to 5, a trap was placed on the exit line to collect liquid or solid products.

Analyses were made in a standard Burrell apparatus using potassium hydroxide, pyrogallol, fuming sulphuric acid, copper oxide, and potassium hydroxide in the order mentioned, followed by combustion with oxygen.

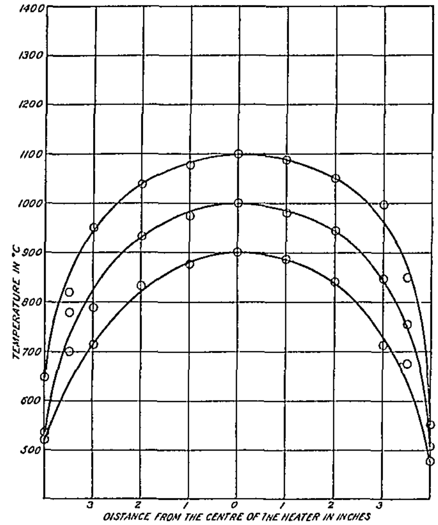

Figure 9 Temperature is plotted against distance from the centre of the heater to show the temperature distribution in the reaction tube.

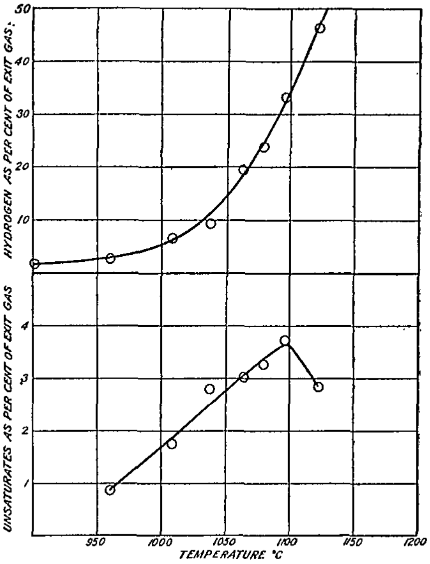

Figure 10 With rate and pressure constant the yields of hydrogen and unsaturated hydrocarbons are plotted against the temperature.

Results

The results of the investigation of the temperature variable are given in Table I, and shown graphically in Figure 10. The temperature given in the second column of Table I is that read by the thermocouple in the centre position, as shown in Figure 9. The rate (R) given in the third column is that of the exit gas in cubic centimetres per second, reduced to 0° C. and atmospheric pressure. This value, divided by the pressure of the experiment, is given in the fourth column $\frac{(\text{R})}{(\text{P(atm.)})}$. The reciprocal of the value of the fourth column is given in the fifth column $\frac{(\text{P(atm.)})}{(\text{R})}$

and is proportional to the time required for the passage of any given molecule through the reactor. This value, the time of contact, cannot be given numerically because of the temperature variation in the reaction chamber. In the experiments on the pressure variable it was attempted to maintain the time of contact at a constant value by increasing the exit rate (R) in proportion to the pressure. Because the range of experiment includes pressures above and below atmospheric, the pressure was recorded both in millimetres of mercury and atmospheres. The products acetylene, ethylene, and benzene, were not separated but absorbed together in fuming sulphuric acid. The proportion (in per cent) of exit gas absorbed in fuming sulphuric acid is given in the column headed "unsaturates". Similarly, the proportion in per cent of the contraction of the exit gas in the copper oxide treatment is given in the column headed "hydrogen".

TABLE I

Experiment No.	Temperature °C.	Rate			Pressure		Unsaturates	Hydrogen
		R c.c./sec. 0° C. 760 mm.	R / P (atm)	P (atm) / (R)	mm. of Hg.	Atm.		
1a.........	902	....	....	....	....	....	....	....
b.........	1008	0·428	0·439	2·27	740·5	0·974	1·75	6·50
c.........	1063	0·445	0·457	2·14	740·5	0·974	3·01	19·52
e.........	1096	0·493	0·506	1·98	740·5	0·974	3·73	33·07
f.........	960	0·443	0·455	2·19	742·0	0·976	0·87	2·71
g.........	1037	0·463	0·475	2·11	742·0	0·976	2·79	9·28
h.........	1079	0·491	0·503	1·99	742·0	0·976	3·26	23·81
i.........	1122	0·551	0·565	1·77	742·0	0·976	2·84	46·30

The experimental results of the investigation of the rate variable are given in Table II, and shown graphically in Figure 11.

TABLE II

Experiment No.	Temperature °C.	Rate			Pressure		Unsaturates	Hydrogen
		R c.c./sec. 0° C. 760 mm.	R / P (atm)	P (atm) / (R)	mm. of Hg.	Atm.		
2a.........	1097	0·377	0·372	2·69	770·0	1·014	3·61	36·75
b.........	1103	0·531	0·524	1·91	770·0	1·014	3·60	30·53
d.........	1101	2·92	2·88	0·347	770·0	1·014	1·84	5·85
c.........	1097	1·51	1·49	0·671	770·0	1·014	2·48	9·70

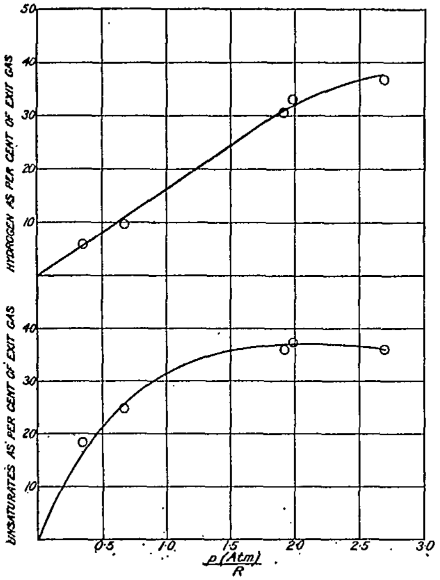

Figure 11 With pressure and temperature constant the yields of hydrogen and unsaturated hydrocarbons are plotted against the pressure divided by the rate.

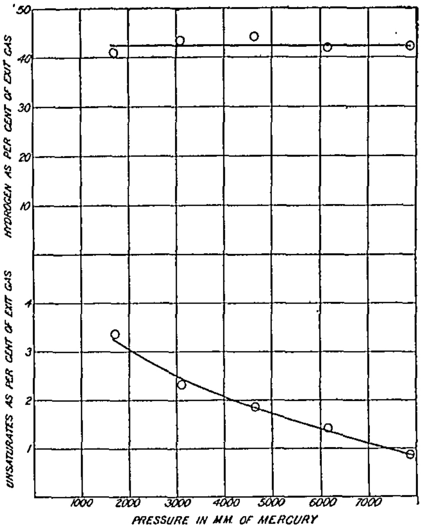

Figure 12 With temperature and $\frac{P}{R}$ constant the yields of hydrogen and unsaturated hydrocarbons are plotted against the pressure.

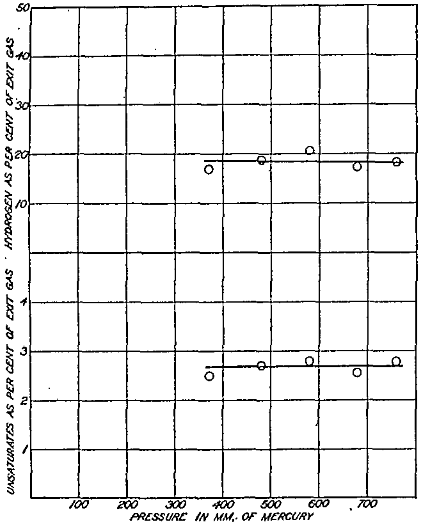

Figure 13 With temperature and $\frac{P}{R}$ constant the yields of hydrogen and unsaturated hydrocarbons are plotted against the pressure.

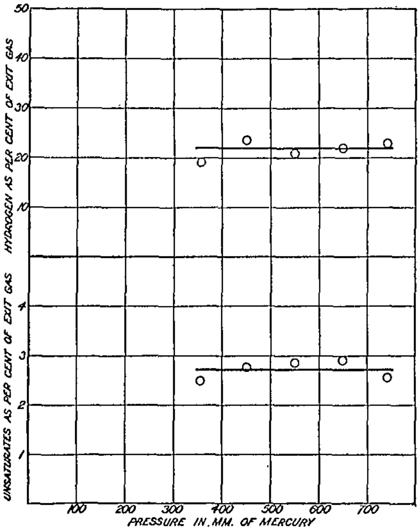

Figure 14 With temperature and $\frac{P}{R}$ constant the yields of hydrogen and unsaturated hydrocarbons are plotted against the pressure.

The experimental results of the investigations of the pressure variable are given in Tables III and IV, and shown graphically in Figures 12, 13, and 14.

TABLE III

Experiment No.	Temperature °C.	Rate			Pressure		Unsaturates	Hydrogen
		R c.c./sec. 0° C. 760 mm.	R / P (atm)	P (atm) / (R)	mm. of Hg.	Atm.		
3a..........	1099	0·867	0·389	2·57	1,692	2·13	3·36	41·00
b..........	1105	1·734	0·427	2·34	3,090	4·06	2·31	43·40
c..........	1115	2·44	0·400	2·50	4,640	6·11	1·86	44·20
d..........	1107	3·45	0·427	2·34	6,140	8·09	1·41	41·80
e..........	1100	3·47	0·336	2·97	7,850	10·33	0·86	42·10
4b..........	1100	10·49	0·232	4·31	34,400	45·30	0·30	30·93
5a..........	1105	(Not observed)			56,400	74·2	0·46	32·35
b..........	1088	19·19	0·185	5·40	78,800	103·7	0·32	20·09
c..........	1110	(Much slower; not observed)			75,100	98·9	0·53	21·10

TABLE IV

Experiment No.	Temperature °C.	Rate			Pressure		Unsaturates	Hydrogen
		R c.c./sec. 0° C. 760 mm.	R / P (atm)	P (atm) / (R)	mm. of Hg.	Atm.		
6a..........	1098	0·533	1·093	0·915	371	0·488	2·49	16·90
d..........	1104	0·693	1·581	0·632	481	0·633	2·70	18·72
c..........	1104	0·774	1·309	0·764	582	0·755	2·78	20·50
f..........	1099	0·925	1·361	0·734	679	0·894	2·55	17·37
g..........	1098	1·087	1·088	0·920	759	0·999	2·79	18·28
7a..........	1098	0·291	0·624	1·600	355	0·467	2·49	19·10
b..........	1104	0·389	0·657	1·520	450	0·592	2·77	23·57
c..........	1103	0·490	0·678	1·475	549	0·723	2·86	20·90
d..........	1098	0·524	0·615	1·626	649	0·854	2·92	21·93
e..........	1103	0·690	0·707	1·444	742	0·976	2·55	22·90

It was found difficult to maintain the rate in proportion to the pressure over the entire pressure range. As has been mentioned, this is necessary in order to have comparable times of contact. Since the time of contact was different, the yields in experiments 4 and 5 should not be compared with those of experiment 3. Experiments 6 and 7 were also made at different times of contact and the yields are not to be compared with those of the other experiments.

Carbon was removed from the apparatus after experiments 1, 2, 3, 4, and 5. Two forms of carbon were observed; one was powdered and non-coherent, the other was coherent and was removed from the walls of the reaction chamber in lustrous curling sheets. At low pressures the latter form predominated, but neither was quantitatively measured.

No evidence of the formation of paraffin hydrocarbons was given by the combustion analysis in any experiment. In experiments 1*e*, 1*h*, and 1*i* (Table I), the solid product was collected and weighed. It smelled of naphthalene and amounted to approximately 1·3, 1·3, and 1·0 per cent, respectively, of the weight of the inlet gas. In no other experiment was so large a yield obtained, and the amounts obtained were not quantitatively measured.

SUMMARY AND CONCLUSIONS

Experiments on the pyrolysis of methane were conducted in a vitreous silica tube of 4 mm. inside diameter. Observations have been made on the effect of pressure on the yields of hydrogen and unsaturated hydrocarbons between 0·467 and 104 atmospheres; the effect of temperature between 902° and 1122 C.; and the effect of rate of flow between 0·377 and 2·92 c.c. per second.

The following conclusions may be drawn from the results obtained:

(1) Increase in pressure from 2 to 10 atmospheres decreases the yields of unsaturated hydrocarbons and has little effect on the yield of hydrogen. At higher pressures there is evidence that the yield of hydrogen also decreases.

(2) Variation in pressure below one atmosphere has little effect on the yield of either hydrogen or unsaturated hydrocarbons.

(3) If the object of the pyrolysis is to produce unsaturated hydrocarbons, there is no advantage in using pressures other than atmospheric.

(4) The variation of the yields of hydrogen and unsaturates with temperature and with the rate of flow are in agreement with the conclusions of other investigators.

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IV

REPORT ON OIL SHALES FROM NEW GLASGOW AREA, PICTOU COUNTY, NOVA SCOTIA, AND FROM PORT DANIEL, BONAVENTURE COUNTY, QUEBEC

A. A. Swinnerton

NEW GLASGOW AREA—PICTOU COUNTY, N.S.

In previous field work[1] conducted in 1928 by the writer in this area outcrop samples were obtained from five different locations designated as beds Nos. A, AB, B, C, and D. From the results of examination of the samples obtained at that time it was decided that all but two locations, viz. B and C, were worthy of further investigation. Consequently fresh samples were obtained from locations A, AB, as well as from E and F as shown in sketch map, Figure 15. Bed A was sampled from the tunnel that had been started by the Torbanite Products, Ltd., at this point; bed AB was sampled where it outcropped again on the bank about 20 feet above low water level. Samples from bed D were not obtained in 1929 as development on the Spence leases at this point was not sufficiently advanced at the time of the writer's visit, and it was also impossible to obtain samples in 1930 as the workings were full of water due to the spring floods. The test pit E which had been opened by Mr. A. T. McKinnon was deepened in order to determine the thickness of the beds of stellarite and underlying shale which were reported to be very thick at this point. Samples were also taken from a small outcrop (F) near Trenton on a lease recently granted to Mr. F. J. Foley.

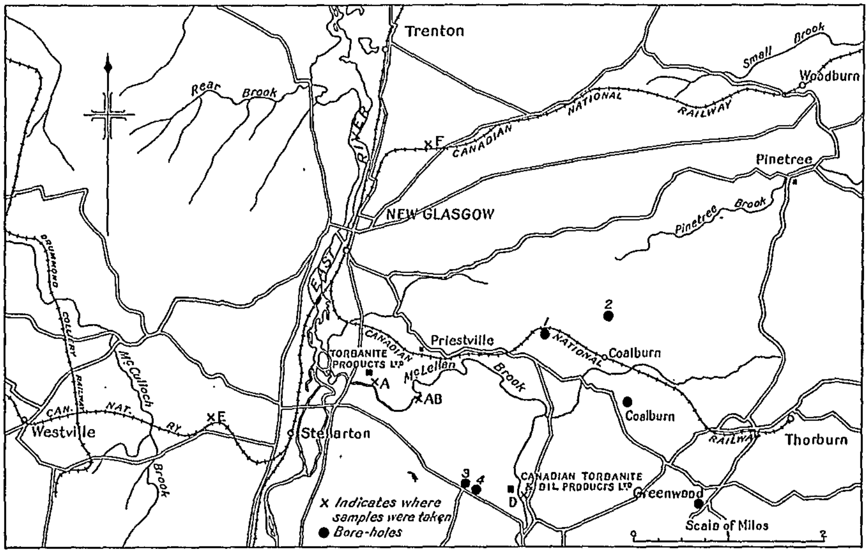

Figure 15. Sketch map showing location of oil-shale outcrops and bore holes, Pictou county, Nova Scotia.

Of the five different outcrops sampled in 1928 two beds, viz. B and C, with thicknesses 11 and 13½ feet respectively had oil contents of only 8·5

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[1] Mines Branch, Dept. of Mines, Canada, Investigations of Fuels and Fuel Testing 1928, pp. 13-24.

and 6·0 Imperial gallons per ton with no section of either seam showing over 11 gallons of crude oil. As judged by the outcrops these two beds were not considered of commercial value and therefore not worth further sampling. Bed A, 4½ feet or more in thickness, showed, according to the 1929 samples, an average yield of slightly over 20 gallons per ton which represents an increase of 2½ gallons over the average for the 1928 samples.

A bed to be worthy of commercial development should, in the opinion of the writer, show an oil yield of at least 20 Imperial gallons per short ton; and as the laboratory yield is likely to be consistently higher than the commercial yield, the figure of 25 gallons per ton as the laboratory assay yield is a preferable standard for judging the commercial possibilities of a given oil-shale deposit. As judged by the 1929 samples, therefore, only one bed, viz. E, showed up to advantage, the laboratory yield being roughly 32 gallons per ton. Bed AB near the junction of Steep brook and McLellan brook when sampled in 1929 at a higher (outcrop) level than in the previous year showed an average oil yield of 16·4 gallons in comparison with 26·4 gallons in the 1928 samples. Indications therefore are that the richer shale worthy of development is to be found at the lower levels of the seam. This observation also applies to bed A from the lower levels of which the 1929 samples, which gave the increased oil yields referred to above, were taken.

DESCRIPTION OF BEDS SAMPLED

Bed "A". This bed outcrops in a cliff on the north side of a small brook running into McLellan brook at Steven Brook's brickyard, about 1½ miles south of New Glasgow, and the samples were taken from a short tunnel that had been driven into this bed by the Torbanite Products Company. This is the same bed that was sampled in 1928, but the samples taken in 1928 were higher up the dip than those taken in 1929.

Section of seam: A1.....Cannel shale.....1 foot 3 inches.
A2.....Flaggy shale.....2 " 6 "
A3.....Cannel shale.....1 " 0 "

Bed "AB." This bed is exposed in McLellan brook about ¾ of a mile upstream from "A" and the samples from this bed were taken from an outcrop on the bank about 20 feet above low water level.

Section of seam: AB1...Massive shale....1 foot 3 inches.
AB2....Flaggy shale.....2 " 0 "
AB3 Massive shale....1 " 3 "

Bed "E". This bed outcrops near Stellarton and is shown as the Oil Coal Seam in Map No. 833 of the Geological Survey. The samples from this bed were taken from a test pit which had been started on the bank of a creek close to the crossing of the Albion Mine road and the Stellarton-Westville branch of the Canadian National railway.

Section of seam: E1.....Coal............1 foot 0 inches
E2.....Stellarite.........2 " 6 "
E3.....Massive shale....2 " 0 "

Bed "F". This bed outcrops near Trenton on the north bank of Smelt brook about 300 yards east of the New Glasgow-Trenton highway. The samples from this bed were taken from a short tunnel that had been driven into the bank at this point by a Mr. F. J. Foley who had taken up some shale leases in this area.

Section of seam: F......Grey shale.......2 feet 6 inches

TABLE I

Distillation Data—Beds A, AB, E, and F

(Maximum Temperature, 550° C.)

Bed		A			AB			E			F
Section,		A1	A2	A3	AB1	AB2	AB3	E1	E2	E3	F
Thickness		1′ 3″	2′ 6″	1′ 0″	1′ 3″	2′ 0″	1′ 3″	1′ 0″	2′ 6″	2′ 0″	2′ 6″
Shale charged (grms.)		350	400	350	350	350	350	350	350	350	400
Proximate Analysis:											
Moisture	per cent	1·4	1·9	1·7	1·5	2·2	1·6	1·9	0·9	1·8	3·5
Ash	“	57·4	75·4	64·0	54·4	76·3	63·3	35·5	59·3	67·3	87·9
Volatile matter	“	25·3	17·4	21·7	26·3	15·1	21·3	26·4	33·5	28·5	8·2
Fixed carbon	“	15·9	5·3	12·6	17·8	6·4	13·8	36·2	6·3	2·4	0·4
Products, Weight Balance:											
Spent shale	“	80·8	87·7	82·7	81·8	88·7	84·9	81·6	74·2	77·2	93·5
Oil (water-free)	“	11·9	6·4	9·7	10·5	5·0	7·8	10·5	20·1	13·9	0·4
Aqueous distillate	“	2·7	3·5	3·6	3·5	4·3	3·7	3·6	2·9	3·7	4·6
Gas (calculated)	“	4·3	1·8	3·3	3·6	1·2	3·1	3·9	3·0	4·5	1·2
Loss (by difference)	“	0·3	0·6	0·7	0·6	0·8	0·5	0·4	—0·2	0·7	0·3
Shale Oil:											
Imperial gal. per 2,000 lb.		26·3	16·5	21·1	22·9	11·3	16·9	21·9	46·7	32·0	0·9
Specific gravity at 60° F.		0·908	0·891	0·919	0·917	0·889	0·929	0·958	0·862	0·872	....
Degrees Baumé (A.P.I)		24·3	27·3	22·5	22·8	27·7	20·8	16·2	32·6	30·8	....
Gas:											
Cubic feet per 2,000 lb.		1,350	1,000	1,570	1,500	730	1,210	1,700	1,360	1,800	510
Calorific value (calc.) B.T.U. per c.f.		315	440	445	580	570	480	530	610	290	245
Density (air = 1)		0·83	0·46	0·54	0·58	0·44	0·65	0·60	0·77	0·75	0·85
Spent Shale:											
Pounds per ton		1,616	1,754	1,654	1,636	1,774	1,698	1,632	1,484	1,544	1,870
Proximate Analysis:											
Moisture	per cent	1·2	0·6	0·6	0·6	0·6	0·6	0·7	0·4	0·6	....
Ash	“	68·7	83·3	72·8	66·9	85·2	73·6	42·3	78·5	84·7	....
Volatile matter	“	9·0	8·6	9·1	7·2	7·3	8·3	8·1	10·2	7·4	....
Fixed carbon	“	21·1	7·5	17·5	25·3	6·9	17·5	48·9	10·9	7·3	....

Summary

	A			AB			E			F
Oil Yield:										
Imperial gal. per ton	26·3	16·5	21·1	22·9	11·3	1·69	21·9	46·7	32·0	1·0
Average nitrogen content of bed ... per cent		1·0			1·0			0·6		
Average oil content of bed:										
Imperial gal. per ton		20·1			16·4			36·9		1·0

TABLE II

Analysis of Oil Obtained by Distillation

Bed A

Characteristics of Crude

Specific gravity at 60°F.	0·913	Degrees A.P.I. at 60°F.	23·5
Sulphur, per cent:		Water, per cent	0·4
Saybolt Univ. Visc. at 70° F.	secs.	Pour point	75°F.
Saybolt Univ. Visc. at 100° F.	64 secs.	Colour: Brownish black.	

Distillation Hempel Method

Air distillation: Barometer: 757 mm. First drop: 45°C. (113°F.)

Temperature °C.	Per cent cut	Cum. per cent	Sp. Gr. cut	A.P.I. cut	Viscosity Say. Univ. at		Cloud Test °F.	Temperature °F.
					100°F.	212°F.		
Up to 50								up to 122
50– 75	1·5	1·5	0·699	70·9				122–167
75–100	2·7	4·2	0·739	60·0				167–212
100–125	0·9	5·1	0·750	57·2				212–257
125–150	2·9	8·0	0·773	51·6				257–302
150–175	4·7	12·7	0·800	45·4				302–347
175–200	5·4	18·1	0·832	38·6				347–392
200–225	5·5	23·6	0·853	34·4				392–437
225–250	6·0	29·6	0·863	32·5				437–482
250–275	7·6	37·2	0·875	30·2				482–527

Vacuum distillation at 40 mm.

Temperature °C.	Per cent cut	Cum. per cent	Sp. Gr. cut	A.P.I. cut	Viscosity Say. Univ. at 100°F.	Viscosity Say. Univ. at 212°F.	Cloud Test °F.	Temperature °F.
up to 200	4·8	4·8	0·886	28·2	43	33	35	up to 392
200–225	7·8	12·6	0·898	26·1	53	34	50	392–437
225–250	9·9	22·5	0·916	23·0	84	37	75	437–482
250–275	8·2	30·7	0·942	18·7	190	43	90	482–527
275–300	10·2	40·9	0·966	15·0	550 (est.)	55	105	527–572

Total distillate: 78·1%. Residuum: 20·6%. Distillation loss: 1·3%.
Carbon residue of residuum: 12·8%. Carbon residue of crude: 2·6%.

Approximate Summary

——	Per cent by vol.	Sp. Gr.	A.P.I.	Viscosity Say. Univ. at 100°F.
Light gasoline	4·2	0·726	63·4	
Total gasoline and naphtha	12·7	0·766	53·2	
Kerosene distillate				
Gas oil	31·0	0·864	32·3	Below 50 secs.
Non-viscous lubricating distillate	12·5	0·894–0·920	26·8–22·3	50–100
Medium lubricating distillate	8·0	0·920–0·943	22·3–18·6	100–200
Viscous lubricating distillate	13·9	0·943–9·980	18·6–12·9	Above 200
Residuum	20·6			
Distillation loss	1·3			
Base of crude	Shale (hybrid)			

Core Drill Samples from New Glasgow Area

During recent years, several important boring operations have been undertaken in the New Glasgow district by the Acadia and Greenwood Coal Co's., in search of coal. The diamond drill cores obtained from these bores were examined by W. A. Bell and samples were taken of all those parts which gave promise of yielding oil on distillation. Although it was realized that the majority probably represented lean oil shales of no commercial value, it was considered that the information obtained from their examination would prove of value when further exploration of the oil shale of Pictou county is undertaken.

The location of the bore holes sampled, and designated 1, 2, 3, 4, Coalburn, and Greenwood, are shown on the accompanying sketch map. From these bore holes 29 samples were taken and submitted for analysis, the results of which are summarized in Table III. A composite sample of the oils obtained by distillation was made and examined by the standard Hempel method and it is considered that the result gives a fair idea of the nature of the oil that would be obtained by the distillation of the oil shales in this field.

TABLE III

Summary of Results

Bore hole	Total thickness of shale bands, ft.	Average oil yield, Imp. gals. per ton	Maximum yield	
			Oil, Imp. gals. per ton	Ammonium sulphate, pound per ton
No. 1	37·7	7·1	13·0 (7·5 ft.)	....
No. 2	43·7	7·4	18·1 (2·5 ft.)	23
No. 3	10·0	7·2	7·6 (4 ft.)	....
No. 4	14·0	5·9	5·9 (14 ft.)	....
Coalburn	45·1	11·4	23·9 (6 ft.)	21
Greenwood	8·0	21·0	21·6 (4 ft.)	21

TABLE IV

Distillation Data—Core Drill Samples, Pictou County, N.S.

Field No.	Depth in hole	Thickness of band	Products				Shale Oil			Ammonium sulphate, lb. per ton	Gas	
			Spent shale	Oil (H_2O free)	Aqueous distillate	Gas and loss	Imp. gals. per ton	Specific gravity at 60 °F.	Deg. A.P.I. at 60° F.		Cu. ft. per ton	Cal. value B.T.U. per cu. ft.
	ft. ft.	ft.	%	%	%	%						
BORE HOLE No. 1: ACADIA COAL CO., 1928												
2812 (4)........	79 — 84	5·0	87·4	4·6	4·9	3·1	10·6	0·872	30·8	....	1,000	320
2812 (3)........	111 —114·7	3·7	91·5	3·2	3·8	1·5	7·0	0·895	26·6	....	630	
2812 (8)........	131 —141	10·0	91·6	1·3	4·3	2·8	3·0	0·879	29·5	....	630	
2812 (2)........	141 —144	3·0	93·1	2·4	3·0	1·5	5·4	0·895	26·6	....	470	
2812 (7)........	436 —440	4·0	90·6	2·5	4·0	2·9	5·8	0·879	29·5	....	790	
2812 (5)........	440·5—448	7·5	87·9	5·9	3·9	2·3	13·0	0·873	30·6	....	860	
2812 (6)........	470·5—472·5	2·0	92·2	2·9	3·1	1·8	6·5	0·889	27·7	....	700	
2812 (1)........	512·3—514·8	2·5	94·2	1·3	2·3	2·2	2·9	0·875	30·2	....	680	
BORE HOLE NO. 2: ACADIA COAL CO., 1928												
2811 (5)........	195 —202	7·0	97·1	trace	1·6	1·3	trace	....	....	....	360	....
2811 (6)........	204·7—209·7	5·0	87·5	6·8	3·4	2·3	15·5	0·873	30·6	19	720	530
2811 (4)........	247 —249·5	2·5	87·0	7·8	3·4	1·8	18·1	0·862	32·7	23	770	
2811 (1)........	317 —318	1·0	90·9	2·8	4·6	1·7	6·5	0·873	30·6	....	570	330
2811 (2)........	421 —428·2	7·2	93·6	0·6	3·3	2·5	1·4	0·875	30·2	....	550	
2811 (8)........	446·5—456·5	10·0	90·4	4·5	3·1	2·0	10·2	0·873	30·6	....	700	
2811 (3)........	598 —599	1·0	90·3	3·4	3·6	2·7	7·6	0·878	29·7	....	770	
2811 (7)........	838 —848	10·0	90·5	3·2	3·8	2·5	7·3	0·873	30·6	....	750	

BORE HOLE No. 3: ACADIA COAL CO., 1928

2834 (2)........	95 —101	6·0	93·1	3·1	2·1	1·7	6·9	0·892	27·1	....	590	350
2834 (1)........	248 —252	4·0	91·2	3·5	2·9	2·4	7·6	0·913	23·5	....	750	

BORE HOLE No. 4: ACADIA COAL CO., 1928

....	88 —102	14·0	90·3	2·7	3·1	3·9	5·9	0·920	22·3	....	1,130	....

COALBURN BORE HOLE: ACADIA COAL CO., 1928

Coalburn....... B.H. 1928.	73 — 76	3·0	85·7	4·3	4·6	5·4	8·8	0·966	15·0	....	1,330	
	231·7—235	3·3	86·7	6·9	3·6	2·8	15·8	0·871	31·0	17	750	520
	334 —340	6·0	82·8	10·4	3·9	2·9	23·9	0·869	31·3	21	800	
	425·6—429·4	3·8	89·6	4·3	3·9	2·2	9·8	0·882	28·9	....	570	340
	652 —655	3·0	90·5	2·8	3·8	2·9	6·3	0·879	29·5	....	770	
	664 —675·5	11·5	87·8	4·4	3·4	4·4	9·8	0·899	25·9	....	1,110	
	664 —675·5	11·5	88·6	4·0	2·9	4·5	8·9	0·895	26·6	....	1,220	
	889 —892	3·0	91·2	3·3	3·8	1·7	7·5	0·885	28·4	....	410	

GREENWOOD BORE HOLE: GREENWOOD COAL CO.

Greenwood (1)	354 —358	4·0	83·3	9·4	4·0	3·3	21·6	0·871	31·0	21	1,090	520
(2)	393 —397	4·0	83·0	8·8	4·1	4·1	20·3	0·871	31·0	19	1,220	

Note.—Tons in above table=2,000 pounds.

Ammonium sulphate figures are based on a 60% yield (the maximum recoverable in practice).

TABLE V

Analysis of Oil Obtained by Distillation of Core Drill Samples

(Composite Sample)

Characteristics of Crude

Specific gravity at 60°F......	0·881	Degrees A.P.I. at 60°F......	29·1
Sulphur, per cent:		Water, per cent.............	1·6
Saybolt Univ. Visc. at 70°F.	..... secs.	Pour point.................	65°F.
Saybolt Univ. Visc. at 100°F	52 secs.	Colour: brownish black	
B.T.U. per pound.........	....	B.T.U. per Imp. gallon......	......

Distillation Hempel Method

Air distillation: Barometer: 754 mm. First drop: 55°C. (131°F.)

Temperature °C.	Per cent cut	Cum. per cent	Sp.Gr. cut.	A.P.I. cut.	Viscosity Say. Univ. at		Cloud Test °F.	Temperature °F.
					100°F.	212°F.		
up to 50								up to 122
50– 75	1·9	1·9	0·709	68·1				122–167
75–100	4·7	6·6	0·747	57·9				167–212
100–125	0·6	7·2	0·774	51·3				212–257
125–150	0·6	7·8						257–302
150–175	4·2	12·0	0·790	47·6				302–347
175–200	5·4	17·4	0·809	43·4				347–392
200–225	5·0	22·4	0·822	40·6				392-437
225–250	5·9	28·3	0·837	37·6				437–482
250–275	8·5	36·8	0·850	35·0				482–527

Vacuum distillation at 40 mm.

Temperature °C.	Per cent cut	Cum. per cent	Sp.Gr. cut.	A.P.I. cut.	Viscosity Say. Univ. at 100°F.	Viscosity Say. Univ. at 212°F.	Cloud Test °F.	Temperature °F.
up to 200	3·6	3·6	0·863	32·5	41	33	40	up to 392
200–225	6·8	10·4	0·873	30·6	47	34	60	392–437
225–250	10·0	20·4	0·894	26·8	75	37	75	437–482
250–275	7·3	27·7	0·900	25·7	92	38	85	482–527
275–300	8·1	35·8	0·914	23·3	161	43	100	527–572

Total distillate: 72·6%. Residuum: 25·4%. Distillation loss: 2·0%.
Carbon residue of residuum: 8·6%. Carbon residue of crude: 2·2%.

Approximate Summary

—	Per cent by vol.	Sp. Gr.	A.P.I.	Viscosity Say. Univ. at 100° F.
Light gasoline	6·6	0·736	60·8	
Total gasoline and naphtha	17·4	0·774	51·3	
Kerosene distillate	5·0	0·822	40·6	
Gas oil	22·2	0·853	34·4	Below 50 secs.
Nonviscous lubricating distillate	17·2	0·875–0·902	30·2–25·4	50–100
Medium lubricating distillate	10·8	0·902–0·921	25·4–22·1	100–200
Viscous lubricating distillate				Above 200
Residuum	25·4			
Distillation loss	2·0			
Base of crude	Shale (intermediate)			

EXPERIMENTAL OIL-SHALE PLANTS NEAR NEW GLASGOW

During 1928 and 1929 two companies, the Torbanite Products, Ltd., and the Canadian Torbanite and Oil Products, Ltd., erected experimental oil-shale plants near New Glasgow, which plants are briefly described below.

Torbanite Products, Ltd.

The building of a shale distillation plant begun by this company near New Glasgow in 1928 was completed in 1930, the opening ceremony taking place on July 4. In September a fire destroyed some of the buildings, and as a result the company ceased operations and is now in liquidation. The main feature of the plant was the patent 'Ginet' retort, which is an externally heated steel cylinder, 3 feet in diameter and 20 feet long, through which the charge is moved by means of scrapers attached to a central revolving shaft. The oil vapours are led off to a condenser by means of an outlet pipe at the top of the retort, and the condensed oil collected in storage tanks. The uncondensed gases are used to heat the retort setting and the spent shale after being cooled is crushed and bagged for shipment, the company claiming to have a market for this material. In addition to the retort the equipment includes a small bank head for mining the shale, crushers, bucket elevators, storage tanks and warehouse for spent shale, etc. Unfortunately, this plant never got beyond the experimental stage owing to the fire in September and its future is, at present, a matter for speculation.

The Canadian Torbanite and Oil Products, Ltd.

This company constructed a small test plant at McLellan brook, about 5 miles from New Glasgow, and sufficient shale was retorted in the latter part of 1929 to provide a few thousand gallons of oil, but during 1930 only experimental work on the oil was carried on. The shale was obtained from a slope driven into an outcrop at the plant side and retorted in two internally fired vertical retorts of 2,500 pounds capacity. The equipment included exhaust pumps, condensers, etc., and a small laboratory building in which refining tests on the oil were conducted.

PORT DANIEL OIL SHALES

The occurrence of bituminous shales in the vicinity of Port Daniel, Bonaventure county, Quebec, has been known for a long time, having been reported by Logan in 1863 and later noted by Ells in 1880. As far back as 1834, this region was prospected as a possible coal area, and pits have been sunk at various times in the hope of locating a seam of coal. About ten years ago, the Imperial Oil Company became interested in these shales and had a report prepared by Mr. J. V. Culbert which, however, contains no analyses nor remarks on the bituminous content of the shales.

OCCURRENCE

The bituminous shales in the Port Daniel area are almost entirely restricted to the Mictaw series of interbedded graptolitic bituminous shales and tuffaceous greywackes of Ordovician age, which have a wide belt of outcrop. On the Middle branch of Port Daniel river they extend from near the head of the barachois to the outcrops of the Clemville formation in range XIII, a distance by airline of 5 miles. Along the combined courses of Middle branch and Mictaw rivers the belt extends over a width of 6 miles by airline. On the North branch the strata extend from the head of the barachois for a distance of a little over two miles to a point in range IX where their place is taken by the Maquereau series.[1]

In spite of the attention that has been paid to these oil shales from time to time, there appears to be practically no record of any analyses. Consequently in August of 1930 the writer was instructed to obtain samples for analyses from outcrops in the neighbourhood of Port Daniel, and the following report gives a description of the beds sampled and the results of distillation tests.[2]

DESCRIPTION OF BEDS SAMPLED

Seven beds in all were examined, six on the Middle branch of the Port Daniel river and one on the North branch, and their locations are shown on the accompanying sketch map (Figure 16).

Bed No. 1: This bed outcrops in the bed of a small stream, range VI, about 200 yards above its junction with Port Daniel river.

Bed No. 2: This bed outcrops in lot 17, range VII, as a high bank on the south side of the river and is composed of black shale.

Beds Nos. 3 and 4: Greyish shales (possibly same bed) occur close together near the junction of lot 15, range VIII and lot 16, range VII.

Bed No. 5: This bed outcrops in lot 16, range VIII, on the north bank of Mictaw river (also known locally as Micwic). This is black shale and very much contorted.

Bed No. 6: This bed of black shale outcrops in lot 13, range IX, on both sides of a small brook which runs into the Middle branch from the south, and samples were taken from both outcrops.

Bed No. 7: This bed outcrops on the North branch of Port Daniel river just above the baseline separating ranges IX and X. It is a lens of "anthracitic" shale of very limited extent and does not appear to be related to the shales on the Middle branch. A test pit was sunk into this bed some 8 or 9 years ago, in the hope of striking coal, and samples were taken from it from time to time, the last occasion being in 1929. At the time of the writer's visit in 1930, the test pit contained about 15 feet of water, so the only samples that could be obtained were from material lying on the dump, which appeared to consist of uniform material.

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[1] The above summary is taken from Dr. W. A. Parks' "Report on the Oil and Gas Resources of the Province of Quebec," pp. 67 et seq., Ann. Rept. Quebec Bureau of Mines, 1929. This should be consulted for further details regarding the geology of these deposits.

[2] A detailed description of the apparatus and method used for the examination of oil-shale samples is given in the Investigations of Fuels and Fuel Testing, 1928, pp. 17-19.

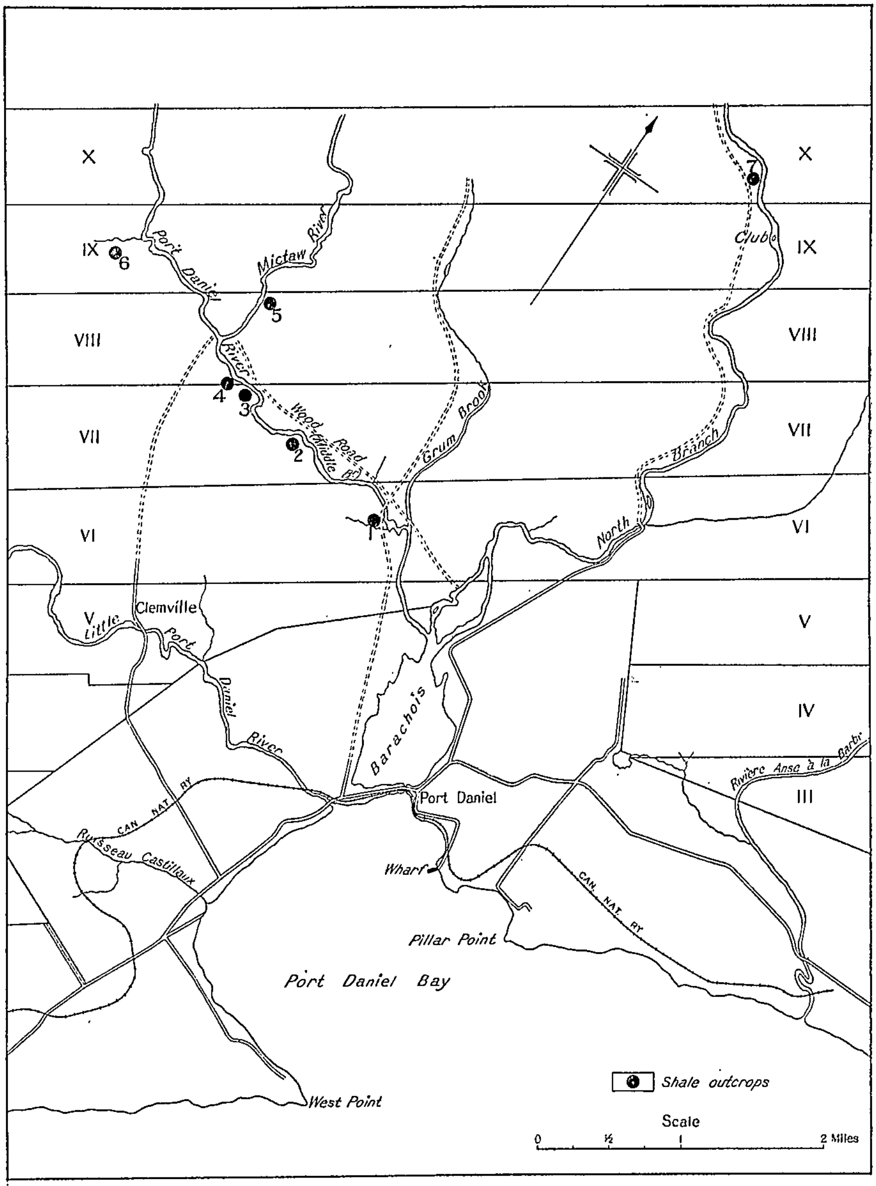

Figure 16. Sketch map showing location of shale outcrops sampled in 1930, Port Daniel, Quebec.

TABLE VI

Distillation Data: Beds 1-7

(*Maximum Temperature 550°C.*)

Bed No. *Lab. No.*	1 7649	2 7642	3 7643	4 7644	5 7647	6R 7645	6L 7646	7 7648
Shale charged (grms.)	400	400	400	400	400	400	400	400
Proximate Analysis—								
Moisture . . . per cent	1·7	2·0	2·5	2·0	1·0	1·3	1·6	0·9
Ash "	88·0	92·9	92·9	93·4	78·8	92·8	94·3	93·0
Volatile matter "	10·8	5·8	5·9	6·1	20·4	7·4	5·1	4·3
Fixed carbon "	9·5	......	......	......	......	......	......	1·8
Products, Weight Balance—								
Spent shale	94·6	94·3	93·5	94·0	93·3	94·1	95·1	97·0
Oil (water-free)	0·3	......	......	......	0·3	......	......	trace
Aqueous distillate	3·7	5·2	5·9	5·4	2·5	4·1	3·9	2·3
Gas	1·4	0·4	0·4	0·6	3·7	1·6	0·9	0·7
Loss	......	0·1	0·2	......	0·2	0·2	0·1	......
YIELDS								
Shale Oil— (Imperial gals. per ton)	0·6	nil	nil	nil	0·6	nil	nil	trace
Gas— (Cubic feet per ton)	410	90	90	180	860	410	350	180
Spent Shale— (Pounds per ton)	1,892	1,886	1,870	1,880	1,866	1,882	1,902	1,940

SUMMARY AND CONCLUSIONS

The results of the analyses and distillation of samples from seven beds are summarized in Table VI, from which it will be seen that there is little or no possibility for the economic extraction of oil from the Port Daniel shales—the best yields being less than one gallon per ton. This is not altogether unexpected in view of the general conclusions reached by Parks[1] and other investigators, but to the best of the writer's knowledge, this report contains the first *published* analytical data regarding these deposits.

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[1] Op. cit.

V

GASOLINE SURVEYS FOR 1930 AND 1931

H. McD. Chantler

The Division of Fuels and Fuel Testing of the Mines Branch has made a continuous study of the gasoline being sold in Canada for the past seven years, and annual reports[1] have been prepared from the results obtained in the laboratories. During the early part of August in 1930, 124 samples were collected[2] from wholesalers or distributors in 13 cities and during the early part of July in 1931, 134 samples were collected in 17 cities. The results of the detailed analysis of the individual samples, collected in these two years have been reported in the Mines Branch Memorandum Series.[3] This report contains a summary and discussion of the results of the laboratory examination of the 1930 and 1931 surveys, a statement of the methods of analysis used, as well as a discussion of the significance of the laboratory tests and the relationship between these tests and actual operation of the fuel in the engine.

SUMMARY AND CONCLUSIONS

In August 1930, 124 samples of gasoline were collected from 13 widely separated Canadian cities, and in July 1931, 134 samples of gasoline were collected from 17 cities, and may be accepted as representative of the gasoline sold in Canada at that time.

The analysis of these samples has shown that the average gasoline sold during 1930 and 1931 was of good quality. The average gasoline sold during 1930 had practically the same volatility as that sold during 1929, and the average gasoline sold during 1931 was slightly less volatile than that sold during the three previous years.

The variation in quality of the average gasoline during 1930 was greater than in the four previous years; but the variation in quality during 1931 was less than in any previous year, indicating a tendency towards a more uniform grade of gasoline.

As indicated by the distillation range, there has been a gradual change in the characteristics of the average gasoline marketed in Canada since 1925. The average temperature of the first drop, 10 per cent, 20 per cent, and also the end point has been lowered, while the average temperature of the 50 per cent, 70 per cent, and 90 per cent has remained fairly constant.

The sulphur content of the gasoline sold during 1930 was 0·07 per cent and during 1931 was 0·05 per cent. These amounts are considerably less than the amount usually accepted as the limit for good gasoline, viz. 0·10 per cent. In 1931, the average sulphur content of gasoline obtained in the western provinces was somewhat higher than for the samples obtained in the eastern provinces.

A marked tendency is shown during the past five years towards the marketing of an increased number of artificially coloured gasolines.

The knock rating of the samples collected in the city of Ottawa shows a relatively high anti-knock value.

SIGNIFICANCE OF TESTS ON GASOLINE

The quality of gasoline is a difficult matter to determine, because quality in this case depends on many factors. If any one of these is low in value the product becomes unsatisfactory, no matter how excellent other factors may be. For instance, if a certain gasoline contained so much gum that the valves of an engine stuck when the fuel was used, the owner of the engine would be prejudiced against the use of it, no matter how satisfactory it might be in all other respects. Another feature that causes much uncertainty among users, is a lack of uniformity in quality. A certain brand of gasoline may be used for a considerable time with every satisfaction by an individual. Then, a poor consignment is received and the user becomes dissatisfied to such an extent that he decides to buy some other brand that is highly recommended. It is a remarkable tribute to the skill and efficiency of the refiners and distributors that so little really poor gasoline is being sold to the public.

It is obvious that laboratory analyses of gasoline are most valuable when they serve to indicate probable performance of a fuel in an engine. The owner of the engine is the final judge of the quality and he generally reaches his conclusion from the responsiveness of the engine. Therefore, the character of motor fuels must change as rapidly as important changes are made in the engines. It appears to the writer that new and desirable characteristics in fuels must not only show at their best in the new engines, but they must also operate the old ones without serious difficulties.

Since the average life of an automobile is about five years, a satisfactory fuel, from the standpoint of the general public must necessarily be somewhat different from the best fuel on the proving grounds of the motor manufacturer, where new engines are tested. The comments on quality of gasoline in relation to laboratory analysis given below, are to be understood as being offered from the standpoint of the average owner of the automobile.

The Characteristics of a Good Motor Fuel

It may be accepted that a good gasoline should possess the following characteristics:—

(1) Permit the engine to start easily.
(2) Permit the engine to develop maximum power.
(3) Allow the engine to run evenly and steadily when throttled down.
(4) Should not evaporate too readily at atmospheric temperatures.
(5) Should not contain sufficient gum to cause sticking valves.
(6) Should not "knock."

Easy Starting. A gasoline, to permit an engine to start readily, should have a reasonably low initial boiling point. Under normal atmospheric temperatures an initial point of about 100° F. will be found satisfactory. In addition, the temperature reached, when 10 per cent has been distilled, should be reasonably low; about 150° F. will give good results. These requirements provide a reasonable quantity of highly volatile materials that will ignite easily.

Maximum Power. Maximum power will be secured from an engine when the carburetor supplies it with an even mixture of gasoline vapour and air, which can be, and is properly burned. The gasoline vapour shoud not carry too much material of high boiling point because such material is usually more difficult to ignite. Neither should it contain too much low-boiling material because such material will burn so rapidly that the engine cannot convert it efficiently into useful work. Therefore, the gasoline should be composed of a series of constituents with gradually increasing boiling point, as is indicated by a smooth, gradually rising, distillation-range curve. A gasoline that will permit an engine to start readily should also permit a satisfactory development of power, provided the distillation range shows 70 per cent distilled over at about 300° F. In addition, the end point should not be too high, a little over 400° F. may be accepted.

Even Running. Smooth running at low speed is more dependent on the design and condition of the engine and accessories, than on the fuel used. However, the volatility of the fuel as a whole should not be so high as to cause it to vaporize or boil in the gasoline lines or carburetor. This condition is known as "vapour lock" and when it occurs the engine usually stops suddenly for no apparent reason. After cooling down, the engine may often be started again as if nothing had happened.

Evaporation. The quantity of gasoline evaporated at normal temperatures is only a factor in the valuation of fuel when the volatility is high. The readiness with which a gasoline evaporates is indicated by the amount of the recovery after distillation. When the recovery is less than 95 per cent the evaporation loss is likely to be excessive. Thus it naturally follows that the mileage obtained from such fuel is low. This would be especially noticeable after the gasoline tank had been allowed to stand for some time exposed to the full rays of the sun.

Distillation Range and Index Number

All of the above points can be estimated from the distillation range that is determined in the laboratory. As an aid in summing up the value to be allotted to the distillation range an index number[4] has been calculated from the temperature readings at which 10, 20, 50, 70, and 90 per cent of the distillate has been recovered. To the sum of these readings is added the temperature reading at the end point of the distillation. The resultant sum is called the "index number". Generally speaking, the smaller the index number the greater the volatility of the fuel. Gasolines may be classified arbitrarily, according to their index numbers, into three groups as follows:—

(a) Gasolines of high volatility having index numbers less than 1,650.

(b) Gasolines of average volatility having index numbers between 1,650 and 1,725.

(c) Gasolines of low volatility having index numbers greater than 1,725.

Specific Gravity

The specific gravity has been used in the petroleum industry for many years as an easy and convenient method of refinery control. On that account it has often been used as a test for the quality of gasoline, although it is not of very much value for that purpose when used alone. It is valuable, however, when used in conjunction with the distillation range to indicate the source of the fuel or the treatment it has received. A gasoline having a low specific gravity is more probably made from a paraffin-base petroleum, and by an ordinary distillation of crude oil, than a gasoline of the same laboratory distillation range having a high specific gravity. The latter would be obtained by cracking petroleum in modern equipment, and probably would be derived from naphthenic-base petroleum.

Baumé and A.P.I. Gravity. The method in common use for expressing specific gravity is often called the "Baumé gravity". According to this method, a scale on which the extreme range of petroleum products could be measured, was divided into one hundred equal parts called degrees. The ten degree point was equivalent to the specific gravity of pure water. Unfortunately, some uncertainty arose regarding the correct value of some of the other points, and two slightly different scales came into use, both being called "Baumé" scales. The American Petroleum Institute, with the co-operation of the petroleum industry and the United States government departments, adopted one of these scales and described it in such a way that no ambiguity is possible. The initials of the Institute (A.P.I.) were chosen to designate this scale in order to avoid confusion. The degrees A.P.I. have nearly the same value in specific gravity as the other Baumé degree scale. The greatest difference occurs when the lighter products are measured and the difference is always less than one degree. The relation between degrees A.P.I. and specific gravity is expressed by the following equation:—

$$\text{Degrees A.P.I.} = \frac{141\cdot5}{\text{Sp. Gr. at } 60^\circ \text{ F.}} - 131\cdot5$$

A comparison of A.P.I. degrees, Baumé degrees, and specific gravity, is shown in Table I.

Colour

Gasoline is a clear water-white liquid when freshly distilled. Exposure to air or sunlight changes the chemical structure slightly, so that a yellowish colour appears and a certain amount of "gum" or "resin" may, or may not, appear. Some gasolines develop more colour than others under the same conditions. Gasoline is treated at the refinery before it is sold to render it more stable to light and air, so that the above change of colour may be minimized. The colour in itself has no effect on quality. It should be stated that the change in colour is not proportional to the amount of gum that may be formed. However, the user of gasoline seems to prefer a clear colourless fuel or one that is artificially coloured. Many gasolines on the market have dissolved in them small quantities of various brightly-coloured dyes in order to make the product more attractive, to distinguish between grades or brands readily, or to indicate the presence of tetra-ethyl lead, so that the gasoline shall not be used for any other purpose than a motor fuel.

Gum

The amount and character of the gum present in gasoline varies greatly. A gasoline may show no gum formation when freshly distilled, but at some later time definite gummy deposits may be obtained. The time and the condition required for the deposition of gum also vary greatly. It is believed that gasolines produced by cracking equipment are more likely to deposit gum than gasolines produced by the ordinary distillation of crude petroleum. The conditions under which it is stored also affect the liability of gasoline to produce gum. It has been proved[1] recently that the soldering fluxes used in the manufacture of gasoline tanks react with the gasoline in an unfavourable manner in this respect. The amount of gum cannot be determined in the laboratory with any degree of certainty so that it represents the result obtained under actual operating conditions. Laboratory results showing gum content of gasoline must be regarded, therefore, as approximations only.

Sulphur

All commercial gasolines contain certain compounds that have a small amount of sulphur present. Some of these materials are detrimental and some are not. Most of them have an offensive odour. Those that are injurious combine with copper or brass to form a grey or a black coating. In severe cases this may become a scale that flakes off and clogs the small carburetor jets. After fuel containing sulphur is burned an acid substance is formed that has a tendency to pit and corrode the polished steel and iron surfaces of the engine bearings, especially those that are not thoroughly lubricated. It has become an accepted practice for the refiner to reduce the sulphur content to less than 0·1 per cent of sulphur. In some cases it may be possible to permit a higher percentage of sulphur without injurious effects, but the difficulty lies in not being able to determine readily whether the sulphur is present in an injurious form or not. In order to be on the safe side the above limit has been accepted.

Anti-Knock Value

Actual operation of internal combustion engines using gasoline as fuel has demonstrated that some fuels burn a great deal more smoothly than others. The smoothness of burning is indicated by an absence of "knocking" in the engine when it is pulling heavily. This tendency of fuels to knock hindered progress in the design of more efficient internal combustion engines for many years, and it is only recently that a method has been developed for improving the fuel to such an extent that the efficiency of the engine could be increased. It was found that the addition of some materials to the fuel improved the burning quality greatly. One of the most satisfactory substances used for this purpose is known as tetra-ethyl lead. A very small amount of this material changes the rate of combustion greatly. It was also found that some materials formed during the treatment of crude petroleum to produce gasoline, which it had been the custom to remove later in the refining process, influenced the combustion beneficially. These materials are known as unsaturates and aromatics. Enormous sums of money have been spent in an effort to devise a really satisfactory laboratory method for establishing the knock-rating of gasolines. The method that has obtained greatest support involves testing the fuel in a single cylinder engine operated under specified

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[1] Aldrich, E. W., Jour. Soc. Automotive Eng., vol. 30, No. 5, p. 206.

conditions and expressing the results in Octane numbers. Octane numbers are really only arbitrarily chosen values. It was found that a certain liquid (2-2-4 tri-methyl-pentane, an iso-octane) burned very smoothly in an ordinary internal combustion engine. Also that another liquid (normal heptane) knocked very badly indeed under the same conditions. Further, that these two compounds could be mixed in all proportions and that the tendency to knock was proportional to the amount of heptane present. Therefore, it was agreed that a scale should be established from the above data so that other fuels might be rated against it. The scale was from 1 to 100, and each division was called an Octane number. Gasolines that are rated against this scale burn more smoothly the higher the Octane number. Pure iso-octane is very expensive and it is obvious that this rating does not mean that there is actually a quantity of iso-octane present in the fuel equivalent to the Octane number. Unfortunately, the knock-ratings obtained by the laboratory engine, under the specified conditions, do not always agree exactly with the observations of operators of motor cars under actual driving conditions. This was particularly noticeable between fuels which had been improved by the addition of tetra-ethyl lead and those which contained a certain proportion of those components produced during the manufacture of the fuel and which were retained in the finished product. The whole problem is under investigation in a number of laboratories in Canada and the the United States.

Chemical Components

Gasoline is composed of an intimate mixture of chemical compounds known as hydrocarbons. These hydrocarbons are subdivided into different classes, viz., unsaturates, aromatics, naphthenes, and paraffins. Of these groups the unsaturates, aromatics, and naphthenes have a beneficial effect on the anti-knock value of the fuels of which they are a part. The paraffins might possibly be considered as neutral or normal. Several efforts have been made by different investigators to obtain from the chemical analyses of fuels an estimation of the anti-knock value of the fuel as a whole. One of these methods was suggested by Egloff and Morrell[5], who obtained a figure which was referred to as a toluene value. This toluene value is obtained by dividing the percentage of unsaturated hydrocarbons by five, by dividing the percentage of naphthenes by four, and adding the sum of these two to the percentage of aromatics. This method of estimating anti-knock values cannot be used when the samples contain tetra-ethyl lead. A large number of tests on engines has failed up to the present time to prove that a definite comparison is possible between the result obtained from the engine and other ratings obtained from the chemical analyses. The results obtained by the writer have also failed to show a definite relationship, although it is evident that different proportions of the hydrocarbons do affect the anti-knock value of the fuel.

METHODS OF ANALYSIS USED

The distillation range was determined according to the American Society for Testing Materials method No. D86-30. The specific gravity was obtained by the use of the chainomatic specific gravity balance at room temperature, and the result calculated to 60° F. according to the

National Petroleum Oil Tables,[6] published by the United States Bureau of Standards. The degrees A.P.I. were obtained by converting the specific gravity according to the above oil tables. The percentage of sulphur was determined according to the A.S.T.M. tentative method No. D90-30T. The knock ratings of the gasoline from the city of Ottawa are expressed in Octane numbers, and were determined in a knock-testing engine manufactured by the Ethyl Gasoline Corporation, known as their Series 30. The operating conditions were 600 r.p.m., a jacket temperature of 212°F., and a spark advance 22 degrees below top dead centre. The percentages of the four series of hydrocarbons and the toluene value were determined and calculated according to the method of Egloff and Morrell.[6]

RESULTS OF LABORATORY EXAMINATION

The average results by cities of the laboratory examination of the gasolines tested in 1930 and 1931 are shown in Tables II and III. The average results obtained by the examination of samples during the nine years from 1923 to 1931 are shown in Table IV, and Figure 17 shows graphically the ranges of average distillation temperatures for the same nine years. In order to determine the variation in quality of the gasoline being sold, the average of the 10 per cent having the highest index numbers and the average of the 10 per cent having the lowest index numbers were calculated for 1930 and 1931. The difference between the average index numbers of the maximum and minimum 10 per cent of the samples collected in the nine years 1923 to 1931 was also calculated and is shown in Table V. Table VI shows the knock ratings of the samples collected in the city of Ottawa in 1931 and, also, the percentage of the four series of hydrocarbons present in gasoline for the same samples.

DISCUSSION OF RESULTS

It is interesting to compare the results obtained with others obtained in previous years. In Table IV are given the average results of eighty-eight samples collected in Canada presumably in 1916, and reported[7] by the laboratories of the Department of Inland Revenue; the average results of the following number of samples collected[3] in Canada in successive years; 48 in 1923; 59, 73, 76, 83, 77, 84, 124, and 134 in 1924-1931 respectively. When judged by the distillation range, which has been the ordinary accepted standard, it will be observed that the gasoline sold in Canada in 1930 shows an average of good quality with practically the same volatility as that sold during 1929. The gasoline sold in Canada in 1931 shows an average of good quality with a lower volatility than that sold during the three previous years. This decrease in volatility in 1931 is equivalent to approximately 3° F. rise in the average temperature of the 20, 50, 70, and 90 per cent points in the distillation range.

Since 1925, there has been a gradual change in the characteristics of the average gasoline marketed in Canada, as indicated in Figure 17. This change is particularly noticeable at the lower end of the distillation range as the average temperature of the first drop, 10 per cent, and 20 per cent points has been lowered. The average temperature of the 50 per cent, 70 per cent, and 90 per cent points has remained fairly constant. The average temperature of the end point has been lowered.

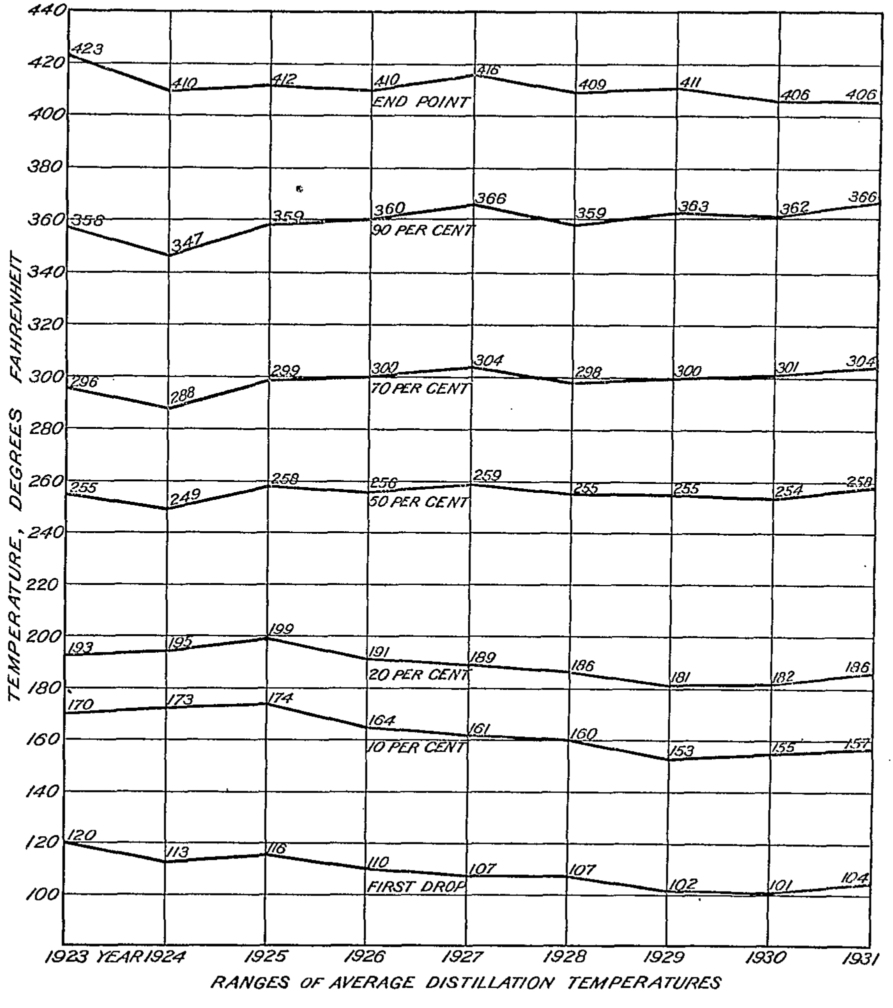
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
TEMPERATURE, DEGREES FAHRENHEIT
423
410
412
410
416
409
411
406
406
END POINT
358
347
359
360
366
359
363
362
366
90 PER CENT
296
288
299
300
304
298
300
301
304
70 PER CENT
255
249
258
256
259
255
255
254
258
50 PER CENT
193
195
199
191
189
186
181
182
186
20 PER CENT
170
173
174
164
161
160
153
155
157
10 PER CENT
120
113
116
110
107
107
102
101
104
FIRST DROP
1923 YEAR 1924
1925
1926
1927
1928
1929
1930
1931
RANGES OF AVERAGE DISTILLATION TEMPERATURES

Figure 17.

The lowering of the average first drop, 10, and 20 per cent is probably due to the increased production of gasoline from natural gas and the increased use of cracking equipment at the refineries. The lowering of the average end point with a corresponding smaller difference between the average 90 per cent point and average end point, is probably due to the use of more efficient fractionating equipment such as bubble towers, etc., at the refineries.

Table V shows the difference between the average index numbers of the maximum 10 per cent and minimum 10 per cent of the samples collected in Canada in the nine years, 1923 to 1931. The difference between the two averages has been used previously for the purpose of comparison, as a measure of the variation in quality. It will be observed that the variation in quality during 1930 was greater than in the preceding four years; while the variation in quality during 1931 was less than in any previous year.

It will be further observed from Table V that, in 1930, the group having the higher volatility has an average volatility greater than corresponding groups examined in the preceding five years. It will be noted that, in 1930, the group having the lower volatility has an average volatility less than the corresponding group examined in 1929.

In 1931, the group having the higher volatility has an average volatility less than corresponding groups examined in previous years. The group having the lower volatility has an average volatility higher than corresponding groups examined in previous years, with the exception of the year 1929, when the volatility of these groups was practically the same. This decrease in the difference of the average volatility in the higher and the lower groups in 1931, indicates a growing tendency towards a more uniform grade of gasoline.

The average sulphur content of gasoline sold in Canada during 1930 was 0·07 per cent and only 6·5 per cent of the 124 samples tested had a sulphur content exceeding 0·1 per cent. The average sulphur content of gasoline sold in Canada during 1931 was 0·05 per cent and only 6·7 per cent of the 134 samples tested had a sulphur content exceeding 0·1 per cent. In 1931, the average sulphur content of samples from the western provinces was 0·08 per cent, while the average sulphur content for the eastern provinces was 0·04 per cent. The reason for this difference is not apparent.

Since 1927 there has been a gradually increasing tendency apparent to colour, artificially, the gasolines being put on the market. The percentages of artificially coloured gasolines sold in Canada during the past five years, according to the samples examined in the annual surveys, were as follows:

Percentages of Artificially Coloured Gasolines in Different Years

Year	Artificially coloured gasolines
	%
1927	10
1928	13
1929	18
1930	26
1931	34

The highest knock rating obtained from the samples collected in the city of Ottawa was 75 Octane numbers and the lowest was 57 Octane numbers. Eight samples, or approximately 27·6 per cent, are in a group ranging from 57 to 64 Octane numbers and the twenty-one samples, or 72·4 per cent, are in the range 65 to 75 Octane numbers. The greater quantity of gasoline sold in Ottawa during 1931 had a relatively good anti-knock value.

TABLE I

Comparison of A.P.I. Degrees, Baumé Degrees, and Specific Gravity

A.P.I. degrees	Baumé degrees	Specific gravity	A.P.I. degrees	Baumé degrees	Specific gravity
40	39·68	0·8251	56	55·51	0·7547
41	40·67	0·8203	57	56·50	0·7507
42	41·66	0·0156	58	57·49	0·7467
43	42·65	0·8109	59	58·48	0·7428
44	43·64	0·8063	60	59·47	0·7389
45	44·63	0·8017	61	60·46	0·7351
46	45·62	0·7972	62	61·45	0·7313
47	46·61	0·7927	63	62·44	0·7275
48	47·60	0·7883	64	63·43	0·7238
49	48·59	0·7839	65	64·42	0·7201
50	49·58	0·7796	66	65·41	0·7165
51	50·57	0·7753	67	66·40	0·7128
52	51·56	0·7711	68	67·39	0·7093
53	52·55	0·7669	69	68·38	0·7057
54	53·54	0·7628	70	69·37	0·7022
55	54·53	0·7587			

TABLE II

Average Results of Analyses by Cities for 1930

City	1st drop °F.	Distillation range					End point °F.	Recovery	Residue	Distillation loss	Index No. °F.	Specific gravity	Degrees A.P.I.	Sulphur %
		10% °F.	20% °F.	50% °F.	70% °F.	90% °F.								
Halifax, N.S..........	96	151	184	265	316	372	410	97·0	1·1	1·9	1698	0·748	57·7	0·05
St. John, N.B.........	100	162	190	256	295	347	389	97·3	1·0	1·7	1639	0·741	59·5	0·05
Quebec, Que..........	97	152	179	251	299	361	402	97·3	1·1	1·6	1644	0·740	59·8	0·05
Montreal, Que.........	101	159	189	269	320	380	416	97·1	1·1	1·8	1733	0·750	57·2	0·06
Ottawa, Ont..........	100	149	176	255	306	368	408	97·0	1·1	1·9	1662	0·741	59·5	0·06
Toronto, Ont..........	102	154	183	258	305	366	403	97·0	1·1	1·9	1669	0·736	60·8	0·05
London, Ont..........	100	157	186	262	308	368	407	96·9	1·1	2·0	1688	0·740	59·7	0·07
Winnipeg, Man........	101	159	187	255	297	354	400	97·5	1·1	1·4	1652	0·735	61·0	0·03
Regina, Sask..........	103	157	183	249	291	350	395	97·2	1·0	1·3	1625	0·731	62·0	0·04
Calgary, Alta.........	103	155	180	247	293	359	407	97·5	1·2	1·3	1641	0·738	60·2	0·09
Edmonton, Alta......	107	157	179	243	288	355	407	97·2	1·1	1·7	1629	0·736	60·8	0·09
Vancouver, B.C.......	104	163	192	255	298	360	409	97·7	1·1	1·2	1677	0·752	56·7	0·06
Victoria, B.C.........	103	162	190	249	293	354	402	97·7	1·1	1·2	1650	0·750	57·2	0·05
Average for Canada*.	101	155	182	254	301	362	406	97·2	1·1	1·7	1660	0·741	59·5	0·07

*This is the average value for all the samples tested.

TABLE III

Average Results of Analyses by Cities for 1931

City	1st drop °F.	Distillation range					End point °F.	Recovery	Residue	Distil-lation loss	Index No. °F.	Specific gravity	Degrees A.P.I.	Sulphur %
		10% °F.	20% °F.	50% °F.	70% °F.	90% °F.								
Halifax, N.S..........	107	166	196	263	303	357	399	97·0	1·2	1·8	1684	0·744	58·7	0·03
St. John, N.B.........	104	162	192	262	303	358	401	96·9	1·2	1·9	1678	0·744	58·7	0·04
Quebec, Que..........	113	167	193	255	294	349	396	96·9	1·3	1·8	1654	0·741	59·5	0·04
Montreal, Que.........	106	155	183	261	310	372	410	96·6	1·3	2·1	1691	0·745	58·4	0·04
Ottawa, Ont..........	104	152	180	259	308	372	410	96·6	1·2	2·2	1681	0·742	59·2	0·04
Toronto, Ont..........	104	161	191	266	311	369	405	97·1	1·2	1·7	1703	0·743	58·9	0·04
Hamilton, Ont........	104	157	186	260	309	373	408	96·7	1·2	2·1	1693	0·740	59·7	0·04
London, Ont..........	103	164	197	270	314	372	407	96·8	1·1	2·1	1724	0·743	58·9	0·05
Fort William., Ont....	109	166	196	259	299	353	396	97·4	1·2	1·4	1669	0·737	60·5	0·04
Winnipeg, Man........	115	156	183	254	300	364	408	96·8	1·2	2·0	1665	0·732	61·8	0·06
Brandon, Man.........	100	155	186	256	298	355	399	97·1	1·2	1·7	1649	0·734	61·3	0·04
Regina, Sask..........	102	151	180	261	312	377	417	97·2	1·3	1·5	1698	0·738	60·2	0·09
Saskatoon, Sask......	101	154	180	256	306	373	412	97·2	1·2	1·6	1681	0·737	60·5	0·07
Calgary, Alta.........	102	150	174	239	285	350	403	97·2	1·3	1·5	1601	0·733	61·5	0·11
Edmonton, Alta......	103	154	179	249	296	363	406	97·2	1·2	1·6	1647	0·739	60·0	0·09
Vancouver, B.C.......	102	162	191	256	297	359	398	96·7	1·0	2·3	1663	0·748	57·7	0·07
Victoria, B.C.........	104	160	191	254	294	360	402	96·9	1·0	2·1	1661	0·747	57·9	0·07
Average for Canada*.	104	157	186	258	304	366	406	96·9	1·3	1·8	1677	0·741	59·5	0·05

*This is the average value for all the samples tested.

TABLE IV

Average Results for Comparison for Canada

Year	1st drop °F.	Distillation range					End point °F	Recovery	Residue and distillation loss	Index No. °F.	Specific gravity	Degrees A.P.I.	Sulphur %
		10% °F.	20% °F.	50% °F.	70% °F.	90% °F.							
1916	125	170	192	237	270	330	380	....	....	1579	0·732	61·8	....
1923	120	170	193	255	296	358	423	97·1	2·9	1695	0·737	60·5	....
1924	113	173	195	249	288	347	410	97·4	2·6	1662	0·736	60·8	....
1925	116	174	199	258	299	359	412	97·0	3·0	1701	0·739	60·0	....
1926	110	164	191	256	300	360	410	97·4	2·6	1681	0·739	60·0	....
1927	107	161	189	259	304	366	416	97·0	3·0	1693	0·741	59·5	....
1928	107	160	186	255	298	359	409	97·3	2·7	1667	0·737	60·5	....
1929	102	153	181	255	300	363	411	97·0	3·0	1663	0·736	60·8	....
1930	101	155	182	254	301	362	406	97·2	2·8	1660	0·741	59·5	0·07
1931	104	157	186	258	304	366	406	96·9	3·1	1677	0·741	59·5	0·05

TABLE V

Difference Between Maximum and Minimum Index[1] Numbers

Year	1923	1924	1925	1926	1927	1928	1929	1930	1931
Maximum 10%.....	1791	1806	1821	1815	1823	1791	1773	1787	1774
Minimum 10%.....	1500	1428	1497	1524	1518	1488	1503	1471	1547
Difference.........	291	378	324	291	305	303	270	316	227

[1] The index number is the sum of the following points in the distillation range: 10%, 20%, 50%, 70%, 90%, and the end point.

TABLE VI

Knock Ratings and Chemical Analyses of Samples from Ottawa

Sample No.	Octane No. at 212° F.	Hydrocarbons				Toluene value	Index No. °F.
		Unsaturates	Aromatics	Naphthenes	Paraffins		
		%	%	%	%	%	
48..............	75	6	10	34	50	19·7*	1561
42..............	74	4	8	32	56	16·8*	1687
32..............	73	5	6	29	60	14·3*	1693
35..............	72	21	21	26	32	31·7	1573
39..............	72	4	8	26	62	15·3*	1728
54..............	71	4	10	29	57	18·1*	1774
55..............	70	9	10	24	57	17·8	1583
50..............	70	11	14	27	48	23·0	1756
29..............	69	8	11	26	55	19·1*	1703
38..............	69	8	8	24	60	15·6	1550
37..............	69	7	7	25	61	14·7	1556
40..............	67	10	14	26	50	22·5	1683
41..............	66	8	11	26	55	19·1	1739
28..............	66	10	7	25	58	15·3	1623
44..............	66	14	19	25	42	28·1	1761
31..............	66	7	10	27	56	18·2	1711
33..............	65	6	9	25	60	16·5	1691
49..............	65	6	8	33	53	17·5	1613
51..............	65	6	11	26	57	18·7	1731
36..............	65	5	11	27	57	18·8	1736
53..............	65	5	11	28	56	19·0	1723
52..............	63	9	9	26	56	17·3	1693
45..............	63	13	15	22	50	23·1	1730
30..............	61	3	4	30	63	12·1	1587
27..............	60	9	14	22	55	21·3	1793
46..............	58	8	9	24	59	16·6	1720
47..............	58	4	4	28	64	11·8	1656
43..............	58	4	5	29	62	13·1	1664
34..............	57	8	8	21	63	14·9	1734
Average........	66	8	10	27	55	18·2	1681

*These samples contain tetra-ethyl lead and therefore the toluene value does not indicate the anti-knock value of the fuel.

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