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)

1929

*Sections I, V and VI published separately as advance sections of Investigations of Fuels and Fuel Testing, 1929.

No. 721

OTTAWA
F. A. ACLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
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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, 1929

GENERAL REVIEW OF INVESTIGATIONS

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

The investigations conducted during 1929, which were of much the same nature as in the previous year, were comprised of both small and large laboratory-scale investigations, the latter being mostly of a continuous nature, not sufficiently advanced to be put into the usual report form for publication. In addition to the low-temperature carbonization tests, caking indices of coals, and the special field work on natural gas reported hereunder, the investigational program included a continuation of the physical and chemical survey of the Phalen coal seam; special examination of Nova Scotia slack and "railway" coal from the storage pile at Windmill Point, Montreal; continuation of laboratory carbonization assays of typical Canadian coals at both high and low temperatures; further taking of oil shale samples in the field, and a continuation of the crude oil analyses survey. The new building, to be known as the Fuel Research Laboratories, was occupied early in the year, and preliminary large-scale tests were made in the experimental pulverized fuel fired boiler installation. The investigations conducted and activities of the technical staff are given in more detail in the Annual Report of the Department of Mines for the fiscal year ending March 31, 1930, certain phases of which are worthy of further amplification here.

Yearly Heating Load Data: by E. S. Malloch and C. E. Baltzer. This investigation, as planned, comprised a general survey of the fuel requirements for domestic heating in the cities and districts of Canada where daily records of the mean outside temperatures have been kept. During the year considerable data were collected as to the daily temperatures for the cities of Toronto and Ottawa for the past ten years, and the monthly fuel consumption (in two cases the daily consumption) in six Ottawa houses heated by gas-fired furnaces, were recorded. By the proper correlation of the accumulative consumption data with the average and specific temperature-time curves, as well as with varying locations as to sun and wind exposure, it is expected that the yearly heating loads for different fuels can be predicted with a fair degree of certainty. The results of this investigation, which is being continued, should be of particular interest to architects and heating contractors.

Oil-shale Survey: by A. A. Swinnerton. Additional oil-shale samples were taken by A. A. Swinnerton from the Pictou area. Outcrops, mainly along McLellan brook, were re-sampled and laboratory assay tests made on two composite seam samples and ten sectional samples. Locations or beds at A, AB, and E, as indicated in the 1928 report, were re-sampled, and a fresh outcrop F, near Trenton, was also examined. Fresh shale, at greater depth in the seam, from the 4¾-foot bed at A showed an oil content ranging from 16·5 to 21·3 Imperial gallons per ton for the different samples, with an average of 20·1 Imperial gallons. This was an increase of more than 2·5 gallons over the former average for the outcrop. The shale at location AB, on the contrary, on re-sampling showed a decrease from 26·5 to 16·4 gallons per ton as the average oil content of the bed. Location E (located but not sampled in 1928) near Stellarton produced shale that analysed 21·9, 46·7, and 32·0 gallons for the three sections respectively of the 5½-foot seam, the average of which was 36·9 gallons per ton of crude shale. Shale at F near Trenton was barren, showing less than one gallon per ton.

On the basis of at least 20 Imperial gallons per ton as the laboratory yield to be worthy of large-scale development and utilization, the shale at E, in addition to that at D previously reported, may be considered favourable for commercial development. Location A also may be added to the list as giving promise of better results as the seam is followed in from the outcrop. The description of the locations from which the samples were obtained and the details of the results of examination will appear in the 1930 Investigations of Fuels and Fuel Testing.

Report of Tests on Sydney Coal by the Illingworth Low-temperature Carbonization Process: by R. A. Strong and E. J. Burrough. The coal used in these tests was supplied by the Dominion Coal Company of Sydney, Nova Scotia, and the main tests were made at the large-scale experimental plant of the Illingworth Carbonization Company at Pontypridd, Wales. As stated in the introduction, and amplified in the preface, the objective of the tests was primarily to determine to what extent this particular coal was amenable to treatment by the Illingworth process for the production of a coke suitable for use as a domestic household fuel in Canada. The yields of tar oils and gas were considered as of secondary importance.

The actual carbonization tests in England were witnessed by the junior author of the report, and supplementary tests were conducted at Ottawa on large samples of both coke and tar oils brought back for that purpose. The coke was examined particularly for density and friability, and general burning tests of a preliminary nature were made in standard house-heating furnaces by C. E. Baltzer. Both washed and unwashed "Sydney" coal were tested, special attention being paid to the distribution of the sulphur during carbonization in comparison with that taking place in high-temperature by-product oven coking.

As is more or less well known, the Illingworth process has as its salient feature a preliminary heat treatment, in order to produce from a strongly coking or swelling coal, a dense smokeless free-burning coke. In present practice this is accomplished by mixing with the coal to be carbonized a certain portion of coke breeze. Provision is also made for discharging the hot coke into a cylindrical (revolving) drum containing raw coal, thus cooling the coke without quenching and also drying the coal to be charged. Eighteen tests on the Sydney coal were made, two of which were in the 50-ton retorting plant, while the remaining 16 tests were made in the experimental single retort, and the optimum proportion of breeze from a previous run in any charge was in the neighbourhood of 10 per cent.

The yields of unscrubbed gas from the washed and unwashed coal were 6,050 and 4,910 cubic feet respectively, the average calorific value of which was 700 B.T.U. per cubic foot. The average yield of dry tar oils was slightly under 13 Imperial gallons, the specific gravity of which was

1·04. The light oil content of this tar was 1·4 gallons, which, when added to 2·8 gallons obtainable from the gas by scrubbing, gave a total of roughly 4 gallons per ton. As a primary crude product, however, it is doubtful if the tar oil, including its light oil content, should be valued, for Canadian industrial purposes, higher than ordinary fuel oil, and no credit should be allocated to the ammonium sulphate obtainable as the average yield of 7 to 8 pounds per ton is not considered high enough to more than pay the cost of recovery.

The coke produced from the Sydney coal tested was black in appearance and of a hard, dense nature, similar to the "Ricoal" product, as the Illingworth coke is termed, from English bituminous coals, and the yield averaged 74 per cent. The ash content of the coke from washed and unwashed coal was 7·6 per cent and 11·8 per cent respectively with corresponding calorific values of 13,700 and 13,275. The apparent density of the coke from the Sydney coal ranged from 0·90 to 0·93, which is noticeably higher than that for by-product oven coke made from the same coal. The porosity of the low-temperature coke produced was approximately 25 per cent as compared with nearly double this figure for the high-temperature product. As for general handling qualities, remarkably good results were obtained, the breakage through one inch in the transportation of nearly one and a half tons of large "cobble" size lumps being only slightly over 5 per cent. The shatter index of the cokes from the washed and unwashed coal averaged 83·5 per cent as compared with 67·5 per cent for by-product oven coke from the same coal. The result of the preliminary burning tests was quite satisfactory. The small amount of clinkers formed, even at high rate of burning, was remarkable, in view of its comparatively low F.P.A. (fusion point of ash), which is in the vicinity of 2,000° F. The free-burning nature of large as well as small lumps was noted, as was also the lasting qualities of the larger lumps. The ash formed was of a granular gritty nature as compared with the flocculent ash from high-temperature coke, and a plausible explanation of its non-clinkering properties is that combustion proceeds to completion below the 2,000° F. ash fusion temperature. With the exception that under ordinary (improper) control of draughts the fuel may be found to be too free-burning, there does not seem to be any reason why this low-temperature coke from Sydney coal should not be successfully adapted to the domestic (household) fuel-market.

The distribution of organic sulphur in the products was found to be different from that taking place in high-temperature by-product oven practice. In comparison with 65 grains per 100 cubic feet in by-product oven gas from a coal containing 3 per cent sulphur, only 35 grains per 100 cubic feet were found in the low-temperature, Illingworth process gas. On the basis of total organic sulphur in 6,000 and 11,000 cubic feet of gas respectively, by the low- and high-temperature processes, this means a reduction of over 70 per cent. This low sulphur content in the gas is explainable by the assumption that appreciable secondary reactions of hydrogen sulphide with hot carbon did not take place at the temperature of carbonization, the maximum of which was 600°C. Similar reductions in the hydrogen sulphide content of the gas (due to absorption in the liquor) and of the total sulphur in the coke were noticed. For these reasons it was concluded that the Illingworth process is suitable for the treatment of coals higher in sulphur than allowable in high-temperature practice.

In the summary and conclusions of the report the authors have briefly discussed the economics and commercial application of the process to coals of the Sydney, Nova Scotia, area and the general conclusion arrived at is that the Illingworth process is quite suitable for the treatment of coal from that area for the production, as a main product, of a coke quite serviceable for domestic household heating purposes.

Notes on Methods for Laboratory Assay of Coals for Carbonization and for General Coking Properties: by R. E. Gilmore. This paper is comprised of two sections, namely: (1) Comparison of low-temperature carbonization results by the "lead bath" and the Gray-King methods, and (2) Relation of caking indices and agglutinating values of coals to their laboratory and plant scale coking properties.

Section 1 shows the results obtained on a series of typical Canadian coals ranging from bituminous to lignite, first on a 3,000-gramme scale with the iron retort immersed in an electrically heated lead bath—the method employed in the Fuel Testing Laboratories at Ottawa since 1918—and then on a 20-gramme scale, being the Gray-King method adopted at the British Fuel Research station. Slight modifications were introduced, consisting of carbonizing in the nearly dry condition rather than completely dry, and heating the charge at a slower rate at the beginning of the test. The latter modification was considered both advisable and necessary for non-coking coals in order to avoid loss of charge from the retort into the condensing train. Otherwise, the directions specified for the Gray-King method were closely followed.

There was a fair agreement only in the yields of *(a)* coke or char, *(b)* gas by weight, and *(c)* the total condensate comprised of water of decomposition, liquor, and tar oils. Appreciable variations were noted in the ratio of liquor to tar by the two methods on the same coal and without exception higher tar oil yields were indicated by the 20-gramme scale method than by the 6¾-pound lead bath scale. For the reason that in the latter method it is the recovered tar oils that are recorded, whereas in the former smaller scale method the yield of tar oils is arrived at by difference, the tar oil yield obtained on the larger lead bath (iron retort) method are considered more reliable for the purposes of plant scale interpretation. The Gray-King method, however, is considered as adaptable for the laboratory assay of bituminous coals for which it was devised, but for typical Canadian non-coking coals, it would appear that the tar oil yields obtained by the Gray-King and similar small laboratory scale methods should be liberally discounted before proceeding to apply a general factor (60 or 70 per cent) in order to interpret laboratory yields in terms of commercial or plant scale recovery of dry (water-free) tar.

Section 2 shows the relation of caking index determinations by the "Gray" method made at the Fuel Research Laboratories and agglutinating values by the Marshall-Bird method made at the Pittsburgh Experiment Station of the United States Bureau of Mines on a series of fifteen standard coals and coal mixtures in comparison with their laboratory and plant scale coking properties. These comparative tests were mostly made subsequent to 1929, the results of which have been considered worthy of advancement to this publication, to supplement the results reported below by Mr. Nicolls on the caking indices of typical bituminous coals. The small laboratory scale coking properties were appraised by examination of the coke button formed in the ordinary volatile matter determination on one gramme of powdered coal, and the plant scale coking data from tests in the two-ton by-product oven at Ottawa. The commercial grading of the coke for domestic heating and metallurgical purposes from several of the standard coals and the relation of the quality of coke obtained in the oven in comparison with that made in the commercial plants from the same coal is shown.

The general conclusion arrived at was that for predicting commercial coking characteristics the caking indices by the Gray method and the agglutinating values by the Marshall-Bird method failed to show greater value than the judgment of the coking property afforded by examination of the coke button obtained in the usual volatile matter determination. Elaborate coke button grading is considered as apt to be a grade higher or lower than that of the by-product coke-oven coke from a given coal, and the coke button grading should be relied on only to indicate whether a coal is non-coking or may be expected to produce commercially a poor, a fair, or a good coke, that is, to show general coking properties of the coal examined.

Caking Indices of Typical Canadian Bituminous Coals: by J. H. H. Nicolls. This paper comprises the results of caking index experiments on bituminous coals from both Canada and the United States. The main objective of these experiments was to find a small-scale laboratory test for predicting the commercial coking propensities of coals to a better degree than obtainable by observing the coke button formed in the regular volatile matter determination in a platinum crucible. The caking index method followed, with minor variations, was that of Gray, using both sand and electrode carbon as inert material in varying proportions with the bituminous coals tested. In this method the caking index is the proportion of inert material (sand, carbon, etc.) that can be mixed with the coal under test to give a coke button that will support a definite weight without being crushed.

On the same coal sample separate consignments, first, of sand and then, of carbon material, were found to give different caking indices and preliminary leaching of the sand with acid was likely to give a different index. The differences between the results obtained with platinum and Illium crucibles were not great and since the latter vessels do not lose their shape nor corrode as badly as platinum, the use of Illium crucibles is recommended for caking index work.

Of special interest are the results obtained on 23 sections from top to bottom of a 7-foot section of the Phalen seam in the Sydney area, Nova Scotia. On these sectional samples the coking properties of which, as judged by the volatile matter coke button, ranged from poor to good, considerable variations in caking indices resulted, but no section had a sufficiently low index to remove it from the range covering "commercial" coking coals. Weathering in the open for periods up to a year caused a considerable reduction in caking indices of typical Nova Scotia and Pennsylvania bituminous coals, but in no case was this reduction sufficient to remove it from the range applying to coals that are suitable for the manufacture of coke when coked alone.

The most satisfactory index as judged by the known caking properties of the respective coals of Canada examined was the index at which the button would just support a 500-gramme weight, and sand was preferable to petroleum coke as the inert matter for the coals tested. However, for predicting commercial scale coking properties, proof is lacking that the caking index is superior to judgment afforded by examining the coke button produced in the determination of volatile matter.

Analyses of Coals and other Solid Fuels: Compiled by J. H. H. Nicolls and C. B. Mohr. This compilation is similar to that included in the annual reports of Investigations of Fuels and Fuel Testing since 1925. As in previous years it comprised three sections, the contents of each section being as follows:—

(a) Analyses of coal and peat native to Canada, originating as follows:

Nova Scotia	14 samples of coal
Ontario	1 sample of peat.
Saskatchewan	18 samples of lignite.
Alberta	63 samples of coal.
British Columbia	11 samples of coal.

(b) Analyses of coals submitted by the Department of Pensions and National Health. This section contains 62 reports of analyses, each analysis being the average of two or more samples of the same lot of coal, and in many cases a single analysis represents the coal from as many as six carloads. Sixty per cent of the total reported (i.e. 38 analyses) is for coals mined in Canada, the remainder being for coals imported from the United States. These analyses are for coals delivered to the hospitals operated by the department, and are important in that the price paid was adjusted for bonuses and penalties based on the variation of the moisture, ash and calorific values of the coal delivered from that guaranteed as "contract" grade.

(c) Analyses of miscellaneous solid fuels, comprising the following:

Bituminous (steam) coals from United States	13 samples
Scotch, Welsh, and American anthracites and semi-anthracites	8 "
Cokes, briquettes and miscellaneous	6 "

Gasoline Survey for 1929: by P. V. Rosewarne and H. McD. Chantler. This is the seventh annual analysis survey of the gasoline marketed in Canada, conducted by the Fuel Research Laboratories. By the hearty co-operation of the officials and inspectors of the Department of Health, 84 samples from 13 different cities were collected and sent in. As in the 1927 and 1928 surveys, the "unsaturates, aromatic, naphthene, and paraffin" contents of the gasolines were determined and reported in addition to the usual specific gravity, distillation range, index values, etc. The laboratory methods employed for the estimation of aromatics, naphthenes and paraffins, and some notes on the "significance of tests" are added. It is of interest to note that the gasoline sold during 1929 was of good quality and was again superior to that sold during the same period in the United States.

The Analysis of Natural Gas from the Turner Valley Field in Alberta: by P. V. Rosewarne and R. J. Offord. In addition to reporting the results of analyses by fractionation of 35 samples of Turner Valley natural gas and naphtha, this report compares the commercial (Smith) separators for removing the crude naphtha from the gas, advances a theory concerning the nature of the wetness of the gas, and comments on the possible utilization in the future of a greater part of the surplus or "waste" gas than practised to date.

The Podbielniak fractional distillation apparatus employed is fully described and the results obtainable compared with those by the Burrell gas analysis apparatus and the Oberfell charcoal absorption apparatus. For natural gas consisting mainly of methane and ethane, such as that in mains of the city of Edmonton, the relative amounts of these two constituents as shown by fractionating method and the Burrell method agreed within one per cent respectively. For the average raw and purified Turner Valley gases, and those refinery gases containing comparatively larger contents of hydrocarbons higher than methane, the Burrell method was proved to give quite erroneous results. In the case of a refinery "stabilizer" gas which showed 25 per cent methane and the remainder higher hydrocarbons by the fractionation method, the Burrell analysis indicated 80 per cent of ethane and higher hydrocarbons (that is, where these are calculated as ethane), this illustrates the uselessness of the Burrell method for this quality of gas. The average analysis for seven samples of purified Turner Valley natural gas from the Calgary city mains was 89·1 per cent methane, 5·5 per cent ethane, 3·2 per cent propane, 1·3 per cent butane, and 0·9 per cent pentanes and higher. Average analysis by the same method of a gas termed as "purified" gas at the refinery in the field, "raw and dry gas after separators" showed results corresponding closely with those just stated, that is, with methane contents in the neighbourhood of 90 per cent, the remaining 10 per cent being ethane and higher hydrocarbons. These results, which are considered as accurate and reliable, are at considerable variation with the analysis by the Burrell method of natural gas from this field, as published in former Mines Branch publications.

So-called "wet" gas from the pipe-lines before the separator failed to show the expected difference in composition from that of the dry and purified gas; in fact, the analysis of certain sets of wet and dry gases were practically identical, which was considered as proof that the "wet" gases collected for analysis contained in the vapour phase practically none of the commercial naphtha. Different methods of sample taking were tried but the net results remained the same. This led the authors to conclude that condensation of the higher hydrocarbons going to form the naphtha takes place at or near the bottom of the well as the gas issues from the limestone, which is considered the point of greatest refrigeration, and that the condensate so formed is carried mechanically in the liquid phase by the velocity of the residual gas, and that such a theory explains why an apparatus as simple as the "Smith" separator is able to recover the naphtha.

I

REPORT OF TESTS ON SYDNEY COAL IN THE ILLINGWORTH LOW-TEMPERATURE CARBONIZATION RETORT

R. A. Strong and E. J. Burrough

PREFACE

B. F. Haanel

Low-temperature carbonization of solid fuels in general has received so much publicity in recent years, and has so successfully attracted large amounts of capital, especially in Great Britain and other European countries, that many coal operators in Canada, who are looking for an extension of their markets, have been led to believe that the introduction of low-temperature carbonization on a comparatively large scale would solve many of their problems. This erroneous idea is fostered by the glowing statements regarding spectacular profits which can be secured through the recovery and refining of by-products. The fact that the oils produced in the course of carbonization at low temperature are of larger quantity and different composition than those resulting from the carbonization of bituminous coal at high temperature has also been seized upon by promoters as a method to attract capital for the promotion of several processes for which ridiculous claims were made regarding exceedingly valuable compounds which it was said such oils contain and which could be cheaply recovered and sold at a high market price. Much confusion also has arisen on account of the partial statements made by technical writers concerning the possible gross profits which can be obtained from the refined products obtained from the crude tar oils, and many processes which have been erected on a commercial scale for carbonizing solid fuels at low temperature have failed on account of the impossibility of realizing these profits and the consequent inability to pay dividends on the capital invested.

Low-temperature carbonization cannot be profitably introduced in every country or in every part of a country where coal exists. There are many economic factors which have to be taken into consideration, such as profitable market for the low-temperature coke, cost of raw fuel at plant, transportation cost of the finished and raw products, and disposal of tar oils and gas. An exceedingly important, and in most instances a governing, factor is the capital cost of plant per ton year output. Several of the many processes developed for carbonizing solid fuels at low temperature, although technically very attractive, cannot be successfully introduced on a commercial scale because of the high capital cost of plant per ton year output. This cost must be materially lower than that which obtains for a by-product recovery coking plant which carbonizes a solid fuel at high temperature, and the cost of operation and upkeep must be as low, or lower, than obtains for the former plant.

The information gained by the writer during his several trips of investigation, through the United States, Great Britain, and Europe, concerning low-temperature carbonization and other processes for treating coals, has given him the opportunity of judging the merits of the several processes which had been developed sufficiently far to enable their commercial possibilities to be predicted. One of the processes which he considered might, under favourable conditions, be introduced into Canada, is the Illingworth process and, in view of a special study of the Nova Scotia coal fields, which was made by the Division of Fuels and Fuel Testing, and other bodies, led him and other officers of the staff of the Fuel Research Laboratories at Ottawa to consider seriously the possibilities which the introduction of the Illingworth process, or a similar one, in the Sidney coal fields would offer for the solution of some of the difficult fuel problems with which that part of the country is faced.

The Department of Mines, at the request of the Dominion Coal Company, undertook in 1928, the revision of the geological sheets of the Sydney coal field, and made a study of the conditions of coal-seam deposition and sedimentation affecting the quality of coal reserves in that area. A large part of the reserves in this field lies under the sea and is, therefore, not capable of being prospected in advance of working by the usual borehole methods. The investigation included an exhaustive geological and chemical study which was embarked upon with the hope that the results obtained would serve as a guide for mine projection towards the most valuable portions of the enormous submarine coal reserves of this unique field and assist in the maintenance of uniformity in the quality of the output.

The Fuel Testing Division of the Mines Branch undertook the chemical portion of this investigation which included analyses of seam samples over the entire working face, laboratory investigation on by-product yields by carbonization both at high and low temperatures, and a study of the chemical nature of the mineral matter in the coal in various portions of the seam selected for this preliminary work. During the course of the investigation it became desirable to inquire into the commercial possibilities of treating certain of the coals mined in this field by low-temperature carbonization, especially those coals which possessed a higher sulphur content than typical of this field and which by reason of this fact were not considered suitable for by-product coke oven treatment.

The use of high-sulphur coal for the production of either metallurgical or domestic coke is extremely limited, owing to several important reasons. Generally speaking, metallurgical coke, by reason of its use in smelting operations, should not exceed 2 per cent sulphur, and must, therefore, be made from a coal containing not more than 2 per cent of sulphur. Domestic coke, on the contrary, may contain sulphur up to 3 per cent, without causing obnoxious odours during burning, and can, therefore, be satisfactorily produced from coals containing 3 per cent or less of sulphur. The production of the highest quality domestic coke has up to the present time been confined entirely to the by-product coke oven, and the capital cost of this type of installation renders it necessary to sell the gas in order to make a profit in operation. The use of high sulphur coals in the manufacture of gas in by-product coke ovens results in the production of hydrogen sulphide and organic sulphur compounds, the former being removable by the oxide process or the wet purification process, but the latter can only be reduced by benzol recovery. The recovery of benzol from the gas effects a reduction of about 50 per cent of the organic sulphur, and as a

3 per cent sulphur coal produces about 65 grammes of organic sulphur per hundred cubic feet of gas, a 50 per cent reduction will barely bring the quantity within the allowable limit, which is usually considered as 35 grains per 100 cubic feet.

The results of the test conducted at Pontypridd and the results of the tests on the coke sent to the Fuel Research Laboratories showed that by means of the Illingworth low-temperature carbonizing process a most remarkable fuel can be produced from Nova Scotia coal.

The coke made from a coal of low fusion point ash exhibits none of the undesirable characteristics of coke made from the same coal at high temperature; it does not clinker, but when burned in a domestic heating plant produces a coarse ash. This coke, moreover, possesses many of the desirable characteristics of Welsh anthracite, viz., it is free-burning and easily ignited. One other very important property is the small amount of fines produced in handling. All these points are recorded in detail in the following report which describes the results of a test on Nova Scotia coal in the experimental plant of the Illingworth Carbonization Company located at Pontypridd, South Wales.

Grateful acknowledgment is herewith made to the officers of the Dominion Coal Company for their co-operation in supplying the coal for the tests, and to the officers of the Illingworth Carbonization Company who spared no pains in obtaining all the data desired by the writers.

INTRODUCTION

The domestic market for fuel in central Canada offers an opportunity for the conversion of bituminous coal into a smokeless product which appears to be attractive. Until recently the demand for domestic fuel in this area was entirely satisfied by the importation of American anthracite, but in recent years the tendency has been to accept substitutes for this fuel. The fuels at present competing for the domestic market in central Canada are, in order of importance, American anthracite, coke, and Welsh anthracite. Statistics, as given by the Dominion Fuel Board, show that the imports of American anthracite in 1929 for Ontario and Quebec were 3,056,253 tons, and that coke consumed for domestic heating in that year was 1,206,000 tons, while imports of British anthracite amounted to 642,914 tons. It is, therefore, apparent that while American anthracite is still the standard fuel for domestic heating the public are willing to accept a fuel of equal quality. The ready acceptance of high-temperature coke by the public has led to an increased interest in the possibility of placing on the market a fuel manufactured from bituminous coal by means of low-temperature carbonization.

The officers of the Division of Fuels and Fuel Testing have kept in close touch with the developments of this new industry, and are convinced that the process developed by the Illingworth Carbonization Company offers economic possibilities for profit in certain favourable areas, inasmuch as the process is designed for the maximum production of a high density solid fuel residue. Since the capital costs are low, it is possible to operate solely for the production of coke without regard to the gas, the liquid by-products being saleable. This company for some years has operated a small test plant at Pontypridd, Wales, which was inspected by the Chief of the Division of Fuels and Fuel Testing, Mines Branch, and as a result of this inspection, he recommended that a Canadian coal be tested in this installation.

After a careful study of the economic conditions in Canada with respect to the establishment of a low-temperature carbonization industry by the engineers of the Fuel Research Laboratories it was decided that the Maritime Provinces offered the best site for the exploitation of this particular process. Consequently representations were made to the Dominion Coal Company to secure the necessary samples of coals for shipment to South Wales for the carrying out of the test. The company expressed itself as greatly interested in the possibilities of this process to extend their markets, and accordingly, samples of coal were selected and shipped to the Illingworth Company for test.

The objective of the tests was primarily to determine whether the Nova Scotia coal was amenable to low-temperature carbonization for the production of a dense, solid, smokeless fuel, the quantity of by-products obtainable, and the suitability of the fuel produced for Canadian conditions of house heating. To determine this the low-temperature coke produced was shipped to Ottawa, Canada, in order to measure the amount of breakage in transit, and form an opinion regarding its ability to withstand the handling required in the retail distribution of domestic fuel. Low temperature coke is a free-burning product and more nearly approximates Welsh anthracite than by-product coke or American anthracite, and it was, therefore, felt that burning tests on large quantities of the fuel should be made under standard Canadian conditions, in order to predict whether it would be successful in competition with the other standard domestic fuels now in use. The burning tests were made under the direction of the engineers of the Division of Fuels and Fuel Testing and carried out in standard equipment—as used in house heating in central Canada.

Another objective was to determine the quantity of organic sulphur formed. Laboratory experiments had indicated that the introduction of low-temperature carbonization in existing gas plants would solve the problem of the use of high-sulphur coals for the manufacture of city gas, and tests were made to demonstrate whether this indication would be confirmed in large-scale operation.

The successful application of low-temperature carbonization offers a great many possibilities in connexion with conditions existing in the Sydney coal field. The vast reserves of coal in this area are capable of a much greater annual output than is at present possible to market owing to the low prices and competitive conditions existing in the industrial coal market. However the conversion of a part of the output into a smokeless product permits competition with a high priced commodity, and immediately opens up an entirely new market. As the successful conversion of bituminous coal into a satisfactory smokeless domestic fuel depends on the quality of the fuel produced and its cost of conversion, these two factors have been borne in mind in the tests and are commented on in the text of this report.

DESCRIPTION OF PLANT AND TESTS ON SYDNEY COAL

The Illingworth system of carbonization is an outgrowth of the studies of coal constitution conducted by Dr. Roy Illingworth during his tenure of office as head of the chemical department of the South Wales and Monmouthshire School of Mines. As a result of researches he noted that the initial formation of coke was related to the decomposition of the resin-like compound known as the gamma constituent. This constituent of coal decomposes at approximately 450°C., and thus coke is formed at this or a little higher temperature. The porosity of coke is due to the evolution of volatile matter from the other coal constituents during the plastic stage. It was found that, if the gamma constituent does not exceed 10 per cent or fall below 5 per cent, it is possible to produce a residue which contracts at low temperatures and yields a dense hard coke. This is accomplished either by pre-treatment or blending.

An experimental plant built at the former gas works of the Pontypridd Urban Council in 1919 has been in operation for 2½ years and is capable of carbonizing 50 tons of coal per day. The retorts consist of vertical fireclay chambers in which are placed cast-iron conductors of H-section, which form a series of rectangular compartments, tapering from the top to the bottom. Each retort consists of 18 of these compartments which vary in size according to the type of coal treated, a smaller section being required for coals having a high caking index than that required for the more feebly caking coals.

The retorts are charged through tubular funnels which are attached to the charging larry, and an arrangement is provided for tamping during charging, in order to increase the coke density. The coal is stationary during the carbonization period, which usually occupies between 10 and 12 hours, and is discharged by means of specially designed balanced doors at the bottom of the retort. A distinctive feature of the retort is the provision for discharging the hot coke into a cylindrical drum which contains raw coal, the drum being revolved 5 times before being discharged. This operation serves a double purpose, in that it cools the coke without quenching and dries the coal which is to be charged. The coke is separated from the coal by screening, the breeze smaller than any desired size being left in the coal to reduce its swelling properties, thus making the blending operation an automatic one.

The retort is heated by means of horizontal flues in which producer gas, or the gas evolved from the coal being used, is burned. The cast-iron conductors allow a rapid transmission of heat to the charge both by conduction and by radiation, and the efficiency of this means is shown by the rapidity of carbonization. An elevation of the experimental retort is shown in Figure 1; Figure 2 being a sectional view of the same installation. Plates IA and IB show the charging-floor and the revolving drum for cooling the coke, respectively.

The fuel produced is black in colour, resembling coal rather than coke. It does not possess the porous appearance of high-temperature coke and is characterized by its high density, which is usually from 0·9 to 1·1, depending on the coal used and the method of operation. The temperature of the charge does not exceed 600°C. and the amount of volatile matter remaining in the coke is consistently between 7 and 8 per cent. It is claimed that the fuel is free-burning, capable of withstanding the necessary handling, and the ash does not cause excessive clinker trouble, even when coal containing a low-fusible ash is used. Plate IIA shows the fuel being discharged from the retort, and Plate IIB and Plate IIIA the fuel as sold for the market in England, while Plate IIIB shows blocks of the fuel made from Sydney coal during various runs.

Two shipments of coal, of 15 tons each, were made for test purposes, one lot being "as mined" and the other washed in Baum washers located at the steel mills of the British Empire Steel Corporation at Sydney. Both shipments were made in bags to eliminate possible mixing, and were opened in the presence of the official Mines Branch representative at the test. This official had been instructed to the effect that he should observe all tests; collect all necessary data, and to return to Canada all coke made, as well as 50 gallons of both tar and light oils for subsequent examination.

Eighteen tests in all were made, two of which were run through the 50-ton unit and from which no data on gas and by-products were obtained. The other 16 runs were made in a single retort attached to the plant, which is provided with a condensing train for the collection of tar. A gas meter was used for determining the volume of gas, the heat value being determined in a calorimeter. A small, wash oil unit was available for the absorption of light oils in the gas and a still was erected for the

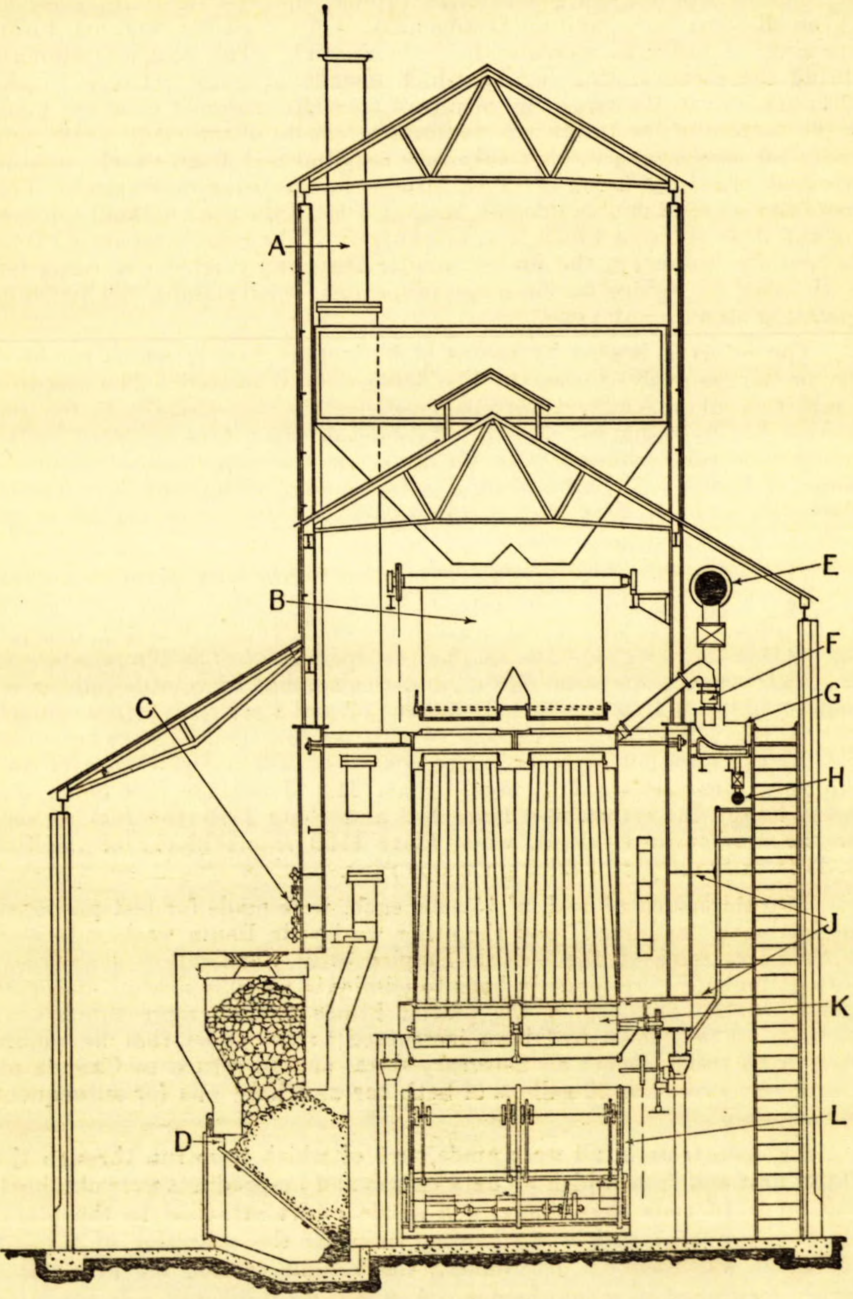

Figure 1. Elevation of installation (retorts heated by producer gas).

recovery of the motor spirit. Eight of the runs on which data were collected were made with washed coal and eight with unwashed coal, the average charge being slightly more than a ton in each case.

The primary consideration in the test was the quality of the fuel produced. Chemical analyses were made on both the coal and coke and in every case the density of the coke was determined. Variations in the method of charging, and blending with breeze, were tried in an effort to determine the necessary conditions for the production of a fuel of the maximum density possible. The yield of fuel was accurately measured; and a screen test was made of both coal and coke in every run, so as to determine the most suitable size for charging and the quantity of saleable fuel produced.

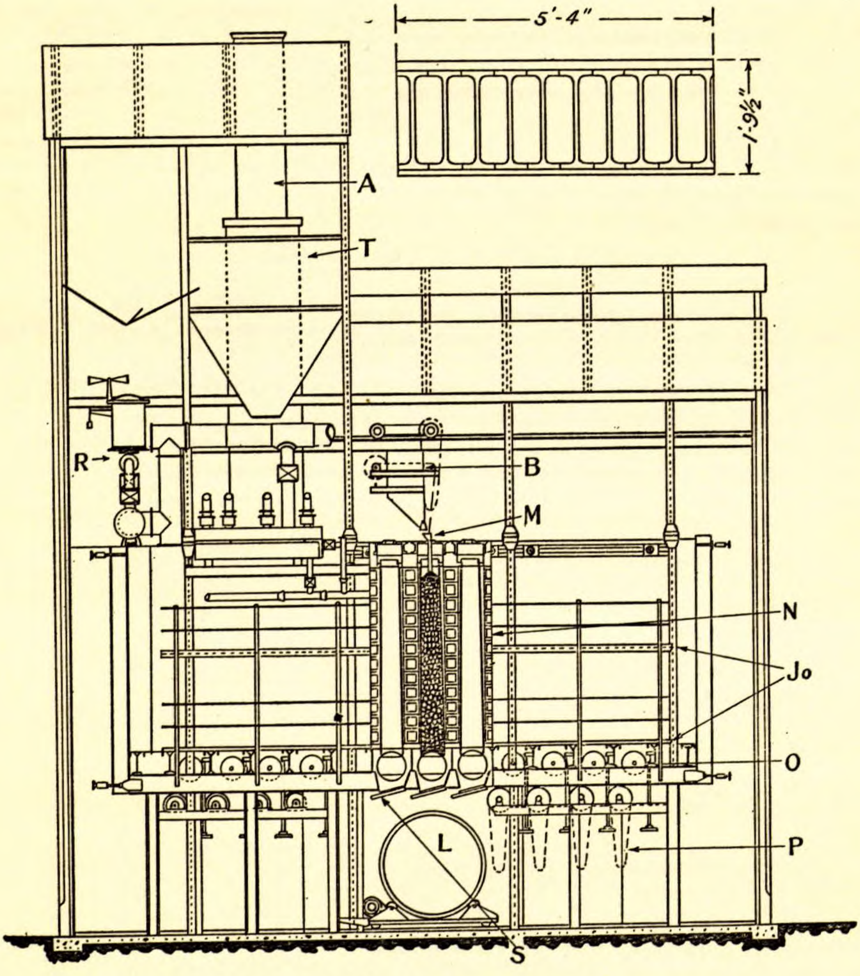

Figure 2. Sectional view of retorts.

The gas was measured and its light oil content determined, as well as the quantity of both organic and inorganic sulphur which it contained. The effect of oil scrubbing for light oils on reduction of organic sulphur in gas was also noted. The calorific value of the gas as obtained from each run was recorded.

The tar was collected at various points in the condensing train and its yield measured as accurately as a test of this size would permit. The water content was determined and several distillations made of typical samples in order to estimate the quantity of motor spirit available from the tar.

In addition to the above observations and tests, a log sheet of each run was made, showing temperatures of flues, retort walls, and of the charge itself.

At the conclusion of the tests the majority of the fuel produced was bagged and shipped to the Fuel Research Laboratories, where tests were carried out on friability and burning. The burning tests were made under normal conditions of firing in heaters, stoves, grates, and furnaces of the usual domestic types. In addition, 50 gallons of tar and 50 gallons of light oil were shipped to the Fuel Research Laboratories where further examination of them is to be made, which when completed will be published in a separate report.

DISCUSSION OF RESULTS

The results of the tests have been tabulated and are shown in the accompanying Tables I to IV. Table I gives a summary of the results and contains the analyses of the coal as charged, and of the coke obtained, as well as the quantity of gas, tar, light oils, and ammonia liquor; Table II contains the analysis of the gas and its heating value; Table III the distillation results of the tar; and Table IV is a résumé of general data including retort temperatures, method and particulars of charging, and a screen analysis of the coal as charged and the coke as discharged.

Coal

The coal as shipped was sampled after arrival in England and analysed in the laboratories of the Illingworth Carbonization Company, with the following results:

——	Washed	Unwashed
Moisture	4·9	3·4
Ash	4·1	9·8
Volatile matter	29·6	30·6
Fixed carbon	61·4	56·2
Sulphur	2·8	3·1

After sampling, the coal selected for each test was blended with the required amount of breeze and the mixture sampled before being charged in the retort. The results of these analyses for each test are shown in Table I.

Sydney coal is a strongly caking coal and apparently contains a large quantity of the gamma constituent referred to above. During distillation over the critical range of temperature it displays three, and sometimes four, distinct changes of state. This characteristic can be shown graphically by means of curves obtained by heating a column of coal progressively and measuring the resistance at various temperatures to the passage of an inert gas. Such a curve is shown in Figure 3 and was made on freshly mined lump coal from the Sydney field. The peaks represent the coal in

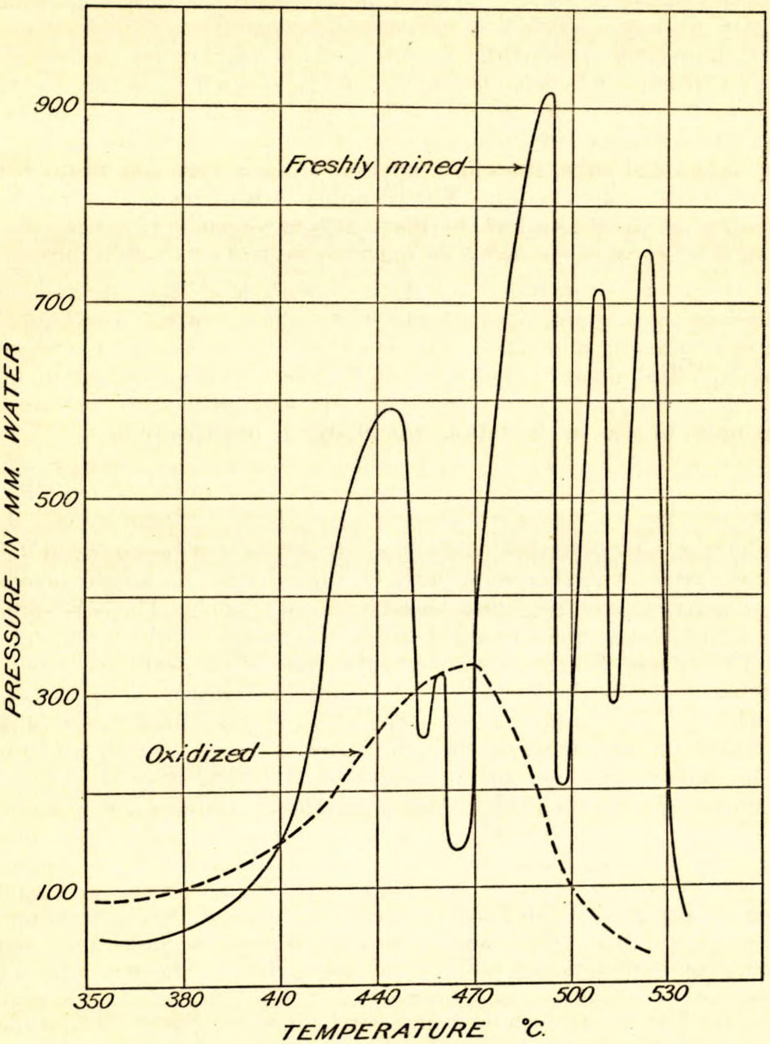

Figure 3. Plasticity curves

a fluid or plastic state offering resistance to gas passage, the valleys being a partial solidification of the mass in a porous condition which relieves pressure. It will be noted that with the particular sample used there exists four distinct physical changes over the critical range. The second curve represents the same coal after being preheated in an oxidizing atmosphere to a temperature of 255°C. The significance of this curve is that it shows that preheating accomplishes a partial destruction of the coking properties, which is desirable and necessary for the production of a dense coke at low temperatures. The method adopted by the Illingworth system of carbonization of preheating the charge by means of the heat of the discharged coke, therefore, appears to be a very significant feature with respect to coke density. The blending of the breeze with the charge also assists in smoothing out the plasticity curve, since it dilutes the coal with an inert substance which also partially destroys its coking properties.

It will be noted in the above analysis of the coal that the moisture in the washed coal is only about 5 per cent. This figure is very low for a wet washed product and can only be accounted for by reason of evaporation in transit. The moisture, however, in the coal is not an important factor, inasmuch as the drum acts as a dryer, and whether washed or unwashed coal is used, in regular operation, the charge is practically dry.

Coke

The coke as discharged, contained 10 per cent of breeze made from a previous run. This, therefore, must be taken from the weight of coke in order to arrive at a correct yield based on a ton of coal. The coke obtained was weighed and a screen analysis made, the results of which are shown in Table IV. These weights are also on the basis of the total discharge from the retort and must be corrected for the breeze content, as in the case of the yields. The average yield for the 16 runs was found to be 74·2 per cent, based on coal without the admixture of breeze, which amounts to 1,484 pounds of fuel per ton of coal charged. The discharge, however, will contain the breeze which, based on 10 per cent or 200 pounds per ton, will then become 1,684 pounds of residue for every 2,200 pounds of charge. The average analysis of this residue as shown in the tables will be 88·8 per cent over 2 inches; 8·2 per cent from 2 inches to ½ inch, and 3·0 per cent of breeze through ½ inch. The 3 per cent of breeze, or 50 pounds, will remain in the charge, and it will, therefore, be necessary to make up 150 pounds of breeze from the remaining fuel. The reduction of the oversize to a standard "egg" product will result in the production of a certain amount of fines below ½ inch, and for sake of safety in estimating saleable fuel, it is better to assume that the entire 150 pounds is obtained from this source. We will then have by means of the following calculation [(1,684 × 88·8%)—150] 1,346 pounds of egg fuel for sale, which is equal to 67·3 per cent of a ton of coal charged. The remaining fuel will be classed as nut (1 to ½ inch) and will amount to (1,684 × 8·2) 138 pounds or 6·9 per cent per ton of coal. Based on a ton of coke it will then be seen that 90·7 per cent can be sold as egg size fuel and 9·3 per cent as "nut".

The following table shows the average analysis of the fuel as discharged, together with its density and porosity.

Analysis	Washed	Unwashed
	%	%
Moisture	0·8	0·8
Ash	7·6	11·8
Volatile matter	8·0	8·0
Fixed carbon	83·6	79·4
Sulphur	2·4	2·5
B.T.U. per lb	13,702	13,277
True density	1·23	1·24
Apparent density	0·90	0·93
Porosity	26·7	24·9

It will be noted from the above that the volatile matter remaining in the coke is in close conformity to the claims of the company, as stated previously. The quantity as shown indicated a smokeless product which will compare with anthracite, inasmuch as American anthracite contains 6 per cent of volatile matter and Welsh anthracite between 8 and 9 per cent. The ash is not excessive, even with an unwashed product, and while it is better to keep the ash below 10 per cent, the average of 11·8 as obtained with the unwashed coal, is superior to the average American anthracite on the market.

The apparent density figures are of especial interest. It will be noted that an average density of 0·90 was obtained from washed and 0·93 from unwashed coal. Reference to Table IV shows that the method of charging has a considerable bearing on the density, in that a density of 0·96 was obtained by tamping the charge during the charging period. It might also be noted that blending a greater quantity of breeze than 10 per cent did not materially increase the density, but the writers venture to predict that crushing the charge to smaller sizes will effect a greater density, inasmuch as greater oxidation will take place during the period when the coal and hot coke are in contact in the revolving drum.

The densities obtained show great promise for this fuel when a comparison is made with the densities of by-product coke.

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

In the above table[1] it will be noted that the low-temperature coke produced in these tests is equal to the average of all samples of by-product coke tested and is superior to the average figure for by-product coke made from this same coal.

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[1] Investigations of Fuels and Fuel Testing, 1925, page 17.

The porosity[1] value is also of interest in that it indicates the cellular space in the coke. A spongy type of coke is usually difficult to control in the furnace as the rate of combustion is proportional to the porosity, other factors being equal. Porosity is also a measure of strength and in this connexion it might be noted that by-product coke made from 100 per cent Sydney coal showed a porosity of 48·7 per cent, as compared to approximately 25 per cent for the low-temperature product.

Handling Qualities of Coke. The ability of a fuel to withstand the handling necessary in marketing is a most important requisite, and in order to obtain definite data on this feature, it was decided to screen the fuel as discharged from the ovens over a 1-inch screen, bag the screened fuel and ship to the Fuel Research Laboratories at Ottawa where a representative sample would be examined for breakage. Such a journey involved the shipping of the bagged fuel to the docks at Cardiff, Wales, loading on board ship, unloading at Montreal, shipment by rail to Ottawa, and truck transportation to the Fuel Research Laboratories. A journey of this nature was considered at least comparable to the ordinary handling necessary in the retail distribution of domestic fuels.

Two complete runs were used in determining the quantity of degradation resulting from shipment, involving a total quantity of 2,700 pounds of coke. The breakage, through one inch, averaged 5·3 per cent for the two tests half of which was breeze, the remainder being saleable. A screen analysis of the material through one inch was as follows:

On ½	35·7 per cent	= Nut coke
On ¼	14·3 per cent	= Pea coke
On 10 mesh	14·3 per cent	= Breeze
Through 10 mesh	35·7 per cent	

The results of a shatter test were equally encouraging. In this test 50 pounds of fuel screened over a 2-inch screen is given four drops of six feet onto a metal plate, the fuel being then rescreened and the quantity remaining on a 2-inch screen expressed as percentage is the shatter index. This is a standard American Society for Testing Materials test which is used in the high-temperature coke industry to indicate friability and is, therefore, a medium of comparison. The results of this test were as follows:

	Per cent
Washed	82·5
Unwashed	84·5

The excellence of the above results may be judged by comparing them with those for high-temperature coke. A sample of by-product oven foundry coke made from Sydney coal tested in the Fuel Research Laboratories[2] had a shatter index of 67·5 per cent, and a shatter index of from 70 to 75 for by-product oven coke for domestic use is considered an average figure. The reason for the higher results obtained with low-temperature Illingworth coke, or "Ricoal" as it is called, is possibly due to its homogeneous structure as compared to the cleavage planes existing in high-temperature coke which are the cause of breakage when dropped.

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[1] Percentage porosity is determined from the formula:

$$\frac{\text{True density} - \text{Apparent density}}{\text{True density}} \times 100$$

[2] Investigations of Fuels and Fuel Testing, 1925, page 17.

General Burning Qualities.—Burning tests on Ricoal from Sydney coal were made by C. E. Baltzer of the Fuel Research Laboratories. A quantity of mixed size (egg, stove, and nut, larger sizes predominating) Ricoal was burned, (1) under banked or low load conditions with furnace draughts closed tight, and (2) at the highest combustion rate obtainable with furnace draughts wide open. The furnace used for these two tests was a No. 9 Gurney round hot-water boiler which was in use for heating the building formerly occupied by the Fuel Testing Laboratory. This furnace was quite old and not in the best state of repair, the setting being rather leaky which did not permit of close control under banked conditions. The object in conducting the test under banked conditions was to obtain an idea of the lasting and control properties of the fuel bed, while the test at the highest rate of burning was made to determine if troublesome clinkers would result.

(1) Two tests were made under banked conditions, the fuel bed lasting for a period of 16 hours in both cases. The time was taken from the moment the fire was banked with all the Sydney Ricoal the fire-pot would hold, to such a time as just sufficient live fuel remained on the grates to ignite a fresh charge of the fuel. The duration of this test would indicate that the fuel has fair lasting qualities and it was apparent that this result would have been better had the furnace been in better condition, allowing of proper fire control. Observations of the burning fuel indicated that the combustion rate was too high for banked conditions, which resulted partly from the leaky condition of the furnace and partly from the free-burning characteristics of the Ricoal.

(2) Approximately 1,000 pounds of fuel was burned at the highest combustion rate obtainable with the furnace and at the end of the test the refuse was examined. Five or six clinkers from 12 to 15 inches in diameter were found on the grate, which were heavy and dense but very friable. This type of clinker should give no serious trouble in operation and the quantity was decidedly small. The ash was of a reddish brown colour, more gritty and not so light or flocculent as the ash from high-temperature coke. This test was eminently satisfactory in view of the high rate of burning. The test lasted 24 hours and based on grate area 10 pounds of coal per square foot per hour was burned. On a basis of 60 per cent efficiency, this would amount to 300,000 B.T.U. per hour radiated, or more than twice the amount considered as high rate of burning in domestic heating[1]. The small amount of clinker formed indicates that with normal heating loads practically no clinker would result, which may be considered as remarkable in view of the fact that the unwashed fuel was used and that the ash fusing point is around 2,000°F.

This characteristic of coke made at low temperatures from low fusion ash coals has been noted by other experimenters. A possible explanation of this phenomenon is that the fuel being free-burning, no localized overheating occurs which is usually the case with fuels of lower reactivity.

Another test was carried out in a small, domestic hot-air furnace. This furnace has an 18-inch diameter grate, is in a good state of repair and is fitted with thermostatic draught control. Ideal combustion

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[1] "Comparative Tests of Various Fuels when Burned in a Domestic Hot Water Boiler;" Mines Branch, Dept. of Mines, Canada, No. 705, p. 60.

control is obtained with this installation using either gas coke or by-product coke. A quantity of the Sydney Ricoal in two sizes, (1) mixed (egg, stove, and nut, larger sizes predominating) as above and (2) nut (through 1-inch and over ½-inch mesh screens), was burned under banked conditions. The banked fire with the mixed Ricoal lasted for a period of 27 hours measured from the time the fire was banked with all the fire-pot would hold to the time when just sufficient live fuel remained on the grates to ignite a fresh charge. The nut Ricoal which was fired in the same way as the mixed lasted for a period of approximately 18 hours. The duration of these tests would indicate that the larger size of Ricoal has good lasting qualities, whereas the nut size has only fair lasting qualities when burned in this type of heater. It may be inferred from these tests that unlike high-temperature coke better combustion control can be obtained by using the larger size of Ricoal which is accounted for by the free-burning nature of the fuel.

Several tests were also made in open grates and in all cases the observers agreed that the fuel was highly suitable for this purpose. The suitability of the fuel for use in a Quebec heater was also tried and was found to be very satisfactory the fire having lasted 27 hours with one filling of the magazine.

In order to further test the clinker-forming tendencies of the fuel a trial was made in a small vertical tube boiler of 6 h.p. This equipment was operated at 150 per cent rating which required the burning of 75 pounds of fuel per hour. After 7 hours of burning at this high rate a clinker had formed which covered the grate but it was found to be very friable and in no greater quantity than that obtained from the use of high-fusion ash fuel.

As a result of both the handling and burning tests it may be stated that Ricoal made from Sydney coal is a hard, dense fuel and will apparently withstand all the handling required without excess degradation. From observations on its burning properties, it may be said that it is similar to the free-burning Welsh coal, although not quite so easily controlled. It is easily ignited and when once burning freely, it will burn itself completely out with all the draughts closed. No clinker troubles will be experienced under normal operation in the ordinary heating appliance. The ash is not soft and flocculent as from high-temperature coke, but coarse and sandy and will, therefore, cause no dust nuisance. Ricoal produces a hot radiant fire which ignites with a long yellow flame and it can be controlled to the extent of lasting for 27 hours in the ordinary domestic furnace.

There does not appear to be any reason why this fuel should not be entirely successful in the domestic market as it possesses many superior qualities as outlined above. The only questionable feature which the writers have been able to discover is that the fuel may be too free-burning. It is believed, however, that this is not an objection and that increased control can be obtained by banking with ashes. It is also considered that this feature is possible of regulation in the manufacture of the fuel and that with slight changes in retort design the density could be increased and the reactivity lessened.

Gas

The quantity of gas obtained for the various tests is shown in Table I, and its analysis in Table II. It will be noted that the results vary considerably in the different runs. This is accounted for by the fact that the exhauster used in the test plant is under capacity which results in some cases in gas loss. While there appear to be wide variations in the different tests the average figures would seem to be about what might be expected. The washed coal gave an average yield of 6,050 cubic feet of 707 B.T.U. gas, while the yield from the unwashed coal was 4,910 cubic feet of 695 B.T.U. gas.

The main purpose in low-temperature carbonization, generally, is the production of a solid smokeless fuel, and it is not usually desired to produce large quantities of gas. The heat requirements of the retort are in the vicinity of 3,500 cubic feet, which leaves between 1,500 and 2,500 cubic feet of gas for other purposes. In a plant located at a mine this excess can be used in the power plant and its quantity is more than sufficient to supply all the power requirements of the process. If the process were used, however, in conjunction with an existing gas plant the retorts would then be heated with producer gas and a portion of the solid fuel would be used for making this gas. It would also be desirable to dilute the gas with a gas having lower heat value for distribution, and in this manner its potential volume would be materially increased.

Tar, Light Oils, and Liquor

The yields of tar in Imperial gallons per ton of coal charged are shown in Table I. The same comment made with respect to the gas applies to the tar, and in commercial operation the figures shown would in all probability be increased. However, the error is on the side of conservatism, which is decidedly preferable. The average tar yield from washed coal was 13·9 gallons which contained an average of 5·5 per cent of water, and from unwashed coal 13·4 gallons with 6·4 per cent of water. The tar has a gravity of 1·043 to 1·044, is fluid, and does not readily emulsify with water; it will, therefore, present no difficulties in dehydration. Several samples of the tar were distilled and the results are shown in Table III. The fraction 0-200°C can be considered as crude light oil, and in plant operation it would probably pay to top the tar and join the distillate to the crude light oil recovered from the gas before refining. The remainder of the tar can only be considered as a fuel oil and will in all probability be worth about 5 cents per gallon. In favoured localities it might be possible to obtain 7 cents but the former figure is probably a more correct evaluation.

The light oils in the gas were absorbed in creosote oil but the quantity per ton was only determined in the laboratory on six runs. In the case of the remaining runs the benzolized oil was sent to a still and the crude spirit recovered for shipment. The average quantity as determined was found to be 2·8 Imperial gallons per ton. An additional 1·4 gallons is available from the tar which will make a total of 4·2 gallons per ton of coal. Light oils obtained by low-temperature carbonization are rather high in unsaturated compounds and the refining loss will be at least 30 per cent, so that for basis of estimate the total refined light oils available as motor spirit can be taken as 3 gallons per ton of coal charged, which may be evaluated at the current prices for gasoline.

The quantity of ammoniacal liquor obtained from each run is shown in Table I, and it will be noted that the variation is from 4·1 to 8·5 gallons per ton. The temperature employed in low-temperature carbonization is not sufficiently high for the production of ammonium sulphate in quantity, and as a consequence it is not customary to consider its recovery. Tests indicate that the quantity produced with Sydney coal by low-temperature carbonization is between 7 and 8 pounds per ton. This is a favourable consideration rather than otherwise, owing to the market for ammonium sulphate having been materially affected by the production of the synthetic fertilizers.

Sulphur

Where the manufacture of town gas is in question the sulphur content of a coal is important owing to its bearing on purification costs. Sulphur in coal is usually considered to be present in four different forms known as resinic, humic, pyritic, and sulphate. In the destructive distillation of coal it is generally conceded that the resinic sulphur remains in the coke, the humic and pyritic are partly volatilized, and the sulphate remains in the coke but in an altered state. The distribution of sulphur in high-temperature carbonization varies with the method used but is roughly as follows:

25 to 45 per cent in the gas or liquor.
59 to 73 per cent in the coke.
1·5 to 4 per cent in the tar.

The sulphur in the gas is present in two forms, viz. inorganic and organic. The former is present as hydrogen sulphide and the latter as carbon sulphur compounds. These are probably the result of secondary reactions and are formed by the association of hydrogen sulphide with hot carbon.

It was assumed that the temperatures employed in low-temperature carbonization were not sufficiently high to produce the secondary reaction mentioned and that the gas obtained by this method would contain more hydrogen sulphide and less organic sulphur than was usual in the high-temperature process. Tests were, therefore, made on the gas for its sulphur content with the following results: Organic sulphur in the gas from a number of tests was found to be 35 grains per 100 cubic feet. The gas volume, as stated above, averages approximately 50 per cent of that obtained by the high-temperature process, and this amount would, therefore, represent an equivalent of 17 grains per 100 cubic feet in high-temperature gas. As previously stated, the organic sulphur from a 3 per cent sulphur coal in by-product ovens is 65 grains; on this basis, therefore, the reduction may be considered 74 per cent of the total organic sulphur.

The hydrogen sulphide was found to be very much lower than was expected but this is explained by the fact that a large quantity of this compound is absorbed by the liquor to form ammonium sulphide. In the high-temperature process where the direct method of ammonia recovery is used the hydrogen sulphide is distilled off with the ammonia from the liquor and is added to the gas. It must later be removed by iron oxide or sodium carbonate. In the low-temperature process, however, where the liquor is run to waste the sulphur content in the gas will only represent that amount which has not been absorbed, and its removal, where necessary, does not present any problem.

The recovery of light oils from the gas by oil washing effects a reduction of the organic sulphur, and in ordinary practice this will be about 50 per cent. Tests were made to determine if this was equally true with low-temperature gas, and it was found that the original 35 grains was reduced to 20 grains.

The quantity of sulphur remaining in the coke based on percentages is usually equal to that in the coal when high temperatures are employed. In low-temperature carbonization, however, partly owing to a higher yield of solid residue, and partly owing to the reaction of sulphur with hot carbon not taking place, the quantity of sulphur in the coke is less than the percentage in the coal from which it is made. In Table I is shown the sulphur in the coal, as well as the coke, and it will be noted that the reduction amounts to between 0·4 and 0·6 per cent, which on a basis of percentage reduction would amount to between 15 and 20 per cent. The importance of this fact when dealing with high sulphur coal is sufficiently apparent without further comment.

SUMMARY AND CONCLUSIONS

The result of processing Sydney coal in the Illingworth Test Plant at Pontypridd, South Wales, may be said to have (1) confirmed the claims of the company for their process, and (2) shown that Sydney coal is suitable for this method of carbonization. The fuel produced is hard and dense, and preliminary tests indicate that it will be entirely suitable for Canadian conditions of house heating.

The success of a plant of this description depends, as far as Canada is concerned, on certain economic considerations, such as location of plant, cost of plant, conversion costs, and markets. In the opinion of the writers the greatest possibility of success with this process would be its installation at a mine, where the raw material is at its lowest cost, provided that the available markets for the product were within reasonable freight hauls. Such conditions appear to exist in Nova Scotia.

The Illingworth Carbonization Company claims a cost for plant of 15 shillings per ton, but for Canadian conditions it might be safer to select a figure of $4.00 per ton year. On the basis of a 1,000 ton per day plant the capital cost would be approximately $1,500,000. In a new process of this kind it will be necessary to allow a rather high depreciation figure and Dr. Illingworth suggests 15 per cent as reasonable. The cost of capital may be estimated as 5 per cent, making a total of 20 per cent fixed charges. The cost of labour may be taken as $1.25 per ton of coal, and as this figure is approximately what may be expected in the way of return from the by-products, as shown above, it may be taken that the labour cost will be balanced by the by-products.

The yield of coke, according to the figures previously shown, is roughly 74 per cent, or on the basis of a 1,000-ton plant, 270,000 tons of coke per annum. This coke, therefore, will have to bear the cost of capital return, which on this yield would be $1.10 cents per ton (1,500,000 × 20 ÷ 270,000). The average transportation costs to market in the case of a plant located in Nova Scotia may be assumed at $1.50 per ton, which added to the conversion cost equals ($1.10 + $1.50) $2.60 per ton. Allowing $8.50 as the average wholesale selling price of a ton of coke, the value of the coal at the plant required for a ton of coke then would be ($8.50 − $2.60) $5.90. On the basis of a 74 per cent yield of saleable fuel it can readily be seen that the maximum price per ton which it is possible to pay will be ($5.90 × 0·74) $4.37. Profits then depend on coal costs below this figure, if the above figures are applicable.

In conclusion, it might be stated that it appears to the writers that in the case of the Sydney coal field there is an exceedingly good chance of converting bituminous coal into a domestic product, comparable to the existing fuels used for heating in central Canada, economically. The advantage of a market for 1,000 tons of coal per day, in addition to the present output, is obvious and requires no further comment.

TABLE I

Summary of Results: Low-Temperature Carbonization Tests on Sydney Coal

(Yields per 2,000 lb. of coal as charged)

Coal	Washed	Washed	Washed	Washed	Washed	Washed	Washed	Washed	Not Washed	Not Washed	Not Washed	Not Washed	Not Washed	Not Washed	Not Washed	Not Washed
Run No.	1	2	2	4	14	16	17	18	5	6	7	9	10	11	12	15
Coal Analysis (as charged)—																
Moisture	1·9	2·1	1·8	1·7	1·9	1·5	1·8	1·4	2·1	1·8	1·9	1·5	1·4	1·3	1·6	2·0
Ash	5·9	6·9	5·2	6·0	5·5	5·1	5·5	5·6	9·7	9·8	9·6	9·4	9·7	9·8	9·7	9·6
Volatile matter	27·1	27·9	27·6	26·2	26·2	27·9	28·4	28·3	26·2	26·8	25·1	27·8	26·1	26·0	25·5	26·5
Fixed carbon	65·1	63·1	65·4	66·1	66·4	65·5	64·3	64·7	62·0	61·6	63·4	61·3	62·8	62·9	63·2	61·9
Sulphur	2·6	2·8	2·8	2·8	2·8	2·8	2·8	2·8	3·0	3·0	3·0	3·0	3·0	3·0	3·0	3·0
Coke Analysis—																
Moisture	0·6	0·7	1·2	1·1	0·8	0·9	0·6	0·7	0·7	0·8	0·9	0·7	0·8	1·0	0·7	0·7
Ash	7·9	7·6	7·8	7·9	7·6	7·4	7·4	6·9	11·8	11·7	11·9	11·5	11·9	11·9	11·9	11·6
Volatile matter	7·4	8·1	7·5	7·9	8·2	8·2	8·2	8·4	8·0	7·7	7·9	8·7	8·4	7·9	8·1	7·9
Fixed carbon	84·1	83·6	83·5	83·1	83·4	83·5	83·8	84·0	79·5	79·8	79·3	79·1	78·9	79·2	79·3	79·8
Sulphur	2·5	2·3	2·3	2·4	2·3	2·4	2·4	2·4	2·5	2·6	2·5	2·5	2·4	2·5	2·4	2·4
B.T.U. per lb	13,310	13,950	13,565	13,720	13,860	13,810	13,760	13,644	13,110	13,200	13,060	13,210	13,360	13,115	13,312	13,850
Gas—																
Cubic feet per ton	5,560	5,080	5,720	6,350	5,740	6,335	7,340	6,280	4,720	3,840	3,345	5,010	4,990	6,055	6,160	5,170
B.T.U. per cu. ft (determined)—Density (air =1)	730	690	700	700	700	710	720	715	695	690	700	710	685	700	720	690
Tar—																
Imperial gallon per ton	13·7	13·7	14·1	14·5	12·9	13·7	13·9	14·2	13·9	13·4	13·2	13·9	13·3	13·0	12·9	13·6
Light oils—																
Imperial gallon per ton	2·7	....	3·1	....	....	2·8	....	....	....	....	....	2·7	2·8	....	....	2·7
Liquor—																
Imperial gallon per ton	4·7	4·1	5·8	8·0	6·7	6·1	7·9	7·3	7·0	5·8	5·8	6·9	4·9	6·2	5·7	8·5

TABLE II

Analyses of Gases: Low-Temperature Carbonization Tests on Sydney Coal

Run No.	1	2	3	9	10	15	16
Density (Air = 1)	0·58	0·57	0·57	0·57	0·57	0·53	0·53
Carbon dioxide	4·5	5·1	4·0	4·2	3·3	4·2	2·3
Illuminants	2·9	1·9	1·5	1·2	3·1	3·6	2·4
Oxygen	1·1	1·1	1·2	1·0	0·8	0·6	0·8
Carbon monoxide	4·6	4·2	5·0	5·2	4·6	2·2	3·4
Hydrogen	20·2	20·5	20·1	20·1	22·5	25·4	24·0
Methane	57·1	57·1	58·0	57·5	53·1	56·2	57·8
Nitrogen	9·6	10·1	10·2	10·8	12·6	7·8	9·3
B.T.U. per cu. ft.—Determined	730	690	700	710	685	690	710

TABLE III

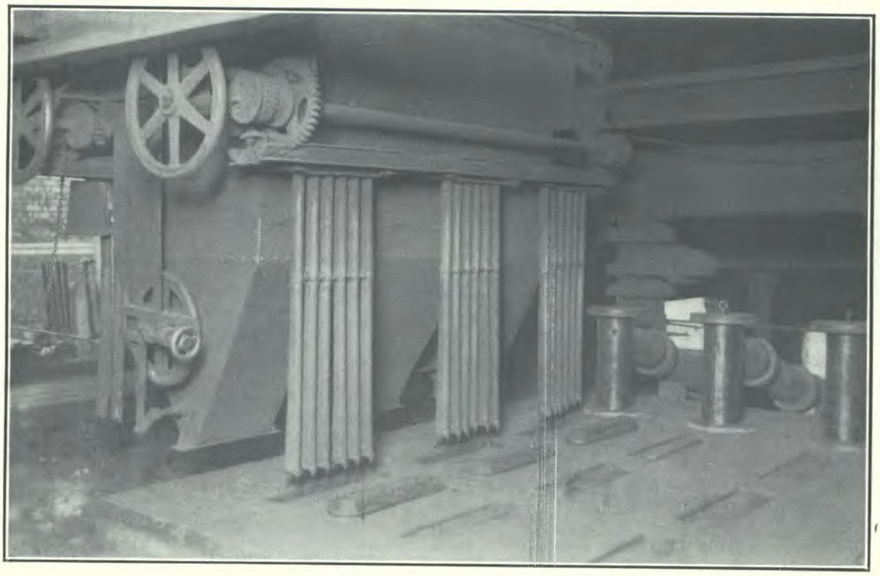
Analyses of Tars: Low-Temperature Carbonization Tests on Sydney Coal

Run No.	1		3		6		9		10		15		16	
Fraction	% Vol.	Cum. %	% Vol.	Cum. %	% Vol.	Cum. %	% Vol.	Cum. %	% Vol.	Cum. %	% Vol.	Cum. %	% Vol.	Cum. %
H_2O	8·0	dry	3·0	dry	6·0	dry	5·0	dry	6·7	dry	6·4	dry	6·1	dry
0–170°C	10·0	10·9	10·4	10·7	10·8	11·5	11·4	12·0	10·9	11·7	10·6	11·3	10·4	11·1
170–200°C	9·0	20·7	9·8	20·8	9·5	21·6	10·1	22·6	9·8	22·2	9·6	21·6	9·5	21·2
200–230°C	12·5	34·3	11·1	32·2	12·2	34·6	9·7	32·8	12·4	35·5	11·4	33·8	11·5	33·5
230–260°C	14·0	49·5	10·3	42·8	11·1	46·4	11·2	44·6	11·7	48·0	12·2	46·8	12·6	46·8
260–290°C	6·0	56·0	12·1	55·3	11·4	58·5	12·1	67·3	10·2	58·9	10·3	57·8	9·3	56·7
290–320°C	9·5	66·3	10·3	65·9	9·8	68·9	8·9	76·7	9·4	69·0	8·2	66·6	9·4	66·7
320–350°C	11·5	78·8	10·2	76·4	12·2	81·9	12·6	90·0	9·2	78·9	10·3	77·6	10·2	77·6
350–400°C	10·5	90·2	11·4	88·2	6·0	88·3	7·2	97·6	8·4	87·9	10·8	89·1	11·6	90·0
Pitch by difference	9·0	100·0	11·4	100·0	11·0	100·0	11·8	100·0	11·3	100·0	10·2	100·0	9·4	100·0
Specific gravity of tar	1·044		1·044		1·043		1·043		1·042		1·044			

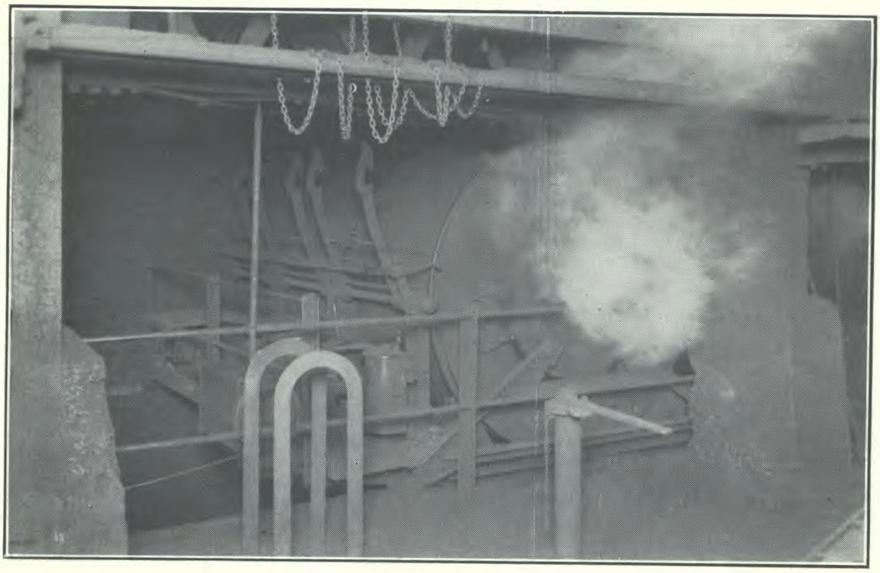
TABLE IV

General Data Table

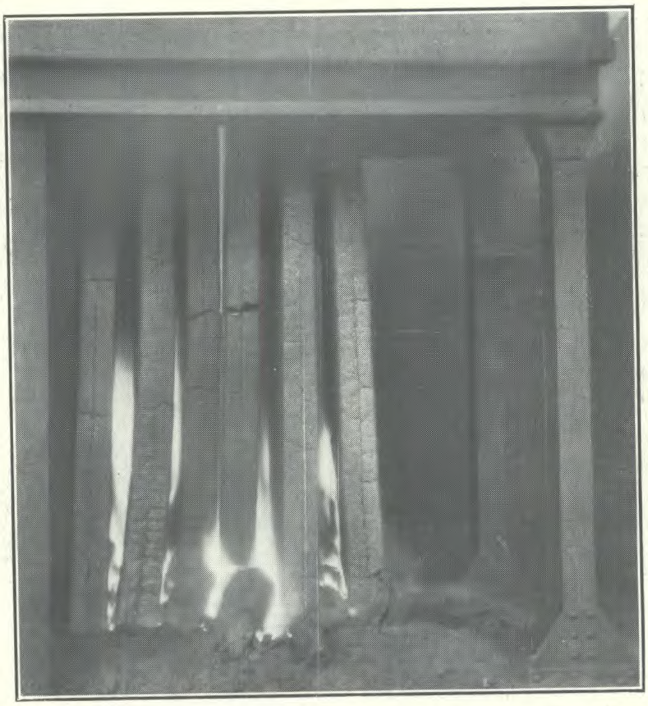
Run No.	Temp. of retort walls		Method of charging	Particulars of charge	Screen Analyses									Apparent density
					Coal as charged					Coke as discharged				
	In	Out			On ½" Per cent	On ¼" Per cent	On ⅛" Per cent	On 1/20" Per cent	Thru 1/20" Per cent	On 2" Per cent	On 1" Per cent	On ½" Per cent	Thru ½" Per cent	
1	600°C.	620°C.	Tapped	10% Breeze (ground)...	....	....	12	72	16	85·3	4·4	6·3	4·0	0·89
2	600°C.	600°C.	“	10% “ “ ..	....	11	19	67	12	88·0	3·6	4·7	3·7	0·91
3	600°C.	600°C.	“	10% “ “ ..	....	13	24	56	7	88·0	3·6	8·4	....	0·90
4	590°C.	590°C.	“	20% “ “ ..	....	12	22	58	8	90·3	1·7	4·4	3·6	0·90
5	600°C.	600°C.	Loose	10% Breeze (as rec'd)..	16	12	26	41	5	82·3	7·6	5·4	4·7	0·91
6	610°C.	620°C.	Tapped	10% “ “ ..	15	13	26	40	6	83·9	3·4	5·9	6·8	0·96
7	600°C.	600°C.	“	10% “ “ ..	16	13	23	42	6	78·0	6·0	9·8	6·2	0·96
9	600°C.	610°C.	Loose	10% Breeze (ground)...	....	13	26	52	9	91·5	4·4	3·5	0·6	0·90
10	620°C.	620°C.	“	10% “ “ ..	....	15	23	56	6	89·8	2·2	4·0	4·0	0·91
11	600°C.	600°C.	Tapped	10% “ “ ..	....	15	27	51	7	90·1	2·0	4·0	3·9	0·96
12	600°C.	600°C.	Loose	10% “ “ ..	....	14	18	58	10	91·7	2·5	2·9	2·9	0·92
14	620°C.	590°C.	“	10% “ “ ..	....	10	18	60	12	90·8	3·2	3·0	3·0	0·91
15	600°C.	610°C.	“	10% “ “ ..	....	10	19	60	11	90·1	2·9	4·3	2·7	0·92
16	600°C.	600°C.	“	10% “ “ ..	....	9	19	60	12	91·2	3·4	3·8	1·6	0·90
17	600°C.	600°C.	“	10% “ “ ..	....	8	18	61	13	94·9	2·8	2·3	....	0·90
18	600°C.	600°C.	“	10% “ “ ..	....	8	22	66	11	95·5	1·8	2·7	....	0·91



A. Charging-floor, Illingworth carbonization retort.



B. Revolving drum for cooling coke, Illingworth carbonization retort.

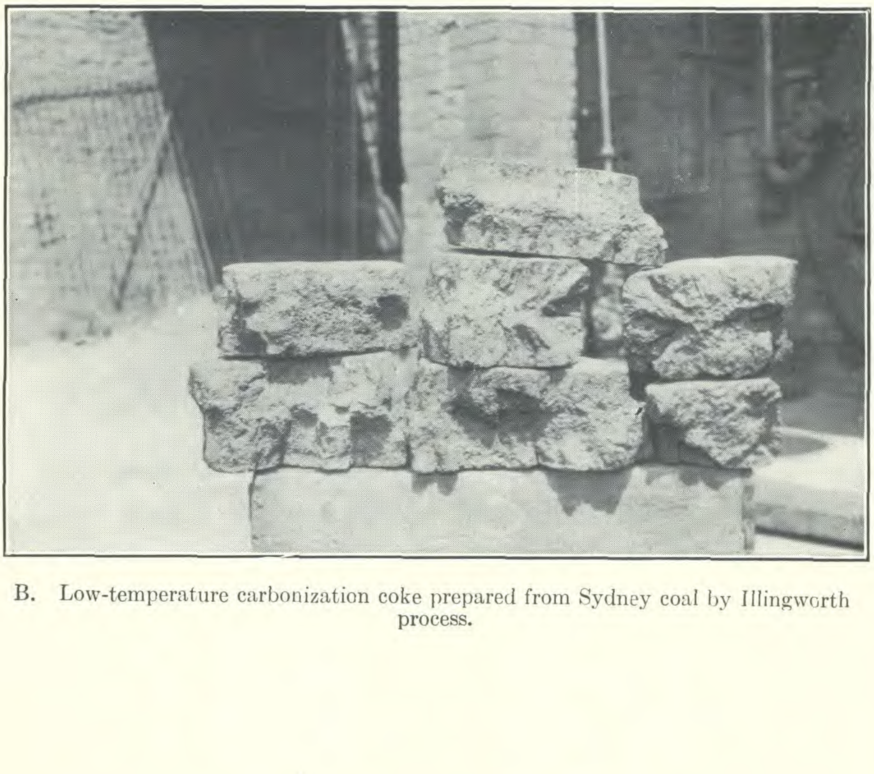


A. Fuel discharging from retort.

B. Low-temperature carbonization coke by Illingworth process as sold on English market

PLATE III

A. Low-temperature carbonization coke by Illingworth process as sold on English market.



B. Low-temperature carbonization coke prepared from Sydney coal by Illingworth process.

II

NOTES ON METHODS FOR THE LABORATORY ASSAY OF COALS FOR CARBONIZATION AND COKING PROPERTIES

R. E. Gilmore

I.—COMPARISON OF LOW-TEMPERATURE CARBONIZATION RESULTS BY THE "LEAD BATH" AND THE GRAY-KING METHODS

Up to 1929 low-temperature carbonization assays in these laboratories were conducted on a 4- to 6-pound scale in an iron retort immersed in a lead bath heated electrically to the desired temperature. This method, known as the "lead bath" method, was described in detail in Summary Report of the Department of Mines for 1918, and modifications of the method with illustrations in subsequent Investigations of Fuels and Fuel Testing.[1] Preliminary work on the comparison of the results obtained by this method with those obtained by the Gray-King[2] method as adopted at the British Fuel Research Station were made and published[3] in 1926. During 1929, work was begun on the comparison of the results obtained by other laboratory methods with those by the lead bath method, and on the development of a new small-scale assay method suitable for all ranks of Canadian coals. Preliminary comparative study and recommendations were made by Strong and Burrough and the investigation was continued during the summer months of 1929 and 1930 by E. A. Smith, with the assistance of G. P. Connell.

In the Gray-King method the apparatus, which is more or less well known and need not be described here, only 20 grammes of coal are used in a single assay test. The main products, coke or char, and total distillate, including the aqueous and tar oils portions, are determined directly by weighing, and the volume of gas being obtained by measurement. By the original Gray-King method, the aqueous content of the total distillate was read off after settling and the difference reported as "tar." For Canadian lignites and other coals of low rank the yield of tar oils thus obtained by difference was found to be quite erroneous, due to the fact that the tar oils have a specific gravity of approximately 1·00, and form a fairly stable oil-water emulsion with proportions of the latter as high as 30 to 35 per cent. This error was corrected to a large extent in the revised Gray-King method by determining the water content by adding toluene to the total distillate and distilling off the water which separates in a distinct lower layer in the special graduated receiver. By this revised method the tar or tar-oil yield is the difference between the total weight of distillate obtained

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[1] Mines Branch publications: No. 671 (1925) p. 66, No. 689 (1926) p. 13, No. 696 (1927) p. 33.

[2] Reports of the Fuel Research Board (Dept. of Scientific and Industrial Research)—Technical Papers Nos. 1 and 21, also Methods of Analysis of Coal (No. 7).

[3] Carbonization of Canadian Fuels, Part II, by R. E. Gilmore, Canadian Chem. & Met., April, 1926, p. 86.

in the carbonization assay, and the weight of water (read by volume) obtained by distillation with toluene. On the assumption, however, that any laboratory, low-temperature carbonization, assay method where the yield of tar oils—one of the main products— is determined by difference, is not free from adverse criticism, modifications of this method were experimented with and a new greatly modified method, if not radically different, has at date of writing been developed, to be known as the Fuel Research Laboratories (F-R-L Ottawa) low-temperature carbonization, assay method.

This new F-R-L method calls for any suitable electrically heated furnace capable of controlling the rate of heating and maximum temperature and a train similar to that used in the Sperr & Rose (Koppers) high-temperature laboratory assay method[1] adopted in these laboratories, which train is practically the same as that employed by the U.S. Steel Corporation.[2] The furnace part of the Gray-King apparatus, as supplied by the apparatus supply companies, has been found quite serviceable, but in contrast with the simplified train used in this method, the F-R-L train is quite elaborate and consists of a steam-heated tar extraction tube attached to the end of the straight, open-mouth, pyrex glass or silica retort tube, an ice-cooled, liquor condensing tube, and Geissler tubes for carbon dioxide, hydrogen sulphide and light oils, and a gas collecting bottle. In this method the charge is the same as in the Gray-King method, namely, 20 grammes, and the heating schedule somewhat the same. In the F-R-L method, where the different rank coals other than coking bituminous are charged in the air-dried state, the tar oils are determined directly by weight and it is in this respect that the F-R-L (Ottawa) method is considered superior and preferable.

This report, however, or rather these notes, have to do with a comparison of carbonization assays by the Gray-King method with those by the lead bath (iron retort) method and results of comparative tests by the new F-R-L method with those by the Gray-King method will appear in future Investigations of Fuels and Fuel Testing.

Comparison of Results by the Lead Bath and the Gray-King Methods

On a typical lignite coal from the Estevan area, Saskatchewan, the same coal as is used for commercial scale carbonizing and briquetting operations at the Bienfait plant, comparative laboratory assays were made by the Gray-King method, and the results compared with carbonization tests at 600° C. in the lead bath apparatus on both the large and intermediate laboratory scale, using 3,000 grammes and 50 grammes respectively. In the assay tests, according to the Gray-King method, the lignite was charged in a partly dried state, while in the lead bath tests, the raw lignite

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[1] Investigations of Fuels and Fuel Testing, 1927, p. 24

[2] Methods of the Chemists of the United States Steel Corporation for the Sampling and Analysis of Coal, Coke and By-products (p. 130) Third Edition—Carnegie Steel Company—Bureau of Technical Instruction, Pittsburgh, Pa.

as received in the laboratory with 33 per cent moisture was used. The weight balances of the main products as a percentage of the coal charged, and calculated to the dry basis, are shown below:—

Method of carbonization	Char (carbonized residue)	Liquor (water of decomposition)	Tar oils (water-free)	Gas	
				By difference	By weight
	%	%	%	%	%
Lead bath (iron retort)—					
3000-gramme scale	65·5	10·9	5·4	18·2	18·8
50-gramme scale	65·4	10·7	6·8	17·1	
Gray-King method, 20-gramme scale	65·3	8·4	7·5	18·8	
Original unrevised method	....	....	(8·3)		

The yield of 8·3 per cent tar oils, equal to roughly 16½ Imperial gallons per ton of dry lignite, was by the original Gray-King unrevised method where the tar yield is obtained by subtracting the water layer from the total distillate, which tar obviously was an emulsion containing 10 per cent or more of water. In the above results it is to be noted that the yields of char agreed closely and there was a rough agreement in the gas yield and also in the total distillate. The noticeable differences in the results obtained on the different scales by the two different methods was in the distribution of the liquor and tar oils which, in respect to rough yields of water-free tar oils, may be summed up as follows:—

Method of carbonization for Saskatchewan lignite	Imp. gals. tar per 2,000 pounds	
	Yield on dry coal basis	Yield on coal as mined with 33 per cent moisture
	gallons	gallons
Gray-King method—		
20 grammes dry lignite in glass retort	15	10
Lead bath (iron retort)—		
50 grammes raw lignite	13½	9
3000 grammes raw lignite	11	7¼

Similar comparative results on a series of five typical Canadian coals, including Saskatchewan lignite mentioned above, were as shown in Table I.

In the carbonization tests by the lead bath (iron retort) method, weight balances to show gains or losses ranging from 0·2 to 0·7 per cent weight of the coal charged on the as mined or partially air-dried basis were obtained. In the tests on the bituminous coal by the Gray-King method, the coal charged was dried until there was no further loss at 105° C., whereas for the non-coking coals from 2 to nearly 10 per cent moisture remained in the charge as carbonized. In some cases for these non-coking coals, instead of running the oven (previously preheated to 300° C.) over the tube holding the charge, the retort was inserted into the cold furnace, the temperature of which was then brought up rapidly to 300° C. before proceeding according to the heating schedule specified. This procedure was found necessary in order to avoid as much as possible the blowing over into the condensing train of portions of the dry powdered charge and with this exception, therefore, the standard Gray-King method was followed. The coals used in the comparative tests were, with two exceptions, from the same laboratory bulk reserve lump sample, and the tests in the lead bath apparatus preceded by periods of one to three years the small-scale tests by the Gray-King method. For these reasons and because a different laboratory sample, though from the same mine, was used in the case of Alberta domestic coal, the figure designating the high difference in tar oil yields on the dry-coal basis for this coal may be questioned.

The obtaining of higher tar oil yields from the lower-rank, non-coking coals by the Gray-King method than those obtainable by other laboratory methods requires further studies. As referred to above, the tar oils are not determined directly in the Gray-King method, but are the difference between the weight of total distillate and the amount of water removed by distillation with toluene in accordance with the Dean-Stark[1] laboratory method for the determination of the water content of oils and oil emulsions. Distillation with toluene will also carry over certain low-boiling organic acids of oily nature, alcohols, etc., known to be present in the "aqueous distillate" obtained in the distillation or carbonization of wood, peat, and lignitic coals, which substances, on account of their being more soluble in toluene than in water, will remain in the upper toluene portion of the "Dean-Stark" distillate rather than in the lower water layer. Hence the tendency is to obtain lower water recoveries, which in turn indicates higher tar oil yields arrived at by difference. This phenomenon, in the writer's opinion, explains why consistently higher yields are obtained by the Gray-King method, than by other laboratory methods where the yields of liquor and tar oils are obtained directly.

Conclusions

A general conclusion from the above comparisons may be drawn; namely that the tar oil yields obtained by the Gray-King laboratory assay method were generally higher than those obtainable by the larger laboratory scale low-temperature carbonization methods using iron retorts and that this difference was appreciably greater for non-coking coals than for coking bituminous coals for which the Gray-King method was originally devised. Furthermore, it would appear that for the lower-rank, non-coking coals on the dry-coal basis the yields obtainable on a 5- to 6-pound scale in an iron retort will average 3 to 5 Imperial gallons per (2,000 pound) ton less than shown by the Gray-King laboratory assay method, and that small laboratory scale yields by this method should be discounted to this extent before proceeding to apply a general factor of 60 to 70 per cent in order to arrive at a plant scale dry tar recovery figure in terms of laboratory yields.

Further comparative work by the new F-R-L (Ottawa) low-temperature carbonization assay method referred to above, whereby the yield

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[1] *See* Jour. Ind. & Eng. Chem., vol. 12 (1920) No. 5, p. 486; also A.S.T.M. D-95-30.

of tar oils will be determined directly rather than by difference, is planned, the results of which will appear either in the technical literature or in future Investigations of Fuels and Fuel Testing.

TABLE I

Showing Comparative Results on Five Typical Canadian Coals by the Gray-King and the Lead Bath (Iron Retort) Methods

—	Ontario lignite	Saskatchewan lignite	Alberta domestic coal	Alberta sub-bituminous	N. S. bituminous
Moisture, as mined, %	50	33	20	10	2·5
Gray-King Method—					
(20-grm. charges, at 600°C.)					
Moisture, as carbonized	4·3%	9·6%	2·1%	0·0%	0·0%
Products as per cent weight on dry-coal basis					
Coke or char	62·2	65·3	68·8	74·3	73·5
Liquor	10·0	8·4	8·3	8·0	14·1
Tar oils	6·5	7·5	7·2	8·0	13·3
Gas (by difference)	21·3	18·8	15·7	9·7	9·1
Lead Bath (Iron Retort) Method—					
(3,000-grm. charges, at 600° C.)					
Moisture as carbonized	40·0	33·0	16·5	7·7	2·2
Products as per cent weight on dry-coal basis					
Coke or char	61·6	65·5	70·0	75·2	73·0
Liquor	16·6	10·9	11·0	8·8	4·5
Tar oils	4·8	5·4	3·8	5·2	12·6
Gas (by difference)	17·0	18·2	15·2	10·8	9·9
Comparative Tar Oil Yields—					
(Imp. gallons per 2,000 pounds of coal)					
Gray-King method	6·5	10·0	11·5	14·4	25·9
Lead bath method	4·8	7·2	6·1	9·4	24·6
Difference in yield—					
As mined basis	1·5	2·8	5·4	5·0	1·3
Dry coal basis	3·4	4·2	6·8	5·6	1·4

2.—RELATION OF CAKING INDICES AND AGGLUTINATING VALUES OF COALS TO THEIR LABORATORY AND PLANT SCALE COKING PROPERTIES

In the table appended are shown the caking indices of fifteen different coals and coal mixtures in comparison with their laboratory and commercial coking properties. The coals are arranged by number in order of their increasing volatile matter contents, calculated to the dry and ash-free basis; and the physical characteristics of the coke including a rough grading for metallurgical purposes were judged by examination of the coke produced in the experimental two-ton by-product coke oven at the Fuel Research Laboratories. The width of this oven is twelve inches and the coking period for the coals was approximately twelve hours.

For the three coals, grading as good when coked alone in the by-product oven, the coking properties as judged by the coke button from the volatile matter determination at 950° C. were good in one case and fair in the other two cases. The corresponding caking indices by the Gray method for these three coals ranged from 30 to 44. For the four coals grading as fair to good in respect to the by-product oven coke produced, the corresponding laboratory coke button properties were fair to good in one case only, and good in the remaining three cases, with corresponding caking indices ranging from 29 to 44. These observations, coupled with the laboratory coking properties of poor to fair for the two coals that showed poor and very poor coke respectively in the oven, show that the laboratory coke button grading is apt to be a grade either higher or lower than the respective coking properties in a by-product coke oven; and, conversely, the physical properties of the commercial coke to be expected from a given coal may be either a grade higher or a grade lower than indicated by the laboratory coke button properties.

Comparison of Caking Indices by the Gray Method and Agglutinating Values by the Marshall-Bird Method

In co-operation with Messrs. A. C. Fieldner and W. A. Selvig of the United States Bureau of Mines, comparative caking index tests were made on a series of coals and coal mixtures prepared and previously tested for large-scale coking properties at these laboratories. The comparative results on fifteen of these coals are shown in Table II and a summary of the results on twenty coals is given below.

The caking indices were determined by Messrs. Nicolls and Swartzman according to the "Gray" method mentioned above, whereas the determinations made at the U.S. Bureau of Mines as reported by Mr. Selvig were made by a Marshall-Bird method and are termed agglutinating values. By the Gray method the caking index is the ratio of sand to coal to produce a coke button that will support a 500-gramme weight, whereas by the Marshall-Bird method[1] a definite mixture of sand and coal, namely, 10 parts by weight of sand to 1 part of coal, is carbonized at 950° C. and

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[1] See Bureau of Mines Report of Investigations RI-3011, June 1930, viz., "A Study of the Marshall-Bird Test for Determining the Agglutinating Value of Coal" by K. A. Johnson and F. H. Yancey; and also Min. & Met. Eng. Tech. pub. 216, 1929, viz., Tests for Measuring Agglutinating Power of Coal—with selected bibliography, by S. M Marshall and B. M. Bird.

the breaking strength, recorded in grammes (or kilograms), of the resultant button is designated the agglutinating value of the coal tested. The arrangement below shows a comparison of the results on the twenty coals, and coal mixtures, first in order of their caking indices, and then in order of their agglutinating values (in kilograms to first place decimal). The Gray method index (1) is the 500-gramme weight index and (2) is the index at which the weight of the powder formed was not over 5 per cent of the amount of coal used.

Lab. No.	Caking index, Gray method (1)	Agglutinating value Marshall-Bird method (kilograms)	Lab. No.	Agglutinating value Marshall-Bird method (kilograms)	Caking index, Gray method		
					(1)	(2)	Average of (1) and (2)
12	46	15·19	2	15·6	44	22	33·0
2	44	15·62	12	15·2	46	33	39·5
8	43	11·87	3	14·5	37	34	35·5
16	41	12·06	4	13·0	29	15	22·0
9	41	12·26	1	12·4	33	15	24·0
11	41	9·92	9	12·3	41	13	27·0
17	40	9·16	16	12·1	41	26	33·5
3	37	14·51	8	11·9	43	19	31·0
10	37	11·58	10	11·6	37	26	31·5
19	33	9·23	20	10·0	30	27	28·5
1	33	12·40	11	9·9	41	32	36·5
14	33	7·64	19	9·2	33	27	28·5
20	30	10·02	17	9·2	40	30	35·0
7	30	8·56	7	8·6	30	25	27·5
4	29	12·95	14	7·6	33	29	31·0
6	27	7·06	6	7·1	27	14	20·5
13	24	5·98	13	6·0	24	24	24·0
15	18	4·61	15	4·6	18	17	20·0
18	22	4·16	18	4·2	22	24	23·0
5	18	3·08	5	3·1	18	16	17·0

While it is realized that caking indices and agglutinating values are serviceable for judging the relative merits of bituminous coals for general combustion and carbonization as well as for coal classification purposes, these notes are of value only in relation to coking properties for a specific use, viz., for the manufacture of a commercial coke. It is therefore here assumed that the caking or agglutinating properties of a coal of a given ash content, to be of value, should predict the plant scale coking characteristics of that coal irrespective of what effect alterations in ash and other constituents by washing would have. It is also assumed that where the large-scale coking properties of a series of coals or coal mixtures are known and can be correlated with small-scale laboratory caking indices and agglutinating values, the value and reliability of these indices may be judged to the extent that they agree with the grading of the coke produced in a commercial size oven. Accordingly, the grading of the cokes as produced in a two-ton capacity by-product oven as shown in Table II may be correlated first with the coking properties of the coke button and then with the caking indices by the Gray method, as well as with agglutinating values by Marshall-Bird method, to judge the serviceability of these indices and values to predict commercial coking characteristics. In this co-relation, or rather comparison, the rough grading of the coke for metallurgical purposes has been according to appearance, fracture, sizing, and shatter test; in other words, according to physical characteristics rather than chemical properties as to ash content, fusibility of ash, reactivity, etc. A summarized comparison is as follows:—

Number of coals tested	Rough grading as metallurgical coke from two-ton oven	Range of caking indices and agglutinating values		Coking properties 1-grm. coke button scale
		Gray method ratio sand to coal	Marshall-Bird method (kilograms)	
Coal Coked Alone—				
3	Good	30 to 44	8·6 to 15·6	Two fair, one good.
4	Fair to good	29 & 43	11·9 & 14·5	One fair to good and three good.
1	Poor	27	7·1	Poor to fair.
1	Very poor	18	3·1	Poor to fair.
Blended Coals—				
3	Good	37 to 46	9·9 to 15·2	All good.
3	Poor	23 to 33	4·6 to 7·6	Poor, poor to fair, and fair.

Summary and Conclusions

It is possible to draw only very general conclusions from the above comparisons, viz., both the caking index and agglutinating value ranges showed considerable overlapping for coals producing cokes graded (metallurgically) as good, fair to good, and fair. The ranges for the fair to good cokes covered a large proportion of the respective ranges for the good cokes, or in other words both the caking index and the agglutinating value ranges for the coals that produce a coke grading as good or better completely overlapped the respective ranges for the coals that produced fair to good cokes. For the coals that gave good coke when blended, the corresponding caking index and agglutinating value ranges are noticeably not so wide as for the coals that gave good coke when coked alone. The (Gray) indices of 27 and below coincide roughly with the (Marshall-Bird) agglutinating values of 7·0 and less, and these points appear to apply to border-line coals between those that will produce fair coke and better on the upper range and those that will give in the lower range a poor or no coke commercially.

The detailed results are, however, contradictory and subject to different interpretations which leads one to the general conclusion that there is little agreement between caking indices and agglutinating values and commercial coking properties. This agrees with the conclusions arrived at by both Braunholtz and Slater, the results of whose work are reported[1] in the literature.

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[1] Fuel in Science and Practice—"The Correlation of the Physical and Chemical Properties of Cokes with their Value in Metallurgical Processes" by Braunholtz, and co-workers, Vol. VIII, No. 9, and "A Comparison of Methods for Testing the Caking Properties of Coal" by L. Slater, vol. IX, No. 12.

For predicting the commercial coking characteristics of the fifteen coals and coal mixtures tested, it may be concluded that the caking indices by the Gray method and the agglutinating values by the Marshall-Bird method failed to show greater value than the coking property judgment afforded by examination of the coke button obtained in the volatile matter determination at 950° C. The results also show that an elaborate coke button grading is apt to be a grade higher or lower than that of the by-product oven coke that can be produced from a given coal. In order, therefore, to predict correct large-scale characteristics, very little reliance should be placed on small-scale laboratory caking index tests, but the one-gramme coke button characteristics may serve first to indicate, general coking properties, and second, to differentiate between the non-coking to poorly coking coals and those coals that will produce a coke that will grade commercially as fair and better, that is, rather than being relied upon to forecast the grade of coke that can be produced commercially, the appearance and structure of the coke button produced in the usual volatile matter determination should serve merely to indicate the general coking properties of the coals tested, in terms of say, non-coking, poor, fair, or good coking properties.

TABLE II

Comparison of Caking Indices and Agglutinating Values with Laboratory and Commercial Coking Properties of Fifteen Typical Coals and Coal Mixtures

Sample No.	Volatile matter, dry and ash-free basis %	Coking[2] properties 1-grm. button	Caking indices, [1]Gray			Properties of coke from 2-ton by-product oven					Agglutinating value by "Marshall-Bird" method (kilograms)
			Index (1)	Index (2)	Average of (1) & (2)	Wharf coke: Total on 2-inch screen	Wharf coke: Breeze, through ½-inch	Remarks as to cross and longitudinal fracture	Shatter index[3] per cent on 2-inch	Rough[4] grading as metallurgical coke	
						Coals Coked Alone					
7............	27·2	Fair........	30	25	27·5	89	2·5	Small amounts of both cross and longitudinal fracture.	77	Good.......	8·56
3............	27·4	(Good).....	37	34	35·5	79	5·5	Appreciable cross fracture; small amount longitudinal fracture.	54	Fair to good	14·51
2............	30·1	Good.......	44	22	33·0	86	2·0	Medium amounts of square cross fracture	57	Good.......	15·62
9............	36·3	Good.......	41	13	27·0	78	3·5	Medium amounts of both cross and longitudinal fracture.	53	Fair to good	12·26
4............	37·1	(Good).....	29	15	22·0	86	5·0	Small to medium amount of both cross and longitudinal fracture.	64	Fair to good	12·95
1............	37·3	Fair........	33	15	24·0	85	2·5	Medium amounts of both cross and longitudinal fracture.	45	Good.......	12·40
8............	38·2	Fair-good...	43	19	31·0	71	1·5	Small to medium cross and considerable longitudinal fracture.	49	Fair to good	11·87
6............	42·5	Poor-fair....	27	14	20·5	70	5·0	Fingery; small cross with considerable longitudinal fracturing.	26	Poor........	7·06
5............	44·6	Poor-fair....	18	16	17·0	55	37·0	Only coal close to oven walls coked to form pebbly coke.	53	Very poor...	3·08

Coal Mixtures (Blends)

12............	28·6	Good.......	46	33	39·5	77	3·5	Small to medium cross and medium longitudinal fracture.	76	Good.......	15·1
11............	33·4	(Good).....	41	32	36·5	91	3·0	Small amounts of both cross and longitudinal fracture.	68	Good.......	9·92
10............	30·8	Good.......	37	26	31·5	88	2·5	Medium cross and small to medium longitudinal fracturing.	58	Good.......	11·58
14............	33·7	Fair........	33	29	31·0	....	....	Only coal close to oven walls coked......	64	Poor........	7·64
13............	36·4	Poor........	24	24	24·0	83	5·0	Large, blocky, very pebbly coke........	70	Poor........	5·98
15............	30·0	Poor-fair....	23	17	20·0	86	5·0	Large, blocky, very pebbly coke........	71	Poor........	4·61

[1] (1) is index at which button will support 500 grammes, and (2) is index at which indicated weight of powder is not greater than 5 per cent.

[2] Coking properties designated as (good), i.e., the word "good" in brackets,—dense coke buttons with more or less sprouting.

[3] Shatter index results reported here were obtained by standard A.S.T.M. shatter test method D141–23.

[4] Grading of coke is according to appearance and other physical characteristics which grading is subject to revision on account of sulphur and ash contents, F.P.A. and other chemical properties, for particular commercial purposes.

NOTE.—The agglutinating values shown in the last column to the right were determined by the Marshall-Bird method and reported by W. A. Selvig of the U. S. Bureau of Mines by permission of A. C. Fieldner.

III

CAKING INDICES OF TYPICAL CANADIAN COKING COALS

J. H. H. Nicolls

It has been the custom in these laboratories, when reporting or publishing analyses, to predict the coking properties of coals as a result of the examination of the "buttons" of carbonized material produced in volatile matter determinations, using only one gramme of coal. The descriptions have been based principally on the sizes of the coke buttons, but also to some extent on their general appearances. In some cases the "coking properties" have been descriptions of the residues obtained from large-scale laboratory carbonization tests employing from one to five pounds of coal. It was realized that the buttons would serve only as indications of the cokes to be expected from commercial ovens and might occasionally be somewhat misleading, and that there was need for a more definitive test.

Accordingly, a careful study was made of the various methods for the determination of "caking index," "caking power," or "agglutinating power," which have been described in the literature of the past few years. These methods were developed first in France, and various procedures for determining coking properties were subsequently evolved in Great Britain and Germany. To the best of the writer's knowledge, the only information in print regarding the caking or agglutinating values of coals from this continent is to be found in two papers published in the United States. The first is by Fulweiler and Cleveland,[1] the second by Marshall and Bird[2] who worked partly under the auspices of the United States Bureau of Mines. The second paper is accompanied by a very comprehensive bibliography, which is worthy of special mention. Methods generally utilized employed sand, electrode (or retort) carbon or anthracite as the inert material to be bound together by the coking coal. It was decided to apply to typical Canadian coals the method of Gray,[3] as developed and with modifications, as being typical of several of the methods described in the bibliography.

Table I contains the analyses of the 66 coal samples used in the tests, 56 of which are Canadian coals, the remaining 10 being coking coals from the United States. As indicated in the third column of the table some of the samples, of about ¼-inch size or larger, had been stored in metal containers for several months prior to the tests here described. Moisture and ash contents are given, as perhaps affecting the caking indices of the coals, while fuel ratios are included to indicate the general classification of the samples. Coking properties are given on three different scales, of which the third, or "box," test is generally found to correspond with commercial practice. In most cases, it is to be noted, there is good agreement between the cokes obtained upon the three scales, although the cokes were not always prepared at the same period. A discussion of "sprouting," which is usually the result of weathering, will be found later in the text of this paper.

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[1] Proceedings Am. Gas Assn., 1399–1410, 1927.

[2] Tech. Pub. No. 216, Am. Inst. Min. & Met. Engrs., 1929.

[3] Fuel in Science and Practice, II, 2, 42, 1923.

Tables II and III contain the caking indices of the 66 samples, as determined with sand or carbon material. Table IV shows the indices of individual bands of coal taken across a vertical section of the Phalen seam in the Sydney area, Nova Scotia. Table V indicates the effects of weathering on caking indices. Table VI deals with changes in the indices brought about by variations of inert material or type of crucible, respectively.

EXPERIMENTAL WORK

The Gray method using sand was adopted to the following extent: The coal samples were ground to the same fineness as is usual for analysis, or so that practically all would pass through a sieve having 100 openings to the linear inch. The inert material used was clean Belgian sand, obtained through the courtesy of a company engaged in the manufacture of glass. Sand passing through a 40-mesh I.M.M. (English) sieve (0·0125-inch opening) and remaining on a 50-mesh sieve (0·0100-inch opening) was dried in a metal tray on a hot plate, and employed in the tests. A mixture weighing exactly 25 grammes was used in each test, the coal and sand being thoroughly shaken up together in a glass-stoppered weighing bottle. The mixture was poured into a 20 c.c. platinum crucible with a capsule, tight-fitting, lid, such as is used for the determination of volatile matter. The crucible was then placed on a platinum triangle over a No. 4 Meker gas burner, so that the bottom of the crucible hung about 1 cm. above the top of the burner, and was heated by the full flame during seven minutes. Previous tests had shown that results obtained with No. 4 Meker burners agreed closely with those obtained with Chaddock burners as generally used in these laboratories for the determination of volatile matter, and also that figures obtained for volatile matter changed very little with varying gas pressures during a working day.

After the crucible had cooled, the lid was removed, a smooth cork placed on the surface of the button, and a small porcelain basin laid upside down on the cork. The whole arrangement was inverted and the crucible lifted, leaving the button formed by carbonizing the mixture of coal and sand standing on top of the cork in the basin. (In many cases the buttons stuck to the crucibles, necessitating tapping to remove them. For this reason it was very difficult to keep the crucibles free from dents, though they were rolled occasionally on a wooden form). The button was lifted carefully off the cork, and placed on a level surface in a position similar to that in which it had rested on the cork. A 500-gramme weight was then laid gently and evenly on top of the button for the purpose of determining whether the coked mass forming the button were sufficiently coherent to support the weight. In order to ascertain the weight of loose powder, the cork was removed so as to leave any powder in the porcelain dish. This was then dusted into a tared metal scoop and weighed.

The ratio of sand to coal which would form a sufficiently strong button to support 500 grammes was designated by Gray as the "caking index," provided that less than five per cent (of the original mixture) by weight of loose powder were produced. As a result of his experiments, Gray suggested that coals having indices of 16 or more might be expected to produce good metallurgical coke, and that those with indices of from 12 to 15 ought to be useful for blending with good coking coals.

DISCUSSION OF RESULTS

Tables II and III give the caking indices of the 66 coals obtained with sand or with carbon material, the latter consisting of petroleum coke calcined at red heat. The sand came from both of the first two consignments, which were so different (*see* Table VI) as to warrant their separation in Table II. The carbon was introduced as a modification of Gray's method and two consignments were used, but these did not differ to the same extent as the two lots of sand. The extra column in Table III indicates from which consignment the carbon employed was taken. It is to be noted that the second lot of carbon had a tendency to give slightly higher indices than the first, in spite of the fact that the analyses of both were very similar. Both consignments contained only traces of moisture, while the first one contained 0·9 per cent of ash as against 0·6 per cent in the second. Volatile matter was determined only in the second consignment, and amounted to 0·8 per cent. A few of the indices shown were determined in Illium crucibles, which were found to give slightly higher values than those obtained with platinum (*see* Table VI), though the differences were smaller than those obtained when using sand. The first column in each table contains the indices at which the buttons were just strong enough to support a 500-gramme weight for at least a minute, and usually two minutes or more; the second principal column contains the indices at which the weights of powder produced were not greater than 5 per cent by weight of the original mixtures (which indices were introduced by Gray), and serves partly to mark coals lacking in binding qualities and partly to mark those which might swell and cause trouble in a coke oven; the third principal column contains the averages of the indices in the other columns, as introduced by the writer in the hope of compensating for the gaps sometimes occurring between such indices. The caking indices of the majority of coals, as defined by Gray, are in the second index column which usually shows the indices at which the buttons will support 500 grammes, and also produce not over 5 per cent of powder. In a few cases, which are marked by the numeral 3, the indices at which not over 5 per cent of powder is produced are greater than those at which the buttons will support 500 grammes; in such cases the caking indices, as defined by Gray, are in the first column.

The same coals are found at the tops and bottoms, respectively, of the tables, but there is a great deal of variation in the positions of the remaining coals. However, it should be borne in mind that all the coals listed were selected because they were known either to produce coke or to have a tendency to do so. Such a test as the caking index could hardly be expected to make clear-cut distinctions between the various coking coals. While, in certain individual cases, the grading in the second and third columns may seem to be the most satisfactory, generally speaking the first column agrees most nearly with the coking properties on either the 100-pound, 1-pound, or 1-gramme scale. The writer is doubtful, however, as to whether this caking index test will indicate coals which would swell, and therefore cause trouble in a coke oven. There are only three instances in which the caking indices fail very considerably to correspond with the coking properties. These are the Hillcrest No. 2 and Luscar No. 3 coals with sand, and the Cassidy coal with carbon, and in each case the index predicts a better coke than was obtained on the 100-pound or 1-pound scale. The position of the coals in the second column in each table is upset, owing to the fact that mixtures of certain good coking coals with inert material (such as some Michel and Phalen samples) stuck badly to the crucibles, with the consequent production of much excess powder. It was hoped that the mean values in the third column would compensate for this, but they did not quite do so, as is evident from the position of two Michel samples at the bottom of the third column in Table III. Comparison of the indices in the two tables led the writer to the conclusion that, as a general rule, those obtained with sand agreed somewhat more closely with the tabulated coking properties of the coals than those obtained with carbon, but that none of them showed a marked superiority over the 1-gramme crucible cokes for the prediction of commercial-scale coking properties.

After a study of the coking properties and of the caking indices obtained, it was decided to class the coals studied either as satisfactory for carbonizing alone, or as suitable for blending with other coals. For this purpose, the following tentative divisions between the classes were made: (1) in Table II, first column—first sand, above 25—second sand, above 20; (2) in Table II, third column—second sand, below 22; (3) in Table III, first column—below 16. It was found to be impracticable to attempt to make divisions in the third columns with either the first sand consignment or the carbon material.

Table IV shows the analyses, coking properties and caking indices of sections taken across the Phalen seam at a location designated for survey purposes. The sections include the bands at the top and bottom of the seam, which are not mined. The indices were determined in platinum crucibles with the second consignment of sand, and do not vary to a very great extent across the seam. Even the band of coal most contaminated with ash and sulphur had a high enough caking index to be graded above the line of division in Table II. However, the results show that any considerable increase in ash has the effect of somewhat lowering the caking index. No one of the coal sections was considered to produce a large excess of powder in the determination of its caking index.

Two other samples of Phalen coal, specially selected because of their high ash contents, were separated by the sink and float test apparatus described in a previous report[1] so that the "float" portions contained 6·7 per cent and 6·8 per cent of ash respectively, as against 13·1 per cent and 17·5 per cent in the untreated coals. Contrary to expectation, these large reductions produced little change either in the coking properties or in the determined caking indices.

EFFECTS OF WEATHERING

Before concluding the determinations of caking indices, a series of tests was carried out in order to determine the effect of weathering produced during one year's storage out-of-doors. The results of these tests are shown in Table V, the first part of which has to do with storage on a small scale at the Fuel Research Laboratories, and the second with storage on a commercial scale in a stock pile at Montreal.

Except for the larger-sized Dominion coal, all the samples weathered at the Fuel Research Laboratories consisted of slack coal which would

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[1] Mines Branch Rept. No. 689, Investigations of Fuels and Fuel Testing, 1926, p. 34.

pass through a screen with ½-inch square openings. The coals, the weights of which varied from 50 to 100 pounds, were stored in conical heaps in an unsheltered place. They were raised from the ground in small bins lined with galvanized iron, which was perforated and permitted fair drainage. During the first six months' storage the upper portions of the heaps were disturbed occasionally for sampling purposes; for most of the second six months they were snow-covered and undisturbed. After a year's exposure, the heaps of coal were removed, and screened, during which procedure the laboratory samples for caking indices were taken from throughout the weathered coals. The samples from the commercial stock pile consisted of screened run-of-mine coal. They were taken on or about the dates specified, and the coarse material was stored indoors in 100-pound sacks until ground for caking index determinations during the month of June following.

The fine coal exposed at Ottawa would undoubtedly have had a greater opportunity of weathering than most of the coarser coal stored at Montreal. This is substantiated by the figures in the table, which show a greater proportional reduction in the caking indices of the samples weathered at these laboratories than in those of the samples from the stock pile. However, none of the samples had its caking index reduced by one year's weathering to such an extent that it could no longer be considered as likely to produce a satisfactory coke when carbonized alone. It will be observed that the weights of powder produced from the buttons supporting 500 grammes did not increase materially with the weathering of the coals, though the indices at which the weights of powder did not exceed 5 per cent showed a tendency to decrease. Contrary, also, to expectation, exposure brought about neither reduction in the fuel ratios nor any considerable change in coking properties, though the "sprouting" referred to below began to develop in the cokes from the weathered coals.

The "sprouting" described as taking place with some of the samples, consisted of swollen protuberances, suggestive, when large, of cauliflower growths, from the faces of the buttons, which were perhaps due to the fact that the temperatures of decomposition of the constituents causing swelling did not coincide with those of the binding constituents. Generally, the appearance of sprouting corresponded with a reduction of coking value as shown by the caking index. Furthermore, coals with good coking properties, when stored for a year or more in the powdered state, often develop sprouting tendencies. This effect of oxidation is indicated by the coke buttons from the Sydney (Phalen seam) samples. Samples 4900, 5031, 5157, 5577, 5580, and 5583 were taken from the neighbourhood of the outcrop, whereas the remaining samples came from well under ground. Sample 5577 is a marked exception to the theory. Sample 4900 is so weakly coking that it may be assumed to have been weathered beyond the stage at which sprouting is produced.

EFFECTS OF VARIATIONS IN METHOD

At the outset of the series of tests it was taken for granted that Belgian sand, such as was used in the glass works, would not vary to any extent in chemical and physical properties, and comparatively little of it was obtained. Subsequently, second and third consignments of sand had to be procured, and it was found that the caking indices as determined with the separate consignments did not show a close agreement. This may have been due to differences in shape of the sand grains, as it has been suggested that spherical grains are the most suitable for this work. The order of the coals in the table was roughly the same with the different lots of sand, but the indices of any particular coal varied considerably.

The first part of Table VI gives the indices of certain coal samples with the various consignments of sand. The first column of figures in the table shows the indices at which the buttons will just support the 500-gramme weight, the second column the average weights of powder produced at these respective indices, and the third column gives the indices at which the weights of powder are not greater than 5 per cent of the original mixtures. This portion of the table shows that the earliest consignment of sand gave caking indices higher than the second one, but that the differences between them ought not to prevent either of them from indicating, on about the same range of indices, whether any particular coal might be expected to produce a satisfactory coke. However, the difference between the two lots of sand was considered to be so great as to make it advisable to tabulate separately the caking indices of the various coals as obtained with them, and this was done in preparing Table II. The third consignment of sand gave values very different from those previously obtained; the buttons produced were much stronger, and, therefore, increased the indices at which the weight was supported, but in many cases they stuck so badly to the crucibles as to lower unreasonably the indices at which the weight of powder was not over 5 per cent. Fortunately, this sand was not used for the ordinary series, but only for some special tests where relative results were desired.

After the various series of tests, as shown in the earlier tables, were completed, it became known to the writer that in some laboratories it was customary to leach the sand with acid. Accordingly, a portion of the third consignment of sand, of 40- to 50-mesh size, was digested with hydrochloric acid diluted with an equal volume of water. The sand was leached, with occasional stirring, for about 30 hours in all, during 10 of which the acid was heated to just below the boiling point, with the evident result that a large amount of iron was dissolved out. Following digestion, the sand was washed with water until acid-free, and then dried on a hot plate. It was afterwards re-screened, when it was found that some 30 per cent would pass through the 50-mesh sieve; in all probability, therefore, all the grains of sand had been somewhat reduced in size.

The second part of Table VI shows caking indices determined with untreated and treated sands, respectively, and it is evident that the effect of acid treatment is to alter such indices materially. This portion of the table also shows that the use of sand digested for four days—heated for about eight hours each day—does not materially alter the caking indices from those obtained with sand digested for only two days.

Another factor to be considered is the size of the sand, which has been shown by several investigators to have a considerable effect on the caking index, on account of the greater surface of fine inert to be covered with the binding material. As has been pointed out, it is quite likely that very little of the 40- to 50-mesh sand was of 40-mesh size following the acid digestion. To avoid such a contingency, a portion of the original unscreened sand was digested with acid for three days, and then screened, so that the 40- to 50-mesh material should consist of all sizes between the screens. The second part of Table VI also shows the caking index of one sample as determined with this sand, and it is evident that the index is practically the same as those obtained with the sand which was screened to the desired size prior to digestion with acid.

Platinum crucibles became dented from the tapping sometimes employed to loosen the buttons, and were liable to become corroded with iron either from the sand or coals or both. It was therefore decided to use Illium crucibles, which were found to retain their shapes rigidly, though the length of time during which they would resist corrosion was not definitely established. The crucibles were of the same shape as those made of platinum, though slightly more tapered and with smaller bases. They were designated as of 20 c.c. capacity. However, the charge normally used was only about 21 grammes. It was found that when 25 grammes were used the buttons were distinctly stronger, owing presumably to the pressure exerted by the lids. In one instance the substitution of 25 for 21 grammes increased from 22 to 28 the index at which the button would support 500 grammes. The percentages of powder from the buttons remained about the same whether 21 or 25 grammes were used.

For the sake of uniformity, the weight of powder obtained with the Illium crucibles was divided by the weight, in grammes, of the coal-sand mixture and multiplied by 25, so that a value of 1·25 so obtained represented 5 per cent of the mixture. Since the figure representing the actual weight of powder obtained had to be increased by the multiplication, thereby adding to the effect of any errors in weighing, it was decided to consider a final figure of 1·35 grammes of powder as corresponding to 5 per cent of the mixture. An even greater proportional allowance was made when carbon material was used instead of sand, as 12 grammes of mixture would nearly fill either type of crucible.

The third part of Table VI compares results obtained with the platinum and Illium crucibles respectively. In most cases, stronger buttons were obtained with the Illium crucibles than with the platinum ones. To compensate for this, the indices at which the weights of powder were not greater than 5 per cent of the mixture were lower with the Illium crucibles, so that, according to Gray's original definition, the caking indices obtained with Illium crucibles would be distinctly lower than those obtained with platinum crucibles.

SUMMARY AND CONCLUSIONS

Fifty-six Canadian coals, originating in the eastern and western parts of the country, and ten coals from eastern United States, the analyses and coking properties of which, on a laboratory or larger scale, were known, were selected for the determination of their caking indices.

A method agreeing very closely with that of Gray was chosen. Both sand and carbon were used as inert materials, and the mixtures of coal and inert were heated over Meker gas burners in either platinum or Illium crucibles. The buttons produced were tested to ascertain their cohesive strength and also to determine what percentage of loose powder was produced.

The caking indices of the 66 coals were determined in all cases with sand, and in the majority of cases with petroleum coke as carbon material. There were determined: (1) the indices at which the buttons would just support a 500-gramme weight; (2) the indices at which the amounts of loose powder produced were not greater than 5 per cent, by weight, of the mixtures of coal and inert material, and (3) indices representing the averages of indices (1) and (2). The coals were tabulated with their indices in numerical order, and it was found that the strengths of the buttons corresponded closely to the previously determined coking properties. Tentative division lines were drawn between coals which might be expected to produce commercial cokes when carbonized alone and those which would probably make better cokes when blended with other coals.

It was decided that the most satisfactory index, by comparison with the determined coking properties, was the index at which the button would just support a 500-gramme weight; also that, while both inert materials gave some irregular results, sand was slightly preferable to petroleum coke for the Canadian coals tested.

It was found that separate consignments of sand and carbon material, respectively, gave different caking indices for the same coal sample; also that leaching of the sand with acid was likely to alter the caking indices obtained with it. The differences between the results obtained with platinum and Illium crucibles were not great, though the latter gave somewhat stronger buttons, at the same time producing slightly more loose powder. Illium crucibles do not lose their shape, do not corrode badly, and are, therefore, to be recommended for caking index work.

The caking indices of 23 sections, or bands, from top to bottom of the Phalen (Sydney area) seam, were determined. There were variations of some magnitude throughout the seam, but each individual section had a sufficiently high index to be classed as a coking coal.

Changes in caking index, due to weathering for one year or less, of four coals from the Sydney area, Nova Scotia, and three coals from the United States, were determined. It was found that the caking indices were considerably reduced, but in no case sufficiently so as to remove any coal from the class in which it was suitable for coking alone to that in which it would require to be blended with some other coal.

There seemed to be no conclusive proof that the caking index determination is superior to the examination of the coke button, produced in the laboratory determination of volatile matter, for predicting commercial-scale coking properties.

TABLE I

Analyses of Coal Samples

No.	Description	Storage prior to caking-index determination	Moisture %	Ash (dry basis) %	Fuel ratio	Coking properties		
						Platinum crucible; Chaddock burner; 1 grm.	Fireclay crucible; gas furnace; 1 lb.	Sheet-iron box; coke oven; 75 to 100 lb.
	Nova Scotia *Sydney Area*							
4528	Dominion (sample No. 1) run-of-mine	Negligible..	2·3	9·3	1·65	Good..................................	....	Good
4827	Dominion (sample No. 2) on ½-inch screen.	" ..	2·6	7·2	1·50	Good..................................	....	....
4828	Dominion (sample No. 3) through ½-inch screen.	" ..	2·7	8·6	1·75	Good..................................	....	....
4900	Phalen seam (sample No. 1).........	8 mos......	5·6	4·4	1·70	Poor to fair..........................	....	....
4930	Phalen seam (sample No. 2).........	10 mos......	2·5	6·8	1·70	Good; tendency to "sprout"........	....	....
5031	Phalen seam (sample No. 3).........	8 mos......	5·7	6·3	1·90	Fair; much "sprouting"............	....	....
5136	Phalen seam (sample No. 4).........	10 mos......	1·8	7·3	1·75	Good; larger than average..........	....	....
5157	Phalen seam (sample No. 5).........	10 mos......	3·6	6·4	1·65	Fair to good; much incipient "sprouting".	....	....
5577	Phalen seam (sample No. 6).........	4 mos......	2·3	7·0	1·80	Good; larger than average..........	....	....
5578	Phalen seam (sample No. 7).........	7 mos......	1·5	7·0	1·80	" " "	....	....
5579	Phalen seam (sample No. 8).........	4 mos......	1·3	12·7	1·75	" " "	....	....
5580	Phalen seam (sample No. 9).........	4 mos......	3·0	9·6	1·55	Good; average size; marked "sprouting".	....	....
5581	Phalen seam (sample No. 10)........	7 mos......	1·2	9·8	1·70	Good; smaller than average.........	....	....
5582	Phalen seam (sample No. 11)........	4 mos......	1·4	10·7	1·55	Good; average size.................	....	....
5583	Phalen seam (sample No. 12)........	4 mos......	2·5	17·5	1·50	Good; smaller than average; much incipient "sprouting".	....	....
5584	Phalen seam (sample No. 13)........	7 mos......	1·7	12·4	1·50	Good; average; decided tendency to "sprout".	....	....
	Pictou Area							
4029	Stellarton (sample No. 1)............	7 mos......	1·6	13·9	2·10	Good; tendency to "sprout"........	Indications that it would be good.	....
4029 A	Stellarton (sample No. 2)............	7 mos......	1·8	12·9	2·15	Fair; much "sprouting".............	Uncertain..........	....
	Springhill Area							
4028	Springhill...........................	7 mos......	2·2	7·6	1·95	Good; larger than average..........	Good................	....

New Brunswick

Minto Area

4030	Minto	11 mos.	1·0	14·7	1·65	Fair to good; slight tendency to "sprout".	Good	

Alberta

Crowsnest Pass Area

4356	Hillcrest (sample No. 1)	17 mos.	1·4	10·9	2·00	Good	Good	
4571	Hillcrest (sample No. 2)	15 mos.	1·1	12·1	2·00	Fair to good		Fair domestic or foundry coke
4036	Blairmore (sample No. 1)	11 mos.	0·6	10·8	2·50	Fair to good; slight tendency to "sprout".		
4354	Blairmore (sample No. 2)	18 mos.	1·0	10·7	2·55	Fair to good	Good	
4572	Blairmore (sample No. 3)	15 mos.	0·8	10·6	2·50	Good; smaller than average; slight tendency to "sprout".		Good domestic, fair to good foundry coke.
4573	Coleman (sample No. 1)	13 mos.	1·4	16·2	2·40	Poor to fair	Fair	Fair domestic or foundry coke.
4038	Coleman (sample No. 2)	14 mos.	1·2	13·0	2·60	Poor		
4355	Coleman (sample No. 3)	18 mos.	1·4	12·4	2·65	Poor to fair	Fair	
4574	Coleman (sample No. 4)	14 mos.	1·2	12·8	2·75	Poor		Fair domestic or foundry coke.

Nordegg Area

4031	Nordegg	11 mos.	1·1	13·9	4·10	Poor	Very poor	

Mountain Park Area

4033	Luscar (sample No. 1)	12 mos.	0·7	13·4	3·20	Fair; incipient "sprouting"		
4358	Luscar (sample No. 2)	17 mos.	1·1	11·6	3·25	Fair to good	Fair	
4576	Luscar (sample No. 3)	16 mos.	0·9	11·2	3·35	Poor to fair; much incipient "sprouting".		Poor domestic or foundry coke.
4035	Mountain Park (sample No. 1)	13 mos.	1·7	12·3	1·95	Fair; slight evidences of "sprouting"		
4357	Mountain Park (sample No. 2)	17 mos.	1·7	9·2	2·00	Good	Good	
4570	Mountain Park (sample No. 3)	15 mos.	1·5	7·9	2·00	Fair; much "sprouting"		Good domestic or foundry coke.
4034	Cadomin (sample No. 1)	7 mos.	1·2	6·8	2·35	Fair to good; a little "sprouting"		
4359	Cadomin (sample No. 2)	18 mos.	1·4	13·8	2·25	Fair to good; much "sprouting"	Good	

TABLE I—*Concluded*

Alberta—*Concluded*

Brulé Area

No.	Description	Storage prior to caking-index determination	Moisture %	Ash (dry basis) %	Coking properties			
					Fuel ratio	Platinum crucible; Chaddock burner; 1 grm.	Fireclay crucible; gas furnace; 1 lb.	Sheet-iron box; coke oven; 75 to 100 lb.
4032	Brulé (sample No. 1)	10 mos.	0·8	15·4	3·35	Good; larger than average; indications of "sprouting".	Poor	
4215	Brulé (sample No. 2)	Negligible	0·7	15·4	3·35	Fair		
4235	Brulé (sample No. 3)	"	1·0	11·5	2·25	Good; larger than average		
4237	Brulé (sample No. 4)	"	0·9	12·2	3·40	Good		

British Columbia

Crowsnest Pass Area

4367	Corbin (sample No. 1)	17 mos.	1·2	12·8	2·65	Poor	Fair	
4575	Corbin (sample No. 2)	13 mos.	1·2	12·5	2·55	Poor		Fair domestic, poor foundry coke.
4039 A	Michel (sample No. 1)	25 mos.	1·9	3·5	2·60	Good; larger than average		
4186	Michel (sample No. 2)	4 mos. ground	1·1	5·9	2·80	" " "		
4187	Michel (sample No. 3)	4 mos. "	1·1	4·2	2·75	Good		
4188	Michel (sample No. 4)	4 mos. "	1·8	3·7	2·45	"		
4189	Michel (sample No. 5)	4 mos. "	2·0	4·2	2·50	"		
4352	Michel (sample No. 6)	17 mos.	2·4	4·9	2·60	"	Good	
4569	Michel (sample No. 7)	13 mos.	1·8	4·4	2·70	"		Very good domestic, excellent foundry, coke.
4040	Coal Creek (sample No. 1)	25 mos.	0·8	4·2	3·25	Good; larger than average		
4353	Coal Creek (sample No. 2)	17 mos.	1·2	6·4	2·60	Good	Good	
4568	Coal Creek (sample No. 3)	13 mos.	1·2	4·9	2·55	Good; larger than average; slight tendency to "sprout".		Very good domestic, excellent foundry coke.

Nanaimo Area

4041	Cassidy	25 mos.	2·2	14·3	1·25	Fair	Poor	

Comox Area

4042	Comox	25 mos.	1·7	10·3	1·90	Good size; a lot of "sprouting"	Probably good	

United States

4340	Pocohontas seam, W. Va. (sample No. 1).	Negligible	1·1	5·0	4·00	Good		
5865	Pocohontas seam, W. Va. (sample No. 2).	"	1·4	6·8	4·30	Fair to good size; some incipient "sprouting".		
4341	Chilton seam, W. Va. (sample No. 1)	"	2·2	4·4	1·60	Fair to good		
4488	Chilton seam, W. Va. (sample No. 2)	"	1·8	6·0	1·80	Good		Good.
4825	Sewickley seam, W. Va. through ½ inch.	"	1·2	10·5	1·30	Fair to good		
5864	Cedar Grove seam, W. Va.	"	1·8	5·5	1·80	"		
4823	"Raven", Pa., through ½ inch	"	0·6	6·4	3·55	Good; larger than average		
4826	Lower Kittanning seam, Pa., through ½ inch.	"	0·8	8·9	3·20	" " "		
5863	Upper and Lower Freeport seams, Pa.	"	1·5	9·6	2·15	Good; a little larger than average; slight indications of "sprouting".		
5862	Blend as charged to commercial ovens.	"	1·6	7·2	2·20	Good; smaller than average		Good.

TABLE II

Caking Indices Determined with Sand as Inert in Platinum Crucibles

(1) Index at which button will support 500 grammes		(2) Index at which powder not more than 5 per cent		(3) Mean of (1) and (2)	
First Consignment of Sand					
Dominion (1)	46	Dominion (1)	38	Dominion (1)	42
Chilton, U.S. (2)	46	Chilton, U.S. (2)	33	Chilton, U.S. (2)	39·5
Michel (3)	41	Brulé (3)	30	Brulé (3)	35
Brulé (3)	40	[3]Brulé (1)	29	Pocohontas, U.S. (1)	31·5
Michel (2)	40	Blairmore (1)	28	Mountain Park (1)	30·5
Mountain Park (1)	37	Pocohontas, U. S. (1)	27	Blairmore (1)	30·5
Chilton, U.S. (1)	37	[3]Brulé (2)	25	Cadomin (1)	29·5
Springhill	37	Mountain Park (1)	24	Springhill	29
Cadomin (1)	36	Cadomin (1)	23	Brulé (1)	27
Pocohontas, U.S. (1)	36	[3]Coleman (2)	23	Michel (3)	26·5
Minto	35	Brulé (4)	22	Minto	26·5
Stellarton (1)	34	[3]Luscar (1)	22	Michel (2)	26
Blairmore (1)	33	Springhill	21	Chilton, U.S. (1)	25
Michel (4)	33	[2]Minto	18	Stellarton (1)	24
Michel (5)	32	Stellarton (1)	18	Michel (4)	24
		Michel (4)	15	Brulé (2)	24
Brulé (1)	25	Michel (5)	14	Brulé (4)	23·5
Stellarton (2)	25	Stellarton (2)	14	Michel (5)	23
Brulé (4)	25	[2]Chilton, U.S. (1)	13	Luscar (1)	22
Brulé (2)	23	[2]Michel (3)	12	Stellarton (2)	21·5
Luscar (1)	20	[2]Michel (2)	12	Coleman (2)	21
Coleman (2)	19				
Nordegg	6				
Second Consignment of Sand					
Sewickley, U.S.	45	Sewickley, U.S	40	Sewickley, U.S	42·5
Phalen (8)	43	Coal Creek (3)	33	Phalen (8)	36·5
Phalen (7)	43	[3]Coal Creek (2)	31	Phalen (7)	36
Phalen (11)	43	Phalen (8)	30	Phelan (11)	34·5
Dominion (2)	40	[3]Hillcrest (2)	30	Dominon (2)	34·5
Raven, U.S	40	Phalen (7)	29[1]	Raven, U.S	33
Lower Kittanning, U.S	40	Dominion (2)	29	Coal Creek (3)	33
Phalen (6)	39	[3]Coal Creek (1)	29	Lower Kittanning, U.S	32·5
Phalen (10)	38	Phalen (9)	28	Phalen (6)	32·5
Phalen (4)	38	[3]Luscar (3)	28	Phalen (10)	32·5
Phalen (13)	37	Phalen (10)	27[1]	Phalen (4)	32·5
Freeport, U.S	36	Phalen (4)	27	Phalen (13)	31
Dominion (3)	35	Michel (1)	27	Coal Creek (2)	30·5
Phalen (12)	34	Phalen (11)	26	Freeport, U.S	30
Phalen (2)	34	Raven, U.S	26	Phalen (12)	30
Coal Creek (3)	33	Phalen (6)	26	Hillcrest (2)	29·5
Blend as charged to commercial ovens, U.S	31	Phalen (12)	26	Dominion (3)	29
Coal Creek (2)	30	Michel (6)	26	Phalen (9)	29
Phalen (9)	30	[3]Blairmore (2)	26	Michel (1)	28·5
Michel (1)	30	Lower Kittanning, U.S	25	Coal Creek (1)	28
Hillcrest (2)	29	Phalen (13)	25[1]	Phalen (2)	27
Blairmore (3)	28	Freeport, U.S	24	Michel (6)	26
Cedar Grove, U.S	28	Mountain Park (3)	24	Luscar (3)	26
Coal Creek (1)	27	[3]Luscar (2)	24	Blend as charged to commercial ovens, U.S	25·5
Mountain Park (2)	27	Dominion (3)	23	Blairmore (3)	25·5
Michel (6)	26	Blairmore (3)	23	Cedar Grove, U.S	25
Michel (7)	26	Mountain Park (2)	23	Mountain Park (2)	25
Mountain Park (3)	25	Cadomin (2)	23	Blairmore (2)	25
Hillcrest (1)	25	Cedar Grove, U.S	22	Mountain Park (3)	24·5
Luscar (3)	24	Phalen (5)	22	Michel (7)	23·5
Blairmore (2)	24	Comox	22	Hillcrest (1)	23
Phalen (5)	22	Michel (7)	21	Phalen (5)	22
		Hillcrest (1)	21		

TABLE II—*Concluded*

Caking Indices Determined with Sand as Inert in Platinum Crucibles—*Concluded*

(1) Index at which button will support 500 grammes		(2) Index at which powder not more than 5 per cent		(3) Mean of (1) and (2)	
Second Consignment of Sand—Concluded					
Phalen (3)	22	Phalen (3)	21	Comox	22
Comox	22	Phalen (2)	20	Cadomin (2)	22
Cadomin (2)	21	Blend as charged to commercial ovens, U.S.	20	Luscar (2)	22
Luscar (2)	20	[3]Coleman (3)	20	Phalen (3)	21·5
Coleman (1)	18	[3]Coleman (4)	20	Coleman (1)	18·5
Cassidy	17	[3]Coleman (1)	19	Cassidy	18
Pocohontas, U.S. (2)	17	[3]Cassidy	19	Pocohontas, U.S. (2)	18
Coleman (3)	16	[3]Pocohontas, U.S. (2)	19	Coleman (4)	18
Coleman (4)	16	[3]Phalen (1)	18	Coleman (3)	18
Phalen (1)	13	[3]Corbin (1)	16	Phalen (1)	15·5
Corbin (1)	13	[3]Corbin (2)	15	Corbin (1)	14·5
Corbin (2)	11			Corbin (2)	13

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[1] These index (2) values not determined but estimated from average index (2) values of Phalen seam samples with index (1) values corrssponding to those in the table.

[2] Buttons stuck badly to crucibles, producing excessive powder.

[3] For explanation see text.

TABLE III

Caking Indices Determined with Retort Carbon as Inert

(1) Index at which button will support 500 grammes	Carbon consignment	(2) Index at which powder not more than 5 per cent	(3) Mean of (1) and (2)
[1]Phalen (4)....42	2	[2]Dominion (1)....20	[1]Phalen (4)....29·5
[1]Phalen (7)....41	2	[2]Chilton, U.S. (2)....19	[1]Phalen (7)....29·5
Freeport, U.S....39	2	[1], [2]Phalen (7)....18	Freeport, U.S....27·5
[1]Phalen (2)....37	2	[1], [2]Phalen (4)....17	[1]Phalen (2)....27·0
[1]Phalen (10)....35	2	[1], [2]Phalen (2)....17	Dominion (1)....24·5
[1]Cedar Grove, U.S....34	2	Michel (1)....17	[1]Phalen (10)....24·0
[1]Phalen (13)....33	2	Coal Creek (1)....17	Cedar Grove, U.S....24·0
Blend as charged to com-		Freeport, U.S....16	[1]Phalen (13)....24·0
mercial ovens, U.S....32[1]	2	[1], [2]Phalen (13)....15	Chilton, U.S. (2)....23·0
[1]Phalen (5)....31	2	[2]Cadomin (2)....15	[1]Phalen (5)....21·5
Hillcrest (2)....30	2	[2]Mountain Park (1)....15	Blend as charged to com-
Dominion (1)....29	1	Brulé (3)....15	mercial ovens, U.S....21·0[1]
Chilton, U.S....27	1	Cadomin (1)....15	Hillcrest (2)....20·5
[1]Blairmore (3)....27	2	[1]Cedar Grove, U.S....14	[1]Blairmore (3)....20·0
Stellarton (1)....27	1	[1], [2]Phalen (10)....13	Michel (1)....19·0
Chilton, U.S. (1)....26	1	[1]Blairmore (3)....13	Stellarton (1)....19·0
Minto....26	1	Springhill....13	Cadomin (2)....19·0
Hillcrest (1)....25	1	[2]Comox....13	Coal Creek (1)....18·5
Michel (3)....24	1	[2]Pocohontas, U.S. (1)....13	Minto....18·5
Michel (1)....23	1	Blairmore (1)....13	Hillcrest (1)....18·5
[1]Luscar (3)....23	2	[1]Phalen (5)....12	Mountain Park (1)....18·0
Mountain Park (3)....23	2	[2]Hillcrest (1)....12	Chilton, U.S. (1)....17·5
Cadomin (2)....23	2	[1]Luscar (3)....12	[1]Luscar (3)....17·5
Mountain Park (1)....21	1	Brulé (1)....12	Brulé (3)....17·5
Brulé (3)....20	1	Cassidy....12	Mountain Park (3)....17·0
Coal Creek (1)....20	1	Brulé (2)....12	Springhill....16·5
Springhill....20	1	[2]Colemau (3)....12	Comox....16·5
Comox....20	1	[2]Hillcrest (2)....11	Michel (3)....16·0
Pocohontas, U.S. (1)....19	1	Stellarton (1)....11	Pocohontas, U.S. (1)....16·0
Blairmore (1)....19	1	[2]Minto....11	Blairmore (1)....16·0
Michel (2)....19	1	[2]Mountain Park (3)....11	Cadomin (1)....15·5
Michel (5)....17	1	Coleman (2)....11	Cassidy....14·0
Brulé (1)....16	1	Brulé (4)....11	Brulé (1)....14·0
Cadomin (1)....16	1	Luscar (1)....11	Michel (2)....13·5
Cassidy....16	1	Stellarton (2)....11	Brulé (2)....13·5
Michel (4)....16	1	[2]Blend as charged to com-	Coleman (2)....13·0
	1	mercial ovens, U.S....10	Coleman (3)....13·0
Brulé (2)....15	1	Pocohontas, U.S. (2)....10	Michel (5)....12·5
Coleman (2)....15	1	[2]Chilton, U.S. (1)....9	Brulé (4)....12·5
Brulé (4)....14	2	[2]Coleman (1)....9	Luscar (1)....12·5
Coleman (3)....14	1	Michel (3)....8	Michel (4)....12·0
Luscar (1)....14	1	Michel (2)....8	Coleman (1)....11·5
Coleman (1)....14	2	Michel (5)....8	Pocohontas, U.S. (2)....11·5
Pocohontas, U.S. (2)....13	1	Michel (4)....8	Stellarton (2)....11·5
Stellarton (2)....12	1	[2]Corbin (1)....7	Corbin (1)....8·5
Corbin (1)....10			

[1] Illium crucibles.

[2] Buttons stuck badly to crucibles, producing excessive powder.

TABLE IV

Caking Indices of Sections of Phalen Seam, Corresponding to Composite Sample 10

Thickness of section	Moisture %	Ash (dry basis) %	Sulphur (dry basis) %	Coking properties—platinum crucibles	Index at which button will support 500 grammes	Weight of powder, grammes, average
				Top of Seam		
2½"–3½"	1·4	34·3	18·3	Poor to fair; very little "sprouting".	23	1·86
2½"	1·3	17·5	9·6	Good; smaller than average.	36	1·74
3½"	1·4	24·3	9·9	Good; average; slight tendency to "sprouting".	36	1·68
5"	1·2	21·3	10·0	Good; smaller than average	37	2·06
4"	1·9	19·2	4·9	Fair to good; slight "sprouting".	37	2·35
3½"	1·9	10·8	4·1	Good; larger than average..	42	1·53
5"	1·5	10·6	3·2	Good; average.............	43	2·49
5½"	1·7	8·8	4·2	Good; larger than average..	42	2·04
3"	1·6	15·1	4·4	Good; smaller than average; slight tendency to "sprouting".	37	2·22
4½"	1·7	6·6	4·7	Good; larger than average..	43	2·39
3¾"	1·8	2·6	2·3	Good; much larger than average.	45	2·36
6"	1·8	4·7	3·1	Good; larger than average..	42	2·21
4"	1·8	11·5	4·7	Good; larger than average; slight tendency to "sprouting".	41	2·06
4½"	1·8	5·7	3·0	Good; much larger than average.	44	2·31
4½"	2·5	3·3	2·3	Good; larger than average..	43	2·02
4½"	2·3	3·1	2·4	Good; larger than average..	45	2·48
4¾"	2·4	6·2	4·4	Good; much larger than average.	43	2·15
4½"	2·1	3·9	3·2	Good; larger than average..	42	2·20
2¼"	1·8	9·7	4·4	" " " ..	39	2·16
3½"	1·6	12·4	9·3	" " " ..	40	2·56
4½"	2·3	9·2	5·5	Same as last, but very slight "sprouting".	37	2·29
2¾"	1·7	13·6	10·6	Good; larger than average..	37	2·18
2½"	1·3	18·8	14·5	Good; average.............	35	2·31
				Bottom of Seam		

TABLE V

Effects of Weathering upon Caking Indices

No.	Description of coal	Data of test, or duration of weathering	Moisture (air-dried) %	Ash (dry basis) %	Fuel ratio	Coking properties—platinum crucible	Index at which button will support 500 grammes	Weight of powder, grammes, average	Index at which powder not more than 5 per cent
				Platinum Crucible—Second Consignment of Sand					
4827	Dominion (sample 2), on ½-inch screen.	Fresh..........	2·6	7·2	1·50	Fair to good......................	40	1·85	29
4827	“ “ “ ..	After 12 months	2·6	8·9	1·65	Fair to good; much “sprouting”.....	29	2·14	22
4828	Dominion (sample 3), through ½-inch screen.	Fresh..........	2·7	8·6	1·75	Fair to good......................	35	2·54	23
4828	“ “ “ ..	After 12 months	2·2	8·2	1·70	Fair to good; much “sprouting”.....	25	1·85	23
4823	“Raven”, Pa., through ½-inch screen	Fresh..........	0·7	6·4	3·55	Good; much larger than average....	40	2·18	26
4823	“ “ “ ..	After 12 months	0·9	7·2	3·70	“ “ “	31	1·67	27
4825	Sewickley seam, W. Va., through ½-inch screen.	Fresh..........	1·2	10·5	1·30	Fair to good......................	45	1·98	40
4825	“ “ “ ..	After 12 months	1·5	10·5	1·40	Fair to good; dirty button; slight tendency to “sprouting”.	38	1·66	30
4826	Lower Kittanning seam, Pa., through ½-inch screen.	Fresh..........	0·8	8·9	3·20	Good; very much swollen..........	40	2·49	25
4826	“ “ “ ..	After 12 months	0·8	8·6	3·25	“ “ “	30	1·58	28
				Illium Crucible—Third Consignment of Sand					
5194 5196 5197	Dominion, screened run-of-mine, from storage pile (location 1).	July 24.......	2·3	7·7	1·70	Good; average.....................	54	4·17	18
5199 to 5203	Dominion, screened run-of-mine, fresh delivery to pile (location 2).	Aug. 13.......	2·4	8·4	1·70	Good; average size; slight “sprouting”.	65	4·26	20
5739 to 5742	Dominion, screened run-of-mine, from storage pile (location 2).	Jan. 16 to 21...	2·7	8·2	1·65	Fair to good; slight tendency to “sprouting”.	54	4·56	17
5777 to 5780	Dominion, screened run-of-mine, from storage pile (location 1).	Feb. 20 to 28...	3·6*	8·5	1·65	Fair; no “sprouting”...............	58	4·68	15
5870 to 5875	“ “ “ ..	April 8.......	3·5	8·3	1·65	Barely fair; tendency to “sprouting”	37	5·07	10

* This coal was probably not air-dried.

TABLE VI

Effects upon Caking Indices of Variations in the Inert Material or in the Type of Crucible

Description of coal	Description of inert	Crucible	(1) Index at which button will support 500 grammes	(2) Weight of powder corresponding to (1) — average, grammes	(3) Index at which powder not more than 5 per cent
Dominion (sample 2), unweathered	1st sand consignment	Platinum	47	2·30	....
“ “ “	2nd “	“	40	1·85	29
“ “ weathered	2nd “	“	29	2·14	22
“ “ “	2nd “	Illium	34	2·92	15
“ “ “	3rd “	“	49	3·90	19
Dominion (sample 3), unweathered	1st “	Platinum	39	2·56	25
“ “ “	2nd “	“	35	2·54	23
“ “ weathered	2nd “	“	25	1·85	23
“ “ “	3rd “	Illium	51	4·80	15
Phalen seam, (sample 5)	2nd “	“	22	1·06	22
“ “	3rd “	“	39	2·83	22
Raven, weathered	2nd “	Platinum	31	1·67	27
“ “	3rd “	Illium	53	2·95	31
Sewickley, weathered	2nd “	Platinum	38	1·66	30
“ “	3rd “	Illium	73	3·75	23
Lower Kittanning, weathered	2nd “	Platinum	30	1·55	28
“ “	3rd “	Illium	52	3·21	27
	All 3rd consignment				
*Blend as charged to commercial ovens	Untreated sand	Illium	44	3·45	27
“ “ “ “	40–50 mesh sand, leached 30 hrs., with hydrochloric	“	34	3·66	21
*Hillcrest (sample 2)	Untreated sand	“	33	3·34	22
“ “	40–50 mesh sand, leached 30 hrs.	“	24	2·80	19
*Blairmore (sample 3)	40–50 mesh sand, leached 2 days	“	33	2·62	24
“ “	40–50 mesh sand, leached 4 days	“	32	2·36	27
“ “	Unscreened sand, leached 3 days, then screened to 40–50 mesh.	“	33	2·36	24

TABLE VI—*Concluded*

Effects upon Caking Indices of Variations in the Inert Material or in the Type of Crucible—*Concluded*

Description of coal	Description of inert	Crucible	(1) Index at which button will support 500 grammes	(2) Weight of powder corresponding to (1) — average, grammes	(3) Index at which powder not more than 5 per cent
Dominion (sample 2), weathered	2nd sand consignment	Platinum	29	2·14	22
" " "	" "	Ilium	34	2·92	15
Hillcrest (sample 2)	" "	Platinum	29	1·11	30
" "	" "	Ilium	34	2·29	24
" "	2nd carbon "	Platinum	30	5·05	11
" "	" "	Ilium	34	5·81	11
Blairmore (sample 3)	2nd sand "	Platinum	28	1·92	23
" "	" "	Ilium	29	2·41	23
Luscar (sample 3)	" "	Platinum	24	0·83	28
" "	" "	Ilium	27	1·12	27
Mountain Park (sample 3)	" "	Platinum	25	1·49	24
" " "	" "	Ilium	27	1·36	24
" " "	2nd carbon "	Platinum	23	3·42	11
" " "	" "	Ilium	23	2·69	13
Cedar Grove	2nd sand "	Platinum	28	2·15	22
"	" "	Ilium	40	3·63	21
Freeport	" "	Platinum	36	2·06	24
"	" "	Ilium	38	2·46	26
"	2nd carbon "	Platinum	39	3·49	16
"	" "	Ilium	36	3·65	15
Blend as charged to commercial ovens	2nd sand "	Platinum	31	2·28	20
" " "	" "	Ilium	36	3·03	21
" " "	2nd carbon "	Platinum	32+	6·0 (approx.)	10
" " "	" "	Ilium	47	5·23	13

* These samples stood for some time as powder, and were therefore probably weathered.

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 year, and in most cases only such data as were asked for by the person submitting the sample are shown. They are tabulated under the three following group headings:—

1. (1) Solid fuels occurring in Canada.
2. (2) Coal samples submitted by the Department of Pensions and National Health.
3. (3) Miscellaneous solid fuels.

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

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 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, either for heating private residences or public buildings, or for various industrial purposes. Because of previous lack of information, stress has been laid upon cannel coals as used in household grates. All these are "commercial" samples. The group also contains two processed fuels which are manufactured on a commercial scale, and in addition two samples of low-temperature coke manufactured by the Illingworth process from "Dominion" coal from Glace Bay, Nova Scotia.

Whenever 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 analysis 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 1-gramme samples in closed platinum crucibles during the determination of volatile matter. These serve only as indications of the cokes to be expected from commercial ovens, and may occasionally be somewhat misleading.

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

TABLE I

Analyses of Solid Fuels Occurring in Canada

—	Dominion Coal Co., Ltd. (Besco), Glace Bay, Nova Scotia											
	Supplied to Fuel Research Laboratories through Department of Public Works										Supplied to Ottawa Public School Board	
Sample No.	5883		6476		6566		6658		6725		6296	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—												
Moisture.......per cent	3·6	....	3·7	....	5·5	....	5·1	....	7·2	....	2·2	....
Ash......."	10·6	11·0	9·7	10·1	8·5	9·0	8·5	8·9	7·8	8·4	6·7	6·9
Volatile matter......."	35·1	36·4	32·8	34·1	32·4	34·3	34·0	35·9	29·8	32·1	35·5	36·3
Fixed carbon......."	50·7	52·6	53·8	55·8	53·6	56·7	52·4	55·2	55·2	59·5	55·6	56·8
Ultimate Analysis—												
Sulphur.......per cent	3·6	3·7	3·8	3·9	3·1	3·2	3·2	3·3	2·9	3·1	2·9	3·0
Calorific Value—												
Calories per gramme, gross...	7,270	7,545	7,305	7,590	7,270	7,685	7,340	7,725	7,150	7,700	7,710	7,885
B.T.U. per pound, gross.......	13,090	13,580	13,150	13,660	13,080	13,830	13,210	13,910	12,870	13,860	13,880	14,190
Fuel ratio.......	1·45		1·65		1·65		1·55		1·85		1·55	
Coking properties.......	Fair		Good		Good		Fair		Good		Fair	
Designation of coal.......	Run-of-mine......		Run-of-mine......		Run-of-mine......		Run-of-mine......		Slack.......		Run-of-mine.	
Kind of sample.......	Commercial; approximately 100 tons monthly.......										Commercial.	
Taken by.......	W. Kritsch, laboratory assistant, Fuel Research Laboratories.......										Public School Board officials.	
Date of sampling.......	During April, 1929		During Nov., 1929		During Dec., 1929		During Jan., 1930.		During Feb., 1930		Sept., 1929.	

TABLE I—*Continued*

Analyses of Solid Fuels Occurring in Canada—*Continued*

—	Indian Cove Coal Co., Ltd., Sydney Mines, Nova Scotia		Tidewater Fuel and Navigation Company, Whiteside, Nova Scotia				Inverness Railway and Coal Company, Inverness, Nova Scotia				Victoria Coal Company, Ltd., New Glasgow, Nova Scotia; mine at River Hebert, Nova Scotia					
							No. 1 mine		No. 4 mine							
Sample No.	6620		5915		5916		6559		6350		6085		6790		6791	
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	....	1·5	....	1·6	....	3·0	....	7·6	....	2·8	....	2·6	....	3·0	....
Ash "	13·6	14·1	13·7	13·9	12·8	13·0	9·3	9·6	11·0	11·9	17·5	18·0	12·2	12·5	9·2	9·5
Volatile matter "	36·1	37·4	33·2	33·7	34·5	35·1	39·0	40·2	36·6	39·6	34·3	35·3	37·3	38·3	39·5	40·7
Fixed carbon "	46·8	48·5	51·6	52·4	51·1	51·9	48·7	50·2	44·8	48·5	45·4	46·7	47·9	49·2	48·3	49·8
Ultimate Analysis—																
Sulphur per cent	6·8	7·0	7·1	7·2	8·4	8·5	6·5	6·7	7·5	8·1	6·0	6·1	6·1	6·3	6·0	6·1
Calorific Value—																
Calories per gramme, gross	6,645	6,885	6,905	7,010	6,910	7,020	6,790	7,000	6,100	6,595	6,360	6,545	6,855	7,035	7,030	7,240
B.T.U. per pound, gross	11,960	12,390	12,430	12,620	12,440	12,640	12,220	12,600	10,980	11,870	11,450	11,780	12,340	12,660	12,650	13,040
Fuel ratio	1·30		1·55		1·50		1·25		1·20		1·30		1·30		1·25	
Coking properties	Fair		Poor		Poor		Fair		Poor		Fair		Fair		Fair	
Designation of coal											Probably run-of-mine.		Principally pea size		Principally buckwheat size	
Kind of sample	Commercial						Mine		Mine							
Location in mine			No. 1 seam		No. 2 seam		East end of 12th level		East end of 3rd level; 4-foot 6-inch bench in 13-foot seam							
Taken by	Dept. of National Defence		Private individual				Both by G. W. H. Norman, Geological Survey				Mine operators					
Date of sampling	During October, 1929		April, 1929				During autumn of 1929				June, 1929		January, 1930			

TABLE I—*Continued*

Analyses of Solid Fuels Occurring in Canada—*Continued*

—	Peat from Alfred, Ontario, prepared by machinery and partially dried.			Coal from near Roche Percée, Saskatchewan, N.W. ¼, sec. 24, tp. 1, R. 7, W. 2 mer.		Anderson mine, Estevan, Saskatchewan, sec. 28, tp. 1, R. 8, W. 2 mer.			Lee mine, Estevan, N.W. ¼, S.E. ¼, sec. 28, tp. 1, R. 8, W. 2 mer.			Underfinger mine, Estevan, N.W. ¼, S.W. ¼, sec. 7, tp. 2, R. 8, W. 2 mer.		
Sample No..................	6463			6633		6244			6243			6242		
Moisture condition...........	R	AD	D	R	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—														
Moisture...........per cent	46·9	24·5	....	32·5	....	34·1	19·3	....	36·6	18·8	....	34·3	18·4	....
Ash............... “	2·6	3·7	4·8	5·5	8·1	10·4	12·7	15·8	5·8	7·4	9·1	13·3	16·5	20·2
Volatile matter.... “	33·6	47·8	63·3	28·0	41·5	23·9	29·3	36·3	27·1	34·7	42·7	23·5	29·2	35·8
Fixed carbon....... “	16·9	24·0	31·9	34·0	50·4	31·6	38·7	47·9	30·5	39·1	48·2	28·9	35·9	44·0
Ultimate Analysis—														
Carbon............per cent	30·0	42·6	56·5	....	....	....	....	....	....	....	....	....	....	..
Hydrogen.......... “	8·1	6·7	5·3	....	....	....	....	....	....	....	....	....	....	....
Ash............... “	2·6	3·7	4·8	....	....	....	....	....	....	....	....	....	....	....
Sulphur............ “	0·1	0·2	0·2	0·4	0·6	0·2	0·3	0·3	0·5	0·7	0·8	1·2	1·5	1·8
Nitrogen........... “	1·1	1·6	2·2	....	....	....	....	....	....	....	....	....	....	....
Oxygen............ “	58·1	45·2	31·0	....	....	....	....	....	....	....	....	....	....	....
Calorific Value—														
Calories per gramme, gross	2,840	4,030	5,345	4,305	6,380	3,705	4,540	5,620	3,730	4,770	5,880	3,555	4,415	5,410
B.T.U. per pound, gross....	5,110	7,260	9,620	7,750	11,480	6,670	8,170	10,120	6,710	8,590	10,580	6,400	7,950	9,740
Fuel ratio...................	0·50			1·20		1·30			1·15			1·25		
Carbon-hydrogen ratio.......	3·7	6·3	10·7	....	....	....	....	....	....	....	....	....	....	....
Coking properties............	....			Non-coking		Non-coking			Non-coking			Non-coking.		
Kind of sample..............	Commercial; 5½ tons....			....		Mine....................			Mine....................			Mine.		
Location in mine............	....			....		Working face............			Abandoned entry.......			Working face.		
Taken by....................	Operators of bog........			Private individual.		R. L. Sutherland, University of North Dakota..........................								
Date of sampling............	Summer of 1928; Lab. sample Nov. 23, 1929.			January, 1930...		Summer of 1929..								

TABLE I—*Continued*

Analyses of Solid Fuels Occurring in Canada—*Continued*

—	Coal samples from Big Muddy valley in southern Saskatchewan														
	From N. E. ½, sec. 7, tp. 2, R. 22, W. 2 mer.									From west side of valley, sec. 4, tp. 2, R. 22, W. 2 mer.			West side of valley, north of Keogh ranch, N.E. ¼, sec. 4, tp. 2, R. 22, W. 2 mer.		
Sample No.	6493			6494			6495			6499			6497		
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—															
Moisture.....per cent	39·3	20·8	....	39·8	20·3	....	37·4	20·4	....	36·2	20·0	....	40·3	18·6	....
Ash "	6·3	8·2	10·3	7·6	10·1	12·7	9·2	11·7	14·7	6·6	8·3	10·4	8·3	11·3	13·8
Volatile matter "	27·8	36·3	45·8	26·5	35·1	44·0	26·6	33·9	42·6	26·0	32·7	40·8	25·5	34·8	42·8
Fixed carbon "	26·6	34·7	43·9	26·1	34·5	43·3	26·8	34·0	42·7	31·2	39·0	48·8	25·9	35·3	43·4
Ultimate Analysis—															
Sulphur.....per cent	....	....	....	0·8	1·0	1·2	0·2	0·3	0·4	0·5	0·6	0·8	....	....	....
Calorific Value—															
Calories per gramme, gross	....	....	....	3,100	4,110	5,155	....	....	....	3,350	4,200	5,255	....	....	....
B.T.U. per pound, gross	....	....	....	5,580	7,400	9,280	....	....	....	6,030	7,560	9,460	....	....	....
Fuel ratio	0·96			0·98			1·00			1·20			1·00		
Coking properties	Non-coking			Non-coking			Non-coking			Non-coking			Non-coking.		
Kind of sample	All prospect														
Location in deposit	3-foot 4-inch seam between Willowbunch clay member (as temporarily designated) and Keogh seam.			3-foot 5-inch seam, 15 feet above previous seam.			4-foot 2-inch and 2-foot 3-inch lower benches of seam of sample No. 6494.			Keogh seam			Keogh seam.		
Taken by	F. H. McLearn, Geological Survey														
Date of sampling	Summer of 1929														

TABLE I—*Continued*

Analyses of Solid Fuels Occurring in Canada—*Continued*

—	Coal samples from southern Saskatchewan											
	From west side of Big Muddy valley, north of Keogh ranch, N.E. ¼, sec. 4, tp. 2, R. 22, W. 2 mer.			From east side of road between St. Victor and Willowbunch, southernmost border of sec. 1, tp. 6, R. 29, W. 2 mer.						From east of Twelve Mile lake, top N.W. ¼, sec. 33, tp. 5, R. 30, W. 2 mer.		
Sample No.	6498			6491			6492			6478		
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—												
Moisture per cent	39·2	19·4	....	40·5	21·0	....	39·3	20·3	....	31·2	22·8	....
Ash "	8·3	11·0	13·7	7·2	9·6	12·1	8·8	11·6	14·6	8·2	9·2	12·0
Volatile matter "	28·0	37·1	46·0	27·1	35·9	45·5	25·6	33·6	42·1	30·9	34·7	44·9
Fixed carbon "	24·5	32·5	40·3	25·2	33·5	42·4	26·3	34·5	43·3	29·7	33·3	43·1
Ultimate Analysis—												
Sulphur per cent	0·9	1·1	1·4	0·6	0·9	1·1	0·3	0·4	0·5	0·5	0·6	0·8
Calorific Value—												
Calories per gramme, gross	2,920	3,870	4,800	2,830	3,755	4,755	2,720	3,570	4,480	3,360	3,780	4,890
B.T.U. per pound, gross	5,260	6,960	8,640	5,090	6,760	8,560	4,890	6,430	8,060	6,050	6,800	8,800
Fuel ratio	0·87			0·93			1·05			0·96		
Coking properties	Non-coking			Non-coking			Non-coking			Non-coking.		
Kind of sample	All prospect											
Location in deposit	2-foot 5-inch seam above Keogh seam.			1-foot 5-inch bottom bench in St. Victor seam.			3-foot 2-inch coal of bottom bench of seam above St. Victor seam.			Kreig, 1-foot 3-inch seam.		
Taken by	F. H. McLearn, Geological Survey											
Date of sampling	Summer of 1929											

TABLE I—*Continued*

Analyses of Solid Fuels Occurring in Canada—*Continued*

—	Coal samples from southern Saskatchewan														
	From north of St. Victor and east of N.S. road			From south side of valley, west of St. Victor, central east part of sec. 12, tp. 6, R. 30, W. 2 mer.						From east side of Twelve Mile lake, south side of road, S.E. corner, sec. 3, tp. 6, R. 1, W. 3 mer.			From Rocky creek, sec. 14, tp. 1, R. 5, W. 3 mer.		
Sample No.	6487			6488			6489			6484			6483		
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—															
Moisture . . . per cent	44·0	20·5	....	38·5	22·0	....	40·2	21·7	....	39·0	22·8	....	31·5	19·3	....
Ash "	9·3	13·2	16·6	10·8	13·7	17·6	8·4	10·9	14·0	12·2	15·4	20·0	12·8	15·0	18·6
Volatile matter "	25·8	36·7	46·1	23·8	30·2	38·7	27·6	36·2	46·2	27·7	35·1	45·4	28·1	33·2	41·1
Fixed carbon "	20·9	29·6	37·3	26·9	34·1	43·7	23·8	31·2	39·8	21·1	26·7	34·6	27·6	32·5	40·3
Ultimate Analysis—															
Sulphur . . . per cent	0·9	1·3	1·7	0·9	1·2	1·5	1·1	1·4	1·8	....	....	....	0·4	0·5	0·6
Calorific Value—															
Calories per gramme, gross	2,415	3,430	4,305	2,755	3,500	4,485	2,650	3,470	4,435	....	....	....	3,160	3,725	4,610
B.T.U. per pound, gross	4,350	6,170	7,750	4,960	6,300	8,070	4,770	6,250	7,980	....	....	....	5,690	6,710	8,300
Fuel ratio	0·81			1·15			0·85			0·76			0·98		
Coking properties	Non-coking			Non-coking			Non-coking			Non-coking			Non-coking		
Kind of sample	All prospect														
Location in deposit	1-foot 5½-inch and 1-foot 10-inch benches of St. Victor seam			3-foot seam in buff beds of Upper Ravenscrag formation			1-foot 4-inch seam, 18 feet below previous seam			Kreig, 1-foot 4½-inch seam			2-foot 4½-inch coal with 2-inch parting, or lowest of 3 seams		
Taken by	F. H. McLearn, Geological Survey														
Date of sampling	Summer of 1929														

TABLE I—*Continued*

Analyses of Solid Fuels Occurring in Canada—*Continued*

—	Cadomin Coal Co., Ltd., No. 693, Cadomin, Alberta, sec. 31, tp. 46, R. 23, W. 5 mer.		From No. 2 seam, tp. 52, R. 3, W. 6 mer., Brulé area, Alberta											
			W. Talbot claim; from 3,000 feet S.E. of Somme creek											
Sample No.	6247		6426			6427			6428			6431		
Moisture condition	R	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—														
Moisture per cent	1·4	....	7·7	4·6	....	8·9	5·1	....	9·0	5·2	....	9·1	6·4	....
Ash "	14·4	14·6	11·7	12·7	12·7	10·7	11·1	11·7	16·8	17·5	18·4	7·2	7·4	7·9
Volatile matter "	24·6	24·9	24·8	25·7	26·9	24·8	25·9	27·3	23·4	24·4	25·8	25·4	26·2	28·0
Fixed carbon "	59·6	60·5	55·8	57·6	60·4	55·6	57·9	61·0	50·8	52·9	55·8	58·3	60·0	64·1
Ultimate Analysis—														
Sulphur per cent	0·3	0·3	0·5	0·5	0·5	0·3	0·3	0·3	0·3	0·3	0·3	0·2	0·2	0·2
Calorific Value—														
Calories per gramme, gross	7,205	7,305	6,295	6,505	6,820	6,200	6,455	6,805	5,600	5,815	6,140	....	....	....
B.T.U. per pound, gross	12,970	13,150	11,330	11,710	12,280	11,160	11,620	12,250	10,080	10,470	11,050	....	....	....
Fuel ratio	2·40		2·25			2·25			2·15			2·30		
Coking properties	Fair		Weak agglomerate			Non-coking			Non-coking			Non-coking		
Kind of sample	Commercial....		All prospect											
Location in deposit	....		No. 16 prospect tunnel, M limb east from North Hay river; seam 48 feet, 6 inches thick											
Designation of coal	....		3 feet, 11 inches comprising 4 bands of varying hardness			4 feet, 2 inches comprising 5 bands of varying hardness			4 feet comprising 6 bands of varying hardness			2 feet comprising 3 bands of varying hardness		
Taken by	Under direction of Board of Railway Commissioners.		B. R. MacKay, Geological Survey											
Date of sampling	Summer of 1929.		October 1, 1929											

TABLE I—*Continued*

Analyses of Solid Fuels Occurring in Canada—*Continued*

—	From No. 2 seam, tp. 52, R. 3, W. 6 mer., Brulé area, Alberta																				
	W. Talbot claim; from 3,000 feet S.E. of Somme creek																				
Sample No.	6432			6433			6434			6435			6436			6438			6439		
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 p.c.	11·4	5·8	....	7·9	4·2	....	11·6	6·4	....	11·2	5·7	....	10·3	5·6	....	15·1	9·7	....	14·3	8·3	....
Ash "	9·3[1]	9·9	10·5	9·3	9·7	10·1	11·5	12·2	13·0	15·1	16·1	17·0	9·7	10·2	10·8	7·3	7·8	8·6	6·0	6·4	7·0
Volatile matter "	22·0[1]	23·3	24·8	22·5	23·4	24·4	22·4[1]	23·8	25·4	20·5[1]	21·8	23·1	24·4	25·7	27·2	21·5[1]	22·8	25·3	21·9[1]	23·5	25·6
Fixed carbon "	57·3	61·0	64·7	60·3	62·7	65·5	54·5	57·6	61·6	53·2	56·4	59·9	55·6	58·5	62·0	56·1	59·7	66·1	57·8	61·8	67·4
Ultimate Analysis—																					
Sulphur p.c.	0·2	0·2	0·2	0·2	0·2	0·2	0·4	0·4	0·5	0·3	0·3	0·3	0·2	0·2	0·2	0·1	0·2	0·2	0·2	0·2	0·2
Calorific Value—																					
Calories per gramme, gross	6,060	6,440	6,840	....	....	....	5,740	6,080	6,500	....	....	....	6,095	6,415	6,795	5,615	5,975	6,615	....	....	....
B.T.U. per pound, gross	10,900	11,590	12,310	....	....	....	10,330	10,950	11,700	....	....	....	10,970	11,550	12,230	10,110	10,760	11,910	....	....	....
Fuel ratio	2·60[1]			2·70			2·45[1]			2·60[1]			2·30			2·60[1]			2·65[1]		
Coking properties	Non-coking			Non-coking			Non-coking			Non-coking			Non-coking			Non-coking			Non-coking.		
Kind of sample	All prospect																				
Location in deposit	No. 16 prospect tunnel, M limb east from North Hay river; seam 48 feet, 6 inches thick																				
Designation of coal	3 feet 1 inch, comprising 5 bands of varying hardness.			1 foot 5 inches of soft coal.			3 feet 1 inch of soft coal.			2 feet 5 inches of hard, crisp coal.			2 feet 5 inches of hard, crisp coal.			2 feet 6 inches of hard, crisp coal.			1 foot 11 inches of hard, crisp coal.		
Taken by	B. R. MacKay, Geological Survey																				
Date of sampling	October 1, 1929																				

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[1] Rapid heating of this coal caused loss by sparking; therefore, slow initial heating was employed in the determination of volatile matter, as is done with coals of low rank.

TABLE I—*Continued*

Analyses of Solid Fuels Occurring in Canada—*Continued*

—	From No. 2 seam, tp. 52, R. 3, W. 6 mer., Brulé area, Alberta														
	W. Talbot claim; from between Somme and Steer creeks, at an elevation of 5,920 feet														
Sample No.	6417			6418			6419			6421			6422		
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—															
Moisture per cent	7·1	2·5	....	7·7	1·9	....	8·6	1·3	....	6·5	1·5	....	7·0	1·5	....
Ash "	9·0	9·5	9·7	13·4	14·2	14·5	15·6	16·9	17·1	13·5	14·2	14·4	10·0	10·5	10·7
Volatile matter "	24·6	25·8	26·5	23·4	24·9	25·4	22·5	24·3	24·6	23·9	25·2	25·6	23·7	25·1	25·5
Fixed carbon "	59·3	62·2	63·8	55·5	59·0	60·1	53·3	57·5	58·3	56·1	59·1	60·0	59·3	62·9	63·8
Ultimate Analysis—															
Sulphur per cent	0·4	0·5	0·5	0·3	0·4	0·4	0·4	0·4	0·4	0·9	0·9	0·9	0·4	0·4	0·4
Calorific Value—															
Calories per gramme, gross	6,880	7,230	7,410	6,535	6,940	7,080	6,500	7,020	7,115	6,845	7,215	7,320	7,115	7,535	7,650
B.T.U. per pound, gross	12,380	13,010	13,330	11,760	12,500	12,740	11,700	12,640	12,810	12,320	12,980	13,180	12,810	13,560	13,770
Fuel ratio	2·40			2·35			2·35			2·35			2·50		
Coking properties	Agglomerate			Agglomerate			Poor			Poor			Poor		
Kind of sample	All prospect														
Location in deposit	No. 12 prospect tunnel, M limb east from North Hay river; seam 37 feet 10 inches thick														
Designation of coal	4 feet 7 inches of hard, crisp coal			6 feet 4 inches, hard and soft band, of coal			4 feet 6 inches, comprising 5 bands of varying hardness			3 feet 8 inches, comprising 2 equal bands of different hardness			3 feet 2 inches, comprising 5 bands of varying hardness		
Taken by	B. R. MacKay, Geological Survey														
Date of sampling	September 29, 1929														

TABLE I—*Continued*

Analyses of Solid Fuels Occurring in Canada—*Continued*

—	From No. 2 seam, tp. 52, R. 3, W. 6 mer., Brulé area, Alberta														
	W. Talbot claim; from between Somme and Steer creeks, at an elevation of 5,920 feet									A. McDougall claim; from ½ mile east of Claim creek					
Sample No.	6423			6424			6425			6392			6393		
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—															
Moisture .... per cent	7·3	1·6	....	8·9	1·5	....	8·2	2·0	....	6·8	2·9	....	6·9	2·6	....
Ash .... "	18·8	19·9	20·2	6·9	7·4	7·5	4·5	4·7	4·8	10·4	10·8	11·1	13·7	14·3	14·7
Volatile matter ...... "	22·4	23·8	24·2	23·0	24·9	25·3	23·8	25·5	26·0	25·6	26·7	27·5	25·2	26·4	27·1
Fixed carbon .... "	51·5	54·7	55·6	61·2	66·2	67·2	63·5	67·8	69·2	57·2	59·6	61·4	54·2	56·7	58·2
Ultimate Analysis—															
Sulphur .... per cent	0·2	0·3	0·3	0·2	0·3	0·3	0·3	0·3	0·4	0·3	0·3	0·3	0·3	0·3	0·3
Calorific Value—															
Calories per gramme, gross	6,215	6,600	6,705	7,000	7,570	7,685	7,295	7,780	7,940	6,630	6,905	7,110	6,400	6,700	6,875
B.T.U. per pound, gross	11,190	11,880	12,070	12,600	13,620	13,830	13,130	14,010	14,300	11,930	12,430	12,800	11,520	12,060	12,380
Fuel ratio	2·30			2·65			2·65			2·25			2·15		
Coking properties	Poor			Poor			Agglomerate			Non-coking			Agglomerate		
Kind of sample	All prospect														
Location in deposit	No. 12 prospect tunnel, M limb east from North Hay river; seam 37 feet 10 inches thick									No. 6 prospect tunnel, M limb east from North Hay river; seam 32 feet 2 inches thick					
Designation of coal	2 feet 8 inches, comprising 2 bands of different hardness			3 feet 6 inches, comprising 2 bands of different hardness			1 foot 3 inches of hard, crisp coal			3 feet of hard coal			2 feet 4 inches of very hard coal		
Taken by	B. R. MacKay, Geological Survey														
Date of sampling	September 29, 1929									September 23, 1929					

TABLE I—*Continued*

Analyses of Solid Fuels Occurring in Canada—*Continued*

—	From No. 2 seam, tp. 52, R. 3, W. 6 mer., Brulé area, Alberta																	
	A. McDougall claim; from ½ mile east of Claim creek																	
Sample No.	6395			6396			6397			6398			6399			6401		
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—																		
Moisture p.c.	6·1	3·1	....	8·0	3·7	....	13·0	3·2	....	12·7	3·3	....	10·5	2·9	....	7·6	3·6	....
Ash "	17·6	18·1	18·7	6·4	6·7	7·0	11·0	12·2	12·6	8·7	9·6	9·9	9·1	9·9	10·2	7·5	7·8	8·1
Volatile matter "	23·3	24·1	24·9	26·3	27·6	28·6	23·8	26·5	27·4	22·7	25·1	26·0	23·8	25·8	26·6	26·2	27·3	28·3
Fixed carbon "	53·0	54·7	56·4	59·3	62·0	64·4	52·2	58·1	60·0	55·9	62·0	64·1	56·6	61·4	63·2	58·7	61·3	63·6
Ultimate Analysis—																		
Sulphur p.c.	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·3	0·3	0·3	0·6	0·6	0·6
Calorific Value—																		
Calories per gramme, gross	....	....	....	....	....	....	6,180	6,870	7,100	....	....	....	....	....	....	6,760	7,050	7,315
B.T.U. per pound, gross	....	....	....	....	....	....	11,120	12,370	12,780	....	....	....	....	....	....	12,170	12,690	13,170
Fuel ratio	2·25			2·25			2·20			2·45			2·40			2·25		
Coking properties	Non-coking			Agglomerate			Weak agglomerate			Non-coking			Weak agglomerate			Weak agglomerate.		
Kind of sample	All prospect																	
Location in deposit	No. 6 prospect tunnel, M limb east from North Hay river; seam 32 feet 2 inches thick																	
Designation of coal	1 foot 3 inches of hard coal.			9 inches of bright, crisp coal.			3 feet 9 inches of coal in hard and soft bands.			2 feet 1 inch of mostly soft coal.			1 foot 3 inches of soft, bright coal.			2 feet 4 inches of hard, crisp, bright coal.		
Taken by	B. R. MacKay, Geological Survey																	
Date of sampling	September 23, 1929																	

TABLE I—*Continued*

Analyses of Solid Fuels Occurring in Canada—*Continued*

—	From No. 2 seam, tp. 52, R. 3, W. 6 mer., Brulé area, Alberta																	
	A. McDougall claim; from ½ mile east of Claim creek																	
Sample No.	6403			6405			6406			6407			6408			6409		
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—																		
Moisture p.c.	8·1	3·1	....	7·7	3·3	....	7·5	3·1	....	11·7	4·4	....	15·8	5·6	....	12·4	5·1	....
Ash "	17·5	18·4	19·0	10·7	11·2	11·6	11·1	11·6	12·0	7·6	8·2	8·6	5·8	6·5	6·9	3·5	3·8	4·0
Volatile matter "	23·7	25·0	25·8	24·1	25·3	26·1	24·2	25·4	26·2	24·6	26·6	27·9	21·2[1]	23·8	25·2	26·3	28·5	30·0
Fixed carbon "	50·7	53·5	55·2	57·5	60·2	62·3	57·2	59·9	61·8	56·1	60·8	63·5	57·2	64·1	67·9	57·8	62·6	66·0
Ultimate Analysis—																		
Sulphur p.c.	0·5	0·6	0·6	0·3	0·3	0·3	0·2	0·3	0·3	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·3	0·3
Calorific Value—																		
Calories per gramme, gross	5,815	6,135	6,330	....	....	....	6,495	6,805	7,020	6,195	6,710	7,015	....	....	....	6,420	6,940	7,315
B.T.U. per pound, gross	10,470	11,040	11,390	....	....	....	11,690	12,250	12,640	11,150	12,080	12,630	....	....	....	11,560	12,490	13,170
Fuel ratio	2·15			2·40			2·35			2·30			2·70[1]			2·20		
Coking properties	Non-coking			Non-coking			Non-coking			Non-coking			Non-coking			Non-coking		
Kind of sample	All prospect																	
Location in deposit	No. 6 prospect tunnel, M limb east from North Hay river; seam 32 feet 2 inches thick																	
Designation of coal	8 inches of bright, very hard coal.			2 feet 5 inches of hard, bright, crisp coal.			3 feet 10 inches of very hard, bright coal.			1 foot 10 inches of hard, crisp coal.			7 inches of soft, broken coal.			10 inches of very hard coal.		
Taken by	B. R. MacKay, Geological Survey																	
Date of sampling	September 23, 1929																	

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[1] Rapid heating of this coal caused loss by sparking; therefore, slow initial heating was employed in the determination of volatile matter, as is done with coals of low rank.

TABLE I—*Continued*

Analyses of Solid Fuels Occurring in Canada—*Continued*

—	From No. 2 seam, tp. 52, R. 3, W. 6 mer., Brulé area, Alberta																	
	J. Errington claim; from west side of Claim creek																	
Sample No.	6376			6377			6378			6380			6382			6383		
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—																		
Moisture p.c.	10·0	4·4	....	17·4	7·9	....	8·7	3·2	....	10·6	3·7	....	16·5	2·2	....	11·9	3·4	....
Ash "	15·4	16·3	17·1	9·0	10·1	11·0	12·9	13·7	14·1	15·0	16·2	16·8	16·1	18·8	19·2	12·0	13·2	13·7
Volatile matter "	23·8	25·3	26·4	22·7	25·3	27·4	24·0	25·4	26·3	23·6	25·4	26·4	21·2	24·8	25·4	24·2	26·6	27·5
Fixed carbon "	50·8	54·0	56·5	50·9	56·7	61·6	54·4	57·7	59·6	50·8	54·7	56·8	46·2	54·2	55·4	51·9	56·8	58·8
Ultimate Analysis—																		
Sulphur p.c.	0·5	0·5	0·5	0·2	0·3	0·3	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2
Calorific Value—																		
Calories per gramme, gross	....	....	....	5,505	6,140	6,665	6,310	6,690	6,910	....	....	....	5,650	6,620	6,765	6,105	6,695	6,930
B.T.U. per pound, gross	....	....	....	9,910	11,050	12,000	11,360	12,050	12,440	....	....	....	10,170	11,910	12,180	10,990	12,050	12,480
Fuel ratio	2·15			2·25			2·25			2·15			2·20			2·15		
Coking properties	Non-coking			Non-coking			Weak agglomerate			Non-coking			Poor			Weak agglomerate		
Kind of sample	All prospect																	
Location in deposit	No. 1 prospect tunnel, M limb east from North Hay river; seam 38 feet 4 inches thick																	
Designation of coal	1 foot 11 inches of crisp coal.			11 inches of soft, powdery coal.			2 feet 7 inches of hard, crisp, clean coal.			1 foot 1 inch of hard coal.			6 inches of dull, soft, coaly shale.			3 feet 2 inches of bright, crisp coal.		
Taken by	B. R. MacKay, Geological Survey																	
Date of sampling	August 21, 1929																	

TABLE I—*Continued*

Analyses of Solid Fuels Occurring in Canada—*Continued*

—	From No. 2 seam, tp. 52, R. 3, W. 6 mer., Brulé area, Alberta														
	J. Errington claim; from west side of Claim creek														
Sample No	6384			6385			6386			6387			6388		
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—															
Moisture ....per cent	10·5	2·1	....	8·1	1·5	....	8·0	3·2	....	11·6	5·4	....	14·0	6·9	....
Ash .... "	7·1	7·8	7·9	11·5	12·3	12·5	8·0	8·5	8·8	12·3	13·2	13·9	12·7	13·8	14·8
Volatile matter ...... "	24·5	26·8	27·4	23·6	25·3	25·7	24·6	25·9	26·7	23·0	24·6	26·1	22·2[1]	24·0	25·8
Fixed carbon .... "	57·9	63·3	64·7	56·8	60·9	61·8	59·4	62·4	64·5	53·1	56·8	60·0	51·1	55·3	59·4
Ultimate Analysis—															
Sulphur .... "	0·2	0·2	0·2	0·2	0·2	0·2	0·4	0·4	0·4	0·3	0·3	0·3	0·2	0·2	0·2
Calorific Value—															
Calories per gramme, gross...	6,945	7,570	7,730	....	....	....	6,740	7,090	7,320	5,715	6,115	6,460	....	....	....
B.T.U. per pound, gross......	12,500	13,620	13,910	....	....	....	12,130	12,760	13,180	10,290	11,000	11,630	....	....	....
Fuel ratio	2·35			2·40			2·40			2·30			2·30[1]		
Coking properties	Agglomerate			Agglomerate			Non-coking			Non-coking			Non-coking		
Kind of sample	All prospect														
Location in deposit	No. 1 prospect tunnel, M limb east from North Hay river; seam 38 feet 4 inches thick														
Designation of coal	1 foot 10 inches of soft, broken coal			11 inches and 1 foot 4 inches of soft coal; omitting 5 inches of clay parting			3 feet 8 inches of hard coal			4 feet 1 inch of hard coal			4 feet 6 inches of mostly hard coal		
Taken by	B. R. MacKay, Geological Survey														
Date of sampling	August 21, 1929														

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[1] Rapid heating of this coal caused loss by sparking; therefore, slow initial heating was employed in the determination of volatile matter, as is done with coals of low rank.

TABLE I—*Continued*

Analyses of Solid Fuels Occurring in Canada—*Continued*

—	From No. 2 seam, tp. 52, R. 3, W. 6 mer., Brulé area, Alberta																				
	J. Errington claim; from west side of Claim creek						Bickell claim; from 2,200 feet northwest of 41-mile creek														
Sample No.	6389			6390			6410			6411			6412			6414			6415		
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 p.c.	12·5	4·7	....	10·2	5·0	....	14·7	6·9	....	18·0	7·8	....	19·6	8·3	....	22·5	10·6	—	17·6	16·1	....
Ash "	8·9	9·6	10·1	8·0	8·5	8·9	8·8	9·6	10·3	14·4	16·1	17·5	11·8	13·4	14·6	10·5	12·1	13·5	9·6	9·7	11·6
Volatile matter "	21·2	23·2	24·3	25·5	26·9	28·3	22·9[1]	25·0	26·9	20·4[1]	23·0	24·9	20·9[1]	23·8	26·0	20·2[1]	23·3	26·1	24·2[1]	24·7	29·4
Fixed carbon "	57·4	62·5	65·6	56·3	59·6	62·8	53·6	58·5	62·8	47·2	53·1	57·6	47·7	54·5	59·4	46·8	54·0	60·4	48·6	49·5	59·0
Ultimate Analysis—																					
Sulphur p.c.	0·2	0·2	0·2	0·2	0·2	0·2	0·3	0·3	0·3	0·2	0·2	0·2	0·1	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2
Calorific Value—																					
Calories per gramme, gross	5,985	6,515	6,840	6,280	6,645	6,995	5,615	6,130	6,590	......	......	......	4,860	5,525	6,020	....	....	....	4,935	5,025	5,990
B.T.U. per pound, gross	10,770	11,730	12,310	11,300	11,960	12,590	10,110	11,030	11,760	....	....	....	8,740	9,940	10,840	....	....	....	8,890	9,040	10,780
Fuel ratio	2·70			2·20			2·35[1]			2·30[1]			2·30[1]			2·30[1]			2·00[1]		
Coking properties	Non-coking			Non-coking			Non-coking			Non-coking			Non-coking			Non-coking			Non-coking		
Kind of sample	All prospect																				
Location in deposit	No. 1 prospect tunnel, M limb east from North Hay river; seam 38 feet, 4 inches thick.						Prospect trench, K limb; seam 27 feet, 4 inches thick														
Designation of coal	10 inches of soft coal			1 foot 10 inches of hard, crisp, bright coal.			3 feet 7 inches, comprising 4 bands of varying appearance.			4 feet 5 inches, comprising 2 bands of bright, soft coal, 1 band of carbonaceous shale and 1 band of shale and coal.			3 feet comprising 2 bands of coal and 1 band of shale and clay.			4 feet 6 inches of rather soft, bright coal.			5 feet 2 inches of soft, powdery coal.		
Taken by	B. R. MacKay, Geological Survey																				
Date of sampling	August 21, 1929						September 25, 1929														

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[1] Rapid heating of this coal caused loss by sparking; therefore, slow initial heating was employed in the determination of volatile matter, as is done with coals of low rank.

TABLE I—*Continued*

Analyses of Solid Fuels Occurring in Canada—*Continued*

—	From National Coal Reserve, Smoky River area, Alberta															
	Adam Joachim claim, lease No. 1048, tp. 56, R's. 8 and 9, W. 6 mer.			From "First" gulch, north of Gustave's flats on Smoky river, tp. 57, R. 8, W. 6 mer.			Moyes claim, lease No. 1674, tps. 57 and 58, R. 9, W. 6 mer.				Campbell claim, lease No. 917, tp. 58, R. 9, W. 6 mer.					
Sample No.	6449			6450			6448		6447		6441			6442		
Moisture condition	R	AD	D	R	AD	D	AD	D	AD	D	R	AD	D	R	AD	D
Proximate Analysis—																
Moisture p.c.	10·5	6·0	....	10·1	4·3	....	2·3	....	2·0	....	4·4	2·7	....	4·6	2·3	....
Ash "	5·3	5·6	5·9	9·0	9·6	10·0	9·7	9·9	5·0	5·1	7·0	7·1	7·3	4·0	4·1	4·2
Volatile matter "	31·9	33·5	35·7	16·4	17·5	18·3	17·2	17·6	18·2	18·5	17·7	18·0	18·5	18·3	18·7	19·1
Fixed carbon "	52·3	54·9	58·4	64·5	68·6	71·7	70·8	72·5	74·8	76·4	70·9	72·2	74·2	73·1	74·9	76·7
Ultimate Analysis—																
Sulphur p.c.	0·3	0·3	0·4	0·5	0·5	0·6	0·4	0·4	0·5	0·5	0·4	0·4	0·4	0·3	0·4	0·4
Calorific Value—																
Calories per gramme, gross	6,215	6,530	6,945	6,360	6,760	7,065	7,230	7,400	7,750	7,910	7,210	7,320	7,525	7,615	7,800	7,985
B.T.U. per pound, gross	11,190	11,750	12,500	11,430	12,160	12,720	13,020	13,320	13,950	14,240	12,950	13,180	13,540	13,710	14,040	14,370
Fuel ratio	1·65			3·95			4·10		4·10		4·00			4·00		
Coking properties	Non-coking			Non-coking			Non-coking		Weak agglomerate		Non-coking			Very weak agglomerate.		
Kind of sample	All prospect															
Location in deposit	13-foot seam on west side of Smoky river opposite to canyon of Sulphur river.			7-foot seam, 75 feet stratigraphically above the conglomerate.			8-foot seam, east side of claim, directly opposite to, and west of, east post of claim.		14-foot seam, ¼ mile north of trail crossing and ¼ mile west of Sheep Creek trail.		Samples taken from top to bottom across 14-foot seam, at east side of claim, near east lobstick on Sheep creek.					
Taken by	B. R. MacKay, Geological Survey															
Date of sampling	September, 1929															

TABLE I—*Continued*

Analyses of Solid Fuels Occurring in Canada—*Continued*

—	Campbell claim, lease No. 917, tp. 58, R. 9, W. 6 mer., National Coal Reserve, Smoky River area, Alberta															Shorts Creek coal deposit; west of Okanagan lake, 16 miles north of Kelowna at elevation of 3,360 feet; ½ mile north of, and 1,100 feet above, Shorts creek, British Columbia.	
Sample No.	6443			6444			6445			6446			6440			6351	
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	D
Proximate Analysis—																	
Moisture p.c.	6·2	2·4	....	8·3	2·9	....	8·0	2·9	....	4·1	2·1	....	5·9	2·5	....	2·8	....
Ash "	3·7	3·9	4·0	2·7	2·9	3·0	13·7	14·5	14·9	9·9	10·1	10·3	4·2	4·3	4·4	30·1	31·0
Volatile matter "	17·7	18·5	19·0	18·1	19·1	19·7	17·7	18·7	19·2	14·9	15·2	15·5	17·7	18·3	18·8	28·4	29·2
Fixed carbon "	72·4	75·2	77·0	70·9	75·1	77·3	60·6	63·9	65·9	71·1	72·6	74·2	72·2	74·9	76·8	38·7	39·8
Ultimate Analysis—																	
Sulphur p.c.	0·4	0·4	0·4	0·5	0·5	0·6	0·6	0·7	0·7	0·5	0·5	0·5	0·4	0·4	0·4	0·4	0·4
Calorific Value—																	
Calories per gramme, gross	7,440	7,735	7,930	7,230	7,655	7,880	6,210	6,560	6,750	7,045	7,190	7,350	7,410	7,675	7,870	5,690	5,850
B.T.U. per pound, gross	13,390	13,930	14,270	13,010	13,780	14,190	11,180	11,800	12,150	12,690	12,950	13,230	13,340	13,820	14,160	10,240	10,530
Fuel ratio	4·05			3·95			3·40			4·80			4·10			1·35	
Coking properties	Very weak agglomerate.			Non-coking			Non-coking			Non-coking			Very weak agglomerate.			Poor.	
Kind of sample	All prospect															Prospect from previously opened workings.	
Location in deposit	Samples taken from top to bottom across 14-foot seam, at east side of claim, near east lobstick on Sheep creek.												14-foot seam at east lobstick, on east side of Sheep creek.			From near west side face, incline adit; 16 inches of best coal in 3-foot seam	
Taken by	B. R. MacKay, Geological Survey															C. E. Cairnes, Geological Survey.	
Date of sampling	September, 1929															Season of 1929.	

TABLE I—*Continued*

Analyses of Solid Fuels Occurring in Canada—*Continued*

—	Pleasant Valley Mining Co., Ltd., Princeton, British Columbia						Tulameen Coal Mines, Ltd., Princeton, British Columbia			Coalmont Collieries, Ltd., Coalmont, British Columbia					
Sample No.	6469			6475			6470			6659			6736		
Moisture condition	R	AD	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—															
Moisture......per cent	24·2	19·8	....	25·7	20·3	....	21·1	17·8	....	7·7	4·1	....	8·2	4·3	....
Ash "	13·3	14·0	17·5	4·6	4·9	6·2	8·6	8·9	10·9	13·0	13·5	14·1	11·6	12·1	12·6
Volatile matter "	26·0	27·6	34·4	32·3	34·7	43·5	28·9	30·1	36·6	34·0	35·3	36·8	32·8	34·2	35·8
Fixed carbon "	36·5	38·6	48·1	37·4	40·1	50·3	41·4	43·2	52·5	45·3	47·1	49·1	47·4	49·4	51·6
Ultimate Analysis—															
Carbon......per cent	47·2	49·9	62·3	....	....	....	54·2	56·5	68·7	63·7	66·2	69·0	64·5	67·2	70·2
Hydrogen "	5·9	5·6	4·2	....	....	....	5·9	5·7	4·5	5·2	5·0	4·7	5·3	5·1	4·8
Ash "	13·3	14·0	17·5	....	....	....	8·6	8·9	10·9	13·0	13·5	14·1	11·6	12·1	12·6
Sulphur "	0·7	0·7	0·9	0·5	0·5	0·7	0·3	0·4	0·4	0·4	0·4	0·4	0·4	0·4	0·4
Nitrogen "	1·3	1·4	1·7	....	....	....	1·6	1·6	2·0	1·3	1·3	1·4	1·3	1·3	1·4
Oxygen "	31·6	28·4	13·4	....	....	....	29·4	26·9	13·5	16·4	13·6	10·4	16·9	13·9	10·6
Calorific Value—															
Calories per gramme, gross	4,530	4,795	5,980	5,200	5,580	7,000	5,210	5,430	6,605	6,220	6,460	6,740	6,255	6,520	6,810
B.T.U. per pound, gross	8,160	8,630	10,770	9,360	10,040	12,600	9,380	9,770	11,890	11,190	11,630	12,130	11,260	11,730	12,260
Fuel ratio		1·40			1·15			1·45			1·35			1·45	
Carbon-hydrogen ratio	8·0	9·0	14·9	....	....	....	9·1	9·9	15·2	12·3	13·3	14·7	12·2	13·3	14·7
Coking properties	Non-coking			Agglomerate			Non-coking			Poor			Poor		
Designation of coal	Lump						Run-of-mine			Run-of-mine					
Kind of sample	Commercial; ½ carload						Commercial; ½ carload			Commercial; carload					
Location in mine	No. 1, or Mullin, seam			New west mine; No. 2 seam											
Taken by	All by mine operators														
Date of sampling	Nov. 12, 1929; lab. sample, Nov. 28, 1929			Nov. 12, 1929			Nov. 12, 1929; lab. sample, Nov. 28, 1929			January 11, 1930 Lab. sample, Feb. 4, 1930			Lab. sample, Mar. 6, 1930		

TABLE I—*Concluded*

Analyses of Solid Fuels Occurring in Canada—*Concluded*

—	Middlesboro Collieries, Ltd., Merritt, British Columbia								Canadian Collieries (Dunsmuir), Ltd., Nanaimo, British Columbia					
									Wellington, No. 5 mine, South Wellington			Reserve mine, Nanaimo		
Sample No.	6280		6565			6714			6722			6721		
Moisture condition	R	D	R	AD	D	R	AD	D	R	AD	D	R	AD	D
Proximate Analysis—														
Moisture, per cent	5·3	....	9·5	7·4	....	8·8	7·2	....	7·7	1·6	....	6·8	1·7	....
Ash, "	5·2	5·5	10·8	11·1	11·9	12·0	12·2	13·2	17·4	18·6	18·8	13·7	14·5	14·7
Volatile matter, "	38·6	40·7	36·0	36·8	39·8	35·4	36·0	38·8	33·8	36·1	36·7	35·8	37·7	38·4
Fixed carbon, "	50·9	53·8	43·7	44·7	48·3	43·8	44·6	48·0	41·1	43·7	44·5	43·7	46·1	46·9
Ultimate Analysis—														
Carbon, per cent	....	....	63·8	65·3	70·5	....	....	....	61·7	65·8	66·9	65·7	69·2	70·4
Hydrogen, "	....	....	5·7	5·5	5·1	....	....	....	5·0	4·6	4·5	5·4	5·1	5·0
Ash, "	....	....	10·8	11·1	11·9	....	....	....	17·4	18·6	18·8	13·7	14·5	14·7
Sulphur, "	....	....	0·6	0·6	0·6	0·6	0·6	0·7	0·9	1·0	1·0	0·8	0·9	0·9
Nitrogen, "	....	....	1·7	1·7	1·9	....	....	....	1·3	1·3	1·4	1·3	1·4	1·4
Oxygen, "	....	....	17·4	15·8	10·0	....	....	....	13·7	8·7	7·4	13·1	8·9	7·6
Calorific Value—														
Calories per gramme, gross	....	....	6,345	6,485	7,005	6,310	6,425	6,915	6,155	6,565	6,670	6,520	6,875	6,995
B.T.U. per pound, gross	....	....	11,420	11,670	12,610	11,360	11,560	12,450	11,080	11,820	12,010	11,740	12,380	12,590
Fuel ratio	1·30		1·20			1·25			1·20			1·20		
Carbon-hydrogen ratio	....	....	11·2	11·8	13·8	....	....	....	12·4	14·3	14·9	12·1	13·5	14·1
Coking properties	Poor		Poor			Agglomerate			Fair			Fair		
Designation of coal	....		Run-of-mine						Both washed slack					
Kind of sample	Commercial		Commercial; carload						Commercial; ½ carload in each case					
Location in mine	Nos. 2 and 4, seams		....						....					
Taken by	Under direction of Board of Railway Commissioners		Mine operators						Mine operators					
Date of sampling	September, 1929		December 10, 1929						February 8, 1930					
			Lab. sample, Dec. 26, 1929			Lab. sample, Feb. 20, 1930			Lab. samples, February 25, 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 Ste. Anne de Bellevue Hospital													
Sample No.	5921 5922	6204 6249	6090 6091	6205 6206 6207	6250	6251 6252	6354 6355	6356 6357	6457	6458 6464	6615 6616	6617	6622 6623	6646 6647
Moisture (as received) per cent	10·3	10·3	2·5	3·1	2·6	3·9	4·1	4·1	6·6	4·7	6·6	6·6	3·5	4·3
Dry Basis—														
Ash “	8·5	9·9	9·5	9·3	10·0	11·0	9·4	9·2	11·5	10·2	12·1	9·3	10·2	10·1
Volatile matter “	33·0	33·3	32·3	32·4	31·9	33·0	32·7	33·1	34·4	35·2	34·3	35·0	32·7	32·6
Fixed carbon “	58·5	56·8	58·2	58·3	58·1	56·0	57·9	57·7	54·1	54·6	53·6	55·7	57·1	57·3
Sulphur “	2·5	2·8	3·2	3·4	3·1	2·5	3·5	3·2	2·3	2·1	2·5	2·4	3·2	3·0
Calories per gramme, gross	7,540	7,285	7,670	7,690	7,580	7,430	7,735	7,720	7,350	7,460	7,295	7,570	7,470	7,500
B.T.U. per pound, gross	13,570	13,110	13,800	13,840	13,640	13,380	13.920	13,900	13,230	13,430	13,130	13,630	13,450	13,500
Number of tons represented by sample	472	342	388	725	252	415	430	483	219	459	497	221	429	499
Date of delivery	April 21 to May 6, 1929	May 20 to June 15	June 20 to July 10	July 11 to Aug. 1	July 31 to Aug. 7	Aug. 7 to 19	Sept. 18 to Oct. 2	Oct. 2 to 16	Oct. 25 to 30	Oct. 31 to Nov. 11	Dec. 2 to 21	Dec. 21 to 26	Dec. 24 to 30	Dec. 24 to Jan. 6, 1929–1930

—	Described as "Dominion" or Glace Bay, Nova Scotia, slack coal					Described as "Bras d'Or" slack, from Sydney Mines district, Nova Scotia			
	Delivered to Camp Hill Hospital, Halifax								
Sample No.	6265 6332	6456	6501	6611	6691	5849	5917	5973	6092
Moisture (as received) per cent	3·4	5·3	4·0	3·8	4·3	6·7	7·5	5·5	5·3
Dry Basis—									
Ash “	8·1	9·5	7·8	7·4	9·2	14·6	15·3	12·8	12·3
Volatile matter “	34·3	33·1	33·8	33·9	32·7	34·2	33·8	33·1	34·4
Fixed carbon “	57·6	57·4	58·4	58·7	58·1	51·2	50·9	54·1	53·3
Sulphur “	2·6	2·9	2·8	2·9	3·0	5·6	5·9	5·3	5·0
Calories per gramme, gross	7,755	7,645	7,745	7,840	7,760	6,915	6,830	7,040	7,080
B.T.U. per pound, gross	13,960	13,760	13,940	14,110	13,970	12,450	12,290	12,680	12,740
Number of tons represented by sample	72	99	167	185	227	204	206	81	75
Date of delivery	Aug. 6 to Sept. 25, 1929	Oct. 11 to 30	Nov. 2 to 30	December, 1929	January, 1930	Mar. 1 to 31, 1929	April 2 to 30	May 10 to 28	June 12 to 29

TABLE II—*Continued*

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

—	Described as run-of-mine coal from Minto Coal Co., Ltd., Minto, New Brunswick.	Described as run-of-mine coal from Welton and Henderson, Ltd., Minto, New Brunswick			
		Delivered to Lancaster Hospital, St. John, New Brunswick			
Sample No.	6261	6455	6502	6613	6720
Moisture (as received) per cent	2·2	2·5	2·1	4·5	2·8
Dry Basis—					
Ash "	15·3	16·8	17·6	18·5	18·8
Volatile matter "	32·6	32·4	32·8	32·2	31·8
Fixed carbon "	52·1	50·8	49·6	49·3	49·4
Sulphur "	7·0	6·4	6·0	6·3	5·9
Calories per gramme, gross	7,110	7,030	6,915	6,875	6,845
B.T.U. per pound, gross	12,800	12,650	12,450	12,380	12,320
Number of tons represented by sample	50	. .	51	49	48
Date of delivery	Aug. 14 to 16, 1929	October, 1929	Dec. 6, 1929	Jan. 6, 1930	Feb. 18, 1930

—	Described as run-of-mine coal from International Coal and Coke Co., Ltd., Coleman, Alberta									
	Delivered to Deer Lodge Hospital, Winnipeg, Manitoba						Delivered to Vetcraft Shops, Winnipeg			
Sample No.	5848	6330	6375	6503	6614	6705	5861	6465	6703	6704
Moisture (as received) per cent	3·5	2·1	2·6	1·9	2·6	1·4	3·3	3·0	1·5	2·6
Dry Basis—										
Ash "	15·5	17·1	17·9	15·0	14·6	15·4	15·6	19·0	15·6	14·1
Volatile matter "	26·2	25·0	24·9	24·0	22·7	24·1	25·3	22·3	24·1	24·8
Fixed carbon "	58·3	57·9	57·2	61·0	62·7	60·5	59·1	58·7	60·3	61·1
Sulphur "	0·6	0·4	0·4	0·4	0·5	0·5	0·6	0·4	0·4	0·5
Calories per gramme, gross	7,060	6,940	6,875	7,130	7,200	7,145	7,105	6,745	7,060	7,260
B.T.U. per pound, gross	12,710	12,490	12,380	12,830	12,960	12,860	12,790	12,140	12,710	13,070
Number of tons represented by sample	30	94	68	78	181	89	16	15	62	31
Date of delivery	Mar. 1 to 31, 1929	Sept. 9 to 30	Oct. 1 to 31	Nov. 1 to 30	Dec. 1 to 31	Jan. 1 to 31, 1930	Mar. 1 to 31, 1929	Sept. 1 to Oct. 31	Oct. 1 to Dec. 31	Jan. 1 to 31, 1930

TABLE II—*Concluded*

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

—	Described as slack from Chilton seam in Logan county, West Virginia; from "Lundale" mine at Lundale, "McGregor" mine at Slagle; or "Paragon" mine at Yolyn							Described as "¾-lump" from Pittsburgh seam in Marion county, West Virginia; from "Morgantown No. 1" mine at Scottdale	Described as slack from Pittsburgh seam in Monongalia county, West Virginia; from "Connellsville No. 1" mine at Pursglove	
	Delivered to Christie Street Hospital, Toronto							Delivered to Westminster Hospital, London		
Sample No....................	5867	5879	5913	5949	5967	5979	6027	6285	6096	6203
Moisture (as received)..per cent	8·8	7·3	7·0	8·4	7·3	7·2	4·0	1·9	1·3	1·8
Dry Basis—										
Ash................. “	8·7	9·0	8·5	8·6	9·6	9·0	9·4	13·6	8·6	9·3
Volatile matter....... “	32·3	32·4	32·2	33·0	31·9	32·2	32·4	35·4	36·3	36·4
Fixed carbon......... “	59·0	58·6	59·3	58·4	58·5	58·8	58·2	51·0	55·1	54·3
Sulphur.............. “	1·4	1·1	1·5	0·9	0·9	1·1	0·8	2·4	3·1	3·3
Calories per gramme, gross...	7,750	7,705	7,730	7,710	7,630	7,670	7,650	7,430	7,830	7,710
B.T.U. per pound, gross......	13·950	13,870	13,920	13,880	13,740	13,810	13.770	13,370	14,090	13,870
Number of tons represented by sample..........................	300	350	320	300	400	360	100	1 carload	540	300
Date of delivery..............	April 2 to 9, 1929	April 16 to 22	April 23 to 29	May 1 to 8	May 13 to 20	May 23 to 30	June 9	September, 1929	July 10 to 22, 1929	July 24 to Aug. 2, 1929

—	Described as slack from Sewickley and Pittsburgh seams in Monongalia county, West Virginia; from "Maiden" mine at Maidsville					Described as slack from Freeport seam in Alleghany county, Pennsylvania; from "Newfield" mine at North Bessemer.					Described as slack from Alleghany county, Pennsylvania; from "Wildwood" mine at Wildwood			
	Delivered to Westminster Hospital, London					Delivered to Christie Street Hospital, Toronto								
Sample No...........................	6287	6349	6359	6454	6468	6466 6467	6557	6564	6619	6640	6706	6715	6723	6724
Moisture (as received)..........per cent	2·2	3·1	2·7	3·2	6·1	8·4	6·0	6·2	7·0	6·9	5·4	7·0	5·1	5·0
Dry Basis—														
Ash......................... “	7·4	8·6	8·4	9·2	10·3	10·3	9·8	12·0	10·4	11·1	11·5	11·5	12·2	10·6
Volatile matter.............. “	35·1	34·5	34·9	34·6	33·4	33·9	34·9	32·9	33·9	33·2	33·7	33·1	33·3	34·9
Fixed carbon................ “	57·5	56·9	56·7	56·2	56·3	55·8	55·3	55·1	55·7	55·7	54·8	55·4	54·5	54·5
Sulphur..................... “	3·0	3·1	2·8	2·7	3·4	1·9	2·2	2·1	1·9	2·3	2·3	2·2	2·8	2·4
Calories per gramme, gross..........	7,850	7,720	7,785	7,710	7,580	7,515	7,530	7,330	7,560	7,455	7,490	7,445	7,430	7,560
B.T.U. per pound, gross.............	14,130	13,900	14,030	13,880	13,640	13,530	13,550	13,200	13,610	13,420	13,480	13,400	13,380	13,610
Number of tons represented by sample.	5	380	378	452	514	120	300	450	350	250	430	350	250	250
Date of delivery.......................	Sept., 1929	Oct. 4 to 16	Oct. 18 to 24	Oct. 26 to Nov. 6	Nov. 2 to 21	Nov. 21 to 26	Dec. 6 to 10	Dec. 16 to 24	Jan. 2 to 7, 1930	Jan. 14 to 22	Jan. 29 to Feb. 10	Feb. 13 to 17	Feb. 17 to 20	Feb. 20

TABLE III

Analyses of Miscellaneous Solid Fuels

—	Scotch anthracite		Welsh anthracite		Pennsylvania anthracite						"McCoy" mine, East Radford, Montgomery and Pulaski counties, Virginia						"Big Vein" mine, Merrimac seam, McCoy, Montgomery county; Virginia Valley coal field	
					D. and H.		From Buck Mountain, Scranton district		—									
Sample No..................	6095		6347		6348		6279		6331		6086		6087		6088		6505	
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	3·2	....	1·4	....	3·7	....	1·6	....	1·8	....	1·1	....	0·8	....	0·8	....	1·2	....
Ash................ "	4·7	4·8	4·6	4·7	8·9	9·2	16·7	17·0	12·7	12·9	15·8	16·0	18·4	18·5	18·6	18·7	19·7	19·9
Volatile matter..... "	7·0	7·3	7·1	7·2	6·4	6·7	8·6	8·7	5·3	5·4	14·0	14·1	13·5	13·6	12·8	13·0	14·4	14·6
Fixed carbon........ "	85·1	87·9	86·9	88·1	81·0	84·1	73·1	74·3	80·2	81·7	69·1	69·9	67·3	67·9	67·8	68·3	64·7	65·5
Ultimate Analysis—																		
Carbon.............per cent	....	....	....	....	....	....	....	....	....	....	....	....	....	....	73·0	73·6	....	....
Hydrogen........... "	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3·4	3·4	....	....
Ash................ "	....	....	....	....	....	....	....	....	....	....	....	....	....	....	18·6	18·7	....	....
Sulphur............ "	0·7	0·7	....	....	0·8	0·9	0·6	0·6	0·7	0·7	0·5	0·5	0·7	0·7	0·7	0·7	0·5	0·5
Nitrogen........... "	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0·9	0·9	....	...
Oxygen............. "	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3·4	2·7	....	....
Calorific Value—																		
Calories per gramme, gross.	7,780	8,040	....	....	7,280	7,560	7,070	7,185	....	....	7,060	7,140	6,850	6,910	6,830	6,890	6,600	6,680
B.T.U. per pound, gross.....	14,000	14,470	....	....	13,100	13,610	12,730	12,920	....	....	12,710	12,850	12,330	12,430	12,290	12,400	11,880	12,020
Fuel ratio.....................	12·15		12·35		12·65		8·55		15·20		4·95		5·00		5·25		4·50	
Carbon-Hydrogen ratio.......	....	....	....	....	....	....	....	....	....	....	....	....	....	....	21·4	21·9	....	....
Coking properties.............	Non-coking		Non-coking		Non-coking		Non-coking		Non-coking		Non-coking		Non-coking		Non-coking		Weak agglomerate	
Designation of coal...........	Cobbles—omitting material passing through ¾" screen.		No. 1 buckwheat.		Egg..........		Nut..........		Buckwheat...		Stove.........		Chestnut......		Pea...........		"Old Dominion."	
											Washed by Rheolaveur process............							
Kind of sample..............	From dealers' stock.........				Delivered in Ottawa to R.C.M.P.		Delivered to Camp Borden, Ontario.		Delivered in Ottawa.		Secured from mine operators...............						Dealer's stock.	
Date.........................	July, 1929.....		Oct., 1929.....		Oct., 1929.....		Sept., 1929....		Oct., 1929.....		July 17, 1929..............................						Dec., 1929.	

TABLE III—*Continued*

Analyses of Miscellaneous Solid Fuels—*Continued*

—	"Raven" semi-bituminous, or "smokeless", coal from Pennsylvania			Pennsylvania Pool No. 1, Navy Standard, "Smokeless" coal				Cannel coal from Holden, Logan county, West Virginia		Cannel coal from Bostonia or New Bethlehem, Armstrong county, Pennsylvania		Cannel coal from No. 20 and "East Brushy" mines, Cannel City, Morgan county, Kentucky			
Sample No.	6504			6297 6298 6299		6300 6301 6302		6371		6372		6373		6374	
Moisture condition	R	AD	D	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—															
Moisture, per cent	3·7	1·3	....	1·1	....	1·2	....	1·0	....	1·1	....	3·5	....	3·3	....
Ash, "	11·2	11·5	11·7	7·2	7·2	7·0	7·1	12·3	12·4	18·7	18·9	8·0	8·3	8·2	8·5
Volatile matter, "	18·7	19·1	19·4	21·2	21·5	20·8	21·1	49·3	49·8	32·5	32·9	42·2	43·7	42·6	44·0
Fixed carbon, "	66·4	68·1	68·9	70·5	71·3	71·0	71·8	37·4	37·8	47·7	48·2	46·3	48·0	45·9	47·5
Ultimate Analysis—															
Carbon, per cent	....	....	....	....	....	....	....	74·7	75·4	....	....	....	....	74·1	76·7
Hydrogen, "	....	....	....	....	....	....	....	6·5	6·5	....	....	....	....	5·8	5·6
Ash, "	....	....	....	....	....	....	....	12·3	12·4	....	....	....	....	8·2	8·5
Sulphur, "	2·8	2·9	2·9	1·2	1·2	1·2	1·2	0·6	0·7	0·7	0·7	0·7	0·7	0·7	0·7
Nitrogen, "	....	....	....	....	....	....	....	1·1	1·1	....	....	....	....	1·6	1·6
Oxygen, "	....	....	....	....	....	....	....	4·8	3·9	....	....	....	....	9·6	6·9
Calorific Value—															
Calories per gramme, gross	7,310	7,495	7,595	8,015	8,105	8,035	8,130	7,950	8,030	6,930	7,010	7,470	7,745	7,510	7,780
B.T.U. per pound, gross	13,160	13,490	13,670	14,430	14,590	14,460	14,640	14,310	14,450	12,480	12,620	13,450	13,940	13,520	14,000
Fuel ratio	3·55			3·35		3·40		0·76		1·45		1·10		1·10	
Carbon-Hydrogen ratio	....	....	....	....	....	....	....	11·4	11·7	....	....	....	....	12·8	13·7
Coking properties	Good			Good		Good		Poor		Hard sintered agglomerate		Poor		Poor	
Designation of coal	....			"Colver" run-of-mine				"Ebony Cube"		"Bostonia"		"Pluto" coal from No. 2 seam			
Kind of sample	From dealer's stock			Delivered to Ottawa Public Schools				From dealers' stocks							
Date	September, 1929			September, 1929				November, 1929							

TABLE III—*Continued*

Analyses of Miscellaneous Solid Fuels—*Continued*

—	Bituminous coals from the United States												
	From Youghiougheny seam; from Connellsville, Pennsylvania		"Royal" mine, Pittsburgh seam, Chestnut Ridge, Fayette county, Pennsylvania						"Delta" mine, "D" or Lower Freeport seam, Spangler, Cambria county, Pennsylvania		"Yatesboro" mine, Upper Freeport seam, Yatesboro, Armstrong county, Pennsylvania		
Sample No.	5952		6358			6635			5845		6059		
Moisture condition	R	D	R	AD	D	R	AD	D	R	D	R	AD	D
Proximate Analysis—													
Moisture per cent	0·8	....	3·1	1·2	....	4·0	1·3	....	1·6	....	2·1	1·5	....
Ash "	8·3	8·4	8·4	8·6	8·7	8·6	8·8	8·9	9·3	9·5	8·7	8·7	8·9
Volatile matter "	36·4	36·7	32·6	33·3	33·7	30·4	31·2	31·7	23·0	23·3	31·8	32·0	32·5
Fixed carbon "	54·5	54·9	55·9	56·9	57·6	57·0	58·7	59·4	66·1	67·2	57·4	57·8	58·6
Ultimate Analysis—													
Carbon per cent	....	....	76·8	78·3	79·3	75·4	77·6	78·6	....	....	....	....	....
Hydrogen "	....	....	5·4	5·2	5·2	5·3	5·2	5·1	....	....	....	....	....
Ash "	....	....	8·4	8·6	8·7	8·6	8·8	8·9	....	....	....	....	....
Sulphur "	3·1	3·1	1·1	1·1	1·1	1·2	1·2	1·3	....	....	1·4	1·4	1·5
Nitrogen "	....	....	1·6	1·7	1·7	1·7	1·7	1·7	....	....	....	....	....
Oxygen "	....	....	6·7	5·1	4·0	7·8	5·5	4·4	....	....	....	....	....
Calorific Value—													
Calories per gramme, gross	7,765	7,830	7,540	7,685	7,780	7,475	7,685	7,785	....	....	7,650	7,695	7,815
B.T.U. per pound, gross	13,980	14,090	13,570	13,830	14,000	13,450	13,830	14,010	....	....	13,770	13,850	14,070
Fuel ratio	1·50		1·70			1·90			2·90		1·80		
Carbon-Hydrogen ratio	....	....	14·3	14·9	15·3	14·1	15·0	15·4	....	....	....	....	....
Coking properties	Fair		Good			Good			Good		Good		
Designation of coal	"Pittsburgh bituminous slack"		Slack						"Smokeless"		Slack		
Kind of sample	Delivered in Hull		Delivered to Fuel Research Laboratories by car-loads						Dealer's stock		Delivered in Ottawa		
Date	May, 1929		Oct. 29, 1929			Jan. 24, 1930			March, 1929		June, 1929		

TABLE III—*Concluded*

Analyses of Miscellaneous Solid Fuels—*Concluded*

—	No. 2 Colliery, New Aberdeen; Dominion Coal Co., Ltd., Glace Bay, Nova Scotia				Low-temperature coke produced by Illingworth process at Pontypridd, Wales				Briquettes from carbonizing and briquetting plant of Western Dominion Collieries Co., Ltd., situated at Bienfait, Saskatchewan		"Ambricoal" briquettes, manufactured with Franklin anthracite from Lykens valley, Pennsylvania	
Sample No.	6362		6363		6364		6365		6563		6267	
Moisture condition	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—												
Moisture ... per cent	1·6	....	1·7	....	2·9	....	2·7	....	3·9	....	2·9	....
Ash ... "	8·8	9·0	4·6	4·7	11·2	11·6	8·4	8·6	14·5	15·1	10·3	10·6
Volatile matter ... "	32·1	32·6	33·9	34·5	9·2	9·4	7·4	7·7	14·6[1]	15·2	11·3	11·7
Fixed carbon ... "	57·5	58·4	59·8	60·8	76·7	79·0	81·5	83·7	67·0	69·7	75·5	77·7
Ultimate Analysis—												
Sulphur ... per cent	3·3	3·3	2·5	2·6	2·4	2·5	2·1	2·2	0·9	0·9	0·7	0·8
Calorific Value—												
Calories per gramme, gross	7,655	7,785	8,000	8,135	7,190	7,400	7,360	7,565	6,695	6,965	7,370	7,585
B.T.U. per pound, gross	13,780	14,010	14,400	14,640	12,940	13,320	13,250	13,620	12,050	12,540	13,260	13,650
Fuel ratio	1·80		1·75		....		....		4·55[1]		6·65	
Coking properties	Good		Good		....		....		Agglomerate		Non-coking	
Designation of fuel	Slack		Slack (No. 6362) cleaned in Baum washer		"Ricoal" from No. 6362		"Ricoal" from No. 6363		....			
Kind of sample	Taken in connexion with special tests								Samples sent to Ottawa			
Date	Autumn of 1929											

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[1] In determining volatile matter in this sample, slow initial heating was employed, as is done with coals of low rank.

V

GASOLINE SURVEY FOR 1929

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

The annual survey of the gasoline sold in Canada has been conducted by the Division of Fuels and Fuel Testing of the Mines Branch during the past six years[3]. This report covers a similar survey for 1929. During the early part of August, 84 samples were collected[4] from wholesalers or distributors in the following cities: Halifax, St. John, Quebec, Montreal, Ottawa, Toronto, London, Winnipeg, Regina, Edmonton, Calgary, Vancouver, and Victoria. The distillation range, specific gravity, and percentage of unsaturates, aromatics, naphthenes, and paraffins were determined for these samples.

The distillation range was tested according to the A.S.T.M. Standard Method designated as, D86-27. From the results so obtained, a weighted index number was calculated after the method advocated by Gruse[5]. By this method the temperature readings at which 10, 20, 50, 70, and 90 per cent of the distillate have been recovered, are added to the temperature reading at the end point of the distillation and the resultant sum is called the "Index Number". The index numbers shown in this report were calculated from the temperatures of the distillation range expressed in degrees Fahrenheit, instead of in degrees Centigrade as was done by Gruse. 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 Standard Petroleum Oil Tables[6]. The degrees A.P.I. were obtained by conversion of the specific gravity according to the above tables.

In addition to the above, each sample was analysed to determine the relative amounts of the different classes of constituents present. The method chosen was that outlined by Egloff and Morrell[7] and although it may be criticised in some respects, it, nevertheless, gives reproducible results in all three determinations.

Estimation of "Unsaturates"

The method of procedure was as follows: 250 c.c. of gasoline was distilled in an apparatus similar to that shown in Plate IVA, until the vapour temperature was 375°F.; the residue was measured and returned to the distilling flask; the distillate was measured and then treated with twice

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[1] Engineer, Division of Fuels and Fuel Testing, Mines Branch.

[2] Chemist, Division of Fuels and Fuel Testing, Mines Branch.

[3] Investigations of Fuels and Fuel Testing, Mines Branch, 1923 to 1927 inclusive; and Memorandum Series No. 35.

[4] The hearty support and co-operation of the Department of Health in taking the samples is gratefully acknowledged.

[5] Chemical and Metallurgical Engineering, vol. 29, No. 22, page 970. Investigations of Fuels and Fuel Testing 1923, page 39.

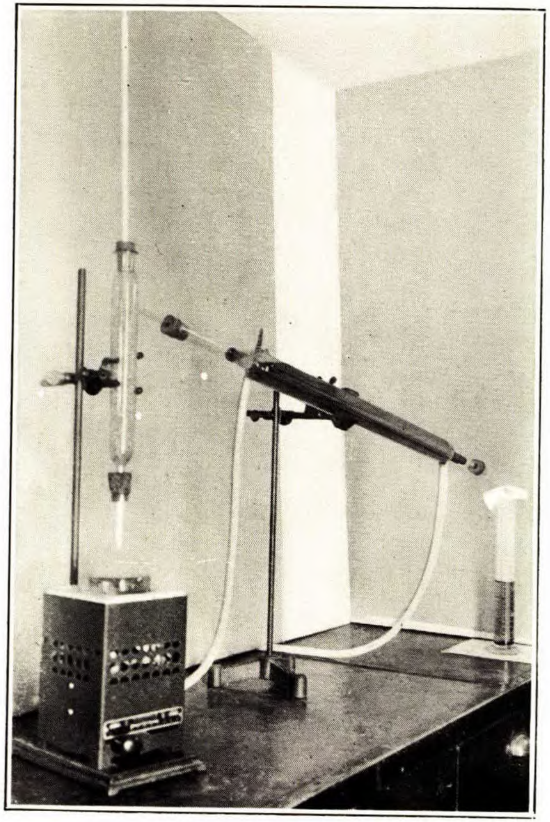
[6] U.S. Bureau of Standards Circular No. 154.

[7] Industrial and Engineering Chemistry, vol. 18, No. 4, p. 354.

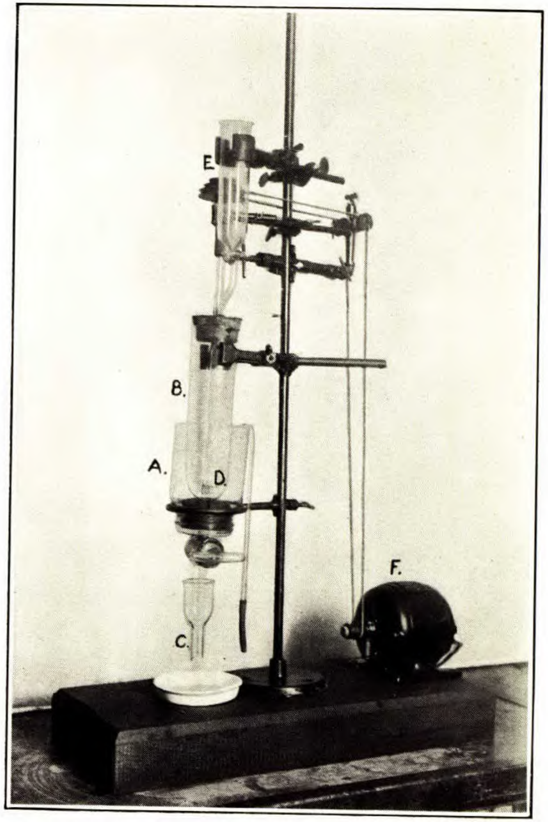
its amount of sulphuric acid of 80 per cent concentration; the acid was drawn off and the remaining fluid was again measured, then washed with water and with a solution of sodium hydroxide of 10 per cent concentration; the neutral liquid was then added to the residue in the distilling flask and the whole redistilled to the same temperature as before; the residue was again measured and the increase in volume between the residue from the first distillation and that from the second was set down as due to polymerization of some of the double bond compounds; this amount was added to the amount of the contraction in volume of the first distillate after it had been treated with sulphuric acid, and the whole calculated to the basis of the original sample. This is reported as percentage of unsaturates. A portion of the second distillate was then nitrated to obtain the percentage of aromatics.

Estimation of "Aromatics"

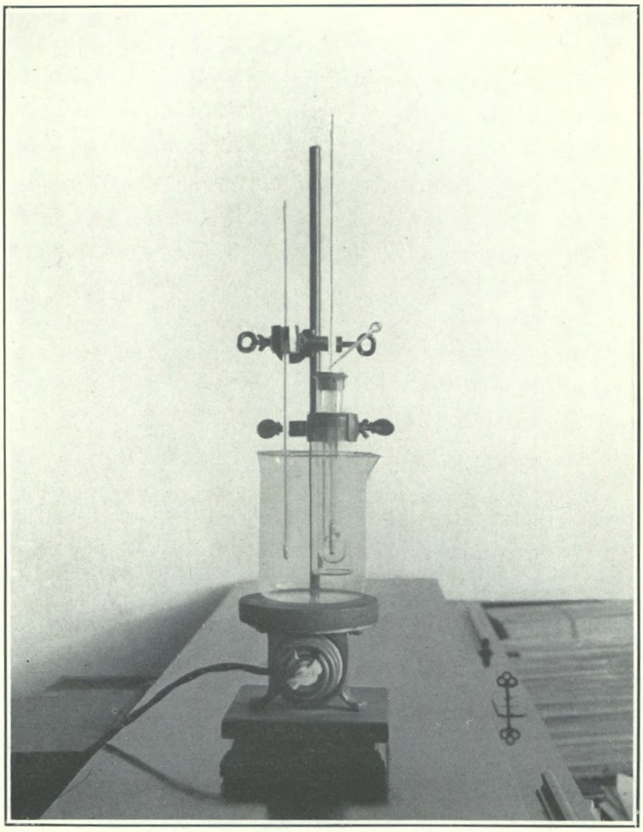
The term "aromatics" is used generally to define benzene and its homologs. However, in this case it includes all those compounds not soluble or only slightly soluble in sulphuric acid of 80 per cent concentration, but which yield on treatment with nitric acid an oil insoluble (or only slightly soluble) in either the sulphuric-nitric acid mixture or in the residual gasoline. For the estimation, 50 c.c. of mixed acid was added to 20 c.c. of the distillate. The nitration operation involved some difficulty due to (a) the small amount of gasoline used, (b) the necessity for keeping the mixture cool, (c) the necessity for thorough and continual agitation, and (d) the small amount of nitro compound to be measured. In order to overcome these difficulties a special nitrating apparatus was designed which was simple and yet effective. It is shown in Plate IVB. The surrounding water bath, A, was made from an ordinary fruit jar with the bottom cut off, the nitrating vessel proper, B, was made very like an ordinary cylindrical separating funnel, except that the glass stopcock was of a large size and separated from the larger portion of the tube by about 2 inches of glass tube of the same size as that extending below the stopcock. The tube was supported within the cooling bath by a large rubber stopper which fitted around the neck of B between the larger portion and the stopcock, and also fitted tightly into the mouth of A. Within the nitrating tube was a thermometer and a stirrer, D, operated by a small electric motor, F. Attached to the cover was a small separating funnel, E, for admitting the reagents. The difficulty of measuring the resultant nitro product was met by the use of special receivers with a constricted and graduated neck. The lower bulb held about 49 c.c. and the upper about 35 c.c. The capacity of the neck was 4 or 5 c.c. and was graduated in 1/10 c.c. One of these receivers is shown in the Plate IVB at C. Two methods of operation were possible, one to add the gasoline to the mixed acid and the other to add the mixed acid to the gasoline. The latter procedure was adopted, and in order to obtain thorough agitation 10 c.c. of concentrated sulphuric acid was first run into the nitrator tube, which quantity was sufficient to fill the space between the stopcock and the stirrer. The 20 c.c. of gasoline was then added, the stirrer started, and finally 40 c.c. of mixed acid run in slowly. The temperature of the reaction mixture was not allowed to rise above 95° F.



A. Apparatus for distillation of gasoline.



B. Nitrating apparatus for determination of aromatics in gasoline.



Apparatus for determining naphthenes and paraffins in gasoline.

The mixed acid was made by mixing 66 parts of chemically pure sulphuric acid of 1·835 specific gravity, with 136 parts of chemically pure nitric acid of 1·42 specific gravity. The composition of the mixture was approximately as follows:—

Sulphuric acid	39 per cent
Nitric acid	45 "
Water	16 "

When 40 c.c. of the above acid was mixed with the 10 c.c. of sulphuric acid already in the nitrator tube, the composition of the mixture became equivalent to that used by Egloff and Morrell[1], namely:—

Sulphuric acid	58 per cent
Nitric acid	25 "
Water	17 "

One hour after starting the run of the mixed acid—it required from 20 to 30 minutes for the 40 c.c. to be run in without too great an increase in temperature—the stirrer was stopped and the mixture allowed to settle for 10 or 15 minutes. The mixture was then drawn off into one of the receivers and the volume of nitro product observed after one hour. This reading was checked several hours later but in no case was an appreciable change in volume noticed. The nitro product is usually a reddish-coloured liquid and settles out between the gasoline and the acid layer. In some cases, especially where the total amount of aromatics was small, the product crystallized before the completion of the estimation, probably due to the high percentage of nitric acid in the spent acid. Usually some crystals formed after standing for several hours.

The volume in c.c. of the nitro product obtained was multiplied by the factor 4·3 to give the percentage of aromatics in the fraction used and the result calculated to the basis of the original sample.

Table I shows that the readings taken when duplicate determinations of nitro products were made on gasolines of widely varying aromatic content. It was felt that these results indicated that the method could be relied upon to give consistent values.

TABLE I

Amount of Nitro Products Obtained from Four Gasolines

	1 c.c.	2 c.c.	3 c.c.	4 c.c.
Test No. 1	Trace	0·5	1·5	3·0
Test No. 2	Trace	0·5	1·5	2·9
Test No. 3	Trace	0·5	1·5	2·9

Portions of a sample of gasoline, which showed no nitration—only a trace of aromatics—were thereupon taken. One of these was mixed with 10·7 per cent of benzene, and the other with 10·7 per cent of toluene. The average volume of nitro products obtained in two determinations on each portion was as follows:—

Nitro products from 20 c.c. of gasoline containing
10·7 per cent benzene=2·3 c.c.
10·7 per cent toluene=2·3 c.c.

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[1] Industrial and Engineering Chemistry, vol. 18, No. 4, p. 354.

It would, therefore, appear that variations in the relative proportions of benzene and toluene, which are the two most common types of aromatic compounds, would have very little effect on the percentage found.

When the above values were calculated to percentages it was found that in both cases there was obtained 11·5 per cent by volume when it was known that only 10·7 per cent of aromatics was present. It would appear, therefore, that 4·66 would be the correct factor for calculating the percentage of aromatics determined by the method described above. This value was felt to be in reasonably good agreement with the factor of 4·3 which was suggested by Egloff and Morrell. In any event more data would have to be obtained than is available at the present time, particularly in regard to the effect of the presence of the more highly methylated aromatics, in order to reach a definite conclusion. It was felt that probably either factor would give as exact results as were warranted by the general scheme of analysis, and since it was highly desirable that these results should be comparable to others, the factor 4·3 was used in compiling the tables.

Estimation of "Naphthenes" and "Paraffins"

The "naphthenes" are those cyclic compounds which are non-benzenoid in structure. They are sometimes called hydrobenzenes, because all the carbon atoms in the nucleus are fully saturated with hydrogen and there are no double linkages in the molecule. As might be expected, these compounds are chemically very inert. The method adopted for estimating the amount of naphthenes present was that proposed by Tizard and Marshall[1] and modified by Egloff and Morrell. It is stated[2] that under the conditions of the test the paraffin hydrocarbons are completely miscible with aniline at 70° C., and that the cloud point is depressed 0·3° C. for each 1 per cent of naphthene hydrocarbon present.

The results shown were obtained by mixing 10 c.c. of freshly distilled aniline and 10 c.c. of gasoline, which had been freed from aromatic constituents by the method described above, and warming the mixture in apparatus shown in Plate V until it was clear and transparent. The gasoline, after nitration and before being mixed with aniline, was washed with water, neutralized with 10 per cent solution of sodium hydroxide, and then dried with calcium chloride. The percentage of naphthenes was calculated by dividing the difference between 70° C. and the critical temperature found for the various samples by 0·3. The value so obtained was then calculated to the basis of the original sample.

The paraffins were determined by difference.

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[1] Journal Soc. Chem. Ind., 40, 20T (1921).

[2] Industrial and Engineering Chemistry, vol. 18, No. 4, p. 354.

TABLE II

Results of Analysis

Sample No.	Brand	Distillation Range								Index No. ° F.	Spec. grav.	Degrees A.P.I.	Hydrocarbons			
		1st drop ° F.	10% ° F.	20% ° F.	50% ° F.	70% ° F.	90% ° F.	End point ° F.	Recovery				Unsaturates %	Aromatics %	Naphthenes %	Paraffins %
	HALIFAX, N.S.															
1	Premier *(a)*..........	100	168	198	268	304	351	396	97·5	1685	0·743	58·9	8	10	25	57
2	White Rose *(b)*......	109	166	185	265	307	367	424	97·0	1714	0·734	61·3	2	3	23	72
3	Sunoco *(c)*...........	110	158	189	269	315	381	421	97·5	1735	0·755	55·9	9	1	37	53
4	Imp. Ethyl *(a)*......	118	173	200	270	316	370	420	97·5	1749	0·757	55·4	5	1	24	70
	Average.........	109	166	193	268	310	367	415	97·3	1720	0·747	57·9	6	4	27	63
	ST. JOHN, N.B.															
5	Primrose *(d)*.........	99	132	157	238	279	340	405	96·5	1551	0·725	63·7	3	3	24	70
6	White Rose *(b)*......	115	171	203	267	311	376	424	97·0	1752	0·739	60·0	3	5	17	75
7	Good Gulf *(e)*.......	90	138	171	263	314	380	421	96·5	1687	0·733	61·5	5	7	22	66
8	Premier *(a)*..........	104	154	179	266	314	372	418	97·0	1703	0·742	59·2	3	7	26	64
9	Fundy *(f)*............	106	153	178	252	293	348	411	97·0	1635	0·733	61·5	3	2	29	66
	Average.........	103	150	178	257	302	363	416	96·8	1666	0·734	61·3	3	5	24	68
	QUEBEC, QUE.															
10	White Rose *(b)*......	98	142	172	255	304	365	410	96·5	1648	0·736	60·8	4	6	24	66
11	Aviation *(g)*.........	112	160	186	249	288	342	388	97·0	1613	0·731	62·1	4	4	24	68
12	Premier *(a)*..........	105	166	191	265	306	358	402	97·0	1688	0·743	58·9	5	8	24	63
13	Good Gulf *(h)*.......	90	136	166	264	313	380	420	97·0	1679	0·734	61·3	4	9	23	64
14	Peerless *(i)*..........	96	148	173	240	282	356	402	96·5	1601	0·724	63·9	4	3	25	68
	Average.........	100	150	178	255	299	360	404	96·8	1646	0·734	61·3	4	6	24	66

TABLE II—Continued

Results of Analysis—(Continued)

Sample No.	Brand	Distillation Range								Index No. ° F.	Spec. grav.	Degrees A.P.I.	Hydrocarbons			
		1st drop ° F.	10% ° F.	20% ° F.	50% ° F.	70% ° F.	90% ° F.	End point ° F.	Recovery				Unsaturates %	Aromatics %	Naphthenes %	Paraffins %
	MONTREAL, QUE.															
15	Super Power *(i)*......	100	156	188	266	310	365	411	97·0	1696	0·742	59·2	4	8	27	61
16	Peerless *(i)*..........	100	146	170	230	270	326	368	97·0	1510	0·722	64·5	3	1	25	71
17	Imp. Ethyl *(a)*......	110	168	196	266	316	372	421	97·5	1739	0·756	55·7	3	11	28	58
18	Premier. *(a)*.........	88	131	159	262	318	380	413	96·0	1663	0·739	60·0	5	15	25	55
19	Marathon (*(j)*.......	98	152	182	262	322	390	425	97·0	1733	0·738	60·2	3	4	21	72
20	Blue Sunoco *(c)*......	105	168	201	273	324	392	429	97·0	1788	0·759	54·9	7	13	37	43
21	Aviation *(g)*.........	98	145	168	231	266	325	371	97·5	1506	0·722	64·5	3	1	24	72
22	Shell *(g)*.............	107	161	185	245	281	340	390	97·5	1602	0·733	61·5	4	3	24	69
	Average.........	101	153	181	254	301	361	403	97·1	1655	0·738	60·2	4	7	26	63

(a) Imperial Oil, Limited.
(b) Canadian Oil Companies, Limited.
(c) Sun Oil Company, Limited.
(d) Irving Oil Company, Limited.
(e) Gulf Refining Company, Limited.
(f) Canadian Independent Oil, Limited.
(g) Shell Company of Canada, Limited.
(h) Eastern Oil Limited.
(i) British American Oil Company, Limited.
(j) McColl-Frontenac Oil Company, Limited.
(k) Super Service Gas and Oil Company, Limited.
(l) Cities Service Oil Company, Limited.
(m) Domestic Storage and Forwarding Company, Limited.
(n) Beach Motors Limited.
(o) Capital City Oil Company, Limited.
(p) Supertest Petroleum Corporation.
(q) Perfection Petroleum Company, Limited.
(r) White Star Refining Company, Limited.
(s) Thayers Limited.
(t) Prairie City Oil Company, Limited.
(u) North Star Oil and Refining Company, Limited.
(v) Union Oil Company of Canada, Limited.
(w) Maple Leaf Oil and Refining Company, Limited.
(x) Regal Oil and Refining Company, Limited.
(y) Richfield Oil Distributors, Limited.
(z) Home Oil Distributors, Limited.
(aa) General Oil Company, Limited.
(bb) Shell Company of California, Limited.
(cc) Victoria Petroleum Company, Limited.

TABLE II—Continued

Results of Analysis—(Continued)

Sample No.	Brand	Distillation Range								Index No. ° F.	Spec. grav.	Degrees A.P.I.	Hydrocarbons			
		1st drop ° F.	10% ° F.	20% ° F.	50% ° F.	70% ° F.	90% ° F.	End point ° F.	Recovery				Unsaturates %	Aromatics %	Naphthenes %	Paraffins %
	OTTAWA, ONT.															
23	Super Service *(k)*....	91	147	183	260	293	344	393	96·5	1620	0·723	64·2	2	4	9	85
24	Marathon *(j)*........	105	164	196	272	327	391	424	97·0	1774	0·740	59·7	4	4	7	85
25	Cyclo *(j)*............	120	168	183	231	303	385	422	97·5	1692	0·780	49·9	7	45	31	17
26	Koolmotor *(l)*.......	96	137	159	229	276	340	399	97·0	1540	0·723	64·2	13	21	6	60
27	Noxless *(m)*.........	92	135	158	234	276	340	393	97·0	1536	0·725	63·7	4	5	27	64
28	White Rose *(b)*......	99	144	171	254	299	364	416	97·0	1648	0·733	61·5	2	5	23	70
29	Red Seal *(b)*.........	102	153	181	265	308	365	412	97·0	1682	0·742	59·2	3	5	17	75
30	Imp. Ethyl *(a)*......	109	163	191	261	304	360	412	97·5	1691	0·749	57·4	2	10	27	61
31	Sup. Quality *(h)*.....	92	130	151	217	259	321	387	97·0	1465	0·720	65·0	3	5	30	62
32	Premier *(a)*..........	101	157	189	267	312	366	413	97·0	1704	0·742	59·2	5	8	14	73
33	Sunoco H.T. *(o)*.....	103	157	179	241	286	351	426	97·0	1640	0·722	64·5	2	4	7	87
34	Sunoco N.T. *(o)*.....	98	151	178	250	296	361	421	97·0	1657	0·731	62·1	2	5	14	79
35	Supertest *(p)*........	103	157	187	265	312	365	415	97·0	1701	0·741	59·5	4	8	27	61
36	Domestic *(m)*.......	89	134	162	236	274	329	373	96·0	1508	0·713	67·0	2	....	3	95
37	Cities Service *(l)*....	98	151	180	257	298	364	416	96·5	1666	0·732	61·8	2	4	20	74
38	Shell *(g)*............	112	164	189	248	290	344	391	97·5	1626	0·734	61·3	2	4	24	70
39	Aviation *(g)*.........	104	152	173	227	265	320	370	97·5	1507	0·722	64·5	5	1	6	68
40	Super Power *(i)*......	107	168	198	270	310	366	414	97·5	1726	0·750	57·2	2	6	33	59
41	Peerless *(i)*..........	98	146	172	236	278	338	386	96·5	1556	0·722	64·5	3	1	25	71
42	B. A. Ethyl *(i)*......	108	159	187	261	310	368	416	97·5	1701	0·748	57·7	2	9	28	61
43	Supertest H.C. *(p)*..	91	129	151	227	275	349	401	96·0	1532	0·721	64·8	6	10	27	57
	Average.........	100	151	177	248	293	354	405	97·0	1627	0·734	61·3	4	8	20	68

TABLE II—Continued

Results of Analysis—(Continued)

Sample No.	Brand	Distillation Range								Index No. °F.	Spec. grav.	Degrees A.P.I.	Hydrocarbons			
		1st drop °F.	10% °F.	20% °F.	50% °F.	70% °F.	90% °F.	End point °F.	Recovery				Unsaturates %	Aromatics %	Naphthenes %	Paraffins %
TORONTO, ONT.																
44	Domestic *(m)*.......	100	143	172	242	286	345	381	96·0	1569	0·717	65·8	4	1	20	75
45	White Rose *(b)*......	106	161	191	261	303	359	416	97·0	1691	0·733	61·5	3	4	19	74
46	Perfection *(q)*........	102	142	166	229	274	338	388	96·5	1537	0·720	65·0	4	1	23	72
47	Premier *(a)*..........	108	166	197	263	304	356	410	97·0	1696	0·744	58·7	3	6	30	61
48	Super Power *(i)*......	101	157	188	265	317	382	426	97·0	1735	0·737	60·5	8	12	20	60
49	Plain Run *(l)*........	102	154	182	250	292	356	420	97·0	1654	0·728	62·9	2	5	15	78
50	Shell *(g)*............	104	150	186	276	333	394	426	97·0	1765	0·744	58·7	4	5	22	69
51	Marathon *(j)*........	99	158	190	268	314	373	417	97·0	1720	0·734	61·3	4	6	20	70
	Average.........	103	154	184	257	303	363	410	96·8	1672	0·732	61·8	4	5	21	70
LONDON, ONT.																
52	Premier *(a)*..........	96	154	190	274	322	382	426	96·5	1748	0·740	59·7	4	11	18	67
53	Marathon *(j)*........	90	137	166	238	280	342	397	97·0	1560	0·722	64·5	3	3	16	78
54	Red Seal *(b)*.........	98	154	188	271	322	377	420	97·0	1732	0·738	60·2	8	8	18	66
55	White Star *(r)*.......	106	148	171	226	259	311	368	97·5	1483	0·719	65·3	3	....	26	71
56	Shell *(g)*............	96	150	178	261	309	378	420	97·5	1696	0·739	60·0	3	4	24	69
57	Blue Sunoco *(c)*......	110	165	198	272	316	374	412	97·0	1737	0·756	55·7	7	14	34	45
58	Super Power *(i)*.....	96	160	187	278	323	380	421	97·0	1749	0·741	59·5	7	11	19	63
59	Sinclair (*s*)...........	91	140	170	252	299	359	406	97·0	1626	0·723	64·2	3	7	12	78
	Average.........	98	151	181	259	308	363	409	97·1	1666	0·735	61·0	5	7	21	67

TABLE II—Continued

Results of Analysis—(Continued)

Sample No.	Brand	Distillation Range								Index No. ° F.	Spec. grav.	Degrees A.P.I.	Hydrocarbons			
		1st drop ° F.	10% ° F.	20% ° F.	50% ° F.	70% ° F.	90% ° F.	End point ° F.	Recovery				Unsaturates %	Aromatics %	Naphthenes %	Paraffins %
							WINNIPEG, MAN.									
60	Red Seal (*b*).........	100	157	191	270	319	377	423	97·0	1737	0·740	59·7	5	8	17	70
61	B. A. Ethyl (*i*)......	95	137	166	264	311	365	410	97·0	1653	0·730	62·3	5	5	17	73
62	Electric (*t*)..........	92	139	163	227	274	348	406	97·0	1557	0·717	65·8	5	1	22	72
63	Red Star (*u*)........	97	140	170	250	302	364	414	97·0	1640	0·728	62·9	4	5	16	75
64	Premier (*a*)..........	99	157	192	270	320	376	424	97·0	1739	0·739	60·0	6	8	19	67
	Average.........	97	146	176	256	305	366	415	97·0	1665	0·731	62·1	5	6	18	71
							REGINA, SASK.									
65	White Rose (*b*)......	108	168	198	270	313	376	420	97·0	1745	0·740	59·7	4	5	19	72
66	Super Power (*i*)......	104	162	192	266	304	376	424	97·5	1724	0·741	59·5	6	15	19	60
67	Imperial (*a*)..........	104	163	192	264	312	376	424	97·5	1731	0·740	59·7	6	11	15	68
68	North Star (*u*)......	104	162	192	266	312	377	426	97·5	1735	0·740	59·7	7	10	21	62
	Average.........	105	164	193	266	310	376	423	97·4	1734	0·740	59·7	6	10	19	65
							EDMONTON, ALTA.									
69	Union (*v*)............	105	159	189	255	301	370	417	97·0	1691	0·748	57·7	3	5	40	52
70	Red Seal (*b*).........	100	143	168	244	302	383	431	96·5	1671	0·729	62·6	5	9	19	67
71	Premier (*a*)..........	106	154	178	256	303	364	420	97·0	1675	0·741	59·5	5	6	28	61
72	Super Power (*i*).....	99	144	168	243	300	383	429	97·0	1667	0·728	62·9	4	9	16	71
	Average.........	102	150	176	249	301	375	424	96·9	1676	0·736	60·8	4	7	26	63

TABLE II—Concluded

Results of Analysis—Concluded

Sample No.	Brand	Distillation Range								Index No. ° F.	Spec. grav.	Degrees A.P.I.	Hydrocarbons			
		1st drop ° F.	10% ° F.	20% ° F.	50% ° F.	70% ° F.	90% ° F.	End point ° F.	Recovery				Unsaturates %	Aromatics %	Naphthenes %	Paraffins %
	CALGARY, ALTA.															
73	Maple Leaf *(w)*......	126	185	211	283	331	390	438	97·5	1838	0·749	57·4	2	6	6	86
74	Regal *(x)*............	125	160	172	217	251	319	395	97·5	1514	0·725	63·7	2	6	23	69
75	Super Power *(i)*.....	104	143	164	234	289	370	427	97·5	1627	0·725	63·7	4	8	21	67
76	Premier *(a)*..........	112	156	182	256	306	366	422	97·5	1688	0·741	59·5	3	6	29	62
	Average.........	117	161	182	247	294	361	420	97·5	1667	0·735	61·0	3	6	20	71
	VANCOUVER, B.C.															
77	Richfield *(y)*........	113	167	202	270	321	385	425	97·5	1770	0·753	56·4	5	6	35	54
78	Home *(z)*............	101	152	182	259	309	377	420	97·5	1699	0·747	57·9	4	6	37	53
79	Premier *(a)*..........	94	142	176	267	317	380	418	96·0	1700	0·743	58·9	5	8	34	53
80	General *(aa)*.........	98	144	174	254	305	372	410	97·0	1659	0·743	58·9	2	8	33	57
	Average.........	101	151	183	262	313	378	418	97·0	1707	0·746	58·2	4	7	35	54
	VICTORIA, B.C.															
81	Union *(v)*...........	98	152	185	254	290	356	412	97·0	1649	0·741	59·5	1	8	31	60
82	Premier 3 Star *(a)*...	102	152	184	254	300	374	418	97·0	1682	0·747	57·9	4	6	40	50
83	Shell *(bb)*...........	108	159	186	252	289	353	399	97·0	1638	0·744	58·7	3	6	36	55
84	Home *(cc)*...........	96	146	180	265	314	376	414	96·0	1695	0·744	58·7	4	7	38	51
	Average.........	101	152	184	256	298	365	411	96·8	1666	0·744	58·7	3	7	36	54

TABLE III

Average Results of Analyses by Cities

District	Distillation Range								Index No. ° F.	Specific gravity	Degrees A.P.I.
	1st drop ° F.	10% ° F.	20% ° F.	50% ° F.	70% ° F.	90% ° F.	End point ° F.	Recovery			
Halifax, N.S.	109	166	193	268	310	367	415	97·3	1720	0·747	57·9
St. John, N.B.	103	150	178	257	302	363	416	96·8	1666	0·734	61·3
Quebec, Que.	100	150	178	255	299	360	404	96·8	1646	0·734	61·3
Montreal, Que.	101	153	181	254	301	361	403	97·1	1655	0·738	60·2
Ottawa, Ont.	100	151	177	248	293	354	405	97·0	1627	0·734	61·3
Toronto, Ont.	103	154	184	257	303	363	410	96·8	1672	0·732	61·8
London, Ont.	98	151	181	259	308	363	409	97·1	1666	0·735	61·0
Winnipeg, Man.	97	146	176	256	305	366	415	97·0	1665	0·731	62·1
Regina, Sask.	105	164	193	266	310	376	423	97·4	1734	0·740	59·7
Edmonton, Alta.	102	150	176	249	301	375	424	96·9	1676	0·736	60·8
Calgary, Alta.	117	161	182	247	294	361	420	97·5	1667	0·735	61·0
Vancouver, B.C.	101	151	183	262	313	378	418	97·0	1707	0·746	58·2
Victoria, B.C.	101	152	184	256	298	365	411	96·8	1666	0·744	58·7
Average*	102	153	181	255	300	363	411	97·0	1663	0·736	60·8

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

COMPARISON OF RESULTS

It is quite interesting to compare the above figures with others obtained in somewhat the same way. Table IV gives the average results of 88 samples collected in Canada presumably in 1916, and reported by the laboratories of the Department of Inland Revenue[1]; the average results of the following number of samples collected in Canada in the year indicated; 48 in 1923[2]; 59 in 1924[3]; 73 in 1925[4]; 76 in 1926[5]; 83 in 1927[6]; 77 in 1928[7]; and 84 in 1929; the average results of 162 samples collected in the United States during July, 1929, and reported by the U.S. Bureau of Mines[8], and the essential features of the specification for motor gasoline adopted by the Specification Board of the United States[9] for the use of the various departments and independent establishments of the United States Government. When judged by the distillation range, which is the ordinarily accepted standard, it will be observed that the gasoline sold in Canada during the present year shows an average of good quality, being slightly more volatile than that sold during 1928. According to the data in Table IV and the distillation curves which are shown in the graph on the page 22 of this report, the gasoline marketed in Canada during August, 1929, was superior to that sold in United States during July, 1929, and to the United States Federal Specifications for the United States Government motor gasoline.

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[1] Department of Inland Revenue, Canada, Bull. No. 362 ("Gasoline").

[2] [3] [4] [5] [6] [7] Investigations of Fuels and Fuel Testing, Mines Branch, 1923, 1924, 1925, 1926, 1927, and 1928, respectively.

[8] U.S. Bureau of Mines, Report of Investigations, Serial No. 2959.

[9] U.S. Bureau of Mines, Technical Paper No. 323-B.

TABLE IV

Average Results for Comparison

—	Distillation Range								Index No. ° F.	Specific gravity	Degrees A.P.I.	Iodine value
	1st drop ° F.	10% ° F.	20% ° F.	50% ° F.	70% ° F.	90% ° F.	End point ° F.	Recovery				
Canada, 1916	125	170	192	237	270	330	380	....	1579	0·732	61·8	17
Canada, 1923	120	170	193	255	296	358	423	97·1	1695	0·737	60·5	19
Canada, 1924	113	173	195	249	288	347	410	97·4	1662	0·736	60·8	18
Canada, 1925	116	174	199	258	299	359	412	97·0	1701	0·739	60·0	18
Canada; 1926	110	164	191	256	300	360	410	97·4	1681	0·739	60·0	21
Canada, 1927	107	161	189	259	304	366	416	97·0	1693	0·741	59·5	....
Canada, 1928	107	160	186	255	298	359	409	97·3	1667	0·737	60·5	25
Canada, 1929	102	153	181	255	300	363	411	97·0	1663	0·736	60·8	....
United States, July, 1929	102	....	187	263	....	378	410	96·1	....	0·748	57·7	....
U.S. Federal Specification	131	....	221	284	....	392	437	....	....	....	....	....

TABLE V

Ten Per Cent of Samples Having Maximum End Point

Sample No.	Brand	Distillation Range								Index No. ° F.	Specific gravity	Degrees A.P.I.
		1st drop ° F.	10% ° F.	20% ° F.	50% ° F.	70% ° F.	90% ° F.	End point ° F.	Recovery			
73	Maple Leaf........................	126	185	211	283	331	390	438	97·5	1838	0·749	57·4
70	Red Seal..........................	100	143	168	244	302	383	431	96·5	1671	0·729	62·6
20	Blue Sunoco......................	105	168	201	273	324	392	429	97·0	1788	0·759	54·9
72	Super Power......................	99	144	168	243	300	383	429	97·0	1667	0·728	62·9
75	Super Power......................	104	143	164	234	289	370	427	97·5	1627	0·725	63·7
50	Shell.............................	104	150	186	276	333	394	426	97·0	1765	0·744	58·7
52	Premier...........................	96	154	190	274	322	382	426	96·5	1748	0·740	59·7
48	Super Power......................	101	157	188	265	317	382	426	97·0	1735	0·737	60·5
	Average..................	104	155	184	262	315	385	429	97·0	1730	0·739	60·0

TABLE VI

Ten Per Cent of Samples Having Minimum End Point

Sample No.	Brand	Distillation Range								Index No. ° F.	Specific gravity	Degrees A.P.I.
		1st drop ° F.	10% ° F.	20% ° F.	50% ° F.	70% ° F.	90% ° F.	End point ° F.	Recovery			
55	White Star.......................	106	148	171	226	259	311	368	97·5	1483	0·719	65·3
16	Peerless..........................	100	146	170	230	270	326	368	97·0	1510	0·722	64·5
39	Aviation..........................	104	152	173	227	265	320	370	97·5	1507	0·722	64·5
21	Aviation..........................	98	145	168	231	266	325	371	97·5	1506	0·722	64·5
36	Domestic.........................	89	134	162	236	274	329	373	96·0	1508	0·713	67·0
44	Domestic.........................	100	143	172	242	286	345	381	96·0	1569	0·717	65·8
41	Peerless..........................	98	146	172	236	278	338	386	96·5	1556	0·722	64·5
31	Super Quality....................	92	130	151	217	259	321	387	97·0	1465	0·720	65·0
	Average..................	98	143	167	231	270	327	375	96·9	1513	0·720	65·0

In order to determine the variation in quality of the gasoline being sold, the average of the 8 samples (approximately 10 per cent of the total 84 samples) having the highest end point, and the average of the 8 samples having the lowest end point, was obtained as in preceding years. The results are shown in Tables V and VI.

TABLE VII

Difference between Maximum and Minimum End Points

—	1916	August 1923	August 1924	August 1925	August 1926	August 1927	August 1928	August 1929
Maximum 10%.............	432	446	459	458	437	438	432	429
Minimum 10%.............	322	381	358	366	379	380	375	375
Difference..........	110	65	101	92	58	58	57	54

Table VII shows the difference between the average end points of the maximum 10 per cent and minimum 10 per cent of the samples collected in Canada in 1916 (16), and in the seven years 1923 to 1929. 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, when determined by the above method, was less than that obtained in any previous year.

The variation in quality is more exactly indicated by the index number, because it represents an aggregate of several points in the distillation range rather than the arbitrarily chosen end point. The procedure adopted was the same as that used above, namely, the average of 10 per cent of the samples having the highest index numbers, and the average of 10 per cent of the samples having the lowest index numbers was calculated. The results obtained for the current year's survey are shown in Tables VIII and IX.

TABLE VIII

Ten Per Cent of Samples Having Maximum Index* Numbers

Sample No.	Brand	Index No. ° F.	Specific gravity	Degrees A.P.I.	Distillation Range						End point ° F.
					1st drop ° F.	10% ° F.	20% ° F.	50% ° F.	70% ° F.	90% ° F.	
73	Maple Leaf	1838	0·749	57·4	126	185	211	283	331	390	438
20	Blue Sunoco	1788	0·759	54·9	105	168	201	273	324	392	429
24	Marathon	1774	0·740	59·7	105	164	196	272	327	391	424
77	Richfield	1770	0·753	56·4	113	167	202	270	321	385	425
50	Shell	1765	0·744	58·7	104	150	186	276	333	394	426
6	White Rose	1752	0·739	60·0	115	171	203	267	311	376	424
58	Super Power	1749	0·741	59·5	96	160	187	278	323	380	421
4	Imp. Ethyl	1749	0·757	55·4	118	173	200	270	316	370	420
	Average	1773	0·748	57·7	110	167	198	274	323	385	426

TABLE IX

Ten Per Cent of Samples Having Minimum Index* Numbers

Sample No.	Brand	Index No. ° F.	Specific gravity	Degrees A.P.I.	Distillation Range						End point ° F.
					1st drop ° F.	10% ° F.	20% ° F.	50% ° F.	70% ° F.	90% ° F.	
31	Super Quality	1465	0·720	65·0	92	130	151	217	259	321	387
55	White Star	1483	0·719	65·3	106	148	171	226	259	311	368
21	Aviation	1506	0·722	64·5	98	145	168	231	266	325	371
39	Aviation	1507	0·722	64·5	104	152	173	227	265	320	370
36	Domestic	1508	0·713	67·0	89	134	162	236	274	329	373
16	Peerless	1510	0·722	64·5	100	146	170	230	270	326	368
74	Regal	1514	0·725	63·7	125	160	172	217	251	319	395
43	Supertest H. C	1532	0·721	64·8	91	129	151	227	275	349	401
	Average	1503	0·720	65·0	101	143	165	226	265	325	379

*The index number is the sum of the following points in the distillation range:—10%, 20%, 50%, 70%, 90%, and End Point.

Similar calculations were made to show the difference between the average index numbers of the maximum 10 per cent and the minimum 10 per cent of the samples collected and analysed in preceding years. These results are shown in Table X.

TABLE X

Difference Between Maximum and Minimum Index Numbers

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

It will be observed that the above index number method of calculation indicates more definitely than the end point method of calculation, that the variation in quality was less in 1929 than that obtained in any previous year.

It will be further observed that the average index number, namely 1773, of 10 per cent of the samples having the highest index numbers of all those examined in 1929 was lower than the average index number of similar grades of samples examined in any previous year. This indicates that the average volatility of that grade of samples was greater in 1929 than the average volatility of similar grades examined in any previous year. It will be noted that the average index number, namely 1503, of 10 per cent of the samples having the lowest index numbers of all those examined in 1929 was higher than the average index number of a similar grade of samples examined in 1928. This indicates that the average volatility of that grade of samples was less in 1929 than the average volatility of a similar grade of samples examined in 1928. Accordingly, it may be said that the lowest grade of samples examined in 1929 was more volatile than similar grades examined in any previous year, and that the highest grade of samples examined in 1929 was less volatile than a similar grade examined in 1928.

Significance of Tests

It is highly probable that someone will desire more information on this subject of gasoline and the way in which the results of analyses should be interpreted. Laboratory analyses are most valuable when they serve to indicate probable performance under operating conditions, hence an attempt will be made to interpret along that line some of the analytical results given above. The owner of the engine is the final judge of the quality of a motor fuel and he reaches his conclusions from the general responsiveness of the engine. It is obvious that the criteria for quality in motor fuels are changing just as rapidly as the engines are being changed. It appears to the writers 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 difficulty.

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

A good gasoline should possess the following characteristics:—

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

Easy Starting. A gasoline that permits an engine to start readily should have a reasonably low initial boiling point, about 100° F. is satisfactory under normal atmospheric temperatures, and the temperature at which 10 per cent has been recovered should also be reasonably low, about 150° F. would probably give good results. This provides for a reasonable quantity of highly volatile material 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 vapours should not carry too much material of high boiling point because such material is usually more difficult to ignite. Nor 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 points.

A gasoline that will permit an engine to start readily and also permit satisfactory power development provided the distillation range shows 70 per cent over at about 300° F. In addition, the end point should not be too high.

Satisfactory Idling. Smooth running at low speed is seemingly 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 carburettor. Obviously, the placing of the parts, the temperature of the engine, and the temperature of the atmosphere will have considerable effect.

Anti-knock Qualities. Some fuels have mixed with them certain chemicals that lessen the tendency of the fuel to cause "knocking". These fuels require elaborate equipment to determine the actual anti-knock value, which equipment was not available when the gasolines that constitute the present report were being analysed. Other fuels that have not been prepared by the addition of anti-knock compounds, such as tetraethyl lead, show rather wide variations in this respect. Generally speaking it may be assumed that gasolines having a high percentage of aromatics and unsaturates will knock less than fuels having a low percentage, providing the gasolines contain no artificially mixed anti-knock compounds.

Evaporation. 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.

Gum. It is very difficult to determine the amount of gum in gasolines in such a manner that definite limits could be set. This is due to the fact that the character and amount of the gum varies greatly in different gasolines. A gasoline may show no gum formation when freshly distilled, but at some time later definite gummy deposits may be obtained. The time and the conditions required for the gum deposits to form also vary greatly. It is believed that unsaturates are more likely to cause gum than any of the other constituents.

The writers desire to emphasize again that the opinions expressed above regarding desirable characteristics for gasoline when used for motor fuel are from the standpoint of the average motor car owner during the summer. It is understood, of course, that atmospheric changes of temperature and pressure would cause considerable modification of the figures.

SUMMARY

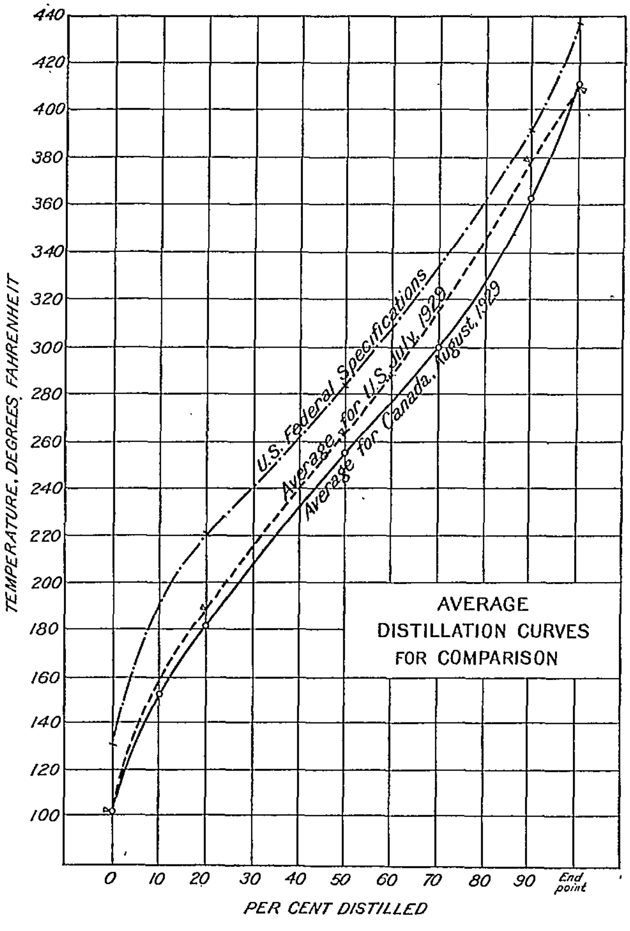
Eighty-four samples of gasoline were collected in August, 1929, from thirteen widely separated Canadian cities, and may be accepted, therefore, as representative of the gasoline sold in Canada at that time.

The analyses and detailed examinations show that the average gasoline sold during 1929 was of good quality, being slightly more votalile than that sold during 1928.

The variation in quality during 1929 was less than that in any previous year.

For comparison of the higher and lower quality gasolines, two groups, each comprising 10 per cent of the total number of samples examined, were chosen as in the former surveys. The average of the higher quality group of the 1929 samples was less volatile than the corresponding group in 1928, while the average of the lower quality group of the 1929 samples was more volatile than the corresponding group in 1928 and in any previous year.

According to distillation range and other data obtained, the gasoline marketed in Canada during August, 1929, as represented by the samples collected for this survey, was superior to that sold in the United States during July, 1929, as represented by the analyses of samples reported by the United States Bureau of Mines, which gasoline in turn was superior to the United States Federal Specifications for United States Government motor gasoline.


440
420
400
380
360
340
320
300
280
260
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220
200
180
160
140
120
100
TEMPERATURE, DEGREES FAHRENHEIT
0
10
20
30
40
50
60
70
80
90
End point
PER CENT DISTILLED
U.S. Federal Specifications
Average for U.S., July, 1929
Average for Canada, August, 1929
AVERAGE
DISTILLATION CURVES
FOR COMPARISON

Figure 4

VI

THE ANALYSIS OF NATURAL GAS FROM THE TURNER VALLEY FIELD IN ALBERTA

P. V. Rosewarne and R. J. Offord

In July, 1929, the writers received instructions to obtain data that would show the relative amounts of the various hydrocarbons present in the surplus natural gas being produced at Turner Valley field in Alberta. This report covers the analyses of 35 samples of natural gas and naphtha from that area. All were subjected to fractional analysis in a special Podbielniak apparatus that was secured and set up in one of the laboratories of the Provincial Institute of Technology at Calgary. In addition, the report briefly describes apparatus for the analysis of gases; commercial separators used in the field to remove crude naphtha from the gas; methods used for collecting the gas samples; compares "wet" and "dry" gases produced; offers some comments regarding the production of naphtha from this area; and points out the relative value of the analysis given. The results of the analyses are given in Tables I to VII in the context, and in Tables VIII to XIV which are appended. The preliminary work on this subject reported herewith has been continued during 1930, and the results will be given in a later report.

OBJECTIVE OF GAS ANALYSIS

The complete analysis of natural gas should indicate the amount of every important constituent present in the sample. Therefore, the following should be determined: total hydrocarbons, carbon dioxide, oxygen, sulphur, nitrogen, and helium. If, in addition to these, it is possible to estimate the amount of the individual hydrocarbons present, so much the better. Olefines should be reported only after tests have proved their presence. The ordinary test, namely, amount of sample absorbed in fuming sulphuric acid or in bromine solution, is not sufficient evidence of itself because the higher paraffins are somewhat soluble in these reagents. The same may be said regarding carbon monoxide with cuprous chloride as reagent.

TYPES OF APPARATUS

Gas analysis requires highly specialized apparatus depending primarily on the character of the constituent, the amount of which it is desired to determine, and it also requires a technique of operation that is almost perfect. Perhaps the earliest type of apparatus that was adapted to the analysis of natural gases was the Hempel absorption pipette. A modified form incorporating two suitably placed electrodes was used to burn the gases so that the products of combustion could be studied. The Hempel type of apparatus was quite satisfactory and even to-day has many adherents. However, it was bulky and somewhat fragile and a large number of "improvements" have made their appearance. There are the Orsat, Morehead, Williams, Haldane, Bone and Wheeler, and others. Most of these have been still further modified by other users to make them more satisfactory for the particular type of gas with which they were being used. There are indications that some features of the Lunge apparatus for the determination of nitrogen have also been adopted. Possibly; he apparatus of this type most often used on this continent for the analysis of natural gas is the one referred to as the Burrell, the U.S. Bureau of Mines, or the U.S. Steel Corporation apparatus.

Another type of apparatus largely used in the natural gas industry depends on the absorptive power of a specially selected charcoal for volatile hydrocarbons. It is known as the Oberfell apparatus or the Charcoal Absorption apparatus. It is adapted to determining the amount of liquid that may be recovered from a natural gas.

A third type of apparatus, more highly specialized than either of the two mentioned above, makes use of the principle of fractional distillation. An apparatus making use of this principle was developed by Burrell, Seibert, and Robertson at the U.S. Bureau of Mines.[1] A modified apparatus was described later by Shepherd and Porter[2] who were also connected with the U.S. Bureau of Mines. An improved form was described still more recently by Shepherd.[3] In the meantime, a simpler type of apparatus was being developed for the Phillips Petroleum Company at the University of Michigan by W. J. Podbielniak.[4] This latter apparatus was considerably more compact, gave good results in a comparatively short time, and was designed so that either gaseous or liquid samples could be analysed. It is probable that the Shepherd and Porter apparatus will give more precise results, but other disadvantages react against its general use by the petroleum industry.

The Burrell Apparatus

The Burrell apparatus is designed to determine percentages of methane, ethane, carbon dioxide, carbon monoxide, hydrogen, olefines, oxygen, and nitrogen by difference. It consists of a measuring burette, a series of absorption pipettes, a combustion pipette, and a small electric furnace and tube, all of which are supported on a suitable framework together with a number of accessories that greatly simplify the procedure of making an analysis. The general appearance of one form of the apparatus is shown in Figure 5. A very complete description and discussion of the apparatus is given in the publications of the U.S. Bureau of Mines.[5]

The Burrell apparatus was developed in the United States during an investigation of natural gas produced in the vicinity of Pittsburgh, Pa. The gas from that field was a dry gas composed largely of methane with a small amount of the higher hydrocarbons. As was pointed out by A. C. Fieldner of the U.S. Bureau of Mines, the apparatus was found to be entirely satisfactory for that gas, and the assumptions made were warranted when they were applied to gases similar in composition to the Pittsburgh

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[1] Burrell, Seibert, and Robertson: "Analysis of Natural Gas by Fractional Distillation"; U.S. Bureau of Mines, Technical Paper 104.

[2] Shepherd and Porter: "An Improved Method for the Separation of Gas Mixtures"; Industrial and Engineering Chemistry, November 1923

[3] Shepherd: "Accurate Determination of Gasoline Content of Natural Gas"; Journal of Research, June 1929, U.S. Bureau of Standards.

[4] Oberfell and Alden: "Fractionation at Low Temperature"; Oil and Gas Journal, October 18, 1928.
Podbielniak, W. J.: "Method of Natural Gasoline Analysis"; Oil and Gas Journal, January 17, 1929.

[5] Burrell and Seibert: "Sampling and Examination of Mine Gases and Natural Gas"; U.S. Bureau of Mines Bulletin No. 42.

gas. With this point of view the writers agree entirely. They believe the apparatus to be reasonably suitable for use with any gas, the methane content of which is greater than 85 per cent of the total hydrocarbon content. However, the apparatus was so convenient that it was enthusiastically adopted on all sides and used for the analysis of gases that differed widely in composition from the Pittsburgh natural gas, and for which the assumptions originally made in calculating the results were not justified Reported analyses are common showing 60 and 70 per cent of methane and the balance practically all ethane. The writers believe that in any case where the methane content indicated by this type of analysis is less than about 85 per cent of the total hydrocarbon content of the sample, it would avoid confusion if the terms "methane" and "ethane" were not used. The sum of these two constituents indicated by the analysis may very properly be reported as "total hydrocarbons" or by some similar general term, and that in most cases it would give valuable information. When the proportion of methane to the other hydrocarbons exceeds 85 per cent, the errors involved in this type of analysis are only important when a very precise analysis is required.

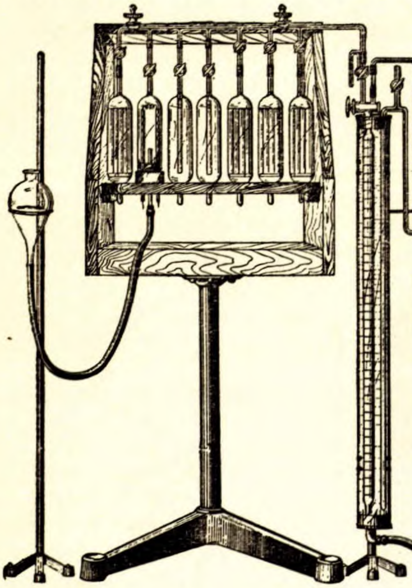

Figure 5. Diagram of gas analysis apparatus of the Burrell or Bureau of Mines type.

A sample of gas was obtained from the Edmonton City mains. Part of it was analysed in a Burrell type apparatus [1] and part of it was fractionated in a Podbielniak apparatus. The Burrell type apparatus showed 91·1 per cent methane and 3·3 per cent ethane and higher. By fractionation 92·1 per cent methane and 2·3 per cent ethane and higher was obtained. This indicates relatively good agreement when the methane content is high. However, another gas low in methane and high in ethane

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[1] By courtesy of Dr. E. H. Boomer, University of Alberta, Edmonton, Alberta.

and higher hydrocarbons was analysed in a Burrell type apparatus at the Fuel Research Laboratories. Repeated tests indicated a total of approximately 180 per cent for ethane and higher hydrocarbons. Tests on other samples containing high methane percentage both before and after the above tests gave normal results. No leak or other defect was found in the apparatus. When fractionated the sample showed approximately the following:—

	%
Methane +	**25**
Ethane	**14**
Propane	**30**
Butanes	**23**
Pentanes +	**8**

It is obvious from the above results that an analysis of such a gas by the Burrell type of apparatus is useless unless proper corrections can be made.

The Oberfell Apparatus

The general appearance of the Oberfell, or Charcoal Absorption, apparatus is shown in Figure 6. It consists of an accurate meter for measuring the gas, a tube containing granulated charcoal, and suitable arrangement of glassware for a distillation. A measured quantity of gas is drawn over the charcoal, and the charcoal with its charge of absorbed hydrocarbons is later distilled from a bath of heated glycerine or mercury.

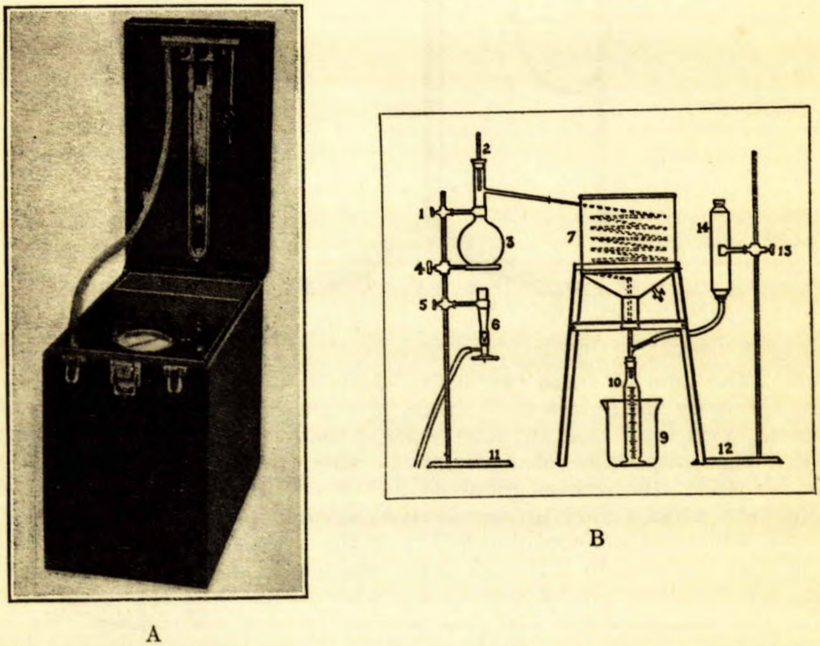

Figure 6. Oberfell charcoal absorption and accessory distillation apparatus.

A. Appearance of Oberfell apparatus (in case) for use in laboratory or field.

B. Diagrammatic sketch of distillation apparatus for recovering the absorbed liquids from the activated charcoal.

As stated above, it is specially adapted for determining the amount of liquid that may be condensed from a gas by ordinary cooling methods. It is obviously difficult to retain and measure very volatile fractions. The writers made no comparative tests on the natural gases from Turner Valley, but according to published reports[1] the agreement between the amount of isobutane and heavier hydrocarbons as shown by fractionation methods, and the amount of condensate recovered by Charcoal Absorption is very good.

The Podbielniak Apparatus

As stated above, this apparatus depends on the principle of fractional distillation. From a practical viewpoint, this means that when the sample is a gas it must first be liquefied and the resulting liquid distilled exactly as if it were liquid at normal temperatures, instead of at sub-normal temperatures. When working under such conditions, it is obvious that suitable precautions must be taken to counteract the effect of handling a liquid in an atmosphere whose temperature is greatly above the boiling point of the liquid involved. In this apparatus (shown in Plate VI and Figure 7) the sample is distilled in a closed system and is liquefied in the same compartment from which it is afterward distilled. The advantage of this procedure is that it avoids transferring the liquefied gas from one vessel to another and, consequently, a possible loss of some of the sample. The refrigerant used is liquid air, liquid oxygen, or liquid nitrogen. The last-named is preferable if it can be obtained, partly due to its inert nature and partly to its lower boiling point.

The apparatus is made almost entirely of Pyrex glass, and consists primarily of a distillation bulb, a fractionation column, and a receiver. Additional apparatus to indicate changes of pressure and temperature, to purify the sample, to vaporize it, to control the effluent temperature and to reduce the pressure as desired, are necessary accessories.

The fractionation column is a long glass tube, to the lower end of which is sealed a small distillation bulb. The column and all of the distillation bulb are thermally insulated by means of an enclosing jacket of glass which is evacuated to a high degree and silvered on the inside to increase its efficiency. The silver deposit is so thin in the middle portion as to be almost transparent, but is much thicker at the ends, particularly at the top, where the jacket is increased in size and fashioned into a double-walled receptacle of the Dewar jar type. This receptacle, during an analysis, is filled with a liquid of low freezing point, such as pentane, and a copper vessel is submerged in the liquid, which vessel contains the liquid air used for controlling the temperature of the effluent gas. This liquid air container almost encircles the outlet from the fractionation column which extends up through the bottom of the Dewar jar receptacle and projects two or three inches above the rim.

The fractionation column contains an inner spirally-wound packing of non-corrosive alloy, such as copel wire. The coil is made by winding a length of wire of about 22 gauge around a small rod of drill steel. The rod varies slightly in diameter because the finished wire coil should fit the inside of the glass tube snugly. Usually, it is about size 28 or 30, i.e. about 2 mm. in diameter. After a sufficient length of wire has been wound,

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[1] "The Use of Gas and Gasoline Analysis in the Practical Operation of a Gasoline Plant"; The Petroleum World, January, 1929.

the rod is removed, and the coil gently drawn out so that adjacent turns remain approximately 1/10th of an inch apart. The correct distance between adjacent turns for the best efficiency depends on the size of the glass tube, and on the type of gas that it is intended to analyse in the apparatus. When the unit is completed it is slipped into place. It resembles the electrical resistance unit used in electric heaters and furnaces.

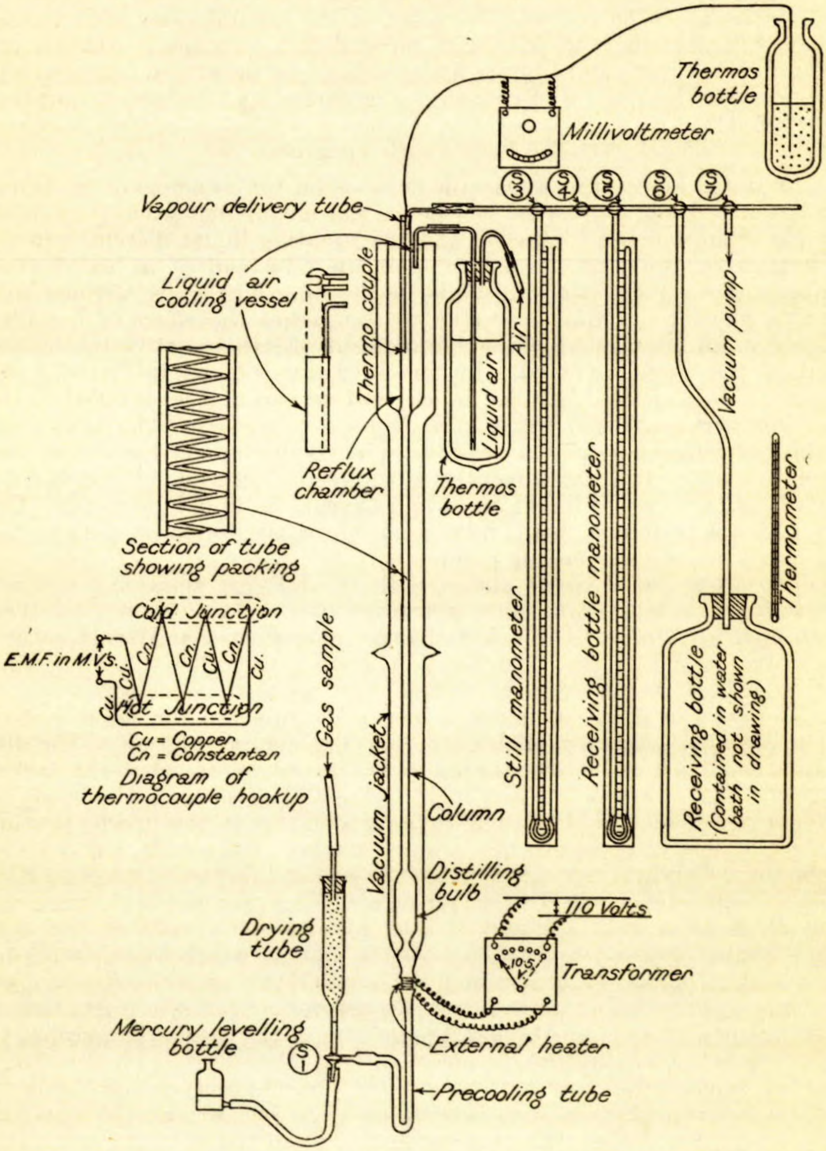


Figure 7. Apparatus for fractional distillation analysis of natural gas gasoline and similar gaseous and volatile liquid mixtures.

The gas outlet tube that projects above the rim of the vacuum jacket is connected to a stopcock manifold by means of a small flexible brass tube, so that strains due to expansion and contraction, or to an accidental blow, shall not result in breakage of the glass parts.

A thermocouple is sealed into the gas outlet tube to indicate the temperature of the gas coming over. This thermocouple is a triple junction copper-constantan unit used in conjunction with a sensitive millivoltmeter. The millivoltmeter is subdivided into tenths of a millivolt and indicates almost 10 degrees Centigrade per millivolt, so that temperature variations of one degree Centigrade may be easily observed.

The stopcock manifold is built up of a sufficient number of stopcocks to permit satisfactory and convenient control of all connecting units. Attached to it are two mercury manometers, one to indicate the pressure in the column, and the other to indicate the pressure in the receiver. Connexions are also provided for a vacuum pump and for the receiver, of course.

The receiver may be any heavy walled glass vessel that can be tightly closed, and whose exact volume can be determined. An ordinary one-, two-, or three-gallon glass bottle serves very well. The receiver is submerged in a large water bath so that temperature changes of the gas may be equalized as promptly as possible.

Below the distillation bulb and connecting directly with it is a pre-cooling tube. This is a narrow U-shaped tube which during the first part of the analysis is surrounded by a Dewar jar containing some liquid air. At the upper part of the pre-cooling tube, close to the distilling bulb, is a short heating unit composed of a large number of turns of No. 32 nichrome wire wound about the outside of the tube. The wire is insulated with asbestos. When heat is required to vaporize the heavier portions of the sample, the tube is filled with mercury up to the bottom of the distillation bulb and an electric current is passed through the unit. The mercury serves as a conductor of the heat from the unit to the liquid in the distilling bulb. The amount of heat supplied is controlled by a small transformer tapped in several places so that the voltage supplied can be regulated.

Operation of the Apparatus:

The apparatus, manifold, and receivers, are first evacuated to a pressure of a few millimetres; a jar of liquid air is placed around the pre-cooling tube; the reflux bath at the top of the fractionating tube is dried and filled with pentane or petrolic ether; and the liquid air container is put in place and filled with liquid air from the vacuum bottle. When the temperature has dropped to a constant value, as indicated by the thermocouple, the gas to be analysed is slowly passed through the solution of potassium hydroxide, and the drying tube, and admitted to the pre-cooling tube, the distilling bulb, and the fractionating column. At the top of the column the hydrocarbons are liquefied and run down to the bottom of the column. Gases non-condensible at the temperature of liquid air such as nitrogen and helium are permitted to pass on to the receiver after the whole apparatus has attained a satisfactorily low temperature. In practice, it is found expedient to allow the greater part of the methane to go over also in this way. When the sample has been admitted the stopcock leading to the gas-holder is closed and the connecting tubes filled with mercury to prevent leakage. The vacuum jar about the pre-cooling tube is removed and the remainder of the distillation regulated by controlling the temperature of the reflux bath at the top of the column with liquid air, and the amount of heat supplied to the base of the column. The entire distillation is carried on at atmospheric pressure as indicated on one of the manometers, until the temperature of the effluent vapour approaches that of the atmosphere. Then the vapour pressure on the column is reduced sufficiently to keep the boiling point well below room temperature so that condensation may not take place in the manifold tubes or receivers.

The amount of distillate is measured by the vapour pressure in the receiver. The receiver is re-evacuated as often as may be necessary, the distillation being checked meanwhile by adding a small excess of liquid air to the cooling-chamber at the top of the fractionation column.

APPARATUS TO TRANSFER SAMPLE

When samples containing a large amount of the higher, less-volatile hydrocarbons are being analysed in the Podbielniak apparatus, the transfer of the sample offers no difficulty because it is not usually necessary to use more than one container full of gas. In such cases, a pair of aspirator bottles connected with a rubber tube and with a three-way stopcock fitted to the mouth of one of the bottles, are quite satisfactory. However, when the samples being analysed contain large proportions of methane, aspirator bottles sufficiently large to hold the sample are too cumbersome and heavy to be handled easily, and to use two or more pair of aspirator bottles for the same sample involves a great deal of trouble in changing over from one to another during a test. The writers, therefore, devised an apparatus that worked very satisfactorily and was of considerable help in maintaining an even flow of gas through the fractionation column. A diagram of it is shown in Figure 8.

It consists of a large metal container, supported on a frame, a five-gallon glass bottle, with suitable connexions made of glass, copper, or rubber tubing, and four taps, which may be made of glass or metal. The metal container used by the writers was a large galvanized bucket such as is ordinarily sold for a garbage can. It was about 18 inches high and 15 inches in diameter. Three outlets were cut in it, one in the side near the top for an overflow, and two in the bottom. The copper tube fitted to one of these bottom outlets extended up inside the container almost to the level of the overflow. The copper tube fitted to the other outlet extended a very short distance inside the container. The glass bottle was fitted with a two-hole rubber stopper, through which projected two tubes. One tube extended only to the lower surface of the stopper, and was connected to the long copper tube mentioned above. The other tube extended almost to the bottom of the glass bottle and was connected to the short copper tube referred to above. A connexion was made to each of the two connecting tubes. One led to the Podbielniak apparatus, and the other led to the drain. The four taps were inserted in the connecting tubes as shown in Figure 8 at A, B, C, and D.

The overflow outlet near the top of the metal container, or pressure tank, was also connected to the drain, and provision was made for supplying water to the tank. The frame supporting the tank was made a convenient height above the glass bottle that serves as a gas-holder.

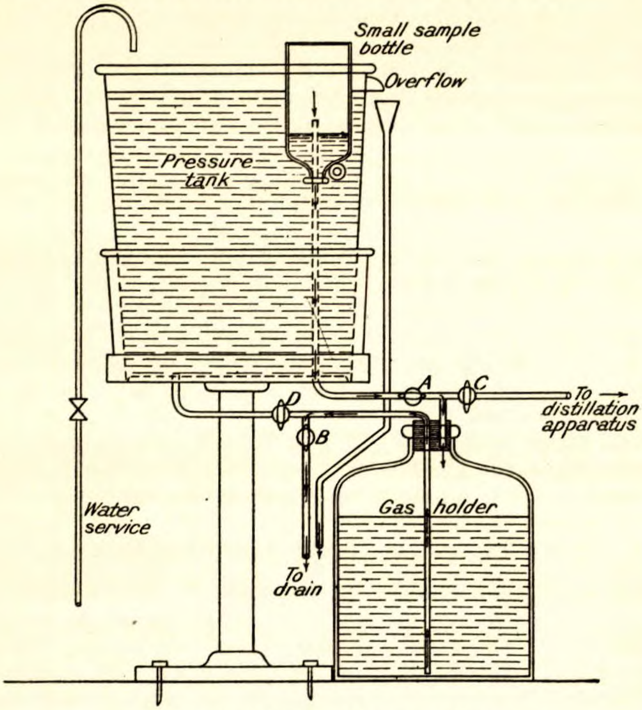


Figure 8. Gas transfer apparatus.

To operate the apparatus, taps A and D are opened and taps B and C are closed. Water is run into the pressure tank until both it and the gas-holder are full and the water overflows. All the connecting tubes are then full of water and taps A and D are closed. One of the bottles containing the sample to be analysed is then placed, mouth downward in the pressure tank, and its stopper withdrawn while the mouth is held below the surface of the water. Still keeping the mouth below the surface, the bottle is moved over until the mouth is above the long tube. It is allowed to sink so that the tube enters the mouth of the bottle. It may then be let go and the weight of the bottle will sink it still further until it comes to equilibrium, as shown in the diagram. Taps A and B are then opened and the pressure on the sample of gas due to the weight of the bottle forces some of the water up the tube from the bottom of gas-holder and out to the drain through tap B. The gas then flows down through A into the gas-holder, and water rises up inside the sample bottle until all the gas has been transferred. When gas has been entirely displaced from the sample bottle, water begins to run down the connecting tube and into the gas-holder. As soon as this happens, taps A and B are closed, the sample bottle lifted off the tube, emptied, and a second bottle of gas transferred to the gas-holder in the same manner. The number of sample bottles which may be used is limited only by the capacity of the gas-holder. It will be noted that in the interval between the transference of successive samples all the connecting tubes are full of water and no opportunity for contamination of the sample is offered. Obviously, any suitable liquid may be used instead of water.

When it is desired to fractionate the sample of gas in the gas-holder, taps A and B are left closed, tap D is opened and water allowed to flow from the pressure tank to the bottom of the gas-holder and so put the gas sample under pressure. Then, the fractionation apparatus having been previously prepared, the valve controlling the water service is opened slightly so that a small stream of water flows into the pressure tank in order to maintain it at a constant level, and the tap C is opened permitting the sample of gas to flow to the fractionation apparatus.

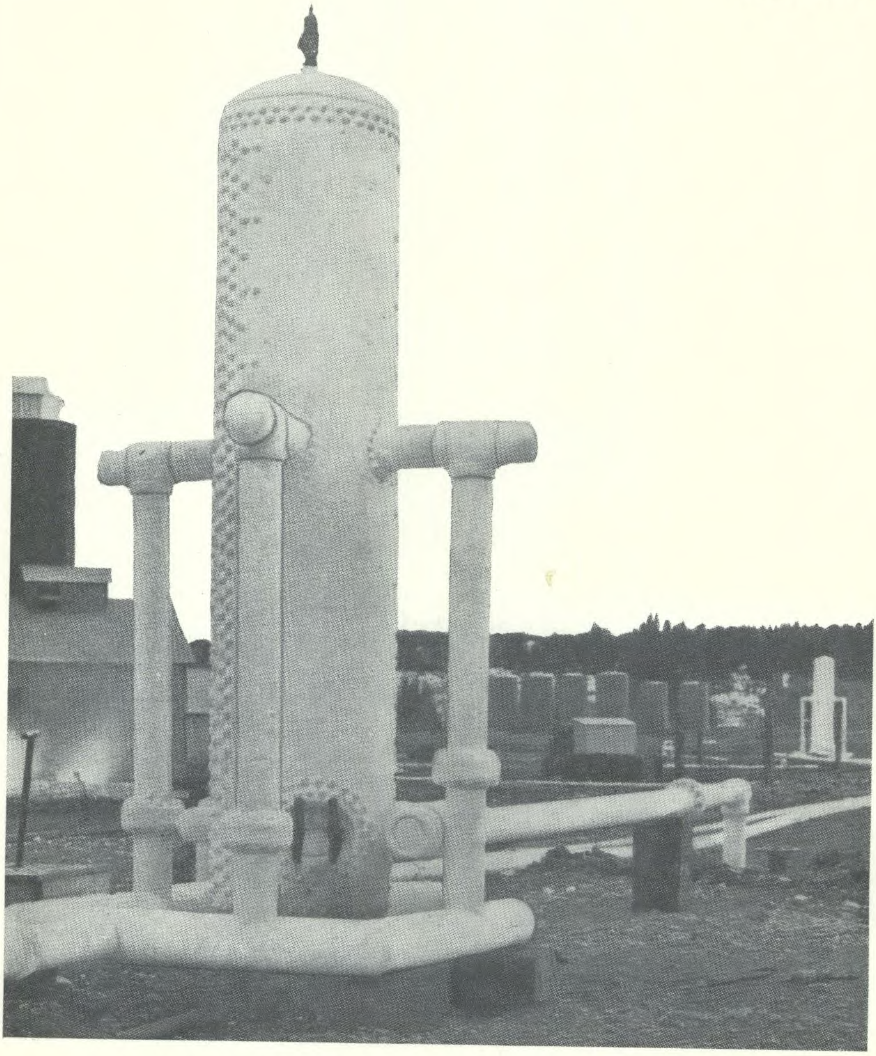
With this apparatus several small samples of gas can be transferred to the gas-holder with no danger of contamination by air; the volume of gas in the gas-holder is obvious at all times, and a fairly constant pressure can be maintained on the gas during the course of a distillation without any attention from the operator after he has properly set the valves at the beginning of the test. It is probable that a similar apparatus could be adapted to many other uses. If it is desired for any reason to recover the gas remaining in the gas-holder it may be collected in a sample bottle without danger of contamination by reversing the procedure.

ACCURACY OF METHOD OF ANALYSIS

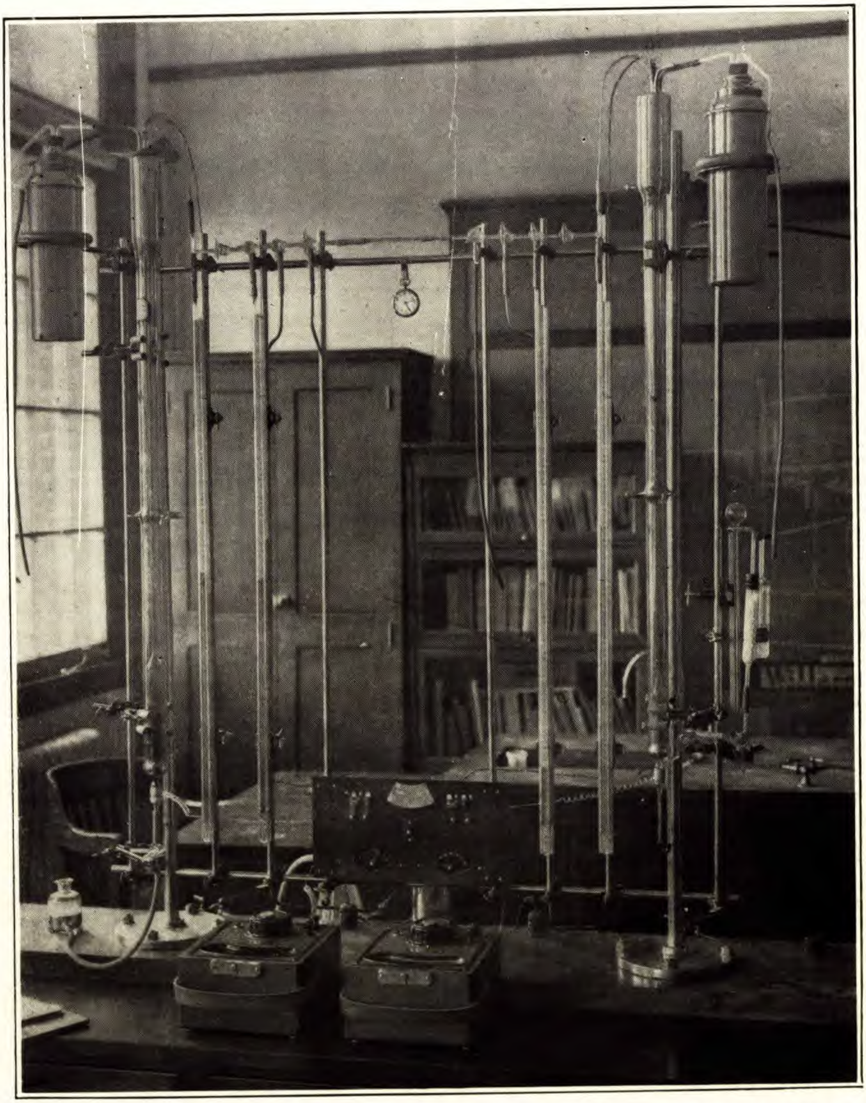
The accuracy of an analysis made with the Podbielniak apparatus is, as has been indicated before, dependent on the size of the sample tested. To give sharply indicated separations of one compound from another, it is necessary to have present in the sample more than sufficient liquid of each component to give a reasonable quantity of it for refluxing and to produce in addition enough vapour to completely fill the fractionation tube and the connexions to the receiver without introducing into the final calculation an appreciable error. Obviously, this condition can be met by increasing the size of sample admitted.

The values shown in the tables are based in all cases on percentage by volume. That shown for methane includes the percentage of all other gases present, whose boiling point is near or below that of methane. The values shown for pentanes include all hydrocarbons whose boiling points are higher than that of pentane. Carbon dioxide and hydrogen sulphide were removed from the sample before it was analysed and the results were not corrected to compensate for this initial purification. The combined amount of these two constituents in no case should be more than 2 per cent.

Table I shows a series of determinations made on natural gas from the gas mains in the city of Calgary. These analyses were made over a period of about three weeks. Since, unfortunately, a gas-holder sufficiently large was not available to permit taking one large sample and dividing it into several parts for consecutive analysis, each analysis was made from a different sample. It will be noticed that the agreement is very good indeed, especially when it is realized that minor fluctuations in composition are quite possible.

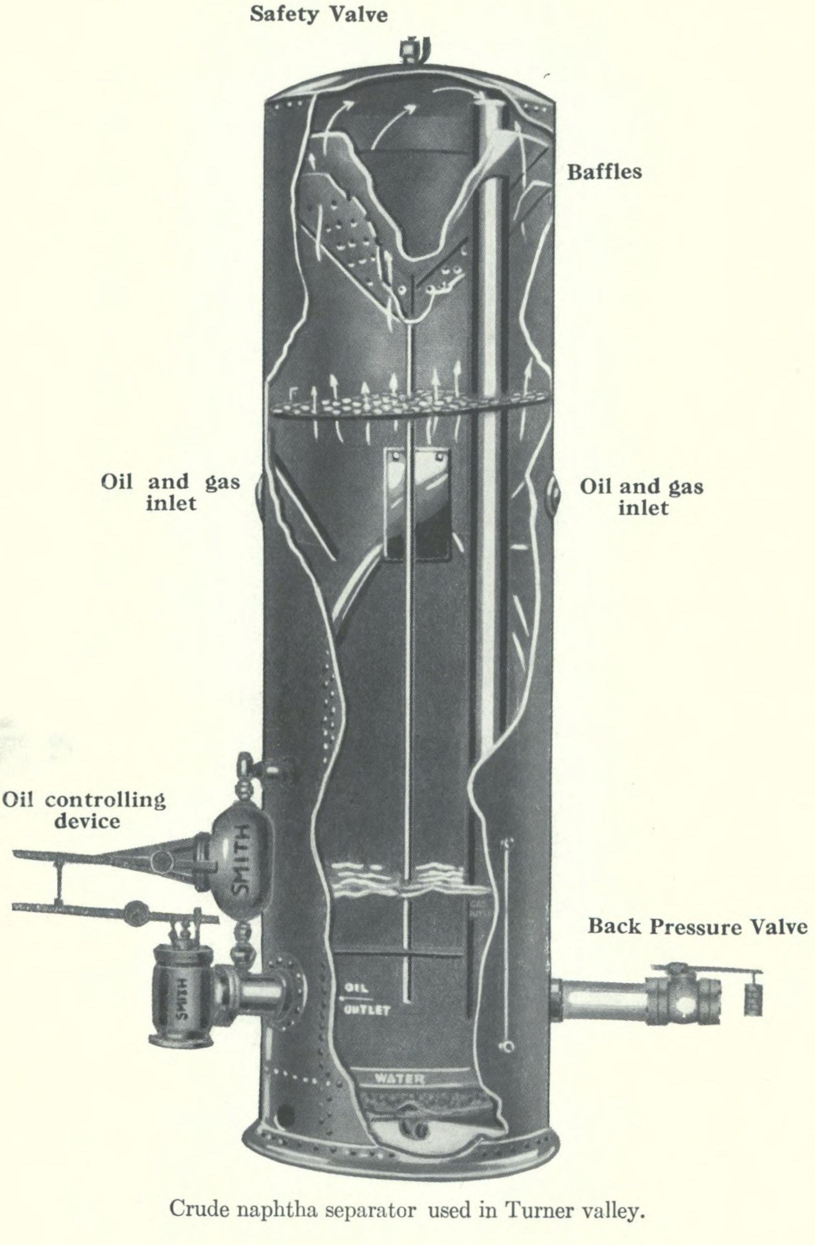


Appearance of crude naphtha separators used in Turner Valley.



Photograph of the Podbielniak apparatus set up in the laboratory of the Provincial Institute of Technology at Calgary, Alberta.

PLATE VIII



Crude naphtha separator used in Turner valley.

TABLE I

Analysis of Purified Natural Gas

Sample No.	Date taken	Methane +	Ethane	Propane	Butanes	Pentanes, +
3	Aug. 30	88·3	6·7	2·8	1·1	1·1
4	" 31	90·5	4·5	3·1	1·1	0·8
5	Sept. 2	89·3	4·9	3·3	1·4	1·0
6	" 3	89·4	5·3	3·3	1·4	0·6
7	" 3	88·2	6·4	3·3	1·3	0·8
13	" 13	88·8	5·4	3·2	1·4	1·2
16	" 19	89·1	5·3	3·3	1·5	0·7
Average		89·1	5·5	3·2	1·3	0·9

NOTE.—All the above samples were taken by ordinary water displacement.

Later, a sample of very rich gas was obtained that required only a small amount for each determination, and this was analysed in triplicate. The results are shown in Table II.

TABLE II

Analysis of Stabilizer Gas

—	Methane +	Ethane	Propane	Butanes	Pentanes +
1	25·6	13·7	29·1	23·3	8·3
2	25·1	13·6	29·5	23·5	8·3
3	25·2	13·4	29·6	23·1	8·7
Average	25·3	13·6	29·4	23·3	8·4

From these results it would appear that the experimental error of the apparatus is considerably less than one per cent when the analysis is made under conditions similar to those outlined above.

SEPARATORS FOR CRUDE NAPHTHA

The separators used in the Turner Valley field for obtaining crude naphtha from the natural gas are usually cylindrical in shape and set vertically. The gas enters part way up the side and is deflected downwards. In rising it passes a series of baffle plates that strip it, more or less completely, of its load of naphtha. The naphtha drops to the bottom of the separator and is periodically removed to storage tanks. The stripped gas passes on to the purifying plant, or it is piped away to a safe distance and burned. An illustration of the external appearance of the separator is shown in Plate VII, and a diagram[1] of the internal arrangement is shown in Plate VIII. It is to be noticed that the outside of the separator and connecting pipe-lines is covered with white frost even during the summer. There is considerable evidence to show that the low temperature of the gas is of major importance in the recovery of naphtha with

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[1] Courtesy of C. C. Ross, Supervising Mining Engineer, Department of the Interior.

this equipment. For instance, the operators report that total yield of naphtha from the separators is greater during cold weather, and that the vapour tension of the product is higher also at such times. This indicates that a greater proportion of the lower boiling constituents than usual has been condensed and it is these constituents, of course, that have increased the vapour tension.

METHODS OF SAMPLING

The need for exercising the greatest possible care in taking a sample is self-evident. At the same time, the method of taking a sample is greatly influenced by the ultimate use to which the result of the analysis is to be put, the normal fluctuations of the material, and the degree of homogeneity in different parts of the mass.

All samples of gas may be subdivided into two classes, namely, so-called "snap" samples and "average" samples. A snap sample is one which is taken from a tank or a pipe-line more or less instantaneously. The actual procedure and equipment may be very simple or may be quite elaborate. The usual method is to fill the gas-holder in a suitable receptacle filled with the same liquid and allow the gas to displace the liquid downward. A glass bottle, a pail of water, and a rubber tube is the equipment generally used in taking samples of natural gas. Sometimes, when sampling gases under high pressure a steel cylinder is used. In such cases it is usually thought sufficient to fill the cylinder with the gas to full pressure, allow the greater part to escape, and fill it again to full pressure. This is repeated several times until the residual air is not sufficient to cause appreciable error. An average sample is one that is taken continuously over a certain period of time, usually 24 hours. Ordinarily, the gas is allowed to flow through a small opening into a relatively large gas-holder, or, if the pressure is not too great, the rate of flow may be regulated by controlling the amount of liquid withdrawn from the gas-holder. An average sample may also be obtained by taking a snap sample at regular intervals over the required time and combining all of them to form one sample.

The snap sample has several advantages over the average sample in that the apparatus required is simple and easily procured, is rapid, and where the gas does not vary appreciably, is quite accurate. It has a further advantage, where the gas does vary, in that a systematic series of samples will show the extent of fluctuation. The average sample is most valuable when it is desired to obtain some data on production from a single analysis.

Sampling Natural Gas in Turner Valley

The problem of sampling was discussed with various authorities before attempting the collection of samples from the Turner Valley field. The conclusion reached was that a sample taken from the pipe-line by downward displacement of water should be reasonably accurate, provided that before taking the sample the valve from which the sample was taken had been opened and ample time allowed for any accumulation of liquid to be blown away. This procedure was accordingly adopted and gave good results. It is agreed that greater accuracy would be secured by using a salt solution instead of water, due to the gases being less soluble in the salt solution, but this precaution seemed to be uncalled for in a preliminary investigation. During the investigation it seemed desirable to check the method of sampling that had been adopted against other methods, because an oily film was observed in some cases on the surface of the water used for displacement, and it seemed obvious that if a representative sample was to be obtained, no oil should appear on the water. Accordingly, samples were taken in a specially designed steel cylinder[1] and also by water displacement after passing the gas through a copper coil.

Sampling with a Steel Cylinder

This cylinder was so designed that the gas was led to the bottom of the cylinder by the inlet pipe. An outlet was provided near the top. In taking a sample with this apparatus the inlet and the outlet valves were both opened wide and the gas allowed to blow through freely. The outlet valve was then gradually closed a little at a time in order to build up a back pressure on the incoming gas, the idea being that in this way a very small pressure differential could be built up that would avoid cooling the gas due to the sudden change in pressure, and the consequent condensation of the higher boiling constituents. However, it was soon found that even when extreme care had been taken in securing the sample, the film of oil appeared when the sample was transferred to the gas-holder of the distillation apparatus.

Two samples of gas were obtained from the pipe-line at Home No. 1, before the gas entered the separator. One sample was taken by the ordinary water-displacement method described in a preceding paragraph, and one was taken in the steel cylinder and by the method described above. The results of the analyses are shown in Table III.

TABLE III

Sampling in a Steel Cylinder under Pressure vs. Water Displacement

—	Methane +	Ethane	Propane	Butanes	Pentanes +
Cylinder	88·3	3·7	3·7	2·3	1·9
Over water	88·4	4·3	2·4	3·1	1·8

It will be noticed that the agreement is very good indeed. Unfortunately, one sample of another pair of samples that were taken to check the above result was broken, so that further exact comparisons cannot be made at the present time. However, sufficient data was obtained to lead the writers to the conclusion that sampling the gases with the steel cylinder was no more satisfactory than sampling in a glass bottle by water displacement.

Sampling with a Copper Coil

On the assumption that the oily condensate was due to adiabatic expansion, and originated at the point of sampling, a special apparatus was designed and tried out. This special apparatus consisted of a coil of copper tubing about 40 feet long. It was made up of four pieces,

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[1] Loaned by courtesy of Supervisory Mining Engineer, Department of the Interior, Calgary, Alberta.

each succeeding piece having a bore slightly larger than the one before. A length of wire was pushed into the bore of the first piece of tubing in order to make the opening as small as possible. The whole coil was fastened in a pail and in taking a sample this pail was filled with hot water. It was hoped that by thus providing external heat and by letting the pressure down gradually the troublesome incipient condensation would be prevented. The efficiency of the apparatus will be apparent when it is noted that with over 300 pounds pressure per square inch on the inlet and with the valve wide open, the gas emerged quite slowly—so slowly, in fact, that it could be held back with the finger for a few moments, much as one could do with city gas—and that it was quite warm. Although no oily film was observed on the water when this apparatus was used, at times a slight fog was noticed issuing from the tube.

Two samples of gas were obtained from the pipe-line at Royalite No. 17, before the gas entered the separator. One sample was taken by the ordinary water-displacement method described in a preceding paragraph and one was taken by inserting the heated copper coil described above between the pipe-line and the sample bottles. The sample bottles were filled with water as in the ordinary water-displacement method. The results of the analyses are shown in Table IV.

TABLE IV

Sampling by Water Displacement, With and Without Heated Copper Coil

——	Methane+	Ethane	Propane	Butanes+
With copper coil...........................	89·9	5·0	3·2	1·9
Without copper coil........................	90·0	4·6	2·7	2·7

It will be observed that in this case also the agreement between the two samples was good. In addition, several other samples taken through the copper coil yielded very similar results, whereas if the gas sample were representative of all the material coming from the wells tested the amount of higher hydrocarbons found should be several times greater than was actually obtained, since in all cases large amounts of crude naphtha were recovered in the separators.

The Effect of Water on the Sample

In order to indicate the effect of different methods of sampling, all of the samples analysed were transferred to the distillation column by means of the gas transfer apparatus described in a preceding paragraph. It was then desired to ascertain whether or not the water used in the process introduced a greater error than the experimental errors incidental to the analysis of the quantity of gas that was being used as a sample. Accordingly, a large cylinder was evacuated, filled with gas and flushed out twice, and filled a third time. From this cylinder was drawn off 5 one-gallon bottles of the gas by water displacement. The contents of these bottles were then transferred to the gas transfer apparatus in the regular way and allowed to stand several days. The gas was then analysed.

Another sample was drawn off from the cylinder, through a reducing valve and led directly to the distillation apparatus without coming in contact with any water other than the potassium hydroxide solution used for removing impurities that would interfere with the distillation. The results of the two analyses are shown in Table V.

TABLE V

Results of Analysis when the Gas has been in Contact with Water, and when it has not

—	Methane+	Ethane	Propane	Butanes	Pentanes+
Over water	91·7	2·8	3·2	1·5	0·8
Not over water	92·3	2·4	3·0	1·5	0·8

It is to be observed from these results that errors due to the use of water as a collecting and transferring medium when analysing natural gases with the characteristics shown, and using samples with a volume of four or five Imperial gallons at atmospheric temperature and pressure, are not greater than ordinary personal and manipulative errors. It is to be understood that the above statement does not mean that no errors occur: it simply points out that the errors are not appreciable under the working conditions adopted for this investigation.

COMPARISON OF "WET" AND "DRY" GASES

It was observed during the investigation that the results obtained were practically identical, whether the sample was taken from the pipe-line before it reached the separators or afterwards. The average of four samples of "wet" gas taken before the gas passed through the separators is shown in Table VI, and the average of four samples of "dry" gas taken after the gas had passed through separators is shown in Table VII.

TABLE VI

Analyses of Four Samples of "Wet" Gas before Separators

Sample No.	10	15	22	23	Average
Date taken	6/9/29	14/9/29	27/9/29	27/9/29	
Name of well	Royalite	Royalite	Royalite	Royalite	
Well No.	17	Composite*	17	4	
Methane+	90·0	88·4	89·9	92·2	90·1
Ethane	4·6	5·9	5·0	4·1	4·9
Propane	2·7	3·4	3·2	2·5	2·9
Butane	0·9**	1·4	1·7	0·5	1·2
Pentanes+	1·8**	0·9	0·2	0·7	0·9

*The composite samples were taken from pipe-lines into which gas was flowing from Royalite wells Nos. 7, 9, 14, 17, and 18. In sample No. 15 the gas from Royalite No. 17 had passed through a separator near the well-head.

**Sample was too small for good separation of these constituents.

TABLE VII

Analyses of Four Samples of "Dry" Gas after Separators

Sample No. Date taken Name of well Well No.	17 17/9/29 Royalite Composite*	24 30/9/29 Home 1	30 14/10/29 Royalite Composite*	32 16/10/29 Royalite Composite*	Average
Methane+	88·6	91·0	89·9	92·1	90·4
Ethane	5·7	4·3	4·5	2·2	4·2
Propane	3·4	3·1	3·4	3·3	3·3
Butane	1·6	0·8	1·3	1·4	1·3
Pentanes+	0·7	0·8	0·9	1·0	0·8

TABLE VIII

Analyses of Seven Samples of Purified Natural Gas Taken from Calgary City Mains

Sample No.	Date taken	Methane+	Ethane	Propane	Butanes	Pentanes+
3	Aug. 30	88·3	6·7	2·8	1·1	1·1
4	" 31	90·5	4·5	3·1	1·1	0·8
5	Sept. 2	89·3	4·9	3·3	1·4	1·0
6	" 3	89·4	5·3	3·3	1·4	0·6
7	" 3	88·2	6·4	3·3	1·3	0·8
13	" 13	88·8	5·4	3·2	1·4	1·2
16	" 19	89·1	5·3	3·3	1·5	0·7
Average	....	89·1	5·5	3·2	1·3	0·9

TABLE IX

Analyses of Purified Gas at Turner Valley

Sample No. Date taken	7015 April 11	7016 April 12	7017 April 14	7018 April 16	Average
Methane+	89·5	90·3	91·7	91·5	90·5
Ethane	4·7	4·4	3·3	4·2	4·4
Propane	3·4	3·2	2·8	2·2	3·1
Butanes	2·4	1·0	1·2	1·0	1·1
Pentanes+		1·1	1·0	1·1	0·9

TABLE X

Analyses of Four Samples of Raw Gas after Separators

Sample No. Date taken Name of well Well No.	17 17/9/29 Royalite Composite*	24 30/9/29 Home 1	30 14/10/29 Royalite Composite*	32 16/10/29 Royalite Composite*	Average
Methane+	88·6	91·0	89·9	92·1	90·4
Ethane	5·7	4·3	4·5	2·2	4·2
Propane	3·4	3·1	3·4	3·3	3·3
Butane	1·6	0·8	1·3	1·4	1·3
Pentanes+	0·7	0·8	0·9	1·0	0·8

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* The composite samples shown above were taken after a separator into which gas from Royalite wells Nos. 7, 9, 14, 17, and 18 was flowing. The gas from Royalite No. 17 had already passed through a previous separator near the well-head.

TABLE XI

Analyses of Four Samples of "Wet" Gas Taken at Royalite Plant

Sample No........................ Date taken........................ Name of well.................... Well No...........................	10 6/9/29 Royalite 17	15 14/9/29 Royalite Composite*	22 27/9/29 Royalite 17	23 27/9/29 Royalite 4	Average
Methane+........................	90·0	88·4	89·9	92·2	90·1
Ethane............................	4·6	5·9	5·0	4·1	4·9
Propane...........................	2·7	3·4	3·2	2·5	2·9
Butane............................	0·9**	1·4	1·7	0·5	1·2
Pentanes+.......................	1·8**	0·9	0·2	0·7	0·9

*The composite samples shown above were taken after a separator into which gas from Royalite wells Nos. 7, 9, 14, 17, and 18 was flowing. The gas from Royalite No. 17 had already passed through a previous separator near the well-head.

**Sample was too small for good separation of these constituents.

TABLE XII

Analyses of Five Samples of "Wet" Gas Taken at Home Wells

Sample No....................... Date taken....................... Name of well.................... Well No...........................	11 7/9/29 Home 1	12 7/9/29 Home 2 and 3	18 20/9/29 Home 3	25 30/9/29 Home 1	26 30/9/29 Home 1	Average
Methane+.......................	88·4	84·4	86·1	88·3	80·8	85·6
Ethane............................	4·3	5·7	6·3	3·7	4·7	4·9
Propane...........................	2·4	3·2	3·6	3·7	4·4	3·5
Butane............................	3·1	2·3	2·1	2·3	3·6	2·7
Pentanes+.......................	1·8	4·4	1·9	1·9	6·5	3·3

TABLE XIII

Analysis, in Triplicate, of a Sample of Gas Taken from the Stabilizers

Sample No..................................	33	33	33	Average
Date taken..................................	16/10/29	—	—	—
Methane+....................................	25·6	25·1	25·2	25·3
Ethane...	13·7	13·6	13·4	13·6
Propane.......................................	29·1	29·5	29·6	29·4
Butanes.......................................	23·3	23·5	23·1	23·3
Pentanes+....................................	8·3	8·3	8·7	8·4

TABLE XIV

Analyses of Naphthas

Sample No.	6609	6589
Description	Crude naphtha from separator	Commercial naphtha from refinery
Date taken	Oct. 16, 1929	Sept. 13, 1929
	% by Vol.	% by Vol.
Propane	2·0	2·3
Butanes	8·8	10·1
Pentanes	17·3	21·3
Hexanes + (by diff.)	71·9	66·3

A THEORY CONCERNING TURNER VALLEY GAS

The similarity of results obtained by different methods of sampling, and the similarity of results obtained from samples of so-called "wet" and "dry" gas, taken with the well-known facts regarding the field, seemed to the writers to offer a very definite indication regarding the mechanism of production of crude naphtha from this area. The facts that seemed especially significant may be itemized as follows:—

1. The wells produce large quantities of natural gas under great pressure. The rush of gas is strong enough to carry fragments of limestone from the well into the separators. The fragments may be heard rattling through the sides of the casing, and they are found in the base of the separator when it is opened for cleaning.
2. Samples of gas taken by different methods devised to secure a representative portion of the total product of the well yield similar results.
3. The wells yield a great deal of naphtha. The analyses of the gases at the well-head do not show a sufficiently large proportion of higher hydrocarbons to account for the naphtha produced.
4. The naphtha is obtained from separators.
5. The interior of the separator contains a series of baffle plates.
6. The exterior of the separator is covered with white frost even on a hot summer's day.
7. Samples of gas taken before it has entered the separator and after it leaves the separator give similar results when analysed.
8. The pipe-lines leading from the well-head are also covered with white frost.
9. Some wells "freeze off".
10. The gas is known to be very cold. It has to be preheated before going to the liquid purification plant in order to avoid danger of freezing the solutions for purification. Temperatures below zero have been reported.
11. The producing horizon is about one mile below the surface.

It would appear, therefore, that the gas is very cold when it reaches the surface and that it is much colder than the strata from which it comes. It seems logical to suppose that more or less condensation of the higher hydrocarbons would occur at the point of lowest temperature through which the gas passes. Further, that the condensate so formed is carried forward in the liquid phase by the velocity of the residual gas, except for such minor changes in composition as occur on account of heat transfer from the earth and atmosphere.

The writers are suggesting, therefore, that the point of greatest refrigeration is at or near the bottom of the well, or near the place at which the gas issues from the limestone, and that the crude naphtha is carried to the surface mechanically by the velocity of the natural gas. Such a theory accounts for all the facts mentioned above that seem difficult to explain. It explains why as simple an apparatus as the separator is able to recover the naphtha. It explains the low temperature of the gas and the consequent coating of white frost on the pipe-lines and separators.

Since only the material in the vapour phase was collected in taking the various samples, the theory explains why similar results were obtained on samples of "wet" and "dry" gas, and why a sufficient proportion of higher hydrocarbons to account for the production of crude naphtha was not found.

UTILIZATION OF WASTE GAS

It would appear from the analyses given that nature has been more than generous in regard to this particular field, in that the gas is not only obtained there but it is found at such high pressures that the expansion of it lowers the temperature to such a point that the greater part of the condensible material may be recovered in liquid form. However, it may be pointed out that the analysis of the stabilizer gas shows a high percentage of propane and butane. And, since this gas is similar to the material lost on "weathering" the crude naphtha to meet the specifications of the refineries and the transportation companies, fairly large quantities of it are available.

Within the past few years there has been developed in the United States a liquefied petroleum industry, and one of the problems of this industry was the profitable marketing of propane and butane. Success has been obtained by building up a demand for these products for domestic use. Propane and butane may be compressed and sold in steel cylinders to isolated communities and individuals, so that they may enjoy all the advantages of cooking and heating with gas, although located at such a distance from urban centres that service by pipe-line is not feasible. Further, the liquefied gas may be sold to existing gas companies for enriching coal or water gas. This has developed to such an extent that gas manufacturing companies in many places are becoming concerned lest this new competitor may prove so powerful that they shall lose much profitable business.

The writers advocate, therefore, the use of stabilizing equipment wherever possible in place of "weathering" in open tanks, and the use of insulating material on exposed pipe-lines and separators, so that as much propane and butane as possible shall be obtained. The use of stabilizing equipment not only makes the recovery of these gases possible, but also permits the more accurate control of the processing, so that the proportion of propane left in the finished naphtha may be lessened. By decreasing the propane content of the naphtha and increasing the butane content larger net yields of naphtha may be secured whose vapour tension will come within the limits set by refineries and transportation companies. This is due to the fact that the vapour pressure of propane is approximately four times that of normal butane, so that a small amount of propane present in the naphtha will have a definite effect on the vapour pressure of the whole liquid. The use of insulating material on the pipe-lines from the well-head to the separator, and on the separator itself, will serve to minimize the effect of changes in atmospheric temperature and will result in the collection of larger amounts of propane and butane, as well as higher boiling compounds, from the gas. These may then be recovered from the stabilizers. Without stabilizing equipment very little additional yield of marketable naphtha could be expected from the use of insulating material alone.

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