

RESEARCH COUNCIL OF ALBERTA

Information Series No. 34

A LOW-TEMPERATURE CARBONIZATION ASSAY OF ALBERTA COALS

by

G. Davies, C. Moreland, and N. Berkowitz



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A LOW-TEMPERATURE CARBONIZATION ASSAY OF ALBERTA COALS

ABSTRACT

By-product yields obtainable from a range of Alberta coals by low-temperature carbonization were evaluated in a laboratory assay unit. The apparatus is essentially similar to assay equipment developed by the U.S. Bureau of Mines, Denver; it is relatively simple to operate and permits mass balances of 100.0 ± 0.5 per cent when used with noncoking coals. Mass balances on coking coals are, for purely technical reasons, slightly less satisfactory (100.0 ± 1.0 per cent).

Results obtained with Alberta coals carbonized at 600°C . are compared with data reported for United States Coals carbonized at 500°C ., and a general parallelism between the two sets is demonstrated. As a rule, subbituminous coals were found to give relatively low tar yields of between 3.2 and 7.5 per cent, and these yields are further reduced when the coals are pre-dried (and thereby slightly oxidized).

Of the noncoking coals examined in the present study, highest tar yields were given by Lethbridge coal.

INTRODUCTION

During extended pilot plant investigations into the low-temperature fluidized-bed carbonization of Alberta subbituminous coals*, it was observed that tar and light oil yields tended to be so low as to make industrial exploitation of the process economically unattractive at the present time. In order to determine whether this feature was a peculiarity of the carbonization procedure or due to the coals per se, a separate study in which carbonization yields were determined in a laboratory assay apparatus was accordingly initiated.

In planning this study, it was envisaged that experiments would be confined to coals examined in the fluidized-bed carbonizer. However, since only isolated by-product data for Alberta coals have so far been reported (3,4) and since there has recently been a revival of interest in such information, it was thought pertinent to widen the scope of the projected investigation, and to examine representative coals drawn from all major producing areas of the province. The results reported

* A full report on these investigations is being prepared by the Research Council of Alberta. For partial accounts, see references 1 and 2.

below, although necessarily far from complete*, include, therefore, bituminous as well as subbituminous coals.

In selecting a carbonization temperature of 600°C., we were influenced by precedents and by the conditions under which the fluidized-bed carbonizer had been operated. But the choice is not otherwise of particular significance. While by-product yields can vary markedly with carbonization temperature, the variation over the range 500° - 600°C. is relatively small; and since low-temperature assays are invariably confined to this range, it is generally possible to compare different sets of data even when the actual test temperatures do not coincide.

It is, however, worth emphasizing that laboratory results can be no more than a guide to what may be expected in full-scale operation under industrial conditions. Quality and quantity of by-products obtainable from any one coal depend critically upon the method of carbonization, on heating rates, and on the physical state of the coal; and in assessing assay data it should be borne in mind that such data will almost always reflect maximum yields.

THE ASSAY APPARATUS

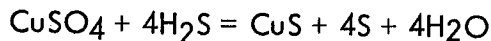
The assay unit, diagrammatically shown in figure 1, is a modified form of equipment described by J. B. Goodman *et al.* (5) and consists, like all such apparatus, of a carbonizer retort, a condenser train for the recovery of condensible by-products, and a gas collector.

The retort (R) is fabricated from mild steel and heated by a thermostatically controlled electric furnace consisting of a suitably machined mild steel block fitted with three 750 watt 'Calrod' elements connected in parallel. Temperatures in the coal charge are measured by a central 1/8-inch stainless steel-sheathed Honeywell 'Megopak' thermocouple connected to a Leeds & Northrup dual-range (0 - 16 - 64 mV) potentiometer box. The temperature of the retort shell is measured by a bare-end thermocouple placed close to the inner wall of the furnace block and connected, by two-way switch, to a Honeywell 'Pyr-O-Vane' temperature controller and potentiometer.

Volatile products leaving the retort enter the condenser train by first passing through an ice-cooled tar trap (B) filled with loosely packed stainless steel turnings. Tar mists remaining entrained in the exit stream are then removed in a

* It is quite possible that coals occurring along the eastern edge of the Rocky Mountain foothills (e.g. in the Pekisko, Morley, and Saunders areas) would equal or better the coals here tested as sources of tar and light oils. However, because of mine closures and the present inaccessibility of many of these mines, this point can only be established by a major sampling program which, under current conditions, was not thought justified.

glass wool-filled vessel (C). Residual moisture is trapped in a calcium chloride tube (D), and hydrogen sulfide is removed from the stream by passing it through crushed Sil-O-Cel impregnated with copper sulfate (E) and depositing elemental sulfur by the reaction



Water formed by this reaction is again eliminated by calcium chloride. Light oils are recovered by passing the product stream from the H₂S-trap (E) through freshly activated carbon (in F), and the remaining gas is finally led to a constant-pressure gas holder (I) in which it is collected over saturated brine.

The gas holder itself consists of a 9 3/4 feet long, 4 inches inside diameter stainless steel cylinder with a total volume of 24.0 liters. The brine reservoir feeding the gas holder is a 15 inches long, 12 inches diameter galvanized steel drum with a capacity of ca. 25 liters and is connected to the gas holder by standard brass and copper fittings. Gas temperatures are measured by dial thermometers inserted at the 3-foot and 8-foot levels of the gas holder, and a number of brass petcocks at various levels allow attachment to a gas recirculation line designed to permit gas homogenization in the system. Constant pressure in the gas holder is provided by a float-operated needle-valve connected as shown in figure 1.

The gas recirculation system consists of a small rubber aspirating bulb (H) connected, at its outlet, to a side-arm of the tar trap and, at its inlet side, through a drying tube (D') and safety trap (G') to the gas holder. Closed off during a run, the bulb is pumped by a simple motor-driven crank system at the end of the test to produce a uniform gas mixture from which samples can be withdrawn for analysis.

TEST PROCEDURE

For operation, the assay retort is charged with an accurately weighed quantity of coal which, depending upon the expected gas yield, can vary between 100 and 200 grams. If a coking coal is used, sand is added to the coal to reduce thermal swelling and prevent blocking of the retort exit by plastic coal.

Heating rates are controlled by a variable autotransformer which permits adjustment to a pre-selected, well-defined schedule. In the tests with noncoking coals, the rate was such that the temperature of the retort wall reached 600°C. within about 90 minutes (i.e. about 6.5°C./minute). In tests with coking coals, heating above 350°C. was programmed at 1°C./minute in order to further reduce thermal swelling. The final carbonization temperature was in each case held for two hours.

At the conclusion of each run, the gas holder is isolated from the brine tank and the collected gas repeatedly recirculated through the entire system for

about 10 minutes. The total gas yield is then computed after adjusting to atmospheric pressure and a sample withdrawn for analysis. A detailed gas calculation is instanced in the appendix.

Yields of by-products are determined by weighing the appropriate condenser train components before and after each run. Water in the tar trap (B) is then quantitatively determined by attaching a Stark-Dean moisture receiver to the trap and distilling the contents with xylol for about one hour. Char yields are established by weighing the empty and filled retort before the test and re-weighing it full and emptied at the conclusion of the run. (Small weight differences between emptied retort weights before and after an experiment were assumed to be due to minor quantities of a 50:50 char/tar mixture sticking to retort walls, and char and tar yields were corrected on this basis).

In general it was found advantageous to renew the activated carbon filling of the light oil trap (F) before each run. The hydrogen sulfide trap (E) had a longer effective life and could be used for 3 to 5 runs; saturation was judged by the degree of blackening produced by copper sulfide.

TEST SAMPLES

Of the 16 coals examined in the present test series, two (taken from the Crowsnest area) are medium volatile bituminous coking coals, and one (from the Cascade area) is a slightly agglomerating low volatile bituminous coal. The others are noncoking prairie coals and, except for one high volatile C bituminous coal, of subbituminous rank.

As indicated in the tables summarizing the experimental results, test samples fall into two categories: the first includes freshly mined coals which were stored in sealed containers until required, and the second comprises coals designated as laboratory samples. The latter differ from freshly mined coals in having been permitted to dry slightly below their respective bed moisture capacities. This distinction is perhaps of little significance since slight drying out is unlikely to be accompanied by oxidation. But it should be noted that bed moisture contents of freshly mined coals (and hence the 'free' water fractions of the total by-product yields) are somewhat greater than those of the corresponding laboratory samples and that yields of char, tar, light oil, etc. obtainable from fresh coals would therefore all be a little smaller than those listed for the laboratory samples.

Assay specimens of noncoking coals were in each case crushed to -10 mesh (Tyler) before carbonization, while coking coals were ground to -100 mesh (Tyler) and assayed as -100 +200 mesh fractions. (This procedure, and the alternative method of adding sand to the coal, are designed to reduce thermal swelling). The small quantities of -200 mesh material produced by grinding were discarded.

Test results also include data recorded with oven- and air-dried samples of Lethbridge coal in order to illustrate the effect of mild oxidation on by-product yields. The conditions of drying are indicated in the tables.

RESULTS

From a practical standpoint, interest in by-product yields is inevitably focused on yields obtainable by carbonization of the 'as mined' or only superficially prepared coal. The low-temperature carbonization data summarized in tables 1(a) - 1(e) therefore list by-product yields on an 'as carbonized' basis defined by the proximate analyses of the test samples. The calorific values which supplement these analyses are taken from previously published information (3).

Gas yields, computed by the procedure given in the appendix, are likewise expressed on an 'as carbonized' basis, but gas compositions are reported on an oxygen- and nitrogen-free basis in order to exclude from the analytical data components of air entrained in the assay unit at the start of a test.

Mass balances, established by summing the various product quantities, are reported as 'total recovery' and indicate the precision of the experimental method in the different tests. In the case of noncoking coals, these mass balances lie within the limits of 100.0 ± 0.5 per cent; in the case of coking coals, recovery is slightly less satisfactory but still quite acceptable (100.0 ± 1.0 per cent).

The finding that subbituminous coals will, as a rule, yield rather small quantities of tar is more systematically illustrated in figure 2, in which tar yields (corrected for moisture and ash of the parent coal, i.e. calculated on a M.A.F. basis) are plotted against coal rank. To facilitate comparison with data reported for United States coals (5), the sum tar + light oil* is used. It will be observed that this sum tends towards a minimum among subbituminous B coals, then rises towards a maximum among high volatile bituminous coals, and finally decreases again among the still more mature coals. Significantly, Alberta coals yield less tar + light oils but more water and gas than do the equivalent United States coals.

Gas compositions also are markedly influenced by coal type; the proportions of CO and CO₂ decrease quite rapidly when passing from subbituminous to bituminous coals, while hydrogen and methane contents show a proportionate increase, as shown in figure 3. On the other hand, total gas yields (like the yields of water

* It should be stressed that the term "light oil" is in this report used to describe the material condensed in the active carbon trap (F). Since this material may contain considerable quantities of gaseous hydrocarbons (and, possibly, some sulfurous gases), light oil yields quoted in the tables may be significantly higher than light oil fractions likely to be recovered in full-scale practice.

other than 'free' water) tend to fall systematically.

The effects of heating rates and coal size on by-product yields are illustrated in table 2 by results obtained with Lethbridge coal: runs No. 25, 58, and 59 show what happens when the heating rate is progressively reduced from the standard 6.5°C./min. to 3° and 1°C./min. respectively, and run No. 60 illustrates the effect of reducing heating rate and particle size simultaneously. While each factor appears to exert a fairly pronounced influence on tar yields, they operate in opposite directions and individual contributions tend therefore to cancel out. The fact that coking coals were carbonized at a lower rate (1°C./min.) than the standard rate adopted for noncoking coals, and also assayed as much more finely comminuted samples than the latter, is consequently not thought to invalidate direct comparison of results obtained with the two types.

Tables 3 and 4 illustrate the variation of by-product yield with carbonization temperature. Of interest here is the observation that while the tar yield obtainable from oven-dried Edmonton coal is not significantly variable between 500° and 600°C. (though showing the expected fall-off at lower and higher temperatures), tar yields from the freshly mined Lethbridge coal pass through a fairly pronounced maximum around 550°C. For the more mature Blairmore coal, maximum tar yields are obtained at (or even above) 600°C. Composite diagrams showing the variation of all carbonization products, and of gas compositions, with carbonization temperature, are reproduced in figures 4 and 5 for Lethbridge coal and in figure 6 for Edmonton coal. To facilitate meaningful comparisons, experimental data are here expressed on a moisture- and ash-free coal basis.

Whether the seeming insensitivity of the Edmonton coal tar yield to carbonization temperature variations is, at least partly, due to the preliminary oven-drying is uncertain. However, that oven-drying at 100°C., and concomitant oxidation of the coal, does affect by-product yields quite profoundly is illustrated in table 5 and by the composite diagrams shown in figures 7 and 8: the principal effects are induced rapidly and lead to pronounced reductions in tar + light oil yields, and to a similar fall in the methane concentration in the gas. Total gas yields increase and there is, in particular, a sharp rise in the CO₂ content of the gas.

By contrast, air-drying at 70°F. has little or no effect on by-product yields as shown in table 6 and figures 9 and 10.

CONCLUSIONS

1. Tabulated results of over 40 assays show that the experimental methods adopted in the present study permit total recoveries of 100.0 ± 0.5 per cent in the case of noncoking coals and 100.0 ± 1.0 per cent in the case of coking coals. The method is therefore regarded as satisfactorily precise.

2. Tar + light oil yields determined for a range of Alberta subbituminous coals are found to be low (between 3.2 and 7.5 per cent), and, if process economics are dependent on these yields, these coals would therefore be generally but poorly suited for low-temperature carbonization. Of the low-rank coals tested, only Lethbridge coal yielded potentially attractive quantities of tar.

3. Tar yields are markedly reduced if the parent coal is oxidized (as during prolonged drying at elevated temperatures). Accordingly, tables 1(a) - 1(e) indicate maximum tar yields obtainable in large-scale operation if freshly mined coal is employed (or if the coal is pre-dried under strictly non-oxidizing conditions).

ACKNOWLEDGMENTS

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* This report (cf. p. 66 et seq.) also contains references to earlier carbonization assays of Alberta coals conducted by the Federal Mines Branch, Ottawa, between 1919 and 1928.

APPENDIX

Low Temperature Assay - Sample Sheet

Date: 20/6/59

Assay No.: 15

Sample: Freshly mined high volatile C bituminous coal, Lethbridge

Carbonization temperature: 600°C.

<u>Weight before run, gm.</u>	<u>Unit</u>	<u>Weight after run, gm.</u>
202.06	tar-water trap	240.51
148.42	tar-mist trap	148.61
66.9398	moisture absorber	67.1581
155.9268	hydrogen sulfide trap	156.6180
89.8864	light oil trap	91.8554
806.88	retort	807.85
956.88	retort + coal/char	902.20
150.00	coal/char	94.35

Final volume of gas (ml.)	17,210 (at 74°F.)
Atmospheric pressure	696 mm. Hg.
Corrected gas volume (ml.)	15,000 (at S.T.P.)

Gas Analysis

	Per cent		Gross calorific value B.t.u./cu.ft.
	Total	Oxygen- and nitrogen-free	Calculated 60°F. 30"Hg.
H ₂	18.5	20.2	65.6
O ₂	2.3	--	--
N ₂	8.9	--	--
CO	12.1	13.3	43.0
CO ₂	20.3	22.3	--
CH ₄	37.5	41.3	418.5
C ₂ H ₆	2.7	2.9	51.1
C ₂ H ₄	--	--	--
Total	102.3	100.0	578.2

Sample Sheet (continued)

Coal and Char Analysis

	Proximate analysis			
	Coal		Char	
	As carbonized	M.A.F.*	H ₂ O free	M.A.F.*
Moisture	10.6	--	--	--
Ash	8.6	--	13.4	--
V.M.	34.4	42.6	9.4	10.8
F.C.	46.4	57.4	77.2	89.2
Calorific Value	11,120 B.t.u./lb.	13,790 B.t.u./lb.	12,400 B.t.u./lb.	14,510 B.t.u./lb.

* Moisture- and ash-free.

Material balance

	Grams	Per cent as carbonized
Weight of coal	150.0	100.0
Free water	15.9	10.6
Water formed	12.3	8.2
Tar	11.1	7.4
Light oil	2.0	1.3
H ₂ S	0.7	0.5
Gas	13.9	9.1
Char	94.8	63.2
Total	150.7	100.3

Gas Calculations

In order to convert gas volumes to percentage yields, the total gas volume (comprising the collected gas plus gas contained in the static volume of the assay apparatus) is first reduced to standard conditions (60°F. and 76 cm. Hg pressure) and then corrected for the partial pressure of water vapour by assuming saturation. The static volume of the assay unit, exclusive of the volume occupied by adsorbents, desiccants and by-products, is for this purpose taken as 1830 ml. (The error introduced by ignoring the small variations due to temperature and product yield variations can be neglected). The corrected total gas yield is next reduced to an oxygen- and nitrogen-free basis to give the net volume of gas produced. Thus,

Observed gas volume = 17,210 ml. at 74°F., 699 mm. Hg pressure

Corrected gas volume = $17,210 \frac{(520)(699)(699 - 21.5)}{760 \cdot 534 \cdot 699} = 15,000 \text{ ml.}$

Volume of gas in assay train = 1830 ml.

Total gas volume = $15,000 + 1830 = 16,830 \text{ ml.}$

Net gas yield (O_2 and N_2 free basis) = $16830 (1.023 - \frac{11.2}{102.3}) = 15,000 \text{ ml.}$

Therefore, net yield gas

$$= \frac{15,000}{150} = 100 \text{ ml./g. (S.T.P. dry) (O}_2 \text{ and N}_2 \text{ free basis) as carbonized}$$

$$= 100 \times \frac{453.6}{28,316} = 1.601 \text{ cu. ft./lb. (S.T.P. dry) (O}_2 \text{ and N}_2 \text{ free basis) as carbonized}$$

The weight-percentage gas yield is then calculated from the molecular distribution of elements in the gas. From the volume-per cent (O_2 and N_2 free basis), the elemental mol. volumes of carbon, hydrogen, and oxygen are obtained (A), and the sum of the elemental mol. volumes, when divided by the calculated average volume for all the gases present (taken as 378 cu.ft./lb.mol.gas at 60°F., and 76 cm. Hg), gives the mols. of the calculated elemental gas (carbon, hydrogen, and oxygen) per 100 cu. ft. of total gas yield (B). The mols. of each elemental gas, when multiplied by their respective molecular weight expressed as pounds, yields the pounds of that gas per 100 cu.ft. of the total assay-gas yield (C). The sum of the pound weights of the elemental gases multiplied by the assay gas yield and expressed as cubic feet of gas produced per pound of coal carbonized will give the pounds of gas produced per 100 pounds of coal carbonized, or the per cent of gas.

To obtain the specific gravity of the assay gas, the weight of the gas in lb./cu.ft. is divided by the weight of 1 cubic foot of air at standard conditions (0.07657 lb./cu.ft. at 60°F. 76 cm. Hg).

A.

Gas analysis (O_2 and N_2 free)	per cent	Mol. volume/100 mols.		
		carbon	hydrogen	oxygen
H_2	20.2	--	20.2	--
CO	13.3	13.3	--	6.65
CO_2	22.3	22.3	--	22.3
CH_4	41.3	41.3	82.6	--
C_2H_6	2.9	5.8	8.7	--
C_2H_4	--	--	--	--
Total	100.0	82.7	111.5	28.95

B.

Mol./100 cu. ft. of gas, (O ₂ and N ₂ free)		
carbon	= $\frac{82.7}{378}$	= 0.219
hydrogen	= $\frac{111.5}{378}$	= 0.295
oxygen	= $\frac{28.95}{378}$	= 0.0766

C.

lb./100 cu. ft. of gas (O ₂ and N ₂ free)		
carbon	= 0.219 × 12.01	= 2.630
hydrogen	= 0.295 × 2.061	= 0.954
oxygen	= 0.0766 × 32.00	= 2.454
Total	=	5.678

$$\begin{aligned} \text{Yield of gas} &= 5.678 \text{ lb./100 cu. ft.} \times 1.601 \text{ cu. ft./lb.} \\ &= 9.10 \text{ lb. gas/100 lb. coal} \\ &= 9.1\% \text{ ('as carbonized' coal basis)} \end{aligned}$$

$$\text{Specific gravity of gas} = \frac{0.05678}{0.07657} = 0.741$$

Table 1(a). Carbonization of Alberta Coals at 600°C.

Assay No.		36	29	31	39
Mine location		Ryley	Sheerness	Camrose	Halkirk
Area		Tofield	Sheerness	Camrose	Castor
Classification		Sub C	Sub C	Sub C	Sub C
Origin		Freshly mined	Freshly mined	Freshly mined	Freshly mined
Proximate analysis					
'as carbonized'	H ₂ O	26.0	25.2	26.2	24.9
	Ash	7.6	6.7	6.8	5.2
	V.M.	28.2	29.0	28.3	30.7
	F.C.	38.2	39.1	38.7	39.2
	B.t.u./lb.*	8,360	8,550	8,740	8,900
Proximate analysis					
M.A.F.**	V.M.	42.6	42.6	42.2	43.9
	F.C.	57.4	57.4	57.8	56.1
By-product yields					
	Char	48.5	50.0	50.1	48.8
	Free water	26.0	25.2	26.2	24.9
	Water	10.4	9.2	8.7	9.5
	Tar	4.1	4.1	4.1	4.9
	Light oil	1.0	1.2	1.2	1.3
	Gas	10.1	9.8	9.5	10.4
	H ₂ S	0.3	0.3	0.3	0.2
	Total recovery	100.4	99.8	100.1	100.0
Char analysis					
H ₂ O free	Ash	13.9	12.3	12.5	9.8
	V.M.	9.2	9.0	9.3	7.9
	F.C.	76.9	78.7	78.2	82.3
	B.t.u./lb.	12,690		13,010	13,440
Gas composition					
volume,					
per cent ***	H ₂	23.0	23.6	22.2	24.7
	CO	14.6	15.5	16.4	13.7
	CO ₂	29.2	27.0	27.2	26.6
	CH ₄	30.9	31.9	32.5	33.0
	C ₂ H ₆	2.1	1.8	1.7	1.8
	C ₂ H ₄	0.2	0.2	--	0.2
	Calculated B.t.u./cu.ft.	476.6	485.8	485.2	494.5
	Net gas yield cu.ft./ton	3220	3284	3188	3574
	('as carbonized' basis)				

* Estimated; cf. reference 3 ** Moisture- and ash-free *** Adjusted to 100%

Table 1(b). Carbonization of Alberta Coals at 600°C.

Assay No.		13	48	24	37
Mine location		Forestburg	Wabamun	Alix	Edmonton
Area		Castor	Pembina	Ardley	Edmonton
Classification		Sub B	Sub B	Sub B	Sub B
Origin		Freshly mined	Freshly mined	Freshly mined	Lab. Sample
Proximate analysis					
'as carbonized'	H ₂ O	23.0	20.1	19.4	19.4
	Ash	5.2	11.7	9.4	8.7
	V.M.	29.5	27.6	27.3	29.3
	F.C.	42.3	40.6	43.9	42.6
	B.t.u./lb.*	9,150	8,530	9,140	9,360
Proximate analysis					
M.A.F.**	V.M.	41.1	40.5	38.4	40.7
	F.C.	58.9	59.5	61.6	59.3
By-product yields					
	Char	50.3	56.7	57.4	55.0
	Free water	23.0	20.1	19.4	19.4
	Water	10.9	8.3	8.9	10.6
	Tar	3.4	3.9	3.7	4.0
	Light oil	1.3	1.1	1.0	1.2
	Gas	10.8	10.0	9.1	9.6
	H ₂ S	0.2	0.1	0.3	0.2
	Total recovery	99.9	100.2	99.8	100.0
Char analysis					
H ₂ O free	Ash	9.8	21.6	15.0	14.8
	V.M.	8.5	8.2	8.3	8.1
	F.C.	81.7	70.2	76.7	77.1
	B.t.u./lb.	--	11,710	12,660	12,690
Gas composition					
volume,					
per cent***	H ₂	21.4	25.5	21.4	23.3
	CO	16.1	13.2	16.8	15.3
	CO ₂	29.2	30.7	25.0	25.5
	CH ₄	31.8	29.2	35.1	33.9
	C ₂ H ₆	1.5	1.4	1.6	1.8
	C ₂ H ₄	--	--	--	0.2
	Calculated B.t.u./cu. ft.	470.9	446.2	508.2	504.4
	Net gas yield cu. ft./ton	3460	3306	3096	3306
	('as carbonized' basis)				

* Estimated; cf. reference 3

** Moisture- and ash-free

*** Adjusted to 100%

Table 1(c). Carbonization of Alberta Coals at 600°C.

Assay No.		61	12	38	34
Mine location		Trochu	Drumheller	E. Coulee	Taber
Area		Carbon	Drumheller	Drumheller	Taber
Classification		Sub B	Sub B	Sub B	Sub A
Origin		Freshly mined	Lab. sample	Lab. sample	Lab. sample
Proximate analysis					
'as carbonized'	H ₂ O	16.7	15.6	12.5	10.5
	Ash	10.4	9.3	6.5	10.6
	V.M.	28.3	31.0	33.8	32.0
	F.C.	44.6	44.1	47.2	46.9
	B.t.u./lb.*	9,570	9,620	10,650	10,620
Proximate analysis					
M.A.F.**	V.M.	38.8	41.3	41.8	40.6
	F.C.	61.2	58.7	58.2	59.4
By-product yields					
	Char	59.5	57.2	60.0	63.1
	Free water	16.7	15.6	12.5	10.5
	Water	9.5	10.2	9.9	8.9
	Tar	4.1	5.8	3.2	6.2
	Light oil	1.5	1.3	1.3	1.5
	Gas	8.3	9.8	12.4	9.5
	H ₂ S	0.1	0.3	0.2	0.3
	Total recovery	99.7	100.2	99.5	100.0
Char analysis					
H ₂ O free	Ash	14.8	15.3	10.6	16.4
	V.M.	7.8	7.1	7.6	8.0
	F.C.	77.4	77.6	81.8	75.6
	B.t.u./lb.	12,780	--	13,510	12,400
Gas composition					
volume, per cent***	H ₂	26.2	23.0	23.1	22.2
	CO	14.7	13.5	14.1	13.5
	CO ₂	21.7	25.4	27.5	22.2
	CH ₄	35.9	36.1	33.5	39.3
	C ₂ H ₆	1.5	2.0	1.8	2.6
	C ₂ H ₄	--	--	--	0.2
	Calculated B.t.u./cu.ft.	524.3	520.4	492.2	563.6
	Net gas yield cu.ft./ton ('as carbonized' basis)	3088	3415	4165	3422

* Estimated; cf. reference 3

** Moisture- and ash-free

*** Adjusted to 100%

Table 1(d). Carbonization of Alberta Coals at 600°C.

Assay No.		15	64	43
Mine location		Lethbridge	Blairmore	Blairmore
Area		Lethbridge	Crowsnest	Crowsnest
Classification		Hv C Bit	Mv Bit	Mv Bit
Origin		Freshly mined	Freshly mined	Freshly mined
Spec. carbonization conditions			-100+200 mesh 1°C./min.	4:1 sand/coal
Proximate analysis				
'as carbonized'	H ₂ O	10.6	0.5	0.7
	Ash	8.6	9.0	10.9
	V.M.	34.4	26.1	27.0
	F.C.	46.4	64.4	61.4
	B.t.u./lb.*	11,120	13,980	13,600
Proximate analysis				
M.A.F.**	V.M.	42.6	28.9	30.6
	F.C.	57.4	71.1	69.4
By-product yields				
	Char	63.2	80.5	77.3
	Free water	10.6	0.5	0.7
	Water	8.2	3.2	3.7
	Tar	7.4	8.7	9.3
	Light oil	1.3	1.3	1.7
	Gas	9.1	5.0	7.3
	H ₂ S	0.5	0.1	--
	Total recovery	100.3	99.3	100.0
Char analysis				
H ₂ O free	Ash	13.4	10.4	14.1
	V.M.	9.4	8.1	11.6
	F.C.	77.2	81.5	74.3
	B.t.u./lb.	12,400	13,700	--
Gas composition				
volume,				
per cent***	H ₂	20.2	34.6	
	CO	13.3	3.9	
	CO ₂	22.3	3.2	
	CH ₄	41.3	55.2	
	C ₂ H ₆	2.9	3.1	
	C ₂ H ₄	--	--	
	Calculated B.t.u./cu.ft.	579.7	740.2	
	Net gas yield cu.ft./ton	3204	2922	
	('as carbonized' basis)			

* Estimated; cf. reference 3

** Moisture- and ash-free

*** Adjusted to 100%

Table 1(a). Carbonization of Alberta Coals at 600°C.

Assay No.	63	45	55
Mine location	Coleman	Coleman	Canmore
Area	Crowsnest	Crowsnest	Cascade
Classification	Mv Bit	Mv Bit	Lv Bit
Origin	Freshly mined	Freshly mined	Lab. sample
Spec. carbonization conditions	-100+200 mesh 4:1 1°C./min. sand/coal		
Proximate analysis			
'as carbonized'			
H ₂ O	0.7	0.8	1.5
Ash	7.8	9.5	9.5
V.M.	20.9	21.4	16.3
F.C.	70.6	68.3	72.7
B.t.u./lb.*	14,170	13,840	13,810
Proximate analysis			
M.A.F.**			
V.M.	22.9	23.8	18.3
F.C.	77.1	76.2	81.7
By-product yields			
Char	84.7	80.6	87.2
Free water	0.7	0.8	1.5
Water	3.0	3.0	2.7
Tar	5.2	7.2	2.4
Light oil	1.1	1.5	1.0
Gas	4.5	6.8	4.9
H ₂ S	--	--	--
Total recovery	99.2	100.0	99.7
Char analysis			
H ₂ O free			
Ash	9.8	10.4	10.1
V.M.	6.3	8.1	6.1
F.C.	83.9	81.5	83.8
B.t.u./lb.	13,760	13,700	13,730
Gas composition			
volume, per cent***			
H ₂	35.0		37.5
CO	4.5		4.4
CO ₂	2.3		3.9
CH ₄	56.1		53.3
C ₂ H ₆	2.1		0.9
C ₂ H ₄	--		--
Calculated B.t.u./cu.ft.	735.0		693.6
Net gas yield cu.ft./ton ('as carbonized' basis)	2669	2582	2941

* Estimated; cf. reference 3 ** Moisture- and ash-free *** Adjusted to 100%

Table 2. Variation of Yields with Heating Rate and Coal Size
(Lethbridge coal carbonized at 600°C.)

Assay No.		25	58	59	60
Pre-treatment		2 1/2 days oven-dried at 80°C.			
Sample size		-10 mesh	-10 mesh	-10 mesh	-200 mesh
Heating rate above 350°C.		6.5°C./min. (standard)	3°C./min.	1°C./min.	1°C./min.
Proximate analysis					
'as carbonized'	H ₂ O	2.2	3.6	3.6	2.3
	Ash	11.9	11.7	11.7	11.8
	V.M.	36.4	35.6	35.6	35.2
	F.C.	49.5	49.1	49.1	50.7
Proximate analysis					
M.A.F.*	V.M.	42.4	42.0	42.0	41.0
	F.C.	57.6	58.0	58.0	59.0
By-product yields					
	Char	69.6	70.3	71.0	69.1
	Free water	2.2	3.6	3.6	2.3
	Water	8.4	6.9	7.0	8.5
	Tar	7.5	6.9	6.2	8.2
	Light oil	1.4	1.2	1.5	1.4
	Gas	10.2	10.6	10.1	10.3
	H ₂ S	0.4	0.2	0.3	0.3
	Total recovery	99.7	99.7	99.7	100.1
Char analysis					
H ₂ O free	Ash	16.3	17.5	16.8	17.4
	V.M.	8.0	8.4	8.5	8.6
	F.C.	75.7	74.1	74.7	74.0
	B.t.u./lb.	12,510	12,290	12,380	12,280
Gas composition					
volume, per cent**	H ₂	18.3	21.3	20.3	18.9
	CO	15.3	13.6	12.6	15.2
	CO ₂	21.0	21.0	21.6	23.6
	CH ₄	41.8	41.1	42.3	39.7
	C ₂ H ₆	3.4	3.0	3.2	2.4
	C ₂ H ₄	0.2	--	--	0.2
	Calculated B.t.u./cu.ft.	592.8	583.2	592.1	555.9
	Net gas yield cu.ft./ton (('as carbonized' basis)	3543	3806	3617	3524

* Moisture- and ash-free

** Adjusted to 100%

Table 3. Variation of Yields with Carbonization Temperature
(Lethbridge and Crowsnest coals)

Assay No.		33	32	40	52
Coal		Lethbridge			Blairmore
Test sample		Freshly mined			4:1
Carbonization temp., °C.		550	500	450	550
Proximate analysis					
'as carbonized'	H ₂ O	9.2	9.2	8.8	0.7
	Ash	10.5	10.5	10.7	10.9
	V.M.	34.6	34.6	34.7	27.0
	F.C.	45.7	45.7	45.8	61.4
Proximate analysis					
M.A.F.*	V.M.	43.1	43.1	43.1	30.6
	F.C.	56.9	56.9	56.9	69.4
By-product yields					
	Char	64.9	68.0	71.5	82.7
	Free water	9.2	9.2	8.8	0.7
	Water	7.9	7.2	6.4	2.9
	Tar	9.5	8.6	7.7	7.9
	Light oil	1.5	1.3	1.4	1.3
	Gas	6.4	5.2	4.1	4.6
	H ₂ S	0.3	0.3	0.2	--
	Total recovery	99.7	99.8	100.1	100.1
Char analysis					
H ₂ O free	Ash	15.9	15.4	14.3	13.3
	V.M.	11.4	15.2	18.1	12.2
	F.C.	72.7	69.4	67.6	74.5
	B.t.u./lb.	12,320	12,130	12,060	--
Gas composition					
volume,					
per cent**	H ₂	19.1	14.2	11.2	27.7
	CO	12.7	12.8	13.5	2.9
	CO ₂	17.9	20.1	29.9	3.1
	CH ₄	46.1	46.8	43.1	63.4
	C ₂ H ₆	4.0	5.1	2.1	2.9
	C ₂ H ₄	0.2	1.0	0.2	--
	Calculated B.t.u./lb.	641.6	652.4	554.0	793.5
	Net gas yield cu.ft./ton	2371	1778	1269	2550
	('as carbonized' basis)				

* Moisture- and ash-free

** Adjusted to 100%

Table 4. Variation of Yields with Carbonization Temperature
(Edmonton coal)

Assay No.		7	6	8	41
Test sample		3 days oven-dried at 80°C.			Freshly mined
Carbonization temp., °C.		500	600	700	400
Proximate analysis					
'as carbonized'	H ₂ O	3.5	3.5	3.5	20.4
	Ash	10.5	10.5	10.5	8.7
	V. M.	33.8	33.8	33.8	28.9
	F. C.	52.2	52.2	52.2	42.0
Proximate analysis					
M. A. F. *	V. M.	39.3	39.3	39.3	40.8
	F. C.	60.7	60.7	60.7	59.2
By-product yields					
	Char	73.9	69.7	66.1	67.7
	Free water	3.5	3.5	3.5	20.4
	Water	7.0	7.0	8.6	5.7
	Tar	3.5	3.7	3.3	2.4
	Light oil	1.3	1.5	1.3	1.4
	Gas	10.6	14.4	17.0	2.8
	H ₂ S	0.2	0.2	0.2	--
	Total recovery	100.0	100.0	100.0	100.4
Char analysis					
H ₂ O free	Ash	12.8	14.0	14.4	12.5
	V. M.	13.8	7.7	3.4	24.3
	F. C.	73.4	78.3	82.2	63.2
	B. t. u. / lb.	--	--	--	11,940
Gas composition		not determined			

* Moisture- and ash-free

Table 5. Effect of Oven-Drying on By-Product Yields
(Lethbridge coal carbonized at 600°C.)

Assay No.		25	50	54	57	17
Test sample		oven-dried at 100°C. for				
		2 days	4 days	14 days	30 days	1 day at 140°C. 36 hours at 80°C.
Proximate analysis						
'as carbonized'	H ₂ O	2.2	1.0	0.6	0.7	2.3
	Ash	11.9	12.3	11.8	11.6	8.8
	V.M.	36.4	36.2	37.1	36.9	35.7
	F.C.	49.5	50.5	50.5	50.8	52.2
Proximate analysis						
M.A.F.*	V.M.	42.4	41.7	42.3	42.1	40.2
	F.C.	57.6	58.3	57.7	57.9	59.8
By-product yields						
	Char	69.6	71.2	70.2	70.1	70.9
	Free water	2.2	1.0	0.6	0.7	2.3
	Water	8.4	7.9	8.6	8.6	7.5
	Tar	7.5	6.0	3.5	4.3	4.5
	Light oil	1.4	1.4	1.4	1.5	1.2
	Gas	10.2	12.1	14.3	15.1	14.1
	H ₂ S	0.4	0.2	0.1	0.2	0.5
	Total recovery	99.7	99.8	98.7	100.5	100.0
Char analysis						
H ₂ O free	Ash	16.3	17.3	17.6	17.1	12.2
	V.M.	8.0	8.9	8.4	8.1	8.3
	F.C.	75.7	73.8	74.0	74.8	79.5
	B.t.u./lb.	12,510	11,840	12,330	12,380	--
Gas composition						
volume, per cent**	H ₂ O	18.3	19.6	18.9	16.5	--
	CO	15.3	15.6	17.4	18.2	--
	CO ₂	21.0	24.8	32.5	32.5	--
	CH ₄	41.8	36.8	29.7	31.4	--
	C ₂ H ₆	3.4	3.2	1.5	1.4	--
	C ₂ H ₄	0.2	--	--	--	--
	Calculated B.t.u./lb.	536.4	543.5	445.1	455.6	
	Net gas yield cu.ft./ton (('as carbonized' basis)	3543	4069	4324	4544	

* Moisture- and ash-free

** Adjusted to 100%

Table 6. Effect of Air-Drying on By-Product Yields
(Carbonization temperature 600°C.)

Assay No.		44	46	47	56	5
Test sample		Lethbridge coal, air-dried at 70°F. for				Edmonton coal, dried at 105°C. in nitrogen
		2 days	4 days	14 days	30 days	
Proximate analysis						
'as carbonized'	H ₂ O	6.0	6.2	6.0	6.0	0.5
	Ash	9.3	8.8	9.3	8.4	10.4
	V.M.	36.0	35.4	35.6	35.7	35.5
	F.C.	48.7	49.6	49.1	49.9	53.6
Proximate analysis						
M.A.F.*	V.M.	42.5	41.7	42.0	41.7	39.8
	F.C.	57.5	58.3	58.0	58.3	60.2
By-product yields						
	Char	65.7	65.5	66.0	66.8	71.4
	Free water	6.0	6.2	6.0	6.0	0.5
	Water	8.7	9.2	7.8	8.7	9.4
	Tar	7.8	7.3	8.2	6.5	5.7
	Light oil	1.8	1.9	1.8	1.6	1.4
	Gas	9.4	9.7	9.6	10.3	11.4
	H ₂ S	0.4	0.2	0.3	0.2	0.2
	Total recovery	99.8	100.0	99.7	100.1	100.0
Char analysis						
H ₂ O free	Ash	14.8	14.4	14.3	13.5	13.7
	V.M.	8.9	8.9	8.6	9.8	7.8
	F.C.	76.3	76.7	77.1	76.7	78.5
	B.t.u./lb.	12,640	12,670	11,820	12,820	
Gas composition						
volume, per cent**	H ₂	22.3	22.0	21.0	21.1	
	CO	14.4	14.6	16.3	14.3	
	CO ₂	19.7	18.8	19.3	21.2	
	CH ₄	41.6	42.6	42.3	41.2	
	C ₂ H ₆	2.0	2.0	1.1	2.1	
	C ₂ H ₄	--	--	--	0.1	
	Calculated B.t.u./lb.	576.3	586.0	569.3	569.8	
	Net gas yield cu.ft./ton (('as carbonized' basis)	3486	3630	3530	3716	

* Moisture- and ash-free

** Adjusted to 100%

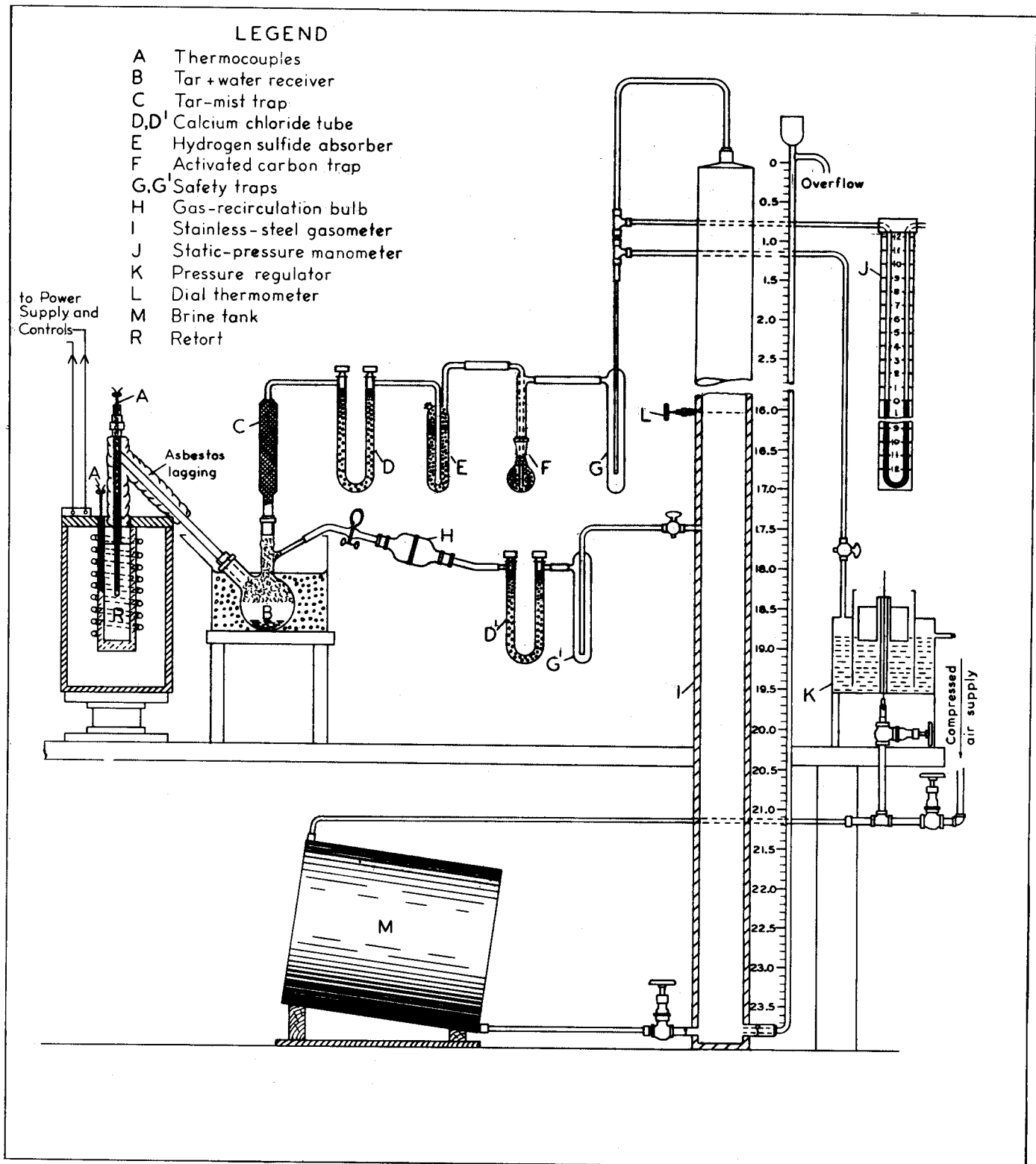
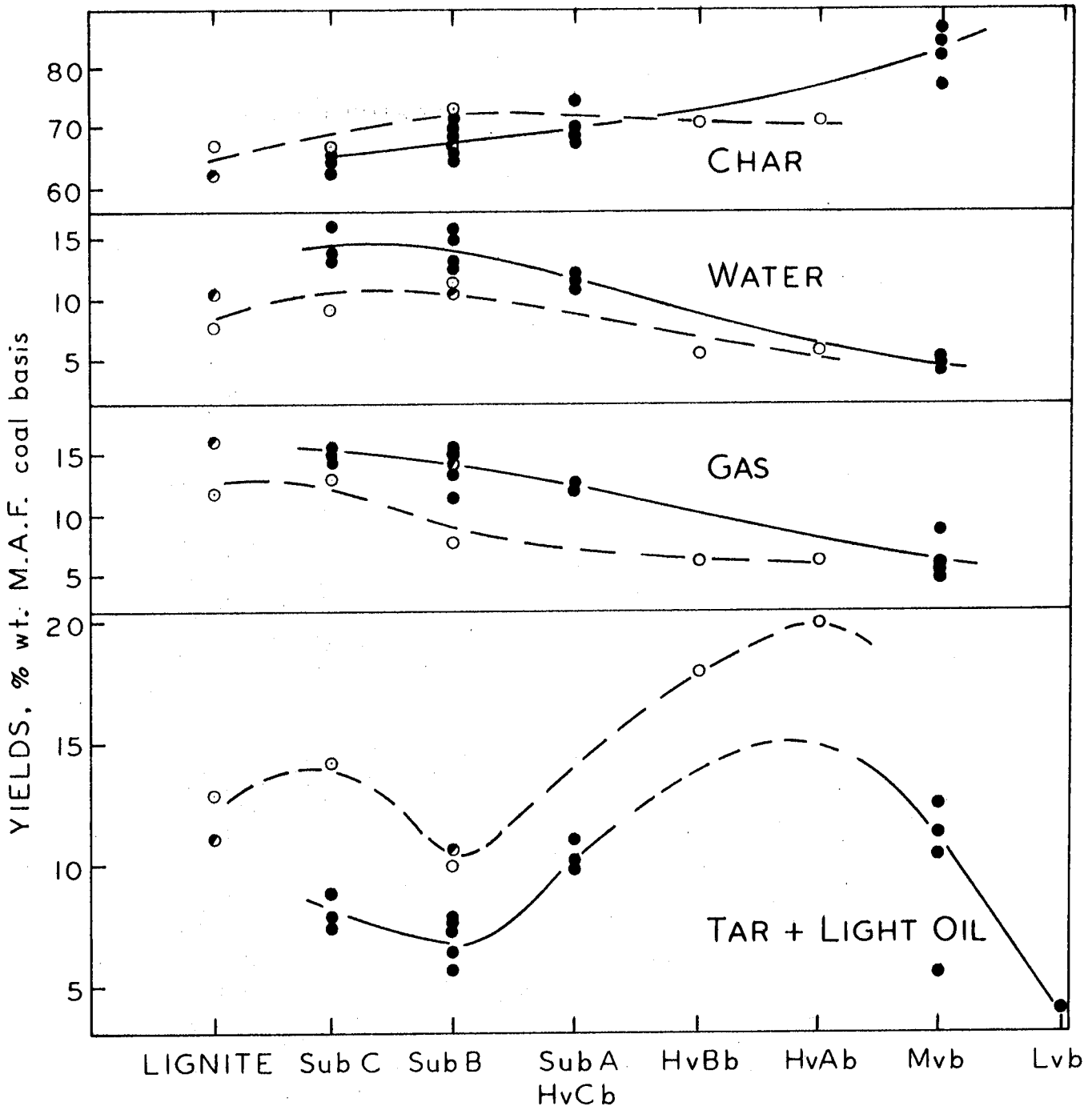


Figure 1. Assay apparatus



- 600°C. } U.S. Bur. Min. reference (5)
- 500°C. }
- 600°C, this study

Figure 2. Variation of product yields with coal rank

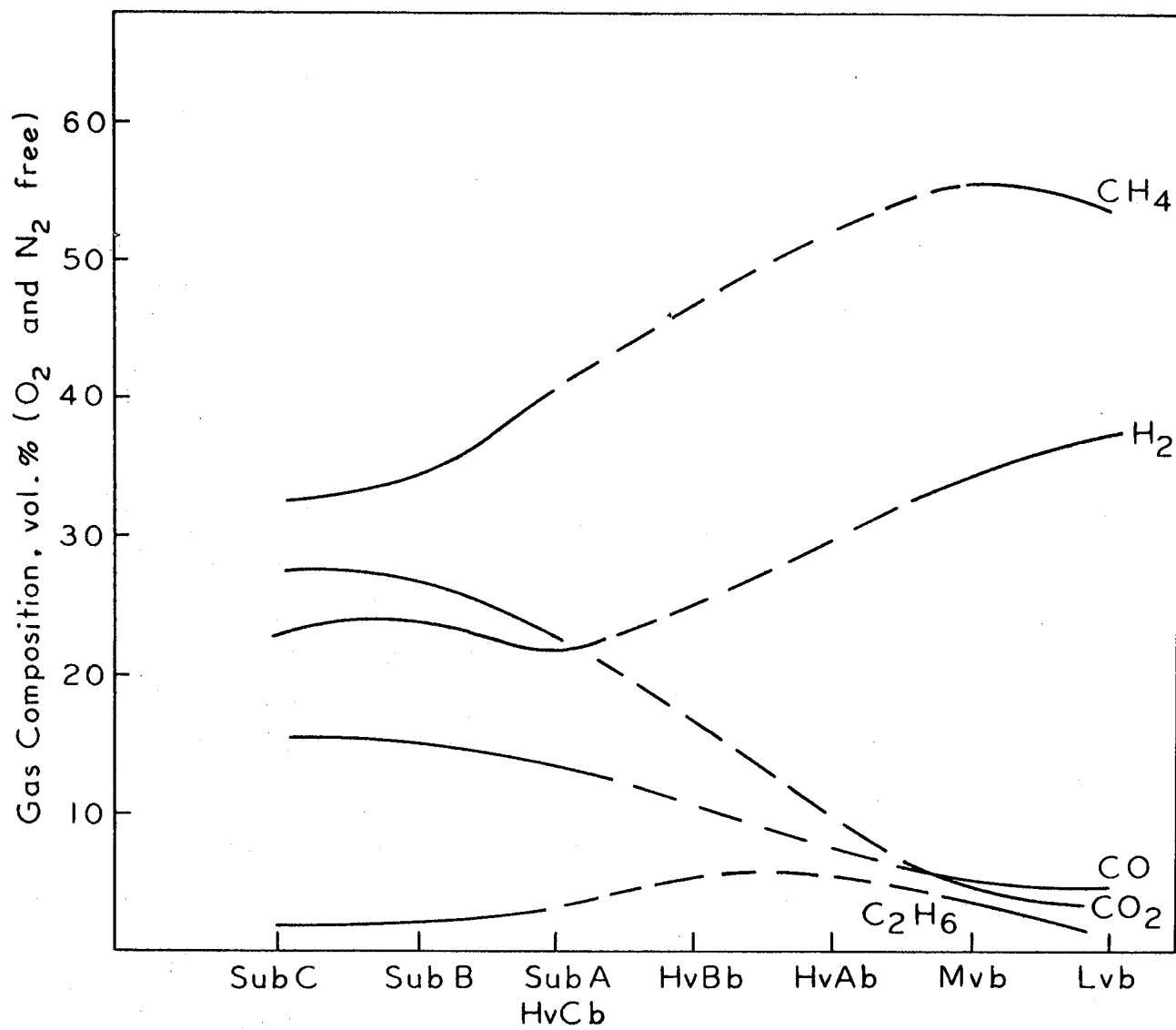


Figure 3. Variation of gas composition with coal rank

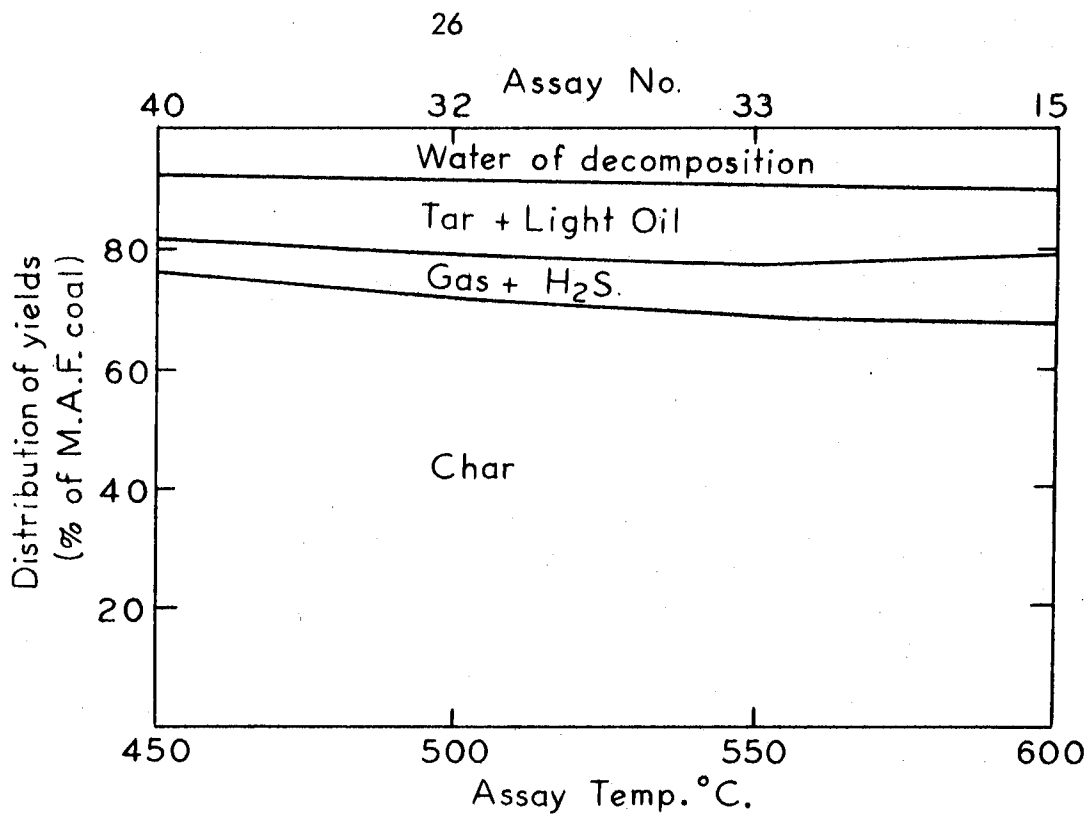


Figure 4. Effect of carbonization temperature on product yields (Lethbridge coal)

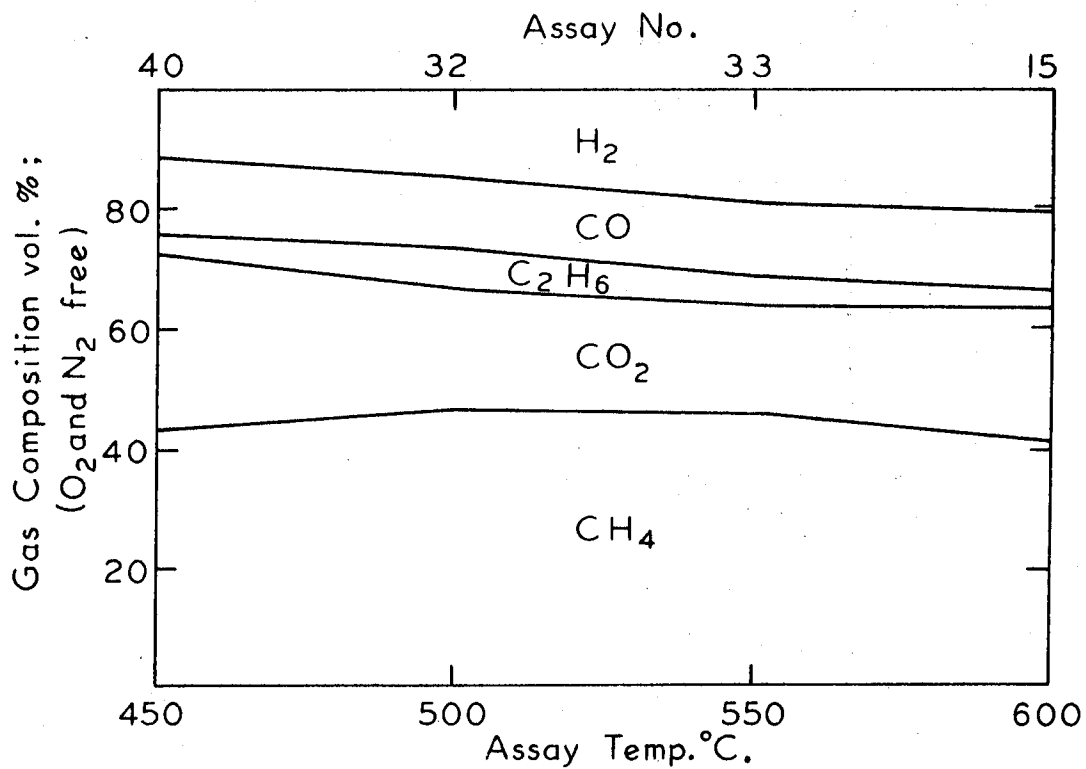


Figure 5. Effect of carbonization temperature on gas composition (Lethbridge coal)

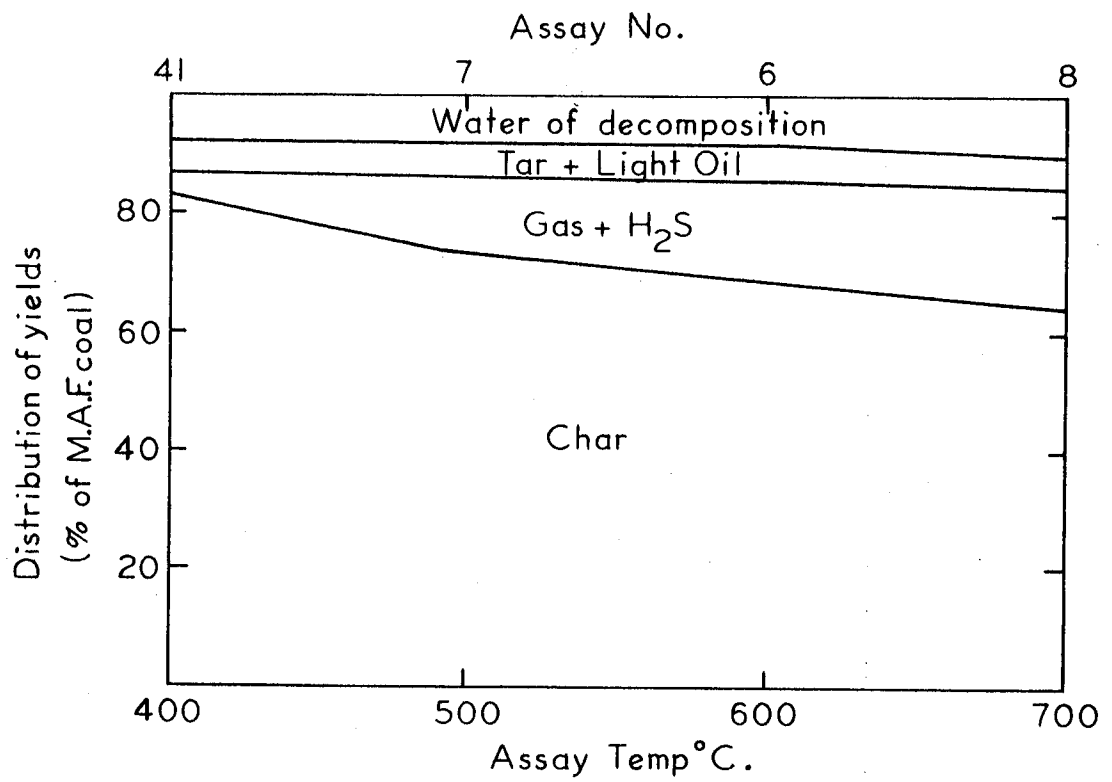


Figure 6. Effect of carbonization temperature on product yields (Edmonton coal)

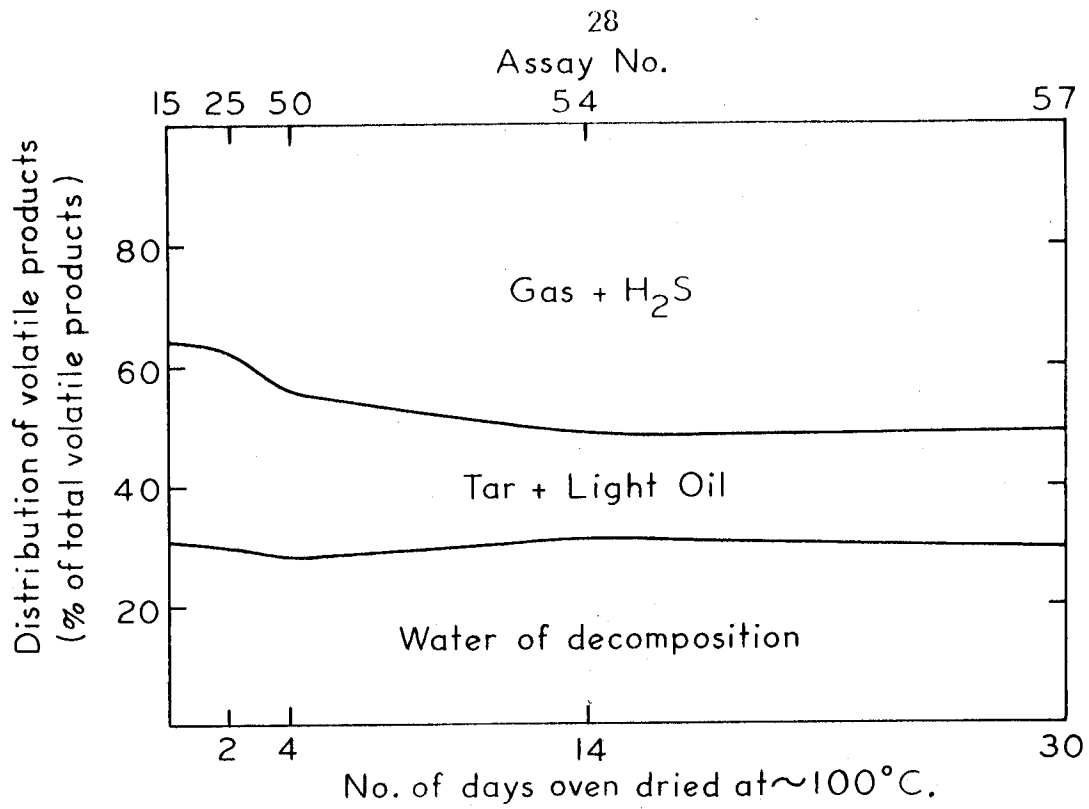


Figure 7. Effect of oven drying (at 100°C.) on yields of volatile products (Lethbridge coal)

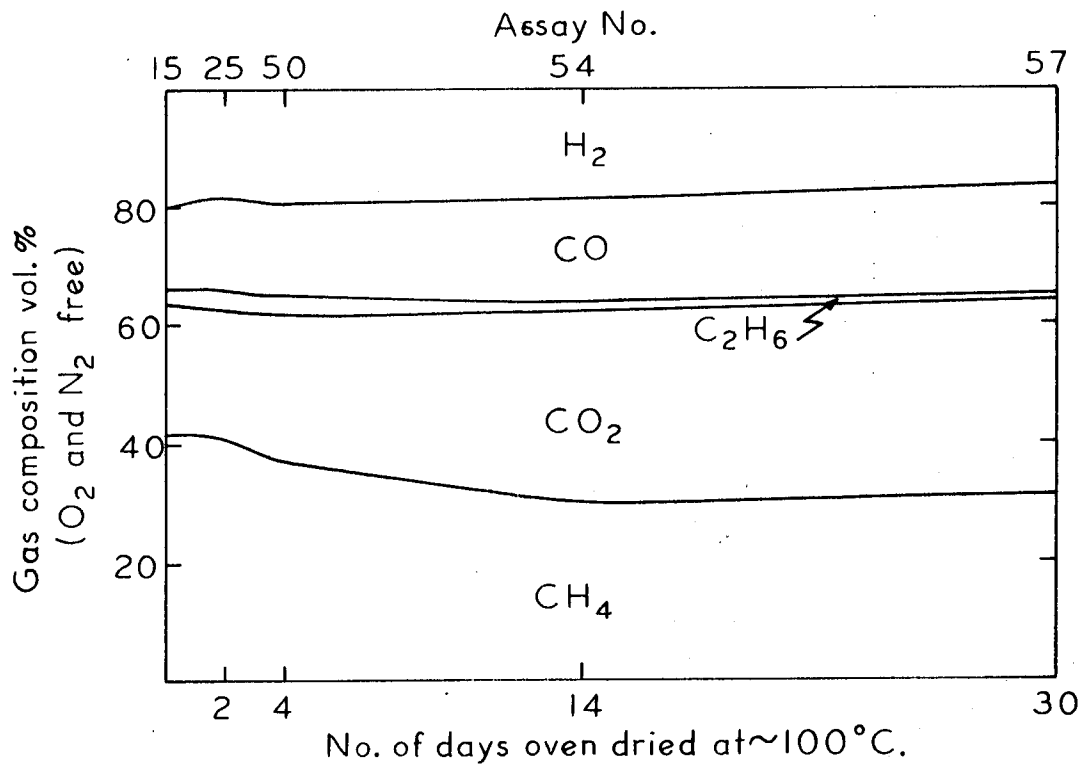


Figure 8. Effect of oven drying (at 100°C.) on gas composition (Lethbridge coal)

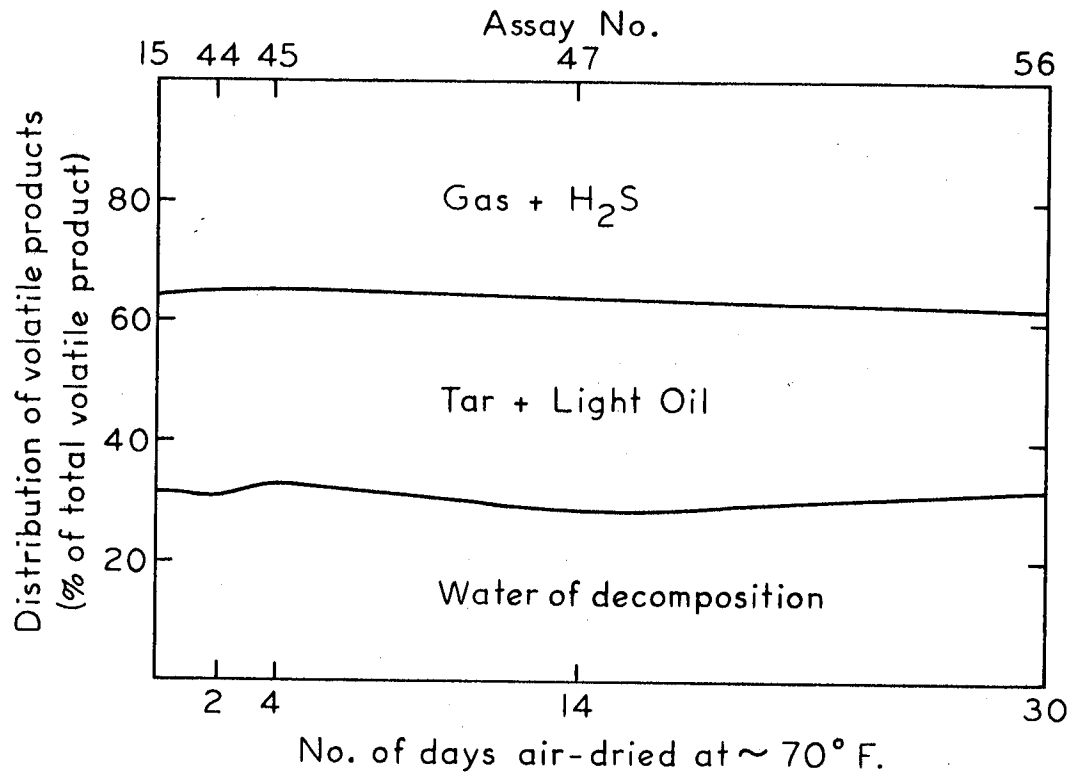


Figure 9. Effect of air drying (at 70°F.) on yields of volatile products (Lethbridge coal)

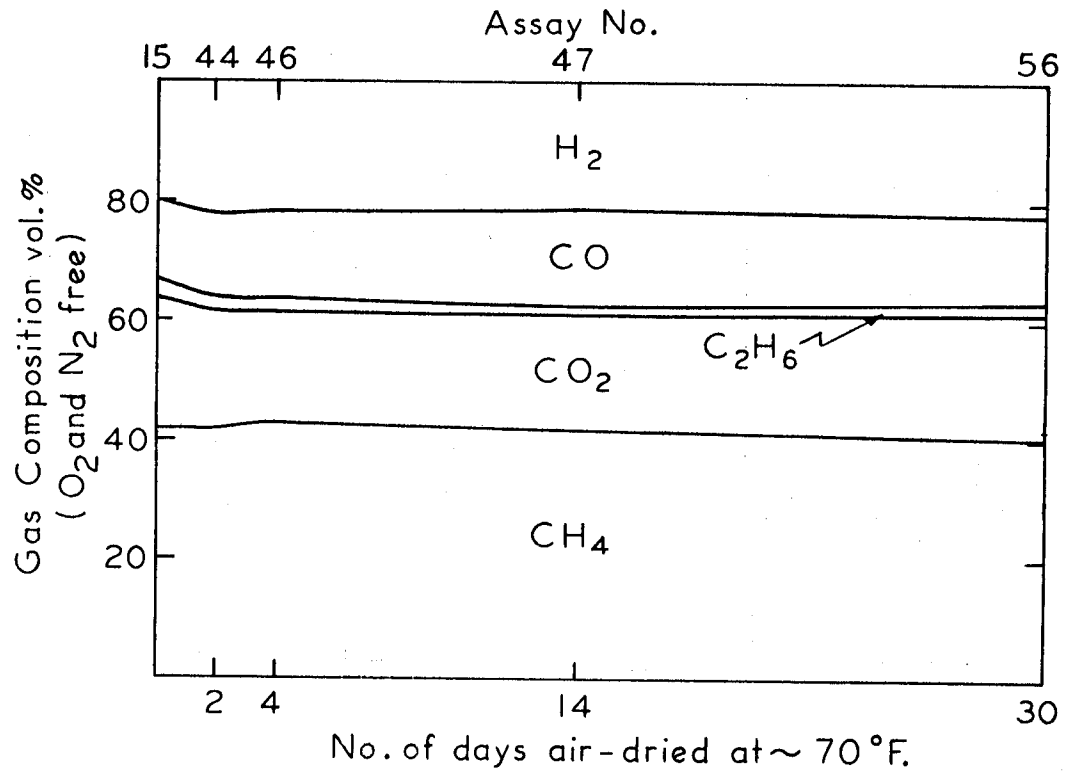


Figure 10. Effect of air drying (at 70°F.) on gas composition (Lethbridge coal)