INVESTIGATION IN THE USE OF HEAVY OILS (AND DERIVATIVES) TO PROCESS COAL

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INTRODUCTION

The use of oil as an energy source started from the beginning of this century, and for many years has been regarded as the cheapest source of liquid fuels. However, the recent dramatic escalation in work oil consumption and price, and the concern over future supplies, which are expected to fall short of demand by the end of this century, have forced the energy industry to consider other sources for the production of liquid fuels. The sources which can provide liquid fuels are coal and lignite, oil sands, oil shales, peat, and biomass.

Coal is the largest source of hydrocarbons in the world which can be converted to liquid fuels, but requires enormous amounts of expensive hydrogen. In an attempt to reduce the cost of hydrogen required to convert coal to liquid fuels, the use of oil sands bitumens, Lloydminster heavy oil, and other liquids derived therefrom, have been reported (1,2) as potential low cost hydrogen donor solvents. The present study is a continuation of the work reported elsewhere (1,2) and reports the effect of process parameters (i.e. temperature, pressure and time) on the extent of the coal conversion and on product distribution.

EXPERIMENTAL

Oil sands bitumen (dry) and coker gas oil were obtained from Great Canadian Oil Sands Ltd. (GCOS)*. Cold Lake bitumen and Lloydminster heavy oil were obtained from the Alberta Research Council sample bank. All samples were used as received.

The experimental conditions for the solvation and catalytic hydrogenation of coal, and the procedure for the fractionation of the bitumen and various liquid derivatives are described elsewhere (2,3).

Elemental compositions were determined by the micro-analysis laboratories of the Alberta Research Council and the University of Alberta. Molecular weights were measured osmotically in pyridine, and the nmr spectra were recorded (carbon tetrachloride solutions) by means of a Varian E-60B spectrometer. Gas analysis were obtained by means of a Hewlett Packard gas chromatograph fitted with a Poropak N column and a molecular sieve.

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The aromatics content, f_a, of the bitumen and derived liquids has been defined elsewhere (2).

RESULTS AND DISCUSSION

The current communication is a continuation of the previous investigations (1,2) whereby coal can be converted to soluble products using oil sands bitumen, Lloydminster heavy oil and liquids derived therefrom as solvents.

The data (Figure 1) indicate that it is, indeed, possible to solubilize part of the coal by using the Athabasca bitumen, and related liquids as solvents, and as previously reported (1,2) the extent of solubilization varies depending upon the type of solvent used. Nevertheless conversion yields using these solvents compared favorably to the results obtained when tetralin (a well-known hydrogen donor for coal liquefaction) was used as a solvent, particularly in the presence of hydrogen. It is note worthy that when tetralin was used as solvent, coal conversion yields from the solvation and noncatalytic and catalytic hydrogenation show little variation (i.e. from 47-50%) and practically remain constant. On the other hand, the percent conversion yields of the other solvents have shown a substantial increase in the presence of hydrogen, for example, from 10 to 24% in coal solvation to 30 to 40% in the catalytic hydrogenation (Figure 1).

CONTROL EXPERIMENTS

Control experiments were performed in the manner described elsewhere (2), in order to determine the degree of coke (toluene insolubles) formation during the thermal treatment of the solvents. Briefly, when these liquids are heated with or without hydrogen (in the absence of catalyst) for 60 minutes at 400°C, an overall increase in the aromatic contents is evident as their H/C atomic ratios decrease and their f_a values increase when compared with the parent solvents (Table 1). In contrast, when the solvents are heated in the presences of hydrogen and catalyst, an overall increase in the aliphatic content is evident. The API gravities of the solvents are generally increased by the heat treatment but surprisingly the API gravities of CGOS bitumen and coker gas oil are drastically reduced (Table 2) when these solvents are heated at 450°C, although liquid products of high fluidity were obtained. In addition, changes in the hetero-atom contents in these solvents (Table 1). For example oxygen and sulphur contents are decreased, particularly during the catalytic hydrogenation of the solvent, while nitrogen contents in general remained unchanged or increased supporting the concept of thermal stability due to its inclusion in hetero-aromatic systems (4). Compositional differences of the solvents as a result of heat treatment also occur (Table 2) and there are variations in the distribution of products--coke (toluene insolubles), liquids (toluene solubles), and gases (Table 3). Coke formation under these conditions (temperature 400°C and 450°C) was anticipated since oil sands bitumen and heavy oil are susceptible to heat (5,6). Composition of gases from the thermal treatment of solvents (Table 4) shows that the gas products mainly consist of hydrocarbons and hydrogen sulfide.

PROCESS CONDITIONS

EFFECT OF TEMPERATURE

a) Coal Solvation

Comparison of the conversion yields of coal solvation, using GCOS bitumen and coker gas oil as solvents (Table 5), shows that the conversion yield is constantly increased with increasing temperature for coal/bitumen processing whilst the conversion yield reaches a maximum value at 400°C, and then drastically drops to almost zero for coal/coker gas oil processing. Trends in the distribution of the reaction products (solids, liquids, and volatiles,(Table 5) using these two solvents were similar.

The toluene insoluble products (solids, undissolved coal plus coke) has a minimum value at 400°C, which coincides with the optimum conditions for the liquid and volatile products, and then drastically increases at 450°C due to coke formation as determined from blank experiments (Table 3). Because coke formation occurs simultaneously while coal is converted to liquid and gaseous products, greater amounts of toluene insolubles are obtained than the initial coal charge at 450°C. Furthermore, the liquid (toluene solubles) and volatile products follow opposite paths; as the reaction temperature increases, the maximum yield of volatiles (at 450°C) correspond to the lowest yield of liquids, suggesting that solids and volatiles are produced at the expense of liquid products.

b) Catalytic Hydrogenation

It is apparent from the data (Table 5) presented that the trends due to increase of reaction temperatures are similar for both solvents with the only difference in the yields of solid products. Thus, the conversion yields for both solvents are increased with temperature but when bitumen is used as solvent coal conversion yields reaches a maximum (at about 400-450°C) while coal conversion yields with coker gas oil continue to increase with temperature.

The percent distribution of the various products derived by processing coal with the two types of solvents show (Table 5) that the yields of liquids are high at lower temperatures (i.e., decrease with increasing temperature) while the yields of volatiles increase with increasing temperature indicating again, that the volatiles are produced at the expense of liquid products. On the other hand, the yield of solids produced using coker gas oil as solvent continuously decreases as temperature increases; the solids decrease and then appear to increase as the temperature exceed 400°C.

EFFECT OF TIME

a) Coal Solvation

The data demonstrate (Table 6) that coal solvation yield with both solvents reaches a maximum value after 60 minutes at 400°C, and then drastically drops. The product distribution (solids, liquids, and volatiles) is similar for both the coker gas oil and bitumen and resembles the product distribution for coal solvation with both solvents (Table 6). It is apparent that a reaction time of 60 minutes at 400°C coincides with the optimum conditions for the most efficient production of liquid products.

b) Catalytic Hydrogenation

Conversion yields using bitumen as solvent reach a maximum after 60 minutes reaction time, and then levels off, while with coker gas oil continues to increase linearly (Table 6). The relationship between time and product distribution by processing coal with bitumen show that there is not a drastic effect as the time exceeds 60 minutes. However, when coker gas oil is used as solvent, the liquid products are steadily increased and solids decrease without a substantial increase of gases indicating that under these conditions, longer periods are beneficial.

EFFECT OF PRESSURE

The limited data available (Table 7) show that conversion yields reach a maximum at a pressure of approximately 1000 psig. There is a pronounced effect on the yields of liquid products which are constantly increased with increasing pressure; volatiles decrease with increasing reaction pressure, while there is a small variation of the solids at pressure over 1000 psig.

Tables 8, 9, and 10 show the relative composition of gases derived from processing coal under various conditions using bitumen and coker gas oil as solvents. As previously discussed, the evolution of oxygen and sulphur from coal as carbon monoxide and dioxide, and as hydrogen sulphide particularly in the catalytic hydrogenation of coal are the most noticeable features.

ACKNOWLEDGEMENT

We thank Dr. M. P. du Plessis for encouragement throughout this work.

REFERENCES

1. Moschopedis, S.E.: "The use of oil sands bitumen and its derivatives as hydrogen donors to coal", Fuel, 59, 67, 1980.

2. Moschopedis, S.E., Hawkins, R.W., Fryer, J.F., and Speight, J.G.: "The use of heavy oils (and derivatives) to process coal". Fuel, 59, 647, 1980.

3. Moschopedis, S.E., Fryer, J.F., and Speight, J.G.: "Investigation of the carbonyl functions in a resin fraction". Fuel, 55, 187, 1976.

4. Moschopedis, S.E, and Speight, J.G. "Investigation of nitrogen types in Athabasca bitumen". Preprints, Am. Chem. Soc., Div. Fuel Chem., 24, (4), 1007, 1979.

5. Speight, J.G. "Thermal cracking of Athabasca bitumen, Athabasca asphaltenes, and Athabasca deasphalted heavy oil", Fuel, 40, 134, 1970.

6. Speight, J.G., and Moschopedis, S.E., "The production of low-sulfur liquids and coke from Athabasca bitumen", Fuel Processing Technology 2, 295, 1979.

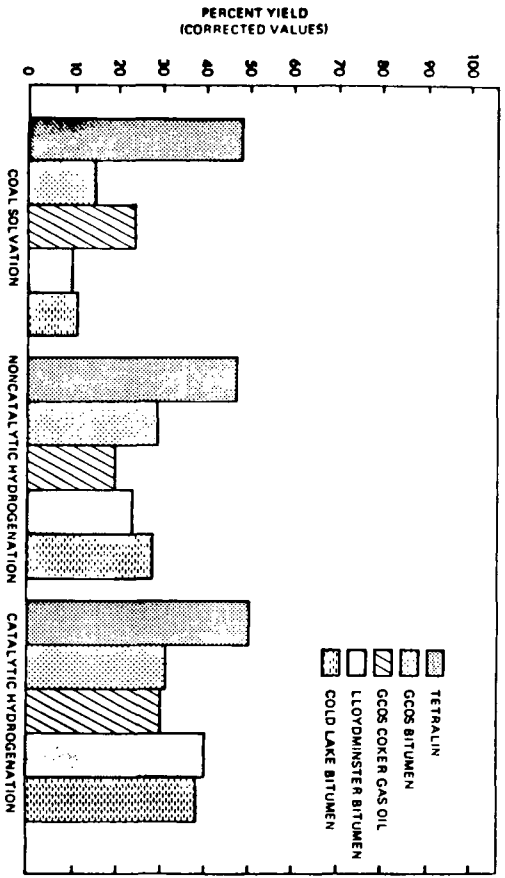

FIGURE 1.

Table 1 Analyses of bitumens and derived liquids

Material description	% Composition C	H	N	O	S	MW	H/C	H_{arom} %	f_a
a) Parent material									
GCOS bitumen Athabasca deposit	84.18	10.31	0.40	0.78	4.33	532	1.47	5.8	29.9
GCOS coker gas oil	84.65	10.95	0.40	0.64	3.34	296	1.55	8.2	28.7
Lloydminster heavy oil	83.75	10.94	0.27	1.47	3.55	410	1.57	7.0	27.1
Cold Lake bitumen	83.68	10.66	0.39	1.13	4.13	508	1.53	7.3	29.1
b) Heated for 60 min at 400° C									
GCOS bitumen Athabasca deposit	84.96	9.98	0.67	0.68	3.41	394	1.41	6.8	34.3
GCOS coker gas oil	85.61	10.73	0.30	0.60	3.32	311	1.50	9.4	31.8
Lloydminster heavy oil	84.77	10.80	0.30	0.81	3.04	335	1.52	9.7	31.0
Cold Lake bitumen	84.54	10.67	0.41	0.80	3.58	468	1.51	9.5	31.5
c) Heated for 60 min at 400°C, H_2 - 1000 psig									
GCOS bitumen Athabasca deposit	85.64	9.90	0.45	0.85	3.13	420	1.39	11.5	38.6
GCOS coker gas oil	84.74	10.52	0.28	0.80	3.65	350	1.49	10.9	33.6
Lloydminster heavy oil	86.08	10.25	0.26	0.83	2.56	410	1.43	12.0	37.1
Cold Lake bitumen	84.84	9.78	0.42	1.24	3.69	374	1.38	9.5	37.4
d) Heated for 60 min at 400°C H_2 - 1000 psig + catalyst									
GCOS bitumen Athabasca deposit	84.88	10.93	0.33	0.69	3.16	551	1.54	4.7	32.8
GCOS coker gas oil	87.81	11.26	0.15	0.11	0.67	341	1.54	5.4	27.1
Lloydminster heavy oil	85.52	11.86	0.19	0.40	2.01	425	1.66	5.0	20.9
Cold Lake bitumen	85.61	11.63	0.30	0.63	1.81	440	1.63	8.8	25.6

Table 2. Composition and properties of bitumens and liquids derived from bitumen heated under various conditions

	Material description	% Asphaltenes	% Resins	% Oils	API gravity
a)	Parent material				
	GCOS bitumen Athabasca deposit	15.4	22.3	62.3	7.5
	GCOS coker gas oil	0.5	5.6	93.9	17.3
	Lloydminster heavy oil	11.9	20.5	67.6	14.8
	Cold Lake bitumen	16.1	18.9	64.9	7.5
b)	Heated for 60 min at 400° C				
	GCOS bitumen Athabasca deposit	15.0	20.1	64.9	9.8
	GCOS coker gas oil	0.2	10.2	89.6	16.0
	Lloydminster heavy oil	12.5	13.5	74.0	14.3
	Cold Lake bitumen	14.5	12.0	73.5	11.4
c)	Heated for 60 min at 450° C				
	GCOS bitumen Athabasca deposit	7.8	11.4	80.8	3.8*
	GCOS coker gas oil	11.2	17.9	70.9	3.6*
d)	Heated for 60 min at 400° C, H_2 - 1000 psig				
	GCOS bitumen Athabasca deposit	8.7	16.5	74.8	17.7
	GCOS coker gas oil	0.2	10.3	89.5	21.9
	Lloydminister heavy oil	6.3	27.0	66.7	16.8
	Cold Lake bitumen	11.2	12.2	76.6	12.9
e)	Heated for 60 min at 400° C, H_2 - 1000 psig + catalyst				
	GCOS bitumen Athabasca deposit	8.4	12.1	79.5	12.5
	GCOS coker gas oil	0	7.9	92.1	23.7
	Lloydminster heavy oil	7.3	15.5	77.2	18.4
	Cold Lake bitumen	7.4	13.3	79.3	17.4
f)	Heated for 60 min at 400° C, H_2 - 2000 psig + catalyst				
	GCOS bitumen Athabasca deposit	8.4	-	91.6	- 13.7
	GCOS coker gas oil	0.3	-	97.7	- 16.2
g)	Heated for 60 min at 450° C, H_2 - 1000 psig + catalyst				
	GCOS bitumen Athabasca deposit	4.7	10.1	85.2	10.3
	GCOS coker gas oil	0	7.0	93.0	20.6

Table 3. Product distribution of bitumen and liquids derived from bitumen heated under various conditions

Material description	Toluene insolubles %	Toluene solubles %	Volatiles plus gas %
a) Heated for 60 min at 400 °C			
GCOS bitumen Athabasca deposit	2.6	90.2	7.2
GCOS coker gas oil	1.4	90.7	7.9
Lloydminster heavy oil	0.2	92.0	7.8
Cold Lake bitumen	2.0	89.8	8.2
b) Heated for 60 min. at 450 °C			
GCOS bitumen Athabasca deposit	26.2	28.7	45.1
GCOS coker gas oil	11.6	47.6	40.8
c) Heated for 60 min. at 400 °C, H_2-1000 psig			
GCOS bitumen Athabasca deposit	1.1	91.2	7.7
GCOS coker gas oil	nil	97.0	3.0
Lloydminster heavy oil	1.5	86.6	11.9
Cold Lake bitumen	1.7	90.6	7.7
d) Heated for 60 min. at 400 °C, H_2 - 1000 psig + catalyst			
GCOS bitumen Athabasca deposit	1.2	91.7	7.1
GCOS coker gas oil	nil	94.0	6.0
Lloydminster heavy oil	0.8	95.9	3.3
Cold Lake bitumen	1.1	94.4	4.5
e) Heated for 60 min. at 400 °C, H_2 - 2000 psig + catalyst			
GCOS bitumen Athabasca deposit	1.0	89.6	8.4
GCOS coker gas oil	nil	96.4	3.6
f) Heated for 60 min. at 450 °C, H_2 - 1000 psig + catalyst			
GCOS bitumen Athabasca deposit	4.3	36.7	59.0
GCOS coker gas oil	0.5	49.5	50.0

Table 4 Gas product distribution derived from bitumens and liquids derived from bitumen heated under various conditions

Material description	Relative composition										
	CO	CO_2	H_2S	CH_4	C_2H_4	C_2H_6	C_2H_2	C_3	C_4^{iso}	C_4^{norm}
I. absence of air										
a) (60 min., 400° C)										
GCOS bitumen Athabasca deposit	-	N.D.								
GCOS coker gas oil		N.D.								
Lloydminster heavy oil	-	-	14.3	37.6	0.9	24.2	-	17.1	1.5	4.4
Cold Lake bitumen	-	1.0	18.4	31.9	0.7	23.9	-	16.3	2.0	5.9
b) 60 min, 450°C										
GCOS bitumen Athabasca deposit	-	0.8	6.6	50.9	0.2	24.5	-	12.9	1.2	2.8
GCOS coker gas oil	-	0.2	2.5	54.9	0.1	26.2	-	12.7	1.2	2.2
c) In presence of H_2-1000 psig (60 min., 400°C)										
GCOS bitumen Athabasca deposit	-	0.8	14.6	26.0	0.3	14.0	-	13.6	——	26.9 ——
GCOS coker gas oil	-	N.D.								
Lloydminster heavy oil	-	-	11.9	29.5	0.3	14.8	-	13.8	——	29.6 ——
Cold Lake bitumen	-	0.5	12.2	27.3	0.3	14.0	-	11.2	——	34.5 ——
d) In presence of H_2-1000 psig + catalyst (60 min., 400°C)										
GCOS bitumen Athabasca deposit		N.D.								
GCOS coker gas oil		N.D.								
Lloydminster heavy oil		31.0	27.0	13.9	1.8	14.5	1.8	7.0	1.0	2.0
Cold Lake bitumen	-	1.6	52.8	17.0	-	15.4	-	8.1	1.6	3.6
In presence of H_2-2000 psig + catalyst (60 min., 400°C)										
GCOS bitumen Athabasca deposit	-	-	63.3	18.6	-	8.2	-	6.8	0.8	2.3
GCOS coker gas oil	-	-	17.5	45.2	-	17.3	-	15.6	-	4.3
e) In presence of H_2 - 1000 psig + catalyst (60 min., 450° C)										
GCOS bitumen Athabasca deposit	-	-	14.8	47.1	-	22.4	-	12.3	1.2	2.2
GCOS coker gas oil	-	-	12.9	41.4	-	27.0	-	14.3	1.5	2.8

N.D. Not determined

Table 5. Temperature effect on coal conversion yields and product distribution (60 minutes, H_2 - 1000 psig)

Conditions	% Yield+	%Toluene insolubles	% Toluene solubles	%Volatile plus gas	Tolune solubles fraction		
					% Pentane insolubles	% Pentane solubles	API gravity
Coal solvation							
GCOS bitumen Athabasca deposit							
300° C	2	28.8	69.8	1.4	16.1	83.9	7.9
350° C	5	28.0	69.4	2.6	19.5	80.5	12.8
400°C	15	26.1	65.4	8.5	19.0	81.0	10.7
450°C	27	40.1	20.9	39.0	15.3	84.7	4.4
GCOS coker gas oil							
300°C	0	27.1	71.9	1	0.4	99.6	17.4
350°C	7	29.1	68.9	2	2.0	98.0	15.[illegible]
400°C	24	23.6	68.2	8.2	3.1	96.9	18.9
450°C	0	39.2	27.7	33.1	3.0	97.0	8.1
Catalytic hydrogenation							
GCOS bitumen Athabasca deposit							
350°C	8	26.2	70.7	3.1	17.0	83.0	13.7
400°C	32	20.8	69.1	10.1	12.5	87.5	12.4
450°C	34	22.6	25.4	52.0	11.8	88.2	1.8
GCOS coker gas oil							
300°C	0	29.6	69.4	1	0.3	99.7	17.4
350°C	7	26.7	71.3	2	1.6	98.4	17.0
400°C	30	20.6	73.9	5.5	1.8	98.2	17.3
450°C	45	16.3	42.3	41.4	4.5	95.5	8.5

+ Calculate yield after subtraction of coke formed from the solvent in blank determinations.

Table 6. Time effect on coal conversion yields and product distribution (400° C, H_2 - 1000 psig)

Reaction time	% Yield+	% Toluene Insolubles	% Toluene solubles	%Volatile plus gas	Toluene solubles fraction		
					%Pentane Insolubles	%Pentane solubles	API gravity
Coal solvation							
GCOS bitumen Athabasca deposit							
1/4 hour	10	26.3	68.4	5.3	21.7	78.3	9.2
1 hour	15	26.1	65.4	8.5	19.0	80.9	10.7
2 hours	0	31.6	51.3	17.1	16.1	83.9	9.9
GCOS coker gas oil							
1/4 hour	10	26.8	70.1	3.1	4.2	95.8	15.8
1 hour	24	23.6	68.2	8.2	3.1	96.9	18.9
2 hours	12	25.6	55.7	18.7	6.4	93.6	12.7
Catalytic hydrogenation							
GCOS bitumen Athabasca deposit							
1/4	17	24.2	69.2	6.6	17.8	82.2	10.1
1 hour	32	20.8	69.1	10.1	12.5	87.5	12.4
2 hours	31	20.1	66.5	13.4	11.5	88.5	13.1
GCOS coker gas oil							
1/4 hour	17	24.2	72.8	3.0	3.5	96.5	17.9
1 hour	30	20.6	73.9	5.5	1.8	98.2	17.3
2 hours	41	17.4	75.5	7.1	3.8	96.2	18.5

+ Calculated yield after subtraction of coke formed from the solvent in blank determinations.

Table 7. Pressure effect on coal conversion yields and product distribution (60 minutes, 400 °C)

	% Yield[a]	% Toluene Insolubles	% Toluene Solubles	% Volatile plus gas	Toluene solubles fraction		
					% Pentane Insolubles	% Pentane Solubles	API gravity
Catalytic hydrogenation							
GCOS bitumen Athabasca deposit							
500	16	24.5	63.3	12.2	17.8	82.2	9.6
1,000	32	20.8	69.1	10.1	12.5	77.5	12.4
1,500	30	21.7	68.3	10.0	15.0	85.0	11.4
2,000	30	21.8	75.0	3.2	14.7	85.3	12.1

Table 8. Gas product distribution derived from processing coal for 60 min. at various temperatures

Temperature	% Relative Composition									
	CO	CO_2	H_2S	CH_4	C_2H_4	C_2H_6	C_2H_2	C_3	C_4 iso	C_4 norr
Coal solvation										
GCOS bitumen Athabasca deposit										
300°C	-	97.8	-	-	-	1.7	-	0.5	-	-
350°C	2.1	74.5	3.6	10.5	-	5.9	-	2.7	-	0.6
400°C	0.6	31.9	7.5	31.6	-	15.4	-	9.8	1.1	2.0
450°C				insufficient sample						
GCOS coker gas oil										
300°C	-	94.0	1.5	-	-	3.8	-	0.6	-	-
350°C	1.6	64.8	2.3	12.7	-	14.6	-	2.9	0.2	0.9
400°C		N.D.								
450°C		N.D.								
Catalytic hydrogenation										
GCOS bitumen Athabasca deposit										
350°C	1.4	55.1	10.3	12.0	-	17.0	-	3.5	-	0.9
400°C	0.7	22.8	24.4	26.0	1.3	13.8	-	8.0	0.9	1.9
450°C	0.3	7.4	7.9	51.9	0.1	19.9	-	9.7	0.9	1.9
GCOS coker gas oil										
300°C	-	95.4	3.7	-	-	-	-	0.9	-	-
350°C	1.7	62.0	17.1	10.9	1.7	2.6	-	3.2	-	0.9
400°C		N.D.								
450°C	0.1	6.1	4.0	56.9	-	20.8	-	9.4	0.9	1.7

N.D: Not Determined

Table 9. Gas product distribution derived from processing coal at 400 C° for various times

Reaction Time	% Relative Composition									
	CO	CO_2	H_2S	CH_4	C_2H_4	C_2H_6	C_2H_2	C_3	C_4 iso	C_4 norm
Coal solvation										
GCOS bitumen Athabasca deposit										
1/4 hour	1.0	44.7	9.9	24.0	-	9.6	-	7.9	0.7	2.1
1 hour	0.6	31.9	7.5	31.6	-	15.4	-	9.8	1.1	2.0
2 hours	2.8	37.7	13.7	24.2	-	10.5	-	8.0	1.0	2.1
GCOS coker gas oil										
1/4 hour	2.9	56.5	3.1	19.8	-	10.1	-	6.2	0.4	1.1
1 hour		N.D.								
2 hours	2.8	23.8	3.4	39.2	0.1	15.7	-	11.0	1.4	1.1
Catalytic hydrogenation										
GCOS bitumen Athabasca deposit										
1/4 hour	0.2	17.0	19.5	27.6	0.4	13.6	-	16.6	2.4	2.9
1 hour	0.7	22.8	24.4	26.0	1.3	13.8	-	8.0	0.9	1.9
2 hours	1.5	23.7	18.4	32.2	-	12.0	-	8.5	1.3	2.3
GCOS coker gas oil										
1/4 hour	4.4	44.4	15.6	22.0	-	7.2	-	5.0	0.3	1.0
1 hour		N.D.								
2 hours	2.6	23.5	17.7	34.9	-	12.0	-	7.1	0.7	1.5

Table 10. Gas product distribution derived from processing coal for 60 min. at 400°C under various pressures

Pressure psig	% Relative composition									
	CO	CO_2	H_2S	CH_4	C_2H_4	C_2H_6	C_2H_2	C_3	C_4 iso	C_4 norm
Catalytic hydrogenation										
GCOS bitumen Athabasca deposit										
500	0.9	33.7	17.6	26.1	-	10.2	-	8.1	1.1	1.3
1,000	0.7	22.8	24.4	26.0	1.3	13.8	-	8.0	0.9	1.9
1,500	3.5	26.2	22.4	26.9	-	10.2	-	7.7	1.0	2.1
2,000	1.2	23.9	21.6	31.5	-	11.1	-	7.6	0.9	0.3