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CANMET COPROCESSING OF LOW-RANK CANADIAN COALS

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by

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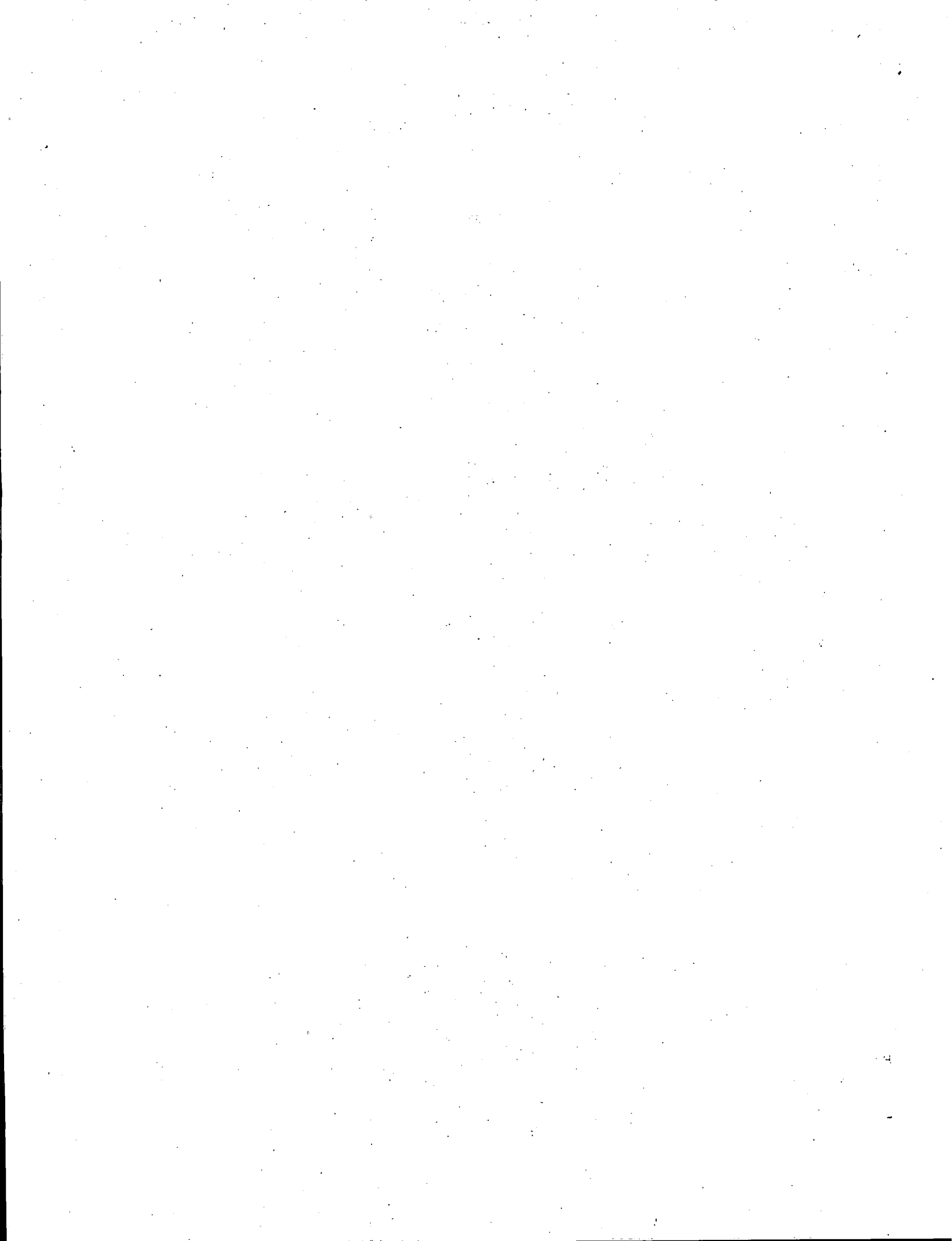
ABSTRACT

An extensive research program is underway at CANMET on the simultaneous liquefaction of coal and upgrading of heavy oil or petroleum residues. CANMET coprocessing is a single-stage once-through process that utilizes an inexpensive disposable catalyst. It can be viewed as an extension of the CANMET hydrocracking process with high coal concentration in the slurry feed.

The feasibility of CANMET coprocessing was tested for a number of coals and residues to assess their suitability as coprocessing feedstocks and to generate a database of the product yield structure for each coal.

The process performance using different feedstocks is compared. Using Cold Lake vacuum bottoms as a coprocessing medium, eight coal feedstocks were investigated. The process was feasible for all the coals with marginal variations, among the low rank coals, in the distillate yields and qualities and in the coal conversions. Similarly, using an Alberta subbituminous coal, the process was shown to be feasible for the residues tested. It was found that the residues originating from bitumens/heavy oils result in higher pitch conversions and higher distillate yields than those originating from conventional crudes. The distillates produced from conventional crude residues, however, are of a better quality than those produced from bitumen/heavy oil residues.

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INTRODUCTION

The coprocessing of coal and heavy oil, bitumen or petroleum residues has attracted the attention of research and development groups as a method for coal and residue conversion. From a coal liquefaction point of view, replacing the recycle solvent with fresh heavy oil or residue offers savings by eliminating the recycle loop. It also makes the utilization of the reactor volume more efficient since the carrier medium is upgraded along with the coal feedstock in a once-through operation. Conversely, from a residue conversion standpoint, the presence of coal in the feedstock results in a slight drop in process performance, but there is a significant opportunity cost in replacing a large portion of expensive residue or heavy oil with lower cost coal, which contributes to the distillate production. Since heavy oil resources in Western Canada are in proximity to low-rank coals, the coprocessing option offers a unique opportunity in utilizing both feedstocks for synthetic fuel production.

CANMET is carrying out an extensive R&D program on coprocessing as an extension of the CANMET hydrocracking process. CANMET coprocessing is a single-stage once-through operation that utilizes an inexpensive disposable catalyst or additive. A continuous-flow bench scale unit has been used to investigate the behaviour of Canadian coals and residues as feedstocks for coprocessing under a range of operating conditions. The effect of process severity as well as the effect of coal concentration on the product yields and qualities were previously discussed (1). As part of the research program, a number of coals were tested using Cold Lake vacuum bottoms as a medium to demonstrate their suitability as coprocessing feedstocks and to generate a database of the yield structure for each coal. Similarly, the suitability of a number of residues from different origins was tested using an Alberta sub-bituminous coal under identical operating conditions. Results are presented from bench-scale runs using different coals and coprocessing media. Process performance of the feedstocks tested is compared.

EXPERIMENTAL

Feedstocks

The coals tested in this investigation were:

- Two lignites from Saskatchewan's Bienfait and Coronach mines, obtained from Saskatchewan Power Corporation.
- Two subbituminous coals from British Columbia's Hat Creek deposit. Hat Creek A is from an upper zone with high ash, and Hat Creek B is a lower zone low ash coal. These were obtained from B.C. Research.
- Two subbituminous coals from Alberta; Forestburg is a subbituminous C coal obtained from Luscar Ltd., and Highvale is a subbituminous B coal obtained from the Alberta Research Council.
- A high-volatile bituminous coal from the Lingan mine in Nova Scotia, obtained from Cape Breton Development Corporation (DEVCO).
- Illinois #6, a U.S. high-volatile bituminous coal obtained from the two-stage liquefaction facility at Wilsonville, Alabama.

Table 1 summarizes the characteristics of all the coals used in this investigation. The residues tested were:

- Cold Lake vacuum bottoms obtained from the Strathcona Refinery of Imperial Oil Ltd.
- Athabasca pitch, a vacuum distillation residue (525°C+), distilled by Gulf Canada Ltd. in Toronto.
- Blend 24 residue, a vacuum distillation residue of a blend of Venezuelan crudes with an API value of 24.
- Ultramar residue, a vacuum distillation residue of Laguna crude oil, distilled at Ultramar Refinery in Montreal.

The characteristics of the four residues are given in Table 2.

Continuous Flow Unit

A 1-L continuous-flow stirred tank reactor was used to conduct the experiments. A schematic diagram of the unit is shown in Fig. 1. The nominal capacity of the unit is 1 kg/h of slurry feed. Product slurry samples were collected over 1-h periods at steady state. For all the experimental runs reported in this paper, the material balances were within ± 5 wt %. For comparison purposes, all the data were proportionately normalized to 100% material balance.

RESULTS AND DISCUSSION

CANADIAN COALS AS COPROCESSING FEEDSTOCKS

Seven Canadian coals and one US coal were tested under identical processing conditions using the same coprocessing medium in order to assess their suitability as feedstocks. Process performance parameters are compared in this section.

Yield Structure

The yield structures for the coals at moderate-high severity are given in Table 3, and those at low severity are shown in Table 4. Tables 3 and 4 show that single-stage once-through CANMET coprocessing is feasible for all the coals tested. Some variations in the yield structure can be noticed for the different coals tested. The Lingan coal produced the highest total distillate yield. Coronach and the Hat Creek coals produced more naphtha and less light gas oil than the other coals with equivalent total distillate yield. The lowest distillate yield for the low rank coals at the higher severity was observed for Highvale. This is not the case at low severity where Highvale produced distillate yields similar to those of the other low-rank coals.

There is no significant variation in the overall residue yield. The yields of the residue components, however, show variation. At moderate-high severity, the preasphaltenes yield varies from 0.2 wt % for Bienfait to 10.3 wt % for Illinois #6. This indicates that the primary coal conversion products are chemically different and that their response to further upgrading would vary considerably.

Coal Conversion

The coal conversion values at both levels of processing severity are given in Table 5 and presented in Fig. 2. It is not possible to derive a correlation between the coal conversion and the coal characteristics from the limited number of coals tested. However, Fig. 2 shows that the CANMET process is feasible for all the coals tested. High volatile bituminous coals lend themselves to higher conversions than low-rank coals. Among the low rank coals, Forestburg showed the highest conversion in the moderate-high severity test, and Highvale showed the lowest conversion at both levels of severity. Highvale coal is rich in inertinites and has a low H/C ratio compared with

the other low-rank coals. Coronach coal is reported in Table 1 as an inertinite-rich coal. On a moisture ash-free basis, however, it contains less inertinites than Highvale. Also the semifusinite and semimacrinite contents are higher for Coronach coal. It appears that, under reaction conditions, these forms of inertinites in Coronach coal become reactive. It is interesting to note that the variation in coal conversion among the coals does not follow the same trend at the two levels of severity. This suggests that the kinetic behaviour of coal conversion is not the same for all the coals.

Pitch Conversion

The pitch conversion values are given in Table 6 and presented in Fig. 2. The pitch conversion is defined as:

$$\text{Pitch conversion} = 1 - \frac{\text{weight of } +525^{\circ}\text{C material in product}}{\text{weight of } +525^{\circ}\text{C material in slurry feed}} \times 100$$

Therefore, the pitch conversion values reflect the conversion of both the pitch in the coprocessing medium and the coal, to distillate and gaseous products. It is clear from Table 6 that for all the coals tested, the pitch conversion is marginally affected by the coal type. This result is significant in that it indicates the feasibility of CANMET coprocessing for all the coals tested. No detrimental effect of a particular coal on the process performance was observed. It should be noted that the pitch conversion values reported in Table 6 are not the optimum values for the process. For the coprocessing of Forestburg subbituminous coal and Cold Lake vacuum bottoms, pitch conversions as high as 84 wt % and distillate yields as high as 72 wt % are possible with coal conversions as high as 94 wt %.

Distillate Characteristics

Despite the variation in the yields of distillate fractions as shown in Table 3, the overall characteristics of the distillate products are similar. Table 7 shows the gross properties of the distillates obtained at moderate-high severity for the various coals. The API gravity falls in the narrow range of 25-29.8, and the H/C atomic ratio in the range of 1.58-1.70. The nitrogen content of the distillate product for all the coals is ≤ 0.5 wt %. Because of the low nitrogen content in the slurry feed, the error in analyzing for nitrogen did not allow determination of reliable values for denitrogena-

tion. However, desulphurization and deoxygenation values were calculated and are listed in Table 8. These are defined as:

$$E_r = \frac{E_{SF} - (E_D + E_R)}{E_{SF}} \times 100$$

where:

- E_r = wt % element removal,
- E_{SF} = amount by weight of element in the slurry feed,
- E_D = amount by weight of element in the distillate product, and
- E_R = amount by weight of element in the residue product.

Table 8 shows that desulphurization occurs to almost the same extent for all the coals whereas there are more noticeable differences in the extent of deoxygenation. Since Cold Lake vacuum bottoms contain a large amount of sulphur (Table 2), the variation in the sulphur content or sulphur form in the coals does not seem to have a significant effect on the degree of desulphurization. However the oxygen originates mainly from the coal part of the feedstock and the variation in the degree of deoxygenation is due to variations in either the oxygen content or the chemical form of oxygen in the coals. Examination of Table 7 shows variations in both the sulphur and the oxygen content of the distillate product. The variations in the oxygen content are more noticeable than those for sulphur content. Table 7 also shows a slight variation in the aromaticity of the distillate between 25 and 30. This suggests that the contribution of coal to the distillate product is similar for the coals tested. Other experiments on processing Forestburg coal in a heavy gas oil II fraction, showed that as much as 50% of the coal portion of the feedstock contributes to the coprocessing distillate product. In general, the quality of the distillate obtained is closer to products from hydrocracking than to products from coal liquefaction (1,2). The effects of coal concentration on the distillate quality was previously examined, and the changes were not significant (1).

EFFECT OF COPROCESSING MEDIUM ON PROCESS PERFORMANCE

Four different residues were tested with Forestburg subbituminous coal. Two were vacuum bottoms from conventional Venezuelan crudes and the other two were vacuum bottoms from heavy oil and bitumen in Western Canada.

Table 2 shows that the residues originating from conventional crudes contained less sulphur, less oxygen and more vanadium than the residues originating from heavy oil and bitumen. In each category there is one residue with much higher pitch content than the other. The process performance for the four residues is compared in this section.

Yield Structure

The yield structure for the residues tested at moderate-high severity is given in Table 9 and for low severity in Table 10. Examination of Table 9 shows that at moderate-high severity the residues from heavy oil and bitumen lend themselves to upgrading more easily than the conventional crude bottoms. A significant difference in the distillate yield can be observed by comparing Athabasca and Cold Lake bottoms with Blend 24 and Ultramar residues. However, examination of the whole distillate product in the four cases shows that it contains the same relative values of each distillate fraction. The residue yields are higher for Blend 24 and Ultramar bottoms than for Athabasca and Cold Lake bottoms. The yields of the residue components, however, show variations among the four residues. The residual oil yield is particularly high for Cold Lake bottoms and the preasphaltenes yield shows noticeable difference for the four residues. Since all the media were tested using the same coal, it appears that the coprocessing medium has a significant effect on the preasphaltene conversion. The hydrocarbon gas production was similar for each medium tested. Hydrogen sulphide generation is higher for the heavy oil and bitumen residues because of their high sulphur content. The variations at low severity (Table 10) are similar but not as noticeable as in the moderate-high severity case.

Coal Conversion

The coal conversion to THF solubles at both levels of processing severity is given in Table 11 and presented in Fig. 3. There is no major variation in the coal conversion for the different residues. As pointed out above, it appears that the secondary upgrading of the primary coal products is dependent on the coprocessing medium. However, overall coal conversion to soluble products does not seem to be affected.

Pitch Conversion

Pitch conversion values are given in Table 12 and are also presented in Fig. 3. It is clear that the residues originating from bitumen and heavy oil are upgraded to a larger extent than those originating from conventional crudes. Figure 4 illustrates this difference.

Distillate Characteristics

The gross properties of the distillate product obtained from the four residues at moderate-high severity are shown in Table 13. Although it was pointed out that the distillate yields from Athabasca and Cold Lake residues were higher than those from conventional crudes, the quality of the distillates is somewhat lower. Table 13 shows that the distillates obtained from conventional crude residues have higher API gravities, higher H/C atomic ratios, lower sulphur contents and lower aromaticities. The degrees of desulphurization and deoxygenation are shown in Table 14. The extent of deoxygenation is similar for the four media whereas a variation exists in the extent of desulphurization. Desulphurization occurred to a larger extent for Athabasca and Cold Lake bottoms. This indicates that the sulphur forms are different for the residues of different origin. A comparison of Tables 14 and 8 show that the deoxygenation is coal dependent and that desulphurization is medium dependent.

CONCLUSIONS

CANMET coprocessing is a single-stage, once-through process that utilizes an inexpensive disposable catalyst. The continuous-flow bench-scale results show that the process is feasible for a variety of coal and residue feedstocks. The type of coal does not have a major effect on the product yield or quality which makes the downstream treatment possible for all the coal feedstocks tested. The process was also shown to be feasible for a number of residue feedstocks of different origins. The residues originating from bitumen/heavy oil resulted in higher pitch conversions and higher distillate yields compared with residues originating from conventional crudes. Depending on the site and the availability of the feedstock, the process can be viewed as a stand-alone operation or as an integral process where the products can be blended with appropriate streams in a conventional refinery.

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Table 1 - Characteristics of coal feedstocks

Coal Rank	Bienfait lignite	Coronach lignite	Hat Creek A subbituminous	Hat Creek B subbituminous	Forestburg subbituminous	Highvale subbituminous	Lingan HV bituminous	Illinois #6 HV bituminous
Moisture	15.30	6.39	18.52	16.50	19.11	16.95	2.86	2.39
Ash	6.87	13.41	42.52	32.41	7.67	11.08	6.83	10.52
Analysis on dry ash-free basis (wt %)								
Carbon	71.04	68.29	61.65	69.45	71.65	73.14	81.10	79.04
Hydrogen	4.82	4.70	4.44	5.12	4.38	3.83	5.15	5.48
Sulphur	0.72	0.98	1.44	0.86	0.56	0.18	1.87	3.57
Nitrogen	1.25	0.92	1.65	1.66	1.82	0.97	1.74	1.87
Oxygen (by difference)	22.17	25.11	29.50	22.91	21.59	21.86	10.14	10.04
Volatile matter	47.52	49.37	57.88	49.99	48.58	41.46	37.37	44.74
Petrographic analysis on "as-received" basis								
Vitrinites	85.2	78.6	74.2	74.2	88.4	75.0	81.0	80.0
Liptinites	5.6	1.4	2.8	2.2	4.0	4.6	6.0	5.0
Inertinites	6.6	19.6	5.4	4.6	5.4	18.6	10.0	8.8
Mean reflectance	0.35	0.23	0.42	0.35	0.41	0.44	0.85	0.55
Heating value								
HJ/kg	21.45	20.89	11.79	13.24	19.88	20.27	32.08	28.76
Btu/lb	9221	8998	5071	5692	8548	8716	13792	12366
H/C atomic ratio	0.81	0.83	0.86	0.89	0.73	0.63	0.76	0.83

Table 2 - Characteristics of residue feedstocks

Residue	Athabasca pitch	Cold Lake pitch	Blend 24 pitch	Ultramar pitch
Specific gravity 15/15	1.064	1.038	1.020	1.024
Pentane insolubles wt %	34.6	23.8	23.0	20.2
Pitch content wt %	99.5	83.0	99.8	87.7
Conradson carbon wt %	27.0	17.1	18.6	18.4
Carbon, wt %	82.08	83.07	84.07	84.83
Hydrogen, wt %	9.65	9.85	10.12	10.11
Nitrogen, wt %	1.05	0.55	0.52	0.63
Sulphur, wt %	5.92	5.50	3.18	3.39
Oxygen, wt %	0.89	1.8	0.69	0.61
H/C atomic ratio	1.41	1.42	1.44	1.43
Metals, ppm				
V	310	235	665	650
Ni	115	93	80	80
Fe	675	18	220	320
Aromaticity, fa	37	33	31	31

Table 3 - Yield* structure for coals processed at moderate-high severity

Coal Rank	Bienfait lignite	Coronach lignite	Hat Creek A subbituminous	Hat Creek B subbituminous	Forestburg subbituminous	Highvale subbituminous	Lingan HV bituminous	Illinois #6 HV bituminous
Gas								
C ₁ -C ₄	4.7	2.9	5.0	4.2	5.2	5.4	4.4	5.9
CO _x	2.0	1.3	1.5	1.6	1.9	1.9	0.2	1.0
H ₂ S	0.9	0.5	1.6	1.1	1.1	0.9	1.2	0.9
Distillate								
Naphtha	15.3	22.5	19.9	17.4	14.9	11.6	23.0	13.0
LGO	21.6	12.3	13.7	22.1	22.7	22.5	13.4	19.9
HGO I	11.7	17.8	18.3	12.2	14.1	13.3	17.7	15.3
HGO II	13.2	13.7	13.7	10.5	12.4	11.2	15.4	11.5
Total	61.8	66.3	65.6	62.2	64.1	58.6	69.5	59.7
Water	5.3	5.6	2.2	3.9	4.2	4.0	1.7	2.7
Residue								
Oils	15.6	14.6	13.4	13.2	12.4	11.6	13.4	2.5
Asphaltenes	7.4	6.4	10.8	11.8	7.8	10.6	10.5	16.2
Preasphaltenes	0.2	0.5	1.7	2.0	2.5	2.0	3.1	10.3
THF insolubles	6.3	5.5	4.1	4.5	4.8	8.3	0.2	4.8
Total	29.5	27.0	30.0	31.5	27.5	32.5	27.2	33.8
Total yield	104.2	103.6	105.9	104.5	104.0	103.3	104.2	104.0
Hydrogen consumption	4.2	3.6	5.9	4.5	4.0	3.3	4.2	4.0

*Based on wt % maf slurry feed.

Table 4 - Yield* structure for coals processed at low severity

Coal Rank	Bienfait lignite	Coronach lignite	Hat Creek A subbituminous	Hat Creek B subbituminous	Forestburg subbituminous	Highvale subbituminous	Lingan HV bituminous	Illinois #6 HV bituminous
Gas								
C ₁ -C ₄	1.50	1.81	1.84	1.57	2.20	2.17	2.10	2.54
CO _x	1.60	1.93	1.44	1.24	2.10	1.95	0.20	0.95
H ₂ S	0.20	0.40	0.90	0.30	0.50	0.60	0.90	1.50
Distillate								
Naphtha	5.3	5.1	5.8	6.4	5.7	5.3	6.9	4.7
LGO	12.9	10.0	9.9	8.1	11.0	9.3	8.4	10.5
HGO I	8.3	8.0	10.5	11.0	11.9	8.2	11.4	10.0
HGO II	13.7	12.3	13.6	14.6	7.7	12.5	17.3	12.9
Total	40.2	35.4	39.8	40.1	36.3	35.3	44.0	38.1
Water	5.0	4.9	3.3	3.3	2.9	3.7	1.4	1.7
Residue								
Oils	28.0	34.3	32.7	31.8	28.7	34.4	27.2	19.1
Asphaltenes	13.7	14.6	17.2	16.6	14.3	13.5	18.2	19.5
Preasphaltenes	2.7	-	1.9	1.2	6.2	1.1	6.9	14.7
THF insolubles	8.8	9.3	5.1	6.7	8.8	10.2	1.6	4.3
Total	53.2	58.2	56.9	56.3	58.0	59.2	53.9	57.6
Total yield	101.7	102.6	104.2	102.8	102.0	102.9	102.5	102.4
Hydrogen consumption	1.7	2.6	4.2	2.8	2.0	2.9	2.5	2.4

*Based on wt % maf slurry feed.

Table 5 - Coal conversion of coals processed at moderate-high and low severity

Coal	Rank	Coal conversion, wt %	
		Moderate-high severity	Low severity
Bienfait	Lignite	81.5	72.0
Coronach	Lignite	82.4	69.9
Hat Creek A	Subbituminous	78.6	73.0
Hat Creek B	Subbituminous	80.0	69.5
Forestburg	Subbituminous	83.9	70.4
Highvale	Subbituminous	69.8	63.2
Lingan	HV bituminous	98.5	83.7
Illinois #6	HV bituminous	84.0	85.6

Table 6 - Pitch conversion for coals processed at moderate-high and low severity

Coal	Rank	Pitch conversion, wt %	
		Moderate-high severity	Low severity
Bienfait	Lignite	67.1	38.4
Coronach	Lignite	68.8	31.9
Hat Creek A	Subbituminous	65.2	34.1
Hat Creek B	Subbituminous	63.8	34.4
Forestburg	Subbituminous	68.4	34.1
Highvale	Subbituminous	63.0	32.5
Lingan	HV Bituminous	67.9	36.4
Illinois #6	HV Bituminous	61.7	34.6

Table 7 - Distillate characteristics for coals processed at moderate-high severity

Coal	Rank	Gravity	H/C	N	S	O	Aromaticity	Paraffins	Olefins	Naphthenes	Aromatics
		°API	atomic	wt %	wt %	wt %	fa	wt %	wt %	wt %	wt %
Bienfait	Lignite	28.4	1.65	0.38	1.46	1.93	26	40.4	7.6	30.6	21.4
Coronach	Lignite	25.4	1.63	0.41	1.55	1.17	27	37.7	5.0	37.8	19.5
Hat Creek A	Subbituminous	27.8	1.63	0.40	1.85	0.42	25	37.7	6.6	38.5	17.0
Hat Creek B	Subbituminous	29.8	1.66	0.38	1.87	0.60	25	48.9	8.5	32.9	9.5
Forestburg	Subbituminous	25.4	1.58	0.50	1.64	1.46	30	38.1	12.4	32.2	17.3
Highvale	Subbituminous	27.8	1.60	0.39	1.30	0.65	28	29.6	2.4	39.5	28.5
Lingan	HV bituminous	29.7	1.70	0.31	1.98	0.50	25	40.9	7.1	37.0	15.0
Illinois #6	HV bituminous	25.0	1.58	0.50	1.92	0.91	26	38.6	13.5	30.3	17.6

Table 8 - Desulphurization and deoxygenation values for coals processed at moderate-high severity

Coal	Rank	Desulphurization	Deoxygenation
		wt %	wt %
Bienfait	Lignite	53.4	76.5
Coronach	Lignite	46.7	70.4
Hat Creek A	Subbituminous	53.3	68.8
Hat Creek B	Subbituminous	45.8	63.3
Forestburg	Subbituminous	52.3	76.7
Highvale	Subbituminous	48.4	90.1
Lingan	HV bituminous	53.5	78.9
Illinois #6	HV bituminous	48.1	70.9

Table 9 - Yield* structure for residues processed at moderate-high severity

Residue	Athabasca bottoms Origin	Cold Lake bottoms Heavy oil	Blend 24 bottoms Conventional	Ultramar bottoms Conventional
Gas				
C ₁ -C ₄	5.8	5.2	5.1	5.6
CO _x	2.1	1.9	2.5	2.4
H ₂ S	1.5	1.1	0.5	0.2
Distillate				
Naphtha	14.5	14.9	12.9	12.3
LGO	20.3	22.7	17.3	19.0
HGO (I)	12.7	14.1	11.9	12.8
HGO (II)	11.7	12.4	12.2	10.7
Total	59.2	64.1	54.3	54.8
Water	4.1	4.2	3.5	3.6
Residue				
Oils	7.0	13.3	10.2	8.6
Asphaltenes	11.9	8.4	13.4	12.0
Preasphaltenes	6.8	2.7	8.9	9.5
THF insolubles	6.2	5.1	5.4	5.8
Total	30.9	27.5	37.9	35.9
Total yield	103.6	103.9	103.8	102.5
Hydrogen consumption	3.6	3.9	3.8	2.5

*Based on wt % maf slurry feed.

Table 10 - Yield* structure for residues processed at low severity

Residue	Athabasca bottoms Origin	Cold Lake bottoms Heavy oil	Blend 24 bottoms Conventional	Ultramar bottoms Conventional
Gas				
C ₁ C ₄	2.5	2.2	1.8	2.2
CO _x	2.0	2.1	1.9	2.0
H ₂ S	0.9	0.5	0.1	trace
Distillate				
Naphtha	5.1	5.7	5.4	4.8
LGO	9.8	11.0	8.8	8.3
HGO (I)	11.2	11.9	5.4	9.5
HGO (II)	9.4	7.7	9.8	11.1
Total	34.5	36.3	29.4	33.7
Water	3.0	2.9	5.5	3.5
Residue				
Oils	29.3	28.7	35.3	30.2
Asphaltenes	17.3	14.3	14.3	14.6
Preasphaltenes	5.3	6.2	5.9	6.3
THF insolubles	7.8	8.8	8.5	8.9
Total	59.4	58.0	64.0	60.0
Total yield	102.3	102.0	102.7	101.4
Hydrogen consumption	2.3	2.0	2.7	1.4

*Based on wt % maf slurry feed.

Table 11 - Coal conversion for residues processed
at moderate-high and low severity

Residue	Coal conversion, wt %	
	Moderate-high severity	Low severity
Athabasca bottoms	79.8	74.6
Cold Lake bottoms	83.9	70.4
Blend 24 bottoms	82.6	72.5
Ultramar bottoms	81.9	71.5

Table 12 - Pitch conversion for residues processed
at moderate-high and low severity

Residue	Pitch conversion, wt %	
	Moderate-high severity	Low severity
Athabasca bottoms	69.0	40.6
Cold Lake bottoms	68.4	34.1
Blend 24 bottoms	62.2	36.0
Ultramar bottoms	58.3	29.0

Table 13 - Distillate characteristics for residues processed at moderate-high severity

Residue	Gravity °API	H/C atomic	N wt %	S wt %	O wt %	Aromaticity fa	Paraffins wt %	Olefins wt %	Naphthenes wt %	Aromatics wt %
Athabasca bottoms	25.5	1.61	0.48	1.70	1.27	28	39.5	12.7	31.4	16.3
Cold Lake bottoms	25.3	1.58	0.50	1.61	1.46	30	38.1	12.4	32.2	17.3
Blend 24 bottoms	27.7	1.65	0.50	1.16	1.21	25	38.9	6.5	39.0	15.5
Ultramar bottoms	26.8	1.64	0.44	1.30	1.34	25	37.6	5.3	41.3	15.8

Table 14 - Desulphurization and deoxygenation values for residues processed at moderate-high severity

Residue	Desulphurization	Deoxygenation
	wt %	wt %
Athabasca bottoms	45.0	70.9
Cold Lake bottoms	52.3	76.7
Blend 24 bottoms	28.6	75.3
Ultramar bottoms	30.4	67.8

Fig. 1 CONMET CONTINUOUS-FLOW COPROCESSING UNIT

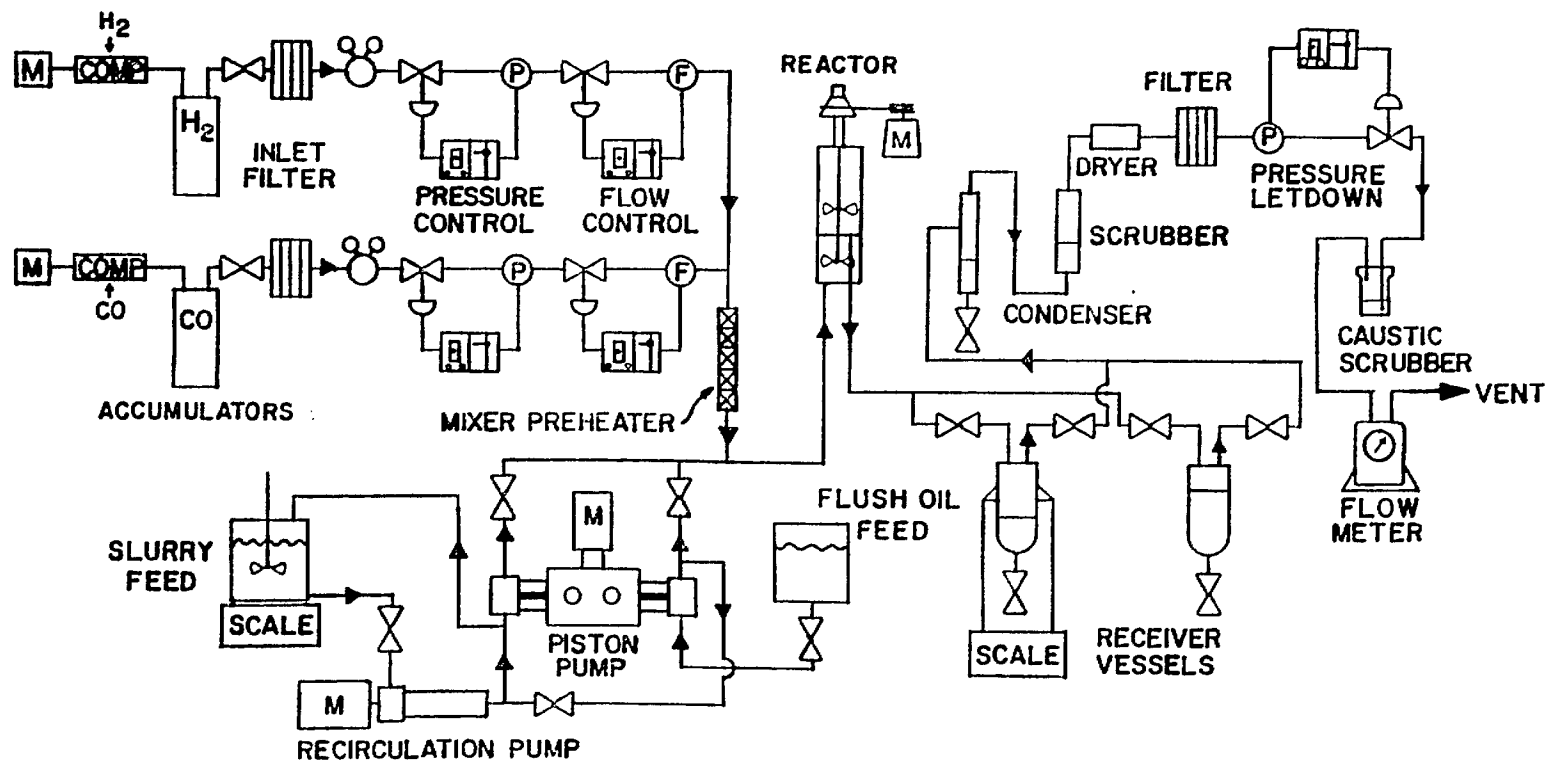


Fig. 2 CONVERSIONS FOR COALS PROCESSED AT MODERATE-HIGH SEVERITY

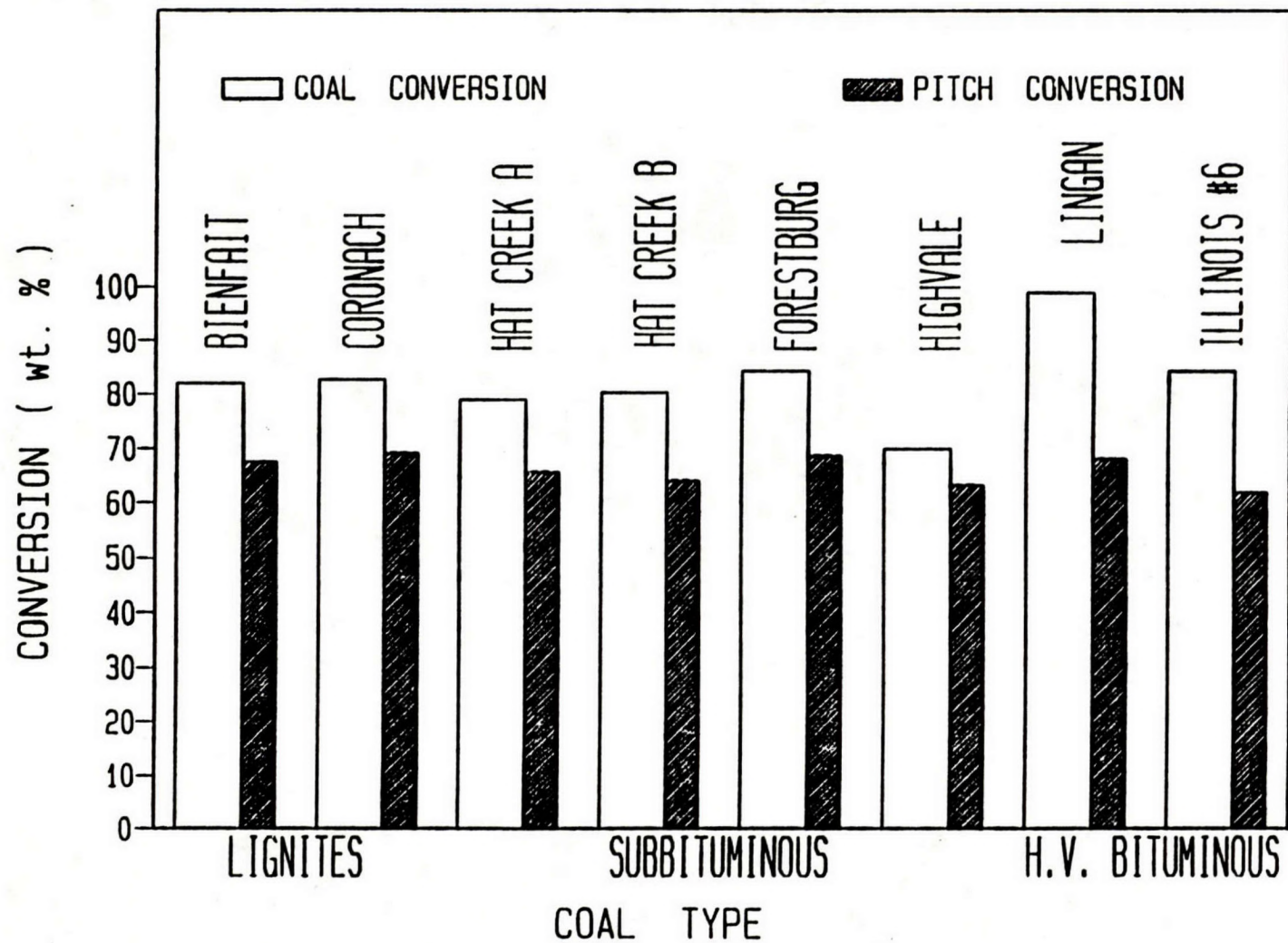


Fig. 3 CONVERSIONS FOR RESIDUES PROCESSED AT MODERATE-HIGH SEVERITY

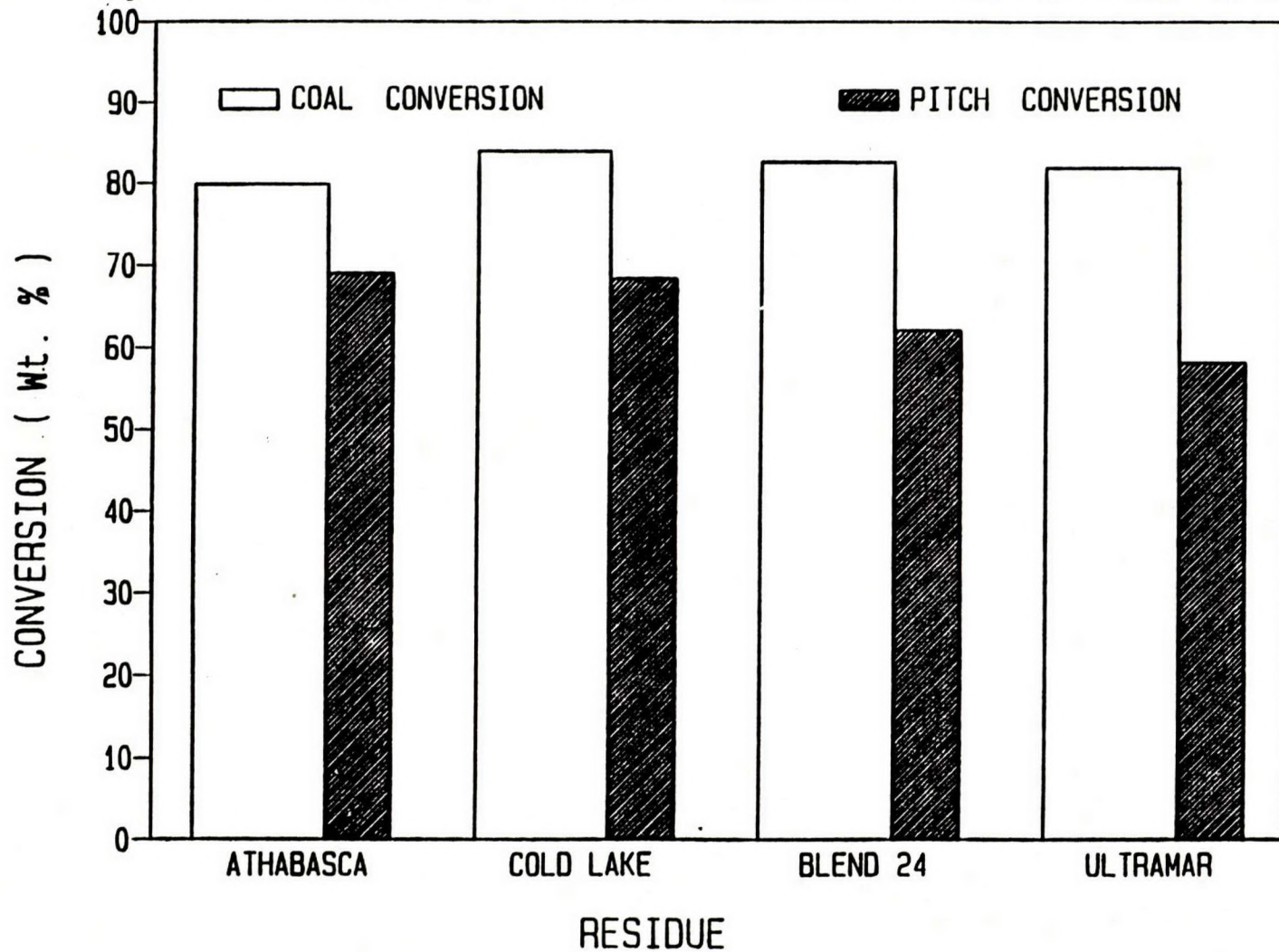


Fig. 4 EFFECT OF RESIDUE/TEMPERATURE ON PITCH CONVERSION

