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COMPARISON OF THERMAL HYDROCRACKING WITH THERMAL CRACKING OF ATHABASCA BITUMEN AT LOW CONVERSIONS

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ENERGY RESEARCH PROGRAM

ENERGY RESEARCH LABORATORIES

COMPARISON OF THERMAL HYDROCRACKING WITH THERMAL
CRACKING OF ATHABASCA BITUMEN AT LOW CONVERSIONS

by

R.B. Logie*, R. Ranganathan*, B.B. Pruden** and J.M. Denis***

ABSTRACT

The thermal hydrocracking process involves hydrogen addition
as opposed to carbon removal in the thermal cracking process. Upgrad-
ing of Athabasca bitumen by thermal hydrocracking has been studied in
the Energy Research Laboratory of CANMET for several years. This pro-
cess allows flexibility in controlling pitch conversions, and at high
conversions it produces more distillable oil than do coking processes.
Low-conversion thermal hydrocracking is also important from the view-
point of transporting the product through pipelines. The present in-
vestigation deals with low-conversion thermal aspects of hydrocrack-
ing. A comparison is made with data from thermal cracking or vis-
breaking.

Tests were conducted with Athabasca bitumen feed in a 1-barrel
/day high pressure pilot plant. Properties of products such as vis-
cosity, gravity, sulphur, nitrogen, saturates, olefins, aromatics,
benzene insolubles and asphaltenes were analyzed. Data on hydrogen
consumption and hydrocarbon gas-make were also obtained.

The thermal hydrocracking process was found to produce less
naphtha and hydrocarbon gases than thermal cracking for the low-con-
version conditions. The hydrocracked distillates contained less ole-
fin than those from thermal cracking. The viscosity results indicated
that pitch conversion of about 50% was sufficient to meet pipeline
viscosity specifications. This showed that the hydrocracking process
is more flexible than coking because the bitumen can be transported
with minimum upgrading.

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UNE COMPARAISON DE L'HYDROCRAQUAGE THERMIQUE ET LE CRAQUAGE
THERMIQUE DU BITUME D'ATHABASCA A BASSES CONVERSIONS

par

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RESUME

Le procédé d'hydrocraquage thermique implique l'addition d'hydrogène contrairement au procédé de craquage thermique qui lui implique l'enlèvement du carbone. Durant plusieurs années, l'enrichissement du bitume d'Athabasca par le procédé d'hydrocraquage thermique a été étudié aux Laboratoires de recherche énergétique du CANMET. Ce procédé permet plus de flexibilité pour régulariser les conversions du brai. En hautes conversions, il produit beaucoup plus d'huile capable d'être distillée que les procédés de cokéfaction. L'hydrocraquage thermique à basse conversion est aussi important du point de vue transport du produit à travers les pipe-lines. La présente étude traite des aspects thermiques du procédé d'hydrocraquage à basse conversion. On compare avec les données du craquage thermique.

Les essais sont effectués sur une alimentation de bitume d'Athabasca dans une usine pilote à haute pression ayant une capacité de 1 baril par jour. Les propriétés des produits telles que la viscosité, la gravité, le soufre, l'azote, les saturés, les oléfines, les aromatiques, les benezènes insolubles et les asphaltènes ont été analysés. Les données sur la consommation d'hydrogène et les propriétés des gaz d'hydrocarbone ont aussi été prélevées.

On a découvert que le procédé d'hydrocraquage thermique produit moins produit moins de naphte et de gaz d'hydrocarbone que le craquage thermique dans des conditions de basse conversion. Les distillats ayant subi l'hydrocraquage contenaient moins d'oléfine que ceux obtenus par le craquage thermique. Les résultats de l'essai sur la viscosité indiquent qu'une conversion du brai d'environ 50% est suffisante pour rencontrer les normes de viscosité requises pour les pipe-lines. On a donc démontré que le procédé d'hydrocraquage est plus flexible que la cokéfaction car le bitume peut être transporté avec un minimum de d'enrichissement.

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INTRODUCTION

Thermal hydrocracking is a high pressure hydrogenation process performed in the presence of hydrogen and absence of a catalyst. Thermal cracking, on the other hand, involves heating the feedstock at high temperatures in the absence of hydrogen. At the Energy Research Laboratories, thermal hydrocracking has been investigated extensively for the upgrading of Athabasca bitumen (1). Pitch conversions (pitch being the +524°C material) sf up to 95% have also been reported. The present investigation is an examination of the below 60% conversion thermal aspects of the hydrocracking process on a pilot plant scale. Athabasca bitumen was selected as the feed in this study, and all conditions were chosen to be compatible with earlier work in which a wide range of operating conditions was studied. These low-conversion thermal hydrocracking data were compared with the thermal cracking results reported in the literature (2,3). Other objectives of the investigation were:

- to extend the range of the earlier report to as low a conversion as possible with accurate measurement of liquid yield, product distribution, hydrocarbon gas yield, and hydrogen consumption;
- to establish a conversion level at which this product may be transported by pipeline;
- to prepare samples for detailed hydrocarbon-type, sulphur-type and nitrogen-type compound analysis;
- to determine pitch conversion at low temperatures so that an estimate could be made for conversion in preheaters and other units in a commercial plant.

EXPERIMENTAL

Feed

The feed was bitumen separated from the oil sands of the Athabasca deposit in northern Alberta. It was supplied by Great Canadian Oil Sands Limited of Fort McMurray and had the properties shown in Table 1.

Table 1 - Properties of the bitumen feed

Property	Value
Specific gravity, 15/15°C	1.009
Sulphur, wt %	4.48
Ash, wt %	0.59
Conradson carbon residue, wt %	13.3
Pentane insolubles, wt %	15.5
Benzene insolubles, wt %	0.72
Vanadium, wt ppm	213
Nickel, wt ppm	67
Acid No., mg KOH/g	2.77
Base No., mg KOH/g	1.89
Carbon, wt %	83.36
Hydrogen, wt %	10.52
Nitrogen, wt %	0.43
Viscosity at 100°C, cSt	113.3
Pitch (+524°C), wt %	51.3
Pitch specific gravity, 15/15°C	1.076

Feed distillate (-524°C)

Fraction		Volume %	Specific gravity 15/15°C	Sulphur wt %	Nitrogen wt %
	Total	100	0.947	2.85	0.13
(1)	IBP-200°C	5.3	0.813	1.63	<0.01
(2)	200-250°C	4.6	0.860	1.13	0.01
(3)	250-333°C	18.6	0.906	1.73	0.02
(4)	333-418°C	38.7	0.955	2.92	0.11
(5)	418-524°C	32.8	0.990	3.77	0.27

Apparatus and Analytical Procedures

A simplified schematic drawing of the thermal hydrocracking pilot plant is shown in Fig. 1. The experimental procedures are described in detail in previous reports (1,4,5,6,7,8). Hydrocracking involves the addition of hydrogen with the feed in a tubular reactor at high pressure and temperature. The liquid product is separated after passing through the reactor into light oil and heavy oil streams. Gases from the separator are scrubbed and recycled with fresh make-up hydrogen. All off-gases and recycle gas are analyzed for composition to estimate the hydrogen consumption and hydrocarbon gas-make.

The extent of converting pitch to distillable hydrocarbon at -524°C product was determined using a Podbielniak equilibrium flash still, Model 500 (9). Determination of pitch was made on the
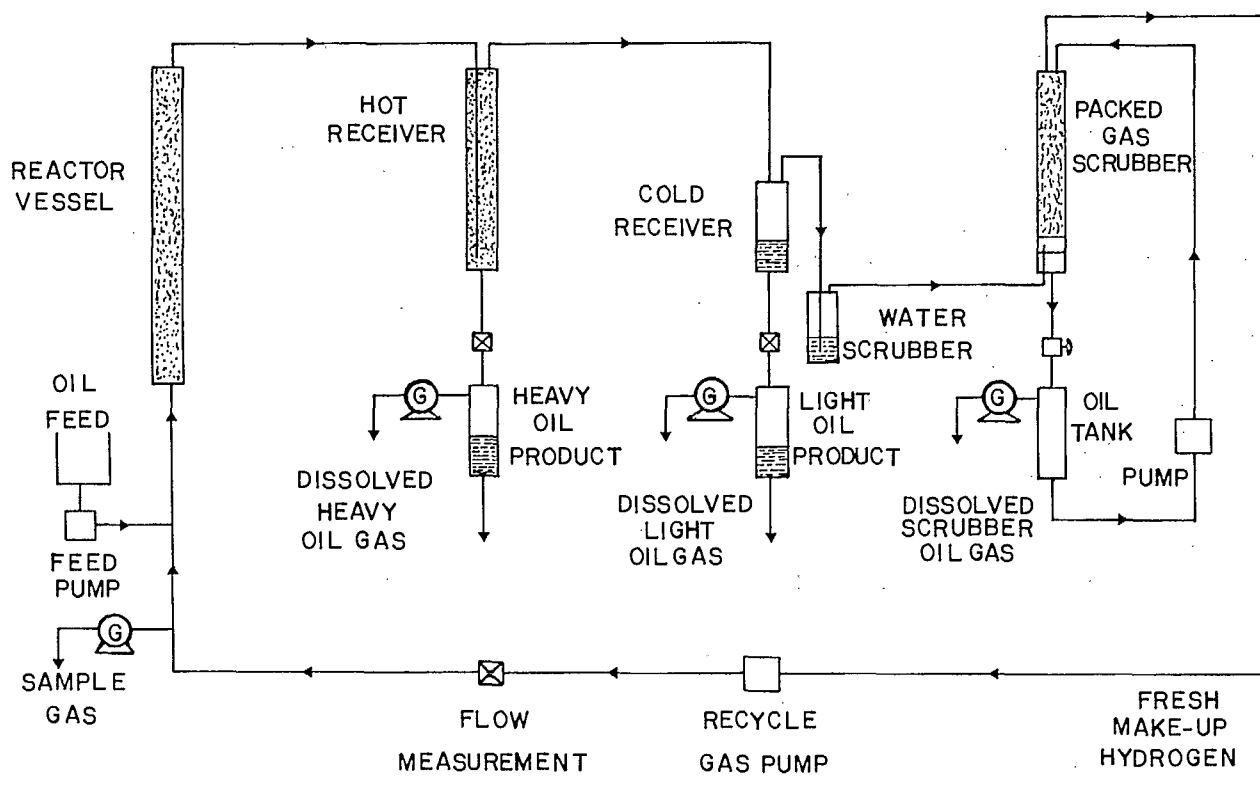
Fig. 1 - Pilot plant schematic diagram

heavy oil product from the hot separator in the flash still. The pitch from the still was retained for further analysis and the distillate was combined in the correct proportion with the light oil product from the cold separator to give a sample of distillable oil. Distribution of this distillable oil was determined using a modified U.S. Bureau of Mines Hempel distillation procedure (9).

Sulphur content of the product was determined by X-ray fluorescence using a Model 4000 Panalyser. The aromatic, olefin and saturate contents were measured using the ASTM FIA method (10).

RESULTS AND DISCUSSION

Data for some preliminary runs at low space velocity are given in Table 2. These runs were made as part of another study to obtain the pitch conversion at low temperatures. They show

that pitch conversion in preheaters, for example, would be low, as liquid hourly space velocity (LHSV) based on preheater volume would be considerably higher than unity.

Operating and yield data for low conversion runs are given in Tables 3 to 7. One representative run was chosen from each of series 92, 93 and 94. Data for all runs are given in Appendix A, Table A-2. All runs were made at an LHSV of 2, 13.89 MPa (2000 psig); and the same gas recycle expressed as m^3 API/t.

Distillate analysis for the three runs is given by fractions in Table 4; comparison with other runs in each series confirms that the runs selected are representative. These data can be recalculated to give analyses for any product required such as naphtha, and yields such as those in Table 9. As discussed earlier, the distillable oil (IBP-524°C) is a composite of the light oil product and the distillate from the heavy oil product shown in Fig. 1.

Table 2 - Operating and yield data for
low conversion runs (LHSV = 1)*

| Conditions and results | Run numbers | |
	86-1-1	83-1-1
Reactor pressure, MPa	13.89	13.89
Reactor temperature, °C	380	400
Gas recycle, m³API/t	1220	1220
Liquid yield, wt % feed	97.4	100.6**
vol % feed	98.9	104.1**
Specific gravity, 15/15°C	0.983	0.978
Pitch conversion, wt %	14.9	27.6
S conversion, wt %		19.6

Product distillate (-524°C), run 83-1-1

Fraction		Volume %	Specific gravity 15/15°C	Sulphur wt %	Nitrogen wt %
	Total		0.929	3.13	0.18
(1)	IBP-200°C	10.1	0.782	1.7	0.01
(2)	200-250°C	7.1	0.B52	1.8	0.02
(3)	250-333°C	21.4	0.906	2.5	0.04
(4)	333-418°C	34.4	0.956	3.3	0.16
(5)	418-524°C	27.0	0.990	3.9	0.33

* Reactor volume 4.5 L

** The high liquid yield data is probably due to experimental
error resulting from very short duration of this run — only
two hours as opposed to four hours and longer for other runs.

Table 3 - Operating and yield data for
low conversion runs (LHSV = 2)*

| Conditions and results | Run numbers | | |
	92-2-1	93-2-1	94-2-1
Conditions			
Reactor pressure, MPa	13.89	13.89	13.89
Reactor temperature, °C	410	420	430
Gas recycle**, m³API/t	610	610	610
Hot separator temperature, °C	390	400	410
Total product			
Liquid yield, wt %	96.7	99.2	96.6
vol %	99.2	101.6	100.8
Specific gravity, 15/15°C	0.984	0.976	0.968
Gravity, °API	12.3	13.5	14.7
Viscosity @ 25°C, cst	964	342	135
Sulphur, wt %	3.76	3.56	3.49
Sulphur conversion, wt %	18.8	20.7	24.7
Pitch conversion, wt %	25.6	34.4	46.5
Distillate yield, wt %	58.6	65.6	69.2
vol %	63.6	71.8	76.2
HC gas yield, wt %	0.7	1.7	2.7
Hydrogen consumption***, g mol/kg	1.11	1.85	2.28

All yields based on feed.

* Reactor volume 4.5 L

** 85% hydrogen

*** gram moles per kilogram of feed

Table 4 - Analyses of distillable oil

Fraction		Volume %	Specific gravity 15/15°C	Sulphur wt %	Nitrogen wt %
Run 92-2-1					
	Total	-	0.931	3.18	0.13
(1)	IBP-200°C	10.5	0.783	2.03	0.010
(2)	200-250°C	7.2	0.854	1.92	0.014
(3)	250-333°C	20.9	0.903	2.36	0.030
(4)	333-41B°C	32.2	0.949	3.22	0.11
(5)	418-524°C	29.2	0.991	4.14	0.28
Run 93-2-1					
	Total	-	0.922	3.02	0.15
(1)	IBP-200°C	12.5	0.778	1.79	0.016
(2)	200-250°C	8.9	0.850	2.04	0.020
(3)	250-333°C	18.2	0.897	2.28	0.047
(4)	333-418°C	31.0	0.945	3.03	0.13
(5)	41B-524°C	29.4	0.995	3.92	0.34
Run 94-2-1					
	Total	-	0.917	3.13	0.16
(1)	IBP-200°C	15.1	0.776	1.88	0.012
(2)	200-250°C	10.1	0.85B	2.05	0.022
(3)	250-333°C	25.1	0.909	2.61	0.060
(4)	333-418°C	27.0	0.959	3.33	0.17
(5)	418-524°C	22.7	1.004	4.37	0.38

The severity of hydrocracking, indicated by the pitch conversion, was increased for the three runs by varying the reaction temperature between 410 and 430°C. As the severity of hydrocracking is increased, specific gravity of the distillate oil decreases, consistent with increased concentration of lighter products — fractions 1 and 2 — and decreased concentration of heavier products — fractions 4 and 5. Nitrogen "migration" into the distillate with increased hydrocracking severity is clearly shown in Table 4, both in total nitrogen content and in the various fractions.

The FIA analysis for aromatic, olefin and saturate contents is given in Table 5 for fractions 1 and 2. Some trends but no dramatic changes are observed; the most consistent trend for both groups being that the olefins tend to increase with increased severity of hydrocracking.

In Table 6, the hydrocarbon gas weight yields are given for the low conversion runs. The hydrocarbon gas analysis on a hydrogen sulphide-free basis is also given. This represents the analysis that would result if all exit gas streams were mixed in the correct proportion and the hydrogen and hydrogen sulphide removed.

Pitch analysis is given in Table 7 for feed and product. The ash concentration follows the pitch yield as confirmed in line 9, giving an ash balance based on feed where:

$$RP = \frac{\text{pitch yield} \times \% \text{ ash}}{51.3 \times 1.21}$$

This value should be unity, as all ash material from the feed should be present in the pitch portion of the product. The Conradson carbon residue (CCR) of line 10 is nearly constant. Asphaltenes, defined as pentane insolubles, PI, less benzene insolubles, BI, increase with the increase in pitch conversion. The ratio of asphaltenes to ash obtained by subtracting values in line 13 from those in line 12 is constant after an initial drop from the feed, indicating that asphaltenes are refractory in this range of pitch conversion. Line 16 indicates that an increasing amount of coke, defined as benzene insolubles less

Table 5 - FIA analysis of feed and products

Fraction	Aromatics vol %	Olefins vol %	Saturates vol %
Feed			
IBP-200	21.5	24.4	54.1
200-250	21.1	10.1	68.8
Run 92-2-1			
IBP-200	20.1	28.9	51.0
200-250	22.8	19.2	5B.0
Run 93-2-1			
IBP-200	22.1	28.9	49
200-250	25.1	20.6	54.3
Run 94-2-1			
IBP-200	15.3	32.4	52.3
200-250	24.3	21.5	54.2

Table 6 - Hydrocarbon gas yields and analysis

Analysis	Run numbers		
	92-2-1	93-2-1	94-2-1
Weight yield wt %	0.7	1.7	2.7
Composition (vol %)			
Methane	38.2	31.4	33.0
Ethane	26.3	29.0	29.2
Propane	16.5	22.1	21.5
n-Butane	0.5	1.4	1.5
i-Butane	6.1	5.4	4.8
Pentane	7.3	5.0	4.6
Ethene	2.0	2.0	1.8
Propene plus mixed butenes	3.1	3.7	3.6

ash material, is formed with increasing hydrocracking severity even at these low conversions. It is apparent from lines 14 and 15 that sulphur and nitrogen compounds contained in the pitch are being reacted at a slightly higher rate than

Table 7 - Pitch analysis, low conversion runs

Property	Feed pitch	Run number		
		92-2-1	93-2-1	94-2-1
1. Ash, wt %	1.21	1.62	1.85	2.15
2. CCR, wt %	24.7	30.3	35.5	39.6
3. Vanadium, wt %	0.038	0.051	0.051	0.071
4. Pentane insol. (PI), wt %	34	32.4	37.4	45.1
5. Benzene insol. (BI), wt %	1.22	1.73	2.2	3.14
6. Sulphur, wt %	5.66	5.6	5.5	5.4
7. Nitrogen, wt %	0.81	0.94	1.02	1.16
8. Pitch yield, g/100 g feed	51.3	38.2	33.7	27.5
9. RP*	1.00	1.00	1.00	0.95
10. CCR/ash	20.4	18.7	19.2	18.4
11. V/ash	0.031	0.031	0.028	0.033
12. PI/ash	28	20	20	21
13. BI/ash	1.0	1.1	1.2	1.5
14. S/ash	4.7	3.5	3.0	2.5
15. N/ash	0.67	0.58	0.55	0.54
16. (BI-ash)/ash	-	0.1	0.2	0.5
17. Pitch conversion	-	25.6	34.4	46.5

*RP = Ash in product/ash in feed computed using ash and pitch analyses.
Should be 1.0.
PI = Pentane insolubles
BI = Benzene insolubles
V = Vanadium
S = Sulphur
N = Nitrogen
CCR = Conradson carbon residue

compounds that do not contain these chemicals, with sulphur compounds being more easily converted.

Hydrogen consumption versus pitch conversion at 13.89 MPa for this work and for higher conversions is plotted in Fig. 2 (1). The rate of increase in hydrogen consumption is higher above 70% pitch conversion. Khulbe et al. found that above 70% the benzene insoluble organic residue decreased rapidly (11) and this might be responsible for the higher rate of increase in hydrogen consumption. In Fig. 3, it is shown that reaction pressure has significant effect on hydrogen consumption. At higher pressure, the hydrogen consumption is more because of increased rate of hydrogenation reaction. Hydrocarbon gas-make follows a trend similar to that of hydrogen consumption, with gas-make increasing rapidly at higher pitch conversions (Fig. 4).

The variation in product viscosity is shown in Fig. 5. It is interesting to note that viscosity reduced rapidly up to $\approx$50% conversion, while higher pitch conversions did not produce any significant change. The viscosity of pipeline blend crude is $\approx$110 mm^2/s at 25°C (12). Figure 5 shows that 50% pitch conversion is sufficient to meet the viscosity specification. This shows that hydrocracking process is more flexible.
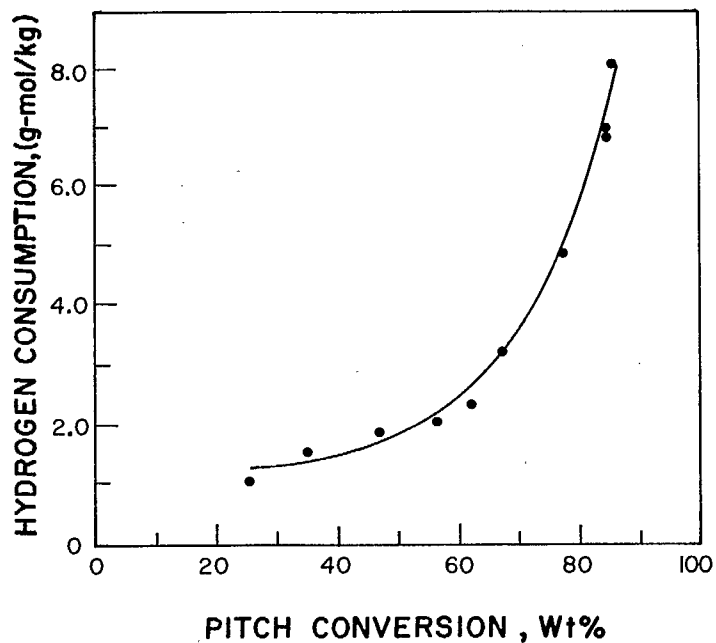
Fig. 2 - Hydrogen consumption as a function of pitch conversion (all experiments at 13.89 MPa pressure)
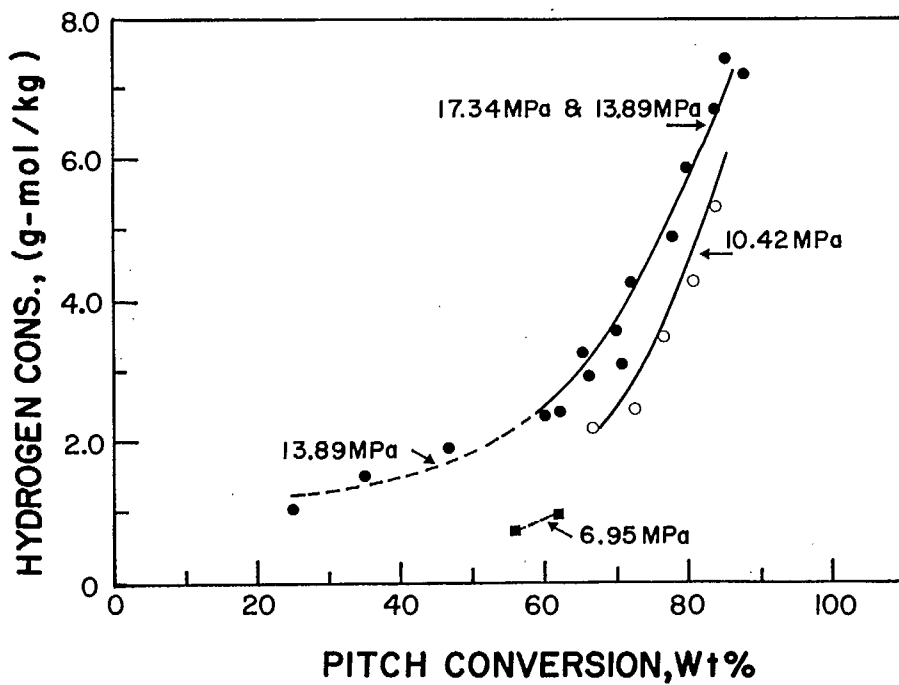

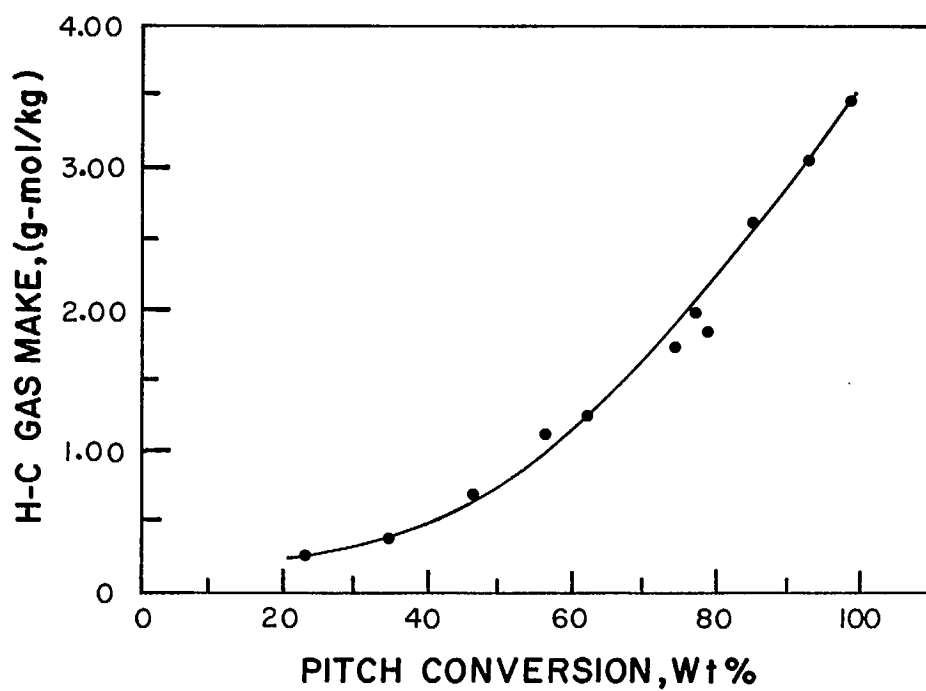Fig. 3 - Hydrogen consumption as a function of pitch conversion (operating pressure as parameter)

Fig. 4 - Hydrocarbon gas-make as a function of pitch conversion
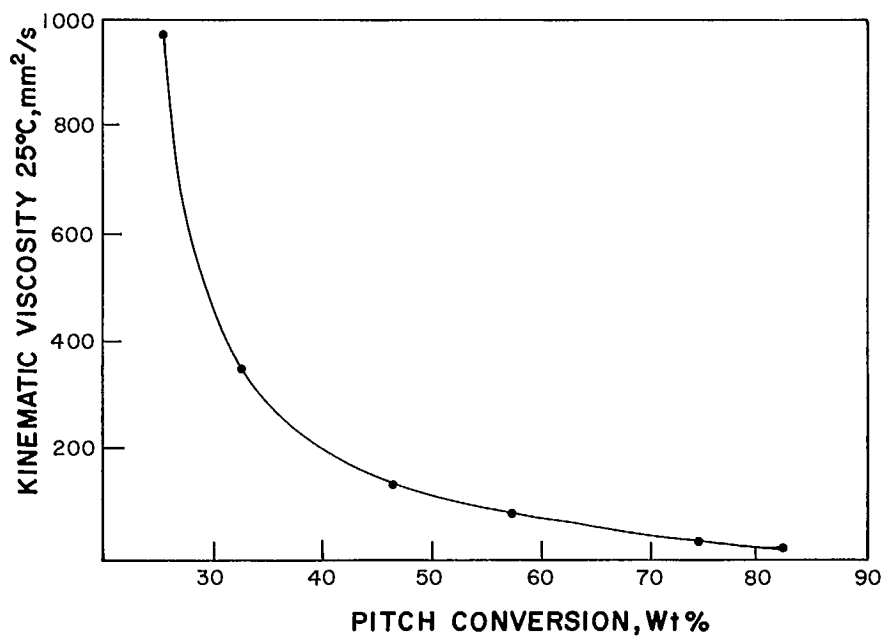

Fig. 5 - Total product viscosity as a function of pitch conversion

The effect of hot separator temperature on pitch conversion, at or below the reactor temperature, is given in Table 8. This shows that if separator temperatures are as high as those in the reactor, the additional conversion must be accounted for. Typically, the hot separator operated with 600 g of liquid holdup, corresponding to a volume of 600/0.75 = 800 cm^3, assuming a gas holdup of 25%. This would change the LHSV by a factor of 4500/(4500 + 800) = 0.85, which at a LHSV of 2.0, would change pitch conversion by about 5% (Fig. 2, reference 7). Pitch conversion at the highest hot separator temperature was about 6% higher than the average for the other temperatures in each series, which agrees well with the above estimate. There is an insignificant contribution due to reaction in the hot separator when its temperature is 20°C below the reactor temperature, up to a reactor temperature of 430°C.

A comparison of products from low conversion thermal hydrocracking and thermal cracking or visbreaking is given in Tables 9 and 10. Note that product cuts are made on a slightly different basis. The thermal visbreaking data were from an experiment at 510°C, 0.693 MPa and LHSV of 30.9.

At the same pitch conversion, more naphtha is produced in thermal visbreaking. On an equivalent basis, thermal visbreaking naphtha (IBP-200°C) is estimated at 15.4 vol %; light gas oil (200-333°C) at 23.0 vol %; heavy gas oil (333-524°C) at 32.6 vol %; and pitch (524°C+) at 32.0 wt %. An additional factor is the gas yield, approximately 4.5% by weight for this experiment. This is consistent with the higher yield of naphtha and lower heavy gas oil yield when compared with hydrocracking at the same pitch conversion. Product properties are given in Table 10. Bromine numbers are higher for the thermal visbreaking products in all cases, indicating higher olefin content and the pitch has lower API gravity and a higher CCR.

Table 11 gives weight yields for another thermal process (Eureka process) in which cracking takes place in the presence of steam (3). The distillate weight yield — the sum of vacuum gas oil and cracked oil — is higher than the yield for either thermal hydrocracking or thermal visbreaking because of the higher pitch conversion. This work is of interest because a fluid pitch is obtained in the Eureka scheme at close to 70% pitch conversion without severe processing difficulties,

Table 8 - Effect of hot separator temperature
on pitch conversion

Run number	Reactor temperature	Hot separator temperature	Pitch conversion
92-1-1	410	370	23.8
92-1-2		370	26.1
92-2-1		390	25.6
92-3-1		410	26.7
93-1-1	420	380	35.2
93-2-1		400	34.4
93-3-1		420	36.8
94-1-1	430	390	46.1
94-2-1		410	46.5
94-3-1		430	49.3

Table 9 - Comparison of thermal hydrocracking and thermal cracking
product distribution (yields based on feed)

Product	Thermal hydrocracking			Thermal
	92-2-1	93-2-1	94-2-1	cracking
Naphtha (IBP-200°C), vol %	6.7	9.0	11.5	12.2*
Light gas oil (200-333°C), vol %	17.9	19.5	26.8	28.1**
Heavy gas oil (333-524°C), vol %	39.1	43.4	37.9	32.4†
Pitch, wt %	38.2	33.7	27.5	30††
Pitch conversion, wt %	25.6	34.4	46.5	40
Liquid yield, wt %	96.7	99.2	96.6	95.6

* C_5 to 180°C
** 180 to 343°C
† 343 to 537°C
†† 537°C plus

Table 10 - Comparison of product properties from low conversion
thermal hydrocracking and thermal visbreaking

Fraction/product	Thermal hydrocracking			*Thermal
	92-2-1	93-2-1	94-2-1	visbreaking
Naphtha (IBP-200°C)				
°API	49	50	51	54
Sulphur, wt %	2.03	1.79	1.88	2.02
Nitrogen, wt %	0.014	0.016	0.012	0.011
Bromine no.	68	72	71	115
Light gas oil (200-333°C)				
°API	27	29	27	25.8
Sulphur, wt %	2.25	2.20	2.45	2.11
Nitrogen, wt %	0.090	0.038	0.05	0.045
Bromine no.	28	30	31	38
Heavy gas oil (333-524°C)				
°API	14.5	14.5	13	13.2
Sulphur, wt %	3.66	3.46	3.8	3.91
Nitrogen, wt %	0.20	0.23	0.27	0.28
Bromine no.	-	-	-	20
Pitch (524°C+)				
°API	-1.33	-2.5	-5.4	-15.5
Sulphur, wt %	5.6	5.5	5.4	7
Nitrogen, wt %	0.94	1.02	1.16	1.3
CCR	30.3	35.5	39.6	57

* Naphtha, IBP-180°C
Light gas oil, 180-343°C
Heavy gas oil, 343-537°C
Pitch, 537°C+

Table 11 - Operating and yield data of the Eureka process
for thermal cracking of oil sand bitumen*

Property/product	Thermal cracking		
	1	2	3
Oil sand bitumen, g	100	100	100
Feed to Eureka process (525°C+), g	50.7	50.7	50.7
Pitch conversion, wt %	63	67	68
Temperature, °C	430	430	430
Residence time, min.	40	47	50
Products: (based on 100 g bitumen)			
Cracked gas	3.8	3.9	4.0
Vacuum gas oil (-525°C), wt %	49.3	49.3	49.3
Cracked oil	28.2	30.2	30.7
Distillate yield (vacuum gas oil + cracked oil)	77.5	79.5	80.0
Pitch	18.7	16.6	16.0

* Reference 3

whereas the limit is about 40% for thermal visbreaking in a coil. Temperature limits for the products and product analyses were not available.

CONCLUSIONS

The conversion range of an earlier report has been extended to include very low conversion thermal hydrocracking. Product analyses and other data have been presented.

A graph of viscosity at 25°C versus pitch conversion shows that low conversion hydrocracking followed by pipeline transport is feasible.

Thermal visbreaking produces more hydrocarbon gas and more naphtha than thermal hydrocracking. Thermal visbreaking distillate products have higher olefinic content than those from hydrocracking.

The hot separator conversion has to be included in calculations when the hot separator is at the reactor temperature. The hot separator conversion is negligible when its temperature is 20°C lower than the reactor, up to a reactor temperature of 430°C.

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APPENDIX A

This appendix contains the data for all runs in series 83, 86, 92, 93 and 94. All runs were of four-hour duration. The error expected in the overall liquid weight yield based on feed is ± 2% assuming a ± 1% error in weight of light oil, heavy oil and feed. The sulphur content is accurate within ± 0.04 wt % and the pitch conversion is accurate within ± 2%.

Table A-1 - Raw data for runs 83-1-1 and 86-1-1

Property/product	Thermal hydrocracking	
	83-1-1	86-1-1
Temperature, °C	400	380
Pressure, MPa	13.89	13.89
Gas rate, m³API/t	1220	1220
LHSV	1.0	1.0
HCP temperature, °C	380	350
Feed, g/h	4505	4425
Light ends, g/h	818	468
Heavy ends, g/h	3714	3841
Total product, g/h	4532	4309
Yield, wt %	100.6	97.4
Yield, vol %	104.1	98.9
Pitch conversion, wt %	27.6	14.9
Sulphur in feed, wt %	4.77	4.48
Sulphur in product, wt %	3.99	-
Sulphur removed, g/h	34.06	-
Sulphur conversion, wt %	15.85	-
Gravities:		
"A" (Total)	0.978	0.993
"B" (-524°C)	0.929	-
"C" (+524°C)	1.08	-

Table A-2 - Raw data for series 92, 93 and 94

Property/product	Thermal hydrocracking									
	92-1-1	92-2-1	92-3-1*	92-1-2	93-1-1	93-2-1	93-3-1	94-1-1	94-2-1	94-3-1
Temperature, °C	410	-	-	-	420			430		
Pressure, MPa	13.89	-	-	-	13.89			13.89		
Gas rate, m³API/t	610	-	-	-	610			610		
LHSV	2.0	-	-	-	2.0			2.0		
HCP temp, °C	370	390	410	370	380	400	420	390	410	430
Feed, g/h	8905	8955	9002	9178	8933	8730	9203	8975	9010	9028
Light ends, g/h	1082	1329	1644	1102	1427	1754	2233	1994	2397	2904
Heavy ends, g/h	7518	7337	7086	7888	7175	6956	6786	6706	6310	5769
Total product, g/h	8600	8666	8730	8990	8602	8710	9019	8700	8707	8673
Yield, wt %	96.6	96.7	97.0	97.9	96.3	99.8	98.0	96.9	96.6	96.1
Yield, vol %	99.0	99.2	99.6	100.4	99.6	103.1	101.5	101.0	100.8	100.6
Pitch conv., wt %	26.1	25.6	26.7	23.8	35.2	34.4	36.8	46.1	46.5	49.3
Sulphur in feed, wt %	4.48	4.48	4.48	4.48	4.48	4.48	4.48	4.48	4.48	4.48
Sulphur in prod, wt %	3.72	3.76	3.80	3.78	3.55	3.56	3.58	3.48	3.49	3.35
Sulphur removed, g/h	79.12	75.34	71.55	71.35	94.83	81.02	89.41	99.32	99.78	113.90
Sulphur conv., wt %	19.83	18.78	17.74	17.35	23.70	20.72	21.69	24.70	24.72	28.16
Gravities:										
"A" (Total)	0.984	0.984	0.983	0.984	0.976	0.976	0.974	0.968	0.968	0.963
"B" (-524°C)	0.931	0.930	0.927	0.930	0.925	0.925	0.922	0.922	0.917	0.914
"C" (+524°C)	1.08	1.08	1.09	1.08	1.09	1.09	1.10	1.11	1.13	1.13
Gas: H_2S, m³/t	6.66	6.31	-	5.83	7.96	6.96	7.28	8.30	8.30	9.46
H-C, m³/t	3.93	5.17	-	6.07	8.58	11.70	11.87	16.90	18.81	19.99
H_2 out, m³/t	19.48	19.45	-	19.64	16.77	16.22	16.00	17.23	17.40	16.55
H_2 fed, m³/t	47.70	44.28	42.47	43.20	48.82	57.58	53.85	67.05	68.37	70.58
H_2 cons., m³/t	28.22	23.83	-	23.56	32.05	41.36	37.85	49.82	50.97	54.03
Flow, m³/t	626.50	623.00	619.75	607.87	624.54	639.06	606.22	621.62	619.20	617.97

*N.B. No H.E. gas analysis

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