

Effect of Coal Concentration on Coprocessing Performance

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Introduction

Coprocessing represents an attractive combination of heavy oil upgrading and coal liquefaction technology. Compared with coal liquefaction, coprocessing eliminates or reduces the use of a recycle oil solvent. This results in a greater proportion of the reactor volume being occupied by upgradable feedstock rather than recycle solvent. The net result is higher effective reactor throughput and lower capital and operating costs. Compared with heavy oil upgrading, coprocessing offers the ability to increase operating margins by replacing expensive oil with lower cost coal. There are also other benefits related to the ability of the added coal to act as an adsorbent for coke formed during the reaction and for heavy metals present in most feedstocks. For some processes and under certain operating conditions there is also the possibility of synergistic effects which results in better process yields (1-2).

In the final analysis the real challenge is to make coprocessing more economically attractive than heavy oil upgrading and this requires a better understanding of the effects that adding more coal to the feed can have on fundamental process behaviour. This paper describes the effects of increasing coal concentration on the coprocessing performance of the CANMET process operating with an Alberta subbituminous coal and Cold Lake vacuum bottoms (CLVB).

Experimental

All experiments were performed with Forestburg subbituminous C coal (from Luscar Ltd.) in minus 200 mesh size (75 μ m). The same coal was used to prepare an iron based disposable additive for the process by impregnation with iron sulphate using a water slurry. Coal characteristics are given in Table 1 and those of the oil feed (CLVB, from Imperial Oil Ltd.) in Table 2. Slurry feeds with coal concentrations up to 39.5 wt. % maf coal were prepared by mixing the coal, the additive and the oil to keep the total iron concentration constant at approximately 0.50 wt. % on a maf slurry feed basis.

Coprocessing experiments were carried out in a single stage bench-scale unit which is described elsewhere (3). For comparison purposes, all experiments were performed at 450°C, 13.9 MPa total pressure, 1.0 kg/h·L nominal space velocity and 71.4 g H₂/kg slurry feed (4500 SCF/B). Details of the product workup procedures are also described elsewhere (3).

Results and Discussion

There was a marked difference in process operability in the absence of coal versus its presence in small concentrations even though the same amount of iron based catalyst was used in both cases. Without coal, reactor outlet plugging was experienced and long term operation was not possible. When coal was used, no operational problems were encountered at up to about 40 wt.% maf coal in the slurry feed. This indicates a potential benefit of coprocessing where the coal is used as a carrier or support for a disposable catalyst.

Process Yields

Gross process yields are shown as a function of coal concentration in Figure 1. The addition of about 2-4 wt.% maf coal results in a significant increase in distillate yield. Similar results have also been reported based on isotopic mass balance measurements for an Athabasca atmospheric resid and Vesta subbituminous coal without the use of a catalyst (4). At coal concentrations over the range of most operational interest for coprocessing, the distillate yield is constant and equal to that for the no coal case until a slight drop is observed starting at about 30 wt.% maf coal. These results indicate a potential synergism at lower coal concentrations for a disposable iron based catalyst process of this type. More experimental work needs to be done to determine how this effect is influenced by different catalyst concentrations and other operating parameters such as temperature and space velocity.

Residue yield is almost a mirror image of the distillate yield as would be expected if gas yield is relatively constant as shown in Figure 1. About 30 to 50% of this residue is pentane soluble oil which with a proper solid separation scheme might be extracted for further upgrading to distillate. With more severe operation, residue yields can be lowered to the 20 wt.% range including pentane soluble oils.

Coal and Pitch Conversion

The effect of coal concentration on coal and pitch conversion is shown in Figure 2. The coal conversion data suggests that two different mechanisms are prevalent; one for low coal concentrations and one for higher concentrations starting at about 10 wt.% maf coal. Similar results have been reported when coal-derived liquids replaced a portion of a heavy oil feed (5). This would explain the higher coal conversion values at higher coal concentrations where more coal derived liquids would be available to enhance hydrogen transfer reactions compared with lower coal concentrations where the predominant effect is due to the oil solvent only. For this reacting system, a coal concentration of about 10 wt.% on a maf slurry feed basis is required to observe an enhancement in coal conversion.

Pitch conversion values are directly proportional to residue yields and this accounts for the similar shapes of these curves which are shown in Figures 1 and 2.

Distillate Characteristics

Gross distillate characteristics as a function of coal concentration are shown in Figure 3. It is apparent that increasing coal concentration in the slurry feed does not decrease the specific gravity or H/C atomic ratio of the overall distillate product. Although the H/C ratio of the product is essentially constant with increasing coal concentration the difference in H/C ratio between slurry feed and distillate product results in a monotonic increase with increasing coal concentration indicating that hydrogen addition reactions are enhanced. This advantage is offset somewhat since with increasing coal concentration the aromaticity of the distillate as determined from ^1H NMR and the Brown-Ladner equation is also increasing as shown in Figure 3. However, an increase in aromaticity of the naphtha fraction, would be an advantage for high octane gasoline production obtained by reforming the naphtha.

Metals Removal

The effect of coal concentration on vanadium and nickel removal is shown in Figure 4. Based on these results, which show a considerable amount of scatter, nickel seems to be preferentially removed at lower coal concentrations even though its concentration in the slurry feed is less than half that of vanadium. As the coal concentration increased, the vanadium and nickel concentration in the slurry feed decreased but as shown in Figure 4 removal of both nickel and vanadium increased. Similar results have been reported for other coals and oil feedstocks (2,6) and this highlights an advantage of coprocessing over other upgrading technologies.

Conclusions

Process operability is improved by the addition of coal. At low coal concentrations in the CANMET process a synergism exists in terms of distillate yields. However, more research needs to be undertaken to determine how other operating parameters affect the degree of potential improvement and if it can be maintained for higher coal concentrations of more interest for commercial operations. The present results indicate that replacing oil with increasing amounts of coal in the feed does not lower the amount of distillate produced up to a coal concentration of about 30 wt.% maf on a slurry feed basis.

Two different mechanisms seem to be operating in terms of coal conversion. For low coal concentrations where the effect of coal derived liquids is negligible, coal conversion decreases with increasing coal concentration. At higher coal concentrations, the presence of coal derived liquids is suggested to result in an increase in coal conversion. Hydrogen addition and metals removal are enhanced with increasing coal concentration but the resulting distillate product becomes more aromatic. This could have significant influence on the type and nature of downstream upgrading to produce marketable products.

References

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Table 1 - Characteristics of Forestburg Subbituminous C Coal

<u>Proximate Analysis</u> (wt.% as received)		<u>Ultimate Analysis</u> (wt.% dry basis)	
Moisture	19.17	Carbon	64.04
Ash	7.68	Hydrogen	3.87
Volatile matter	34.00	Sulphur	0.53
Fixed carbon	39.15	Nitrogen	1.65
		Ash	9.50
		Oxygen (by diff.)	20.41
<u>Metal Content, ppm</u>		<u>Calorific Value</u>	
Fe	2379	cal/g	4933
Ni	18	btu/lb	8879
V	trace		
<u>Petrographic analysis, vol.% as received on -200 mesh size</u>			
Vitrinite	92.2		
Liptinite	2.6		
Inertinite	3.1		
Mean reflectance	0.42		

Table 2 - Characteristics of Cold Lake Vacuum Bottoms

<u>General</u>	
Specific Gravity, 15/15°C	1.038
Conradson Carbon Residue, wt.%	17.1
Pentane Insolubles, wt.%	23.48
Benzene Insolubles, wt.%	0.20
Aromaticity (¹ H NMR)	34.5
Viscosity, at 80°C, poise	249.12
at 110°C, poise	21.59
<u>Distillation (Spinning Band)</u>	
IBP, °C	420
Distillate (-525°C), wt.%	16.8
Residue (+525°C), wt.%	83.25
<u>Elemental Analysis, wt.%</u>	
Carbon	78.6
Hydrogen	9.3
Sulphur	5.5
Nitrogen	0.6
Ash	0.0
Oxygen (by difference)	5.9
<u>Metal content, ppm</u>	
Fe	18
Ni	93
V	235

Figure 1
Effect of Coal Concentration on Yields

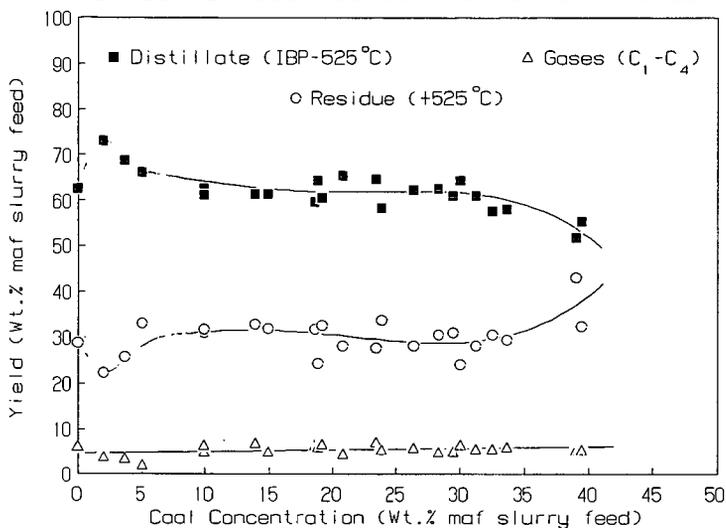


Figure 2
Effect of Coal Concentration on Conversion

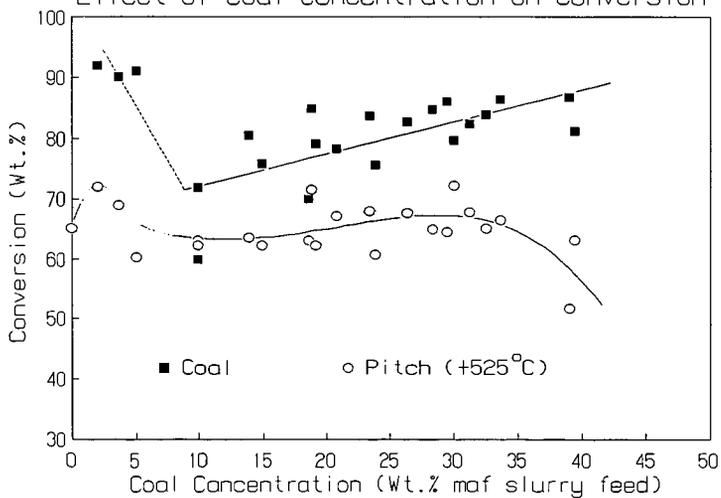


Figure 3
Effect of Coal Concentration on
Distillate Characteristics

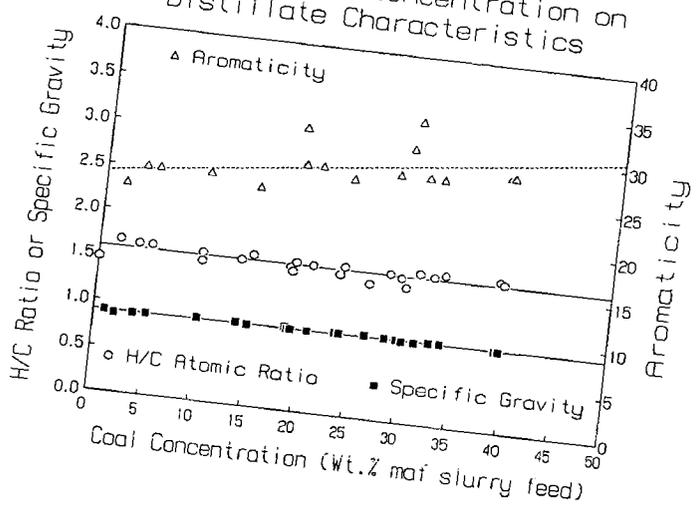


Figure 4
Effect of Coal Concentration on Metals Removal

