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THE USE OF TaBoRR[®] AS A HEAVY OIL UPGRADER

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DISCLAIMER

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ABSTRACT

Preliminary testing has shown that Western Research Institute's (WRI) Tank Bottom Recovery and Remediation (TaBoRR[®]) technology shows promise for heavy oil upgrading. Approximately 70 to 75 wt% of a Canadian Cold Lake bitumen feed was converted to a partially upgraded overhead product that could be transported directly by pipeline or blended with the parent bitumen to produce transportable crude.

TaBoRR[®] was originally developed to remediate tank bottom wastes by producing a distillate product and solid waste. TaBoRR[®]'s processing steps include breaking a water-oil emulsion, recovering a light hydrocarbon fraction by distillation in a stripper unit, and pyrolyzing the residua reducing it to additional overhead and a benign coke for disposal.

Cold Lake bitumen was tested in WRI's bench-scale equipment to evaluate the potential use of TaBoRR[®] technology for heavy oil upgrading to produce a stable, partially (or fully) upgraded product that will allow diluent-reduced or diluent-free transportation of bitumen or ultra-heavy crudes to market. Runs were conducted at temperatures of low, intermediate and high severity in the stripper to produce stripper overhead and bottoms. The bottoms from each of these runs were processed further in a 6-inch screw pyrolyzer to produce pyrolyzer overhead for blending with the corresponding stripper overheads. Proceeding in this fashion yielded three partially upgraded crudes. The products from TaBoRR[®] processing, the parent bitumen, and bitumen blends were subjected to stability and compatibility testing at the National Centre for Upgrading Technology (NCUT). Chemical analyses of the overhead product blends have met pipeline specifications for viscosity and density; however the bromine number does not, which might indicate the need for mild hydrotreating. Storage stability tests showed the blends to be stable. The blends were also soluble and compatible with most other Alberta crudes.

EXECUTIVE SUMMARY

Preliminary testing has shown that Western Research Institute's (WRI) Tank Bottom Recovery and Remediation (TaBoRR[®]) technology shows promise for heavy oil upgrading. Approximately 70 to 75 wt% of a Canadian Cold Lake bitumen feed was converted to a partially upgraded overhead product that could be transported directly by pipeline (some hydrotreating may be required) or blended with the parent bitumen to produce a transportable crude.

TaBoRR[®] was originally developed to remediate tank bottom wastes by producing a distillate product and solid waste. TaBoRR[®]'s processing steps include breaking a water-oil emulsion, recovering a light hydrocarbon fraction by distillation in a stripper unit, and pyrolyzing the residua reducing it to additional overhead and a benign coke for disposal. This methodology is similar to upgrading an ultra-heavy oil or bitumen, but modifications would be required to use TaBoRR[®] as a field upgrader. When used to treat slop oil, processing volumes were small relative to field production rates and dilution was appropriate for handling the olefinic overhead material produced by the pyrolyzer. However as a field upgrader, the TaBoRR[®] technology would have to be modified to process significantly greater quantities of feed and the pyrolyzer operation would have to be integrated into a hydrotreating scheme.

Cold Lake bitumen was tested in WRI's bench-scale equipment to evaluate the potential use of TaBoRR[®] technology for heavy oil upgrading to produce a stable, partially (or fully) upgraded product that will allow diluent-reduced or diluent-free transportation of bitumen or ultra-heavy crudes to market. Runs were conducted at temperatures of low, intermediate and high severity in the stripper to produce stripper overhead and bottoms. The bottoms from each of these runs were processed further in a 6-inch screw pyrolyzer to produce pyrolyzer overhead for blending with the corresponding stripper overheads. Proceeding in this fashion yielded three partially upgraded crudes. The products from TaBoRR[®] processing, the parent bitumen, and bitumen blends were subjected to stability and compatibility testing at the National Centre for Upgrading Technology (NCUT).

Measurements performed by NCUT showed that the stripper overheads (SOH), the pyrolyzer overheads (POH), and blends of the two in the ratios in which they were produced met or exceeded the Canadian pipeline specifications for viscosity. The stripper overheads and the blends made with POH also met the pipeline specifications for density. The bromine numbers of the whole distillate fractions, however, were higher than the pipeline specification. However, diene values (used in the refining industry as a measure of stability) indicated that the blended SOH and POH would tend not to foul processing equipment.

Storage stability tests of the SOH and POH samples performed at 109°F (43°C) for up to 4 weeks showed that the amounts of total solids (filterable solids + adherent gums) were small (0.012wt%) and the viscosity of the liquids did not change significantly during the test period. Measured solubility parameters for the POH, SOH, and four Alberta crudes, indicated that the overhead products were stable and compatible with most other Alberta crudes.

BACKGROUND

The U.S. remains dependent upon foreign sources of oil even after some 30 years since the oil embargo of the 1970's. Currently, the U.S consumes 20.7 million barrels per day (b/d) of the worldwide consumption of 84 million b/d and is projected by the Energy Information Administration to consume another 5.4 million barrels per day of oil globally by 2025. This is in light of increased international demand for oil by China and India of another 7.8 million barrels per day of oil by 2025 (Clark, 2007).

A Federal Task Force on Unconventional Fuels (established under the Energy Policy Act of 2005) concluded that the high cost and volume of oil imports have worsened the nation's trade deficit, weakened the dollar against other currencies, and put national security and economic stability at risk (Clark, 2007). The Task Force recommended the development of a domestic unconventional fuels program, taking advantage of oil shale, tar sands, coal-to-liquids, and heavy oil resources, the major resource being oil shale in Colorado, Utah and Wyoming. The estimated growth of an unconventional fuels program by 2035 was only 7.5 million barrels per day, including an optimistic 2.6 million from coal-to-liquids (CTL) and an increase of 1.3 million barrels per day from EOR via CO₂ injection. This barely keeps pace with the growth for demand, and leaves the US in the same position in 2035 as it is today as far as oil imports.

The continuing trend of high oil imports from unfriendly and unstable regions of the world argues for other source for energy security. One possibility is increasing the use of the imports from friendly neighbors, such as Canada and their oil sands resources. The Canadian oil sands contain an estimated 2.5 trillion barrels of bitumen, 20% more than the total oil shale, tar sands and heavy oil reserves in the US combined. Assuming 40% in situ recovery via steam assisted gravity drainage (SAGD) would yield approximately 1 trillion barrels of recoverable heavy oil, enough to cover total oil needs of the US under current consumption rates for over 50 years.

Canada's current production includes oil sands mining and in-situ production by SAGD. Currently, the limited coking capacity of US refineries presents an impediment to marketing in situ produced heavy oil. A potential method for addressing this issue is the development and deployment of cost effective field upgrading technologies. Field upgrading refers to processes sited at the point of production that upgrade the bitumen to a higher value product slate. The upgraded product exhibits a reduced viscosity that makes the crude amenable for pipeline transport without the addition of diluent. Current field upgrading involves the modification of the product's H/C ratio either by rejecting carbon via a coker or by adding hydrogen or both. With cokers, the coke disposition needs to be understood and its potential use as a fuel for SAGD to supplement the limited supply of natural gas. In the case of hydrogen addition, a source of hydrogen must be found, which may come from methane reforming or coke gasification.

INTRODUCTION

Canada supplies a significant quantity of heavy crude to the US. Heavy refers to both bitumen and conventional heavy crudes, but excludes diluent and feedstocks for synthetic crudes, which is also produced in Canada. While the Canadian heavy crude supply is expected to grow significantly to meet future demands, the corresponding growth in bitumen production will present both problems and opportunities.

Canadian producers face several options for marketing their heavy crude. A blend can be made, but the limited availability of diluent and finding refineries with sufficient coking capacity to utilize the crude will limit the demand for the product. Another option is to invest in a complex and expensive upgrader to produce highly upgraded and expensive synthetic crude. Or, producers can partially upgrade bitumen to a slightly higher quality, upgraded crude that is pumpable and sold to a refiner which completes the next stage of product upgrading.

Partial upgrading, field upgrading and pipelineable bitumen all refer to the processing of bitumen or heavy oil in field settings, rather than at a refinery, to improve its quality and make it a refinery-compatible feedstock. In Canada the primary driving force for such an effort is to reduce or eliminate entirely the need for diluent (condensate) required for blending in order to transport the product through a pipeline.

Upgrading processes change the H/C ratio of the feedstock, either through the addition of hydrogen or the rejection of carbon. For example, Athabasca bitumen has an H/C ratio of 1.5 (C/H mass ratio of eight) and an API gravity of 8. Partially upgraded heavy crudes have H/C of around 1.6 (C/H of 7.5) and API gravities of 22-25. Typical synthetic crude has an H/C near 1.7 (C/H of 7) and an API gravity of approximately 33. Previous conventional practice has been to upgrade bitumen by hydrotreating at refineries to improve markets and quality, which leads to higher prices for the finished products. The value derived from hydrogen addition has traditionally been assumed to exceed its cost.

Today's market finds bitumen to be cheap and plentiful and hydrogen to be expensive. This results from both the higher cost of natural gas and the higher specific capital investments associated with field upgrading. As a result, coking processes may offer distinct advantages over hydrotreating processes, especially in the smaller sizes required for field upgraders. This competitive advantage held by coking processes, particularly those which are capable of continuous and reliable coking, has lead the Western Research Institute (WRI) to evaluate its TaBoRR[®] technology as a possible candidate for a field operated heavy oil upgrader.

OBJECTIVES

Western Research Institute (WRI) is evaluating its Tank Bottoms Recovery and Remediation (TaBoRR[®]) technology (U.S. Patent No. 5,259,945) for application as a heavy oil upgrader, which would produce a stable, partially (or perhaps fully) upgraded product that will allow diluent-reduced or diluent-free transportation of bitumen or other ultra-heavy crudes to market.

The TaBoRR[®] system is a custom-engineered package of mobile process equipment designed to recover upgraded, distillate product oil and to remediate the remaining tank bottom wastes. The technology has progressed from laboratory studies in bench-scale equipment to subsequently a 300-barrel-per-day pilot or process development unit. Processing involves the following steps. First, the emulsion is broken and water removed as a vapor. Then distilled, residuum-free hydrocarbons are collected in the stripping unit's product recovery system. Finally, the remaining materials are processed through a pyrolyzer that generates additional overhead plus inert coke that is disposed of in an environmentally acceptable manner. The overheads from the stripper and pyrolyzer are sold as an upgraded oil product. This processing methodology is similar to upgrading an ultra-heavy oil or bitumen, but modifications would be required to use TaBoRR[®] as a field upgrader. When used to treat slop oil, processing volumes were small relative to field production rates and dilution was appropriate for handling the olefinic overhead material produced by the pyrolyzer. However for field upgrading, the TaBoRR[®] technology would have to be modified to process significantly greater quantities of feed and potentially operate under different conditions of temperature and residence time. In addition, the pyrolyzer operation would have to be integrated into a hydrotreating scheme.

For this report, WRI's bench-scale units processed Canadian Cold Lake bitumen using its TaBoRR[®] technology and the products were subsequently analyzed. The objectives of the tests were to:

1. Evaluate the feasibility of TaBoRR[®] technology to upgrade bitumen and other heavy oils into a pipelineable crude with a reduced requirement for diluent.
2. Determine the stability of TaBoRR[®] generated overhead products and their compatibility with both the parent and other upgraded crudes.

METHODS USED TO EVALUATE TaBoRR[®] FOR BITUMEN UPGRADING

For the tests described in this report, WRI used its bench-scale equipment to process Cold Lake bitumen. Tests and subsequent analyses determined product yields and composition, as well as stability and compatibility of the products with other Canadian crude. These data would be necessary for evaluating the feasibility of the technology and for developing engineering calculations to design and construct a field upgrader.

Equipment Used for Testing

WRI uses bench-scale test equipment to predict the compositions and yields of products expected when commercially processing crudes with the TaBoRR[®] process. This equipment consists of a reactor that simulates the flashing and stripping operations of the TaBoRR[®] process and six-inch rotary screw reactor designed to simulate the pyrolyzer.

Flash-Stripper Unit A schematic of the bench-scale equipment used to simulate the flash and stripper unit operations is shown in Figure 1. Tank bottom wastes or heavy oils flow from a feed tank through a pump that pressurizes the material into an electrically heated feed pre-heater (Stripper Unit 1). A pressure let-down valve (flash valve) controls the pressure. The separator removes the water as vapor where it subsequently condenses as overhead in KO-1 as Product 1. Substantially water-free material flows successively from the bottom of the flash tank through four Stripping Units. Each unit is an electrically heated vessel with its own temperature controller, sweep gas provisions, and equipment for product recovery. Gases produced in any of the heated vessels can be sampled and analyzed. The material of construction used throughout the system is type 316 L stainless steel. This selection was in part dictated by the fact that some of the feedstocks used in earlier investigations contained high concentrations of chlorides and sulfur. Previous refinery experience indicated that type 316 L is adequate for this service. All flows in and out of the bench-scale test unit are monitored and continuously logged by computer, as are all temperatures and pressures.

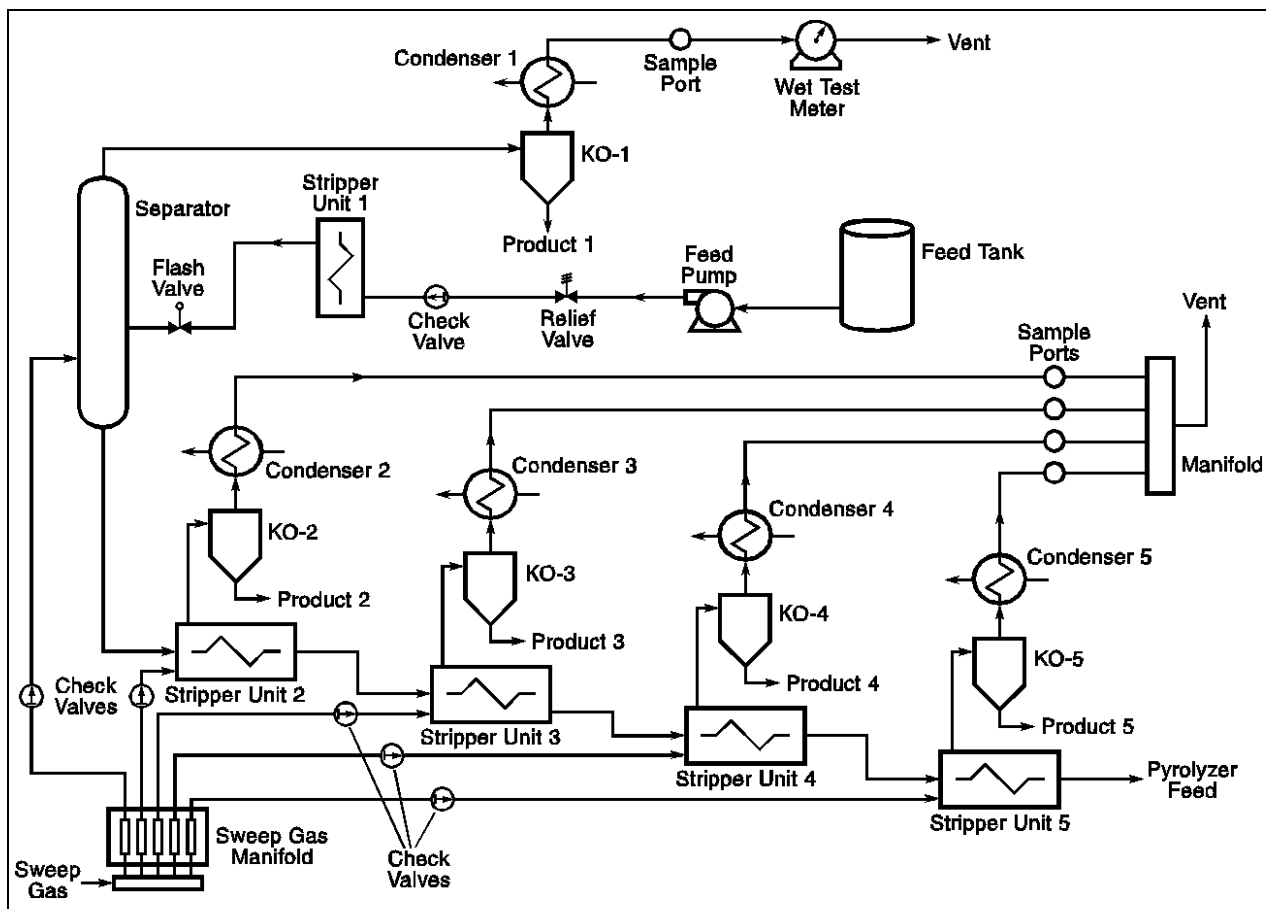


Figure 1. Schematic of the TaBoRR[®] bench-scale flash-stripper unit.

Pyrolyzer unit A 6-inch twin rotary screw reactor simulates the pyrolyzer unit operation. The setup consists of an electrically heated twin screw that can process crudes, tank bottoms, or stripper bottoms at three progressively higher temperatures. The temperatures of the three heating zones are controlled with individual clamshell heaters that encircle the barrel of the screw. The overhead liquid product recovery train consists of condensers and knock-out pots with provisions for gas sampling. A gear pump feeds the screw. Samples of processed solids may be collected during the test. The data acquisition system controls and records the temperatures, pressures and other related conditions. A schematic of the reactor is shown in Figure 2.

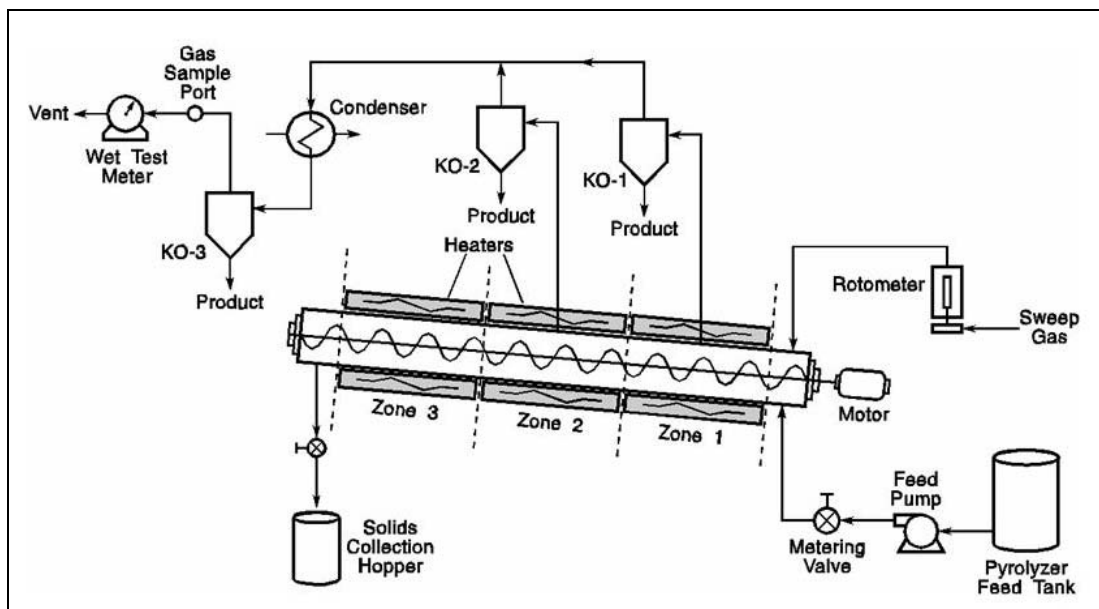


Figure 2. Schematic of the TaBoRR[®] bench-scale pyrolyzer unit.

EXPERIMENTAL PROCEDURE

An experimental program was conducted to determine the feasibility of WRI's TaBoRR[®] process to produce upgraded products from Canadian bitumen and to determine the stability and compatibility of these products. A series of six tests conducted with Cold Lake bitumen received from Alberta Energy Company (now EnCana) was processed in the stripper at temperature conditions ranging from very low to very high severity. Three of these tests were selected for detailed chemical analysis by the National Centre for Upgrading Technology (NCUT). The stripper bottoms (SB) from each of these selected runs were subsequently processed in the 6-inch screw pyrolyzer to produce pyrolyzer overhead (POH) for blending with the corresponding stripper overheads (SOH) for stability testing. Storage stability of the liquid products was determined by ASTM D462 and the compatibility tests were carried out according to a method developed by Wiehe (2000).

The three selected tests were run at three temperature conditions corresponding to low, intermediate, and high levels of severity. The temperature in stage 5 reflected the maximum processing severity for the run. The overheads from each of the stripper units were combined into a single composite product for the run. The bottoms material (residuum) from each stripper test condition was subsequently processed (individually) in the pyrolyzer. The pyrolyzer was operated at substantially constant conditions for each of the feeds. As with the stripper, the overhead from the individual knock outs were combined into a single composite product.

RESULTS AND DISCUSSION

The product distributions from bench-scale processing of Cold Lake bitumen at three stripper temperatures are shown in Table 1. (The conditions T1, T2, and T3 shown in Table 1 and elsewhere represent increased processing severity based on stage 5 temperature, with T1 being the lowest, T2 intermediate, and T3 most severe.) The bitumen contained 16.8wt% C₅ asphaltenes, with a microcarbon residue (MCR) of 13.4wt%, an API gravity of 9.9°, and a relatively high viscosity of 1870 cSt @ 212°F (100°C). When this material was processed in the TaBoRR[®] equipment at the final stripper temperatures shown in Table 1, and the SB from each run was then pyrolyzed at identical feed rate and temperature, the total liquid products obtained, based on feed, varied from 70.7wt% to 75.4wt%, the balance comprising gaseous products and coke. The results showed that increased overhead liquid recovery corresponded to increased process severity. Overhead product properties for both stripper and pyrolyzer overheads are summarized in Table 2.

The recovery of overhead product from all stripper runs at corresponding processing temperatures is shown in Figures 3 and B-4 along with the normal boiling point curve for the Cold Lake bitumen (developed by NCUT). Although reliable stripper data from testing was not available at lower temperatures, the results indicated that processing in the TaBoRR[®] stripper recovered overhead in excess of what would be expected from conventional distillation.

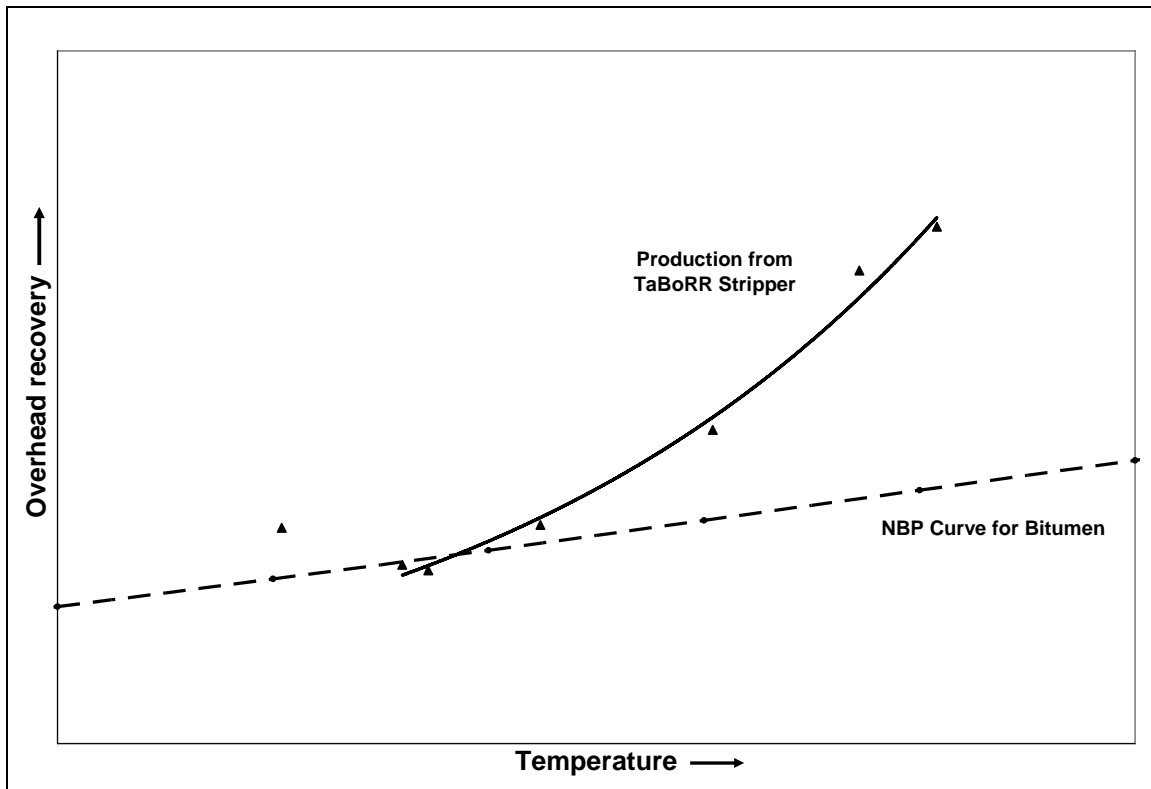


Figure 3. Overhead recovery from TaBoRR[®] stripper unit compared to the normal boiling point curve, both for a Cold Lake bitumen.

A critical issue for developers of field-upgrading processes, and producers who ultimately will use them, is the stability of the resultant upgraded products and their compatibility with both the parent and other crudes. Because the TaBoRR[®] process subjects the starting crude to a thermal separation in the stripper and coking in the pyrolyzer, both of which alter chemical structure, the stability and compatibility of these overhead streams is a concern. Accordingly, the analysis described in this paper address the following issues:

1. Properties of the liquid products.
2. Stability of TaBoRR[®] product streams and blends over time.
3. Compatibility of TaBoRR[®] product streams with other product streams, the virgin crude, and with other common crudes.
4. Fouling or coking tendency of TaBoRR[®] products and blends on heating.

The properties of the SOH and POH are shown in Table 2. Although the densities of SOH exceeded the pipeline specification (19°API), the densities of the POH products did not. As expected because of differences in processing temperatures, the H/C ratios of the POH samples were lower than the SOH samples, and both nitrogen and sulfur were higher in the POH compared to SOH. The viscosities of all fractions met or exceeded pipeline specification (350 cSt, 52°F [11°C]). The bromine and diene numbers were significantly higher for the POH samples, as compared with the SOH samples, and were highest for the most severe processing condition, POH-T3. The pipeline specification for bromine number (BN) is less than 10 for the fraction boiling at temperatures less than 482°F (i.e.-482°F) [250°C]. Although the bromine numbers shown in Table 2 for both SOH and POH exceeded this specification, both sets of samples contained materials boiling above 482°F (250°C), and it is known that other components in the higher boiling fractions could have interfered with the bromine number measurement. The validity of the bromine numbers, therefore, was verified by NCUT for the appropriate boiling range in subsequent testing.

To more precisely determine the bromine number, NCUT distilled TaBoRR[®] overhead products to obtain -482°F (-250°C) fractions. The weight percentage of these fractions and associated properties are shown in Tables 3 and 4, respectively. The results indicated that SOH fractions contain a slightly higher percentage of -482°F (-250°C) cut than did the POH. Because of the effect of increased processing severity in pyrolysis compared to stripping, analysis (done by Fluorescence Indicator Absorbance [FIA]) showed that the saturated content of SOH fractions was higher than in POH fractions, and decreased with severity. Conversely, the aromatic content was higher for POH than SOH fractions. The olefin vol% was significantly higher in POH fractions, and this resulted in high bromine and diene numbers (Table 4). NCUT found that both SOH and POH fractions contained a significant concentration of aromatics that can affect the accuracy of the bromine index. However, both the olefin content and the bromine numbers

followed the same trend. NCUT suggested that diene number might better reflect fouling tendencies. Experience has shown that petroleum fractions having diene numbers greater than 4 (g I₂/100g) could cause fouling problems in refinery equipment. Although the diene numbers in the TaBoRR[®] POH fractions were high, when blended with SOH fractions the values for diene numbers were expected to be less than 4.

Regarding pipelineable blends, because the viscosities of both SOH and POH exceed the pipeline specification (350 cSt, 52°F [11°C]), these materials could be blended with the original Cold Lake bitumen feedstock. For instance, to meet pipeline specification using blends of POH and feed, it was shown that the blends prepared from POH at three stripper conditions required approximately between 10-to- 30vol% of Cold Lake bitumen.

Storage stability tests for SOH and POH samples were performed according to ASTM-D4625 at 109°F (43°C) for up to 4 weeks. The ASTM method was applied after the as received samples were centrifuged to remove any initial solids that were present. The total insoluble material for SOH and POH as a function of time are shown in Table 5. Although the data exhibits scatter, in general the POH samples had more initial solids than the SOH samples. In addition, more solids formed during the 4-week period in the POH compared to the SOH. This will be an important area of ongoing study.

To determine stability and compatibility of liquid products, the parameters of solubility blending number (S_{BN}) and insolubility number (I_N) were determined using a method developed by Wiehe (2000). For stable petroleum products, S_{BN} must be greater than I_N . As shown in Table 6, the S_{BN} of the feed and the TaBoRR[®] products were all higher than the corresponding I_N . The SOH samples contained no asphaltenes and were considered to be solvent oil. The results in Table 6 show that as the temperature of the stripper increased the stability (S_{BN}/I_N) of liquid products decreased.

Regarding compatibility and fouling tendency, the preliminary results indicated that the liquid products from the TaBoRR[®] process were all compatible with Alberta crudes and exhibited relatively low fouling tendencies. This will be an important area of ongoing study.

CONCLUSIONS

Processing Cold Lake bitumen in WRI's TaBoRR[®] bench-scale equipment resulted in increasing product yields with increasing processing severity. Yields up to 75 pounds of product per 100 pounds of feed (on a water free basis) were obtained in this study.

The SOH samples contained no asphaltenes and are considered to be solvent oil. All SOH samples had densities and viscosities that exceeded pipeline specifications. The POH samples had viscosities that exceeded pipeline specifications but densities that did not.

However, when blended with their corresponding SOH fraction, all the resultant blends met or exceeded both density and viscosity specifications.

On a whole crude basis, none of the blends met the pipeline specification for bromine number, as was the case for the -482°F (-250°C) overhead fractions. However diene numbers resulting from blending the -482°F (-250°C) SOH and POH fractions tended to indicate that fouling in petroleum refinery equipment would not occur.

Storage stability tests of the SOH and POH samples were performed at 109°F (43°C) for up to 4 weeks. The results showed that the amounts of total solids (filterable solids + adherent gums) were small (0.012wt%) and the viscosity of the liquids did not change significantly during the test period. Based on the measured solubility parameters of the POH, SOH, with four Alberta crudes, it was concluded that these samples were stable and compatible.

Table 1. Product distribution as a function of stripper temperature (wt%, feed)

Stripper Conditions	SB	SOH	POH*	Total Oil
Severity T1	91.90	8.10	62.58	70.68
Severity T2	77.85	22.15	48.11	70.26
Severity T3	61.10	38.90	36.48	75.38

*Identical pyrolyzer top temperature used for all runs.

Table 2. Properties of SOH and POH

Test	SOH-T1	SOH-T2	SOH-T3	POH-T1	POH-T2	POH-T3
Water, wt%	0.04	0.029	0.049	0.024	0.024	0.033
Density (API)	0.891(27)	0.8972(26)	0.9018(25)	0.9462(18)	0.9452(18)	0.9561(16)
Elemental, wt%						
C	85.4	84.86	84.61	84.63	84.88	84.4
H	12.9	12.74	12.71	11.66	11.66	11.24
N	0.03	0.0426	0.06616	0.27	0.26	0.33
S	1.98	2.3	2.72	3.83	3.84	3.88
H/C, atomic	1.81	1.80	1.80	1.65	1.65	1.60
Viscosity, cSt						
68°F (20°C)	10.151	11.607	12.593	65.607	55.723	84.847
104°F (40°C)	5.229	5.99	6.478	23.246	20.416	27.956
176°F (80°C)	2.249	2.561	2.835	6.193	5.77	7.101
BN, gBr ₂ /100g	11.0	10.6	17.1	22.7	22.3	24.4
Diene, g I ₂ /100g	0.2	0.9	1.3	5.0	4.4	5.7
Pour Point, °F (°C)	< -76 (-60)	-71 (-57)	-33 (-36)	-11 (-24)	0 (-18)	16 (-9)

Table 3. D1160 Distillation of TaBoRR[®] products at 482°F (250°C) cut point

Cut Point	SOH-T1 wt%	SOH-T2 wt%	SOH-T3 wt%	POH-T1 wt%	POH-T2 wt%	POH-T3 wt%
IBP-482°F (250°C)	10.9	10.8	9.9	7.1	6.4	6.5
+482°F (+250°C)	89.0	89.1	90.0	92.8	93.5	93.4
Loss	0.1	0.1	0.1	0.1	0.1	0.1

Table 4. Properties of 482°F (250°C) cut point of TaBoRR[®] overhead products

Tests	SOH-T1	SOH-T2	SOH-T3	POH-T1	POH-T2	POH-T3
FIA	Vol%	Vol%	Vol%	Vol%	Vol%	Vol%
Saturates	74.9	64.7	53.9	31.7	33.8	30.8
Aromatics	20.2	15.8	15.6	27.3	23.6	24.8
Olefins	15.0	19.5	30.5	41.0	42.6	44.4
BN(gBr ₂ /100g)	29.5	41.5	57.8	67.9	57.8	67.1
Diene (gI ₂ /100g)	0.63	1.15	1.48	6.45	4.65	5.44

Table 5. Accelerated stability using method D4625 (mg/100g)

	SOH-T1	SOH-T2	SOH-T3	POH-T1	POH-T2	POH-T3
Week 0 (after centrifugation)	1.4	1.3	1.1	2.8	5.4	7.7
Week 2	9.2	4.9	4.0	8.2	9.7	11.0
Week 2 Repeat		4.3				7.5

Table 6. Solubility numbers of feed and TaBoRR[®] products

Solubility #	Cold Lake	SOH-T1	SOH-T2	SOH-T3	POH-T1	POH-T2	POH-T3
I _N	33.6				32.5	45.6	48.7
S _{BN}	104.1				51.3	67.5	71.1
S _{SO} *		51.5	50.0	49.3			

*S_{SO} = Solubility blend of the solvent oil

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