Partial upgrading of heavy oil reserves

Partial upgrading using solvent deasphalting addresses multiple issues associated with the recovery of stranded heavy oils

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As the world's population aspires to a better quality of life, global energy consumption and the demand for transportation fuels can only be projected to increase for the foreseeable future. This increase in energy demand can, in turn, only be met by economically mobilising all available energy resources. As the demand for transportation fuels outpaces the supply of traditional crudes, increased production from non-traditional hydrocarbon deposits, such as Canadian tar sands, Venezuelan heavy oils and other South American stranded crudes, becomes economically attractive.

Today, heavy oils, extra-heavy oils and bitumen represent only a small portion of worldwide oil production, and viable solutions to monetise these stranded resources could likely double current proven oil reserves. The strategic importance of monetising these crudes in the face of the overall gap in global supply and demand presents interesting challenges for many block owners, while opening up unique opportunities for technology providers to offer niche upgrading solutions.

These heavy and extra-heavy oils are regarded as unconventional because of the difficulties associated with production, dewatering, transportation and processing of these valuable resources. The methods of production and the degree of upgrading are highly dependent on local infrastructure and the availability of natural gas and power. This, in turn, means that remote fields and offshore heavy oil fields are not well suited to installing traditional, capital-intensive upgrading processes that involve hydrogen addition or carbon rejection. In such cases, the economic solution may gravitate towards the use of minimal upgrading at remote fields, sufficient to enable the transport of these materials for processing in more conventional upgrading or refinery assets.

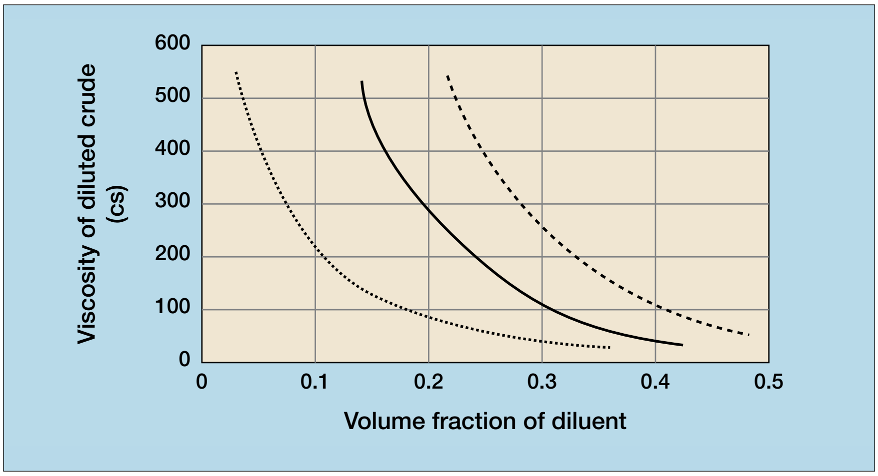

Figure 1 Volume fraction of diluent required for heavy crude

Production
High viscosity and density make the production of heavy crude oil a difficult and energy-intensive task. Traditional recovery methods utilise steam flood, cyclic steam stimulation, steam-assisted gravity drainage (SAGD) or solvent injection. While all of these are now proven and commercially practised, the costs associated with the generation of steam and power remain an issue that negatively affects the cost of oil production. For example, in the case of SAGD, a 3–5 steam-to-oil ratio is needed to extract a barrel of bitumen from tar sands. In many facilities, this can only be accomplished by burning imported natural gas (as most of these heavy deposits have little or no associated gas), whole crude or crude-derived light distillate products.

Dewatering
Due to the relatively small difference in density, dewatering of these extra-heavy crudes and bitumens at the production site often involves the use of lengthy residence times, large storage capacity, addition of expensive chemicals or diluent-assisted dewatering. The associated capital investment and the cost of utilities and chemicals for the conventional dewatering process can add up to a significant 25–50¢/bbl oil.

Transportation
High viscosities mean that transporting these heavy crudes remains the single largest inhibitor to the effective monetisation of these stranded assets. The only sustainable economic means of transportation is through pipelines,

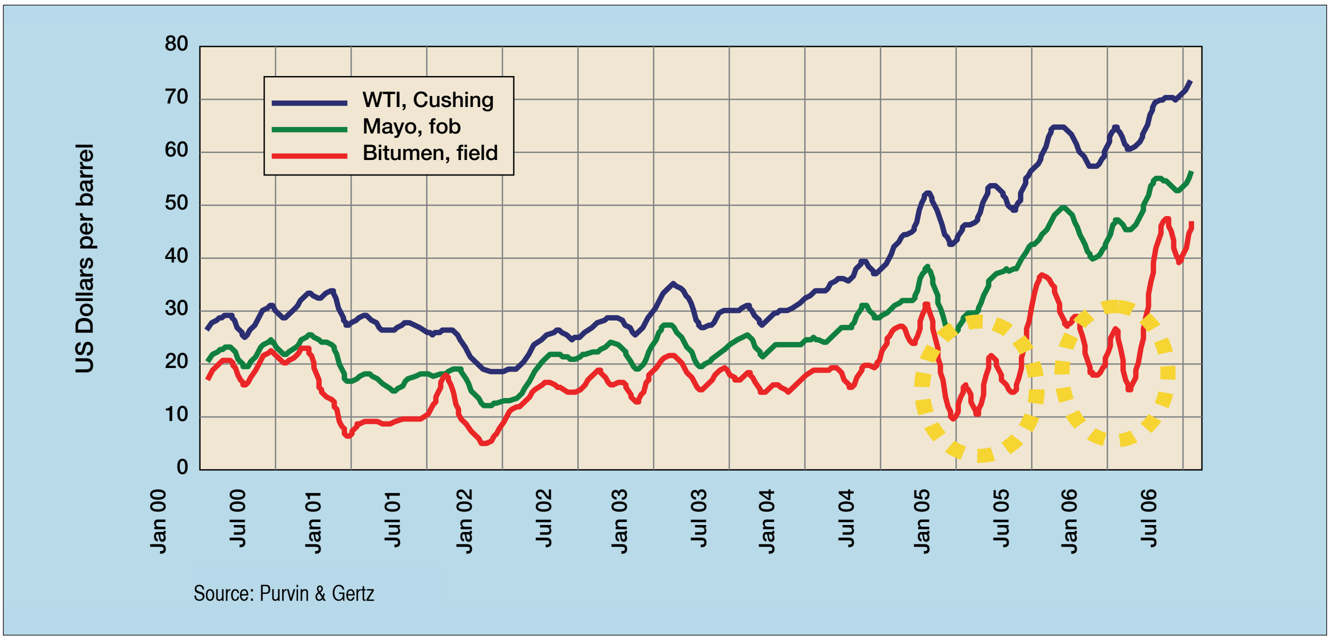

Figure 2 Heavy crude prices drop as demand for fuel falls

which requires that the material be upgraded to a transport viscosity specification. This often translates to about 250–300 cSt at pumping temperature conditions.

Diluents

By necessity rather than by choice, the dilution of heavy oil with a less viscous hydrocarbon such as condensate, natural gasoline or naphtha is widely practised. While this may appear to be simple on the surface, it is clearly an expensive proposition. Figure 1 illustrates the amount of diluent needed to lower the viscosity of heavy crude deposits to make them economically transportable. To meet transport viscosity specifications, many block owners use a diluent fraction that could be as high as 30% of the transported heavy oil. In many areas, the availability of diluent itself poses a significant problem. While recycling may mitigate the issues linked to availability, it still involves substantial operating costs associated with the distillation of the solvent from the crude mix. Recycling also involves a large capital investment incurred by the dual pipeline arrangement required for the supply of diluent, the additional capacity required for moving the diluted crude, as well as the diluent recovery facilities.

The type and volume of diluent requires careful scrutiny, as incompatibility with the crude can lead to asphaltene precipitation in the pipeline, which may cause fouling-related operating problems.

Heated pipelines

Some owners use heated pipelines in order to enhance the oil's flow properties. Implementation of heated pipelines involves complex design criteria to address expansion

To meet transport viscosity specifications, many block owners use a diluent fraction that could be as high as 30% of the transported heavy oil

of the pipelines, pumping/heating stations, heat losses and so on, as well as greater corrosion rates arising from elevated temperatures. However, the biggest issue is the low availability of the asset, which seems to be the primary reason why many owners seek to abandon this approach in search of more reliable options. Loss of electricity, heating medium and pipeline flow can cause heavy crude oil to solidify, requiring expensive and time-consuming processes to clear, which may result in an extended loss of service.

Thermal processes

Another method for reducing the viscosity of heavy oil, and thus enabling it to be transported by pipeline, is the use of thermal treatment (with or without a catalyst) in the field in moderately scaled reactors. During thermal treatment, asphaltenes will begin to precipitate and subsequently form deposits, which, if not controlled, will cause instability in the resulting oil. Moreover, in upgrading the viscosity of crude oil by cracking, the olefins and diolefins produced will tend to polymerise, making the crude unstable and unsuitable for transportation through pipelines. Therefore, most refiners are reluctant to process cracked stocks in their crude diet, which only drives down the marketability and value of the crude.

Refining problems

Heavy crudes can cause a threefold increase in the amount of resid coming to the refinery. Beyond the obvious strain imposed on the capacities of vacuum distillation units and delayed cokers (or other bottom-of-the-barrel processing units), they cause a severe imbalance in the refinery, often leading

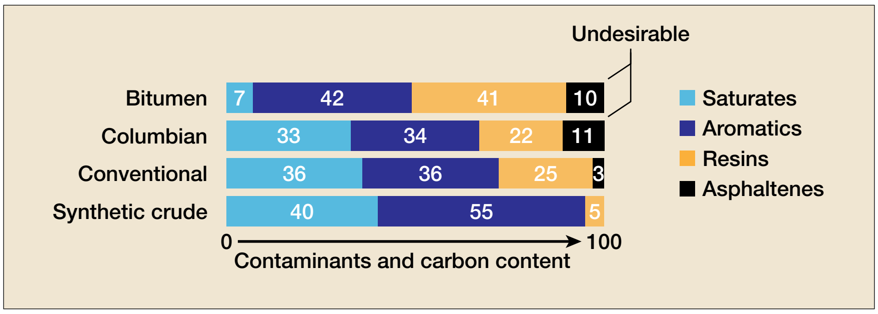

Figure 3 SARA analysis for typical crudes

to under-utilisation of light end processing assets.

While refiners blend these heavy crudes with other lighter crudes for processing, careful attention must be paid to crude compatibility issues, since heavy crudes have a higher propensity for fouling from asphaltene precipitation.

In general, these issues limit the amount of heavy oil intake in the crude diet and collectively contribute to the lower heavy oil demand and the consequent light heavy differential that is apparent today. While refiners have endeavoured to take advantage of this spread by selective investments in the bottom-of-the-barrel sections, the heavy oil producer is still faced with a product value that increases the breakeven threshold for investments that are required to monetise the heavy oil acreage. According to Figure 2, historical data shows that, in times of slow demand, refiners tend preferentially to drop the heavier oils from the crude diet, further straining the economic viability and survival of the heavy oil producer.

The questions that daunt heavy oil producers concern the economics and the degree of upgrading required. While full upgrading to light, sweet, bottomless synthetic crude oil may be one option that will command widespread market acceptability and positive economics, this can be capital intensive and may not be suitable for all locations.

Against a background of high volatility in the markets, which is expected to continue, the optimal solution for smaller blocks in remote locations with little or no infrastructure may rest with partial upgrading. This is especially true in an environment of uncertain margins, where the size of capital investment can come under a higher threshold of serious scrutiny over traditional project return-on-investment criteria.

It is in this context that a lower-cost option involving the ability to achieve partial benefits by moving the crude at relatively low initial investments, while preserving the option for incremental benefits with higher, full upgrader investment in the future, gains increasing importance.

Principles of molecule management

The principles of molecule management dictate that the best economics are derived by capturing the highest value of every molecule present in naturally occurring crude oils at every point in the process. When viewed in this context, it is evident that much can be learnt by analysing the whole heavy crude in general and the more problematic residuum fraction in particular; not by the traditional barometers of boiling range and gravity, but by molecular speciation.

Crude oil consists of hydrocarbons in the form of saturates, aromatics, resins and asphaltenes (SARA). To understand a heavy oil's characteristics and the problems associated with its production, transportation and refining, it is essential to understand the chemistry and composition of the heavy crudes. SARA analysis, illustrated in Figure 3, is a method for the characterisation of heavy oils into saturates, aromatics, resins and asphaltenes based on solubility-based fractionation, whereby a heavy oil sample is separated into smaller quantities or fractions, with each fraction having a different composition. The separation is based on the solubility of hydrocarbon components in various solvents used in this test. Each fraction consists of a solubility class containing a range of different molecular-weight species.

Saturates are generally iso- and cyclo-paraffins, while aromatics, resins and asphaltenes form a continuum of molecules with increasing molecular weight, aromaticity and heteroatom contents.

Asphaltenes to a large extent, and resins to some extent, contain all the CCR, metals (such as nickel and vanadium) and a substantial portion of the polars — sulphur and nitrogen. As Figure 4 shows, all heavy crudes have very high asphaltene contents (>10%) compared to light crudes (0–5%).

While analysing the physical and transport properties of the

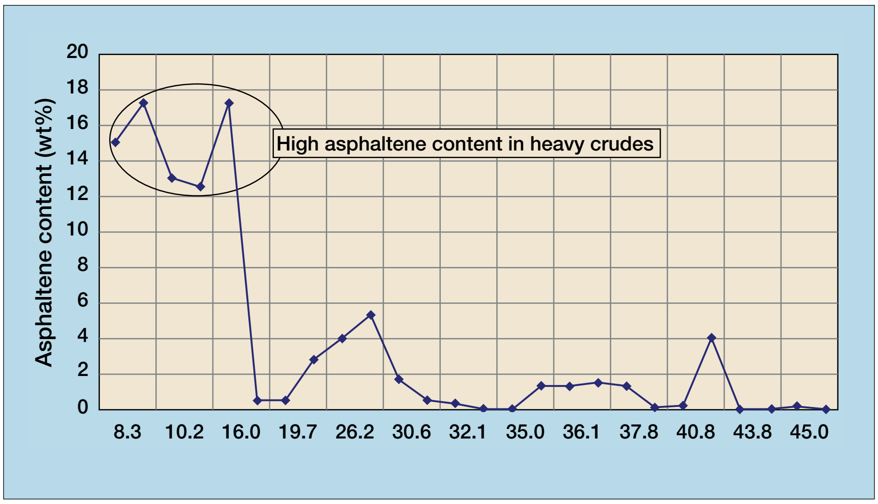

Figure 4 Asphaltene-to-crude API typical relationship

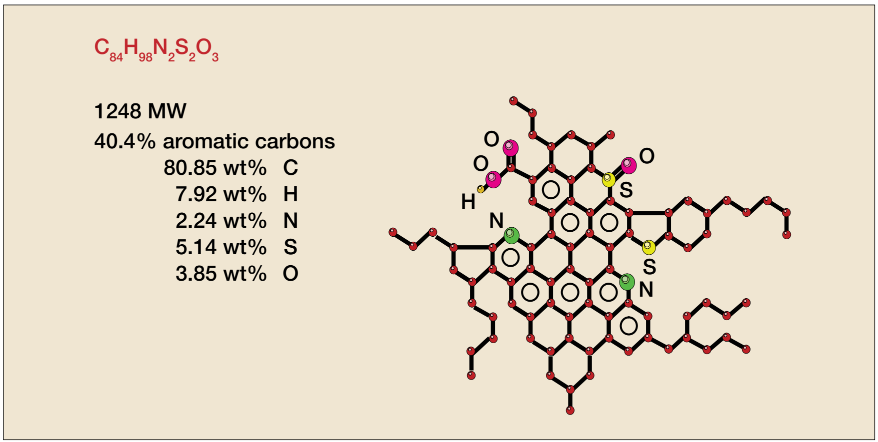

Figure 5 Asphaltene materials with complex structures

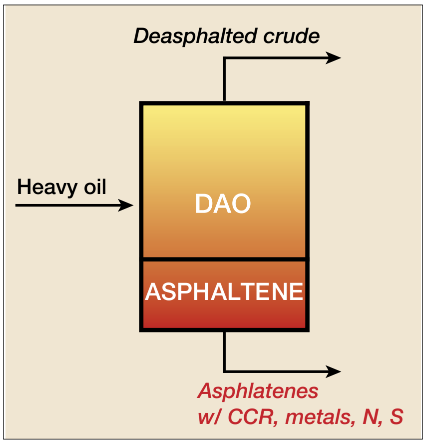

Figure 6 Conversion of heavy oil

asphaltene fraction, it becomes evident that most of the problems associated with heavy oil production, transportation and refining can be resolved by removing this fraction from the heavy crude.

Asphaltenes, as Figure 5 shows, represent the heaviest and most aromatic and polar fraction of a crude oil. These molecules are composed of poly-condensed aromatic rings carrying aliphatic chains that contain acid base and polar groups at their edge. Due to their chemical characteristics, they self-assemble through physical interactions and increase the viscosity of the medium to which they are added. The resultant high density and viscosity of the crude oil contribute to production and transport problems.

Asphaltenes can also foul and plug pipelines if they are destabilised by mixing with another crude oil during transportation, or by other steps in oil processing. Due to the high metals and CCR inherently present in the asphaltene fraction, it is highly undesirable for processing in conventional refineries. It is ironic that all traditional solutions incur substantial capital and operating costs to transport the least desirable molecules in the crude to the refiner only to be rejected as low-value fuel oil or coke at the refinery.

Refining processes are designed to change the high C:H ratio present in naturally occurring crude oils to a high H:C ratio needed for transportation fuels. Saturates are the easiest to crack and hence the most suitable for the refiner's purpose.

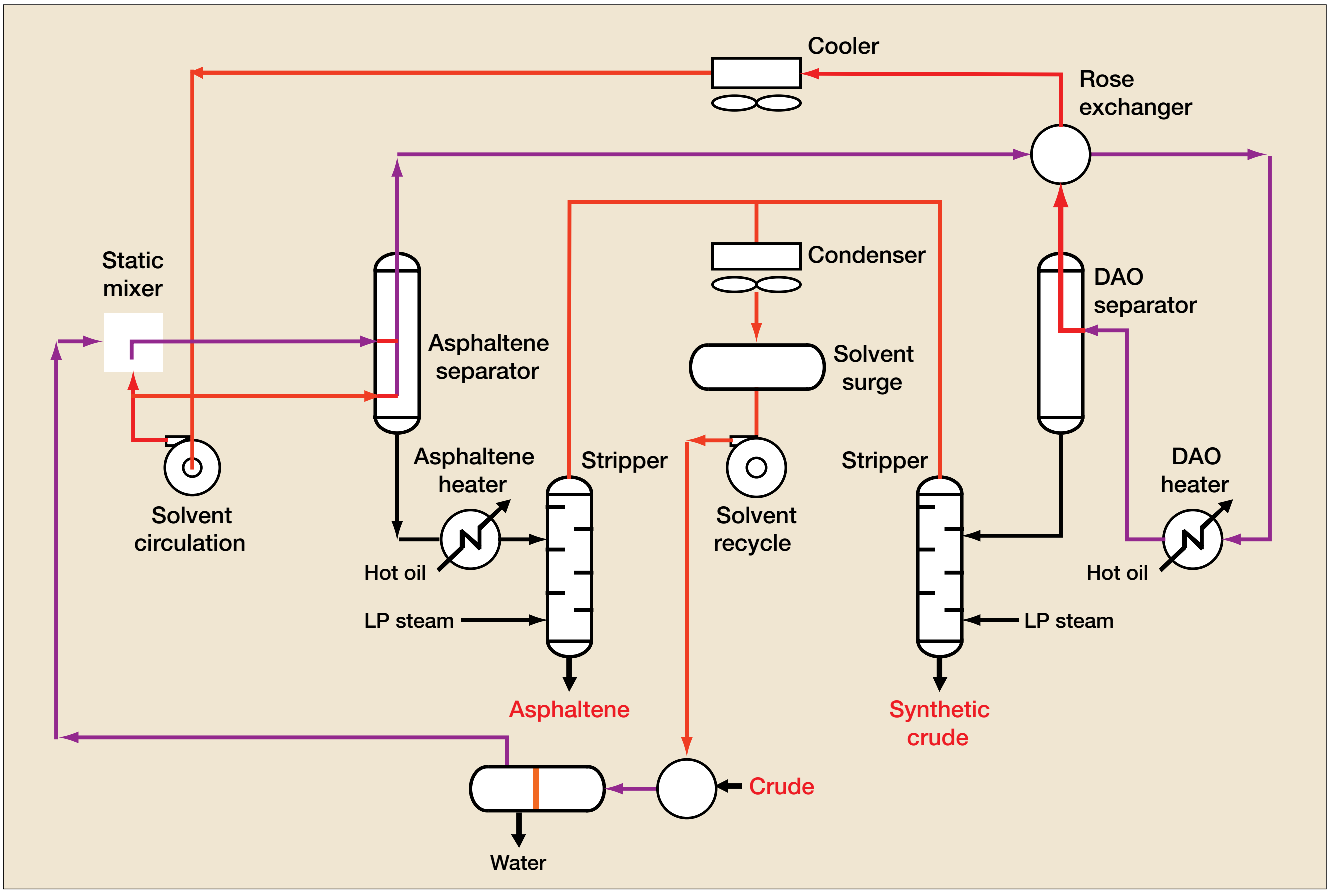

Figure 7 Roseflow process to dewater and lower crude viscosity

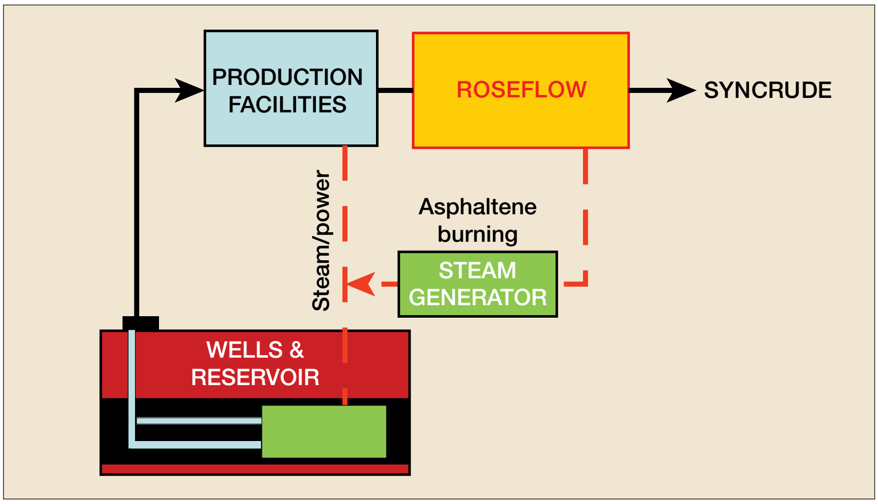

Figure 8 Roseflow process applied to field upgrading of heavy oil

Crude properties of case study feed

Stream properties	Crude
Yield, wt% on crude	100
Yield, lv% on crude	100
Specific gravity @ 60°F	0.9826
°API gravity	12.5
Nitrogen, wt%	0.38
Sulphur, wt%	1.32
Conradson carbon, wt%	12.7
Nickel, wppm	37
Vanadium, wppm	147
Viscosity	
cSt @ 210°F	51
cSt @ 80°F	7372
cSt @ 550°F	3
R&B softening point, °F	20

Table 1

Although simple aromatic molecules typically display enhanced chemical stability when compared to similar non-aromatic molecules, they can also be cracked to form useful fractions in the refinery. Resins can be cracked in traditional thermal cracking processes. However, asphaltenes are much tougher to crack and, hence, are the least preferred from the refiner's perspective.

Asphaltenes are the primary contributor to refining incompatibility and the principle reason for the high price differential between light and heavy crudes. Therefore, it is obvious that a substantial improvement in capital and operating costs incurred, and a significant upgrade in crude value, will be achieved by removing this fraction directly at the production site. The resulting near-bottomless crude, improved in its density and viscosity, with substantially lower contaminant levels, can now be transported to refineries by traditional methods. This deasphalted crude will be more compatible with other, lighter crudes on the market, enabling a refinery to accept a greater fraction of cheaper, heavier material into its crude diet.

Solvent deasphalting

The solution involves the use of a proven, solubility-based physical separation process, solvent deasphalting, wherein saturates and aromatics (and much of the resinic molecules) can be effectively separated from asphaltenic molecules contained in the residuum. Solvent deasphalting uses a paraffinic solvent, which, by molecular structure (like dissolves like), preferentially dissolves paraffinic and naphthenic molecules while rejecting the complex aromatic-rich molecules in pitch. Although light paraffin solvent-based deasphalting is often referred to as a metals or CCR rejection process, in essence it is a complex aromatics rejection technology. The reject contains complex aromatic molecules, or asphaltenes, that are the least soluble in paraffinic solvents, are highly hydrogen deficient, exhibit very high viscosities and contain the majority of polars that are least desirable when fed to a hydroprocessing or catalytic conversion unit.

Asphaltenes can foul and plug pipelines if they are destabilised by mixing with another crude oil during transportation

The resulting deasphalted oil will exhibit substantial improvement in density and viscosity, enabling it to be transported to the refinery, and substantial improvement in hydrogen content, CCR, metals, sulphur and nitrogen, making it more compatible with traditional refining operations.

The reject asphaltenes can be used to generate power and steam, support exploration and transportation infrastructure needs, or solidified and transported for use as solid fuel in other industries.

Inherent in the design of the KBR Roseflow process (see Figure 7) is the ability to dewater the whole crude without incurring any additional capital or operating expense. This feature involves simple mechanics, but entails a more complex understanding of the principles and behaviour of residuum molecules to arrive at this solution.

At a molecular level, while solving the dewatering, transport and refining problems, this concept also preserves the higher value white oil molecules for use as synthetic crude and the eventual production of higher value transport fuels. The rejected lower value pitch may be reserved for use as fuel at the production site, which, in essence, maximises the value of every barrel of extra-heavy crude oil produced.

Case study

In this illustration, a heavy oil production site would like to produce and transport 50 000 b/d of heavy, sour crude (API 12.5) through pipelines. The crude is associated with approximately 30% water with very little gravity difference to aid in separation. The production site is a remote location

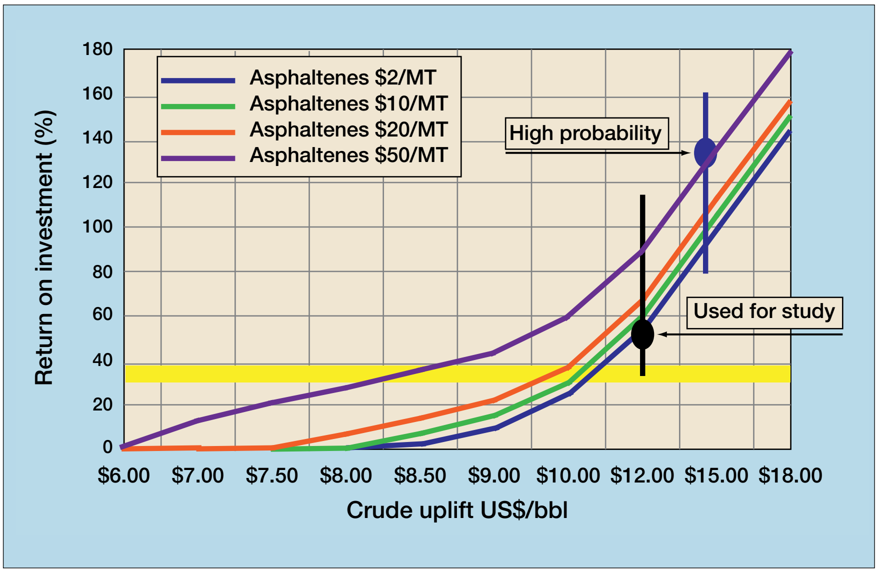

Figure 9 Case study economics of Roseflow process

Roseflow material balance

Stream properties	Crude	Asphaltene	Synthetic crude
Yield, wt% on crude	100	20.8	79.2
Yield, lv% on crude	100	17.7	82.3
Specific gravity @ 60°F	0.9826	1.149	0.9466
°API gravity	12.5	-8.3	18
Nitrogen, wt%	0.38	1.07	0.19
Sulphur, wt%	1.32	2.54	0.95
Conradson carbon, wt%	12.7	50.72	2.91
Nickel, wppm	37	180	2
Vanadium, wppm	147	671	7
Viscosity			
cSt @ 210°F	51	–	–
cSt @ 80°F	7372	–	203 @100F
cSt @ 550°F	3	3275 cp @512F	–
R&B softening point, °F	20	362	–

Table 2

with little infrastructure and no available natural gas. Table 1 shows the properties of this crude.

For monetisation, the crude must be economically dewatered and upgraded to a minimum of 16.5 API and a minimum viscosity of 250 cSt at a pumping temperature of 100°F (38°C).

Integrated partial upgrader

The whole crude was tested in the Roseflow process pilot plant to confirm dewatering and viscosity and gravity improvements. Figure 8 shows a block-level schematic of the process.

The dewatering feature of the Roseflow unit was successfully tested to ensure that the whole crude was dewatered to less than 0.5 wt% moisture. The crude was then processed in the unit, and the conditions were adjusted to meet a target viscosity specification of 250 cSt at 100°F (38°C). Several runs, including multiple solvents, solvent-to-oil ratio and operating conditions, were tested to arrive at the optimal operating conditions. The conditions were repeated to ensure accuracy. Large samples of the products were collected for third-party assay analysis and supply to prospective refiners, and the pitch samples were used to ascertain fuel value and establish the balance for infrastructure power and steam needs.

The pilot plant results are summarised in Table 2. It is evident that, while the crude was deasphalted to a pipeline viscosity specification, the owner also realised the incremental benefits of gravity improvement and a substantial quality improvement through the reduction in CCR, metals, nitrogen and sulphur.

Return on investment

On average, with the integration of a partial upgrading facility, it was determined that the potential uplift on crude value could be anywhere in the range $12–20/bbl, and the marketability of the crude was enhanced.

The return on investment of the unit as a function of crude price uplift and pitch price are shown in Figure 9. As illustrated, the economics of the operation at virtually zero pitch price and at the low end of the crude price improvement is very attractive. At the high probability end, the payout is well below one year.

Conclusion

Partial upgrading using Roseflow is a very effective technology to solve multiple issues associated with monetising stranded heavy oil and extra-heavy oil fields. A fully integrated solution can be used effectively to dewater, deasphalt and transport the high-quality synthetic crude through conventional pipelines. The use of pitch as fuel enhances oil recovery and offsets infrastructure needs, improves project margins and results in a total solution at an investment that is a fraction of that required for traditional upgraders.

ROSEFLOW is a mark of KBR.

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