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HYDROCARBON PROCESSING®

Consider new methods for bottom of the barrel processing—Part 1

Advanced methods use molecule management to upgrade heavy ends

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Large price differentials between light, sweet crudes vs. heavy, sour crudes have created strong incentives for refiners to lower costs by incorporating as much heavy crude blends into the refinery processing in scheme as it can tolerate. Several refineries have little or no bottoms processing capabilities, thus yielding large volumes of high-sulfur fuel oil (FO). New bunker-fuel legislation and pending carbon-footprint initiatives create the need to further upgrade refinery resid products, both for expansion and enhancement reasons. Several case histories will cover the staggered investment options to produce premium road asphalt and solid fuels (Fig. 1).

Changing crude diet. Recent economic and geopolitical global uncertainties are factors in the steep rise in crude prices, thus affecting refinery operations worldwide. Refiners are finding themselves faced with the difficult quest to search for crude blends to maximize margins. While refinery margins will continue to be dictated by processing heavier, more sour crudes, the dramatic increase in residuum content from 10% in light sweet crudes to 50% in extra heavy crudes poses interesting challenges, while presenting some unique opportunities. The bulk of the global operating refineries have little or no residuum processing capabilities and produce large volumes of high-sulfur FO (HSFO) and bunker fuel.

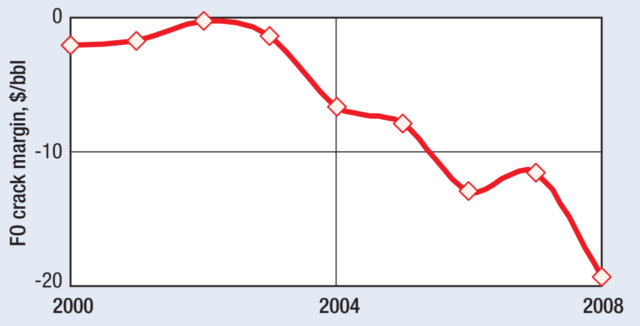
As demand shifts to natural gas, FO demand is expected to drop adversely, thus affecting FO prices in the future (Fig. 2). This situation is only expected to worsen as refiners face regulatory pressures ranging from new maritime bunker fuel specifications to carbon dioxide cap-and-trade and carbon footprint limitations. As the world moves towards cleaner bunker fuels, finding alternative means to upgrade bottom of the barrel streams will become increasingly important.

In parallel, the demand for jet fuel and diesel is expected to grow, and many refiners are actively focused on shifting demand from motor gasoline to diesel, while still analyzing all available options. The price differential between diesel and gasoline is likely to be sustained over the long-term and is validated by the billions of dollars of investment announcements by the major international and national oil companies toward dieselization. In markets dominated by fluid catalytic cracking (FCC)-based refineries, this need to increase distillate production has taken on a new dimension that will impact long-term refining margins.

Changes in C/H ratios. In its simplest form, refining is the process of changing the carbon-to-hydrogen (C/H) ratio of naturally occurring crude oils. Thus, at the molecular level, the operation of all 650 refineries in the world is essentially targeted at converting high C/H ratio feedstocks into high hydrogen to carbon ratio for transportation fuels. This ratio change between the crudes and products can only be accomplished through two broad processing routes: carbon rejection and hydrogen addition.

While profitability can only be sustained by economically converting the large volumes of residuum into high-value transport fuels, these objectives must be accomplished in a difficult business climate that mandates applying low-investment solutions while optimizing usage of existing refinery resources.

FIG. 1 The residuum oil supercritical extraction unit at the Navaho Refinery.



Source: Singapore margins w.r.t. Dubai crude from Platts

FIG. 2 FO cracking margins 2000 to 2008.

Carbon rejection. Carbon rejection is favored by low crude prices and high hydrogen prices, when it is economical to reject the residuum as petroleum coke, while producing the required transport fuel volumes by incremental crude oil processing. During these processes, the bulk of feed contaminants are rejected with the carbon into the coke, rather than into the liquid products. Traditional carbon rejection techniques include FCC, resid fluidized catalytic cracking (RFCC), delayed coking (DC) and visbreaking (VB).

FCC and RFCC in combination are widely used carbon rejection technologies to convert the high-boiling, high-molecular weight hydrocarbon fractions into more valuable gasoline, olefinic gases and other products. However, due to the nature of the process, they are limited in processing lighter, low-metals, low-sulfur residues. **Visbreakers** are essentially a means of improving viscosity of the residuum so as to minimize the addition of valuable distillate boiling range cutter stock to meet FO specifications. In addition, with the increasing shift in product demand from motor gasoline to diesel and jet fuels, these technologies will no longer be the first choice.

Residues from heavy crude oils contain high concentrations of sulfur, complex hydrocarbons and heavy metals such as nickel and vanadium. Due to the nature of these residues, **delayed coking** technology is the most commonly used carbon-rejection technology. However, this process produces highly hydrogen-deficient, unstable products that require further processing and yields coke residue—a high C/H ratio molecule, as a byproduct.

Although, **coking** is a mature technology with low implementation risks, in a carbon footprint future, this technology is likely to face stiff environmental and regulatory resistance even in the face of lower crude prices. High-sulfur petroleum coke prices are distressed and as is evident in the Canadian inland environment, coke is just being piled up in large quantities with no real economic outlet. This trend cannot be sustained in the long run.

Hydrogen addition. Conversely, hydrogen addition is favored by high crude prices and low hydrogen prices when it is more economical to upgrade the residuum to transport fuels, while maximizing the transport fuels production from the base crude capacity. Thus far, residue-hydrogen addition technologies have focused on fixed-bed hydrocracking as against ebullated-bed hydrocracking and slurry-phase hydrocracking, the former requiring periodic shutdowns to regenerate catalyst.

Ebullated-bed processes are continuous and produce higher levels of liquid fuels (no coke). But they are unable to achieve complete resid conversion and still produce 20%–30% of heavy-resid product. Ebullated beds have also been prone to high operating costs, and have sometimes been plagued with poor operability. The quality of liquid products, although improved over coking, still requires secondary processing to produce clean fuels. The inability to achieve near complete conversion requires further processing of unconverted resid. As a result, ebullated-bed technologies have not achieved huge deployment, which, when coupled with the high capital cost, makes them the least robust at low-oil price scenarios.

Slurry-phase hydrocracking. The recent flurry of activities indicates the advent of slurry-phase hydrocracking into the market place. This technology adopts high operating pressures and can achieve near complete conversion of the residuum while producing finished saleable products. While the projected economic conditions of high crude prices and low gas prices are ideal for investment in these high-pressure/high conversion technologies, the capital investment requirements may have some dampening effect for immediate widespread adaptation.

Principles of molecule management. In the background of high volatility within the markets, which is expected to continue, the optimal solution may require most refiners to adopt a combination of carbon rejection and hydrogen addition processes. This is especially true in an environment of uncertain refining margins where the size of capital investment can come under a higher scrutiny over traditional project "return on investment" criteria. It is in this context that a staggered investment option involving the ability to achieve partial benefits at lower initial investments, while preserving options for incremental benefits with higher investment in the future, gains increasing importance.

Refiners are often constrained by the need to convert a defined crude slate to a set product slate without realizing the change required at the molecule level and the cost associated with such conversion. Refiners can also be blinded by the compelling need to produce traditional refinery products such as transport fuels and petrochemical feedstock from every barrel of crude, often expending substantial capital in the process, while ignoring economic synergistic opportunities that may exist with other nontraditional industrial applications.

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 it will be prudent to analyze the residuum fraction not only by the traditional barometers of boiling range and gravity, but by molecular speciation.

While distillation based separation schemes for the virgin crude fractions are economical and adopted almost universally, in almost all cases, the volume and quality of the residuum is essentially determined by the quality of the vacuum gasoil (VGO) fraction and the ability to process this fraction through conventional hydroprocessing or catalytic cracking conversion units.

In most cases, the limiting factor is the metals content or the Conradson Carbon Residue (CCR) in the GO. The residuum volume and quality is, by balance, a reject defined by GO quality, and is characterized as **black oil**. By conventional wisdom, this stream is either removed as FO or asphalt, or is subject to thermal conversion processes for upgrading.

While it is a well-established fact that hydro or catalytic conversion of the heavy gasoil (HGO) fractions will result in substantially better yields and qualities of transport fuels (gasoline, jet fuel and diesel) than thermal conversion processes, and the incentive to maximize this fraction of the crude exists, operating economics are substantially influenced by the incremental concentration of impurities (metals and CCR) in the feed due to their impact on conversion unit catalysts.

When analyzing the residuum at a molecular level, it will be evident that a substantial volume of higher boiling range white oil molecules worthy of effective catalytic upgrading are present in this fraction, which by conventional methods, are rejected as black oil products or subjected to thermal conversion processes. This phenomenon is essentially caused by limitations in distillation-based separation processes where the lowest boiling point species of the undesirable impurity is the determining factor in the volumes of the GO and residuum derived. This impacts the refinery product slate and economics negatively.

It is, therefore, essential to look at supplemental alternate separation technologies to effectively extract these higher boiling white oil molecules from the residuum. The options become obvious when analyzing these molecular species, and it is clear that these undesirable impurities are essentially asphaltenic or resinic in nature and can be separated by solubility driven processes.

White oil molecule management. The solution involves applying the solubility-based physical separation process, solvent deasphalting (SDA), wherein the saturates can be effectively separated from the resinic and asphaltenic molecules contained in the residuum. SDA uses a paraffinic solvent, which by molecular structure (*like dissolves like*) preferentially dissolves paraffinic and naphthenic molecules while rejecting the aromatic-rich molecules in the pitch (Fig. 3).

Although light-paraffin solvent-based deasphalting is often referred to as a metals or CCR rejection process, in essence, it is an aromatics-rejection technology. The reject contains complex aromatic molecules that are the least soluble in paraffinic solvents, are highly hydrogen deficient and contain a majority of polars (metals and CCR) that are least desirable when fed to a hydro or catalytic conversion unit.

Conversely, the extract or the deasphalted oil (DAO) contains essentially the saturates, with very low metals and CCR, making this a white oil ideal for conversion processes. Also, the top barrel of DAO derived from the residue via solvent extraction by all measures, will always represent a superior conversion feedstock to any secondary unit when compared to the last barrel of VGO derived from a distillation process.

When examining the suitability of feedstocks to a conversion process, the inherent molecular content (as opposed to boiling range) and their impact on conversion unit performance will become obvious. For example, a close examination of the Watson K factors of feeds derived from GO fractions and resids from staple Arabian crudes to an FCC unit will reveal that the DAO derived from a solvent extraction process brings in resid boiling range white oil molecules that are not otherwise achievable by conventional distillation based processes (Table 1).

The DAO, rich in paraffins and saturates, is an excellent feed to the FCC. Also, due to the inherent nature of the aromatic rejection associated with solvent-based separation processes, the DAO will always have a higher Watson K than the corresponding VGO from the same crude.

As listed in Table 2, the FCC yields and product qualities derived from a DAO based feed (Mid Continent) is very similar to the VGO yields from the same crude in spite of processing heavier molecules derived from the resid boiling range. The alternate option would be to reject these valuable resid white oil molecules to lower value black oil products, or to process through a lower yield thermal conversion process while reprocessing the derived coker GOs in the FCC. The understanding of the value of these high hydrogen content resid molecules and their disposition is a critical data point in determining refinery yields and economics.

An understanding of the metals and CCR content in the DAO stream and their impact on conversion unit catalysis is critical to determining the extractable volume of white oil molecules contained in the residuum. While metals are inherently addressed by demetalization catalysis in a hydrocracker, or by FCC catalyst consumption, and the economics are easy to calculate, the understanding of the CCR is more complicated (Table 2).

Notice that the CCR content of DAO is nearly 10 times higher than the VGO, yet the yields and product qualities and coke make are still comparable. The obvious inference is that the CCR in this case does not impact the conversion simply by virtue of the molecules that contribute to it.

In its simplest form, CCR is the residue derived from a test wherein a heavy hydrocarbon is subject to a temperature-time exposure. While the temptation to use CCR as a parameter to establish conversion unit performance exists, a molecular level examination will highlight significant differences. In short, all CCRs are not the same. While the heptane insolubles have an almost direct permanent deactivation effect on downstream process catalysts, the other CCR molecules have a far less telling effect.

The CCR derived from a distillation-based separation process will contain substantial C_7 insolubles, while that in a DAO derived from a solvent extraction, by definition, should be nondetectable. This distinction can be clearly demonstrated by operating performance differences between units processing atmospheric or vacuum resids and those processing DAOs with identical CCR content. This difference is often not well understood by refiners while correlating the impact of CCR on their unit performance.

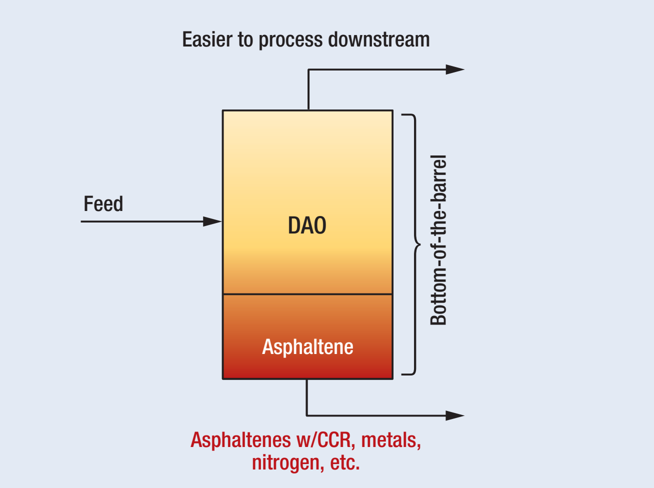


FIG. 3 Solvent de-asphalting process and product streams.

TABLE 1. Watson K of FCC feed fractions

Feedstock source	Atmospheric resid	VGO	Propane DAO	Butane DAO	Coker GO
Arabian light	11.60	11.68	11.81	11.74	11.4
Arabian heavy	11.44	11.62	11.86	11.78	11.4

TABLE 2. FCC yields from Mid-Continent VGO/DAO and CGO

	100% DAO	100% VGO	100% CGO
API	19.2	24.7	19.0
S, wt%	0.79	0.75	
CCR, wt%	3.9	0.39	Less than 1
Ni + V, PPM	16	1	Less than 1
FCC yields, wt%			
Conversion	80.3	81.05	63.2
C_2^-	4.86	3.65	1.49
Total C_3's	6.37	6.80	4.60
Total C_4's	10.30	11.76	8.87
Total gasoline	48.98	52.12	40.16
Total cycle oil	19.70	18.95	35.78
Coke	9.79	6.72	6.00

TABLE 3. Commercial data for conversion

	Supercritical SDA	After conversion to residuum oil supercritical extraction
Feed rate, bpsd	7,000	10,000 (up to 15,000)
Solvent ratio vol/vol	4.5–6	5–6
Energy MMBtu/bbl	99	69
Deasphalted oil quality		
Yield, LV%	65–75	70–85
Asphaltene, (C_7 insols) ppmw	200–800	< 25
CCR, wt%	12–13	9–11
High pressure vessels		
Extractor	With trays	With advanced intervals
DAO separator	With mesh pad	With advanced intervals

While the DAO must theoretically contain no C_7 insolubles, an examination of the DAO derived from conventional SDA processes would often indicate levels ranging from 300–1,000 ppmw. This can only be explained by the phenomenon of entrainment. With the advent of state of the art structured-packing based internals into the solvent deasphalter separator vessels in 1995, the level of C_7 insolubles is now controlled at or below 100 ppmw in most deasphalting units and below 25 ppmw in several high performing units. As an added benefit, the process unit can now operate at about twice the phase rates of conventional separators and provides about twice the mass transfer efficiency of conventional extraction contacting devices.

Table 3 lists commercial data published by a US refiner that shows the before and after conversion of a non-supercritical SDA unit to an advanced residuum oil supercritical extraction technology with advanced internals. As evident from the data, the addition of new internals and adoption of residuum oil supercritical extraction methods achieved a higher throughput, higher yield and a better DAO product quality. All this was achieved at similar operating conditions with significantly lower specific energy consumption. Note, the decrease in asphaltene content of the DAO to nearly below detectable limits, conforming the assertion that the presence of C_7 insolubles in the DAO is an artifact of entrainment that can be controlled by good technology and internal design features. **HP**

Next month. In Part 2, the authors discuss new supercritical extraction methods that can be applied to optimize molecule management of residuum.

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HYDROCARBON PROCESSING®

Consider new methods for bottom of the barrel processing—Part 2

New principles of molecule management dictate the best economics when upgrading residuum

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Globally, refiners are often constrained by the need to convert a defined crude feed slate into a desired finished product slate without realizing the reaction changes required at the molecule level and associated costs for such conversions. Too often, refiners can be blinded by the compelling need to produce traditional refinery products such as transportation fuels and petrochemical feedstocks from every barrel of crude. Such actions involve expending substantial capital in the process, while ignoring economic synergistic opportunities that may exist with other nontraditional processing applications. For example, cost-effective upgrading of the bottom of the barrel can involve applying new supercritical extraction technologies that can manage the "black" molecules or residuum oil and produce end products other than transportation fuels.

Black oil molecule management. In Part 1, the merits of DAO as a valuable feedstock to conversion units were presented. However, the limited outlets for the effective disposition of the pitch has historically had some dampening effects on the widespread acceptance of this molecular solution. The commercially practiced solutions, so far, involve using the pitch as a high-sulfur FO (HSFO) blending component, a road-asphalt blending component, thermal or delayed coke feedstock, or as a liquid feed to a gasifier.

Although the blend out to FO will lower the refinery HSFO production, with the diminishing outlets for FO, the ultimate goal of a refiner to eliminate this product is not achieved. In addition, using high-value distillate boiling range cutter stock will have a negative impact on refinery economics.

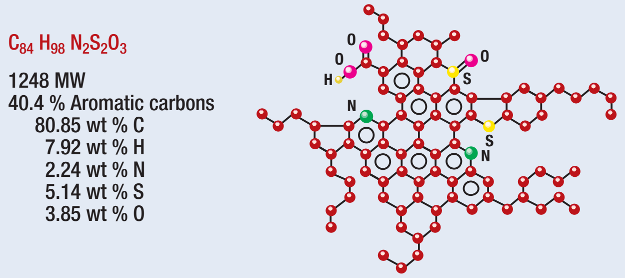
As an alternate option, the most obvious solution would be to direct these black oil molecules to a delayed coker. As the CCR content of the pitch is essentially a product of a concentration effect, its inherent limitation in the delayed coker feed and its impact on coker furnace run length must be considered. In commercial applications, this parameter is closely monitored and is often limited to about 34 wt%, with the option to go up to 38 wt% in a grassroots design. This, in turn, means that limitations in coker feed CCR can sometimes be the controlling factor in the amount of white oil molecules that can be lifted from the residuum.

In many cases, the asphaltene molecules directly produced from a traditional SDA process are too hard to be sold as road asphalt. The production of road asphalt would require the overall lift of the white molecules from the residuum to be very low, making this entire solution uneconomical.

Road asphalt is often driven by seasonal demand changes, and refiners address this through direct air blowing of the vacuum resids (VRs). While air blowing is a solution of convenience, when viewed through the prism of molecule management, it involves the downgrading of valuable white oil molecules contained in the VR to a black oil product—an economic negative, not withstanding the implications of the associated environmental control issues that come with it.

An interesting refinery hydrogen balance can be established through gasification of the pitch. The liquid feed system lowers the net capital investment requirements, although it can still be very high when viewed in absolute terms. In addition, commercial experience suggests a substantial improvement in reliability—in some cases, twice as that of traditional solid-fuel based gasifiers. However, with the projection of depressed natural gas prices, a cheaper hydrogen source availability in the long-term, refiners may find it difficult to justify large investments in gasification technologies.

Pitch molecule management. Against this background, eliminating the pitch at the molecular level will be required to explore all available options to maximize the benefits of the solubility driven process. The pitch consists of essentially asphaltenic and resinic molecules. For this exercise, resinic molecules are



Asphaltene materials with complex structures
Precipitated from crude oils by aliphatic solvents. Soluble in benzene.
Mol. wt. 1,000–3,000. High in S, N, O and metals (V + Ni).

FIG. 4 Asphaltene materials with complex structures.

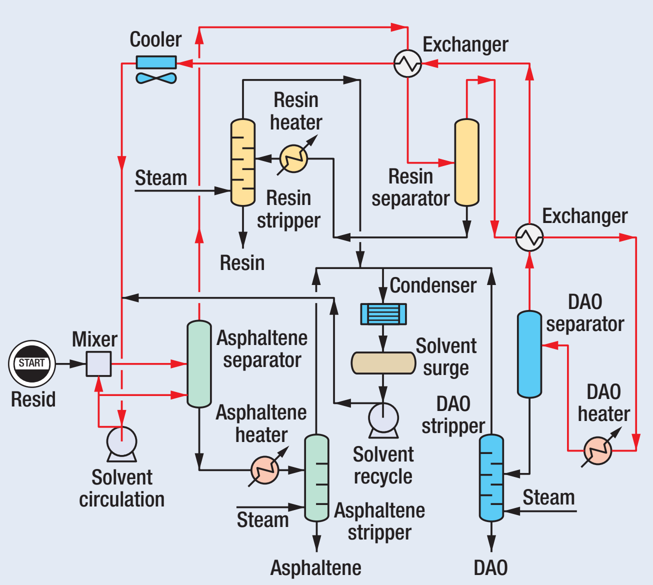


FIG. 5 Flow diagram of a residuum oil supercritical extraction process.

FIG. 6 Solid asphaltene pellets are easier to transport and store.

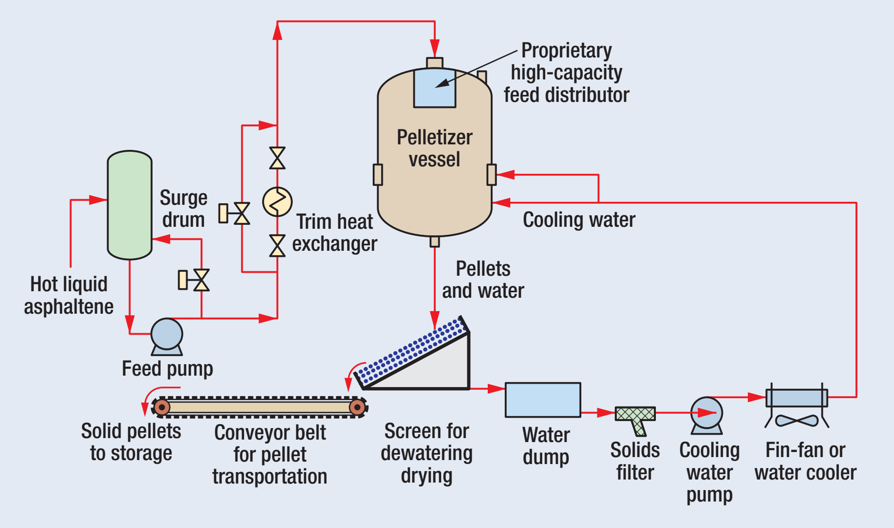


FIG. 7 Flow diagram of asphaltene solid pelletizing unit.

those composed of aromatic rings with long side chains, while asphaltenic molecules are complex aromatic compounds with relatively shorter side chains (Fig. 4). This observation leads to the obvious questions associated with the ability to separate the pitch into two distinct molecular fractions and the refinery benefits that can be derived by finding economic outlets for these fractions.

New supercritical extraction methods. In a solubility driven process, the type of molecular structure is a critical parameter in determining the distribution coefficient of that molecule between the two liquid phases. Therefore, the expectation of separation between structure-based resinic and asphaltenic molecules in this process will not be unreasonable (Fig. 5).

In reality, this is practiced in three operating commercial residuum oil supercritical extraction units where the operating conditions of the asphaltene separator are adjusted to lift the resinic molecules in the DAO. The resinic molecules are then recovered from the DAO by partially expanding the solvent under supercritical conditions.

The intent is to fractionate the DAO exiting the asphaltene separator (that contains saturates and resins) into a light DAO (predominantly saturates) and a resin product. This is accomplished by adjusting the operating conditions of the resin separator so that sufficient expansion of the solvent is realized to selectively drop out the heavy part of the oil, resulting in solubility based separation at supercritical conditions. The yield and quality of the resin may be varied to influence the quality and quantity of the DAO.

This arrangement will also provide the flexibility to balance the streams to the downstream processing needs, while consistently meeting the required DAO quality and exercising other disposition options for the intermediate resin stream.

Resins and road asphalt. Examining the properties of the resin fraction will reveal that this stream can now manifest into multiple product outlets. One economic outlet is the direct road asphalt production—solely from black oil molecules without further processing. The resin molecules are lighter than road asphalt and the required grade of road asphalt can be produced by selectively blending the asphaltenic molecules in the required proportion. Due to the dewaxed nature of these molecules, they exhibit excellent ductility properties at the same penetration not otherwise achievable by traditional technology options.

Inherent in the process is the ability to adjust the volume and quality of the resin. Seasonal demand variations in road asphalt may be addressed by adjusting the resin volumes derived and by selectively directing the excess to either the DAO or the asphaltene fraction.

Asphaltenic rejects. While this solution provides an attractive economic option to produce premium-grade road asphalt, the challenges associated with dealing with the residual asphaltenic molecules remain.

The asphaltenic molecules are high in CCR, metals and sulfur content and are basically not worthy of upgrading. This represents the lowest-value true black oil content of the residues, and the best economics lies in solutions that divert these molecules away from the refinery to industries or end users outside the refining business that have an incentive to process these streams.

The major challenge here is in the handling and transportation of these molecules. The asphaltene product is produced as a high-viscosity liquid that solidifies at ambient temperature. A low-cost, high-capacity solid-pelletization technology is the obvious transport solution and will help refiners to economically store and move these rejects to a more desirable end use (Fig. 6).

Solid fuel. This represents a simple and cost-effective option for asphaltene disposition for the cement and steel market where a large demand for high Btu solid fuel exists.

There are existing commercial technologies that produce solid fuel from the asphaltene rejects. However, these processes are generally capacity limited, high in maintenance, low in reliability, and are manpower intensive. A new solid-pelletizing technology is an ideal solution to solidify asphaltenes and other heavy hydrocarbons. This method is a low-cost process, easy to operate, and has a high expected onstream factor.

The produced pellets are resistant to dusting and can be easily handled, stored, and transported. These pellets are near spherical with an expected size distribution between 1 mm and 3 mm, and they have good grindability, storage and transportation characteristics as indicated by the high Hargrove Grindability Index (HGI), storage test temperature and low friability. The high angle of repose provides high capacity on conveyors. The small amount of residual moisture on the pellets helps to minimize dust formation during transport (Fig. 7).

The asphaltene pellets can be used as solid fuel in the cement kilns, steel industry and in utility industries. The pellets can be added to fuel-grade coke or coal as additive to enhance combustion characteristics. The heating value, organic carbon, and chemical properties such as sulfur, nickel and vanadium are governed by the crude properties. The asphaltene pellets have 20%–50% higher heating value than petroleum coke. In view of the superior heating value, combustion characteristics and ease of grinding, the asphaltene pellets should demand a higher value per ton when compared to fuel-grade coke and coal.

TABLE 4. Interim solution: unit yields, (resin yield 20%, DAO yield 30%, asphaltene yield 50 wt%)

	Feed VR	Asphaltene	Products resin	DAO
Yield on VR, tpd	6,230	3,115	1,246	1869
S.G.@ 60°F	1.033	1.112	0.984	0.952
Nitrogen, wt%	0.4	0.6	0.3	0.2
Sulfur, wt%	5.5	7	4.5	3.7
CCR, wt%	24	40	12.5	5
Nickel, wppm	29	56	4	0.9
Vanadium, wppm	110	216	7.4	1.7
R&B softening pt, °F		250		

TABLE 5. Overall material balance, interim solution

	VR	Virgin VGO	Road asphalt	Solid fuel	FCC feed blend	VGO export
Yield on VR, tpd	6,230	8,847	1,908	2,453	6,869	3,847
S.G.@ 60°F	1.033	0.922	1.025	1.112	0.930	0.922
Nitrogen, wt%	0.4	0.1	0.4	0.6	0.1	0.1
Sulfur, wt%	5.5	3.3	5.3	7	3.4	3.3
CCR, wt%	24	0.9	22.1	40	2	0.9
Nickel, wppm	29	0.1	21.8	56	0.3	0.1
Vanadium, wppm	110	0.4	79.8	216	0.7	0.4
R&B softening pt, °F				250		

Refinery case illustration. In this Base Case, a 200,000 bpsd refinery processes heavy, sour, Middle Eastern crude (API 31.4) producing 6,230 tpd of VR and 8,847 tpd VGO (Fig. 8). The refinery has no bottoms processing units and is currently using high-value distillates to cut its VRs to produce large volumes of low-value HSFO (Tables 4 and 5).

Interim investment option. In this interim option, the refiner invests in a residuum oil supercritical extraction unit and asphaltene solid pelletizing unit, essentially eliminating the production of HSFO. The investment in the ISBL portion of the two units will amount to about US$ 65–75 million (Fig. 9).

This combination represents the most ideal short-term solution to allow all the DAO produced to be processed in the existing FCC units offsetting the equivalent VGO that may be sold. The change in FCC feed will have a small effect on the FCC yields.

The lower the DAO make, the better quality of the DAO, but a higher, lighter resin volume must be handled. The higher volume, lighter resin will lead to a higher road asphalt volume make, and a resultant lower solid fuel production (Table 6).

Final investment option. In this ultimate option, the refiner invests in a product residuum oil supercritical extraction unit and

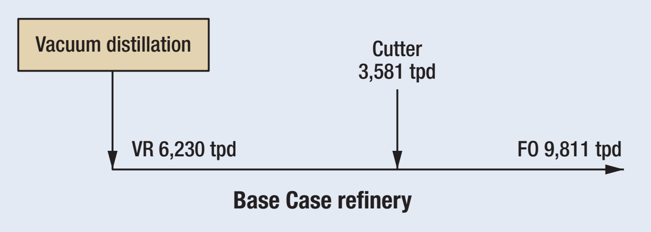


FIG. 8 Base Case refinery processes heavy crude with no bottoms processing capability.

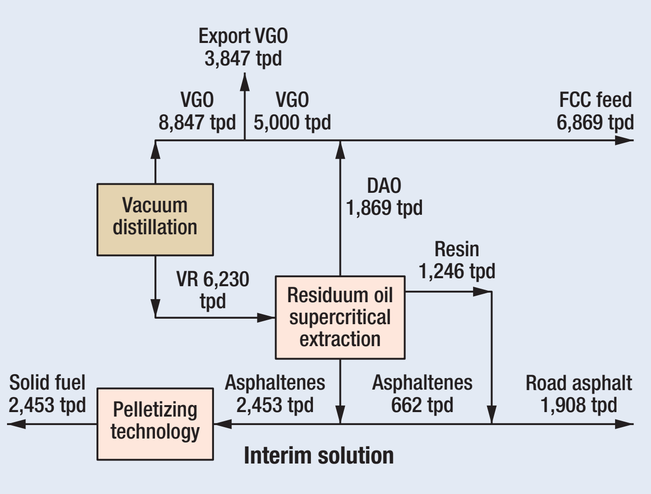


FIG. 9 Base Case refinery processes heavy crude with residuum oil supercritical extraction unit and solid asphaltene pelletizing unit.

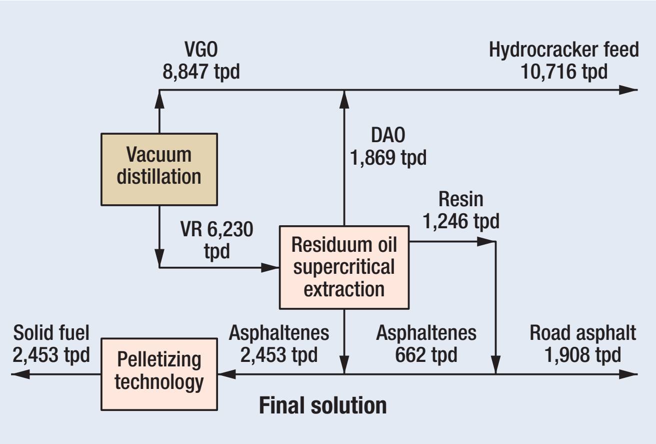


FIG. 10 Base Case refinery processes heavy crude with residuum oil supercritical extraction unit and solid asphaltene pelletizing unit with hydrocracking unit to upgrade extra DAO product.

an asphaltene solid pelletizing unit, essentially eliminating HSFO production. The higher volume of conversion feedstock available will have to be processed in a hydroprocessing unit.

The required conversion can vary from a nominal 20% that is associated with a traditional catfeed hydrotreater to a nominal 65% conversion achievable in a once-through conversion unit.

The design and operating pressure of the hydrocracker can be adjusted to vary the conversion from 15%–55% by varying the operating conditions of the hydrocracker beds. This, in turn, will provide the refiner with the additional flexibility to vary the gasoline-to-diesel ratio derived from the two conversion units, while eliminating the production of fuel oil altogether. The cost of this investment for a large hydrocracker can vary from $400–600 million and can be differed until economic conditions warrant (Fig. 10).

In the low-conversion mode, the FCC will be at its maximum capacity, and the yields and quality are expected to be better than current operations (Table 7). In the high conversion mode, the FCC will be at low throughput and out of heat balance, prompting the need for a small bypass DAO or resin feed to be sent directly to the FCC.

Molecule management summary. When adopting the principles of molecule management, it is clear that the best value is derived by directing the selected residuum molecule to the appropriate end user. The optimal solution will involve adopting unique means of integrating the principles of carbon rejection and hydrogen addition while maintaining a keen recognition of the prevalent investment climate.

The combination of SDA and asphaltene pelletizer technologies represents an economic low-cost solution to eliminate FO production and can be implemented at a fraction of the cost of all other resid processing options. The DAO is an excellent feedstock and can be easily processed in the refinery FCC or hydrocracker units. Premium road asphalt can be derived from the pitch, and the reject solid asphaltene pellets can be sold to the cement, steel and power industries. **HP**

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TABLE 6. Overall material balance, final solution

	VR	Virgin VGO	Road asphalt	Solid fuel	HC feed
Yield on VR, tpd	6,230	8,847	1,908	2,453	10,716
S.G.@ 60°F	1.033	0.922	1.025	1.112	0.928
Nitrogen, wt%	0.4	0.1	0.4	0.6	0.1
Sulfur, wt%	5.5	3.3	5.3	7	3.3
CCR, wt%	24	0.9	22.1	40	1.6
Nickel, wppm	29	0.1	21.8	56	0.3
Vanadium, wppm	110	0.4	79.8	216	0.6
R&B softening pt, °F				250	

TABLE 7. Hydrocracker yields

Case	Low conversion	High conversion
Pressure, psig	1,960	1,960
H_2 circulation, scf/bbl	6,000	6,000
Temperature °F	Base	Base +25
650°F+ conversion	15	53
H_2 consumption	825	1,530
Yields, vol%		
Naphtha, C_5-180°F	0.2	7.2
Kerosine, 180°F–330°F	1.8	17
Diesel, 330°F–650°F	14.6	39.9
FCC feed	85.2	47.5