

## DEEP CUT VACUUM TOWER PROCESSING PROVIDES MAJOR INCENTIVES

### Nontraditional Operating Conditions Offer Significant Benefits For Various Crudes

Running a crude vacuum tower in a deep cut mode can provide economic and operational benefits to the refiner. Fully evaluating these benefits usually requires an engineering study. Crude type, furnace, tower, exchanger and vacuum jet equipment all play important roles in the ultimate capacity, low-pressure capability and revamp cost of each specific unit. However, a simplified analysis can benefit initial project feasibility reviews. Economic judgments can be made to determine project feasibilities and potential project payouts. Accurate feed characterization and effective process simulation are key factors in evaluating the deep cut option.

Deep cut incentives for typical light and heavy crudes, Brent and Arabian Heavy, are compared. Analyzing resultant yields and payouts establishes economic calculations for various charge rates. This technique is valuable in determining project potential and equipment requirements. By examining deep cut concerns, a structure for benefit and risk analysis can be developed.

### Background

Vacuum towers are one of the simpler refinery units since they are not a conversion unit like a hydro-cracker or FCCU. However, vacuum units are important because, along with crude units, they process all of a refinery's incoming crude. Crude and vacuum unit performance affects all downstream operations.

Vacuum units have improved over the years. Originally, many vacuum units had trays for mass transfer. In fuels type vacuum towers where low pressures improve heavy vacuum gas oil (HVGO) recovery and profitability, trays gradually were replaced with random packing. The packing had lower pressure drops than trays, reducing flash zone pressures and overall column pressure drop. In the '70s and '80s, structured packings were successfully installed in many units. Structured packing has an even higher capacity than random packing and is now the dominant contacting device in vacuum service.

Improved vacuum tower operation meets the demands of the ever-heavier world crude slate. Better technology and operation not only accommodate heavier feeds, but allow yield improvements by upgrading residue to HVGC). Increasing HVGO recovery provides a large economic incentive per barrel, and may reduce the need for capital expenditure. Reducing residue production through deep cut vacuum tower operation helps mitigate the effects of heavier crude slates, reducing the need for additional residue processing capacity like coking.

### Deep cut

These operations are characterized by increased gas oil yields and lower column bottoms flowrates. For a vacuum tower, this means a higher residue initial boiling point and greater HVGO production. Because traditional crude vacuum fractionation columns deliver a HVGO/residue cut-point of approximately 1,050 Fahrenheit, deep cut operation is considered to commence when higher cutpoints are implemented. However, many vacuum columns operate at cutpoints below 1,050 Fahrenheit. These units may benefit greatly from higher cutpoints. Cutting deeper into the bottoms to recover desirable product is not a new strategy for any fractionation system. Increased product recovery has always been beneficial to profit enhancement. However, vacuum column operations present an arduous environment for efficient fractionation, which makes upgrading product from bottoms to distillate more difficult than other services.

There are many challenges to atmospheric bottoms vacuum fractionation. High heat removal requirements make pumparounds a necessity. These zones require column height but reduce separation efficiency. Coking and column feed thermal degradation must be managed to ensure efficient and continued equipment operation. Generating and maintaining a vacuum for column operation is often a constant battle. Even with these problems, cutting deeper into the vacuum bottoms product to recover valuable gas oil product is increasingly practiced. This is partially due to technology development. Vacuum tower fractionation technology has improved with better structured-packing options, more knowledge about their operation and coke formation mitigation. Not only distillation technology has improved--conversion units such as FCCs are better equipped to handle heavier gas oil feeds. Ways have also been found to debottleneck these units and raise their yields, increasing the demand

for feed. Finally, refinery crude feeds have been getting increasingly heavier. This trend raises the importance of distillate production and of downstream conversion capacity. These factors combine to focus attention on the potential for deep cut operations.

## Simulation

Today's process simulators are powerful tools for evaluating processes and designing facilities. Many plant revamps and almost all new designs begin with a computer model of the existing or planned process. This model allows the examination of process parameters, whatever the scenarios and equipment requirements. Deep cut operations are candidates for process modeling like any other system. These models provide for low risk economic and facilities requirement analyses. A technical evaluation of an existing facility being considered for a deep cut upgrade should include a process simulation.

## Component characterization

One aspect of modeling is especially pertinent to vacuum system simulation--feed heavy component characterization. Typically, the heaviest portion of a crude feed is the least likely to be understood or accurately represented in a computer simulation. This is partially due to the difficulty in analyzing heavy materials. High-boiling-point, high-molecular-weight hydrocarbons that are messy in the refinery, are even less forgiving when introduced into laboratory equipment. Special requests and justifications are often needed to obtain desired analyses. Additionally, heavy components are usually not extensively examined because the vacuum bottoms' properties are normally not as critical as those of distillates. The bottom is the bottom--you get what comes out. However, if the goal is upgrading bottoms to gas oil, as with a deep cut scenario, the importance of representative heavy fraction data increases.

Characterizing the heavy fractions of a deep cut candidate feed is important for a number of reasons. The first deep cut question to be asked may be "How much potential gas oil may be recovered from the residue?" Assay data may not be detailed enough to supply accurate yield data. Additional testing is probably necessary.

After the volume of potentially available gas oil is assessed, the material's composition should be examined. Its aromaticity, metals content, sulfur content and nitrogen content should be evaluated. Again, assay data may not be adequate for the detail required and supplemental tests are probably needed. The heavier crude fractions typically contain increasing concentrations of these components. If possible, establishing a boiling point distribution of these and any other important contaminants assists deep cut prospect analysis. These data can be inserted into a process model as pseudocomponent properties that are evaluated like any other physical property. This allows design optimization relative to contaminant risks concurrent with yield evaluations.

Within the process simulation, it is important to ensure that there are sufficient pseudocomponent cuts in the HVGO fraction region. Typical algorithms for separating an assay into pseudocomponent cuts place decreasing value on increasing boiling point. Ordinarily this strategy speeds computation by reducing the number of components. However, if the assay region under scrutiny is not broken into enough cuts, model output may not accurately represent reality.

## Molecular weight estimation

This is another area in which the simulator may require special attention.

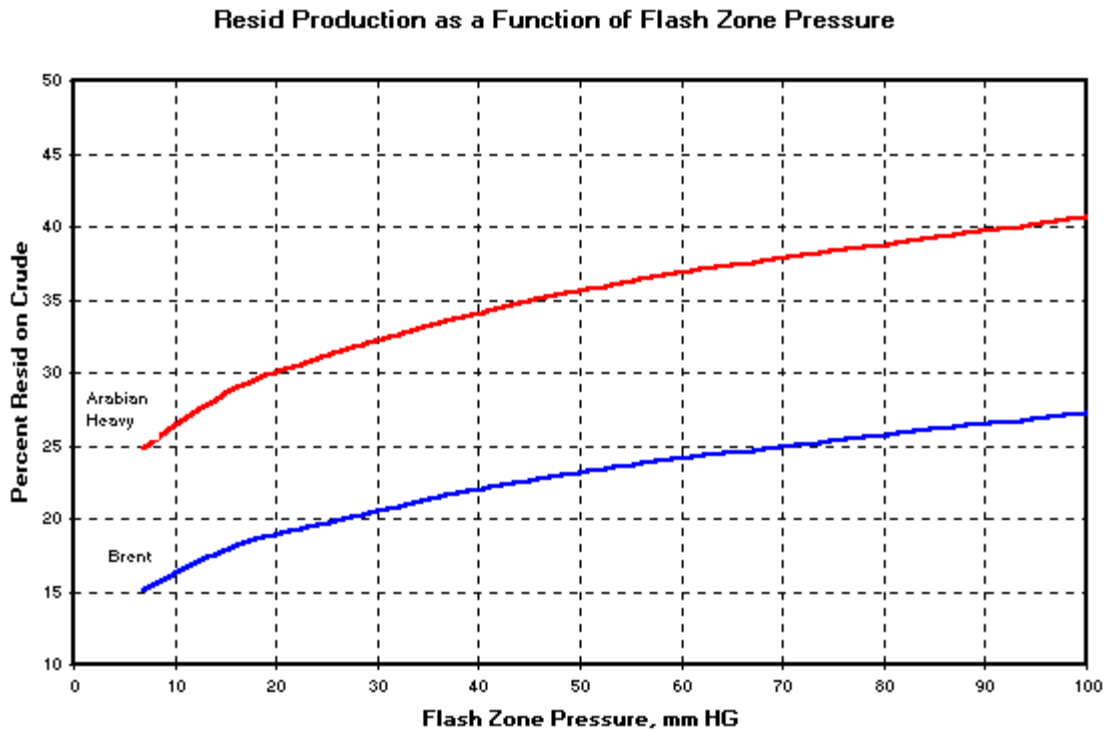
Deep cut operations often result in a vacuum tower bottoms product that is equivalent to a bunch of big rocks. The bottoms product molecules are large and bulky. This is especially true of heavier crudes that are often considered for deep cut operation. Accurate molecular weight characterization is critical to reliable equilibrium evaluation. Once again, special analyses may be required to gather sufficient data. If an existing plant is being reviewed, a process simulation of the current operation may be used to better approximate heavy end molecular weights. This is done by altering model molecular weight correlations or values until operating parameters, especially vacuum column bottoms temperature, are met.

Even if accurate laboratory molecular weight data are obtained, using available existing plant data to confirm and fine-tune the information is recommended. Molecular weight correlations supported by computer simulators vary widely and can change from version to version. In addition, they yield strikingly different results. There is substantial variation between the methods, which suggests review is required in any vacuum column model.

## Study

Deep cut incentives for two major export crudes--Brent and Arabian Heavy are compared. Brent (38.3 Degree API) is a typical light crude, while Arabian Heavy is a typical heavy crude 27.4 Degree API). Product yields and properties were approximated using a computer model of a crude and vacuum column. This type of analysis is useful for preliminary examination of project economics. Simulations done for this presentation use assays from literature.(n1,n2). Crude column side products are steam stripped and the vacuum column operates without steam stripping. Model operating parameters were varied in examining several operating effects. Results are presented graphically for interpretation. Vacuum column flash-zone pressure and column total pressure drops have significant operating and yield impacts.

Figure 1 illustrates the effect of reducing the flash-zone pressure at constant flash-zone temperature on residue production for both Brent and Arabian Heavy crudes.



Operating at a 100-mmHg flash-zone pressure is typical of old, high pressure units. Operating at 16 mmHg and lower typifies a modern, low-pressure deep cut design. Reducing the flashzone pressure from 100 mmHg to 16 mmHg reduces the Arabian Heavy residue production from 37% to 25% of the crude charge rate. Brent shows similar residue reductions, although it contains less residue material than Arabian Heavy.

Figure 2 shows the same pressure effect on the residue cutpoint, again at constant flash-zone temperature.

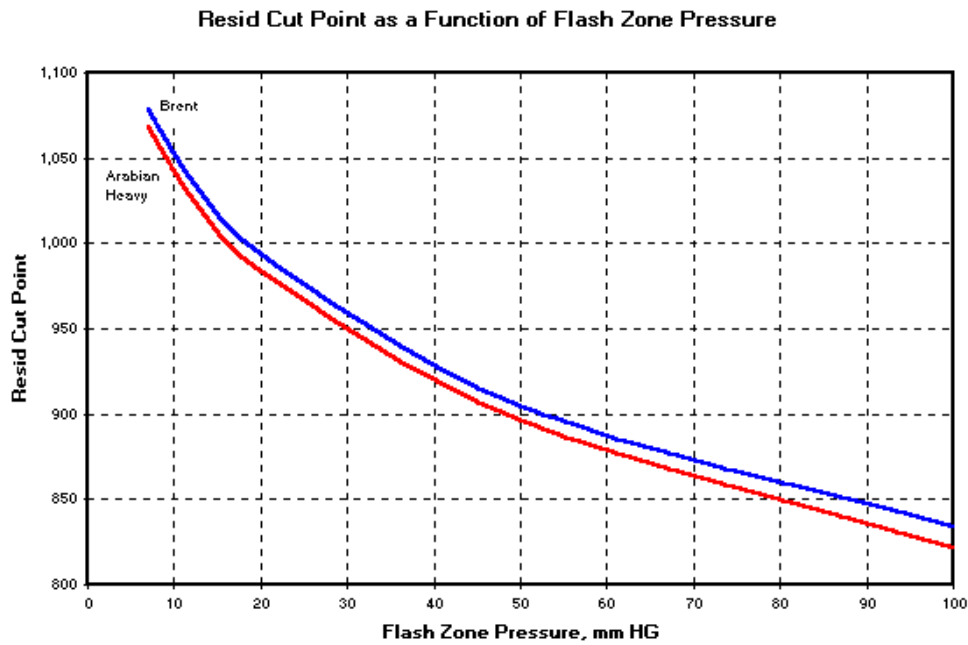


Figure 1 suggests residue make is reduced approximately 5% on crude by moving from a flash-zone pressure of 50 mmHg to 20 mmHg. If the crude unit charge rate was 100 Mbpsd, the residue rate would drop 5,000 bpsd. Table 1 provides a simplified method to evaluate payouts for increased HVGO production. For example, if HVGO is worth \$1/bbl more than residue, the 5,000 bpsd of increased HVGO production is worth \$1.8 million/yr. If the revamp costs for the unit in question are less than this \$1.8 million, the project payout is less than a year to reduce the flash-zone pressure from 50 to 20 mmHg.

Figures 3 and 4 illustrate the effects of temperature on residue production and cutpoint at constant flash-zone pressure and column pressure drop.

Figure 3

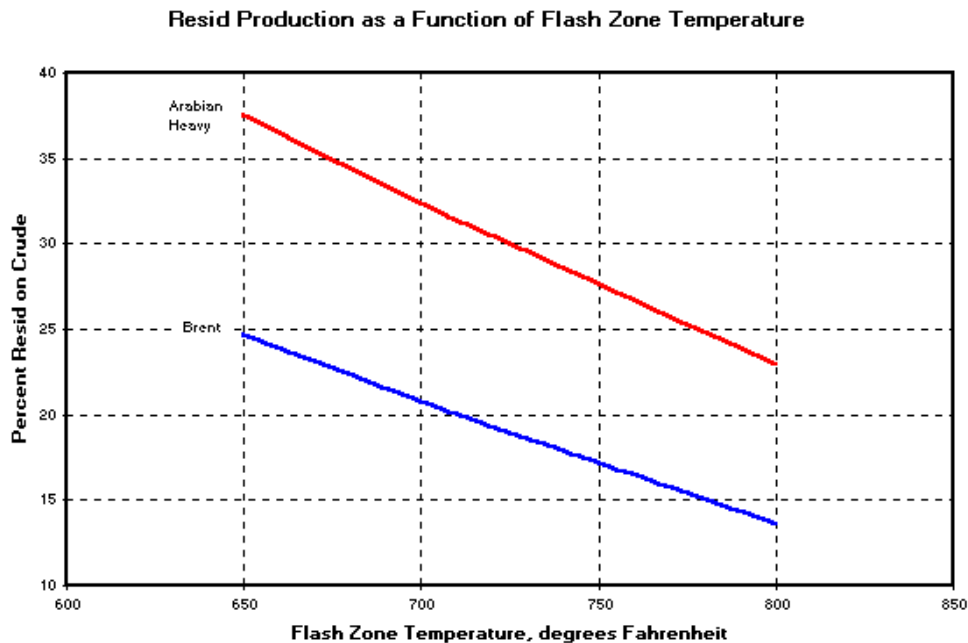
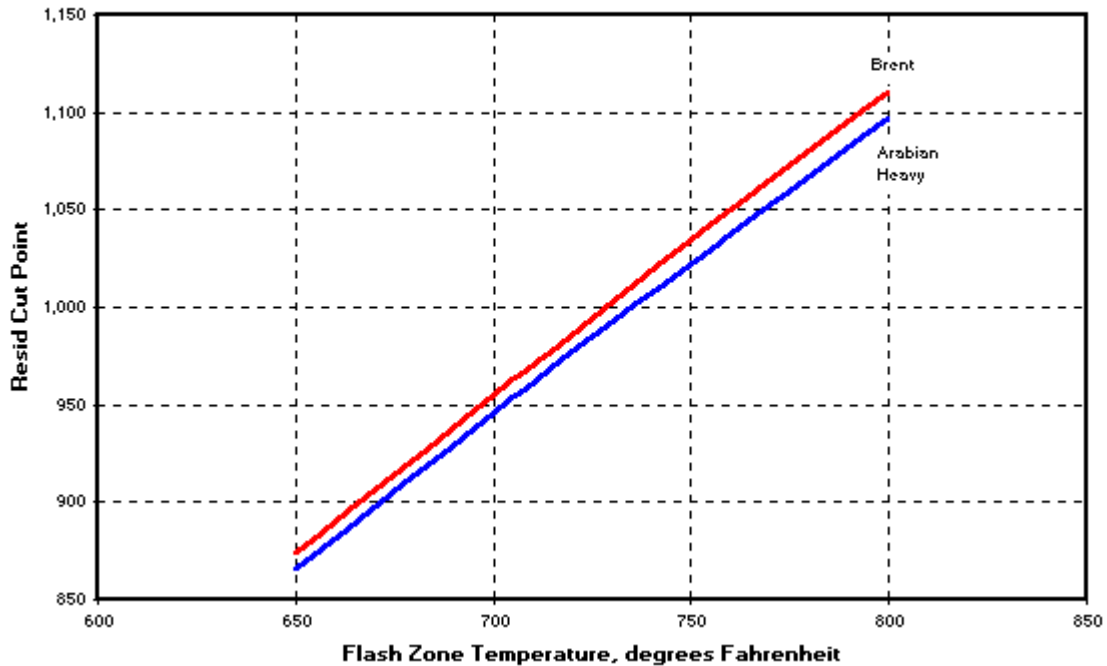


Figure 4

**Resid Cut Point as a Function of Flash Zone Temperature**



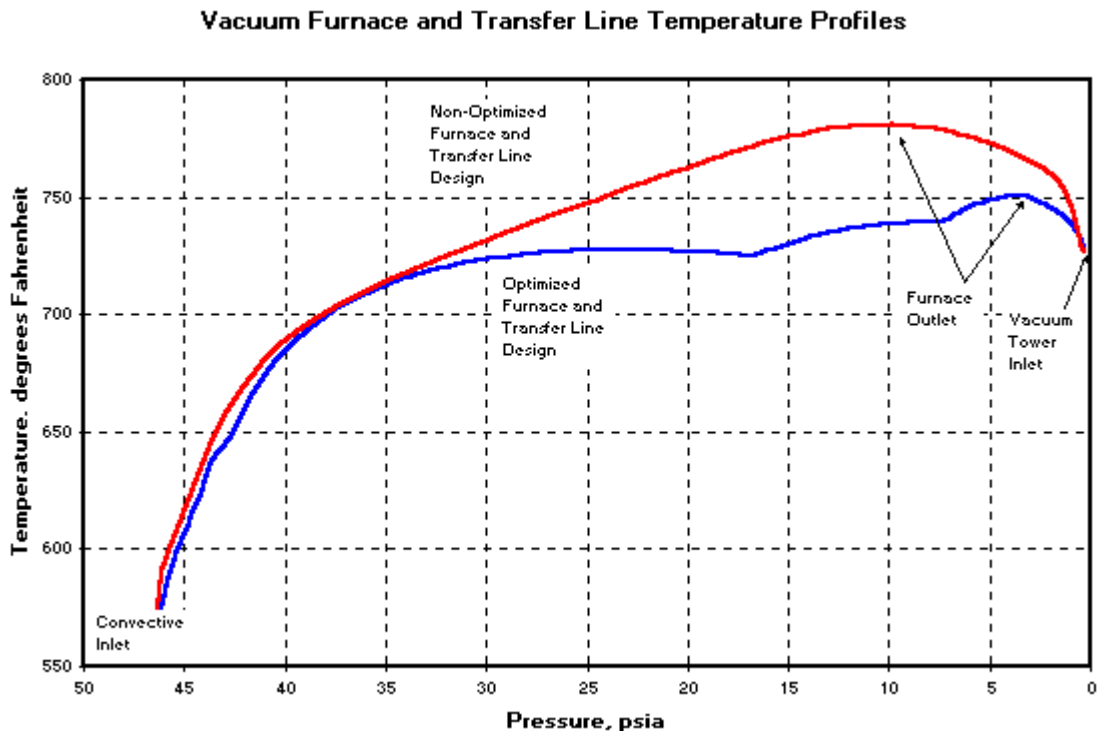
No surprises here--the higher the flash-zone temperature, the lower the residue production. Fuels refiners trying to minimize residue production typically maximize the flash-zone temperature up to the temperature limit at which excessive cracking and/or coking occurs in the furnace and column.

Unit design can affect the maximum temperature of the vacuum tower feed before it reaches the flash zone, and the resulting amount of cracking and coking potential. A great deal of focus is commonly placed on vacuum column internals--especially the wash zone. This equipment certainly warrants a high level of interest. However, the furnace and its transfer line also play an important role in vacuum tower operation, even without the rigors of deep cut performance.

The top curve in Fig 10 shows the temperature/pressure profile in a nonoptimized vacuum furnace and transfer line design. The vacuum tower feed enters the furnace at the left of the curve at low temperature and high pressure. As the oil flows through the furnace, it is heated while two-phase flow causes the pressure to drop. The nonoptimized example shown has a furnace outlet temperature of 775 Fahrenheit to achieve a flash-zone temperature of 725 Fahrenheit. The pressure drop in the restrictive transfer line piping causes a substantial pressure drop between the furnace outlet and the vacuum tower flash zone. This pressure drop results in transfer line flashing and an accompanying diminishing temperature. The latter portions of the radiant tubes also display high pressure drops, causing high temperatures to be maintained throughout much of the heater and increasing the fouling susceptibility.

There are other potential furnace flow aberrations. Due to inherently low vacuum column operating pressures that result in low vapor densities, furnace tube flowrates can approach sonic velocities. Sonic discontinuities across the furnace outlet can occur before the furnace outlet laterals (typically larger pipe or a lead to the large transfer line) are able to provide for reduced velocities. This flow phenomenon results in fluid flowrates insensitive to pressure decreases downstream of the critical flow region. High furnace outlet temperatures and increased thermal degradation and coking are products of this condition. Additionally, the high velocities can lead to erosion as particulates are swept through the furnace. Furnace tube velocities should be kept below 85% of sonic, if possible.

The lower curve in Figure 10 presents an optimized furnace and transfer line design.



To achieve the same flash-zone temperature of 725 Fahrenheit the furnace outlet temperature is only 750 Fahrenheit. Also, the latter radiant coils are significantly larger, reducing the pressure drop in the heater's high-temperature section. The overall benefit of the cooler temperature profile in the optimized design is represented by the difference in area between the two curves. The resulting benefits are reduced thermal degradation and coking.

The advantage of a lower pressure drop design is that the flash-zone temperature can be increased with a minimal increase in the cracking/coking tendency of the vacuum tower feed. In the example shown, the flash-zone temperature probably could be increased almost 50 Fahrenheit to experience a similar coking tendency as the nonoptimized design. Deep cut profit incentives often must account for furnace modifications as well as tower upgrades.

## Deep Cut Concerns

Keep in mind a number of concerns while examining deep cut profitability benefits. Yield evaluation does not provide a sufficiently broad perspective to determine project viability. The effects of HVGO composition changes on vacuum tower operation and on downstream units can be significant and could substantially erode perceived deep cut advantages.

A primary concern for vacuum column operation under any yield slate is coke formation. Coke forms within vacuum towers resulting from hydrocarbon thermal degradation due to temperatures and residence times in the furnace, column bottoms, and column flash and wash zones. Simply increasing operating severity in an effort to improve gas oil yields may exacerbate coke formation. Review column and furnace design along with operating limits for acceptability and required upgrades.

Downstream unit operation can be adversely affected by HVGO quality degradation under deep cut scenarios. As the residue initial boiling point is raised, higher quantities of high molecular-weight polycyclic aromatics (PCA) or asphaltenes are drawn into the HVGO. The presence of these compounds can be measured by quantifying the amount of material that is not dissolved by a selected solvent. Heptane is commonly used. The HVGO heptane-insolubles content could increase due to flash-zone entrainment or ineffective wash-zone operation. If the HVGO is fed to a hydrocracker, 100 ppmw maximum heptane insolubles is a typical limit beyond which hydrocracker catalyst deactivation, fouling and plugging is expected. VGO FCC units are less sensitive to higher levels of heptane insolubles with acceptable concentrations greater than 2,000 ppmw.

Deep cut operation may also increase the HVGO metals content. As the residue initial boiling point increases, HVGO metals concentration typically increases as heavier organometallic species migrate up the column. Vanadium and nickel are two primary metal components that may be swept into HVGO under deep cut

production. FCC units in particular are sensitive to these materials. Vanadium negatively impacts FCC catalyst activity by poisoning the catalyst and by increasing dehydrogenation reactions. This increases FCC coke formation and lowers gasoline and distillate yields through increased offgas production. Nickel catalyzes dehydrogenation reactions to a greater degree than vanadium. Methods exist for mitigating feed vanadium and nickel contamination in FCC units; these costs should be included in deep cut analyses, where applicable.

HVGO sulfur and nitrogen content may also increase in deep cut scenarios. The primary result of these increases is added treating loads; sulfur and H<sub>2</sub>S removal systems may require review. Increased sulfur and nitrogen composition will also raise hydroprocessing reactor heat release and hydrogen uptake. Basic nitrogen compounds can temporarily poison FCC catalyst by interfering with catalytic acid sites. These compounds are rejected as NO<sub>x</sub> from the regenerator and from the CO boiler.

Residue composition is also affected by deep cut operation. Increasing the residue initial boiling point clearly results in a heavier bottoms product with a higher molecular weight. The average concentration of contaminants, such as metals, will likely go up with front-end material removal. Conradson carbon will increase and downstream yields may shift to higher coke production.

## Final thoughts

Improved separations technology (deep cut) allows the application of traditional methods of yield improvement in nontraditional ways. Improved analytical technology, simulation and analyzer tools provides the means to assess deep cut opportunities to lower the risk and maximize the profitability of its implementation.

**Table 1. Incremental profit for increased HVGO recovery \$1,000/yr**  
**Incremental Profit per Year**  
**for Increased HVGO Recovery, \$1,000/yr.**

Upgrade Incentive	Recovered HVGO, BPSD							
	\$/bbl	0	500	1,000	2,000	5,000	10,000	20,000
0.0	0	0	0	0	0	0	0	0
0.5	0	91	183	365	730	1,825	3,650	7,300
1.0	0	183	365	730	1,460	3,650	7,300	14,600
1.5	0	274	548	1,095	2,190	5,475	10,950	21,900
2.0	0	365	730	1,460	2,920	7,300	14,600	29,200
2.5	0	456	913	1,825	3,650	9,125	18,250	36,500

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