Diesel and VGO recovery

Fundamental design considerations influencing diesel and vacuum gas oil (VGO) recovery when revamping existing or designing grassroots crude units. By increasing vacuum column diesel recovery, crude throughputs through major

Tony Barletta

Process Consulting Services, Texas, USA

Good fractionation is basic to achieving maximum return on every barrel of charged crude. This is so obvious that it is puzzling why some refiners ignore innovative changes to traditional crude unit design, which can increase the yield of higher value streams, unload the FCC, hydrotreater and coker, permit more efficient use of energy, and allow higher crude charge rates. Yet, in many cases, all this can be accomplished with relatively modest investment.

Specifically, two increasingly important crude unit design considerations are diesel and FCC feedstock recovery. Large amounts of 650°F (343°C) -minus diesel boiling range hydrocarbons in the FCC feed and 1 100°F (593°C)-minus VGO boiling range material in the coker feed unit consume capacity of these units. Because often one or both of these units operates at maximum capacity, low recovery can limit crude throughput or the amount of heavy crude in the crude blend.

Crude units

Typically, US refiners produce diesel and a small amount of FCC feed as atmospheric gas oil (AGO) from the crude unit's atmospheric column. The remainder of the FCC feed comes from the vacuum column (Figure 1). Most non-US refiners, on the other hand, produce diesel product from both the atmospheric and vacuum crude columns (Figure 2) and no FCC or hydrocracker feedstocks from the atmospheric column. Because US refiners have historically focused on gasoline production, they have not been too concerned about diesel recovery, but outside the US the primary motor fuel is diesel, hence recovery is generally high. The result is that many US refiners produce FCC feedstock containing 20–25 vol% diesel, whereas non-US refiners' FCCU feed contain less than 5 volume % 650°F (343°C)-minus material. Improving diesel recovery can unload the FCC or hydrocracker, allowing VGO recovery to be increased to fill these conversion units.

VGO recovery varies widely and depends on the design and operation of the vacuum unit as well as the type and contaminant levels of crude oils processed. Refiners running lighter crudes tend to have higher heavy vacuum gas oil (HVGO) cutpoints because the vacuum unit feed is easier to vaporize. Conversely, it is not uncommon for refiners processing heavy crudes to have HVGO TBP cutpoints of less than 950°F (510°C). In these cases the coker unit feed contains as much as 5–7 vol% of the crude charge as recoverable gas oil.

When revamping or designing grassroots crude units, diesel and VGO recovery are important design

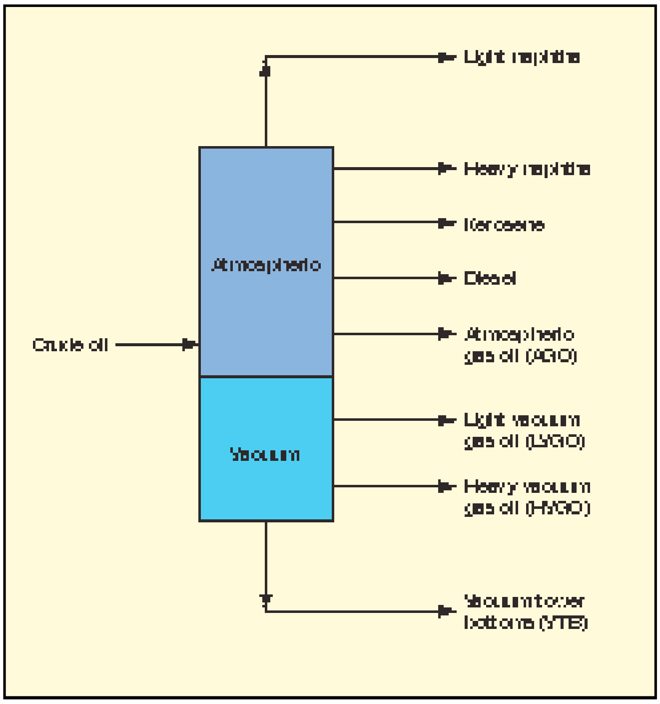

Figure 1 *Typical US refiner CDU configuration*

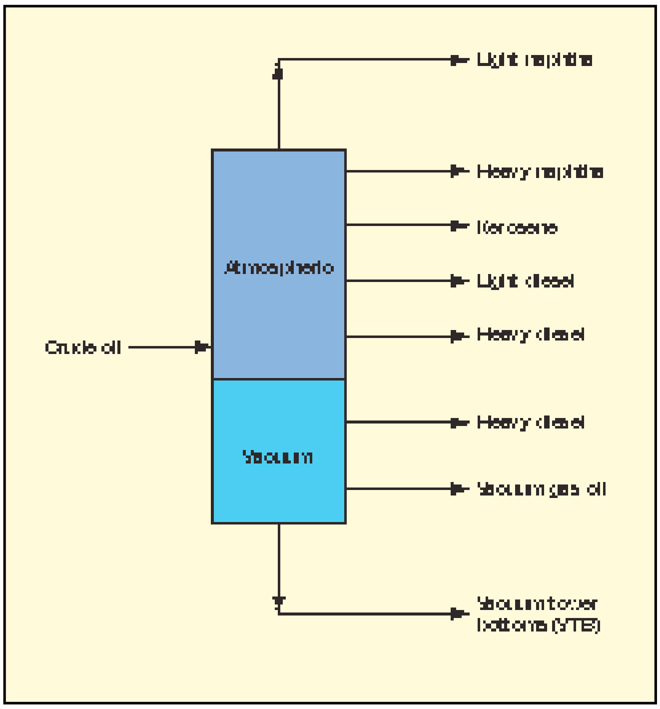

Figure 2 *Typical non-US refiner CDU configuration*

considerations that impact crude charge rate or the amount of heavy opportunity crude that can be processed within downstream unit capacity limitations. Furthermore, as new ULSD specifications go into effect, being able to sharply fractionate diesel from the FCC feed will have significant economic benefits by increasing ULSD hydrotreater run length and capacity.

Diesel recovery

As noted, non-US refiners have designed their crude units to maximise diesel recovery. Their atmospheric crude columns have 8–12 trays between the flash zone and heavy diesel draw and have heat integration schemes that allow the units to be operated at 4–6vol% overflash. Moreover, these units have been designed to produce diesel from the vacuum column top product draw or have been revamped to produce a vacuum diesel stream. On the other hand, many US refiners have only 3–6 trays between the diesel and AGO product draws and little reflux below the diesel product draw resulting in AGO product containing more than 50–60vol% diesel. Furthermore, it is not unusual for US refiners' vacuum column feeds to contain 8–10% diesel with only a very few vacuum units producing a diesel product. Thus, it is not unusual for the light vacuum gas oil (LVGO) product to contain 70–90% 650°F (343°C)-minus diesel boiling range material. In most cases this diesel ends up in the FCC unit or the hydrocracker.

Atmospheric column diesel recovery is inherently difficult because the molar liquid-to-vapour (L/V) ratio in the fractionation section is typically less than 0.1, whereas in the vacuum unit it is 0.3–0.5. It is simply impossible to achieve high recovery without a diesel product draw on the vacuum column. Fractionation basics favour this solution. Thus it is not surprising that crude units are designed differently where diesel product is the primary motor fuel and economics favour high recovery.

Heat recovery and VGO product recoverydetermine optimum split when producing diesel from the atmospheric and vacuum columns. High atmospheric column diesel recovery makes the feed heavier to the vacuum unit, reducing VGO product yield. VGO yield decreases as atmospheric distillate yield increases at a fixed vacuum heater outlet temperature and column flash zone pressure. Heat recovery and crude preheat depend on atmospheric diesel yield. Diesel draw temperature is 530°F (276°C) or higher in the atmospheric column compared to 250°F (121°C) from the vacuum column. Consequently, all the heat duty needed to condense vacuum diesel is lost to air and water, whereas all the condensing heat and approximately half the product cooling heat are recoverable to crude oils from the atmospheric column.

VGO recovery

There are wide variations in VGO recovery, depending on several factors. Some units have high recovery but many still operate at low or moderate TBP cutpoints. Low pressure and high temperature, and residue steam stripping are variables used to adjust yield. Flash zone pressure should be minimised to the column diameter limitation. Vacuum heater outlet temperature should be maintained as high as possible while achieving acceptable heater run lengths. Refiners processing medium to low API gravity crude oils must use steam in the heater coils and design the column with a stripping section to achieve reasonable recovery. HVGO product TBP cutpoints can be increased by up to 80°F when designing the unit with a proper stripping section.

Improved diesel recovery

In a typical US refinery, higher diesel recovery requires yielding more atmospheric column diesel or modifying the vacuum unit to produce diesel. Raising atmospheric column diesel yield demands better stripping, higher flash zone temperature, lower column operating pressure, higher diesel/AGO fractionation section reflux or more fractionation efficiency. In some instances this is the most practical and cost-effective solution. Yet in other cases modifying the atmospheric column is very high-cost with relatively small yield improvement. Each case must be treated individually.

Modifying the vacuum column to produce diesel from the top section can be a relatively low-cost alternative. Some vacuum columns can have a fractionation section added within the existing vessel dimensions while others require the top section of the column to be replaced. Because the top section diameter is small, often no foundation changes are needed. In one case diesel yield was increased by 40% with an investment less than US$3MM. By increasing diesel recovery, some refiners have been able to unload the FCC, allowing higher crude charge rates without exceeding FCC capacity.

Most US refiners produce an AGO product stream containing 50–60% or more diesel and only FCCU feed is recovered from the vacuum column (Figure 3). Routing the AGO directly to the vacuum column, where it flashes, allows the diesel to be recovered from the top product draw to further increase diesel recovery. Figure 4 shows a vacuum column feeding AGO product below the fractionation section.

VGO yield

The coker unit charge rate and feed composition is determined by VGO yield. Low VGO recovery consumes coker unit capacity, converts some of the VGO to coke and reduces FCC feed quality. Generally, the slope of the whole crude TBP curve between 950–1 100°F (510–593°C) results in a 1vol% change for every 20°F (11°C) TBP temperature change. Therefore, raising the HVGO product TPB cutpoint from 950°F (510°C) to 1 050°F (565°C) increases vacuum gas yield by approximately 5vol% on whole crude. When coker charge represents 25% of the crude oil, increasing VGO yield by 5% on crude reduces the charge rate to the coker by 20%. In some cases, when increasing crude charge rate, it is more cost effective to revamp the vacuum unit to increase VGO yield than to expand the coker capacity when increasing crude charge rate.

Feed distillation

VGO depends on feed distillation. The heavier the feed the more difficult it is to vapourise. Once the feed composition is determined by the atmospheric column distillate yield then vacuum unit heater outlet temperature, heater outlet pressure, amount of coil steam, flash zone pressure and stripping section efficiency control VGO product yield. Increasing VGO yield requires manipulating one or more of these variables.

Heater outlet temperature and pressure

Maximum heater outlet temperature depends primarily on the heater design and to a lesser extent on oil thermal stability. A well-designed heater can be operated at coil outlet temperatures of 790–805°F (421–429°C) without excessive thermal cracking and coke formation. Conversely, a poorly designed heater will have a short run length even though it operates at only 760°F (404°C) outlet temperature. The rate of coke formation depends on the heater design more than on the outlet temperature. Many vacuum heaters are improperly designed for high outlet temperatures and have large pass heat flux variations. Therefore, heater outlet temperature is low and run lengths are short. Nw vacuum heaters and transfer lines are often required to operate at a heater outlet pressure of 3psia and maximum outlet temperature.

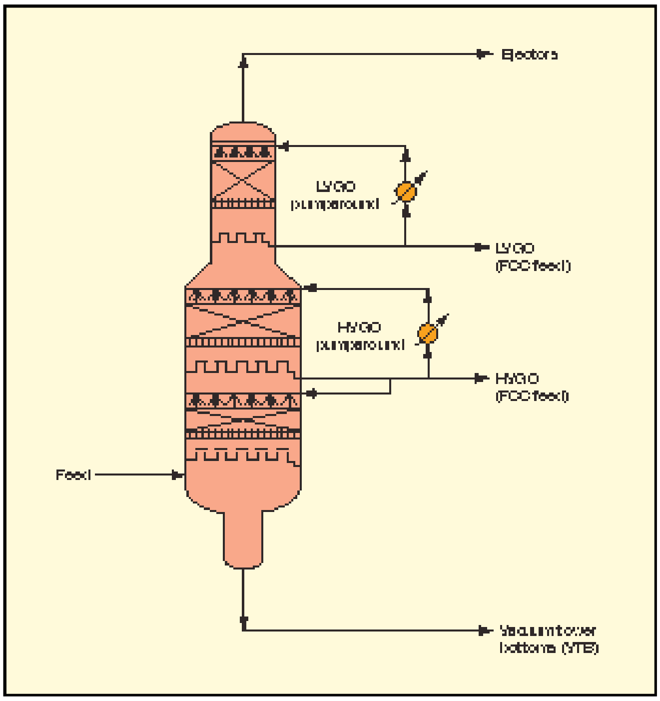

Figure 3 *Vacuum column configuration typically seen in US refineries producing an LVGO/HVGO FCC feed*

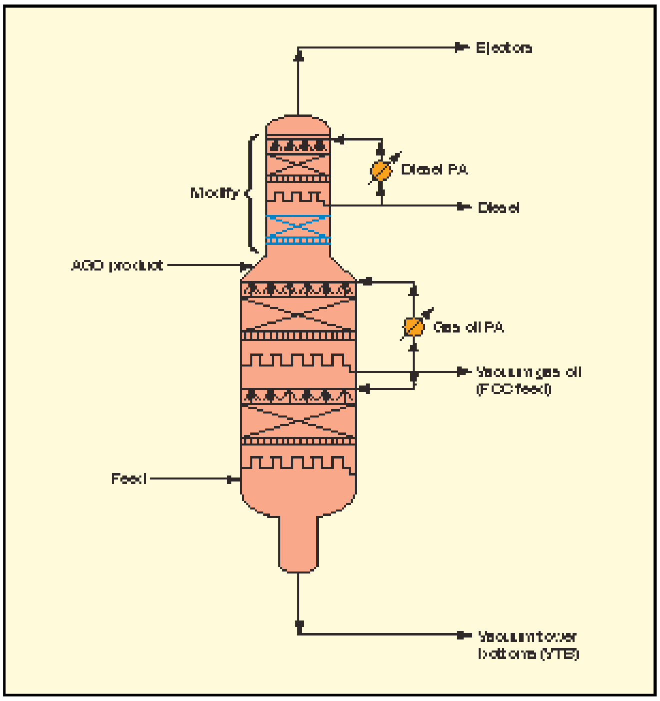

Figure 4 *Vacuum column feeding AGO product below modified fractionation section*

Coil steam is used to reduce oil residence inside the heater tube and lower flash zone oil partial pressure. A dry heater will have a radiant section oil residence time of 60–90 seconds, whereas in a heater using 0.5wt % coil steam, it will be less than 30 seconds. When coil steam is used, the steam rate sets the load on the first stage ejector. If the first stage ejector and inter-condenser systems are not designed to handle the higher rates then column flash zone pressure will increase. In practice, the optimum coil steam rate can be determined by adjusting it until the gas oil yield decreases or the amount of ejector system off-gas increases significantly. Too much coil steam actually reduces vacuum gas yield, while too little raises oil residence time and rate of coke formation. For many units a significant revamp to the ejector system is needed to increase or add coil steam.

Flash zone pressure is set by load on the first stage ejector as long as the first stage ejector discharge pressure is below its maximum discharge pressure (MDP). Minimum flash zone operating pressure is determined by ejector system capacity or the column diameter. Ideally the first stage ejector has sufficient capacity to reduce flash zone pressure to the column vapour capacity limit by using spillback to adjust first stage gas load. Once minimum pressure is reached, VTB entrainment begins to increase rapidly resulting in high metals and microcarbon residue (MCR) in the HVGO product.

Properly designed stripping sections have raised the VGO cutpoint by close to 80°F (44°C) when processing medium and heavy crude oils. A new vacuum unit should incorporate a well-designed stripping section with sufficient steam rate. Interestingly ,some vacuum units processing extra heavy Venezuelan crudes built in the last five years have no stripping sections. Hence, they operate at VGO TBP cutpoints of only 950°F (510°C). Adding a stripping section to an existing vacuum column is sometimes feasible at reasonable cost.

Vacuum unit design

Because several refiners are considering new crude or vacuum units, they have asked what maximum HVGO cutpoint can be achieved. In practice, it will depend on refinery capital limitations. Basics, however, drive the design. Producing diesel as the top product should be considered as part of the ULSD strategy. Crude unit diesel contains the least amount of sterically hindered sulphur compounds that are difficult to treat, hence maximising yield raises refinery ULSD production and frees up FCC capacity to 650°F plus boiling range

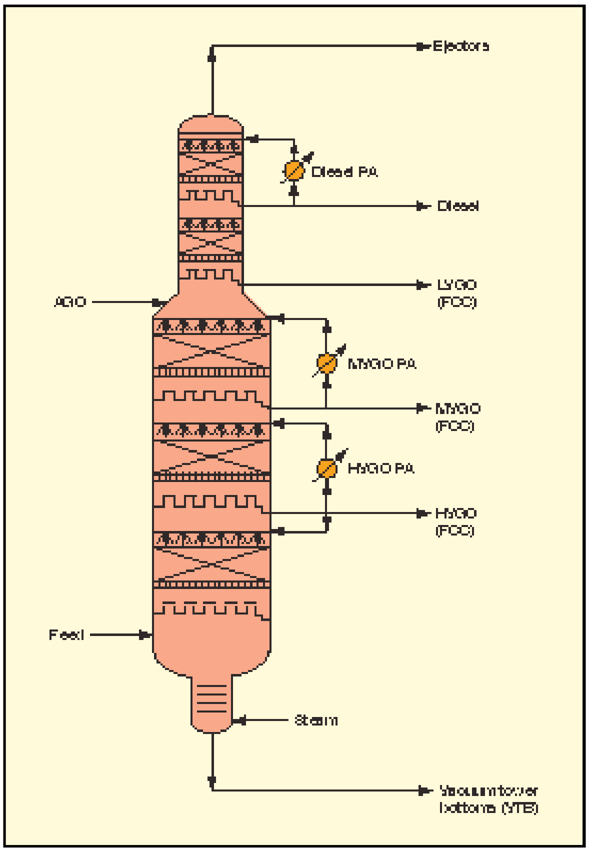

Figure 5 *Vacuum column designed for diesel production while achieving high VGO cutpoint and maximum energy recovery*

hydrocarbons. Removing diesel permits higher VGO product TBP cutpoints to fill the FCC unit. Vacuum gas oil TBP cutpoints of 1100°F (593°C) are possible with moderate gravity crude blends (28–30° API), whereas they are limited to 1050 to 1080°F (565–582°C) with heavy and extra-heavy crude blends because volatile vanadium and MCR can be high.

A typical vacuum column has only two pumparounds (PAs) such as what was previously shown in Figure 3. All the LVGO PA heat is lost to air or water. Only the HVGO PA draw temperature is high enough (450–520°F or 232–271°C) to exchange efficiently against crude. Because the amount of HVGO PA heat is quite high and the temperature is relatively low, it is not unusual to have to generate low-pressure steam to meet the HVGO PA duty.

Figure 5 shows a schematic of a vacuum column designed to produce diesel, achieve high VGO cutpoint and maximise energy recovery. The design uses four product draws, three PAs, wash and stripping sections. The fractionation section separates diesel from LVGO. Three PAs allow draw temperatures to be optimised to maximise heat recovery into crude preheat.

Installing an MVGO and HVGO PA raises the HVGO product draw temperature to 580–620°F (304–327°C), thereby permitting all MVGO and HVGO PA heat to be exchanged against crude oil with minimum exchanger surface area. The LVGO product draw below the diesel fractionation bed raises the MVGO PA draw temperature. Three PAs allow crude preheat temperature to be increased, and eliminate the need for low-pressure steam generation and minimise top PA duty.

When processing high metals crude oils such as Canadian LLB, Mexican Maya or Venezuelan BCF and Merey, managing VGO product contaminants is essential. Total crude unit vanadium contents of 3–5ppm wt are not unusual. Stripping sections vapourise lower boiling range hydrocarbons when compared to higher heater outlet temperatures. Therefore, the VGO vanadium level for a given HVGO product cutpoint is always lower with a stripping section.

To sum up, improving fractionation in crude units to raise cutpoints, can improve diesel yield, unload FCC and coker units, and improve energy usage.

Tony Barletta is a chemical engineer with Process Consulting Services Inc. in Houston, Texas, USA. His primary responsibilities are conceptual process design (CPD) and process design packages (PDPs) for large capital revamps. Barletta's CPD work involves heater and other major equipment modifications.
E-mail: tbarletta@revamps.com