Maximising diesel recovery from crude

The CDU/VDU process flow scheme is reviewed, including equipment design and operating fundamentals used to maximise straight-run diesel recovery. Factors important to increasing diesel yield are discussed in detail

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Increased recovery of straight-run (SR) diesel from crude oil improves refinery profitability. Low crude/vacuum unit (CDU/VDU) SR diesel recovery is caused by existing unit process flow schemes, equipment designs and operating conditions. Since many FCC or hydrocracker feeds contain 25–35% or more diesel boiling-range material, there is significant opportunity to improve recovery. Low or moderate capital investments have increased refinery ULSD product yields by more than 5% on whole crude.

CDU/VDU diesel recovery

Refiners in the US have until recently targeted maximum gasoline production with little focus on CDU/VDU SR diesel recovery. Not surprisingly, few US refiners achieve good SR diesel recovery. This is because most of the existing process flow schemes and equipment were not designed to maximise the SR diesel yield from crude, nor were the operating variables associated with these flow schemes optimised for maximum SR diesel recovery. Most US refiners produce SR diesel only from their atmospheric crude columns. Even some of the new CDU/VDUs have not been designed for maximum recovery, because many major E&Cs (and some refiners) continue to believe that diesel should be produced only from the atmospheric column. Even though diesel margins are very strong, there are still many misunderstandings about maximising CDU/VDU diesel production.

Many non-US refiners have designed their CDU/VDU to maximise diesel recovery. Their atmospheric crude columns have 10–14 trays between the flash zone and the diesel product draws. They do not produce an atmospheric gas oil (AGO) product as FCC or hydrocracker feed. Moreover, the CDU/VDUs have been designed or revamped to produce diesel from the vacuum column's top side-draw. Conversely, many US refiners have only two to five fractionating trays between the diesel and AGO product draws, and operate with very little reflux below the diesel product draw. Furthermore, it is not unusual for a US refiner's vacuum column feeds to contain 8–10% diesel, with only a few VDUs producing a vacuum diesel product. It is also not unusual for a US refiner's top vacuum column side-draw product to contain 70–90% 650°F (343°C) minus diesel boiling-range material. In most cases, this diesel ends up in the FCCU.

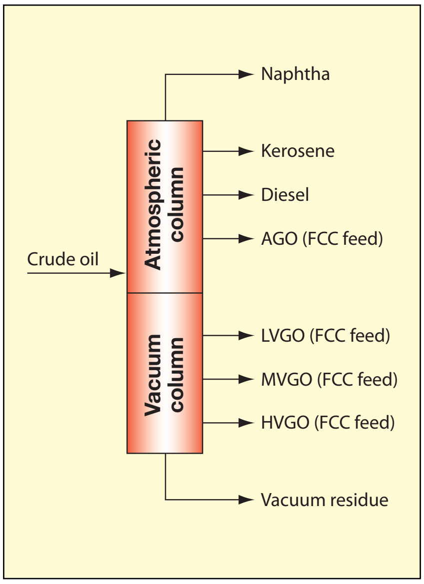

***Figure 1** Atmospheric column diesel product — no diesel from vacuum column*

Refiners can quickly determine their CDU/VDU performance by evaluating the amount of 650°F (343°C) minus diesel material in the CDU/VDU streams feeding the FCC or hydrocracker. Even though hydrocrackers may recover some of this diesel boiling-range material, it may not be the most cost-effective place to process it. A well-designed CDU/VDU produces FCC or hydrocracker feed streams containing less than 5 vol% diesel boiling-range material.

Process flow scheme

Most US refiners produce diesel product only from the atmospheric crude column (Figure 1). Changes to the CDU process flow scheme and atmospheric column equipment design and operating changes can improve recovery. However, diesel recovery is limited by process and distillation fundamentals in the atmospheric column. It can be optimised, but it has fundamental limitations that constrain recovery. Only a few US and many non-US refiners produce both atmospheric and vacuum diesel products (Figure 2). Fractionation is inherently better in a vacuum column, therefore diesel recovery is greatly improved. Fractionation is driven by column internal efficiency and the fractionation section's liquid-to-vapour (L/V) ratio. The top section of the vacuum column has a much higher L/V ratio than the atmospheric column, hence vacuum columns fractionate better than atmospheric columns no matter how good the CDU design. Better fractionation reduces the vacuum diesel product 95% to endpoint tail compared to atmospheric column diesel. Additionally, the combined atmospheric and vacuum diesel products have better cold flow properties due to improved fractionation. The CDU/VDU process flow scheme has the largest influence on SR diesel recovery. The CDU/VDU must have a vacuum diesel product draw to maximise recovery.

It is common for US refiners to produce an AGO product (Figure 1). This stream is often combined with the vacuum gas oil (VGO) products feeding an FCC or hydrocracker. Since atmospheric crude column fractionation is inherently poor, AGO product contains 30–70% or more diesel boiling-range material. To maximise diesel recovery, no AGO product should be produced or it should be fed into the upper section of the vacuum column (Figure 3), where it can be fractionated into vacuum diesel and VGO products. Overall CDU/VDU diesel product recovery and energy consumption are improved when atmospheric column AGO is fed to the vacuum column. The amount of diesel in the AGO product will determine

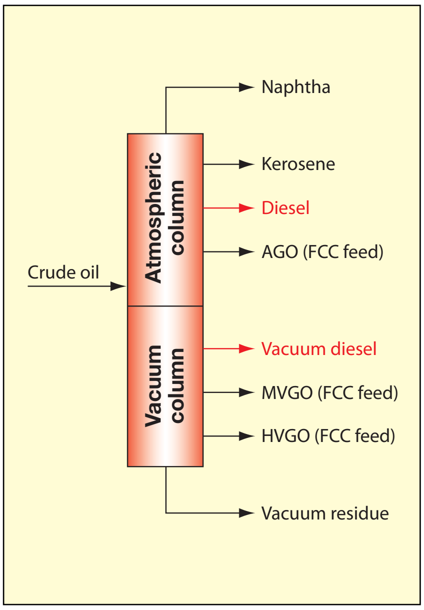

***Figure 2** Atmospheric and vacuum column diesel products*

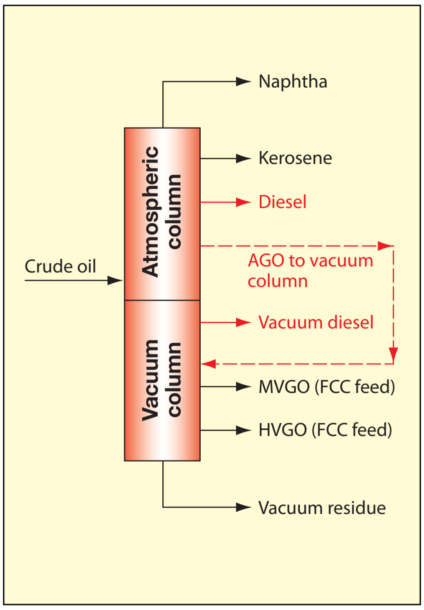

***Figure 3** Atmospheric and vacuum column diesel products with AGO feeding the vacuum column*

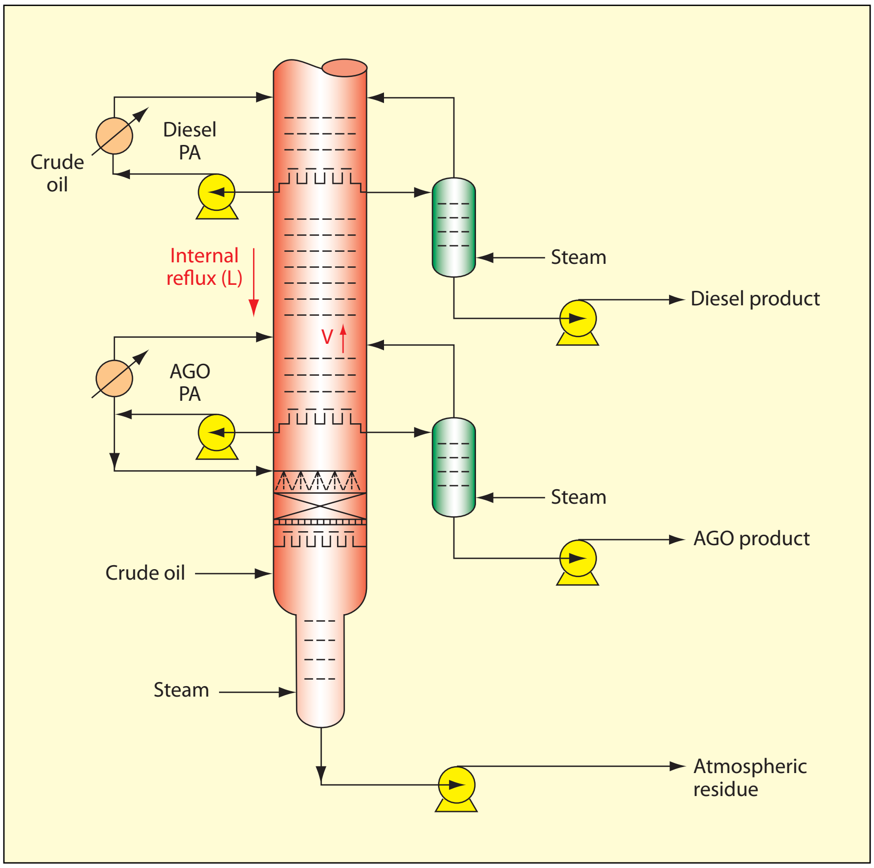

***Figure 4** Atmospheric column internal reflux rate*

incremental recovery from processing AGO in the vacuum column.

When revamping or designing a new CDU/VDU to improve diesel recovery, selecting the most economic process flow scheme should also consider energy efficiency and VGO product yield. Energy optimisation may set the proper amounts of diesel from the atmospheric crude and vacuum columns. Atmospheric column diesel product is withdrawn at 525–575°F (273–302°C), depending on operating pressure and diesel product distillation. This energy can be used to preheat crude, whereas the same diesel boiling-range material produced from the vacuum column is withdrawn at only 250–300°F (121–149°C), making it impossible to cost-effectively recover the heat. Balancing diesel production between the atmospheric and vacuum columns saves energy, especially with light and moderately heavy crude oils.

Refiners processing heavy and extra-heavy crudes like Merey or BCF 17 must balance atmospheric and vacuum column distillate yields against VDU VGO product yield objectives. Atmospheric residues from heavy crudes are so difficult to vapourise even with the best VDU design that atmospheric column distillate yields must be constrained. Increasing the amount of diesel in the atmospheric residue increases the VGO product yield. Conversely, as atmospheric residue gets heavier, VGO product decreases and vacuum residue production increases. Since maximising the VGO product yield increases the overall refinery liquid volume yield and reduces coke production, balancing atmospheric and vacuum column diesel yields is crucial when processing heavy and extra-heavy crudes.

Atmospheric crude fundamentals

Understanding atmospheric and vacuum column distillation fundamental principles is crucial to optimising CDU/VDU economics. The atmospheric column internal reflux rate below the diesel product draw and fractionation efficiency determines the diesel yield (Figure 4). The column design requires the correct number of trays or amount of packing efficiency and it also needs optimum internal reflux (L). Fractionation efficiency alone will not produce maximum diesel product. Fractionation section L/V ratio is one of the fundamental principles that determines product yield. The vapour rate into the fractionation section is set by the vapour leaving the flash zone and the column heat balance. In an atmospheric column, the vapour rate (V) is large because it consists of overhead product gas, naphtha, kerosene and diesel product, in addition to the internal reflux. Internal reflux (L) is relatively small because it consists only of overflash and AGO product. Consequently, the fractionation section L/V ratio is typically less than 0.1 on a molar basis. Atmospheric column diesel and AGO product fractionation are inherently poor. All factors influencing the internal reflux rate (L) should be considered when revamping or designing a new CDU to maximise the atmospheric column diesel yield.

Fractionation efficiency depends on equipment design. Ideally, the diesel fractionation section should have at least eight properly designed trays or a packed bed with at least five theoretical stages of efficiency. Since atmospheric crude columns are typically large diameter, the fractionating sections are designed with two- or four-pass trays to maintain a reasonable flow path length. Tray chord lengths are long, while the tray liquid rate is low. Therefore, it is not unusual to have poor tray efficiency in the diesel/AGO fractionation section due to very low weir loadings. Since the internal reflux (L) decreases from the tray directly below the diesel product draw to the bottom fractionating tray, it is critical to reduce the weir length (picket fencing) based on the minimum liquid rate. Maintaining weir loading of approximately 2 gpm/in of the weir on the bottom fractionation tray maintains tray efficiency at its intrinsic limit of approximately 60%. If weir loading drops below 1 gpm/in of the weir tray, efficiency drops quickly. When using packing, good distribution of the internal reflux (L) and adequate vapour distribution at the bottom of the fractionation section are key to maintaining efficiency. Proper equipment design can materially improve diesel yield or quality for a given internal reflux (L).

The atmospheric column diesel product yield depends on the internal reflux rate once a column is built. The internal reflux rate (L) is controlled by several variables, including the heater outlet temperature, column operating pressure, pumparound heat removal location, stripping section efficiency and stripping steam rate. Raising the heater outlet temperature or reducing the column operating pressure increases the amount of vapour generated in the flash zone. This allows a higher internal reflux when the column heat balance is properly controlled. Improved stripping section performance either through higher efficiency or a higher stripping steam rate also increases the amount of flash zone vapour, permitting higher internal reflux in the diesel fractionating section. For a given flash zone vapour rate, the diesel fractionating section's internal reflux is determined by heat balance.

Controlling column heat balance is essential to maintain an optimum internal reflux rate. Figure 5 shows a column with an AGO pumparound located below the diesel fractionation section. AGO PAs are used because the pumparound draw temperature is 50–100°F (28–56°C) higher than the diesel PA. Higher temperature AGO pumparound heat is easier to recover against crude. Heat recovery and fractionation compete against each other. Increasing the AGO PA duty may increase crude preheat, but it also reduces the reflux rate below the diesel product draw, which lowers the diesel product yield and increases the AGO product yield. As the AGO product yield increases, so does the amount of diesel boiling-range material in the AGO. As crudes get heavier and the flash zone vapour rate decreases, the AGO PA duty must be reduced to maintain adequate diesel fractionation section reflux. When processing extra-heavy crude oils, the

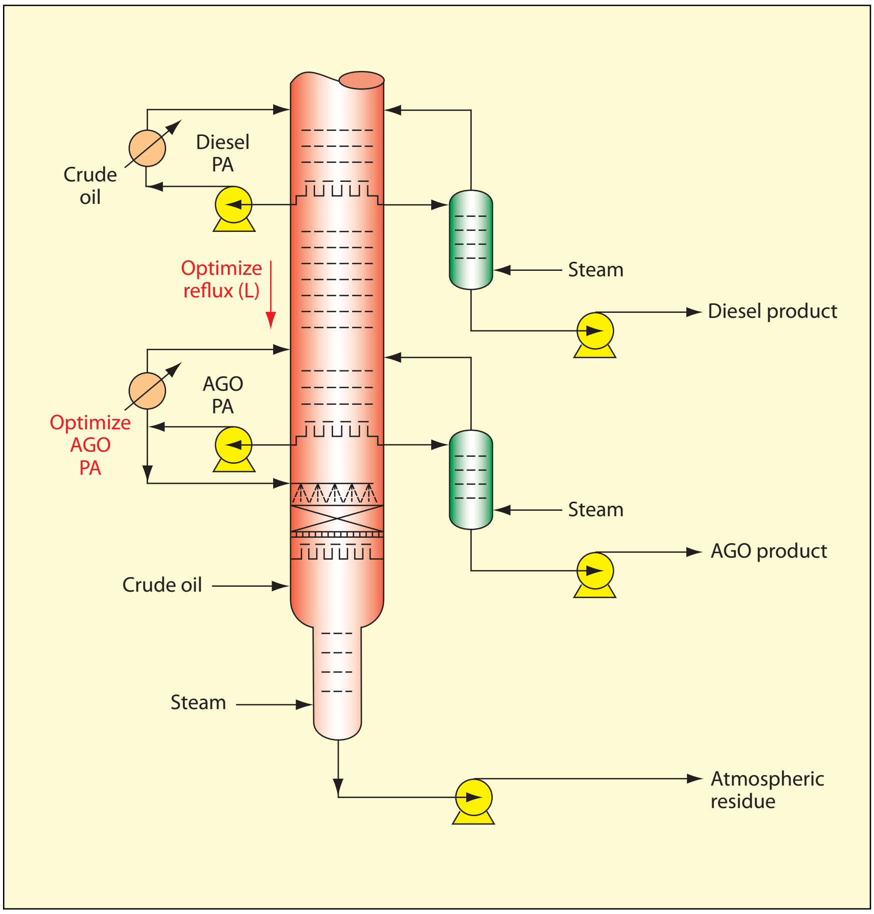

***Figure 5** Optimising atmospheric column heat balance*

CDU should be designed without an AGO PA because the amount of flash zone vapour is so low it is impossible to remove any heat below the diesel product draw and have a reasonable fractionation section internal reflux rate. Optimising the column heat balance is critical to optimising the internal reflux and diesel product yield.

Stripping section performance is often overlooked when considering diesel product yield improvements (Figure 6). The stripping section vapourises the front end of the flash zone liquid as it flows down through the trays. Improved tray design and an increased number of trays raise efficiency, increasing the amount of flash zone vapour and reducing the amount of diesel in the atmospheric residue. The optimum number of stripping trays is eight to ten. A customised rectangular tray designed at very high weir loadings maximises efficiency and helps prevent fouling throughout the run length. Maximum stripping section efficiency allows the diesel fractionation section reflux to be increased. The optimum stripping steam rate is 5–8 lb/barrel of atmospheric residue, depending on stripping section efficiency.

Higher CDU/VDU diesel recovery requires yielding more atmospheric column diesel or modifying the VDU to produce vacuum diesel. Raising the 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, modifying the atmospheric column may materially increase diesel recovery at a reasonable cost. Yet, in other cases, modifying the atmospheric column is very high cost, with relatively small yield improvements.

Vacuum crude fundamentals

Maximising CDU/VDU diesel recovery requires a diesel product draw on the vacuum column. Yet only a few US refiners produce a vacuum diesel product. Most still produce FCC feed from the top side-draw product, and it is not unusual for it to contain 60–80% diesel boiling-range material. Many non-US refiners already produce diesel product from the top side-draw of the vacuum column. Revamping an existing column or designing a new VDU to produce vacuum diesel requires a fractionation section (Figure 7). Fractionation is inherently better in the vacuum column because the L/V ratio is much higher than the atmospheric column. The top pumparound condenses the vacuum diesel product and reflux (L) for the fractionation section. Since the reflux flow rate is low, it must be metered and flow controlled to ensure it is maintained within the distributor

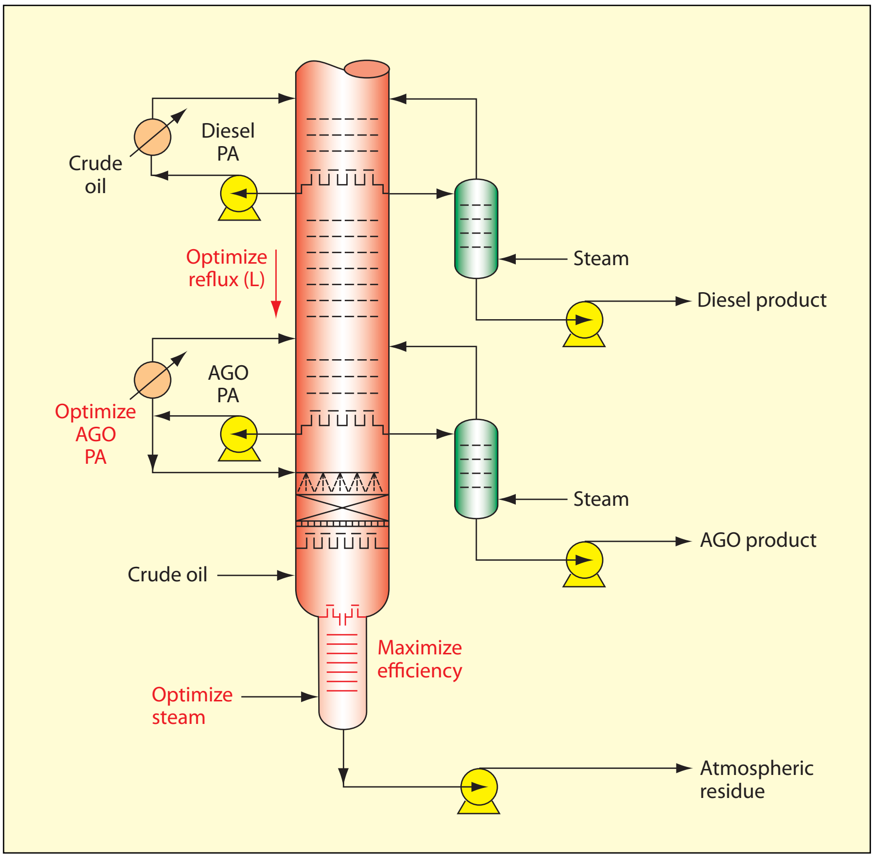

***Figure 6** Atmospheric column stripping section*

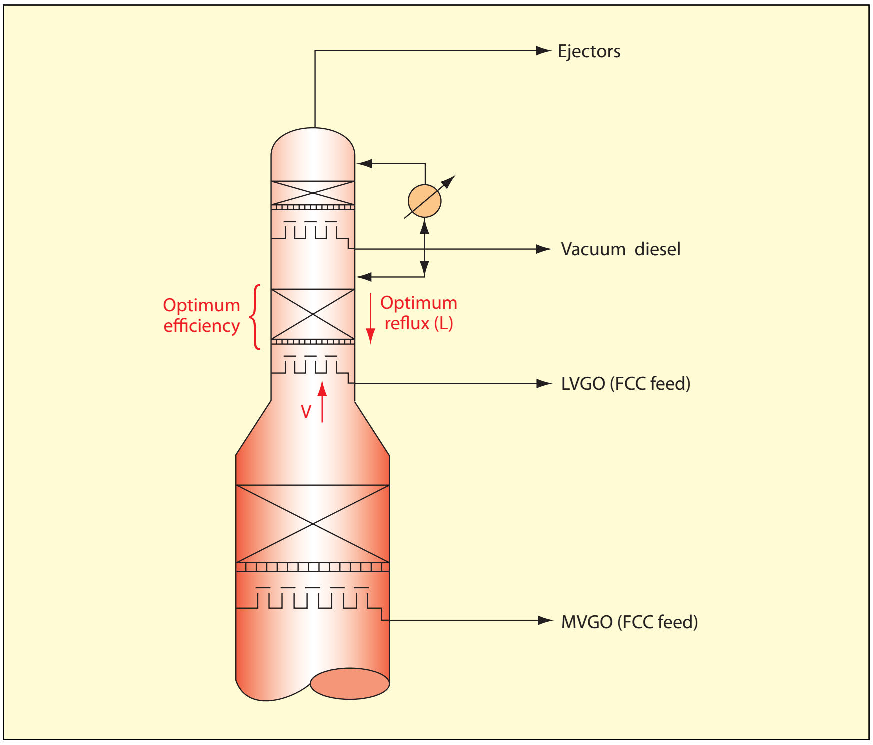

***Figure 7** Vacuum column diesel products*

limitations. Good control of the column heat balance is needed to generate sufficient fractionation section reflux.

The vacuum column diesel/LVGO fractionation section L/V ratio is high compared to the atmospheric column. The fractionation section reflux rate is typically 40–100% of the vacuum diesel product rate. Since the vapour rate leaving the top pumparound is extremely low, the vapour rate to the fractionation section is primarily vacuum diesel product and LVGO product. While in the atmospheric crude column, the vapour rate leaving the diesel pumparound contains overhead receiver gas, naphtha and kerosene, as well as the kerosene fractionation section reflux. Therefore, atmospheric column diesel fractionation section molar L/V ratio is typically 0.1 or less, whereas the vacuum column fractionation section L/V ratio is 0.3–0.5. Since the vacuum column L/V ratio is much higher than the atmospheric column, it has better fractionation.

The vacuum column pumparound heat balance determines the amount of vacuum diesel that can be produced. The top pumparound duty must be sufficient to condense the available vacuum diesel product and the internal reflux. It is not unusual for too much heat to be removed in the lower pumparounds, resulting in low vacuum diesel product recovery even with a properly designed fractionation section. When packing efficiency is adequate (~ three theoretical stages) but the internal reflux is low, the vacuum diesel product yield will be low. Fractionation efficiency alone will not provide high vacuum diesel product recovery. Optimising the internal reflux (L) allows the maximum amount of vacuum diesel product yield.

Maximising CDU/VDU diesel product requires either no AGO product from the atmospheric column, or the AGO can be fed to the vacuum column to recover the diesel boiling-range material. When atmospheric column AGO contains a large amount of diesel, it must be fed to the vacuum column to maximise overall recovery. Since the atmospheric column operates above atmospheric pressure and vacuum below, the majority of the AGO product vapourises when it enters the vacuum column. It should be fed to the vacuum column below the fractionating bed for maximum vacuum diesel product and energy recovery (Figure 8). Selecting the proper location is critical. In a vacuum column with both an MVGO and HVGO pumparound, it should be fed below the MVGO pumparound for maximum heat recovery.

Conclusion

Atmospheric column diesel recovery is inherently difficult because the fractionation section molar L/V ratio is typically less than 0.1, whereas in the vacuum column 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 the CDU/VDUs are designed differently where diesel product is the primary motor fuel and economics favour high recovery. Today that should also include US refiners.

Atmospheric and vacuum column diesel product yield should be optimised based on VDU performance and energy recovery. High atmospheric column diesel recovery makes the VDU feed heavier, reducing the VGO yield, especially with heavy and extra-heavy crudes. Heat recovery and crude preheat depend on atmospheric diesel and AGO product yield. Diesel draw temperature is much higher in the atmospheric column compared with the vacuum column. Consequently, all the heat duty needed to condense vacuum diesel and its internal reflux is lost to air and water, whereas all the condensing heat and approximately half the product cooling heat are recoverable to crude oil from the atmospheric column.

Modifying the vacuum column to produce diesel from the top section can be a relatively low- to moderate-cost revamp with a high return. 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. Since the top section diameter is small, often no foundation changes are needed. In one case, the CDU/VDU diesel yield was increased by 40% by installing a new top section on the vacuum column with an investment of less than $5 MM. Furthermore, by increasing diesel recovery, some refiners have been able to unload their FCC and hydrocracker, allowing higher crude charge rates without exceeding these conversion unit capacities.

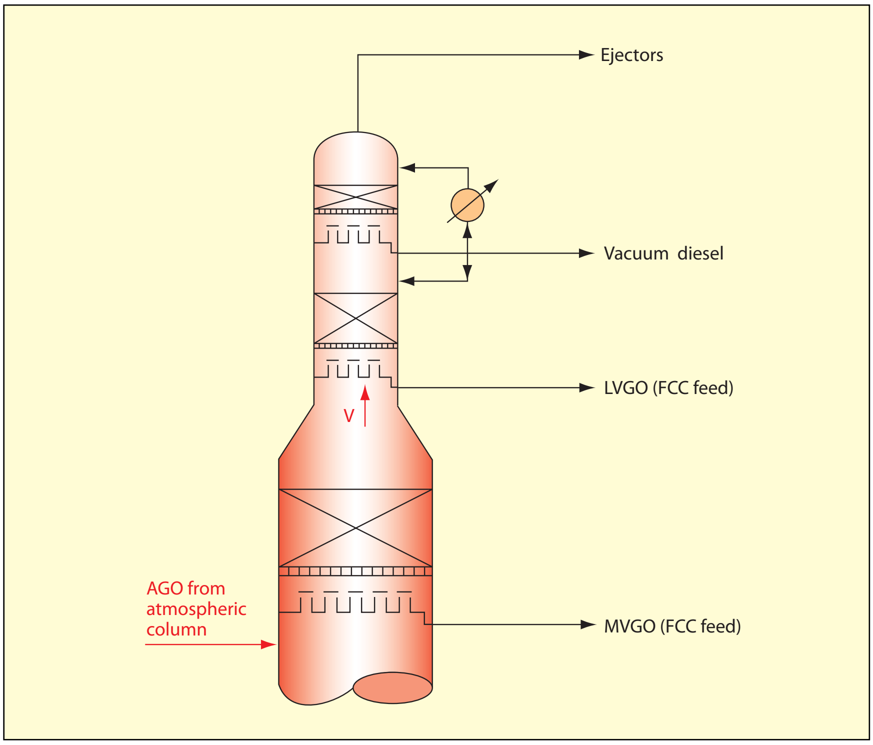

Figure 8 *Maximum diesel product yield*

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