Low-capital crude unit revamp increases product yield

Daryl W. Hanson
Process Consulting
Services
Houston

Joanne Langston
James Keen
Craig Johnson
Lyondell-Citgo
Refining LP
Houston

In 2001, Lyondell-Citgo Refining LP improved diesel yield by 4.8% and atmospheric gas oil (AGO) product yield by 0.5% on whole crude by implementing a low-capital cost revamp in its Houston refinery (OGJ, Mar. 18, 2002, p. 70; July 30, 1984, p. 197).

Lyondell-Citgo produces more gas oil than its FCC can process; therefore, the crude revamp enabled the refiner to upgrade high-sulfur vacuum gas oil to diesel at an average of $2.50/bbl.

Before the revamp, tray fouling in the atmospheric-column stripping section forced Lyondell-Citgo to lower the steam rate as the run-length progressed to avoid atmospheric tower bottoms (ATB) entrainment, which turns the AGO product black.

The lower stripping steam rate reduced diesel product recovery and increased vacuum residue production.

Lyondell-Citgo processes heavy crude blends that present some unique processing problems including high vanadium and carbon residue contents. These heavy Venezuelan crude blends include Merey, BCF 17, and Pilon; their ATB contains 300-400 ppm (wt) vanadium.

ATB entrainment in the AGO increases catalyst deactivation in the cat feed hydrotreater (CFHT) and reduces unit run length. Another consequence of fouled stripping trays is more vacuum tower bottoms (VTB) yield caused by a higher vacuum unit charge rate.

The most substantial benefits of improved stripping section performance were increased heavy vacuum gas oil product yield and higher crude preheat temperature. The low-capital modifications to the atmospheric column had a simple payout of less than 2 months.

**Background**

In 1996 Lyondell-Citgo modified its Houston refinery to process heavy Venezuelan crudes and upgrade heavy crudes to light oil products.

As part of the refinery-wide improvements, Lyondell-Citgo installed a new crude unit to process 16° API gravity crude blends.

Since initial start-up, Lyondell-Citgo personnel made unit improvements, including changes to the crude preheat exchanger network that raised crude heater inlet temperature and increased crude capacity by 15%.

Before a scheduled 2001 turnaround, the refiner studied various low-capital-cost options further to improve unit profitability within existing major equipment constraints. Any modifications would also have to meet process requirements, stringent capital expenditure payout criteria, and turnaround schedule demands.

Several refineries process heavy crudes and produce various grades of high-performance asphalts; yet Lyondell-Citgo is only one of a few refineries in the world that can upgrade 16° API gravity heavy crude oil blends to light oil products.

These heavy crudes create many problems because they have high viscosities, some contain more than 60 lb
of salts/1,000 bbl, several have total acid numbers as high as 3.2, and all are difficult to distill.1-3

Some of these heavy crudes have lower thermal stability than other crude oils, which increases fouling tendency due to a greater likelihood of asphaltene precipitation. Refiners, therefore, try to maximize atmospheric crude column stripping section performance while avoiding fouling as the run-length progresses.

Atmospheric column stripping section problems are common. Heavy oil thermal stability and low flash-zone vaporization make the ATB stripping section operations important.

Heavy oil stripping requires more robust stripping section equipment designs. These robust designs also need to accommodate severe service; otherwise, the results will include lower diesel recovery, more diesel-boiling-range material in the FCC feed, and increased ATB yield.

When a vacuum unit has many simultaneous equipment constraints, as did Lyondell-Citgo’s, ATB stripping can impact VTB yields and gas oil cutpoint.4-5 Mechanical integrity, fouling resistance, tray efficiency, number of trays, and stripping steam rate ultimately determine stripping section performance. Damaged trays, no matter how efficient, will not contribute to flash-zone oil vaporization.

Fouling lowers distillate yield because the operator must reduce the stripping steam rate; in some instances fouling has caused unscheduled shutdowns.

Once mechanical integrity and fouling problems are mitigated through customized design features, then the operator can address the more detailed stripping section performance considerations. Refiners must address damage and fouling for long-term crude tower reliability.

During most grassroots crude unit constructions and many revamps, atmospheric crude column stripping section design is just one of many design activities. Most stripping sections are designed incorrectly with only 3-4 conventionally designed stripping trays and less than 3 lb of steam/bbl of ATB.

Fundamental tray design errors, including the use of the same open area on each tray, cause efficiencies less than 15%. Many stripping section column diameters are too large to allow good tray efficiency with low vapor rates.

In several cases, inadequate stripping lowered diesel product true boiling point cut points by 30-80°F. Low stripping-section efficiency, in conjunction with the resulting low diesel-AGO fractionation section efficiency, reduces profitability.

Fig. 1 shows revamp options to improve diesel and AGO yield.

**Heavy crude distillation**

Heavy crude blends contain fewer atmospheric distillates and as much as 75% ATB; therefore, the process and equipment designs must be optimized to achieve high diesel product recovery.

To maximize diesel recovery, the refiner must optimize stripping section and diesel-AGO product fractionation. Stripping sections help generate flash-zone vapor that contributes to distillate yield and permits higher diesel-AGO section reflux.

An incremental barrel of stripped vapor contains more diesel than a barrel generated with furnace temperature alone. In one case, total atmospheric distillates increased from 20 vol% to 33 vol% on whole crude when the atmospheric unit process and atmospheric column equipment were revamped.

Poorly designed flow scheme and equipment yielded 20 vol% atmospheric distillates and 80 vol% ATB, whereas the post-revamp design produced 33 vol% atmospheric distillate and 67 vol% ATB at higher crude charge rate.

Atmospheric column diesel product recovery is a function of many variables; ATB cut point has a large influence. A higher ATB cut point with proper column heat balance changes improves diesel recovery.

Enhanced diesel recovery requires more feed vaporization to generate sufficient reflux in the diesel-AGO fractionation section, which allows higher diesel product yield at the distillation specifications.

Heavy crudes are difficult to vaporize at atmospheric flash-zone operating pressures of 13-20 psig because there is little LPG and naphtha, as in lighter crude oil blends, to help flash-zone vaporization. Some heavy crudes contain only 4-7 vol% naphtha.

With a poor stripping section efficiency the crude heater outlet temperature needs to be 735-45°F to achieve an ATB cut point of 700°F. Few crude heaters can operate at these high outlet temperatures; thus, crude heater temperature alone will not generate an optimum diesel product yield.

Furthermore, whereas an operator can use the heater temperature to meet a targeted ATB cut point, less diesel product leaves the atmospheric column flash zone vs. an equivalent ATB cut point with optimized stripping section performance.

During the Lyondell-Citgo revamp in 2001, another refiner’s heavy crude unit processing the same crudes could not meet product yield targets. The crude unit could not charge the design feed rate because CFHT unit capacity was limited due to poor atmospheric column diesel recovery.

A revamp that increased atmospheric distillate from 20 vol% to 33 vol% on whole crude incorporated improved stripping section design and also modified the process flow scheme to eliminate the AGO pumparound and maximize diesel-AGO section reflux. Diesel recovery represented 10% of the yield improvement.

When processing heavy crude oil blends, the operator must evaluate fundamental process flow scheme changes and optimized ATB stripping section performance to maximize unit profitability.
Many crude units that process heavy crudes have an AGO pumbaround (PA) to maximize crude preheat. An ATB cut point of only 700°F, however, will result in a low flash-zone vapor rate even with good stripping section performance. It will be difficult, therefore, for the operator to generate a sufficient diesel-AGO fractionation section reflux and recover much AGO pumparound heat.

With heavier crude oil blends and improved diesel-recovery economics, the operator must reduce AGO PA duty to generate acceptable diesel-AGO fractionation (OGJ, Oct. 14, 2002, p. 54).

When possible, the operator should recover incremental heat removal from optimized ATB stripping in the diesel PA section. Heat rejection in this PA produces more reflux to the diesel-AGO fractionation zone and often increases tray efficiency, which leads to higher diesel product recovery.

Lyondell-Citgo’s atmospheric unit has a two-drum overhead system in which overhead vapor is exchanged against crude. A kerosine, diesel, and AGO PA system provide additional crude preheat.

The ATB stripping section was designed with six stripping trays with the same open area. Before the revamp and tray fouling occurred, Lyondell-Citgo operated stripping steam rate at about 16,000 lb/hr.

Diesel product yield on whole crude was about 10 vol%, AGO product contained about 40% diesel, and the vacuum unit’s middle vacuum gas oil product contained recoverable diesel.

Lyondell-Citgo’s atmospheric crude unit operated at maximum heater firing, was designed with an AGO pumparound, and had non-optimum ATB stripping. The diesel-AGO fractionation section had a low reflux; thus, Lyondell-Citgo had an opportunity to improve diesel recovery from ATB and AGO products.

**Improving diesel recovery**

Fundamental process and equipment design parameters that influence diesel recovery were optimized, which include:

- ATB stripper efficiency.
- ATB stripping steam rate.
- AGO stripper steam rate.
- Diesel-AGO fractionation section reflux.

More trays with a different design increased ATB stripping-section efficiency. In many cases, a proper tray design can increase tray efficiency to 30-35% from 10% or less.

Before the revamp, Lyondell-Citgo used four conventional trays in its stripping section. The revamp included seven trays with a customized non-fouling tray design, which increased flash-zone vaporization, raised the quantity of diesel vaporized, and increased the diesel-AGO fractionation section reflux rate.

Raising the stripping steam rate further improved diesel recovery.

Fig. 2 shows Watkins stripping steam curves, which show that stripping steam rates up to about 10 lbsteam/bbl of ATB product can improve yields. Actual recovery does not show the same response because steam rate influences the column operating pressure due to its effect on condenser duty.

Fig. 3 shows the actual response of Lyondell-Citgo’s diesel yield to changes in stripping steam rate.

Improved stripping section performance increases the flash-zone vapor rate, which allows a higher recovery of diesel. AGO stripper feed still contains considerable amounts of recoverable diesel product, however.

Increasing the AGO product stripper steam rate decreases the diesel-boiling-range material in the AGO product. Lyondell-Citgo was able to improve diesel recovery by optimizing the AGO product stripping steam rate.

Optimum AGO product stripping steam rates are unit dependent. Lyondell-Citgo was ultimately able to decrease diesel in the AGO product from more than 40% to about 20%.

Diesel-AGO fractionation section efficiency is a function of the efficiency and number of fractionating trays.

Low tray weir loadings, which reduce tray efficiency, are a function of reflux rate and tray design. A higher diesel section reflux can improve tray efficiency when the fractionation section tray weir loadings are low.

Before the revamp, Lyondell-Citgo had a low reflux rate in its fractionation section. Improved stripping and higher AGO product stripping allowed diesel section reflux to increase significantly, which led to higher tray efficiency.

The resulting higher tray efficiency contributed to Lyondell-Citgo’s diesel recovery improvements.

**Improved ATB stripper efficiency**

ATB stripping sections often have the same diameter as the column flash zone or use a smaller diameter that is too large. This leads to low tray efficiency and increases tray fouling. With heavy crudes and some unstable lighter crude oils, this fundamental design error increases fouling, which results in lower stripping steam rates.

Some designers reduce tray active area by using parallel plates with no hole area outside the baffles or by using oversized downcomers. Both these solutions effectively reduce active area and increase tray efficiency, but the design features can cause rapid tray fouling due to large stagnant areas and neither technique should be used to improve tray efficiency.

Stripping sections have sieve trays designed with 0.75-1.0-in. diameter sieve holes and no stagnant areas on the tray deck or downcomers. A rectangular tray design, high weir loading, low weir height, special weir design, high downcomer clearance, and downcomers designed at minimum cross-sectional area will minimize fouling.

These custom design features allow maximum tray efficiency and minimal
fouling tendency. Each tray open area should have a design that reflects the changes in the vapor rate that occur across the stripping section.

The bottom tray should typically have an open area with approximately 25% of the top tray’s open area. The operator, therefore, should select a stripping section column cross-sectional area based on column loadings that keep fouling material flowing with the ATB. This will prevent accumulations on the active deck and downcomers.

Fig. 4 shows the crude unit stripping section.

Decreasing ATB entrainment

ATB entrainment carries contaminants into the AGO product, which poisons the CFHT desulfurization catalyst.

In addition to fouled stripping section trays, a seemingly small flash-zone design error that entrained liquid from the bottom wash section tray with the rising vapor caused Lyondell-Citgo’s ATB entrainment.

Because two-phase feed enters the column at 100 fps, the flash zone must separate vapor from the unstripped ATB liquid and allow stripper vapors to flow up the tower with minimum entrainment.

Material on Lyondell-Citgo’s bottom wash section tray overflowed and entrained into the rising flash-zone vapor. The revamp included a modified bottom wash-section seal pan overflow that routed this liquid to the collector tray below the flash zone.

This low-cost design modification allows Lyondell-Citgo to produce low-metals AGO product at high crude charge and high stripping steam rates. The largest impact of the revamp was to unload the vacuum heater and increase heavy-vacuum gas oil cut point.

References

The authors
Daryl W. Hanson is a chemical engineer with Process Consulting Services, Houston. His previous experience includes lead process specialist for Koch-Glitsch Inc., Dallas, where he was involved in more than 100 column revamps including heavy oils and light-ends recovery. Hanson holds a BS in chemical engineering from Texas A&M University.

James G. Keen is a senior chemical engineer at Lyondell-Citgo Refining LP, Houston. His refinery experience includes process optimization, debottlenecking, and troubleshooting on delayed coking, crude-vacuum distillation, and tubular distillation-hydrotreating units. Previously, he was a process engineer and business analyst for Exxon Corp’s domestic butyl polymers business. Keen holds a BS in chemical engineering from University of Oklahoma, Norman.

Craig Johnson a process engineer in Lyondell-Citgo’s process design and technology department. He has experience in engineering, troubleshooting, operation, and design in more than 10 refineries. Johnson holds a BS in chemical engineering from Iowa State University, Ames.