Benefit of revamping a main fractionator

Additional FCCU capacity can often be achieved by implementing new packing and distributor designs, even if the main fractionator has already been revamped. The author presents some of the factors to be considered in evaluating a revamp

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The FCCU main fractionator is a key part of one of the most profitable units in most refineries, and, typically, the source of one of the unit's major bottlenecks. For this reason, the fractionator can often benefit from a review of the existing internals, taking into account current or proposed operating conditions, problems and possible solutions, as well as improvements to potential capacity, efficiency and reliability.

Main fractionator pressure drop can contribute to main air blower or wet gas compressor constraints. During the last 25 years, refiners have revamped the fractionator with high capacity trays or structured packing to increase capacity, reduce pressure drop, or both. Structured packing has been applied in approximately 100 main fractionators, resulting in significant capacity gains.

However, many of these towers have been in service for several years with no additional modifications, despite the fact that unit charge rate and/or severity has increased, significantly altering the internal loads on the tower. Trays, packing, and distributors may now be operating outside of their design range, causing loss in capacity or efficiency, or both.

New clean fuels regulations also potentially impact on main fractionator operation. Whether splitting FCC naphtha, undercutting LCO or naphtha, or cat feed hydrotreating, the main fractionator loads will probably change. Existing equipment may not perform well under the new loads. Undercutting FCC naphtha in the main fractionator also increases the potential for salt deposition at the top of the tower due to the lower overhead temperature. This must be considered to ensure proper design and operating procedures. Otherwise, unit reliability and performance may be compromised.

Years of operation in the severe environment presented by the FCCU main fractionator can cause failure or damage to tower internals even if originally designed with this severity in mind. Experience gained from many applications has resulted in improved reliability through better design practices and more thorough understanding of the application. Older packed main fractionators can often benefit from a review of the installation with these new developments in mind.

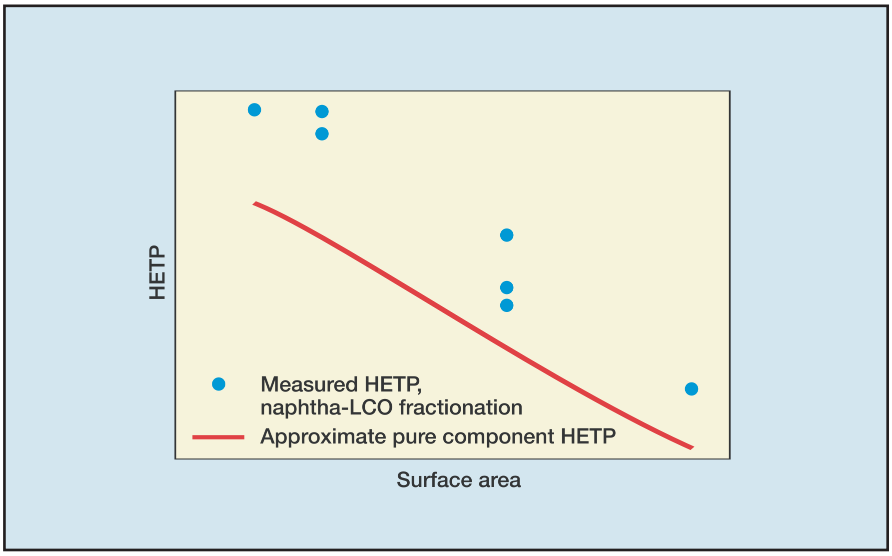

Figure 1 *Measured HETP for structured packing in FCCU main fractionator naphtha-LCO fractionation*

Significant improvements in both technology and application offer better process performance and reliability. New packing and distributor designs offer greater capacity, improved efficiency, and reliability improvements. Main fractionators that were revamped more than a few years ago can often achieve improvements in capacity or reliability through implementation of these enhancements.

There are many factors to consider when evaluating a potential FCCU main fractionator revamp. If the unit has been revamped previously and is now being pushed closer to the ultimate limit, these considerations are even more critical. Improper design can severely undermine project economics. A thorough review of the existing unit along with operating history and projected heat and material balance is necessary. Some important review considerations include separation efficiency versus capacity, liquid distributor capacity, clean fuels considerations and reliability.

Efficiency vs capacity

In general, when revamping from conventional trays to high capacity trays, there will be no loss in fractionation capability. When revamping from trays to structured packing, separation efficiency sometimes must be sacrificed, depending on column configuration. When revamping a tower that is already fully packed for higher capacity, a loss in separation efficiency is sometimes unavoidable, because capacity increases are obtained by using packing with a lower surface area. Lower surface area packing has lower separation efficiency (Figure 1).

Fortunately, separation in refinery fractionators is generally more sensitive to reflux rate than theoretical stage count, because the reflux ratio, even in fractionation zones, is typically very low [Laird D, Fractionation impact on FCC gasoline and LCO sulfur content; NPRA Annual Meeting, 17–19 March 2002]. Adjusting the tower heat balance to increase the reflux ratio in the critical fractionation zones can often compensate for the loss in theoretical stages. However, this must be considered during scope development to ensure all external equipment (condensers, pumps and so forth) have sufficient capacity for the new operating conditions.

To address concerns with loss in efficiency when low surface area packings are being considered, proprietary Intalox structured packing has been employed. It is designed with a patented feature that aids in liquid spreading and surface wetting, resulting in enhanced efficiency. The advantages of this structured packing are especially apparent in the lower surface area packings, typically used when debottlenecking main fractionators. These packings have greater efficiency for a given surface area than conventional structured packing without sacrificing capacity.

Finally, when designing an FCCU main fractionator revamp, it is important to use realistic estimates of packing efficiency. Most, if not all, published HETP data for structured packing are based on pure component separations. As shown in Figure 1, pure component HETP is significantly lower than the HETP experienced in actual main fractionator operation. Process design must be based on knowledge of the specific system or product quality and unit throughput may suffer.

Distributor capacity

When revamping a tower that is already fully or partially packed, it is important to evaluate the capacity of the existing liquid distributors, even if the packing in the same bed has sufficient capacity. Failure to replace or modify distributors that are not properly sized for the proposed revamp can have consequences ranging from insignificant to catastrophic.

The four primary types of liquid distributor used in FCCU main fractionators are trough distributors, spray distributors, orifice or deck distributors and slurry trough distributors. These distributors have varying degrees of tolerance for operating outside design ranges. None of them provide good distribution at turndown below their lower operating point. Some can tolerate overflowing liquid with minimal consequences, depending on the application. Others malfunction at high vapour rates even if the liquid flow rate is within the design range.

High efficiency trough distributors are generally used above fractionation beds in the FCCU main fractionator. While these distributors will not generally limit tower capacity if they overflow, product quality may suffer. Entrainment will also increase from an overflowing distributor. At extremely high capacity factor, or C_s (Equation 1), it may be necessary to utilise special distributor design features to prevent entrainment.

$$C_s = v\sqrt{\frac{\rho_v}{\rho_l - \rho_v}} \qquad (1)$$

where

v = superficial vapour velocity, ft/s
ρ_v = vapour density, lb/ft^3
ρ_l = liquid density, lb/ft^3

Distributor open area should also be reviewed at high C_s. Table 1 lists some guidelines for tower capacity relative to C_s.

C_s guidelines

	C_s
Low	< 0.25
Moderate	0.25 < C_s < 0.38
High	0.38 < C_s < 0.45
Extremely high	> 0.45

Table 1

Spray distributors are used above pumparounds in FCCU main fractionators. When operated above their design rate, these distributors will have a very high pressure drop and generate small droplets. This increases entrainment to the bed above, especially at high tower C_s. They should not be used on flashing feeds, so are not appropriate for pumparounds containing rich sponge oil returning to the main fractionator. They should also be avoided in the slurry pumparound due to the potential for erosion of the nozzles.

Orifice distributors are used for pumparounds and less critical fractionation zones in the FCCU main fractionator. They can function as a combination collector-distributor, reducing the required tower height in some installations. Because they have less open area than other designs, severe entrainment can occur when the distributor overflows. Also, the liquid height on the distributor is a function of both the liquid pressure drop through the orifice and the vapour pressure drop through the risers.

Increased vapour traffic may cause the distributor to flood even if the liquid rate is within the design range, potentially impacting on fractionation in the bed above or restricting tower capacity. This is a frequent problem in installations where charge rate has increased significantly since the original design.

Slurry trough distributors are specifically designed to handle the high liquid rates and severe environment of the slurry pumparound zone in the FCCU main fractionator. They are equipped with large slotted drip points, which often have a triangular overflow notch for extra protection should the distributor slots become plugged. A guide baffle is also recommended at high C_s to minimise entrainment. Troughs are wide and the openings are large resulting in superior fouling resistance. They will generally continue to provide adequate distribution even if overflowing, although they will generate more entrainment. The distributor capacity is not impacted by vapour velocity, although distributor open area should be reviewed at high C_s.

Distributor design and selection requires thorough understanding of the FCCU main fractionator constraints and the individual distributor capabilities. Improper application or design has the potential to significantly constrain unit capability.

Clean fuel considerations

The FCCU is the primary source of the refinery gasoline pool sulphur for most refineries [Keyworth D A et al, Offsetting the cost of lower sulfur in gasoline; NPRA Annual Meeting, 22–24 March 1992] and is also the source of a significant amount of the difficult-to-hydrotreat sulphur species in the diesel pool [Mayo S et al, Elegant solutions for ultra low sulfur diesel; NPRA Annual Meeting, 18–20 March 2001].

There are several modifications that can be implemented in the main fractionator to help refiners address new lower sulphur fuels requirements, which should be reviewed as part of the future refinery clean fuels strategy.

One strategy for meeting low sulphur gasoline regulations is to post-hydrotreat FCCU naphtha. To avoid excessive octane loss due to saturation of the olefins in the front end of the naphtha, the full range naphtha is split into light and heavy cuts. This can be accomplished in the main fractionator or by using a two drum overhead system. Either modification will result in an increased load to the wet gas compressor. Also, neither approach is capable of making an extremely tight split between the light and heavy naphtha.

A low cost solution to meet gasoline sulphur regulations is to undercut FCCU naphtha. Most refiners will also probably employ this strategy on a periodic basis for "trim" sulphur control during turnarounds, refinery upsets etc. The main fractionator internals should be carefully evaluated to ensure they will function properly in this mode of operation.

Undercutting and splitting naphtha in the main fractionator both result in a lower tower overhead temperature. This lower temperature can dramatically increase the risk of salt deposition in the top of the tower. If the refiner plans to operate at lower overhead temperatures, even periodically, the risk of salt formation must be carefully evaluated. If salt can be expected to form at tower operating conditions, it is necessary to design the tower to allow for online removal of the salt deposits. Alternative metallurgy should also be evaluated. If salting is expected, trays are generally much more suitable than packing. If packing is used in a salting environment, special design practices must be followed. No method has proven completely effective for online removal of salt deposits from a packed bed.

Light cycle oil (LCO) contains sterically hindered dibenzothiophenes, which are difficult to remove by conventional hydrotreating. They account for much of the sulphur remaining after hydrotreating diesel to 500ppm sulphur, as required by current regulations [Tippett T et al, Ultra low sulfur diesel: catalyst and process options; NPRA Annual Meeting, 21–23 March 1999].

The LCO cutpoint must be reduced to significantly lower their concentration. This results in a loss of LCO to slurry and may cause flooding in the main fractionator.

The main fractionator can be revamped to pull a heavy cycle oil (HCO) or heavy LCO draw. The LCO cutpoint can then be reduced and the lost yield recovered in the HCO draw. This stream will concentrate the sterically hindered dibenzothiophenes into a relatively small stream. This stream can be fed to a hydrocracker or gasoil hydrotreater or used for off-road diesel or industrial fuel oil blending, depending on refinery configuration.

Reliability

With refiners pushing FCCU turnaround cycles to four or five years, damage to the tower, limiting capacity or efficiency, can cost the refiner millions of dollars in lost revenue. All tower internals must be designed with this severity and longer cycles in mind to ensure that poor or degraded tower performance does not limit unit capability over the course of the run.

FCCU main fractionators are subject to surges from many sources, including wet stripping steam, submerged feed nozzles and flashing feeds. The internals must be designed properly to prevent damage from these surges. A good design practice is to design internals for a minimum of 1psi uplift resistance. For distributors and packing supports, using more or larger beams and tower attachments is recommended. For packed beds, hold-down grids are used. These grids can be attached to the vessel shell or anchored by the use of through rods.

The feed velocity to the FCC is very high, typically over 100ft/s. This is especially true for units that have been revamped and expanded several times without replacing the reactor vapour line. At feed velocities above 120ft/s, the risk of damage or coking of tower internals becomes significant. The feed nozzle size should be increased to lower the velocity, or a vapour distributor should be considered.

If the refiner chooses to increase the feed nozzle size, they must increase the line size several line diameters upstream of the feed nozzle to achieve significant benefits. Some refiners have swaged-up immediately upstream of the feed nozzle. However, no benefits have been observed from this practice. Sufficient spacing must also be left above and below the nozzle or other problems can be created. Proposed changes should be reviewed with the mass transfer supplier to insure proper design practices are followed.

Main fractionator vapour feed distributors are often a cost effective alternative to increasing feed nozzle size. The feed distributor must be carefully designed to provide vapour distribution without increasing the risk of coking. They must also be designed to withstand the high temperature erosive environment. Conventional designs (vapour horns, vane inlet devices, v-baffles) have proven not to work in FCCU main fractionators due to coking, erosion, or both. Poorly designed distributors have coked to the point that vapour flow was obstructed, resulting in premature shutdowns. A properly designed distributor provides more uniform flow entering the slurry pumparound bed.

High open-area distributors, such as the proprietary Koch-Glitsch Model 798 vapour distributor, improve distribution significantly but resist damage and coking. Vapour distribution comparisons can be done using computational fluid dynamics (CFD) analysis.

The slurry pumparound zone presents a special reliability challenge. The reactor vapour entering the zone is superheated to approximately 1000°F and contains FCCU catalyst fines. Condensed slurry is cooled and re-circulated to the top of the bed to cool the vapour before it enters the upper section of the tower. The circulating slurry stream contains catalyst fines as well as coke particles that are formed in the bottom of the tower and the heat exchanger circuit.

The internals in this section must be able to transfer the required heat duty as well as resist fouling and upset. As previously discussed, special distributors have been developed that resist fouling while maintaining good liquid distribution. Traditional installations

Figure 2 Flexigrid style 2 removed from slurry pumparound

have used shed or disc and donut trays to provide vapour-liquid contacting. However, as refiners push their main fractionators, these trays often do not have the capacity or efficiency to obtain the desired rate.

The proprietary Koch-Glitsch Flexigrid Style 2 grid packing has proven to provide as good or better reliability than shed trays in the slurry pumparound section with significant increase in capacity. Slurry pumparounds with this packing are in operation at C_s over 0.5ft/s. Figure 2 shows Flexigrid packing that has been removed for inspection after 12 years in slurry pumparound service without being removed. The grid was re-installed without cleaning.

Case study
Increased conversion

An independent refiner planned a revamp to increase conversion in the FCCU. This increase had to be accomplished without sacrificing unit charge rate or product quality. The main fractionator was a unit bottleneck, but had already been revamped to increase capacity several times, and was fully packed. In addition, as shown in Figure 3, this tower is already one of the most heavily loaded FCCU main fractionators in the refining industry. A thorough test run was conducted to define base case unit operation.

The test run data was used to develop a simulation of the tower, which allowed evaluation of the existing internals (Figure 4). The evaluation showed that, although the entire tower was very close to flood (in some cases over 90% of calculated flood point), the only component flooded at the base case conditions was the orifice type LCO pumparound distributor. Gamma scans confirmed this distributor was flooded, with liquid backing up 4–6ft into the naphtha/LCO fractionation bed.

A pressure survey conducted as part of the test run showed damage to the naphtha pumparound/reflux spray distributor at the top of the tower. This damage explained poor distribution indicated by the gamma scan.

In addition to a detailed test run, including field pressure surveys, revamp scope development should include a detailed review of prior turnaround inspection records. This review should evaluate areas of recurring damage to the main fractionator and identify the root cause. In this case, two areas of primary concern were identified:

1. Minor damage was noted to the bottom of the slurry pumparound bed in each of the two previous turnarounds. The damaged area was reinforced without removing the bed. This bed consisted of approximately 11ft of Flexigrid 2 packing supported directly on a support ring and beams and had been in service for 12 years. Newer designs use a bolted support grid below the Flexigrid packing, which is more reliable. However, despite the damage, the bed had provided trouble-free operation for the entire 12-year life with only minor maintenance during the two previous turnarounds

2. The LCO pumparound return, containing the rich sponge oil returning from the gas plant, returns into a false downcomer above the orifice plate distributor. This false downcomer was repeatedly found blown apart and laying on the distributor. The downcomer was not constructed to withstand the force caused by the vaporisation as the rich sponge oil was flashed to main column pressure. The base case simulation was adjusted using projected post-turnaround yields. Because the main fractionator pump-arounds are heat-integrated

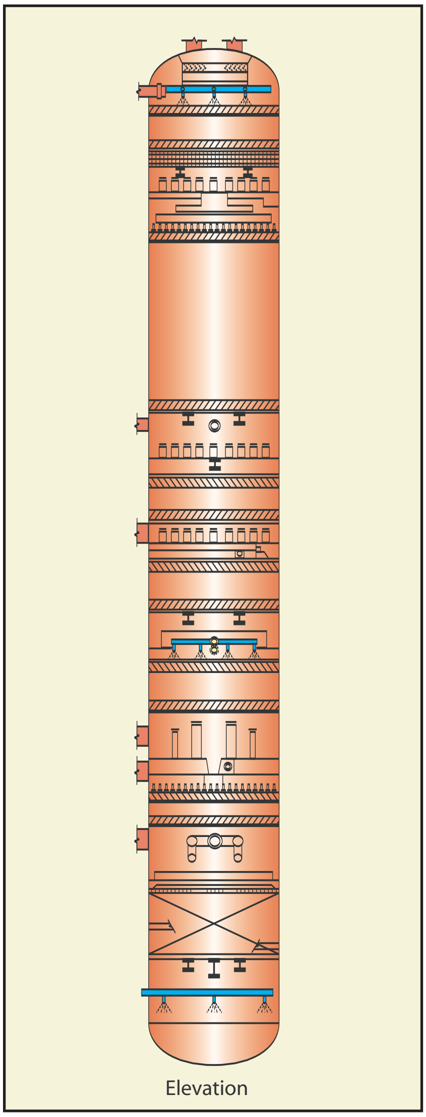

Figure 4 Main fractionator arrangement

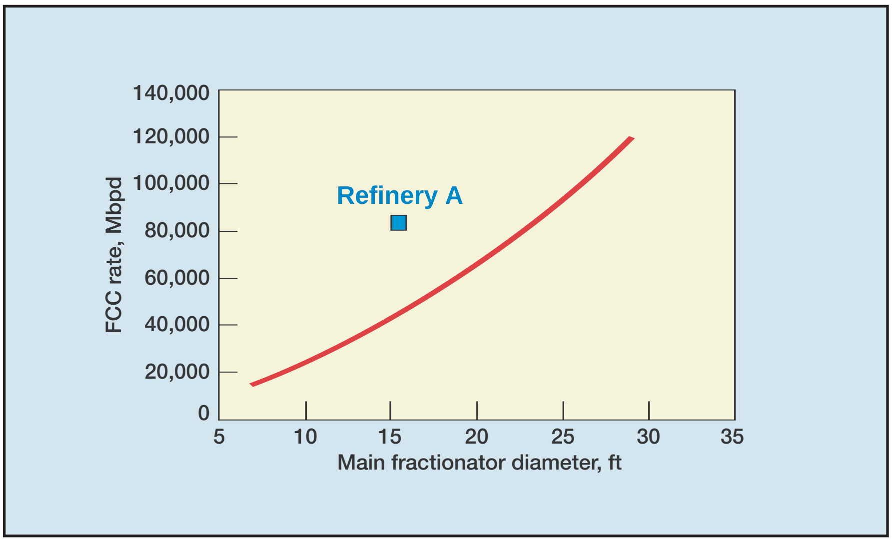

Figure 3 North American FCC capacity

PDF courtesy of PTQ. First published PTQ Winter 2005.

Figure 5 *Flash box supported, using feed pipe and existing tower attachments*

5TX packing rates approximately 90% of flood at the design conditions. This packing was selected to replace the naphtha/LCO bed.

A new support grid was designed for the slurry pumparound bed. A new, reinforced spray distributor design was also developed for the top pumparound/reflux. Although neither of these problems had been severe enough to limit capacity during previous runs, the refiner planned to extend the duration between turnaround cycles and wanted to ensure the main fractionator would not be a limit.

The high vapour and liquid rates made it impractical to replace the existing LCO pumparound distributor with a similar orifice type distributor. A trough distributor was selected instead. However, the design was complicated by the fact that the refiner did not want to remove the LCO pumparound bed due to turnaround time constraints.

As a result of this constraint, no welding was allowed. A special beam-supported design was developed that could re-use the support ring for the existing orifice distributor.

A new flash box was also designed for this distributor to allow for disengagement of the vapour from the rich sponge oil. The flash box also had to use existing tower attachments with no welding. A reinforced design (Figure 5) was developed to prevent damage similar to that experienced in previous runs.

A performance test was conducted on the tower after startup. During the test, it was apparent that the tower stability had improved compared to pre-revamp operation, and had less oscillation in the pressure drop across the naphtha/ LCO bed. In addition, overall column pressure drop was lower by approximately 8.0 in H_2O, or 0.3psi.

The data from the test run were again used to construct a simulation representing actual tower operation. The tower simulation heat and material balance were adjusted to match the field data and the theoretical stage count was adjusted to meet product properties. The naphtha/LCO fractionation section performance was of primary concern because of the extremely high loads and the importance of the separation.

The performance of the new bed is compared to the old in Table 2.

Naphtha/LCO fractionation bed performance

	Before revamp Flexipac 3Y	Post revamp Intalox 5TX
C_s, ft/s	0.48	0.52
HETP, in	43*	44
Measured DP, in H_2O	11.5	5.7
Calculated DP, in H_2O	9.9	8.2
Naphtha/LCO 90%/10% gap, °F		+5

*Adjusted for flooding in bottom 4ft of bed from overflowing LCO pumparound distributor

Table 2

with the FCCU gas plant, the modified simulation was constrained to meet the required gas plant heat loads. Other constraints, including overhead condenser, wet gas compressor, and operating pressure were maintained. The main fractionator internals were re-evaluated using this simulation.

Upon evaluation of the existing internals with the revamp simulation, two distributors were identified that required replacement for the new operating conditions, in addition to replacing the LCO pumparound distributor already noted. Also, the HCO pumparound packing would be expected to flood. However, the greatest concern was the naphtha/LCO fractionation bed.

This bed consisted of approximately 21.5ft of Flexipac 3Y structured packing. The maximum load in this bed was projected to be at 100% rated flood with a C_s of 0.53ft/s after the revamp. This is the critical fractionation bed in the tower and cannot tolerate the loss in fractionation efficiency associated with changing to higher capacity packing.

Intalox structured packings have been shown to have slightly greater efficiency than other structured packing of similar surface area. As noted earlier, this is especially true for the lower surface area structured packings. In this case, Intalox

Clearly, the Intalox 5TX packing provides performance equal to or better than the Flexipac 3Y packing despite the higher loads. Also interesting is that the naphtha/LCO section is operating at 109% of system limit flood predicted using Fractionation Research Institute (FRI) Topical Report 1335. System limit flood is the theoretical ultimate capacity based on the physical properties (liquid and vapour) of the system.

There is some disagreement regarding measurement and calculation of the system limit. Several correlations exist and give inconsistent predictions. Therefore, the true ultimate system capacity cannot be precisely predicted. However, the Intalox 5TX packing capacity exceeds previously recognised limits.

Profitability

The FCCU main fractionator is an important piece of the FCCU. Its capacity, efficiency, and reliability greatly influence the overall profitability of the FCCU. When evaluating potential FCCU revamp projects, or even when approaching a maintenance turnaround, it is important to review current and historical operation of the tower with respect to future operating goals.

This review should consider improvements in basic technology, as well as new technology developments that can dramatically increase main fractionator capacity and reliability. These improvements, if properly designed and executed, can significantly increase the revenue from the FCCU during the subsequent run.

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