

Catalyst stripper improves FCC unit performance

Stripper internals with improved mass transfer characteristics improve the performance of an FCC unit

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FCC unit performance is dictated by a delicate coke and heat balance^{1,2} because the reactor produces the necessary amount of coke to satisfy the unit heat balance. The heat produced by the combustion of coke in the regenerator supplies the required heat (via circulating catalyst) for the endothermic riser-reactor.

The coke is classified into four types: contaminant coke, catalytic coke, additive coke and catalyst-to-oil coke. Generally, catalytic, contaminant and additive coke production are functions of feed quality, catalyst type and reactor operating temperature. However, catalyst-to-oil coke is a result of the hydrocarbons entrained within the spent catalyst as it enters the regenerator. This coke includes hydrocarbons absorbed on the catalyst surface and within the catalyst pores. It is very important to strip off these hydrocarbons (coke precursors) by employing an efficient stripper. Removal of these hydrocarbons from the catalyst before it enters the regenerator can significantly improve over-

all performance and hence profitability of the FCC unit. This article discusses the design and implementation of Lummus Technology's patented ModGrid stripper and the improvements achieved in commercial FCC units.

Coke yield and delta coke

Understanding delta coke and its relationship to coke yield and heat balance is important for assessing the impact of stripper performance on unit profitability:

$$\text{Coke yield} = \text{Catalyst-to-oil} \times (\text{delta coke}) \quad (1)$$

$$\text{Delta coke [or (CSC-CRC)]} \propto (T_{rg} - T_{rx}) \quad (2)$$

Where:

- Coke yield is expressed in wt% of the fresh feed rate to the FCC unit, which is determined by the heat balance around the reactor and regenerator
- Catalyst-to-oil is the ratio of catalyst circulation rate to fresh feed rate, which is dimensionless. In general, the higher the

catalyst-to-oil ratio, the higher the conversion of feed to valuable products

- Delta coke, or (CSC-CRC), is the difference between the coke on spent catalyst (CSC) leaving the stripper and the coke on regenerated catalyst (CRC) leaving the regenerator, which is expressed in wt% of catalyst
- T_{rg} is the catalyst bed temperature in the regenerator
- T_{rx} is the riser or reactor outlet temperature.

The coke yield is essentially set by operating conditions such as the riser-reactor outlet temperature and feed preheat temperature, while the delta coke is directly influenced by catalyst type, feed quality and unit hardware design. To achieve a higher catalyst-to-oil ratio and hence higher conversion, it is necessary to reduce delta coke or reduce T_{rg} for a given T_{rx} . T_{rg} is a function of regenerator efficiency and CSC (amount of coke carried from the stripper to the regenerator). Therefore, it is important that stripper efficiency be maximised to achieve a higher catalyst-to-oil ratio and conversion.

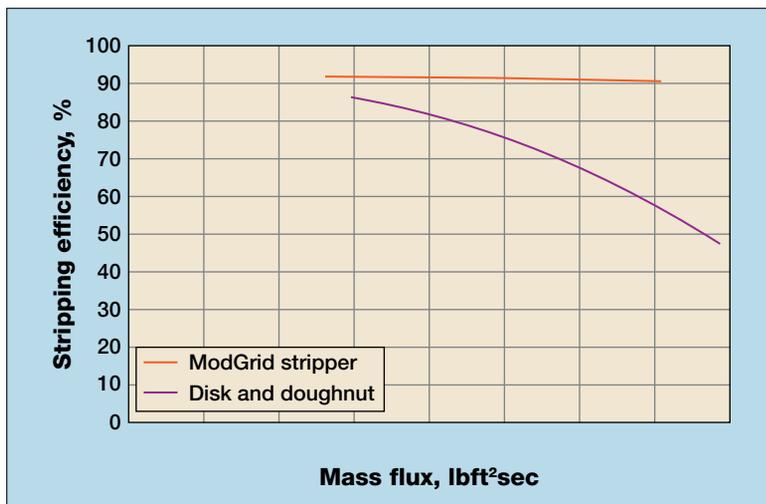


Figure 1 Stripping efficiency comparison

Characteristics of efficient stripper design

An efficient catalyst stripper design is one that maximises mass transfer between the two phases (the stripping steam flowing up and the fluidised catalyst flowing down the stripper vessel). Hydrocarbons in the catalyst phase need to be replaced with steam. To enhance this mass transfer phenomenon, the stripper internals should have the following characteristics:

- Maximum surface area for mass transfer per unit volume of the stripper vessel
- Maximum cross-sectional area of the vessel available for catalyst and steam to flow through it
- Maximum active volume (ie, no stagnation or dead zones)
- Uniform distribution of catalyst and steam to avoid channelling and by-passing
- Increased contact time and mixing between the two phases
- Excellent fluidisation quality
- Plug flow conditions
- Mechanically robust to withstand service.

ModGrid design features

The ModGrid stripper design has all the characteristics described above and has delivered superior FCC unit performance in several commercial units currently in operation. This design was conceptualised and then developed by conducting large-scale

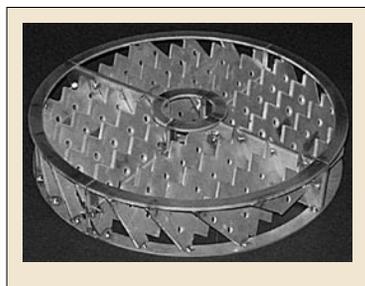


Figure 2 Modular Grid (ModGrid) stripper internal

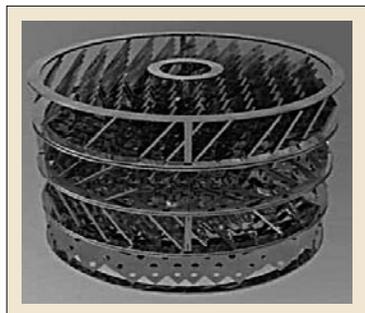


Figure 3 ModGrid stripper section

cold-flow model tests that compared the efficiency of this design to the conventional disk-and-doughnut baffle design. The tests were done at various catalyst flux rates to determine the effect of higher catalyst flux rates on stripping efficiency with the two systems. Figure 1 compares the efficiencies in the two cases. At all flux rates, the ModGrid stripper design's efficiency is higher than the conventional design and it does not drop with an increase in catalyst flows. The design has been in commercial operation for more than six years.

Figure 2 shows the typical ModGrid stripper internal. This modular grid consists of baffles that are angled and oriented such that fluidised catalyst can easily and uniformly flow over these baffles like a curtain. The baffles have holes, and steam passes from under the baffles, through the holes and then through the curtain of fluidised catalyst. The contact of steam and catalyst occurs over these baffles, which provide the maximum surface area for mass transfer and hence higher efficiency. The manner in which the baffles are angled and oriented also results in a maximum cross-sectional area available for catalyst flow through the modular grid. This, in turn, lowers steam and catalyst velocities and increases contact time, which further improves mass transfer efficiency. The notches at both the top and bottom edges along the full length of the baffles break up steam bubbles so these bubbles do not increase in size as they flow up through the modular grids.

Benefits of ModGrid stripper internals (US refinery)

Post-revamp results

Dry gas	-0.9 wt%
Gasoline	+0.9 wt%
Light cycle oil	+1.4 wt%
Stripping steam rate	-30%
Feed rate	+12%

Table 1

The baffles that form the modular grid are sized to extend the full width of the stripper diameter. The baffles are organised and built into modular grids for ease of installation and removal. Figure 3 shows that four to six modular grids are grouped to form a section or assembly of modular grids. Each alternating modular grid is oriented so that the catalyst takes a 360-540-degree turn as it flows down the modular grid assembly. This zigzag flow pattern provides enhanced contact between the catalyst and steam phases, and also reduces the possibility of channelling and/or dead spots. A typical ModGrid stripper design will contain two or three such modular grid assemblies.

Commercial results

In one US refinery revamp, a conventional FCC stripper with disc-and-doughnut-type baffles was replaced with the ModGrid stripper design. The refinery was able to increase the fresh feed throughput and improve the yield of higher-value products. The results are shown in Table 1.

Implementing the ModGrid stripper design in a European FCC unit enabled the refinery to process heavier feed. The refinery increased Conradson carbon in the FCC unit feed

and increased the fresh feed throughput while maintaining the same regenerator dense bed temperature as before the revamp. These results are shown in Table 2.

Assessment of stripper performance

Hydrogen in coke is traditionally used as a primary indicator when assessing the performance of a FCC spent catalyst stripper. Hydrogen in coke is calculated from regenerator flue gas composition data. Since the flue gas data is also the basis for the heat balance calculations, it will influence many of the calculated operating variables such as unit coke make, catalyst circulation rate, heat of reaction and, most important, hydrogen in coke.

The implications of using hydrogen in coke as a stripper performance indicator are well described elsewhere by Grace Davison.³ From this reference, the formula used to estimate hydrogen in coke is:

$$\text{Hydrogen in coke} = (100 \times A) / [(A + 2.979 \times (\text{CO}_2 + \text{CO}))]$$

Where:

- $A = 20.95/79.05 \times (100 - \text{CO}_2 - \text{CO} - \text{O}_2) - (\text{O}_2 + \text{CO}_2 + \frac{1}{2}\text{CO})$
- CO_2 , CO and O_2 are flue gas components in mol% carbon dioxide, carbon monoxide and oxygen, respectively.

From these equations, one can deduce that the hydrogen in coke may vary between 2 and 15 wt% if the CO_2 is changed from 14 to 18 mol%. In other words, small inaccuracies in flue gas analysis can lead to significant variations in the calculated hydrogen in coke. Therefore, hydrogen in

Benefits of ModGrid stripper internals (European refinery)

Post-revamp results

Feed rate	+ 6%
Feed CCR	+ 0.4%
Metals in feed	+2.7 ppmw
Riser outlet temperature	+5°C
Regenerator bed temperature	No change

Table 2

coke is not a very reliable indicator of stripper performance. The following variables are recommended — measured before and after the stripper revamp — to assess the revamp benefits. (However, hydrogen in coke can still be used as a secondary parameter to check for consistency of delta coke/heat balance calculations.):

- Regenerator dense bed temperatures for a given set of riser outlet temperature and feed preheat temperature combinations
- Product yields corrected for a specified boiling range
- The combustion air required at a given oxygen concentration in flue gas
- Feedstock analysis data (Conradson carbon, nickel, vanadium, and so on)
- Coke on the spent catalyst and regenerated catalyst (to determine delta coke)
- Measured delta coke value compared with estimated delta coke value based on flue gas analysis data.

In other words, the overall performance of the unit before and after the stripper revamp should be used to quantify the benefits of the stripper revamp.

Conclusions

Use of the ModGrid stripper internals design significantly improves performance and

hence profitability of an FCC unit. It is important to understand the coke yield, delta coke, their relationship to the catalyst-to-oil ratio, and the influence of these variables on FCC unit performance. It is also necessary to utilise the correct measured variables to assess the stripper performance after the revamp.

References

1 FCC heat balance for heavy oils, *Oil & Gas Journal*, 21 Oct 1985, 64.

2 FCC Heat Balance Fundamentals with a Mechanical Perspective, NPRA 2008 (CAT-08-101).

3 *Grace Davison Catalagram*, Fall 2009, 106, 33.

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