



Revamping FCC Units: Debutanizer Reboiler Fouling

Don't Treat the Symptoms

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FCC Debutanizer reboiler shell-side fouling is becoming more common. Existing exchanger designs that have operated without major problems are experiencing severe fouling and are causing unscheduled shut-downs. Severe shell-side fouling is characterized by dramatically lower heat transfer coefficients, which result in very poor fractionation. If the exchanger is not taken out of service to clean the shell-side, the fouling material eventually turns into hard coke, which can deform the exchanger bundle and shell. Once this occurs, the tube bundle is difficult or impossible to remove from the shell, and the exchanger must be replaced.

Fouling reduces fractionation due to lower reboiler heat input and lower column reflux. This increases FCC gasoline RVP, increases C_5 's in the overhead product, reduces the amount of butane and C_3 's that can be blended into refinery gasoline, and/or reduces FCC unit capacity. All these lower refinery profitability.

Reboiler system revamps should address the fouling root-cause and not treat the symptoms. Expensive solutions such as adding a parallel reboiler system treat the symptom. One or a combination of the following items may be required to reduce or eliminate shell-side fouling:

- Lowering the heat medium temperature;
- Altering the heating medium stream for co-current flow;
- Modifying the reboiler mechanical design; and
- Reducing shell-side percentage vaporization.

Shell-side Fouling

FCCU debutanizer reboiler shell-side fouling is caused by iron catalyzed diolefin polymerization, which eventually turns into coke. Diolefin and iron concentration, in combination with

reboiler tube wall temperature, determine the severity of debutanizer reboiler fouling because C_5 and heavier diolefins formed in the reactor concentrate in FCC gasoline. Reactor operating temperature, feedstock quality (atmospheric and vacuum residues or low API gas oils make more diolefins) and reactor hardware affect diolefins yields. Iron is a byproduct of equipment corrosion. Diolefins and iron are always present in varying quantities; therefore, little can be done about these factors. However, reboiler tube wall temperature can be controlled through process and equipment design.

High shell-side tube wall temperature increases the polymerization reaction rate, thus the rate of fouling goes up. Shell-side tube wall temperatures are set by the heating medium temperature and reboiler design. High-temperature reboiler heat streams, such as hot slurry and/or HCO, are common sources of debutanizer heat. High localized shell-side temperatures are also a significant factor.

Reducing Reboiler Tube Wall Temperatures

Reducing reboiler tube wall temperatures is necessary to



Photo 1. Example of localized fouling.

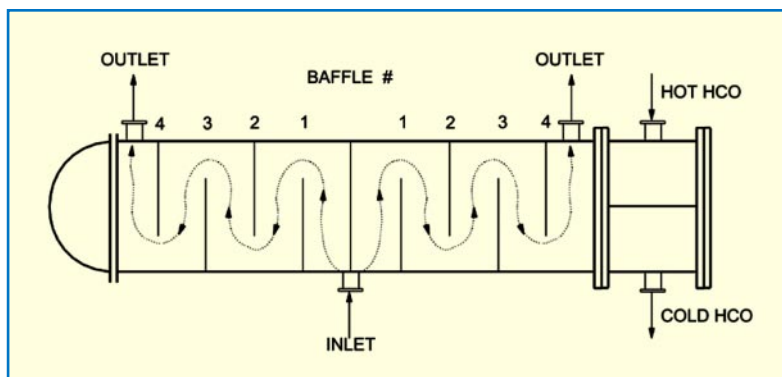


Figure 1. "J" type thermosyphon reboiler.

reduce the rate of fouling or eliminate it. Figure 1 shows a typical J-type shell reboiler that uses main fractionator HCO and/or slurry streams for heat. HCO and slurry stream temperatures will vary from 540°F to 700°F depending on the process flow scheme, column heat balance and operating philosophy. Main column slurry streams contain FCC catalyst fines and a high concentration of asphaltenes that contribute to low heat transfer, so it is natural to assume tube-side fouling causes poor reboiler performance.

Often, refiners assume fouling is mainly on the tube-side because both slurry and HCO streams have a high fouling tendency. But this can be a mistake. Refiners that clean the tubes in-place but do not clean the shell-side may find that heat transfer coefficients in the exchanger are still low, and debutanizer performance suffers.

Watch Out For Localized High Tube Wall Temperature

When shell-side fouling occurs, it is important to inspect the tube bundle to determine the exact location of the fouling. Often, severe shell-side fouling tends to be localized. A part of the bundle may be severely fouled, while the rest of the bundle may be relatively clean. When this is the case, rigorous heat exchanger modeling with a program such as Heat Transfer Research Institute's (HTRI™) IST program can help pinpoint areas of high localized tube wall temperature. High heat medium temperature increases the tube wall temperatures. In other words, high-heating medium temperature and exchanger design can result in very high localized tube wall temperature.

Often, J-type thermosyphon reboilers are used with vertically cut baffles. With a J-type reboiler, the shell-side feed enters the bottom in the middle of the shell and flows toward the outlets at both ends of the shell. The J-type exchanger shell-side fluid does not flow from one end of the exchanger to the other as with an E-type shell. The J-type shell is used because it generates low shell-side pressure drop.

However, the low exchanger pressure drop comes at a cost. Low pressure drop means low mass velocity, and low mass velocity removes less heat from the outer tube wall. It is common practice for the tube-side to be in countercurrent flow. The hot heating medium enters the top of the exchanger, and cold tube fluid leaves the bottom. Therefore, the highest outer tube wall (shell-side of the exchanger) should occur where the hot fluid enters. However, sometimes, this is not the case.

Case History

A circulating thermosyphon reboiler experienced severe shell side fouling, tube bundle coking and shell deformations that were significant enough that the exchanger had to be replaced. The reboiler was a TEMA J-type shell with vertically cut single segmental baffles. HCO pumparound was used for reboiler heat, with tube inlet temperatures ranging from 554°F to 626°F depending on main column operation. HCO entered the top of the two-pass bundle and exited the bottom (countercurrent flow). After the tube bundle was cut from the shell, visual inspection showed severe localized

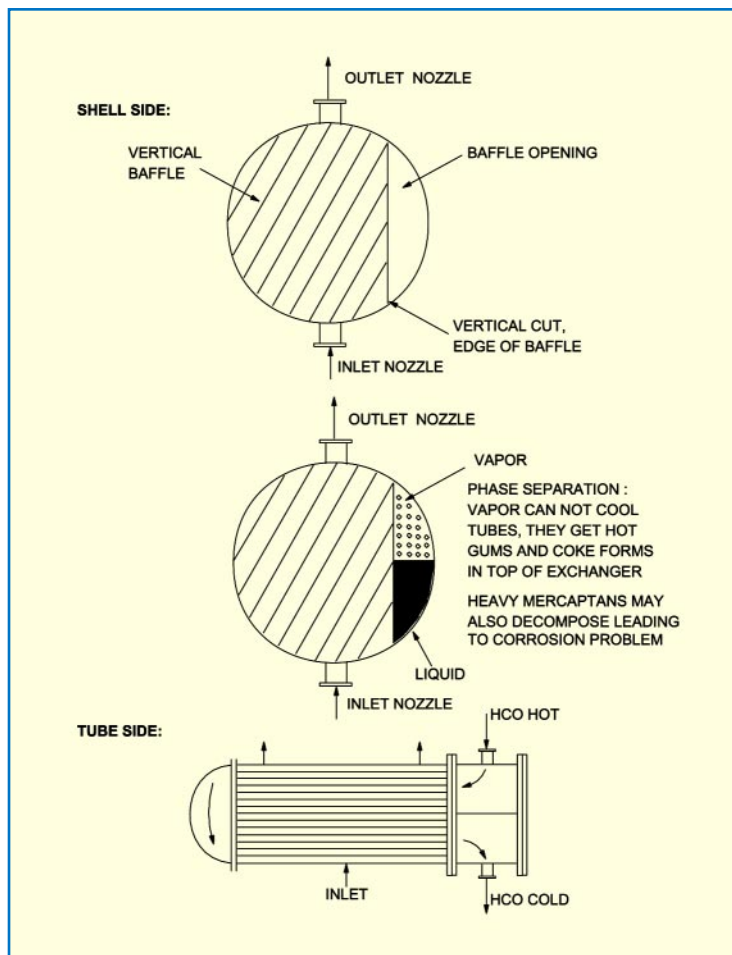


Figure 2. Baffle window phase separation.

bundle coke formation. Rigorous exchanger evaluations using HTRI's IST program and visual inspection of the coked tube bundle helped identify the cause of the fouling.

The location of the coke indicated why the exchanger coked. The bundle coking and deformation was a result of the following items:

- Vapor/liquid phase separation in the window between the first and third baffles;
- Low heat removal where phase separation occurred, which increased tube wall temperatures; and
- High tube wall temperature, which increased the polymerization reaction rate.

High localized temperatures caused by vapor and liquid-phase separation in the baffle window between the first and third baffles caused the coking (Figure 2). Phase separation caused vapor to flow through the top of the bundle and liquid through the bottom. When the phase separation occurred, the tube wall temperature in the upper part of the bundle increased due to low mass flow (vapor density is low), whereas high mass flow (liquid) was needed to remove the heat. In addition, heat transfer coefficients are low for superheated vapor compared to liquid, the system experienced localized high outer tube wall temperatures that overheated the vapor, increased the reaction rate and formed coke.

Additionally, the tubes in the top part of the bundle expanded at a higher rate than the bottom of the bundle, which resulted in "bowing" and damage to the bundle and shell. The tubes directly below the outlet nozzle, where the hot HCO enters the exchanger, had no coke. Below the shell-side outlet nozzle there is no phase separation because the vapor and liquid flow together and keep the tube wall "wetted." Therefore, no overheating occurred in these areas.

Eliminating phase separation reduces outer tube wall temperature. In this case, this requires horizontally cut baffles with the baffle spacing selected so that "dead" zones in the exchanger are minimized. Horizontal baffles increase shell-side pressure drop. Higher-pressure drop decreases fluid circulation, and a complete system hydraulic evaluation must be done to ensure no other problems are created.

Solution: Reboiler System Design

In this situation, shell-side tube wall temperature needs to be minimized to eliminate shell-side fouling. The following

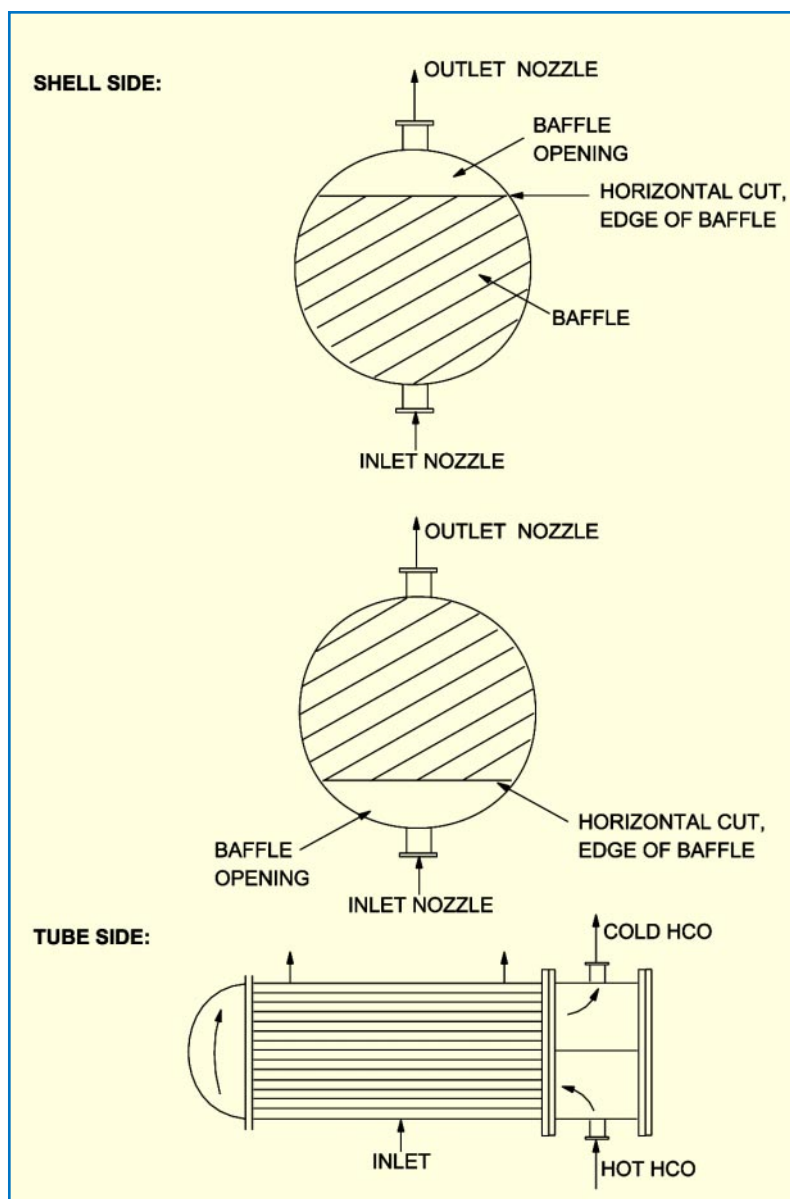


Figure 3. Revamp design.

process and equipment design changes must be implemented to reduce operating temperature and eliminate coking:

- Cool the heating medium stream to 540°F to 560°F or less;
- Pipe the exchanger for co-current flow; HCO inlet against cold shell-side inlet; and
- Design the tube bundles with horizontal baffles to eliminate phase separation.

All these reduce the tube wall temperature and the reaction rate for diolefin polymerization, and therefore, fouling is reduced. In some cases, only a tube bundle design change is required to extend the run-length. In residue cracking, where diolefins production is very high, it may be necessary to make all these changes to eliminate coking (Figure 3). ●



The Author

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