# FCC Reactor Vapor Line Coking

## Identifying the causes, penalties and possible solutions to coking in the FCC reactor vapor line, particularly with regard to inlet nozzle coking affecting unit capacity, conversion, reliability and pressure and heat balance

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Coking in the FCC reactor vapor line (VPL) increases pressure drop between the air blower discharge and the wet gas compressor (Figure 1) suction. As pressure drop increases, wet gas compressor suction pressure must be lowered or regenerator pressure increased to maintain pressure balance. Moreover, when it occurs at the main column inlet it has caused coke to accumulate in the bottom of the main column, increased main column bottoms (MCB) system fouling, higher rates of erosion of the MCB pumps, and premature flooding of the main column slurry PA section internals when column loading was high. With heavier feeds containing more aromatic species and higher reactor operating temperatures to produce light olefins as petrochemical feedstocks, coking problems in vapor lines have begun to reappear (Photo 1).

In one documented case, vapor line coking increased VPL pressure drop by 6 psi [Mauleon, J.L., Reactor and "Vapor Line Coking Problems in Fluid Catalytic Cracking Unit", Grace Seminar on FCCU, June 28, 1989, Paris, France] when the main column inlet nozzle became partially blocked with coke. Because many FCC's already operate against the air blower or wet gas compressor volume or driver limit, feed rate or conversion must be reduced to stay within compressor constraints. But when it forms in the main column inlet nozzle there are many adverse consequences that reduce unit profitability. Mauleon and others have previously covered VPL coking; however, the authors will review causes, penalties, and possible solutions to inlet nozzle coking.

## Why Coke Forms

Heavier feeds, cold spots along the VPL low VPL velocity, line configuration near the main column inlet, and main column bottoms liquid being sucked into the VPL all have caused coke to form. Higher boiling point reactor products can condense where there are cold spots or some reaction products can polymerize to form large molecules that are non-volatile at VPL temperatures. Cold spots attributable to inadequate insulation or high heat loss near fitting such as flanges facilitate condensation. If these liquids have sufficient residence time in the VPL, coke begins to accumulate on the inside of the line.

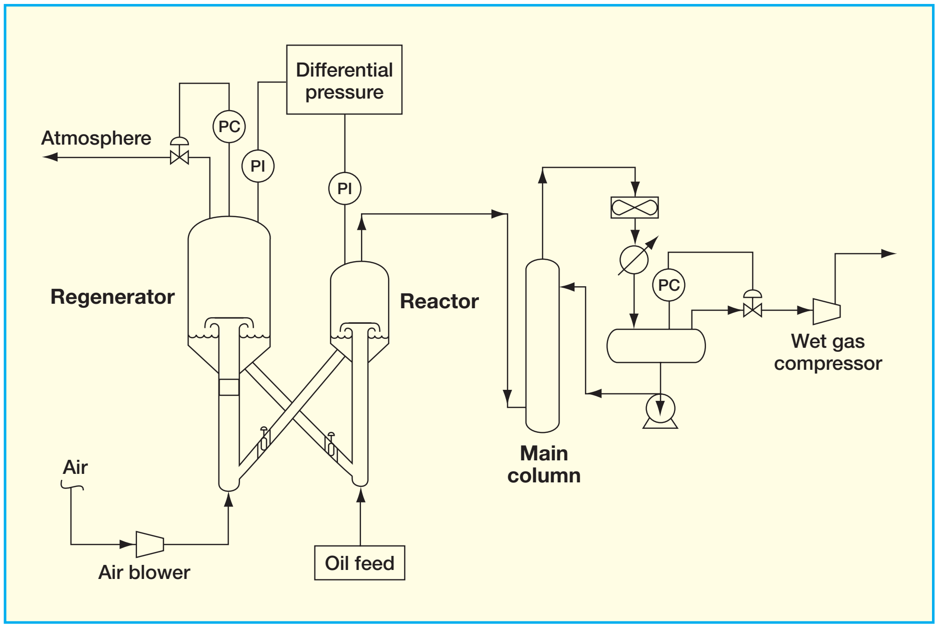

***Figure 1.*** *Pressure profile influenced by reactor vapor line coke*

***Photo 1.*** *Reactor vapor transfer line coke*

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Long vapor transfer lines, horizontal runs, and lines that are not free draining to the column are also factors. Once coke is formed, additional coke has a surface where it grows more easily. In several instances coke has blocked more than 50% of the cross sectional area of the line (Photo 1), thereby increasing pressure drop up to 6 psi (0.41 bar) or more. In one example, main column inlet velocity increased to over 90 m/s through the open portion of the inlet nozzle donut of coke.

VPL configuration plays a central role in nozzle coking. Long horizontal runs into the main column create a "vena contractor" near the inlet nozzle as vapor rapidly expands into the main column. Liquid becomes trapped in these low-pressure regions where residence time becomes very high. Flow is always from high to low pressure; therefore liquid can flow from inside the main column into the VPL. When this happens a donut of coke with a hole in the middle is created (Figure 2). Additionally, many lines have a 90° elbow oriented horizontally before entering the main column. This creates a low-pressure zone in the inside radius as high velocity vapor flows faster along the outer radius. Liquid becomes trapped along the inside radius causing coke to form (Figure 2). This coking pattern is very distinct. Any piping configuration that creates low-pressure regions and is not free draining produces areas that trap liquid.

## Feedstock, Catalyst and Reactor Hardware

Feedstock, catalyst, and reactor hardware all play a role in coke formation. This was well documented by L.J. McPherson ["Causes of FCC Reactor Coke Deposits Identified". O&G Journal, Sept. 10,1984] among others. Feedstock properties influence the specific reactor species (aromatic, olefins, etc.) formed. High endpoint compounds more easily condense and di-olefins can react to form non-volatile compounds. Catalyst formulations in recent years have resulted in greater usage of high hydrogen transfer reaction catalysts because low gasoline boiling range olefins are desirable and gasoline octane has not been a driving force. These high hydrogen transfer catalysts, in conjunction with the heavier aromatic feeds tend to produce higher boiling point polynuclear aromatics which are more likely to condense in the VPL. Once these heavy aromatics condense in the VPL they easily form coke. Some catalyst formulations, such as higher matrix activity better cracks some of the very heavy hydrocarbons. This has reduced coking when unconverted liquid was being carried into the VPL from the reactor. In other examples, high matrix activity has raised the rate of coking because the heavy cracked species were more inclined to polymerize to form non-volatile compounds in the VPL that also leads to coke.

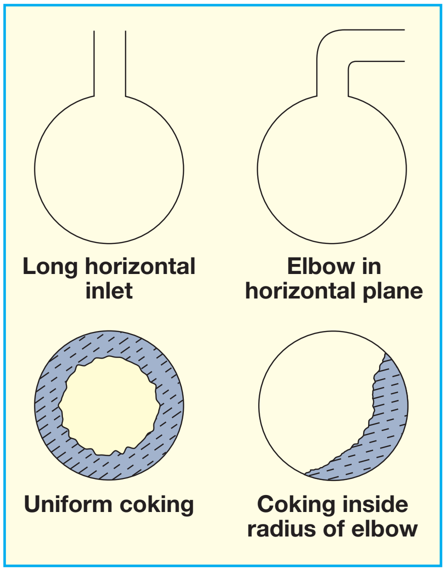

***Figure 2.*** *Vapor line orientation influences coking*

Moreover, reactor feed mixing, riser disengagement, and higher reactor temperatures can increase di-olefin formation thereby producing more reactive species that form non-volatile compounds. Also reactor conditions that produce higher boiling point products lead to higher VPL coking rates. Because the VPL closest to the main column is the coldest portion of the line due to heat loss along the line and the large inlet flanges or valves, this area creates the most favorable conditions for coke to form.

## Increased Pressure Drop

When wet gas compressor or air blower is limiting, higher system pressure drop lowers unit profitability because conversion or feed rate must be lowered. Understanding each component of system pressure drop and its magnitude is essential when optimizing or revamping. In one case, a low-pressure unit operated at 3-4 psig in the main column overhead receiver, while the regenerator ran at approximately 14 psig. Coke formation in the VPL raised pressure drop by 2 psi, thereby reducing wet gas compressor inlet suction pressure to 1 psig. With some feeds lower compressor inlet pressure was possible because dry gas and hydrogen yields were low. However, many times higher pressure drop forced feed rate to be reduced to stay within the wet gas compressor capacity. Reducing wet gas suction pressure from 4 to 1 psig requires more than 20% additional volume capacity and significant driver power increase. Sometime regenerator pressure had to be increased to maintain adequate slide valve differential which reduced air blower capacity.

## Main Column Bottoms System Fouling

When coke forms in the main column inlet nozzle, it increases the rate of fouling in the main column bottoms (MCB) system, causes higher rates of erosion in the MCB pumps, and raises the vapor velocity into the main column. As coke continuously forms and erodes it accumulates in the bottom of the main column where some of it is pumped through the MCB system. Because the MCB system removes approximately 30-40% of the reactor effluent heat, often reactor temperature must be reduced or feed rate lowered to stay within degraded total main column heat removal. As exchanger heat removal decreases, reactor temperature or feed rate has to be reduced.

Furthermore, because typical MCB heat sinks include FCC feed, steam generation, and gas plant reboilers, fouling influences more than main column heat balance. Since fouling generates higher exchanger pressure drop, MCB pump speed must be increased to compensate for the increased head requirements. As pump speed increases, pump life is reduced. As exchangers foul the MCB pumps must circulate more MCB, thus pump speed must be further increased. Pump erosion by coke fines can reduce pump flow and discharge pressure further decreasing heat removal. Therefore, reactor line coking reduces MCB system reliability.

Historically MCB exchangers have been designed with tube-side velocities of 4 - 8 ft/sec (1.2 - 2.4 m/sec). The small coke particles created as chunks of coke are ground up as they pass through the MCB pumps easily drop out in the exchanger channel heads and inside the tubes. Larger chunks of coke can block the exchanger tube

**Photo 2.** *Debutanizer reboiler shell-side fouling*

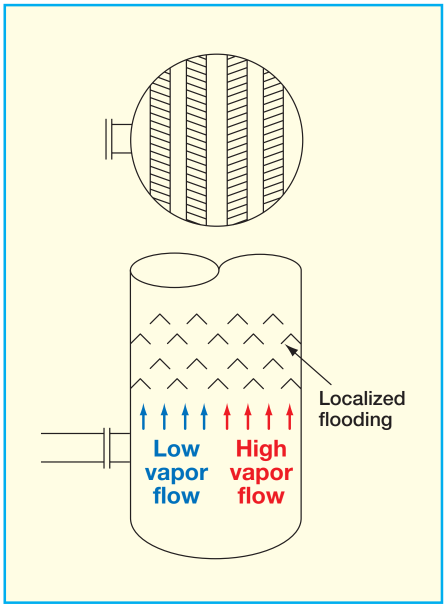

**Figure 3.** *Localized flooding from coke*

sheet. As fouling increases, the layer on the inside of the tubes progressively increases the resistance to heat transfer. For a fouled MCB exchanger, the fouling is between 50-85 percent of the total resistance to heat transfer. A heavily fouled steam generator heat transfer coefficient is 75 btu/hr-ft$^2$-°F (366 kcal/hr-m$^2$-°C), while a clean one is 150-220 btu/hr-ft$^2$-°F (733-1075 kcal/hr-m$^2$-°C). When exchanger fouls it limits slurry pump-around heat removal, reactor temperature, and unit feed rate. In several instances, MCB steam generator heat transfer coefficients have dropped from 150-240 btu/hr-ft$^2$-°F (732-1171 kcal/hr-m$^2$-°C) to 75 btu/hr-ft$^2$-°F (366 kcal/hr-m$^2$-°C) or lower in less than 4 weeks. When main column bottoms is used for debutanizer heat, further penalties for fouling (Photo 2) include reduced debutanizer reboiler duty, which raises gasoline RVP and LPG $C_5$ content. Often slurry is used for feed preheat, as these exchangers foul the temperature leaving the MCB/fresh feed exchangers decrease. In some instances feed rate must be reduced because targeted riser temperature cannot be met.

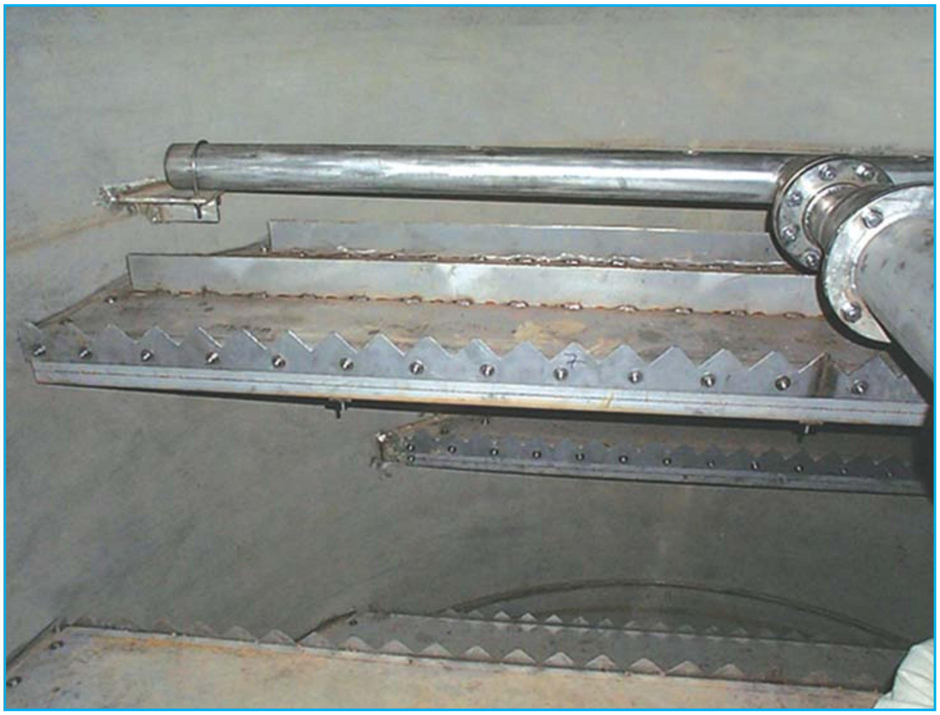

**Photo 3.** *Slurry PA shed trays*

## Main Column Flooding

Reactor effluent entering the main column is cooled through direct contact with cold slurry pumparound. Many columns use shed (baffle) or disc and donut trays to contact the two streams. These trays (Photo 3) work by creating a sheet of liquid that the hot vapor must pass through. Ideally the vapor and liquid are uniformly distributed. However, in practice this uniform vapor and liquid distribution does not occur. Liquid and vapor distribution is generally poor, hence the shed or disc and donut trays flood below their rated capacity. It is common to over-predict capacity which ultimately reduces unit capacity.

In some instances more than 50% of the main column inlet nozzle is blocked with coke raising vapor velocity to well over 70 m/sec. Therefore more vapor flows up the column 180° from the inlet nozzle which causes localized flooding of the shed trays (Figure 3). Columns fitted with thermocouples located directly above the main column inlet nozzle and 180° from the inlet nozzle have temperature differences of more than 50°C. Once the shed tray flood, cold slurry is entrained into the wash trays located directly above the shed trays. Once flooding begins the wash tray pressure drop increases and system pressure drop goes up.

**System pressure drop**

| Components | ΔP, psi (bar) |
|---|---|
| VPL | 2 (0.21) |
| Main column | 4 (0.41) |
| Condenser | 4 (0.41) |
| Miscellaneous piping | 2 (0.21) |
| **Total** | **12 (0.82)** |

*Table 1.*

## Reactor-Regenerator Pressure Balance

Reactor-regenerator pressure balance is a critical operating variable in an FCC. Differential pressure allows catalyst to circulate between the two vessels and provides a portion of the slide valve pressure drop needed to control catalyst circulation rate. Because coke restricts the VPL, it increases the pressure drop requiring adjustment in one or both of the vessels operating pressure to maintain differential pressure. Wet gas inlet pressure must be lowered or air blower discharge pressure must be increased which can reduce either compressors capacity, and it raises total compressor driver horsepower.

Table 1 shows reactor-to-wet gas compressor inlet pressure drop components. A well-designed unit will have only 12 psi (0.82 bar) pressure drop. VPL coking can easily raise total system pressure drop by 10-50%.

Higher VPL pressure drop requires lower wet gas compressor inlet pressure or higher air blower discharge pressure. Lower wet gas compressor suction pressure increases wet gas production because condensation decreases at lower pressure as overhead receiver pressure drops. Furthermore it increases wet gas density and raises compressor polytropic head. All these factors require extra wet gas compressor volume and driver capacity.

Conversely, wet gas compressor inlet pressure can be held constant while the regenerator pressure is increased. Higher regenerator pressure raises air blower adiabatic head requirements. At minimum this increases driver horsepower, but it also requires more speed to maintain air flow on a variable speed compressor or higher vane opening in the case of a fixed speed variable stator vane axial blower.

## Avoid Inlet Nozzle Coking

VPL length, configuration, vapor velocity, and stagnant zones are all factors in coking. When VPL length is long due to plot space then vapor velocity must be increased to minimize liquid residence. Mauleon and others recommend 30m to 35 m/s as a minimum range when the line is short, but, as line length increases velocity may need to be increased to 45 m/s to keep liquid moving in a horizontal portion of the line. While this increases line pressure loss it helps avoid coke formation that can dramatically increase pressure loss. Furthermore, Mauleon recommends maintaining turbulent flow throughout the nozzle cross-section to eliminate low-pressure areas that allow liquid to stagnate and form coke. A 90° elbow oriented horizontally should never be used so that stagnant zones along the inside radius are eliminated. Ideally the VPL should be designed with a short radius elbow oriented vertically so that gravity will settle any liquid that may be aspirated into the nozzle.

When VPL line velocity exceeds 40 m/s, often it is necessary to use a vapor distributor to ensure localized flooding of the main column does not occur. The authors recommend increasing the VPL size entering the main column so that velocity is maintained at approximately 35 m/s. Furthermore, Mauleon and the authors recommend using a vapor distributor to allow the vapor to expand more slowly eliminating these low-pressure regions. However, only one vapor distributor has proven effective to roughly distribute the vapor while remaining coke free throughout the run.

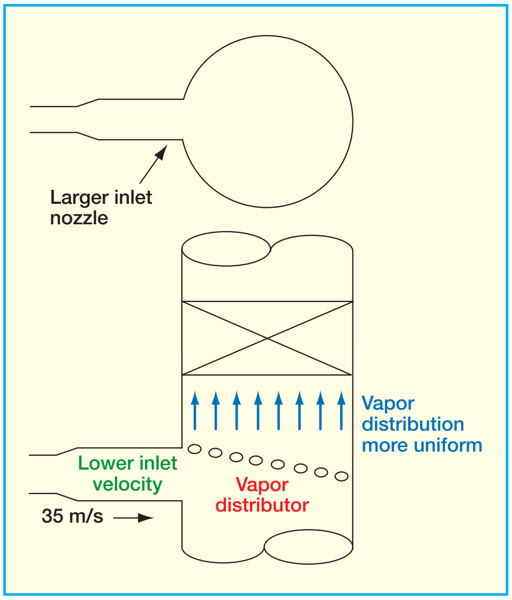

*Figure 4.* *Main column vapor distributor*

Figure 4 shows design velocity, expansion near the column, and the vapor distributor used to both help maintain turbulent flow in the horizontal line and distribute vapor into the main column to avoid localized flooding of shed and disc and donut trays. If a vapor distributor is not utilized, the horizontal vapor line could be expanded and free draining starting approximately 20 to 30 feet before the main column inlet in order to reduce the velocity.

## THE AUTHORS

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