Solve the Five Most Common FCC Problems

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Abstract

The problems encountered in the operation of FCC units are as varied as their hardware and catalysts, their feedstocks and desired products, and their operating strategy. However, given broad enough description of the type of operating problems, general yet useful categories of troubles can be examined and solutions can be discussed.

The five most common troubles encountered in the operation of an FCC unit include catalyst fluidization and flow instability in the Reactor, poor stripping, poor regeneration, catalyst losses through cyclones, and poor reaction and maintenance of catalyst properties. In this paper, we will discuss these and suggest systematic approaches for understanding and resolving them.

Introduction

It would be impossible to determine what specific problems are most usual to the Fluid Catalytic Cracking Unit. There are more than 20 variations in mechanical designs of the Regenerator and Reactor still operating throughout the world and countless technology component designs that have been applied either from licensor development or refiner internal conception and fabrication . However, if a broad view is applied to the common elements of all FCCU, then it is possible to define and resolve the major problems that can be encountered regardless of unit configuration.

1. Poor Reactor Performance

Poor reaction results occur when conversion and liquid product yields do not match expected or predicted results. This may be due to catalyst contamination and activity but can also be related to other factors in the FCC Riser such as feed and catalyst distribution. Any element that adversely influences delta coke and catalyst circulation rate will bring about a loss of converted product and selectivity. Many FCC operations have excellent catalyst activity maintenance and low contaminants but still experience relatively poor conversion. In these cases, Riser hydrodynamics can be the primary reason. Poor distribution of feed into the catalyst or poor distribution of catalyst into the feed can be crucial to achieving optimum yields.

To achieve optimum yields, it is desirable to have uniform catalyst density in the Riser. If the catalyst is poorly mixed with the feed, areas will be formed in the Riser where there is either too much feed and not enough catalyst and too much catalyst and not enough feed. This is easily pictured by viewing the catalyst density profile across the Riser. Figure 1 shows the variation in density from below the feed injection distributors to an elevation 4 pipe diameters above. This plot indicates the feed and catalyst are distributed and mixed efficiently due to the uniform densities. Figure 2 presents a gamma scan of the cross-sectional density profile in a Riser. In this example, the densities are nearly equal and it can be concluded that catalyst and feed are being properly distributed and mixed.

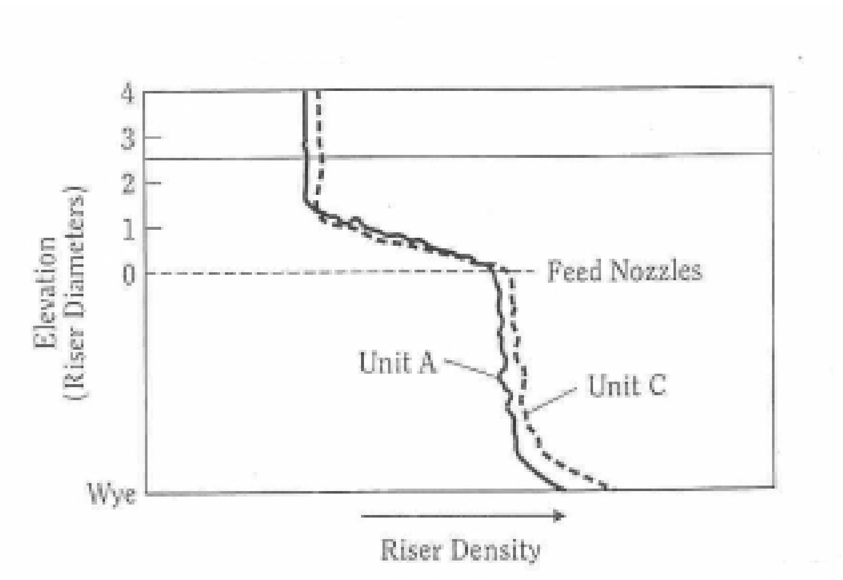


Figure 1. **Riser Density vs. Elevation**

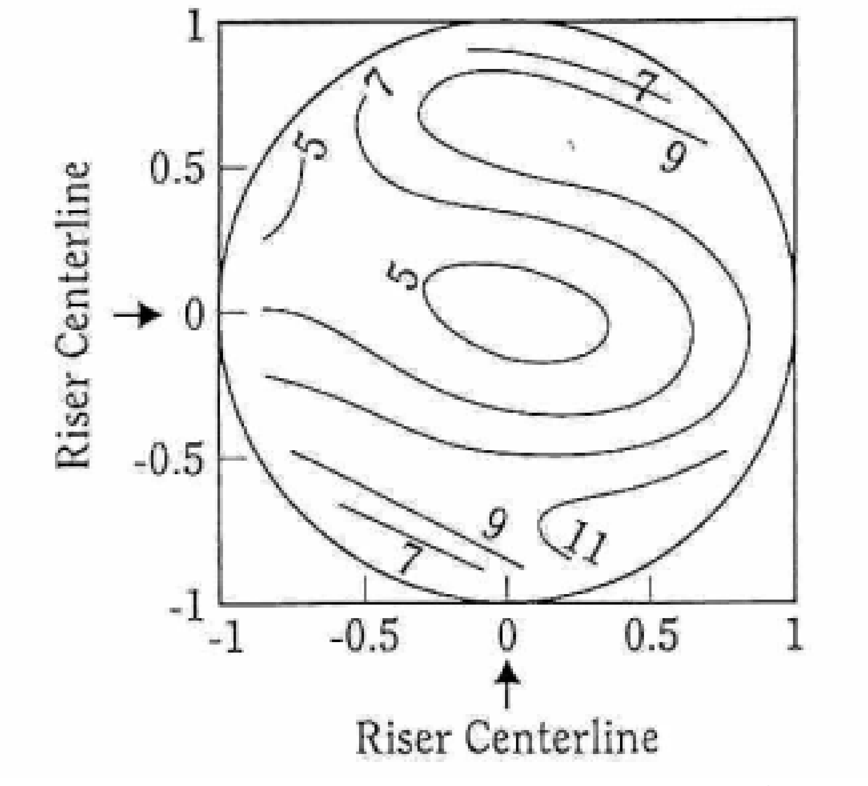


Figure 2. Riser Cross-Sectional Density Profile

If poor Riser hydrodynamics is suspected, the following actions should be considered to improve or alleviate the conditions.

- <u>Vary Feed Dispersion Steam:</u> The feed dispersion steam serves many purposes. It provides the motive energy to generate smaller oil droplets from the feed distributors, outlet velocity to distribute the droplets into the catalyst and decreases the hydrocarbon partial pressure at the feed injection elevation to increase the oil-feed vaporization rate. In general, higher feed dispersion steam is desirable but it is limited by the its impacts on erosion of the distributors or internal Riser refractory, Riser vapor residence time, Main Fractionator loading and overhead cooling duty and Sour Water production.

- <u>Vary Wye Steams or Lift Gases:</u> Steam or fuel gas may be injected into the base of the Wye sections. This can improve the distribution of catalyst flowing up to the feed distributors and decrease the oil–feed partial pressure at the feed injection elevation. As with feed dispersion steam, these flows are limited by erosion potential, Riser residence time and Main Fractionator loading concerns.

- <u>Survey and Review Feed Distributor Pressure Drop for Mal-Distribution:</u> Most state-of-the art feed distributor designs are pressure balanced. The oil side supply pressure is dependent on the pressure drop through the distributors. The pressure drop is primarily dependent on the steam flow since it accounts for 70-80% of the total volume through the distributors. If board mounted instruments are not available, a local, single gauge pressure survey can determine if mal-distribution of steam and oil is occurring.

  If steam flow is restricted or blocked to one distributor, this causes the controlled steam flow to flow through one less nozzle. As such, the pressure drop through those nozzles will be greater and the oil flow will be lower to the open nozzles and higher through the distributor with less or no steam.

  If the oil flow is restricted or blocked to any one distributor, then more steam will flow through that distributor since there is no oil contributing to its pressure drop. As such, less steam will flow to the other nozzles with more oil.

  A pressure survey can be very useful provided base readings are available when it is known all distributors are open on both the oil and steam side. This provides a reference pressure differential between the steam and oil. If steam is restricted to one or more distributors, then the steam supply pressure will rise and the oil supply pressure drop and the differential will increase. Conversely, if oil is restricted to one or more distributors, then the steam pressure will drop and the oil rise and the differential will decrease.

  Another useful indication is the control valve position on the dispersion steam. If one distributor were plugged, the steam supply pressure would increase and control valve would need to open further to supply the same flow setpoint. The valve would close if the oil were restricted or blocked to a distributor as the supply pressure would decrease.

- Survey and Review Riser Differential Pressure: The Riser differential pressure is a relative indicator of catalyst and oil mixing and distribution. Lower pressure drop signifies that there is less catalyst back-mixing and a more uniform density profile through the Riser. This is advantageous to minimizing delta coke and maximizing yields and conversion. Pressure drop will vary by catalyst circulation and Riser design in terms of both height and width. Base values are specific to each unit but decreased pressure drop is desirable for all FCC.

  Riser differential pressure should be collected at various process conditions such as feed rate, Riser temperature, feed dispersion steam, Wye steams/lift gases, and catalyst circulation rates. This data can be useful towards determining the optimum flows that minimize pressure drop. These will be the same conditions that optimize yields.

- Perform Riser Tracer Study: A radiation detection survey can be perfomed by a company such as Tracerco. This method can determine radial non-uniformity of flow at various elevations in the Riser. Process conditions can be adjusted to minimize or eliminate the mal-distribution and improve conversion and yields.

- Monitor Wet Gas Compressor Suction Flow: The most rapid response to improving Riser hydrodynamics will be in the gas yield. In almost all operating scenarios, any process operational change that improves catalyst and feed distribution and mixing will decreases gas make. This should always be more profitable as more liquid product must be made when less gas product is. The suction flow or quantity of first stage spillback to the Wet Gas Compressor can be quickly monitored to determine if there is a positive or negative directional response.

2. Poor Stripper Operation

Stripping efficiency is often a victim of the increased feed rates and resulting catalyst circulation over the years. As catalyst circulation (and flux through the Stripper) increases, without commensurate raising of Stripper parameters (both mechanical hardware and operations), countercurrent contacting of the spent catalyst with steam becomes less efficient, and more of the unstripped hydrocarbons are carried into the Regenerator. These result in:

- Loss of yield and conversion

- Consumption of air for the combustion of unstripped hydrocarbons instead of hard, catalytic coke

- High Regenerator temperatures or increased afterburn.

Inefficient stripping could involve hardware design limitations (Stripper diameter, trays, open area) as well as operating limitation (inadequate or maldistributed stripping steam).

Table 1 shows a sample result with a Stripper pushed beyond its design catalyst flux resulting in significant carryover of unstripped hydrocarbons to the Regenerator. Note that, at high enough catalyst flux rates, increasing stripping steam has not benefit as much of the added steam is simply carried down into the Regenerator with the catalyst.

Table 1. Effect of catalyst circulation on operation of stripper with too small an open area. (Multiple case composite.)

Case	Low Cat Circ	High Cat Circ
Catalyst Circulation (tons per minute)	42	50
Stripping Steam (Mlb/hr)	8	17
Restricted Catalyst Flux in Tray Section (lb/ft2.s)	35	41
Catalytic Coke to Regenerator (Mlb/hr)	35	44
Unstripped Hydrocarbons to Regenerator (Mlb/hr)	4	8
Unstripped/Total Coke	9%	15%

2.1 Analysis of Stripper Operation

A number of methods exist for determining whether a Stripper is adequately designed and operated based on current needs. These are presented in the approximate order of complexity and required effort.

- Basic calculations: Based on experience with various designs of Strippers, formulae and correlations exists which allow the expert to use simple calculations involving hardware parameters *(i.e.*, Stripper type, diameter, length, area, volume, restricted area; tray design, tray types and numbers and gaps and holes; steam distributor design parameters, quantity, and location) and operating parameters *(i.e.*, catalyst circulation, pressure and temperature, steam rate, Stripper catalyst density, superficial and restricted flux, steam velocities and residence times) to estimate the extent to which the Stripper might be overloaded.

- Regenerator temperature survey: A temperature survey can provide information on the presence of extra unstripped hydrocarbons which result in higher Regenerator temperatures or afterburn.

- Stripper survey: The primary objective of a Stripper survey is to determine the flows of steam and unstripped hydrocarbons to the Regenerator. Vapor samples are concurrently withdrawn using standard procedures from the Stripper standpipe and the Reactor transfer line to the main column and (if possible) the Reactor void space (for units with closed cyclones). Based on the analysis of these samples and captured operating information, fairly accurate balances for steam and hydrocarbons can be constructed with reliable information about the operation of the Stripper, both in terms of hardware design and operations (steam adequacy).

- Radioactive Tracer scans: Tracer studies (where a light or heavy tracer follows the hydrodynamics of the vapors or the catalyst) can be used to determine Stripper vapor maldistribution or catalyst density variations within the Stripper. Light tracers can also be used to follow steam injected into the Stripper. Typically, a tracer is injected at a certain location (*e.g.*, steam ring) and the variation of this tracer is followed at other locations (*e.g.*, spent catalyst standpipe, Stripper top at different angles and elevations). The time it take for the tracer to appear at a location, the time for it to peak, and the length of the "skirt" can be used along with an understanding of the hardware to evaluate the design and operation of the Stripper.

- Radioactive cord scans: Cord scans can also be used to evaluate the catalyst density variation in the Stripper (see the discussion on the Regenerator), though this is more often used in examining the performance of the standpipes.

2.2 Improving Stripper Operation

Depending on matters of schedule and urgency and capital restrictions, and the understanding of the root cause of the problem, a number of options exist. These are listed below in approximate order of complexity.

- Reduce catalyst flux: This is trivial as, one assumes, the increase in catalyst flux due to higher FCC feed rates is the essence of the problem.

- Increase steam rate: If additional steam is available, it should be increased, at least as a test to optimize steam-to-catalyst rates. (See Table 2.)

- Modify or add steam rings or nozzles: In order to improve distribution of steam throughout the Stripper (vertical as well as radial).

- Modify Stripper internals: Designs have been developed for increasing the Stripper open area by reducing tray "footprint" while at the same time improving steam/catalyst contact efficiency.

- Increase Stripper diameter: This most drastic measure requires, in practice, the design and construction of a wholly new Stripper.

Table 2. Effect of increasing stripping steam on stripper operation. (Multiple case composite.)

Case	Low Steam	High Steam
Catalyst Circulation (tons per minute)	50	49
Stripping Steam (Mlb/hr)	15	23
Catalytic Coke to Regenerator (Mlb/hr)	44	45
Unstripped Hydrocarbons to Regenerator (Mlb/hr)	8	5
Unstripped/Total Coke	15%	10%
Regenerator Dense Bed Temperature (F)	Base	Base-11
Conversion (vol% of feed)	Base	Base+2.5%

3. Poor Regeneration

The “ideal” Regenerator, at least in the dense phase, can be conceptualized to be very much like a classical CFSTR (albeit a two-phase one) with spent/stripped catalyst and air mixed perfectly, with no mixing and separation zones, and no boundary layers resulting in temperature or concentration/density variations. To the extent that the dense phase parts from this ideal (*i.e.*, imperfect distribution of catalyst, air, and temperature), problems result. The improper mixing can be radial or tangential due to mis-design of, malfunction of, or damage to systems used to introduce the catalyst and air into the Regenerator and those for removing the regenerated catalyst and flue gas out: slide valves and nozzles, showerhead, air rings, sparger pipes, “Christmas trees,” air grids, etc. (See Figure 3.)

Another mode of improper mixing involves the vertical jetting of air beyond the dense bed surface into the dilute phase. (See Figure 4.) This results in sub-optimal use of oxygen, not to mention high catalyst losses into the flue gas.

The distribution and mixing of catalyst and air can also be adversely impacted by spent catalyst particle size distribution. Spent catalyst with too much “fines” is entrapped more easily into air jets and carried to the dilute phase (see discussion on cyclones) whereas catalyst with not enough fines might result in significant dead or slow spots where mixing is inadequate.

An additional key source of poor regeneration is inadequate oxygen. This problem becomes common as the FCC is pushed beyond original design limits with higher feed rates and lower quality (heavier) feeds.

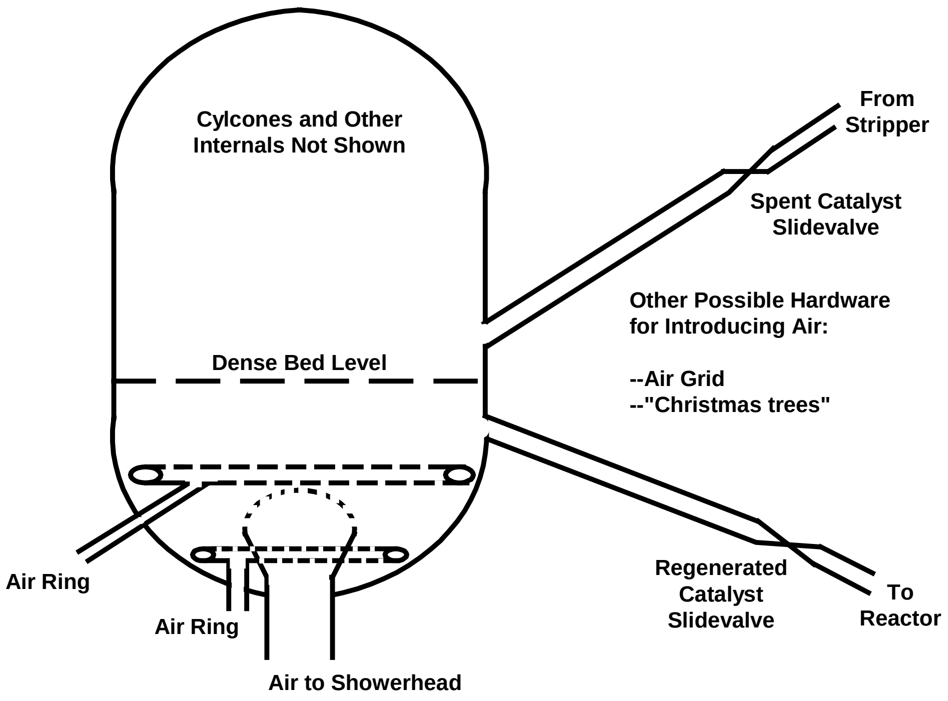


Figure 3. Regenerator example showing possible hardware for introducing air and spent catalyst. Note how the location of the standpipe and pressure distribution in the air rings can affect mixing.

As a result of all these non-idealities, one often encounters inadequate coke burn in the Regenerator, resulting in low E-cat activity. These are further manifested in low conversion and yields and sub-optimal FCC operation in areas such as cat-to-oil and heat balance.

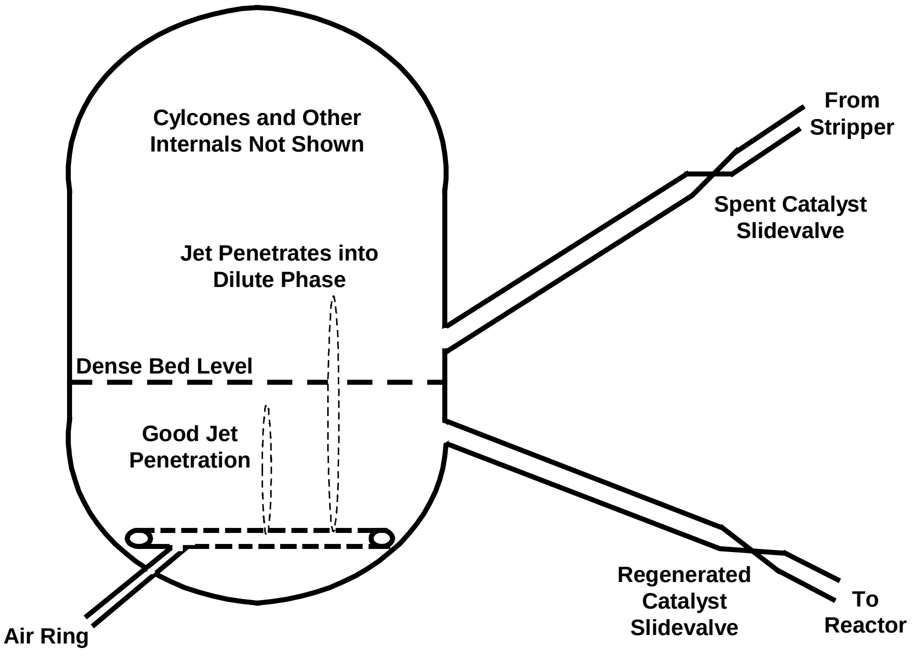


Figure 4. Jet penetration into dilute phase and vertical maldistribution of catalyst and air.

Note that poor regeneration is separate from the reduction of E-cat activity caused by deposition of metals such as vanadium, nickel, iron, etc. Whereas coke on catalyst is, almost by definition, reversible through regeneration with oxygen, the latter, metals on catalyst can be either irreversible (and must be withdrawn from the system and discarded) or require processing, again outside the FCC system, using novel technologies. (See discussion on catalyst maintenance.)

3.1. Analysis of Dense Bed Mixing of Air with Spent Catalyst

A number of tools and observations are used to study whether improper mixing is occurring in the Regenerator. To an extent, the strategy for studying this is affected by existing facilities in a particular unit. Typical tools, ranging from relatively simple and inexpensive (if available) to complex include:

- Temperature observations: These include tangential and vertical wall or near-well temperatures and their variation. Regions of unmixed (and un-regenerated) air and spent catalyst are colder than well-mixed air and catalyst.

- E-cat and fresh catalyst analysis: Analysis by catalyst vendor including PSD. (See Figure 5.) Particularly large particle sizes can result in dead zones. High fines in fresh catalyst can help increase bypass through jetting.

- Pressure surveys: Pressure surveys around the Regenerator, particularly in the dense phase, can help determine whether dead zones exist and whether bypassing (jetting) is occurring.

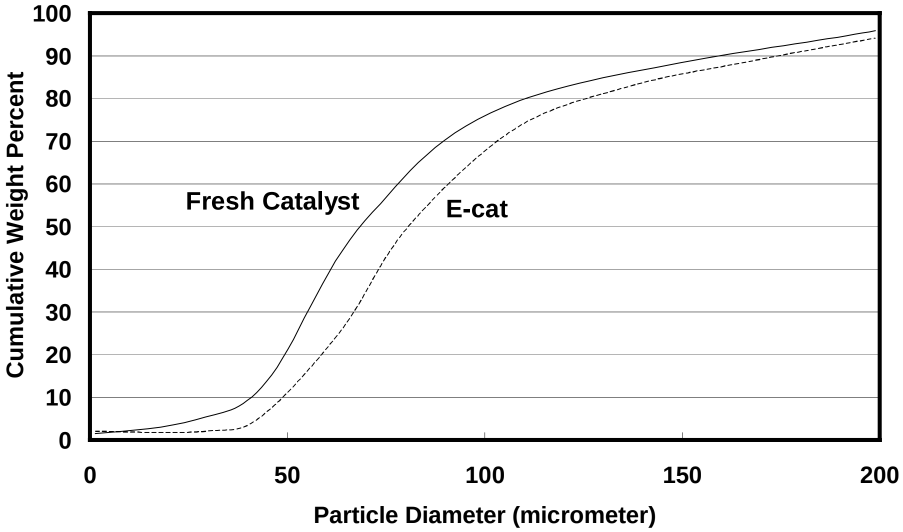


Figure 5. Sample fresh and equilibrium catalyst PSD curves.

- Hydrodynamic calculations: The above information, along with hardware design parameters (such as type of air hardware—grid, showerhead, "Christmas tree," rings—, location and dimensions of catalyst inlet, nozzle/orifice diameters, numbers, distributions) and operating parameters (such as catalyst circulation, air blower rates, temperatures, pressures, dense bed level, etc.) can be used in estimating the hydrodynamics of the Regenerator. Hydrodynamic information obtained can include nozzle particle attrition information, air velocities, bubble sizes and distribution, jet directions and penetrations, catalyst entrainment rates, as well as the transport disengaging height (TDH).

- Regenerator γ-cord scans: These can produce significant information involving catalyst density variations. (See Figure 6.) Careful design is important not only to select the best cords (based on previous observations and calculations), but also to avoid the internal hardware such as cyclones and their diplegs or structures such as permanent scaffolds.

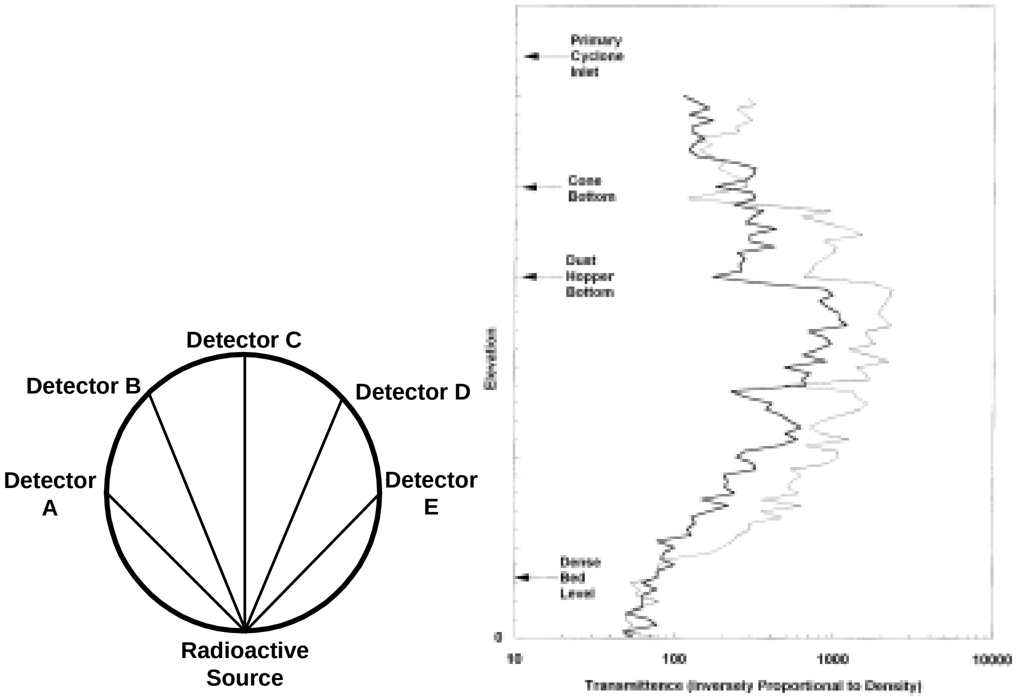


Figure 6. A) Example gamma cord scan pattern. The source and detectors move down the regenerator. B) Example of two cords. Note that different densities suggest mal-distribution of catalyst in the freeboard.

3.2. Solutions for Improving Dense Bed Mixing

Depending on the magnitude and causes of the problem, its urgency, fund availability, and turnaround schedules, a number of approaches exist. These include:

- E-cat modification: The vendor can change the PSD of the fresh catalyst (adding fines, reducing fines, re-design of the catalyst) to assist in improving Regenerator bed hydrodynamics. Fines can be added independently for faster effect.

- Operational changes: These include changing the catalyst circulation rate and increasing or decreasing Regenerator dense bed level.

- Hardware redesign: Many dense bed maldistribution problems are caused by poor hardware (design, damage) and can ultimately be solved only through hardware modifications during the turnaround. During a turnaround, damaged air nozzles, grids, and showerhead holes can be repaired, new nozzle and orifice designs can be introduced (if previous nozzles are inadequate as originally designed), novel internals introduced to improve mixing and minimize dead zones, and ultimately the locations and methods of introducing air and spent catalyst altered.

3.3. Analysis of Problems Associated with Inadequate Oxygen in Regenerator

Typically, over the years, the load on every Regenerator rises as feed rates increase and quality dips (especially with the incorporation of resid) well beyond the original design parameters. Many units also have to contend with variability as refineries try to improve profitability by making rapid changes in feedstocks, product mix, and operations.

In such an environment, it is critical to deliver adequate oxygen to the Regenerator for proper decoking to take place. A number of observations and methods can point to inadequate oxygen:

- Calculations: Using information on blower operations and air-to-coke as well as basic coke combustion chemistry, we can estimate whether enough oxygen is being supplied.

- Afterburn: The combustion of carbon monoxide with lean oxygen over the dense bad (in the dilute phase, cyclones, or plenum), resulting in higher temperatures in these areas, is another indicator.

3.4. Solutions for Inadequate Oxygen in Regenerator

Depending on limitations on hardware and the possibility of changing operations, the following approaches are available:

- Increasing air rate: This, more often than not, requires either additional blowers or re-rating existing blowers.

- Oxygen enrichment: Using a richer source of oxygen (instead of air) in order to deliver more oxygen using the same blower, pressure, and temperature. Issues of safety as well as cost are considerations.

- Operational changes: Parameters, such Reactor temperature, can be changed in order to decrease delta coke.

4. Poor Cyclone Performance

Problems with cyclones in the FCC Regenerator or Reactor systems present a significant issue with refiners due to the impact on operational stability, variable costs and profitability and potential environmental effects. The most common manifestation is increased catalyst losses from the Regenerator into the Flue Gas system or from the Reactor into the Main Fractionator. Two Stage Cyclone systems that are properly designed and operated within normally acceptable ranges of velocity and mass flux can attain overall catalyst fines recoveries above 99.99%. However, when the conditions fall outside of normal criteria, cyclone performance can rapidly deteriorate. (See Figure 7.) Among the many causes of poor recoveries are eroded barrels, hopper cones and diplegs, internal refractory or metallurgical component damage, excessive catalyst loading, high inlet or outlet velocities, coke or refractory plugged diplegs and immovable dipleg outlet flappers. (See Figure 8.) "Soft" fresh catalyst or catalyst with an abnormal particle size distribution can also contribute to higher losses.

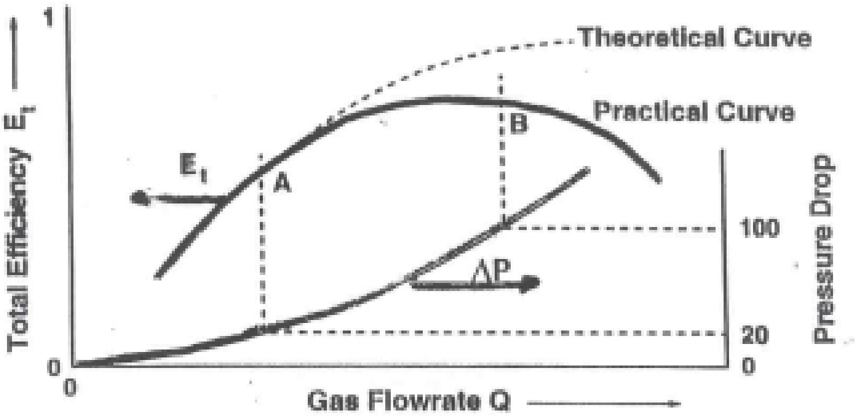


Figure 7. Cyclone Efficiency Curve: Efficiency vs. Vapor Flow Rate and Pressure Drop

Many of these effects can be corrected by applying the proper design standards in relation to the typical operation of the FCC. However, in some instances, increased catalyst losses can occur although all the design and operational parameters are within acceptable ranges. In these cases, it is important to be able to identify that losses have increased and enact the appropriate response.

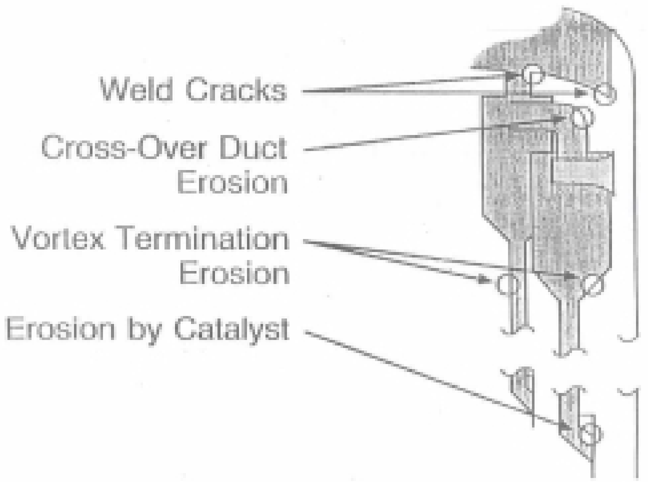


Figure 8. Likely Places for Cyclone Holes (With High Catalyst Losses and Falling Fines Concentration)

On the Regenerator side, poor cyclone performance can be ascertained by a change in the daily or weekly data monitored to assess unit performance. These could include:

- Increased Fresh or Equilibrium Catalyst loadings to maintain unit inventory
- Decreasing Regen level at constant catalyst loading and constant Reactor level or decreasing rate of change of the Regenerator level if fresh catalyst loadings are typically greater than the total Regenerator plus Reactor losses
- Increased fines catch from the Electrostatic Precipitator
- Need for more frequent Soot Blowing to maintain heat transfer in the Waste Heat Boiler or CO Boiler
- Increased, more erratic or spiking Flue Gas Stack Opacity measurement
- Shift in the Equilibrium Catalyst Analysis 0-40 micron, 0-80 micron or Average Particle size distributions
- Increase in Microactivity (MAT) and decrease in metal contaminants at higher fresh or equilibrium catalyst loading

On the Reactor side, poor cyclone performance can also be determined by changes in the daily or weekly data.

- Increase in Main Fractionator Bottoms pumparound or Slurry Product streams Basic Sediment & Water (BS&W) or Ash analyses.

- Decrease in heat transfer in Main Fractionator Bottoms pumparound exchangers. (Catalyst settling or fouling causing increasing pumparound return temperature at constant flow.)

- Decrease in Slurry Product rundown pumping capacity (Catalyst settling in piping and exchangers)

The first action is to assess if the increased losses are from the Regenerator or Reactor side. Although this is normally apparent, losses originating from one vessel can influence losses from the other. Once this is determined, cyclone performance issues can be classified into two classes; operational or mechanical. Responses should include one or more of the following.

- Assure the Regenerator or Reactor Level Transmitter is reading correctly: High or low level can result in significantly increased catalyst losses. In many instances, simply recalibrating the level transmitter or completing a local single gauge pressure survey can determine if the indication is correct.

- Vary the Regenerator or Reactor level: The level plays an important role in the performance and stability of the cyclone systems. High level will result in flooding of the dipleg and re-entrainment of catalyst to the cyclone outlet. Low level can impact the cyclone pressure balance and cause bypassing up the dipleg.

- Vary the Regenerator Air Flow or Pressure: The actual air flow (ACFS) sets the superficial vapor velocity in the Regenerator and the catalyst entrainment to the cyclones. Lower entrainment should lead to lower losses if high loading or high inlet/outlet velocities affect the cyclone system.

- Vary the Reactor Vapor Flow or Pressure: The actual hydrocarbon plus steam flow to the Riser sets either the superficial vapor velocity in the vessel or the cyclone inlet velocity, if Riser cyclones are employed. Catalyst loading is dependent on the catalyst circulation rate in the latter case. Feed steam can be decreased to affect the velocity or in severe cases, the oil feed flow can be varied. Step changing the vessel pressure may succeed in dislodging coke or refractory plugs or freeing stuck dipleg flapper valves.

- Check For High Velocity Impingement Vapor Sources: Catalyst losses can be increased by attrition of the unit inventory. This can be caused by sources of high velocity vapor into the catalyst bed, such as missing purge orifices in instrument nozzles, torch oil steam purges and damaged or eroded stripping steam or air distributor nozzles.

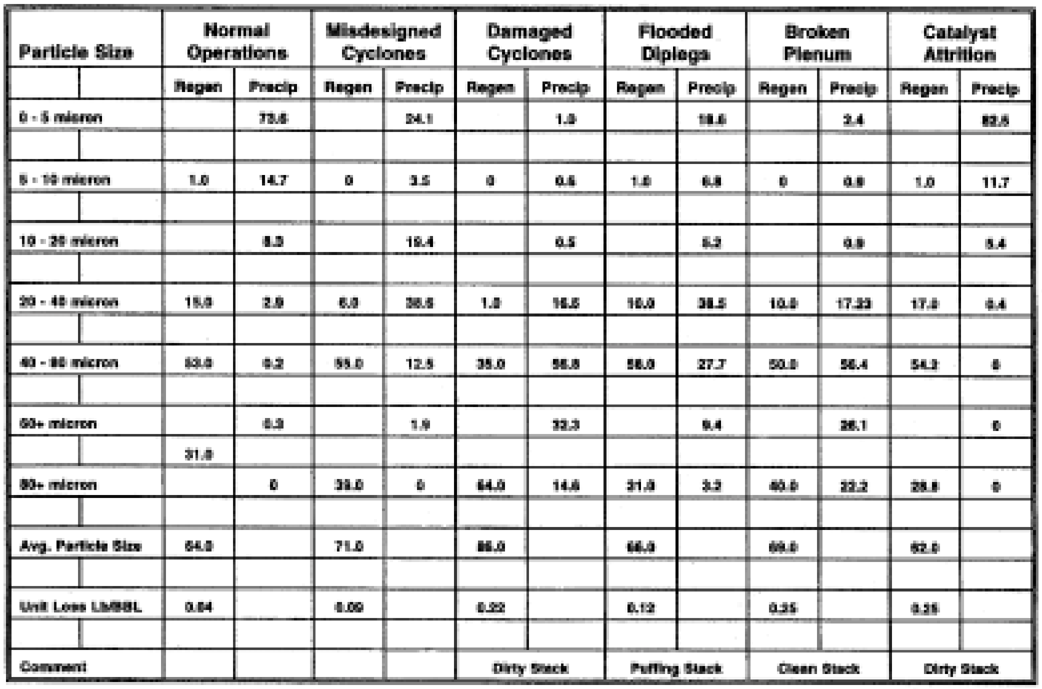
If the losses are unresponsive to operational changes, then it is likely that mechanical damage or failure is responsible. Once this has been determined, then the following can be reviewed to discover the probable source:

- Review Cyclone Inlet and Outlet Temperature Distributions: Historical data can be analyzed to determine if there has been any shift in the radial or axial temperature differentials within and between cyclones. Increased delta-T can be indicative of higher catalyst losses and lower delta-T symptomatic of plugging or loss of flow.

- Review Equilibrium and Fresh Catalyst Particle Size Distributions: Shifts in particle size can identify certain failures. Cyclones damaged by holes or erosion would be expected to show a decrease in the 0-40 micron particles with a large increase in 80+ microns and Average Particle Size (APS). Flooded diplegs would show the same trends in particle size distribution as damaged cyclones but the extent of the shift would not be as great as with damaged cyclones. Flooding is usually characterized by cycling of the flue gas opacity rather than a step change and constant value from damaged cyclones. Weld cracks or holes in the outlet plenums would be apparent from a large decrease in 80+ micron catalyst while catalyst attrition would increase 0-40 microns as these particles are produced. In rare cases, soft, fresh catalyst that easily attrits or has a fine, small particle size may lead to higher losses since it will not be recoverable in the cyclones. Table 3 shows the relative shifts in the particle size distributions for these cases.

Table 3

WT.% EQUILIBRIUM CATALYST SIZE AS AN INDICATION OF REGENERATOR LOSS PROBLEMS



Particle Size	Normal Operations		Misdesigned Cyclones		Damaged Cyclones		Flooded Diplegs		Broken Plenum		Catalyst Attrition	
	Regen	Precip	Regen	Precip	Regen	Precip	Regen	Precip	Regen	Precip	Regen	Precip
0 - 5 micron		73.6		24.1		1.0		18.6		2.4		82.6
5 - 10 micron	1.0	14.7	0	3.5	0	0.6	1.0	6.8	0	0.8	1.0	11.7
10 - 20 micron		8.3		19.4		0.5		6.2		0.8		5.4
20 - 40 micron	15.0	2.9	6.0	38.6	1.0	16.5	10.0	38.5	10.0	17.33	17.0	0.4
40 - 80 micron	53.0	0.2	55.0	12.5	35.0	56.8	58.0	27.7	50.0	56.4	54.2	0
60+ micron		0.3		1.9		32.3		9.4		26.1		0
	31.0											
80+ micron		0	39.0	0	64.0	14.6	31.0	3.2	40.0	22.2	28.8	0
Avg. Particle Size	64.0		71.0		86.0		66.0		69.0		62.0	
Unit Loss Lb/BBL	0.04		0.09		0.22		0.12		0.35		0.35	
Comment					Dirty Stack		Puffing Stack		Clean Stack		Dirty Stack	

5. Maintenance of Catalyst Properties

Maintenance of catalyst activity is critical to optimized FCC operation and profitability. The loss of yield, conversion and selectivity can be acute if catalyst contaminants and microactivity are not sustained at appropriate levels. Effective catalyst management must be practiced to minimize delta coke and dry gas yields.

Fresh catalyst microactivity (MAT) is determined by the proprietary components and formulations of the supply companies. In the U.S., FCC catalyst is primarily supplied by 3 vendors; Grace Davison, Engelhard and Akzo. Each can custom formulate a catalyst to meet the specific processing goals of the refiner. In general, this falls into three categories; maximum gasoline, maximum octane or maximum octane-barrels of gasoline. However, each unique catalyst's performance is negatively affected by the accumulation of contaminants absorbed from the feed oil in the Reaction Riser. The primary contaminants are nickel and vanadium and to a lesser degree, sodium and iron. Table 4 and Figure 9 show the relative impact of nickel and vanadium on FCC conversion, hydrogen yield, gasoline and coke.

Table 4. Relative Effects of Nickel and Vanadium On Equilibrium Catalyst

Effects On:	**Nickel**	**Vanadium**
Conversion	**1.0**	**3 to 4**
Gasoline Yield	**1.0**	**1.2**
H_2 Yield	**1.0**	**0.5**
Coke Yield	**1.0**	**0.4**

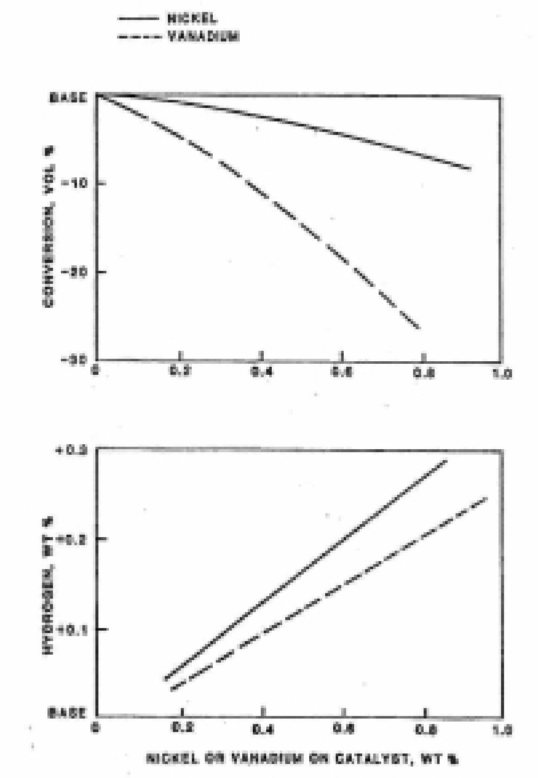


Figure 9. Relative impact of nickel and vanadium on FCC conversion and hydrogen yield.

Increasing concentrations of these additive contaminants function to shift the reaction mechanisms to those less desirable to the FCC processing goals. The main negative aspects of nickel accumulation are:

- Deposits on catalyst surface with minimal migration
- Catalyzes undesirable dehydrogenation reactions and coke
- Slightly decreases equilibrium MAT
- Increases delta coke and decreases catalyst circulation rate and cat-to-oil ratio, leading to lower conversion, lower gasoline yield, lower gasoline selectivity, and lower total liquid yield. Fuel gas yield and olefinicity of liquid products will be increased.

The main negative aspects of vanadium accumulation are:

- Migrates to the active zeolite components and destroys them
- Decreases equilibrium MAT
- Slightly catalyzes undesirable dehydrogenation reactions and coke
- Decreased MAT leads to lower gasoline and LPG liquid yields, lower gasoline selectivity, and lower total liquid yield.

Overall, high catalyst contaminant concentrations are always unfavorable as they result in gasoline and LPG product yield decreases with corresponding increases in Light Cycle Oil (LCO), Slurry, Dry Gas and Coke. Whether by reaction mechanism or zeolite destruction, delta coke increases with a resultant increase in Regenerator temperatures, loss of catalyst circulation rate and loss of cat-to-oil. Stripper operation may also be affected due to increased heavier, hydrocarbon undercarry.

Although each FCC is unique, certain common tools and analyses are useful to maintain the proper activity and contaminant levels. These include:

- Routine laboratory analysis of feed contaminant concentrations to allow variation of catalyst addition/withdrawal strategies
- Weekly Equilibrium Catalyst analysis by the FCC supplier to determine trends in contaminant concentrations and impact on MAT and surface areas
- Survey and review of Regenerator temperatures to assess shifts related to changing MAT or contaminants

- Frequent computation and review of heat and material balances and key performance indicators. These would include coke yield, delta coke, air-to-coke ratio, catalyst circulation rate, cat-to-oil ratio, conversion, gasoline yield, gasoline selectivity, gasoline octane or olefinicity, total liquid yield, total dry gas yield, dry gas SCFB, dry gas hydrogen concentration, and dry gas hydrogen to methane ratio.

- Injection of nickel or vanadium passivation additives to counteract metals effects. Increasing steam or injection of sour lift gas into the Riser may also have a slight benefit to decreasing nickel and vanadium effects

- Optimized catalyst addition and withdrawal program to maintain a desirable range of contaminant concentrations. Figure 10 shows the necessary fresh catalyst additions based on feed total Ni+V concentration to arrive at an equilibrium metals concentration on the catalyst in the inventory.

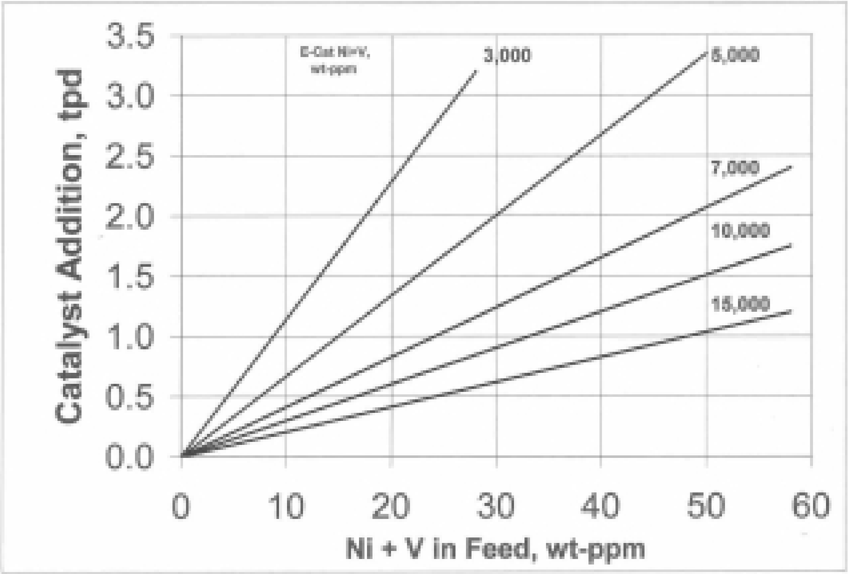


Figure 4. Equilibrium Catalyst Ni+V in Relation to Fresh Catalyst Addition and Feed Ni+V

Summary

FCCU operational and mechanical problems can be vary widely due to the complexity and dynamics of the process. There are common threads that link almost all units together such as Riser cracking, full or complete combustion regeneration, stripping, reaction catalyst, and fluidization. The majority of problems encountered are typically central to these shared elements. In most instances, problem resolution can be accomplished by a fundamental understanding of the critical aspects in FCCU and application of some basic responses. This paper has presented constructive actions to deal with these most common problems.

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Biographies

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Previous posts with Mobil and Coastal corporations involved responsibilities for the development, evaluation, and commercialization of a variety of refinery process technologies ranging from clean fuels and light gas upgrading to FCC and resid processing. Over the years, he has provided technical support to a number of FCC units in areas related hardware design, catalyst selection, and Regenerator and Stripper operations, among others.

Dr. Rahmim is a long-standing member of the AIChE, an associate member of the State Bar of Texas (Oil, Gas, and Energy Resources Law Section), and the president of the International Association for Energy Economics—Houston. He holds a number of patents in refining technologies, has authored papers in a variety of technical areas, and has presented in and chaired sessions at national conferences, including at previous Spring AIChE Meetings.