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20 questions: Identify probable causes for high FCC catalyst loss

Here is a list to troubleshoot your catalyst problems

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Fluid catalytic cracking unit (FCCU) performance and reliability are the primary drivers of refinery economics. Containment of the finely powdered catalyst within the circulating FCC unit inventory is a critical element of effective FCC operation. Identifying the probable causes of high catalyst losses from a FCCU remains one of the more important yet esoteric challenges that can be faced by FCC operators and engineers. The answers to 20 key questions provide a basis to list the more likely causes of high losses. Armed with this list, a refiner can develop cost-effective mitigation strategies to relieve, if not solve, the problem online or be prepared to confirm and correct the situation during the next unit shutdown. This can prevent chasing unlikely solutions, while the real culprits escape detection.

Workhorse unit of the refinery. FCCU performance and reliability do impact refinery economics. Containment and minimizing losses of the finely powdered catalyst within the circulating FCC unit inventory is critical. It is remarkable that two-stage reactor and regenerator cyclones, as depicted in Fig. 1, typically capture more than 99.997% of the catalyst dust entrained with the product and flue gas vapors. Any significant loss in the ability to contain the catalyst will have serious negative economic consequences, such as:

- Catalyst contamination of slurry-oil product reducing its value in the market.
- Severe erosion of slurry-circulation pumps
- Required cleaning of heavy oil tanks due to catalyst buildup
- Loss of compliance with permitted atmospheric particulate emissions
- Premature failure of flue gas power recovery turbines
- Loss of catalyst fluidity causes irregular or unstable catalyst circulation leading to lower FCC unit throughput and less desirable product yields
- Several fold increase in fresh catalyst makeup costs.

After a refinery notices an increase in FCC catalyst loss rate, it may prematurely conclude that the high loss rate must be due to mechanical problems that can only be cured by a unit shutdown and repairs. This scenario can then deepen when no obvious mechanical damage is found during the shutdown and it becomes apparent that the root cause of the losses can only be diagnosed by gathering clues and studying unit operations while the FCC unit is in service. Indeed, the worst thing that can be found during the shutdown and inspection could be finding *nothing at all.*

There are three categories of questions that can be asked when gathering clues to determine the most likely cause of high FCC catalyst losses:

- Questions with answers at your fingertips
- Questions that should have readily available answers
- Questions whose answers require data or analysis beyond that considered routine.

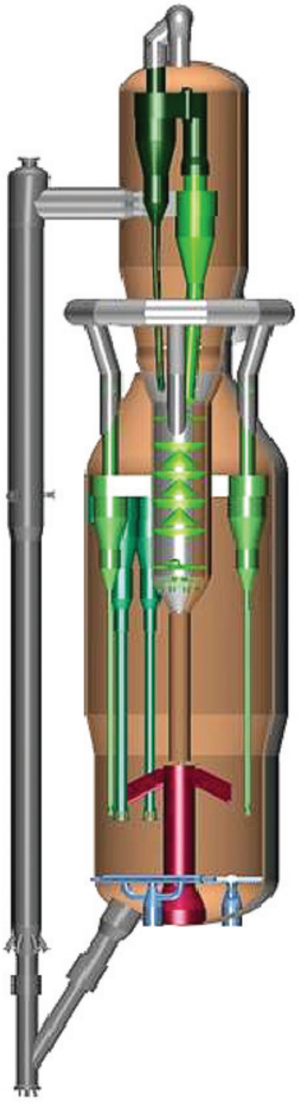

FIG. 1 Cut-away view of FCC unit.

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These listed groupings can provide an order for an investigation, starting with the questions where answers are most easily available, and working down the list toward those requiring more time and costs to answer.

Another complicating factor in FCC catalyst loss investigations, like many troubleshooting exercises, is that some of the supposed evidence may be corrupt or just plain wrong. It is up to the investigator to look for what is being indicated by the preponderance of the evidence, and not be drawn into making premature conclusions based on limited data.

First things first: Q1–Q7. If the increased rate of catalyst loss is not severe, the first indication may be the report of higher than expected fresh catalyst additions needed to maintain the unit catalyst inventory. The first order of business is to ascertain which side of the reactor-regenerator system, if not both sides, is responsible for the increased catalyst loss, as listed in Table 1.

Q1: What is the relative rate of catalyst loss in the fractionator bottoms compared to normal? Calculating the catalyst loss rate through the reactor cyclones is normally a straightforward multiplication of the slurry oil production rate times the concentration of ash in the slurry oil product.

Q2: What is the relative stack opacity or rate of fines catch compared to normal? An increase in regenerator stack opacity generally indicates an increase in stack catalyst emissions. It is noted that particles with diameters greater than a few microns generally have an increasingly smaller impact on opacity while those with diameters in the range of 0.1 to 1.0 microns have the larger impact on opacity.[1,2] The presence of third-stage separators, electrostatic precipitators and flue gas scrubbers can obscure the impact of increased regenerator catalyst losses on stack opacity.[3]

A concept referred to throughout this article is "What is normal?" Unfortunately, in many cases, this "normal" data may be difficult to obtain as the incentive to document problems often gets more priority than collecting data concerning what things look like when all is well.

It is also noteworthy if either the reactor or regenerator loss rate has decreased while losses from the other vessel have increased. With a constant rate of fines input (fresh catalyst) and fines generation by attrition, anything that reduces the fines losses from one vessel will increase the fines concentration in the unit and result in a corresponding increase in fines flowrate from the other vessel. For instance, commissioning a catalyst slurry oil filter with recycle back to the riser will increase the loss rate from a regenerator.

TABLE. 1. Questions with answers at your finertips

1. What is the relative rate of catalyst loss in the fractionator bottoms compared to normal?
2. What is the relative stack opacity or rate of fines catch compared to normal?
3. What is the relative amount of equilibrium catalyst in the 0–40 micron range?
4. What is the average equilibrium catalyst APS compared to normal?
5. How does the volumetric flowrate of reactor product vapors through the cyclones compare to normal?
6. How does the volumetric flowrate of air or flue gas through the regenerator compare to normal?
7. How does the catalyst circulation rate compare to normal?

TABLE 2. Questions needing more investigation to resolve

8. What is the relative rate of catalyst loss from the regenerator compared to normal?
9. How does the fresh catalyst makeup rate compare to normal?
10. Are the losses steady or intermittent?
11. When did you last change the type of fresh FCC catalyst?
12. When did the loss increase first occur?
13. How long did it take for the losses to increase from a normal rate?

TABLE 3. More difficult to resolve questions on FCC operations

14. What is the relative angularity of the equilibrium catalyst?
15. What is the relative angularity of lost catalyst?
16. What is the relative APS of the catalyst in the reactor carryover?
17. What is the shape of the differential particle size curve of the catalyst in the reactor carryover?
18. What is the relative APS of the catalysts in the regenerator carryover?
19. What is the shape of the differential particle size curve of the catalysts in the regenerator carryover?
20. How does the cyclone system pressure drop compare to normal?

The equilibrium catalyst data sheet provides a long-term accounting of many important equilibrium catalyst properties that are useful in diagnosing catalyst loss issues. Chief among these is the particle size data.[4]

Q3: What is the relative amount of equilibrium catalyst in the 0–40 micron range? An equilibrium catalyst data sheet provides a long-term accounting of many important equilibrium catalyst properties that are useful in diagnosing catalyst loss issues. Chief among these is the particle size data.[4] The relative amount of fines in the catalyst inventory is often indicated by the percentage of the catalyst particles having a diameter less than 40 microns. This parameter provides an indication of whether or not the increased loss rate is due to cyclone malfunction versus an increase in fines generation due to increased attrition or a higher loading of fines with the fresh catalyst.

Q4: What is the average equilibrium catalyst APS compared to normal? The change in average particle size (APS) of the equilibrium catalyst generally moves opposite the fraction of fines in the catalyst. However, APS can also increase over time due to decreasing equilibrium catalyst withdrawals that traps the largest particles within the circulating catalyst inventory.

Q5: How does the volumetric flowrate of reactor product vapors through the cyclones compare to normal? The volumetric rate of vapor flowing through the reactor cyclones can be estimated based on the reactor operating temperature and pressure together with the hydrocarbon product rate, reactor and stripper steam rates, and an estimate of the hydrocarbon product molecular weight. The rates and molecular weights of any hydrocarbon recycle streams should also be included in the calculations.

Q6: How does the volumetric flowrate of air or flue gas through the regenerator compare to normal? The regenerator air rate together with the regenerator operating temperature and pressure provide an

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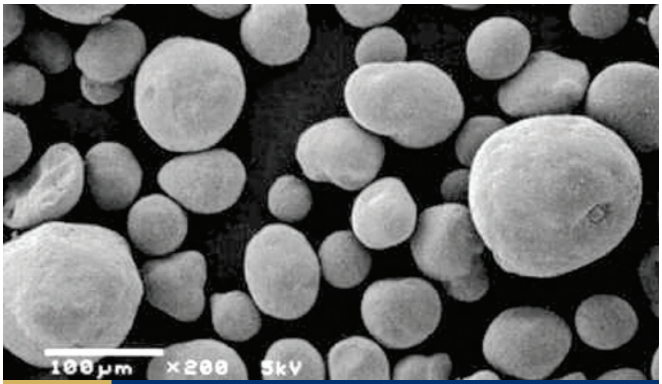

FIG. 2 Microscopic view of FCC catalyst.

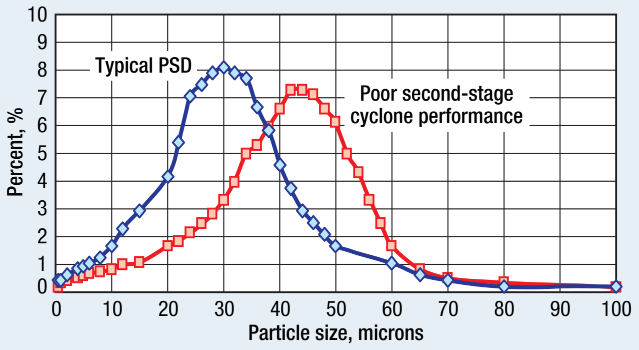

FIG. 3 Reduced system efficiency.

indication of the volumetric vapor traffic through the regenerator and its cyclone system. Even better accuracy can be obtained by calculating the molar rate of the flue gas based on the air rate and flue gas composition.

Q7: How does the catalyst circulation rate compare to normal? The most common method of estimating the catalyst circulation rate is based on the regenerator air rate, flue gas analysis, and reactor and regenerator temperatures. For the purpose of catalyst loss troubleshooting, the consistency of method is more important than the absolute accuracy of the method.

The next level. As listed in Table 2:

Q8: What is the relative rate of catalyst loss from the regenerator compared to normal? On the regenerator side, quantification of the catalyst loss rate is best determined over a period of time by subtracting the reactor catalyst loss rate from the catalyst addition rate. Careful attention to changes in the unit and catalyst hopper inventories over the same time period is important for the catalyst balance.

Previously, the presence of particulate capture devices downstream of the regenerator may obscure the impact of increased regenerator catalyst losses on stack opacity. In these cases, the investigator can review the catalyst catch rate in the post-regenerator flue gas cleanup equipment. For instance, data on the catch rate in a fourth-stage cyclone fines hopper or in an electrostatic precipitator (ESP) dust bins can provide more evidence of increased regenerator catalyst loss.

Q9: How does the fresh catalyst makeup rate compare to normal? Documentation of catalyst additions is important for several reasons. Firstly, after accounting for any changes in routine equilibrium catalyst withdrawal rates, increasing fresh catalyst additions to maintain unit inventory corroborates other indications of increasing catalyst losses. Second, increasing the fresh catalyst addition rate generally leads to increased losses due to increased fines input with the fresh catalyst and because the newer catalyst may have surfaces that are more easily abraded.[5]

Q10: Are the losses steady or intermittent? If the increased catalyst losses seem to come and go with time, this is an indication that the problem may be more related to operating conditions than mechanical damage. For instance, the diplegs may be operating close to a flooded condition, where changes in gas rate or catalyst loading drastically affect the cyclone efficiency. In a counter-example, if the increased loss rate is due to a hole in a plenum or cyclone outlet tube, then the losses are more likely continuous and increasing.

Q11: When did you last change the type of fresh FCC catalyst? If the type of fresh catalyst has changed in a timeframe that could coincide with the increased catalyst losses, the catalyst itself becomes suspect. Similarly, the same is true if the fresh catalyst receipts show significant physical property changes, especially in terms of the fraction of fines, density or Attrition Index.[6]

Q12: When did the loss increase first occur? It is also worthwhile to consider the date when the increased catalyst losses seemed to begin. Look for coincidences with other significant events in the FCC operation. For instance, did the time of the increased loss rate correspond with a unit turnaround or upset? Equipment damage is more likely to occur during a startup, upset or shutdown. Loss of restriction orifices that can cause an attrition problem more commonly occurs during a turnaround. Were there other significant changes in the operation corresponding to the time of the increase in catalyst losses such as changes in feedrate, combustion air rate, catalyst circulation rate or feedstock quality?

Q13: How long did it take for the losses to increase from a normal rate? If the catalyst loss rate made a step change from normal to a higher value, then this generally indicates that the problem is not an erosion induced hole somewhere in the cyclone system; as the hole size will increase gradually if erosion is to blame.

Harder-to-answer questions. As shown in Table 3, these require sample capture and/or laboratory testing that would be considered non-routine.

Q14: What is the relative angularity of the equilibrium catalyst? As shown in Fig. 2, looking at the sample of the equilibrium catalyst loss under a microscope can be very revealing. If the sample contains a lot of small, jagged or broken pieces, it indicates an abnormally severe degree of catalyst attrition.[7]

Q15: What is the relative angularity of lost catalyst? Generally speaking, samples of catalyst lost from the reactor are readily available from a sampling of the slurry oil product or circulating slurry oil. The slurry oil can be washed and filtered in a laboratory, and the captured catalyst can be viewed under a microscope. If available, samples of catalyst lost from the regenera-

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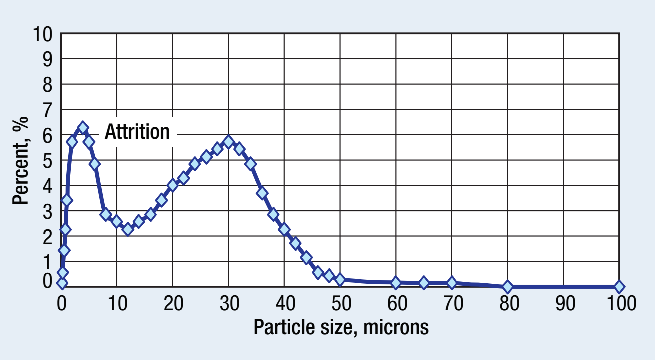

FIG. 4 Bi-modal distribution indicating an attrition problem.

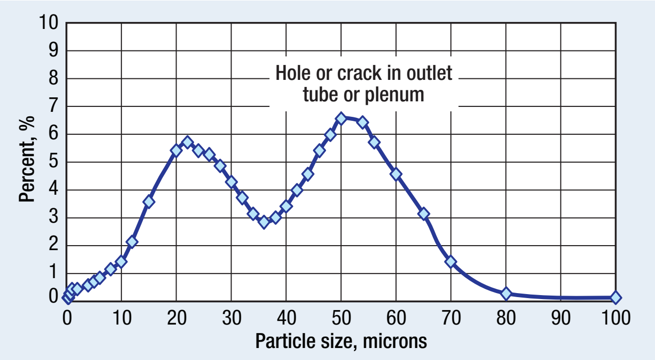

FIG. 5 Bi-modal distribution indicating cyclone bypass.

What can be done to correct an attrition problem online?

- Locate and correct any missing orifices or valve openings.

What can be done to correct a plugged reactor cyclone dipleg online?

- Lower the stripper bed level to unseal the diplegs.
- Pressure bump the unit by changing the vessel operating pressure rapidly, say 4 psi in 15 seconds.

tor can be viewed under a microscope. The microscope can reveal whether the sample contains a high concentration of small, jagged or broken pieces indicating an abnormally severe degree of catalyst attrition.

Q16: What is the relative APS of the catalyst in the reactor carryover? Catalyst taken from the slurry oil can be subjected to the all important particle size analysis. For a given rate of fines input and fines generation within the unit, material balance considerations dictate that the APS of the lost catalyst must increase as the loss rate increases. The image from the microscope can corroborate the particle size analysis by showing more than an expected fraction of larger particles and even very large particles that would never escape a properly functioning cyclone system.

- If the APS of the lost catalyst is smaller than normal, and if the loss rate is higher than normal, then that would indicate an increased degree of fines input or increased catalyst attrition.
- Moderately increasing APS would indicate some loss of cyclone efficiency; if the loss rate is higher than normal or a reduction in fines input or attrition if the loss rate is less than normal.
- Moderately increasing APS indicates a reduction in fines input or attrition if the loss rate is less than normal.
- A large increase in APS indicates a major cyclone malfunction or serious damage.

Q17: What is the shape of the differential particle size curve of the catalyst in the reactor carryover? The particle size analysis of a loss sample can also be reported as differential particle size distribution, indicating the fraction of particles falling in narrow size ranges. This is a different presentation than a cumulative particle size distribution displaying the weigh percentage of particles having less than a given diameter.[8] The shape of the differential particle size distribution curve can be insightful:

- If the curve has only a single broad peak centered about a higher than normal particle size, as shown in Fig. 3, this could indicate a partial loss of cyclone efficiency but not complete bypassing of solids.
- A bimodal curve having a peak near that considered normal, as well as a secondary peak at a lower than normal particle size as shown in Fig. 4, may indicate a catalyst attrition problem.
- Some bypassing of material around the cyclones altogether would occur with a breached plenum chamber or a hole in a secondary cyclone outlet tube, as shown in Fig. 5. This would exhibit itself with a bimodal curve having peaks near that considered normal, as well as a secondary peak at a higher than normal particle size.

Q18: What is the relative APS of the catalysts in the regenerator carryover? Collecting a representative sample of catalyst lost from the regenerator is less straightforward than the collection of fines from slurry oil. Ideally, a dust sample can be collected from the regenerator effluent, and the results can be analyzed as previously discussed with respect to catalyst separated from slurry oil. If dust collection equipment exists downstream of the regenerator, such as a scrubber, ESP or TSS, the fines catch can also be analyzed and used in the investigation.

Q19: What is the shape of the differential particle size curve of the catalysts in the regenerator carryover? If a dust sample from the regenerator effluent can be obtained, the results can be analyzed as previously discussed with respect to catalyst separated from slurry oil.

Q20: How does the cyclone system pressure drop compare to normal? Some FCC units are instrumented with differential pressure measurements across the vessel disengaging space and the vapor outlet. This provides an indication of the pressure drop through the cyclone system and it will indicate whether there has been a significant change in the catalyst or vapor loadings of the cyclones.

Once answers to many of the 20 questions are available, these answers can be analyzed for fit with the characteristics of the problems described below to establish the more likely causes of the catalyst loss problem.

Possible FCC catalyst losses. More common causes of high catalyst losses are:

Excessive attrition in a fluid bed. Catalyst attrition in a fluid bed is caused by catalyst particles colliding at high velocity with other particles or solid surfaces. The high particle velocities in a fluid bed are chiefly the result of particle

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acceleration driven by high-velocity gas jets within the fluid bed. The focus of an investigation into the source of excessive catalyst attrition can include looking for these problems:

- Missing restriction orifices or open orifice bypasses associated with pressure taps, torch oil nozzles, and other vessel connections intended to pass only a small amount of gas, air or steam.
- High-velocity gas jets can also emanate from broken or eroded steam or air distributors where gas escapes without traveling through a velocity reducing nozzle typically used in the design of such distributors.

A high fines concentration in the lost catalyst; high fines content in the catalyst inventory; and splintered, broken and jagged particles as viewed with a microscope, all are indicative of a catalyst attrition problem.

Excessive reactor or regenerator dilute phase attrition. Since there is little catalyst in a dilute phase, by definition, high attrition rates in this region are likely associated with particle impacts on solid surfaces within the cyclones, especially cyclones with high exit velocities.

- The nature of the solid surfaces can also play a role in catalyst attrition with badly damaged refractory or unusually rough refractory surfaces providing more opportunity for abrupt impact of the travelling catalyst.

Plugged reactor secondary cyclone dipleg. Secondary cyclone dipleg plugging is much more common than the plugging of primary cyclone diplegs. The reason is smaller diameter diplegs. The plugging of a second-stage reactor cyclone dipleg often calls for an immediate shutdown of the FCC unit due to high catalyst losses.

- Coke can form in a reactor cyclone and then fall into the dipleg, causing a full or partial plug.[9]
- If feed is introduced into the reactor before the internals are sufficiently heated, such as can happen during startup or upsets, then large amounts of coke can appear wherever feedstock can condense.
- Some cyclones have check valves on the dipleg. Anything that can cause the flapper to stick or be held closed, including design problems or hinge coking, will provide an effectively plugged dipleg.
- Failures of the cyclone hexsteel attachments to the cyclone interior shell can release sheets of hexsteel and refractory sufficiently large enough to plug even large diameter diplegs. Such failures can be attributed to poor hexsteel design or installation as well as coke induced refractory anchor failure.[10]

Plugged reactor primary cyclone dipleg. The causes of primary reactor cyclone dipleg plugging are the same as those given for the plugging of reactor secondary cyclone diplegs. Plugging of reactor primary cyclone diplegs is relatively uncommon due to the large dipleg diameters normally associated with primary cyclones. If a primary cyclone dipleg does become plugged, and if the vapor outlet is associated with a secondary cyclone, as is common, the catalyst loading to the secondary cyclone may exceed the capacity of the secondary cyclone dipleg. In this event, the secondary cyclone will become flooded with catalyst, and full-range catalyst will begin flowing at a high rate from the secondary cyclone outlet.

Plugged regenerator cyclone diplegs. Plugging of regenerator cyclone diplegs has similar causes and effects to those encountered with respect to the reactor cyclones, but plugging of regenerator cyclone diplegs is less common. In the regenerator, the coking phenomenon that is at the root of most reactor cyclone plugging problems does not exist. There are, however, some situations peculiar to the regenerator cyclones:

- A phenomenon unique to regenerator secondary cyclone diplegs is that the almost extinct use of spray water in the regenerator primary cyclone outlets can lead to the formation of wet catalyst in dipleg, preventing catalyst flow.
- Regenerator upsets, such as a sudden drop in pressure or the activation of emergency spent catalyst riser lift steam, can precipitate a large catalyst carryover that may persist even after the disturbance is gone. This has been explained by noting that defluidized solids will drain from a cyclone much more slowly than fluidized solids. So much catalyst can be thrown into the cyclones that it defluidizes before it can get into the dipleg. Then, even at normal entrainment, the catalyst will not drain out of the cyclone fast enough to eliminate the packed catalyst level in the cyclone.[11]

Holes in plenum or second-stage cyclone outlet tube. A hole in a plenum or secondary cyclone outlet tube, as shown in Fig. 6 provides a direct path for catalyst escape, bypassing the cyclone system, and allowing even large catalyst particles to show up in the main fractionator bottoms

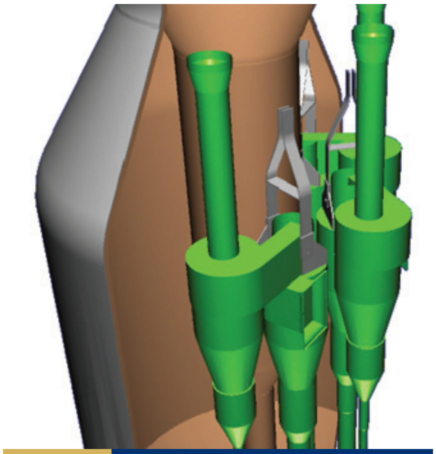

FIG. 6 Two-stage regenerator cyclone system.

FIG. 7 Cyclone dipleg check valve.

What can be done online to correct a plugged regenerator cyclone dipleg?

- Pressure bump the unit by changing the vessel operating pressure rapidly, say, 4 psi in 15 seconds
- Partially unload the catalyst and then return to a normal operating level.
- Following a cyclone overload, sometimes normal operation can be restored by reducing the air rate to a very low level for several minutes so that overfilled cyclone hoppers can drain the defluidized catalyst.

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or flue gas system. Even a 10-mm hole can increase the catalyst losses several fold. In time, the passage of high velocity catalyst through the hole will increase the hole size, and the catalyst losses will intensify.

- Holes often start as cracks or tears in the metal; in time, they grow due to the erosive effects of the catalyst flow. If the catalyst loss problem is not yet severe, a unit inspection may have difficulty finding the cracks, as the cracks may tend to close as the unit cools.
- The impact of a hole in the outlet tube or plenum of a reactor with riser cyclones will be less than with an inertial riser termination device because there will be little catalyst in the dilute phase that can be sucked into the hole.

Holes in a second-stage cyclone. Holes in a secondary cyclone (or a single stage cyclone), including holes in the cyclone dipleg, will have serious consequences on catalyst containment. The rate of performance deterioration will be controlled by how quickly the hole enlarges due to erosion. Holes in the dipleg allow the vapor flow into and up the dipleg. This can restrict the ability of catalyst to flow down the dipleg. If the hole is in the cyclone body, then the incoming vapor jet can disrupt the desired vapor profile in the cyclone, damaging the collection efficiency.

Holes in first-stage cyclone. Holes in primary cyclones are not as common due to the lower velocities in primary cyclones. The catalyst loss impact from a hole in a primary cyclone will be much less severe compared to a hole in a secondary cyclone, because the secondary cyclone will catch almost all the catalyst lost from the primary cyclone. In fact, it may be difficult to even notice the increased catalyst loss associated with a hole in a primary cyclone.

Stuck open or missing flapper in first-stage cyclone. Most first stage cyclones are submerged in a fluid bed and do not have or need check valves because the catalyst traffic is sufficiently high enough that gas does not force itself up the dipleg. Sometimes check valves, as shown in Fig. 7, are included to limit losses during startup when the diplegs are not submerged. In these cases, a stuck-open flapper will be of little consequence during normal operations.

In some cases, due to the unit geometry or technical preference, the primary cyclones can be designed to discharge above the bed. In these cases, assuming the cyclone is not a positive pressure riser cyclone, a properly functioning valve is required. The consequences of a valve that is stuck open would be a major loss of cyclone efficiency, increasing the loading to the secondary cyclones and increasing the catalyst losses from the unit.

Stuck open or missing flapper in second-stage cyclone. A flapper that is stuck open or missing may not affect the cyclone performance if the dipleg is submerged sufficiently in a well-fluidized bed. If the bed fluidization is erratic, then the losses may increase due to unsteady catalyst flow down the dipleg or due to gas bypassing up the dipleg. If the secondary cyclone dipleg is not submerged into the fluid bed, a stuck open or missing flapper turns the dipleg into a vacuum tube sucking vapors into the cyclone; destroying the cyclone efficiency. A detached dipleg would have similar consequences.

Reactor cyclone overload. A reactor cyclone system can become overloaded if the catalyst or vapor traffic exceeds the design hydraulic capability of the cyclone system. The cyclone system pressure drop increases with both catalyst and vapor loading. As the pressure drop increases, the catalyst in the dipleg must backup to a higher elevation, as shown in Fig. 8, to provide enough static head to force the catalyst out of the dipleg. When the catalyst height in the dipleg reaches the dipleg top, the swirling vapors in the bottom of the cyclone will reentrain the catalyst and drastically reduce cyclone collection efficiency. This situation is referred to as "cyclone flooding." Increasing reactor vapor traffic beyond the cyclone dipleg hydraulic limit can occur by operating at an increased feedrate, higher conversion, and reduced operating pressure.

- Catalyst loss can be intermittent when cyclone dipleg hydraulic limitations are the issue.
- When operating near the cyclone dipleg hydraulic limit, even a small increase in catalyst circulation or vapor rate can result in increased catalyst losses.
- Dipleg sizing is rarely a limitation during normal operations, but if the regenerator temperature falls to very low levels while maintaining riser outlet temperature, the catalyst circulation will increase. At extreme conditions, the reactor cyclone dipleg can restrict the flow of catalyst.

Regenerator cyclone overload. A regenerator cyclone system can also become overloaded when catalyst and vapor traffic exceed the hydraulic capability of the cyclone system:

- Catalyst loss can be intermittent when cyclone dipleg hydraulic limitations are the issue. In some cases, the flue gas stack can appear to be puffing.
- Increasing vapor traffic beyond the cyclone dipleg hydraulic limit can occur by operating at increased regenerator air rate, higher temperature and reduced operating pressure.
- Catalyst overload in regenerator cyclones can occur for the same reasons

What can be done to correct a stuck open or detached check valve online?

- It may be possible to reduce catalyst losses by raising the bed level to seal the dipleg.

What can be done to correct a cyclone design issue online?

- Nothing, but try to rule out the other possible causes before shutting down.
- Adjust operating conditions to minimize losses until design modifications are possible.

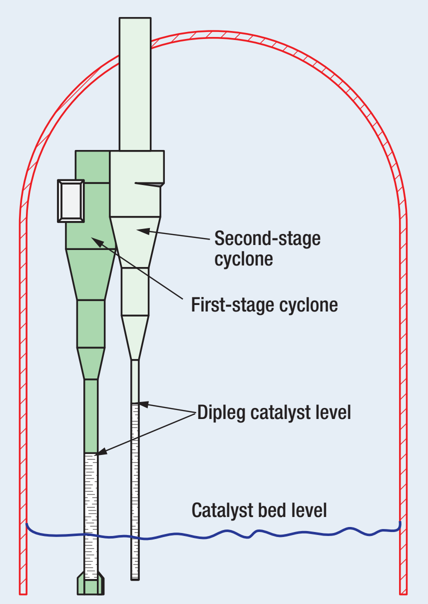

FIG. 8 Cyclone hydraulic balance.

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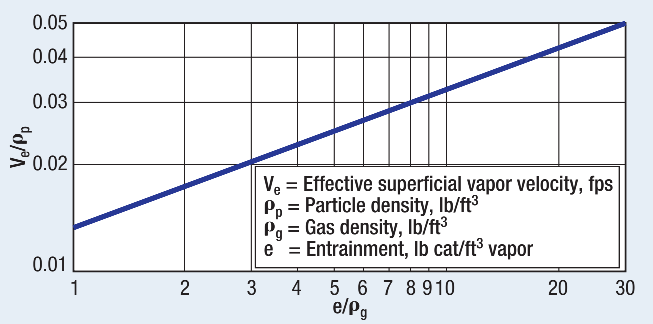

FIG. 9 Catalyst entrainment correlation.

What can be done to correct catalyst-induced loss problem online?

Sometimes refiners purposely add fresh catalyst with high fines content, low density, lower Attrition Index, or just an increase in fresh catalyst makeup rate to improve the fluidity of the catalyst inventory. With that in mind, consider:

- Ordering fresh catalyst with lower agreed limits on 0–40 micron particle content.
- Changing to a catalyst with higher particle density or one with increased attrition resistance.
- Reducing the fresh catalyst makeup rate.

as vapor overload because the catalyst entrainment rate to regenerator cyclones, as shown in Fig. 9, is a function of regenerator superficial vapor velocity.[12]

Poor efficiency—Cyclone design. The suspicion of a poor efficiency cyclone design will typically be raised only after the installation of a new set of cyclones. Poor reactor cyclone efficiency due to coke formation within the cyclone has also been reported.[9]

Having said this, it would be a characteristic of a low efficiency cyclone design to exhibit a rather large average catalyst particle size in the lost catalyst. Also, the differential particle size analysis curve would have only a single peak as opposed to a bi-modal peak associated with a damaged cyclone. A low concentration of fines in the circulating inventory would also be characteristic of low cyclone system efficiency.

Poor efficiency—Regenerator design. It would be a characteristic of a low-efficiency regenerator design to lack sufficient height or diameter to effectively disengage the catalyst rising from the fluid bed. Such a regenerator would exhibit a rather large average catalyst particle size in the lost catalyst while the differential particle size analysis curve would have only a single peak as opposed to a bi-modal peak associated with a damaged cyclone. A low concentration of fines in the inventory would also be characteristic of a low-efficiency regenerator design. The quality of the bed fluidization may also affect the catalyst entrainment rate and cyclone operability:

- Defluidized sections of the bed may inhibit flow from the submerged diplegs.
- Spouting spent catalyst risers can throw more catalyst up to the cyclones.
- Specially designed baffles placed within the bed have been observed to reduce catalyst entrainment.[13]

Fresh catalyst too soft. Soft FCC catalyst is one that inherently suffers from a higher than average attrition rate when subjected to the rigors of circulation in the FCC unit. The softness of a catalyst is the opposite of its hardness, a parameter defined by the catalyst manufacturers as an Attrition Index.[5] This index is based on a laboratory simulation of FCC catalyst attrition relying on the punishment of a laboratory sample with a high-velocity gas jet at defined standard conditions.

- Catalyst manufacturers offer varying degrees of catalyst hardness. Soft catalyst is rarely an explanation for a catalyst loss problem today.
- Catalyst that is too soft will manifest itself as higher catalyst losses from both the reactor and regenerator and higher than normal equilibrium catalyst fines content.

Fresh catalyst—High 0–40 micron content. A fresh catalyst with a high 0–40 micron content is one that is shipped with a larger than typical fraction of particles having diameters less than 40 microns. Catalyst with this character will lose a higher percentage of their mass from the inventory shortly after being loaded into the unit.

Fresh catalyst—High addition rate. FCC unit catalyst losses have a definite correlation with the rate of fresh catalyst additions because increasing fresh catalyst addition rate increases fines input and because the fresh catalyst may have fragile edges that are lost more easily when the catalyst is first introduced into the unit.

- Higher catalyst losses are an expected, normal result of increasing fresh catalyst addition rate.

Increased reactor fines retention. Whenever changes occur that limit the ability of fines to escape from a reactor system, the fines will find their way out of the unit via a different avenues, which are limited to the regenerator cyclones and increased catalyst withdrawals. Examples of changes that increase reactor catalyst retention are:

What can be done to correct a dipleg hydraulic problem online?

- Reduce dipleg submergence by lowering the catalyst bed level
- Lower vapor and/or catalyst circulation rates.
- Increase operating pressure.

- Recycle of fines from the fractionator bottoms back to the FCC reactor via conventional slurry oil recycle system or a slurry-oil filter system.
- Installation of new reactor cyclones having a higher design efficiency.

Increased regenerator fines retention. If the catalyst fines cannot get out through the regenerator, they will be forced to exit the unit through the reactor. Examples of changes that increase regenerator catalyst retention are:

- Recycle of fines from an electrostatic precipitator or third-stage separator back to the regenerator.
- Installation of new regenerator cyclones having a higher design efficiency
- Feed contaminants and regenerator operating conditions that lead to sticky catalyst within the regenerator.

In the presence of high levels of fluxing agents such as sodium, potassium, calcium, chlorides or vanadium that can be introduced with contaminated feedstock, and especially at high temperatures, the catalyst can become sticky. These fluxing agents can form low melting eutectics with the catalyst at temperatures as low as 930°F to 1,200°F.[5]

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There will be times that even with thoughtful consideration of the answers to the 20 questions, and even after unit shutdowns and inspections, the cause of high FCC catalyst losses will remain elusive. However, FCC product economics, reliability and environmental concerns may compel refiners to resort to extraordinary tactics for finding the source of the high losses.

Extraordinary measures. A number of more costly and time-consuming options in searching for the root cause of high catalyst losses include:

- Cold-flow modeling
- Radioactive tracers and gamma ray scans
- Cyclone pressure testing
- Computational fluid dynamic simulations.

The road to the conclusion of an investigation into the cause of high catalyst losses may prove to be long and arduous. However, if the investigation stays the course, the road will usually lead to success. **HP**

LITERATURE CITED

[1] Ensor D. S., and M. J. Pilat, “Calculation of Smoke Plume Opacity from Particulate Air Pollutant Properties,” 63rd Annual Meeting of the Air Pollution Control Association, St. Louis, Missouri, June 14–18, 1970.

[2] McClung, R. G., “Effect of FCC Catalyst Fines Particle Distribution on Stack Opacity,” The Catalyst Report, Engelhard Corp., 1994.

[3] Niccum, P. K., E. Gbordzoe and S. Lang, “FCC Emission Options,” NPRA Annual Meeting, March 2002, San Antonio.

[4] Montgomery, J. A., “More about Davison’s Equilibrium Fluid Cracking Catalyst Analysis Program,” Davison Catalagram, No. 63, Davison Chemical Division, W. R. Grace & Co., 1981.

[5] Linden, D. H., “Catalyst Deposition in FCC Power Recovery Systems,” Katalistiks’ 7th Annual Fluid Cat Cracking Symposium, Venice, Italy, May 12–13, 1986.

[6] Weeks, S. A. and P. Dumbill, “Method speeds FCC catalyst attrition resistance determinations,” *Oil & Gas Journal*, April 16, 1990, pp. 38–40.

[7] Zhou, F., C. Liu, J. Liu and S. Shu, “Use micrographs to diagnose FCC operations,” *Hydrocarbon Processing*, March 2006.

[8] Fletcher, R., “Stepwise method determines source of FCC catalyst losses,” *OGJ*, Aug. 28, 1995.

[9] McPherson, L. J., “Causes of FCC Reactor Coke Deposits Identified,” *OGJ*, Sept. 10, 1984.

[10] Session II.A-Fluid Catalytic Cracking, Mechanical Question 6, NPRA Q&A Session on Refining and Petrochemical Technology, 1994.

[11] Zenz, F. A. and D. F. Othmer, *Fluidization and Fluid-Particle Systems*, Reinhold Publishing Co., New York, 1960.

[12] Giuricich, N. L. and B. Kalen, “Dominant Criteria in FCC Cyclone Design,” Katalistiks’ 3rd Annual Fluid Cat Cracking Symposium, May 26–27, 1982, Marriot Hotel, Amsterdam, The Netherlands.

[13] Miller, R. B., Y-Lin Yang, T. E. Johnson, S. J. McCarthy and K. W. Schatz, “REGENMAX™ Technology: Staged Combustion in a Single Regenerator,” NPRA Annul Meeting, March 1999, San Antonio.

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