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Troubleshooting Catalyst Losses in the FCC Unit
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Overview

- Introduction
- Cyclone Fundamentals
- Catalyst Attrition
- Monitoring and Troubleshooting Catalyst Losses
- Handling High Catalyst Losses
- Questions
Almost all FCC units have experienced a catalyst loss problem.

Main causes of elevated catalyst losses include:

- Cyclone problem
- Catalyst attrition

High catalyst losses can eventually lead to a unit shutdown due to:

- Erosion in the slurry circuit
- Stack opacity that is out of consent
- Catalyst circulation instability or inability to fluidize
- Excessive catalyst additions
Cyclones use centrifugal force to separate catalyst particles from the gas:

- The particles are forced to the walls of the cyclone and fall into the dipleg.
- The gas accelerates to the outlet tube at the top of the cyclone.

The recovery efficiency of a conventional two-stage cyclone system is very high at over 99.99%!

For example, for a typical 40 mbpd FCC unit, >30,000 tons/day of catalyst are circulated through the cyclones with a total loss of 2.2 tons per day!
Velocity is a key operating parameter for cyclone performance:

- Collection efficiency increases with velocity and then drops off due to catalyst re-entrainment.
- Catalyst attrition to micro-fines occurs within cyclones and increases with velocity.

The overall cyclone collection efficiency depends on numerous factors including:

- Number of spirals within the barrel and cone
- Inlet velocity
- Particle density and size
- Catalyst loading
## Cyclone Operation

What are the most commonly accepted design limits for cyclones?

<table>
<thead>
<tr>
<th>Primary Cyclones</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Velocity</td>
<td>65 ft/s</td>
</tr>
<tr>
<td>Outlet Velocity</td>
<td>150 ft/s</td>
</tr>
<tr>
<td>Operating Temperature (304H SS)</td>
<td>1400°F</td>
</tr>
<tr>
<td>Dipleg Mass Flux</td>
<td>150 lb/ft².s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Secondary Cyclones</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Velocity</td>
<td>75 ft/s</td>
</tr>
<tr>
<td>Outlet Velocity</td>
<td>175 ft/s</td>
</tr>
<tr>
<td>Dipleg Mass Flux</td>
<td>40 lb/ft².s</td>
</tr>
</tbody>
</table>

- High velocities can increase catalyst attrition
- Dipleg choke can be a concern for primary cyclones
- Sustained high temperatures will reduce the life of the cyclones
Cyclone Lifespan

Well designed cyclones may have a service life of 20 years or more

- Minimize erosion by:
  - Increasing cyclone length (min L/D of 4)
  - Design to avoid excessive velocities
  - Add a vortex stabilizer to secondary cyclones

- Ensuring good inspection and maintenance of refractory during each turnaround

- Control afterburn with CO Promoter and ensure even distribution of air and spent catalyst, to minimize creep and sigma phase embrittlement due to high temperature

- Replacing cyclones? Don’t just replace in kind – review!!
Catalyst Entrainment

- Cyclone efficiency increases **BUT** catalyst losses also increase as catalyst loading increases to the cyclones:
  - **Reactor**: increases with catalyst circulation rate
  - **Regenerator**: entrainment from the bed increases with *superficial velocity*, and also higher dense bed level if the height of the Cyclone Inlet above the Bed Height is below the Transport Disengaging Height

![Graph showing the relationship between Bed Velocity and Entrainment](image)

![Diagram of a cyclone](image)
Refractory Lining

- Hexmesh is the most common anchor for the refractory, which is typically hand-packed
- Reactor-side hexmesh must be fully welded to prevent coke from growing underneath

![Non-Coking Service](image1)

![Coking Service](image2)
Common Cyclone Problems: Dipleg Malfunction

Flooded diplegs → catalyst carryover due to:

• High catalyst loading/cyclone ΔP/catalyst bed level
• Plugging by refractory, debris, coke or catalyst deposit
• Trickle valve, flapper plate or counterweight plate movement restricted, e.g. due to external coke build-up
• Operation in a de-fluidized dense bed

Unsealed diplegs → excessive gas leakage and catalyst re-entrainment due to:

• Low bed level (at start-up; use low velocity initially)
• Loss of sealing plate when operating in dilute phase
• Flapper valve plate stuck in an open position
Common Cyclone Problems: Cyclone Holes

Holes in the cyclone system can occur due to:

• Catalyst erosion of refractory/metal from high velocities. Erosion rate proportional velocity to the power of 3 to 5.
• Thermal cycling when unit shuts down/restarts – may cause cracks in the plenum head, allowing catalyst to directly bypass from the dilute phase.

Holes can result in gas leakage and disruption of cyclone operation

• Often a hole will lead to a gradual increase in losses as the hole enlarges due to erosion
• Higher losses from 1\textsuperscript{st} Stage cyclones may be partly handled by 2\textsuperscript{nd} Stage cyclones
• Mechanical problem will require unit entry to repair
Mechanical Problems

- Dipleg hole
- Dipleg obstruction
- Coke build on outlet tube
- Trickle valve erosion
- Dustbowl refractory loss
Reactor Cyclone Coking

- Coke will accumulate and grow in cracks and crevices in the refractory, pushing the refractory away from the metal.
- Hex mesh anchors in the reactor should be fully welded along each seam, and any cracks should be properly repaired during turnarounds.
- Coke will often deposit on the outside of reactor cyclone gas tubes. In the event of an upset / thermal cycling, this coke may spall and block the cyclone dipleg.
- As a preventative measure, vee anchors can be installed to prevent coke from spalling.
Refractory Damage

Photos courtesy of: QUARTIS
Catalyst Attrition Mechanisms

Catalyst breaks into smaller particles by fracturing and abrasion

- Large mass of catalyst impacts cyclone refractory walls
- Jets of oil/steam/air cause catalyst particles to collide against each other
- Excessive jet velocities from the air or steam distributors (>300 ft/s) and catalyst loadings to the cyclones can generate micro-fines
- Population balance modelling indicates that *abrasion* is the dominant attrition mechanism in FCC
- The ASTM D5757 air jet test most closely mimics attrition mechanisms in the commercial unit
Causes of Attrition

1. Excessive velocities
   - Missing restriction orifice on steam or air nozzles used for aeration, torch oil nozzles etc.
   - Eroded or lost stripping steam distributor and/or air grid nozzles
   - Feed injectors, air grid, cyclones operating above design guidelines

2. Higher catalyst loading to cyclones
   - Cat circulation rate
   - Entrainment to regenerator cyclones

3. Catalyst properties and management
   - Unsuitable fresh catalyst attrition properties
   - Excessive air rate for pneumatic conveying during catalyst loading to/from hopper
Minimizing micro-fines is particularly important for low stack opacity

- Micro-fines are 0.5-2.5 micron material
- Fines generation increases with higher fresh catalyst addition rate

Attrition is just one aspect of catalyst design and formulation

- A low catalyst attrition may be needed in some cases due to local emission limits or unique aspects of the FCC unit design
- Often a lower attrition requires a compromise on other aspects of catalyst performance
- Discuss the attrition requirements of your FCC catalyst with your catalyst supplier
Catalyst Loss Monitoring

- Good base line monitoring is essential

**Earlier identification of loss problems**

- Gives more time to troubleshoot, potentially correcting the problem *before* emissions limits are exceeded, or implementing steps to achieve *sustainable* operation until the next turnaround.

**More effective troubleshooting when loss problems occur**

- The first troubleshooting step is finding *what has changed* compared to normal operation? A baseline is essential.
A best practice is to calculate the catalyst mass balance every month.

Catalyst Additions = Regen Losses + Reactor Losses + Withdrawals + Accumulation

- Verify catalyst additions using hopper dips or loader weigh cells, and reconcile with fresh catalyst deliveries – remember to correct for Loss On Ignition.
- Regenerator losses are calculated by difference. If you collect fines from the regenerator flue gas, determine the amount to calculate stack losses.
- Reactor Losses = Slurry rate x Ash content.
- Monitor spent catalyst withdrawals via hopper dips or weigh bridge.
- Estimate change in unit inventory based on Reactor and Regenerator levels.
Additional monitoring of the unit should include:

- Regular review of fresh catalyst properties – PSD, ABD, LOI, Attrition Index
- Weekly testing of equilibrium catalyst physical properties – PSD, ABD
- Particle size analysis of slurry fines, third stage fines, etc. at least monthly
- Slurry ash content 1-2 times per week, and daily BS&W testing

A regular review of data and monthly catalyst balance will give the best chance to identify a loss problem.

- It may take several weeks for a loss problem to be confirmed
Catalyst Loss Troubleshooting: Identifying the Problem

Fines analysis is the most useful source of data for identifying the type of loss problem!

**Blocked dipleg or loss of efficiency**

A step change or gradual increase in losses from *either* the reactor or regenerator side, and a decrease in Ecat fines content (<45μm). Fines will have an abnormally high peak at around 30-50 microns, and the attrition peak will be small.

PSD of losses (Slurry Fines, 3rd Stage Fines, ESP):
Catalyst Loss Troubleshooting: Identifying the Problem

Fines analysis is the most useful source of data for identifying the type of loss problem!

Hole in cyclone or plenum

A hole or plenum crack will often present as a gradual increase in losses from either the reactor or regenerator. Depending upon the extent of losses, the Ecat fines (<45μm) may not decrease. Fines PSD will often show a new peak at around 70-80 microns.
Catalyst Loss Troubleshooting: Identifying the Problem

Fines analysis is the most useful source of data for identifying the type of loss problem!

Attrition problem

Often a gradual onset, with an increase in both reactor and regenerator losses, and an increase in Ecat fines content (<45μm). Fines will have an abnormal peak at around 1-2 microns.

PSD of losses (Slurry Fines, 3rd Stage Fines, ESP):
Investigation Steps to Consider

- Review the nature of the losses:
  - Gradual increase with increased <2.5μm peak in fines PSD → Attrition
  - Gradual increase with increased peak in fines PSD ~ 70μm → Hole enlarging
  - Step change → Mechanical failure or operating problem
  - Intermittent → Operating close to cyclone dipleg flooding limit

- Check potential attrition sources: Equipment velocities, steam distributor P, catalyst properties/additions, confirm all flow RO’s in place, blast steam closed, etc.

- Review operating conditions: Sudden loss in vessel pressure, regenerator bed defluidization due to low air rate, higher feed rate leading to reactor cyclone flooding, etc.

- Review inspection history: Has a similar problem occurred in the past?

- Conduct tests: Gamma scans for vessel and cyclone dipleg levels, radioactive tracers for gas/catalyst flow distribution, etc.
Review Operating Conditions

Review operating conditions to check for a significant deviation from normal/original design, for example:

- Sudden vessel pressure loss
- Regenerator bed de-fluidization due to low air rate
- Capacity creep

**Reactor cyclone flooding may be caused by:**

- High velocity (higher feed rate, more gas, lower pressure etc.)
- High cat circulation rate
- High stripper level

**Regenerator cyclone flooding may be caused by:**

- Excessive catalyst entrainment to cyclones from bed due to
  - High bed velocity, higher bed level, lower pressure, lower density catalyst
- High cyclone velocity (increased air rate, lower pressure etc.)
- High regenerator bed level
Catalyst Loss Troubleshooting – Examples

- Missing RO in torch oil nozzle steam purge line led to catalyst attrition due to high velocity steam jet
- Led to double the fines content in the ecat

- Refractory (turnaround repair) dropped from plenum roof and plugged a cyclone dipleg
- Led to losses to the main column (seen in the high slurry ash)

- Cyclone plenum crack (aged plenum) opened during the run following a thermal cycle due to a unit shutdown
- Led to gradual increase in losses
### Immediate actions
- Adjust operating conditions, reduce throughput slightly and observe effect on losses
- Check instrumentation, especially levels
- Conduct pressure bumping
- Try unloading / re-loading catalyst

### Longer term actions
- Maintain inventory with Ecat and Fines
- Recycle catalyst back from ESP / 3rd Stage separator
- If reactor side losses:
  - Expect erosion in slurry pumps, and monitor slurry pumparound for fouling.
  - Consider slurry recycle to reduce Fractionator Bottoms ash content
Handling Catalyst Losses: Attrition Problem

Immediate actions
- Review operating conditions
- Check potential attrition sources in the unit
- Check fresh catalyst properties

Longer term actions
- Reformulate to a more attrition resistant catalyst
- If the unit has an ESP, seek to reduce opacity with NH$_3$ injection, optimize gas inlet temperature, etc
- Consider settling aid chemicals if slurry ash content is high to improve tank settling
Appendix
Dipleg Pressure Balance

\[ P_{\text{hopper}} + \rho_{\text{Dipleg}} h_{\text{Dipleg}} = P_{\text{dilute}} + \rho_{\text{Bed}} h_{\text{Bed}} + \Delta P_{\text{Valve}} \]

\[ h_{\text{Dipleg}} = \frac{\Delta P_{\text{cyclone}} + \rho_{\text{Bed}} h_{\text{Bed}} + \Delta P_{\text{Valve}}}{\rho_{\text{Dipleg}}} \]

Note: \( h_{\text{bed}} \) and \( h_{\text{dipleg}} \) are relative to the dipleg bottom

The above equation highlights some potential causes of dipleg flooding:

- Cyclone \( \Delta P \) (high velocity)
- High bed level
- Dipleg valve \( \Delta P \), i.e. opening is restricted