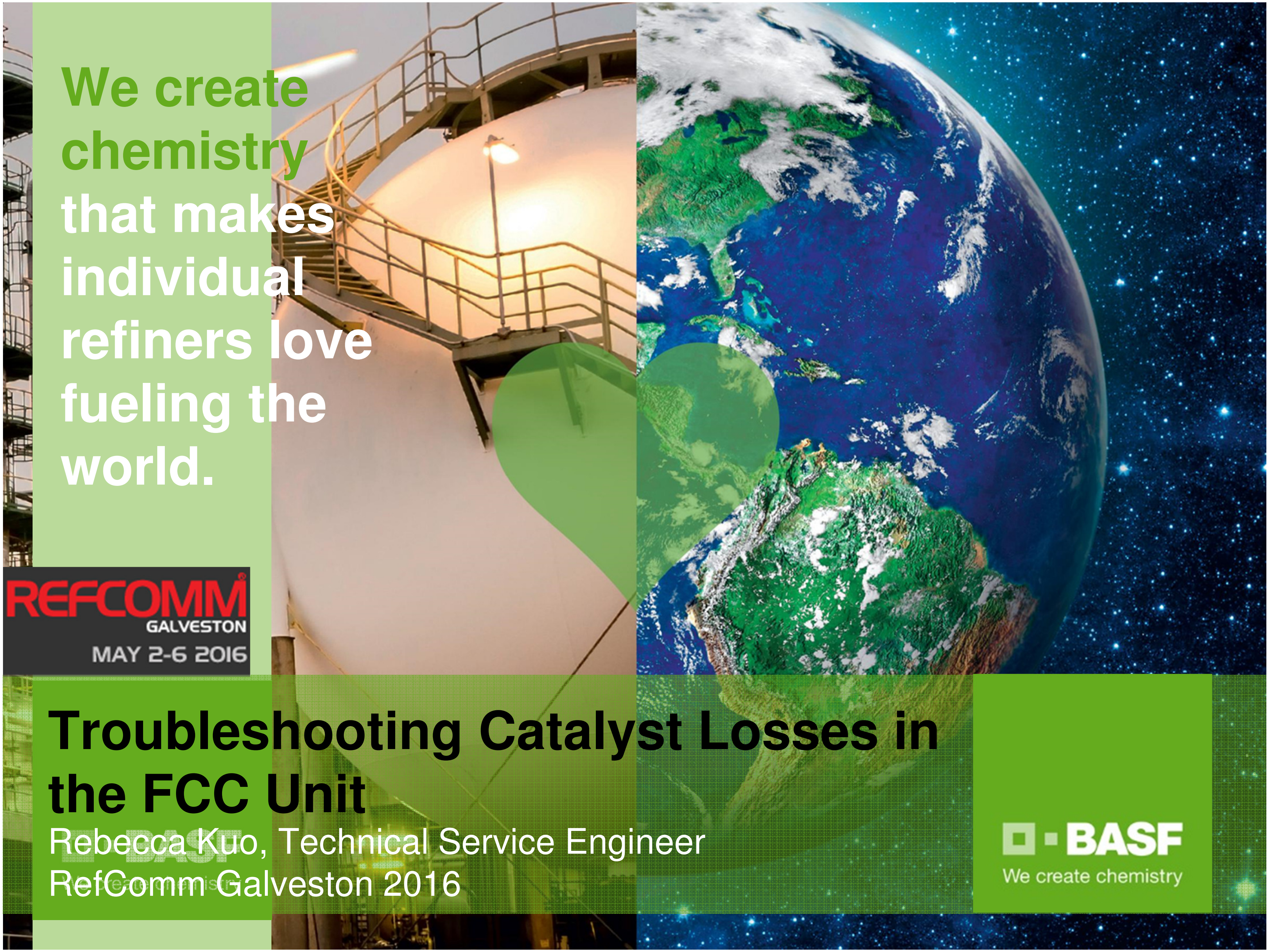

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REFCOMM GALVESTON
MAY 2-6 2016

Troubleshooting Catalyst Losses in the FCC Unit

Rebecca Kuo, Technical Service Engineer
RefComm Galveston 2016

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Overview

- Introduction
- Cyclone Fundamentals
- Catalyst Attrition
- Monitoring and Troubleshooting Catalyst Losses
- Handling High Catalyst Losses
- Questions

Introduction

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- 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

Cyclone Fundamentals

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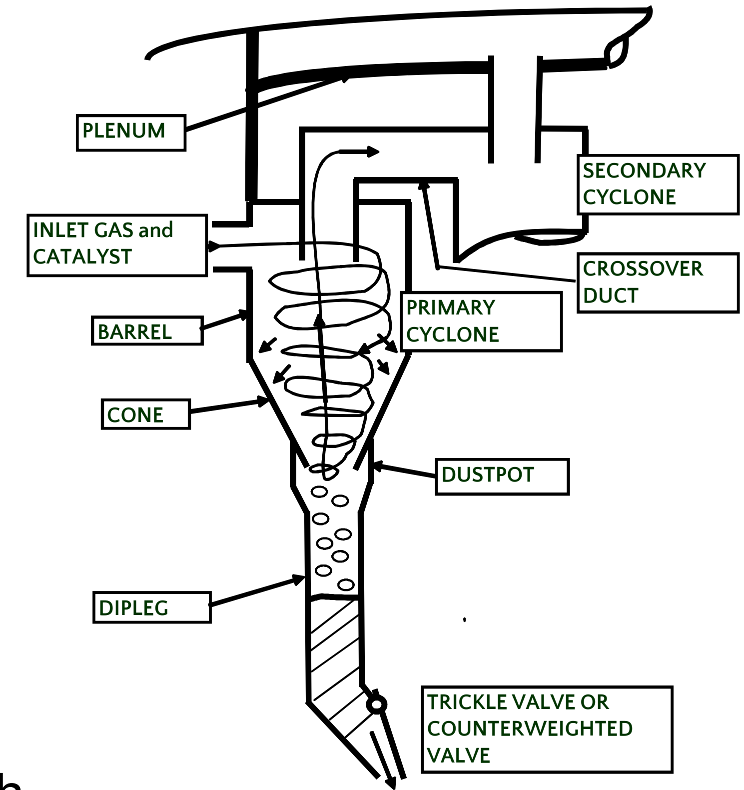
- Cyclones use centrifugal force to separate catalyst particles from the gas
  - The particles are forced to the walls of the cyclone and fall into the dipleg
  - The gas accelerates to the outlet tube at the top of the cyclone
- The recovery efficiency of a conventional two-stage cyclone system is very 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 <u>total loss of 2.2 tons per day</u>!



Cyclone Operation

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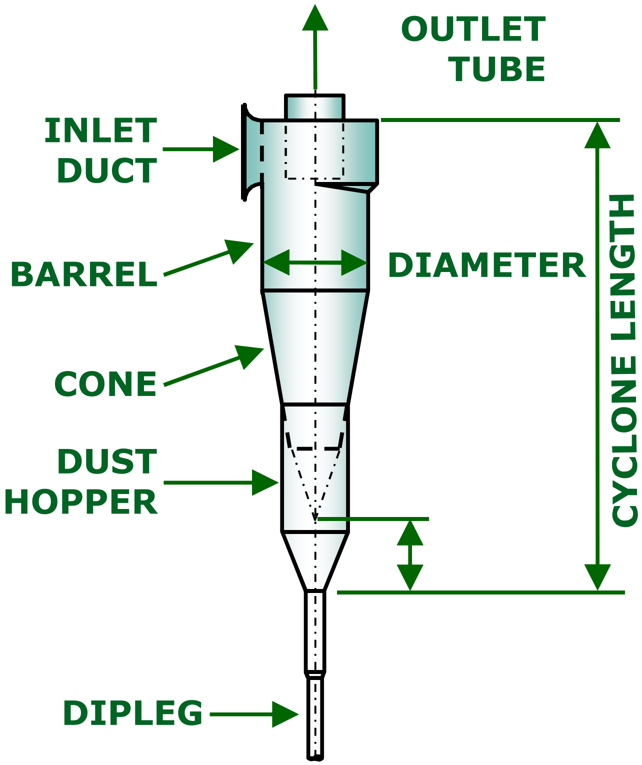
- Velocity is a key operating parameter for cyclone performance:
  - Collection efficiency increases with velocity and then drops off due to catalyst re-entrainment
  - Catalyst attrition to micro-fines occurs within cyclones and increases with velocity
- The overall cyclone collection efficiency depends 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?

Primary Cyclones	Maximum
Inlet Velocity	65 ft/s
Outlet Velocity	150 ft/s
Operating Temperature (304H SS)	1400 °F
Dipleg Mass Flux	150 $lb/ft^2.s$
Secondary Cyclones	**Maximum**
Inlet Velocity	75 ft/s
Outlet Velocity	175 ft/s
Dipleg Mass Flux	40 $lb/ft^2.s$

- 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

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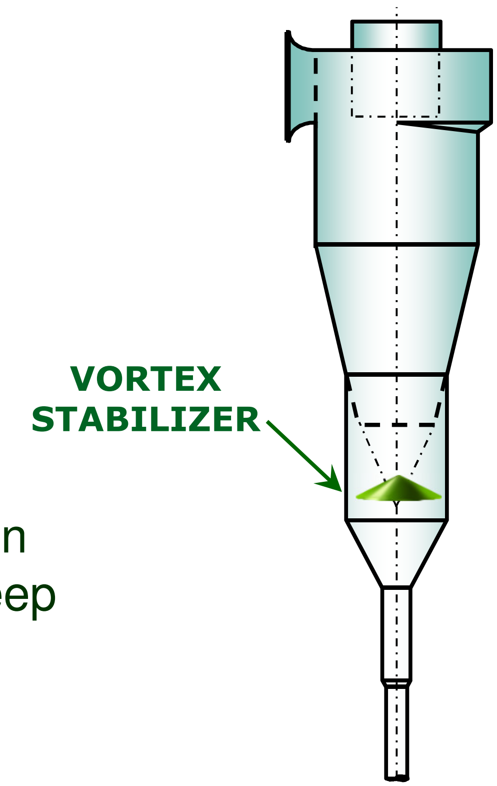
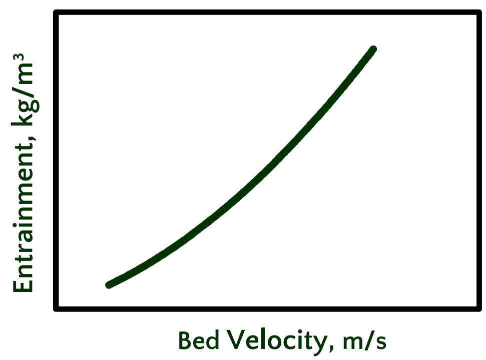
Well designed cyclones may have a service life of 20 years or more

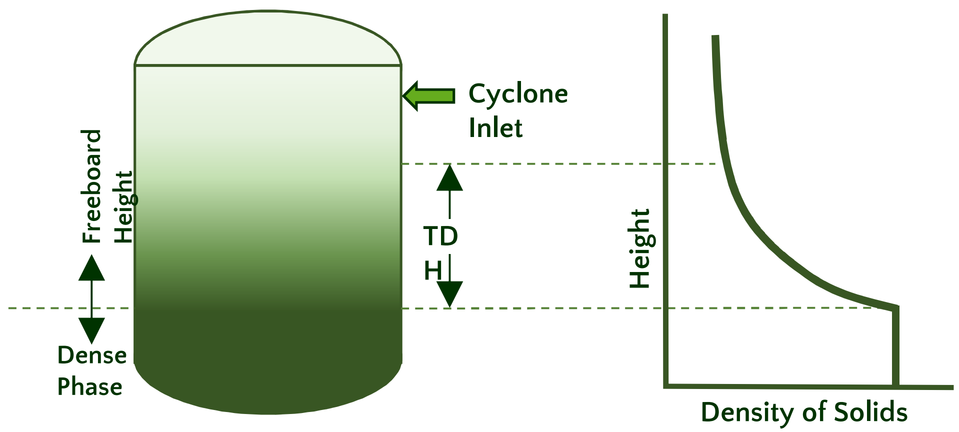
- Minimize erosion by:
  - Increasing cyclone length (min L/D of 4)
  - Design to avoid excessive velocities
  - Add a ***vortex stabilizer*** to secondary cyclones
- Ensuring good inspection and maintenance of refractory during each turnaround
- Control afterburn with CO Promoter and ensure even distribution 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

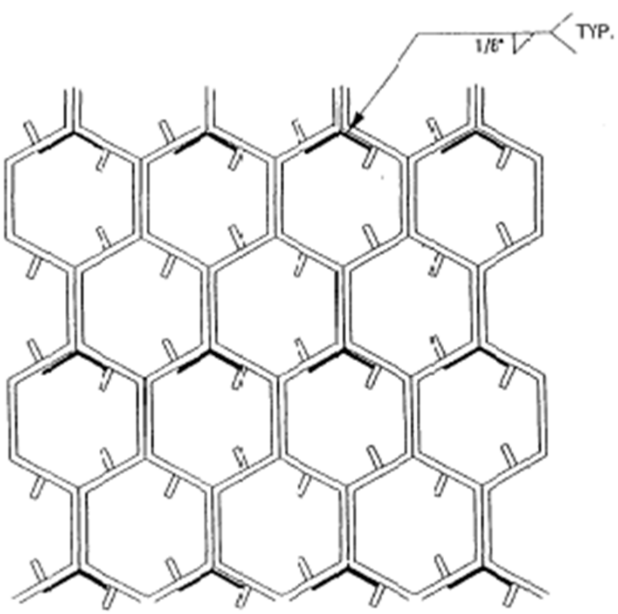
- **Cyclone efficiency increases <u>BUT</u> catalyst losses also increase as catalyst loading increases to the cyclones:**
  - **Reactor:** increases with catalyst circulation rate
  - **Regenerator:** entrainment from the bed increases with ***superficial velocity***, and also higher dense bed level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



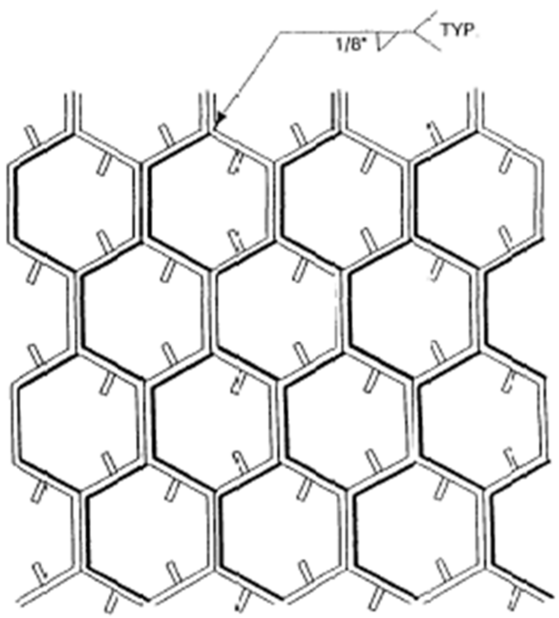


Refractory Lining

- 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



Coking Service

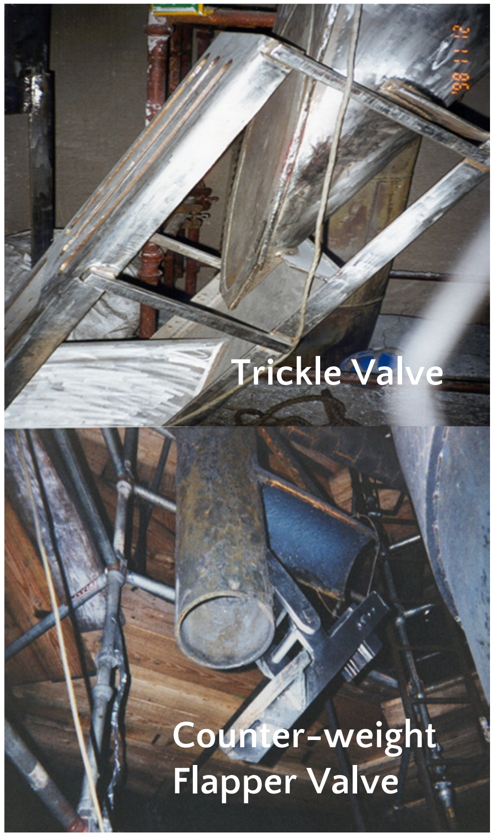
Common Cyclone Problems: Dipleg Malfunction

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

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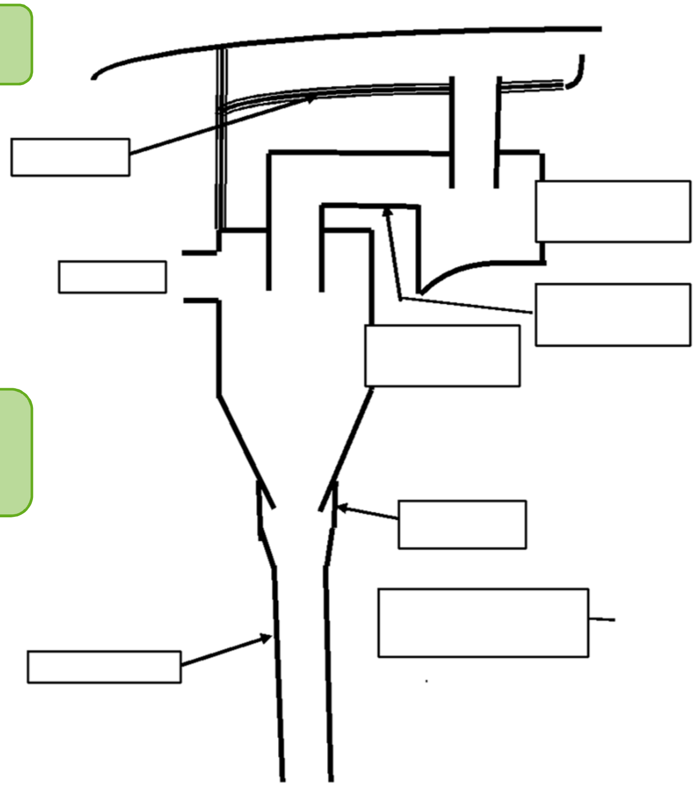
Holes in the cyclone system can occur due to:

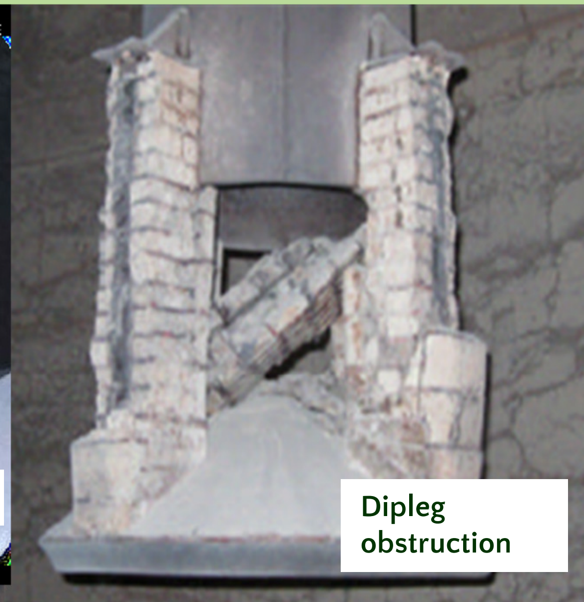
- Catalyst erosion of refractory/metal from high velocities. Erosion rate proportional velocity to the power of 3 to 5.
- Thermal cycling when unit shuts down/restarts – may cause cracks in the plenum head, allowing catalyst to directly bypass from the dilute phase.

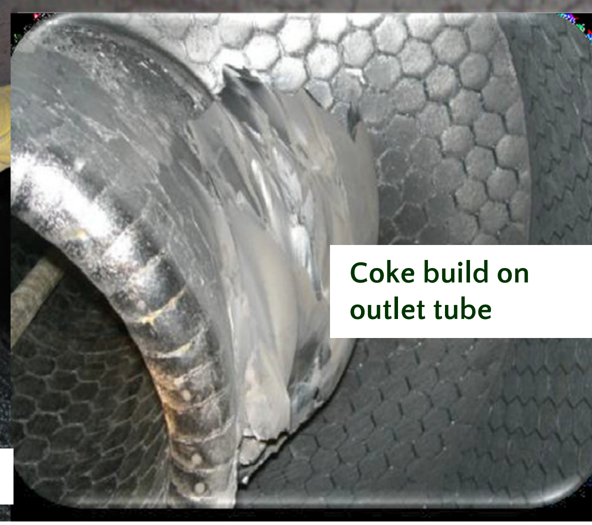
Holes can result in gas leakage and disruption of cyclone operation

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



Mechanical Problems





Reactor Cyclone Coking

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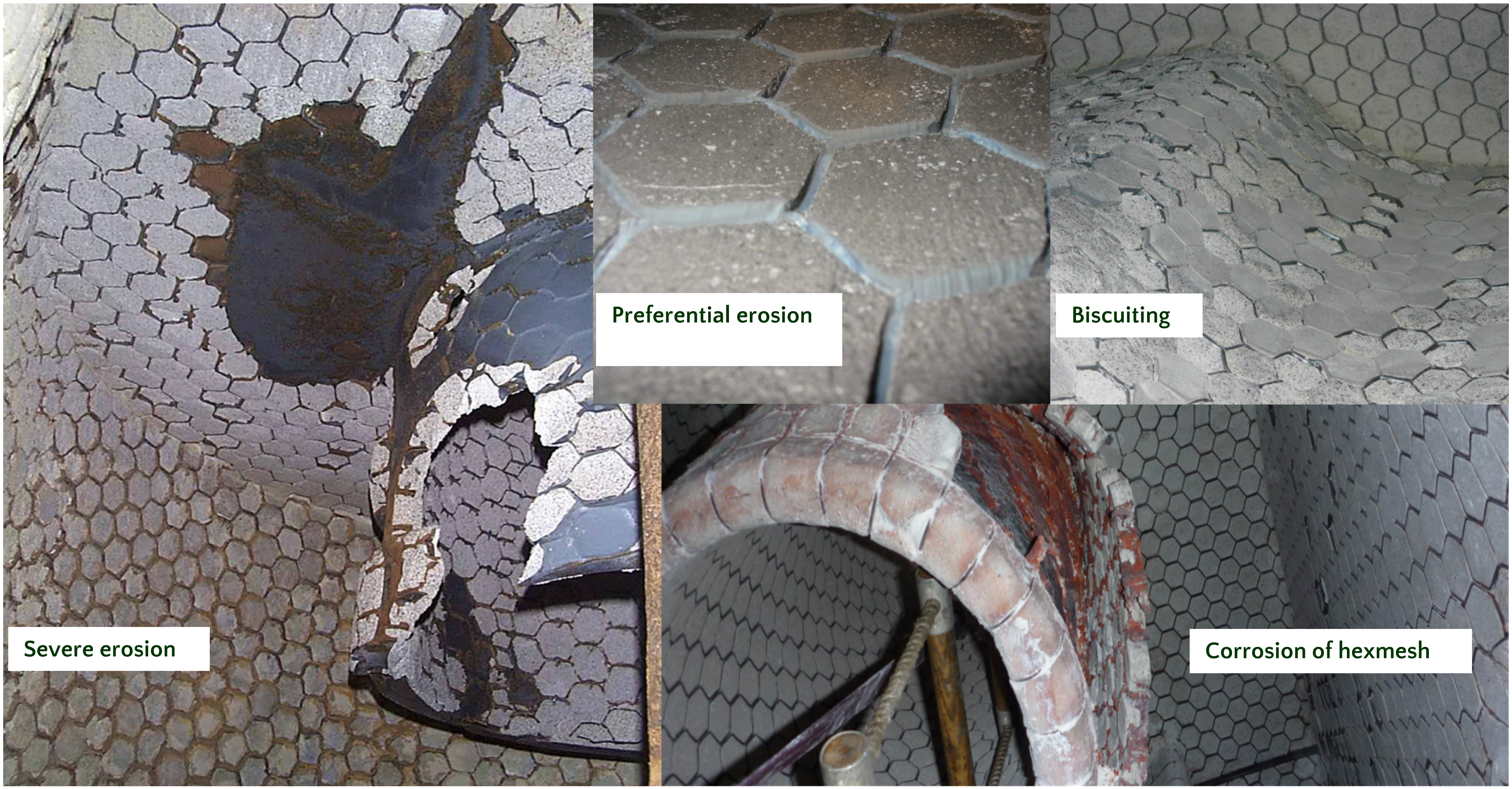
- Coke will accumulate and grow in cracks and crevices in the refractory, pushing the refractory away from the metal.
- Hex mesh anchors in the reactor should be fully welded along each seam, and any cracks should be properly repaired during turnarounds.
- Coke will often deposit on the outside of reactor 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

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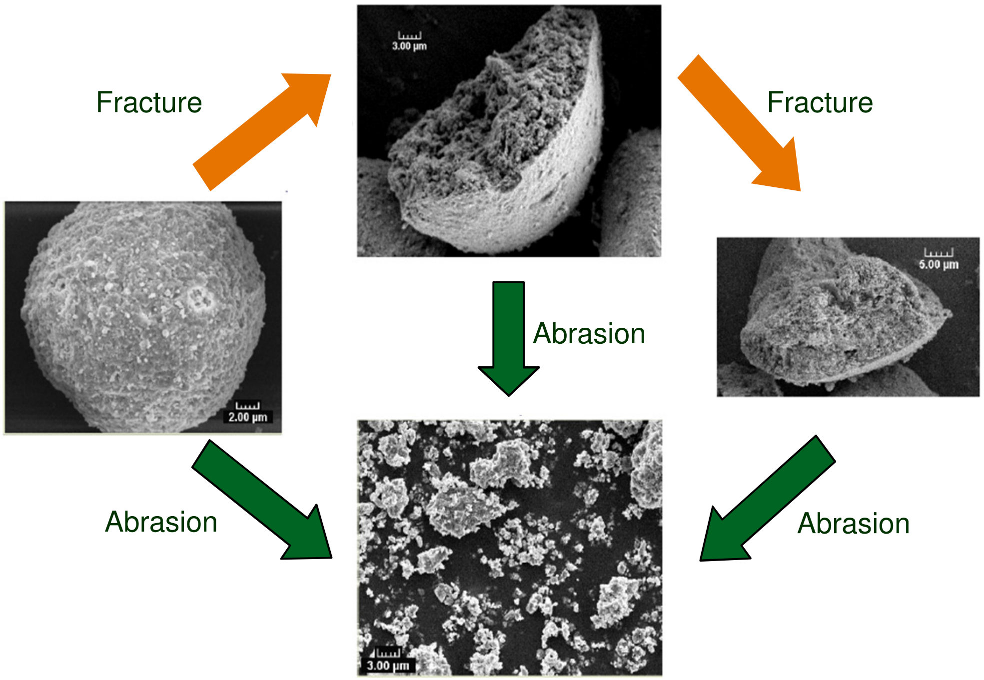
Catalyst breaks into smaller particles by fracturing and abrasion

- 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


Eroded Steam Nozzle

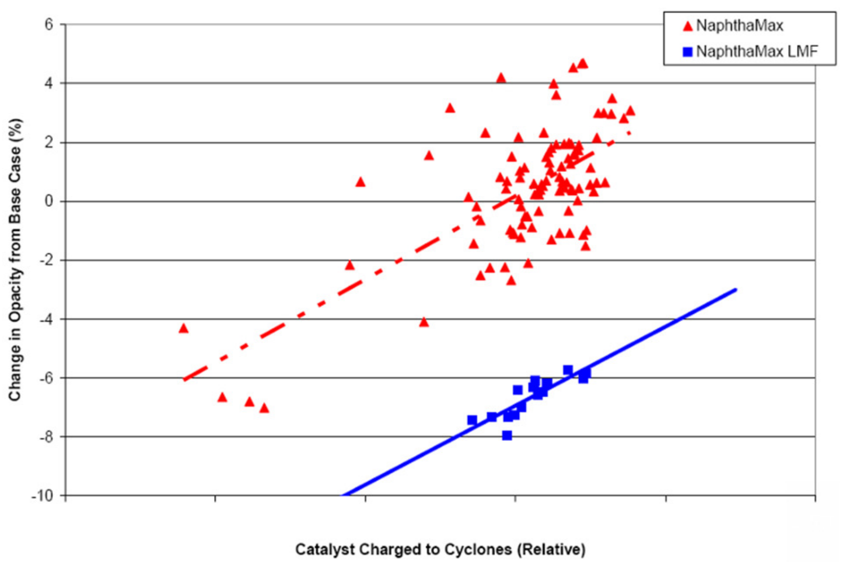
Catalyst Attrition Properties

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

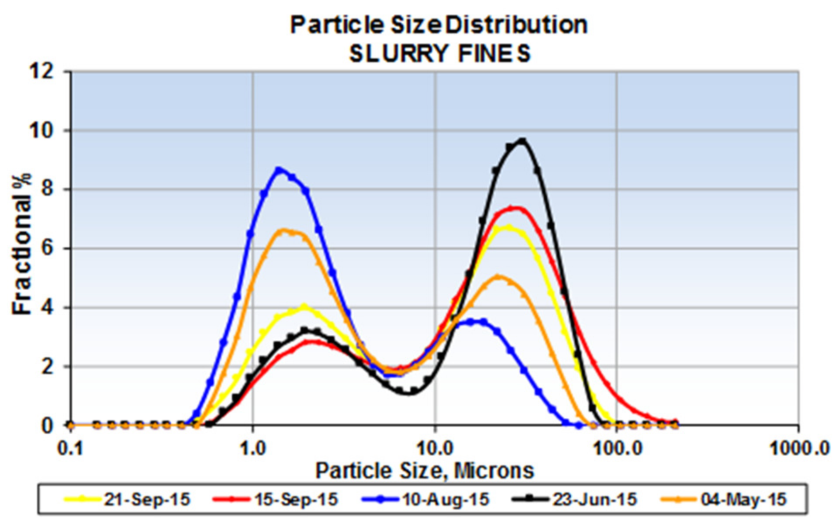
- Good base line monitoring is essential

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.



Catalyst Balance

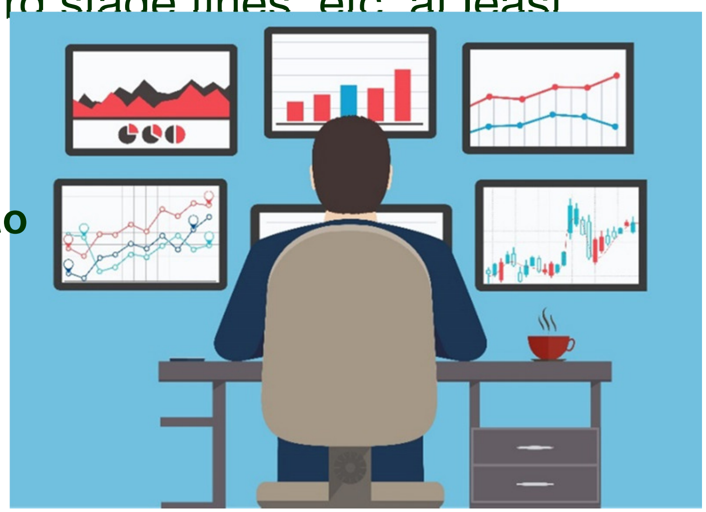
- A best practice is to calculate the catalyst mass balance every month

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

Catalyst Loss Monitoring

- **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

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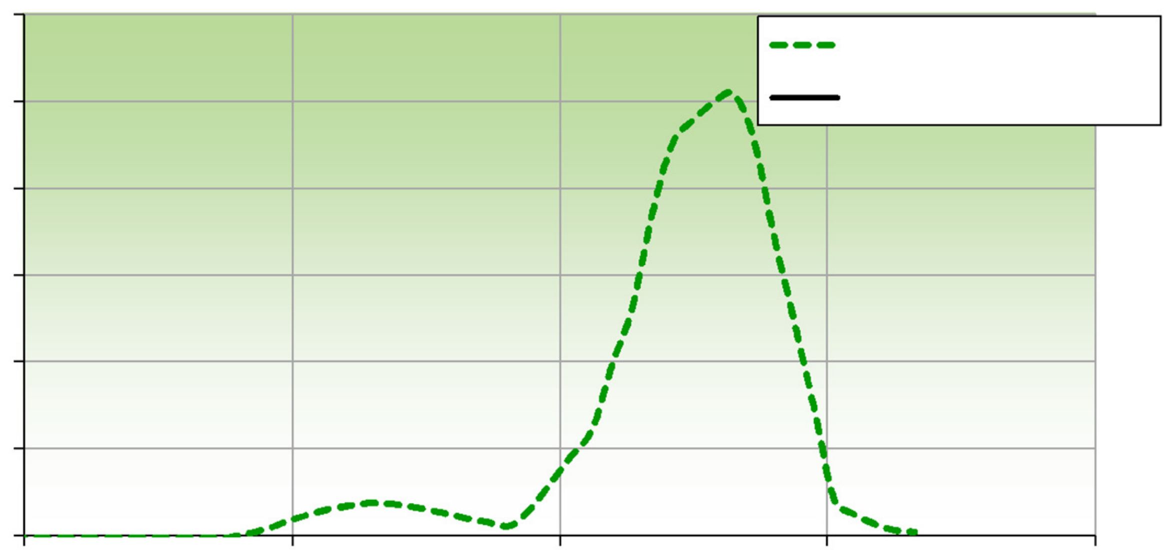
Fines analysis is the most useful source of data for identifying the type of loss problem!

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

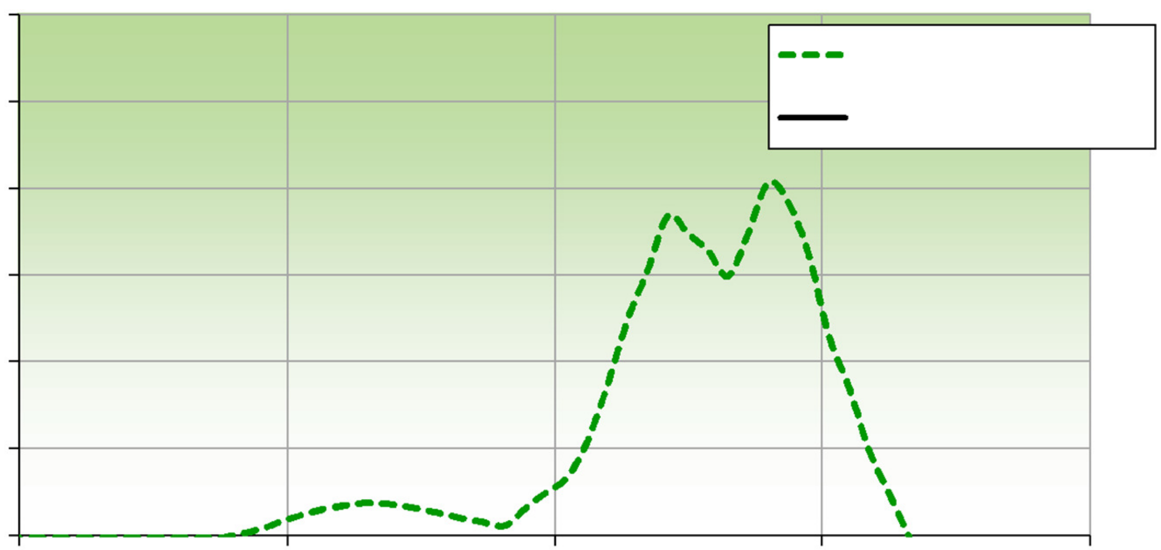
Fines analysis is the most useful source of data for identifying the type of loss problem!

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.

PSD of losses (Slurry Fines, 3rd Stage Fines, ESP):



Catalyst Loss Troubleshooting: Identifying the Problem

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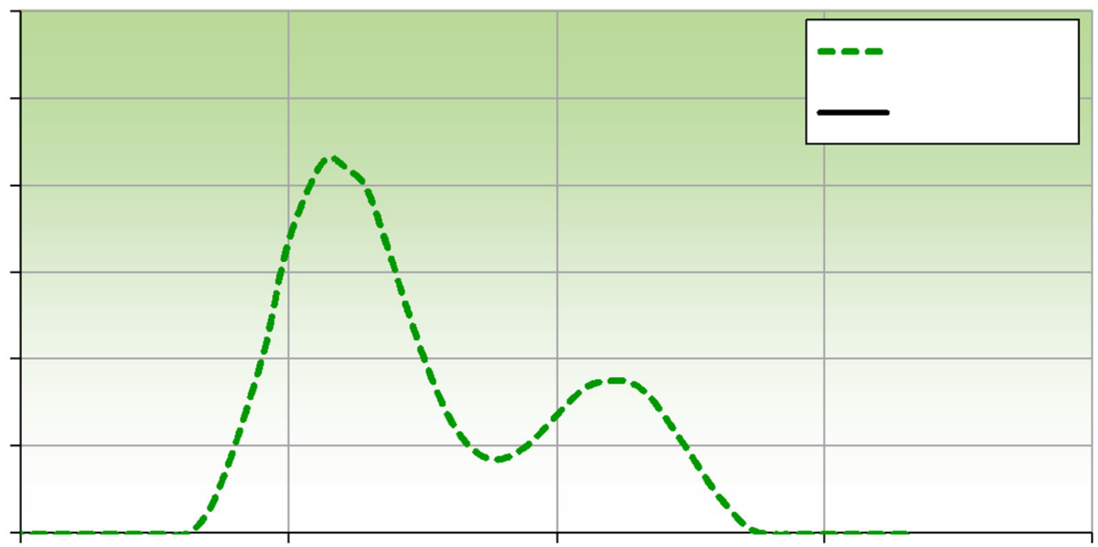
Fines analysis is the most useful source of data for identifying the type of loss problem!

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

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- **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:

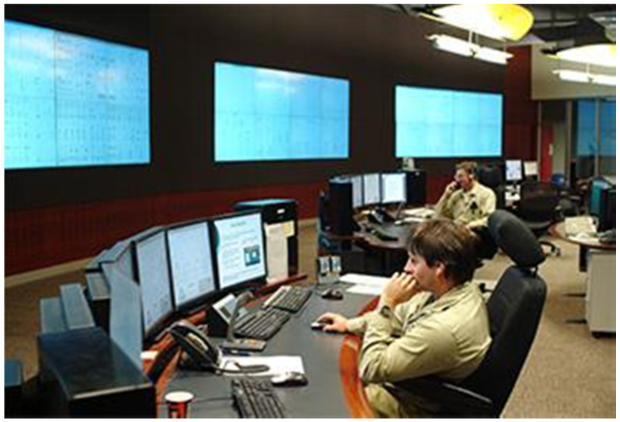
- Sudden vessel pressure loss
- Regenerator bed de-fluidization due to low air rate
- Capacity creep

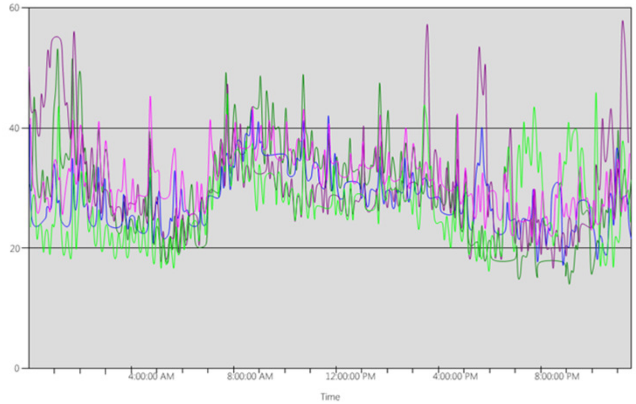
Reactor cyclone flooding may be caused by:

- 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

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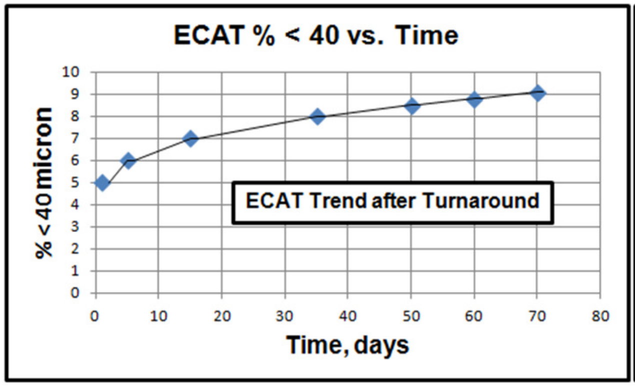

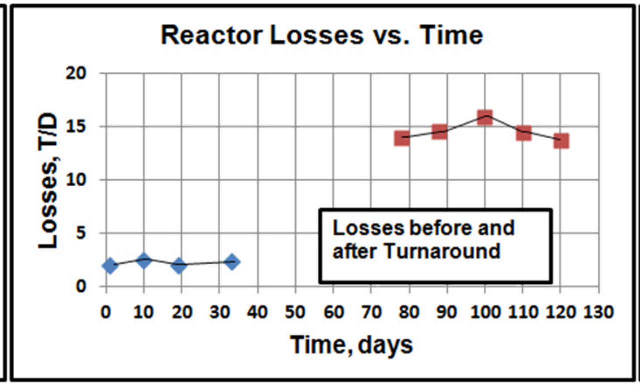

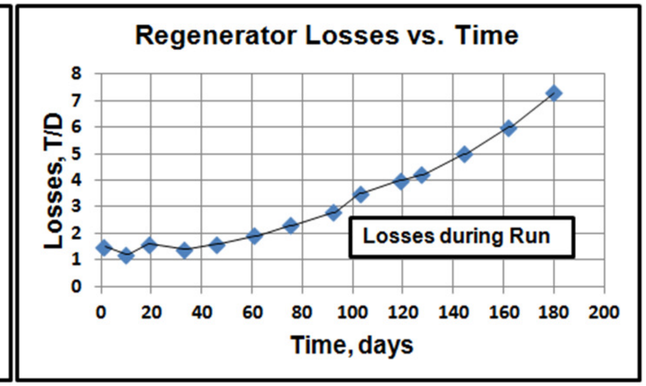

- Missing RO in torch oil nozzle steam purge line led to catalyst attrition due to high velocity steam jet
- Led to double the fines content in the ecat

- 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

Handling Catalyst Losses: Mechanical Problem

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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

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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

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Appendix

Dipleg Pressure Balance

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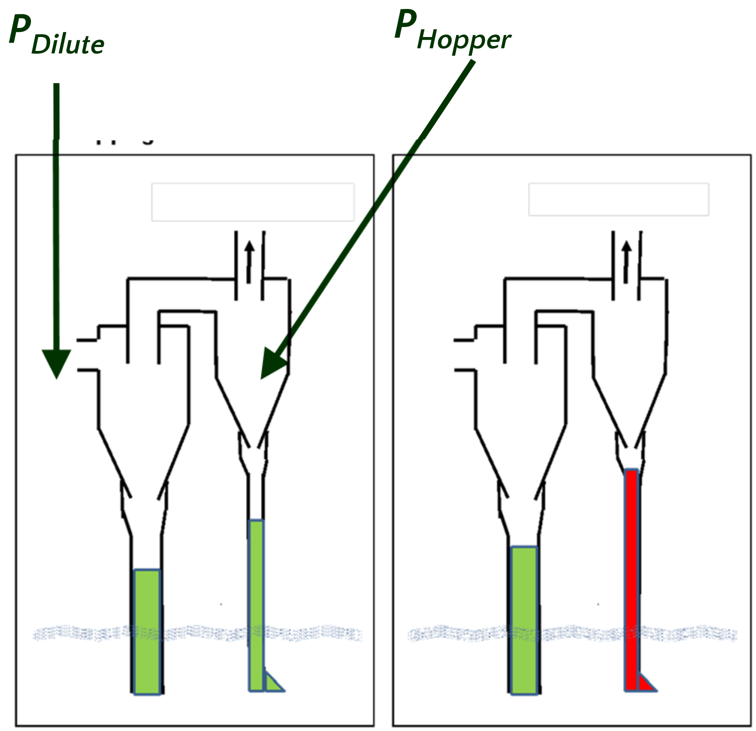

$$P_{hopper} + \rho_{Dipleg} h_{Dipleg} = P_{dilute} + \rho_{Bed} h_{Bed} + \Delta P_{Valve}$$

$$h_{Dipleg} = \frac{\Delta P_{cyclone} + \rho_{Bed} h_{Bed} + \Delta P_{Valve}}{\rho_{Dipleg}}$$

Note: h_{bed} and h_{dipleg} are relative to the dipleg bottom

The above equation highlights some potential causes of dipleg flooding:

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