FCC Regenerator Design to Minimize Catalyst Deactivation and Emissions

Steve Tragesser
Shaw Energy and Chemicals Group
Shaw Stone & Webster FCCs

42 RFCC/FCC/DCC Units Licensed

- Resid RFCCs (R2R)
- Other FCC/DCCs (R1R)
Regenerator Design Objectives

- Effective regeneration of catalyst
- Minimum catalyst deactivation
- Efficient use of available air blower capacity
- Minimum damage to equipment
- Minimum toxic emissions
Typical Regenerator Designs

Counter-Current Regeneration

Co-Current Regeneration
Typical Co-Current Regenerator

Reactors

Spent catalyst

Air
Typical Counter-Current Regenerator

- Reactor
- Regenerator
- Spent catalyst
- Air
Afterburn

Burning of CO Above the Regenerator Bed

1. Can occur in dilute phase, cyclones, plenum chamber and/or flue gas line
2. Temperatures can damage regenerator internals
3. Can be limiting temperature in regenerator
Spent Catalyst Distribution
Spent Catalyst Without Distributor
Elimination of Serious Afterburn Problems

**Principle Causes**
- Spent Catalyst Distribution
- Air Distribution
- Shallow Bed

**Solutions**
- Distribute Spent Catalyst Across Bed
- Minimum Bed Height (3 – 5 meters)
- Air Distribution
  - Multiple Rings
  - Pipe Grids
Spent Catalyst Distribution

Poor catalyst distribution

High coke concentration

Even catalyst distribution

Side Entry Regenerator
No Distributor

Axens/Stone & Webster Distributor
Bathtub Spent Cat Distributor
Bathtub for Counter-current Regeneration and Low NOx
Spent Catalyst Distributor
Bathtub Spent Cat Distributor
Bathtub CFD Modeling
Combustion Air Ring

- Refractory Lining
- Tee Inlet
- Hinged Supports
- Refractory Lining

Cross Section of Ring

Cross Section of Tee
Air Ring Installation
Air Ring Nozzle Layout
Two Stage Regeneration – The Key to Resid Processing

Why Two Stages for Resid?

• Heat balance control for high concarbon feeds
• Minimizes catalyst deactivation for severe regeneration required
  – Lower average catalyst particle temperature
  – Less hydrothermal deactivation
  – Less vanadic acid deactivation
Two Stage Regeneration Concept

1. First stage regenerator design
   - Countercurrent Regeneration
   - Heat Removal Via CO Production (partial burn)

2. Second stage regenerator design
   - Complete combustion
   - Minimum moisture
Catalyst Cooler
R2R with Catalyst Cooler

SRC Singapore

Catalyst Cooler
Regenerator Emissions

- Particulates
- CO
- SOx
- NOx
Primary Causes of Particulate Losses

- Catalyst Attrition
  - Fracture
  - Abrasion
- Cyclone Design
- High Superficial Velocities
- Damaged Equipment
  - Air Distributor
  - Cyclone System
- Operation
  - Bed Level
  - High Velocity Nozzles
Final Particulate Removal Options

- 3rd stage cyclonic separation (80 mg/Nm³)
- 3rd stage cyclonic separation with 4th stage underflow filter (50 mg/Nm³)
- Wet gas scrubbing (10 to 20 mg/Nm³)
- Electrostatic precipitation (10 mg/Nm³)
- Physical filtration (less than 10 mg/Nm³)
BP Kwinana Flue Gas Filter

Tubesheet Installation

Overview Pictures courtesy of Pall
SOx Strategies

- Minimize Coke Yield (Reaction technology)
- Use Desox additive to control small amounts SOx
- Use scrubber to control large amounts SOx
- Avoid Recycle of heavy streams
Wet Gas Scrubbing for SO$_x$ Removal

Belco®'s EDV Wet Gas Scrubber
<table>
<thead>
<tr>
<th>Variables</th>
<th>Effect on SOx Additive Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Stock Type</td>
<td>Level and type of sulfur in feed</td>
</tr>
<tr>
<td>Recycle streams</td>
<td>Usually heavy coke-sulfur forming</td>
</tr>
<tr>
<td>Fresh Catalyst</td>
<td>Higher alumina improves SOx efficiency</td>
</tr>
<tr>
<td>Equilibrium Catalyst</td>
<td>Activity and additives present (SOx &amp; CO)</td>
</tr>
<tr>
<td>Circulation Rate</td>
<td>Higher rate improves efficiency</td>
</tr>
<tr>
<td>Regenerator Inventory</td>
<td>Larger inventories reduce efficiency</td>
</tr>
<tr>
<td>Regenerator Operation</td>
<td>Increasing excess O₂ improves efficiency</td>
</tr>
<tr>
<td>Regenerator Temp.</td>
<td>Increase favors SO₂ oxidation, hinders SO₃ absorption</td>
</tr>
<tr>
<td>Reactor Temperature</td>
<td>Higher temp. favors reduction of sulfates to H₂S</td>
</tr>
<tr>
<td>CO Promoter Usage</td>
<td>Increasing CO promoter improves efficiency</td>
</tr>
<tr>
<td>Additive Addition</td>
<td>Near-continuous addition improves efficiency</td>
</tr>
<tr>
<td>Stripper Operation</td>
<td>Poor stripping will increase SOx</td>
</tr>
</tbody>
</table>
NOx Control

- Very complex
- Related to feed nitrogen, not combustion air
- High platinum CO promoter & excess oxygen amplifies NOx
- Much of NOx is reduced to $N_2$ or leaves as NH3, HCN, etc. (70 – 95%)
Comparison of NOx Emissions in Commercial FCC Regenerators

% N in Coke to NOx

Excess Oxygen in Flue Gas

- Counter-Current (Swirl)
- Counter-Current (Bathtub)
Optimum Regenerator Design

- Turbulent bed
- Countercurrent regeneration
- Minimum excess oxygen
- Spent catalyst distributed across entire bed
- Minimum gas residence time of 4 seconds
Thank You

The Shaw Group Inc.