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Outline

- SCR System Basics
- Catalyst Designs
- Catalyst Deactivation
- Regeneration Basics
- Catalyst Testing
- Regeneration vs New
- Gas Catalyst Regeneration Sample Results
- Economics
Selective Catalytic Reduction (SCR) is the process of removing NOx (NO and NO₂) out of the flue gas stream by injecting ammonia (NH₃) into the flue gas as a reagent.

The flue gas passes over a fixed bed of catalyst installed in a reactor.

Ammonia reacts with nitrous oxides on the catalyst surface to form safe and clean nitrogen and water.

\[
\begin{align*}
4\text{NO} + 4\text{NH}_3 + \text{O}_2 & \rightarrow 4\text{N}_2 + 6\text{H}_2\text{O} \\
2\text{NO} + 2\text{NO}_2 + 4\text{NH}_3 & \rightarrow 4\text{N}_2 + 6\text{H}_2\text{O}
\end{align*}
\]
Typical SCR System Design
SCR Catalyst – Combined & Simple cycle

- Designed to reduce NOx from engine exhaust
- >90% Reduction typical
- Ammonia (NH₃) Slip typically 5-10 ppm
- Performance of new catalyst will slowly degrade over time...”Deactivation”
## SCR Catalyst Types

<table>
<thead>
<tr>
<th>Plate</th>
<th>Honeycomb</th>
<th>Corrugated</th>
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</thead>
<tbody>
<tr>
<td>Metal carrier, surface coated with active ingredients</td>
<td>Extruded homogeneous</td>
<td>Glass fiber carrier, surface coated with active ingredients</td>
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</table>
SCR Catalyst Deactivation

- Catalyst deactivation over time will reduce performance
  - With natural gas fuel, deactivation rate is low (catalyst deactivates very slowly)
- SCR Catalyst deactivation is caused by several mechanisms...
  - Poisons such as phosphorous, sulfur, silica, etc.
  - Fouling
  - Sintering (support and active metal)
- Poisoning in Combined Cycle units is rare
- Most mechanisms are reversible, except for support sintering (causes permanent catalyst pore structure damage)
SCR Catalyst Sintering

- Catalyst sintering due to exposure to high temperatures
  - Depending on the catalyst type, sintering could take place >875°F
- Combined Cycle units won’t normally experience high temperatures due to heat recovery upstream of SCR
- Active metal sintering is a slow process and occurs at normal temps

501F GT with N-E HRSG
SCR Catalyst Sintering

- For Simple Cycle Units, sintering is a significant concern if catalyst not properly designed for operating temperatures
- Example below shows activity testing of Simple Cycle catalyst that was eventually replaced...
SCR Catalyst Fouling

- Catalyst Fouling can result in significant drop in performance
  - Increased Pressure Drop
  - Poor NOx Reduction
  - High Ammonia Slip & Increased Ammonia Consumption
- Periodic Inspections recommended
- Cleaning can reverse the impacts
  - In-Depth cleaning may be required
SCR Catalyst Element & Seal Damage
SCR Catalyst Deactivation

Signs of Catalyst Deactivation...

- Ammonia Flow Increase. Trend ammonia flow to understand performance.
- Increased ammonia flow will continue to the point where stack ammonia slip is exceeded or NOx becomes difficult to control.
- Periodic testing is strongly recommended.
SCR Catalyst Deactivation

- Catalyst deactivation over time will be gradual (with natural gas), unless there is an unusual event, or poisoning or sintering takes place.

- Catalyst sample testing is critical.
SCR Catalyst Performance Recovery

If catalyst reaches the end of its life, either by poisoning or general deactivation, there are two main options to regain performance:

- Regeneration
- Replacement
SCR Catalyst Regeneration Experience (Coal)

- Regeneration Experience by Installed Base:
  - 81,000 Regen. Modules Vs 125,000 Installed
  - 35% Regenerated Modules, 65% Current Installed Base

- Regeneration Experience by Catalyst Type:
  - Honeycomb: 45%
  - Plate: 11%
  - Corrugated: 44%

- Regeneration Experience by Utilities:
  - 51 of 65 Utilities
  - 22% Have Regenerated, 78% Have Not Regenerated

- Regeneration Experience by Installed Mw:
  - 133,000 Mw of 148,000 Mw
  - 10% Have Regenerated, 90% Have Not Regenerated
SCR Catalyst Regeneration

Catalyst Regeneration is the process of bringing the performance of the catalyst elements back to that of new catalyst. The process includes...

- Cleaning to remove fly ash (from coal fired power generators) and other particles that cause plugging.
- Soaking in a series of chemical baths to remove deposits and other poisons that reduce performance. Active metal is also removed
- Impregnation to add active metal back to restore full catalyst activity level.
- Heat treatment or re-calcination to re-establish mechanical strength and converting the active metal to the oxide form.
- Test samples of regenerated catalyst
SCR Catalyst Regeneration
SCR Catalyst Regeneration

- $V_2O_5$ is the primary material impregnated on the original catalyst.

- Natural gas catalyst has much higher levels of Vanadium as $SO_2$ oxidation is not limiting

- If the pore structure of the base catalyst is damaged by sintering, then regeneration is usually not possible
  
    - Sample testing will determine if catalyst can be regenerated and what performance can be achieved
SCR Catalyst Testing – Bench Reactor

- Bench testing utilizes full-size elements
  - Not “core” sample or micro reactor tests
- Bench testing more accurately represents gas conditions
SCR Catalyst Testing – Bench Reactor

Bench testing utilizes full-size elements
SCR Catalyst Testing

EPRI has a test procedure...
SCR Catalyst Testing

Testing will provide determination of the catalyst activity...

![DeNOx Activity Ratio vs Operating Time Graph]
SCR Catalyst Testing

Testing will show when it’s time to replace the catalyst...
SCR Catalyst Regeneration vs New Catalyst

- Generally speaking, regenerated catalyst can be restored to original catalyst’s performance
- Regeneration can change the original catalyst formulation to better meet plant operating conditions
- Good News... The regeneration evaluation process has greatly improved (minimizes surprises)
SCR Catalyst Regeneration Example

- Two (2) catalyst modules in a Baseload GE 7FA turbine HRSG were removed and regenerated.
- Samples were tested for 4 years in order to determine deactivation of catalyst.
After 4 years, no deactivation has been observed.

![Graph showing SCR Catalyst Regeneration Example](image)

**Regenerated Catalyst Performance**

- **Activity, K**
  - X-axis: Time (hours)
  - Y-axis: Activity, K

**Legend**
- Blue diamonds: Regenerated
e- Red square: Deactivated Catalyst (Before Regen)

Minimum Required (Horizontal line at 50 units on the Y-axis)
SCR Catalyst Regeneration vs New Catalyst

Drivers for Selecting to Regenerate Catalyst...

- Short turnaround time (Express or “Hot” Regen)
  - Used catalyst can be regenerated in 1-2 weeks, depending on location
  - New catalyst manufacturing cycle > 4 months

- Multiple Identical Units (can utilize a “seed” layer)
SCR Catalyst Regeneration vs New Catalyst

Drivers for Selecting New Catalyst...

- Can be customized for conditions
- Designed to Fit into ANY HRSG*

* HRSG designs can vary greatly, therefore modules must be 100% interchangeable for Regeneration to make sense.
SCR Catalyst Regeneration Limitations

Two Catalyst Beds, both for 7FA HRSG’s

- Coal units have a standard module footprint, so interchanging modules between different reactors and plants is very common.
- Interchanging catalyst modules between non-identical HRSG units not possible.
  - Catalyst modules specifically for each HRSG.

<table>
<thead>
<tr>
<th>20’W x 65’H</th>
<th>36’W x 67’H</th>
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<tbody>
<tr>
<td>84 Blocks</td>
<td>50 Blocks</td>
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SCR Catalyst Regeneration - Economics

Sample Project – Frame 7FA HRSG SCR

- 9 ppm inlet NOx
- 2.5 ppm outlet NOx
- 5 ppm NH₃ Slip
- Catalyst Removal & Installation Costs Assumed Equal for New and Regenerated

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
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<tbody>
<tr>
<td>New Catalyst Cost</td>
<td>$250,000</td>
</tr>
<tr>
<td>Cost Factor for Regeneration</td>
<td>60%</td>
</tr>
<tr>
<td>Regeneration Cost</td>
<td>$150,000</td>
</tr>
<tr>
<td>Savings</td>
<td>$100,000</td>
</tr>
</tbody>
</table>
SCR Catalyst Regeneration - Economics

Factors to Consider

• Compare Guarantees
• Condition of old Catalyst...wise to regenerate?
• Test regeneration on sample should be conducted prior to outage to establish regeneration process.
• Compare multiple new catalyst bids to regenerated catalyst...not just OEM
• Disposal cost for old catalyst?
SCR Catalyst Regeneration - Economics

Summary

✓ Regeneration has proven success from coal industry

☐ Gas catalyst regeneration is very simple compared to coal
  • No plugging or physical damage
  • Generally no plugging or physical damage
  • Lower poison levels
  • SO₂ conversion is not critical

✓ Catalyst testing is strongly recommended to provided assurance that it can be done successfully

✓ Gas catalyst regeneration has shown to be successful, but data is limited

✓ Economic evaluation is critical since it’s very case-specific
Acknowlegdements

- Cormetech, Inc. (formerly Steag SCR-Tech)
QUESTIONS ??