Fundamentals of SCR

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Outline

- NOx
- SCR System Basics
- Catalyst Designs
- Ammonia Systems
- Ammonia Injection Grid (AIG)
- Flow Modeling
- Testing & Troubleshooting
What is NOx?

- Nitrogen, one of the earth’s most abundant elements, is essential for life on earth. It is an important plant nutrient and a key building block of proteins.
- The burning of fossil fuels is one of the major atmospheric sources of nitrogen. Combustion of fuels at high temperatures converts the elemental nitrogen in the air and fuel to nitrogen oxides (NOx).
- Emissions from power plants and mobile sources are the largest source of NOx in the US.
Why Do We Need to Reduce NOx?

- Nitrogen oxides are dangerous to breathe. When released from power plants or cars into nearby neighborhoods, they are associated with respiratory side effects such as asthma attacks.
- Ozone pollution (ground level ozone or smog) forms when NOx reacts with hydrocarbons in the presence of heat and sunlight. Ozone at ground level is linked with asthma attacks and even birth defects and also retards growth of trees and crops.
- Nitrogen oxides form small nitrate particles that are associated with serious health impacts like heart attacks and result in hazy skylines in our cities and national parks.
- Nitrogen oxides lead to pollution of soils, groundwater and estuaries.
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.

\[
4\text{NO} + 4\text{NH}_3 + \text{O}_2 \rightarrow 4\text{N}_2 + 6\text{H}_2\text{O} \\
2\text{NO} + 2\text{NO}_2 + 4\text{NH}_3 \rightarrow 4\text{N}_2 + 6\text{H}_2\text{O}
\]
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
# SCR Catalyst Types

<table>
<thead>
<tr>
<th>Plate</th>
<th>Honeycomb</th>
<th>Corrugated</th>
</tr>
</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>
</tr>
</tbody>
</table>
Catalyst typically located in HRSG where temperature is 550 - 750°F

501F GT with N-E HRSG
Ammonia Systems

Three Types of Reagents for SCR

- Anhydrous Ammonia
- Aqueous Ammonia
- Urea
Types of Reagents

Anhydrous
- NH$_3$
- Pres. Liquid
- BP = -28°F
- MP = -108°F

Aqueous
- NH$_4$OH
- Liquid
- BP = 97°F
- MP = -98°F

Urea
- (NH$_2$)$_2$CO
- Solid
- BP = NA
- MP = 270°F
Anhydrous Ammonia

- Pure (99.5%) NH$_3$
- Lowest Capital and Operating Cost
- Unloading and Storage Facility Requires RMP (Risk Management Plan) which can be costly to initiate and maintain
- Vaporization
  - Requires the least amount of energy for vaporization
  - Electric is commonly used
Anhydrous Ammonia – Storage & Forwarding
Anhydrous Ammonia – Storage & Forwarding
Aqueous Ammonia

- 19% to 29% (by weight) NH₃...the rest is water
- Higher capital and operating costs
  - Storing, forwarding and vaporizing large amounts of water
- Less stringent safety requirements
- Conventional Vaporization
  - Flue Gas Vaporization or Electric Vaporizers
Aqueous Ammonia Vaporizer – Typical Flow Diagram
Ammonia Flow Control Unit (AFCU)

From HRSG or Ambient Air
Urea to Ammonia Conversion

- Urea – a very safe material – is converted to NH₃, H₂O and CO₂ by a hydrolysis process
- Urea is usually delivered as a liquid solution
  - DEF...Diesel Exhaust Fluid (32.5% Urea)
- Urea Solution (NH₂CONH₂)
  - Clear, colorless or slightly hazy liquid
  - Light ammonia (pungent) odor
  - Non Flammable
  - Stable Material
- No shipping, handling, storage or transfer of ammonia
  - Used where SCR is in close proximity to residential areas
  - Easier public acceptance
Urea to Ammonia Conversion

Urea Storage → Ammonia on Demand (AOD) → 5% NH₃ Product Gas → SCR Injection
Urea to Ammonia Conversion
Direct Injection

Direct Aqueous or Urea Injection
Direct Injection

- Direct aqueous ammonia or urea injection utilizes dual fluid nozzles to introduce liquid and atomizing air into the turbine exhaust
- Uses the heat of the flue gas to vaporize the ammonia (or decompose urea to ammonia)
- Relies on turbulence at GT exhaust to blend NH₃ with NOx

Pros
- Does not require AIG or vaporizer
- Can be retrofit into compact HRSG designs

Cons
- Tuning of nozzles can be difficult or impossible
- Nozzles subject to extremely turbulent conditions...longevity and pluggage an issue
- Decomposition of urea to ammonia unpredictable. Lack of experience
Ammonia Injection Grid

- AIG used to distribute ammonia/air mixture into exhaust flue, upstream of SCR catalyst
- Located downstream of CO catalyst
  - Otherwise CO catalyst would oxidize ammonia and convert to NOx
- AIG designed so that it can be tuned
  - Tuning should not be necessary if the system is properly design and modeled
Ammonia Injection Grid - Tuning

- AIG tuning done via branches or zones, with control valves
- # of Zones dependent on size of flue and desired controllability
- Valves can be in centralized balancing header, or along side of HRSG
Ammonia Injection Grid - Lances

- Lances are typically SS or CS pipes with drilled holes
- Carbon steel piping not recommended...rust or scale can plug holes
Fluid Flow & CFD Modeling

- Poor flow distribution can have huge effect on system performance
- CFD or Physical modeling is an effective economical means to identify AND fix flow problems
- Poor flow, ammonia and temperature distribution can affect:
  1. CO performance
  2. SCR performance
    1. NOx reduction
    2. Ammonia Slip
    3. Ammonia Usage
CFD modeling should be used to design all new systems. It can be used to optimize existing systems to improve performance. An example below shows how significant improvements can be made to ammonia distribution, with a minimal increase in pressure drop.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Baseline AIG</th>
<th>Final (New) AIG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia Distribution</td>
<td>%RMS</td>
<td>70.2</td>
<td>5.8</td>
</tr>
<tr>
<td>Maximum Deviation from Avg.</td>
<td>%</td>
<td>+439</td>
<td>+13</td>
</tr>
<tr>
<td>Minimum Deviation from Avg.</td>
<td>%</td>
<td>-44</td>
<td>-21</td>
</tr>
<tr>
<td>Pressure Drop</td>
<td>in. w.c.</td>
<td>~0</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Testing & Troubleshooting

Signs of Poor Performance

- 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.

- Typical Causes
  - NH3/NOx Distribution,
  - Bypass
  - Catalyst Deactivation

![Testing at a repeatable temperature & flow rate](image)
AIG Tuning

- AIG should be designed with ability to tune as much as possible.
- Systems designed with no tuning capability have very limited flexibility to improve distribution.
- Adjustments to AIG can have significant benefit to performance.
SCR Sealing Systems

Inspections are a great method for identifying performance problems

- Check for Leaks - Gas Bypass is major contributor to performance problems
  - Seals between modules and along perimeter of reactor should be checked
## SCR Sealing Systems

<table>
<thead>
<tr>
<th>Test Date</th>
<th>Configuration</th>
<th>Ammonia Slip, ppmvd @ 15% O₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-16-12</td>
<td>Original Sealing System</td>
<td>6.8</td>
</tr>
<tr>
<td>9-6-12</td>
<td>With Modified Sealing/Gas Reinforcement System</td>
<td>2.0</td>
</tr>
</tbody>
</table>
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

Testing will provide determination of the catalyst activity...
SCR Catalyst Testing

Testing will show when it’s time to replace the catalyst...
CO Catalyst

- Designed to reduce CO from engine
- Simple reaction (no reagent required):
  \[ \text{O}_2 + 2\text{CO} \rightarrow 2\text{CO}_2 \]
- Made from stainless steel substrate with precious metals added (platinum)
- >90% Reduction typical
- Deactivation over time can dramatically reduce performance
CO Catalyst Sampling

- Should be tested when performance problems develop
- Annual testing can identify problems before problems develop
CO Catalyst Deactivation

- Catalyst deactivation (aging) causes performance degradation
- There are fewer active sites on the catalyst and the “lightoff” temperatures will increase, with a slower ramp up
- Maximum conversions will also be lower
SCR Catalyst Management

- “Cost effective planning for end of catalyst life”
- Testing is a significant aid to optimal catalyst management
  - Sample testing
  - Performance testing
  - Operations
- Options:
  - Replace catalyst with new
  - Regenerate used catalyst
QUESTIONS ??