Diagnostic Tools for Gas Turbine CO and SCR Systems

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Simple Cycle Gas Turbine SCR

- SCR Performance Parameters:
  - NO\textsubscript{x} Reduction
  - Ammonia Slip

- Uniform NH\textsubscript{3}/NO\textsubscript{x} Profile at Catalyst Inlet is Critical!
Cogeneration Gas Turbine SCR

- No Diffuser Vanes
- No Perforated Plates
- No Tempering Air

Ammonia Injection Grid (AIG)

SCR Catalyst

CO Catalyst

Steam Tube Banks

Flue gas ~550-650°F

• SCR Performance Parameters:
  - NO\textsubscript{x} Reduction
  - Ammonia Slip

• Uniform NH\textsubscript{3}/NO\textsubscript{x} Profile at Catalyst Inlet is Critical!

NH\textsubscript{3} Dilution Air
Topics

- Troubleshooting - How to Distinguish NH$_3$ Maldistribution from Bypass
- AIG Tuning - Catalyst Inlet NH$_3$/NO$_x$ Distribution
- Identifying Flue Gas Bypass
- Catalyst Management/Measuring Catalyst Activity
What Can Lead to Non-Compliance: NH$_3$/NO$_x$ Maldistribution, Bypass?
A simple stack test can distinguish

- NH₃ Maldistribution
- Flue Gas Bypass
Stack NH₃ vs. NOₓ

NH₃/NOₓ RMS Effects

Bypass Effects

RMS=10%
RMS=20%
RMS=30%

ByPass=0%
ByPass=2.5%
ByPass=5%
ByPass=7.5%
Stack NH₃ vs. NOₓ

NH₃/NOₓ RMS Effects

Bypass Effects

How to best generate this data?

- Wet Chemical NH₃ measurements?
- Continuous NH₃ measurements?
TDL Instrumentation

- Testing facilitated using a continuous TDL NH$_3$ analyzer
- Data set can be generated in less than a day
- Data available in real time

- **Unisearch NH$_3$ TDL**
  - Dual Path
  - Two Channel
  - Fiber Optic Coupled
NH₃-TDL Lines of Site

NH₃ TDL Optical Paths

Gas Flow
TDL NH₃ Measurements on a Large Combined Cycle

NH₃/NOₓ RMS Effects

Bypass Effects
AIG Tuning
Gas Turbine SCR AIG Tuning

- Tuning is Facilitated by Installing a Permanent Sample Grid at the Catalyst Exit:
  - Not feasible to manually traverse a large combined cycle system for AIG tuning
  - Typically need 36 to 60 probes depending on AIG design

- With Permanent Probes Tuning can Typically be done in One Day

- The NO\textsubscript{x} Profiles at the Exit of the Catalyst can also Help Identify Bypass
NH$_3$/NO$_x$ Distribution and AIG Tuning

**New Catalyst**

![Graph showing NH$_3$ Slip vs NOx Reduction for New Catalyst](image)

**Catalyst Near End-of-Life**

![Graph showing NH$_3$ Slip vs NOx Reduction for Catalyst Near End-of-Life](image)
How Well is Your AIG Tuned? (As Found RMS Values)

Most of the GT AIGs we encounter are not tuned very well!
How Important is the NH$_3$/NO$_x$ Distribution?

- SCAQMD is pushing NO$_x$ from 5 to 2 ppm in So. Cal.
- Assumption is that just adding more catalyst will be the solution

**RMS=20% Add Catalyst**

<table>
<thead>
<tr>
<th>NH$_3$ slip, ppm @15% O2 dry</th>
<th>NO$_x$, ppm @15% O2 dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>K=80/RMS=20%</td>
<td>RMS=20%, 25% More Cat</td>
</tr>
</tbody>
</table>

**Tune AIG To RMS=10%**

<table>
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<tr>
<th>NH$_3$ slip, ppm @15% O2 dry</th>
<th>NO$_x$, ppm @15% O2 dry</th>
</tr>
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<tbody>
<tr>
<td>K=80/RMS=10%</td>
<td>K=80/RMS=20%</td>
</tr>
</tbody>
</table>

- Just tuning the AIG allows 2 ppm NO$_x$ to be achieved
- Adding 50% more catalyst helps, but not as much as tuning
Outside View of a Permanent Sample Grid on a Large Combined Cycle

Sample probe exit ports

Sample probe lines brought down to grade
Sample Probes Attached to Catalyst Modules
FERCo’s Multipoint Instrumentation

- Samples 48 points in 15 minutes
- NO\textsubscript{x} and O\textsubscript{2}
AIG Design Affects Tuning

- **No Adjustments**: Some systems have no adjustment valves - Bad Idea!

- **1-D**: Commonly used design

- **Multi Zone**: Better
  - Two Horizontal Zones
  - Horizontal and Vertical Lances
  - Three Horizontal Zones
AIG With No Adjustability
AIG: No Adjustability

Permanent Probe Grid for Tuning. Difficult to Tune Without!
Normalized NH$_3$/NO$_x$ Profiles – As Found

Orig. AIG RMS = 35%
CFD RESULTS

Case 1 - Current AIG Design, RMS = 20.6%

Case 2 - Modified AIG Design, RMS = 0.9%

Ammonia Enters This Side
Normalized NH$_3$/NO$_x$ Profiles – Before & After

Orig. AIG RMS = 35%

All Holes Resized RMS = 16%

NH$_3$ Header

NH$_3$ Header
Duct Burners Impact AIG Tuning

Duct Burners Off (Inlet NO\textsubscript{x} ppm)

Duct Burners On (Inlet NO\textsubscript{x} ppm)

AIG Difficult to Tune

NH\textsubscript{3}
AIG Tuning, 1-D AIG Design; NH$_3$/NO$_x$

As Found, RMS = 22%

Tuned, RMS = 13%

Adjustments across the width not possible
AIG Tuning, 1-D AIG Design; Outlet NO\textsubscript{x}

As Found

Tuned

Reagent consumption reduced 5%

NH\textsubscript{3}
AIG Tuning, Multi Zone AIG Design; NH$_3$/NO$_x$

As Found, RMS = 19%

Tuned, RMS = 5%
Benefits of AIG Tuning

• Ability to meet NO\textsubscript{x} and NH\textsubscript{3} slip requirements

• Reduce NH\textsubscript{3} slip at required outlet NO\textsubscript{x}

• Reduced Reagent Consumption

<table>
<thead>
<tr>
<th>GT Load As Found</th>
<th>Tuned</th>
<th>Reagent Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW</td>
<td>lb/hr</td>
<td>lb/hr</td>
</tr>
<tr>
<td>244</td>
<td>669</td>
<td>633</td>
</tr>
<tr>
<td>174</td>
<td>410</td>
<td>355</td>
</tr>
<tr>
<td>29</td>
<td>42</td>
<td>35</td>
</tr>
</tbody>
</table>

• Reduced Required GT Water Injection

<table>
<thead>
<tr>
<th>GT Water Inj</th>
<th>Inlet NO\textsubscript{x}</th>
<th>NH\textsubscript{3} Slip</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPM</td>
<td>ppm</td>
<td>ppm</td>
</tr>
<tr>
<td>30</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>26</td>
<td>26</td>
<td>3.5</td>
</tr>
</tbody>
</table>
Bypass
NO$_x$ Profiles Can Also Help Detect Bypass
$\text{NO}_x$ Profiles Can Also Help Detect Bypass

Possible Bypass
Catalyst Management
Catalyst Management

- Tracking catalyst activity and NH$_3$/NO$_x$ distribution
- Ensure continued environmental compliance
- Plan for catalyst replacements

![Graph showing NH$_3$ slip and K/Ko over operating hours with three different RMS levels: 10%, 20%, and 22.5%. The graph indicates 5%/10k Hrs as a threshold.]
Catalyst management for a combined cycle SCR system entails tracking key parameters so you know when the catalyst must be changed.

These Parameters are:

1. Catalyst Activity (K, m/hr)
2. Reactor Potential (RP, dimensionless)
Catalyst Activity

• Catalyst Activity determines how well a catalyst is performing regarding NO$_x$ reduction.

• Typical poisons in a combined cycle SCR include sodium and phosphorous.
  
  • Na: GT water injection, water for aqueous NH3 production, ambient sources (ocean air).

  • P: GT lube oil
Reactor Potential

• Although catalyst activity is important, the key parameter for determining SCR performance is the reactor potential $RP$.

• $RP$ is essentially the activity multiplied by the total catalyst surface area per unit of exhaust gas.

$$RP = (K)(A_{surface}) = \frac{K}{Q} A_v$$

• $RP$ is important because it reflects the effects of both catalyst activity and area velocity.
Catalyst Activity

• Laboratory activity measurements historically has been a key step in catalyst management

• Until recently there were no standard testing guidelines for GT SCR or CO catalyst. This led to variations among laboratories.

• EPRI recently released a Guideline for testing Gas Turbine SCR and CO catalyst

• Available at the EPRI Website (Report 3002006042)
EPRI GT SCR/CO Testing Guidelines

- Developed by an industry consortium

- SCR Catalyst: Outlines Standardized Test Methods
  - Activity, K
  - $\Delta$NOx @ NH$_3$ slip limit

- CO Catalyst

- Chemical and Physical Analysis
Measure RP Insitu

• While sending samples to a lab for activity measurements historically has been a key step in catalyst management, it is no longer necessary.

• Today an owner operator can take control of catalyst management with the CatalysTraK®, a system that measures catalyst activity and RP in-situ.

• Insitu tests are performed at actual full scale operating conditions

• Tests can be conducted at any time, no outage required
  • Performed during an annual compliance test
  • At any time there may be an issue with catalyst performance

• Applicable to both NO\textsubscript{x} and CO catalyst
Similar to the lab approach for SCR catalyst, NO\textsubscript{x} reduction is measured across a small cross section (test section) of the catalyst bed. A small supplemental ammonia injection grid (AIG) is permanently mounted upstream of the test section.
Additionally, an inlet gas sampling probe is installed directly upstream of the AIG, and an outlet gas sampling probe is installed immediately downstream of the catalyst bed at the test section. The supplemental AIG is used to increase the NH$_3$/NO$_x$ level and provide excess ammonia across the catalyst test section.

The RP calculation then is based on the maximum NO$_x$ reduction measured across this catalyst test section.
Supplemental injection grids located upstream of both CO and NO\textsubscript{x} Catalysts.
CatalysTraK® Access Ports on a Small Combined Cycle

CO Measurement Access Ports
CatalysTraK® History

CatalysTraK® was originally developed for coal-fired SCR’s. These systems are characterized by multiple catalyst layers.
One issue related to the application of CatalysTraK® to a GT SCR is that these systems have a single layer of catalyst and it contains all of the reactors RP.

Thus when the catalyst is relatively new, the measured NO$_x$ reduction across a layer of GT catalyst can be greater than 99%. This can make it difficult to accurately determine the reactor potential RP.
CatalysTraK® Application to Turbines

The bottom line: Early in a catalyst’s life, the CatalysTraK® measurement may have a higher degree of uncertainty associated with RP, but at that point in the catalyst’s lifecycle it is not critical that the RP be precise. *This is also an issue in laboratory testing of new GT SCR catalyst!*
CatalysTraK® tests run over two years show the RP is well above the minimum level required.

![Average Reactor Potential Graph](image)
As with SCR catalyst, CO catalyst performance also degrades over time. Historically core samples are drilled out or pulled from test panels and tested in a lab. The test involves just measuring the amount of CO oxidation that occurs across the sample, while simulating full-scale temperature and space velocity.

Why not just measure the oxidation across the actual CO catalyst bed while it is operating?
CatalysTraK® CO Catalyst Test Results

The tests run over two years show CO oxidation rates of between 96% and 98%.
Summary

• Simple stack measurements (NH$_3$ vs NO$_x$) can distinguish **Gas Bypass** from NH$_3$/NO$_x$ maldistribution

  • Facilitated by using a continuous TDL analyzer to make the NH$_3$ measurements

• AIG tuning facilitated using a permanent probe grid at the catalyst exit

  • With a probe grid and multipoint sampling, AIG tuning completed in one day

• AIG Design affects how well a unit can be tuned

• NO$_x$ profiles at the SCR outlet can also help diagnose areas of Gas Bypass
• Historically, lab tests have been used to monitor the performance of both SCR and CO catalysts over time.

• EPRI recently released GT SCR/CO testing guidelines (Report 3002006042)

• Recent tests showed both SCR and CO catalysts can easily be characterized in-situ.

• The in-situ technique is simple.

• It can be done easily during the annual compliance test, does not require an outage, and provides an opportunity to obtain a more comprehensive data set.
Questions?

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