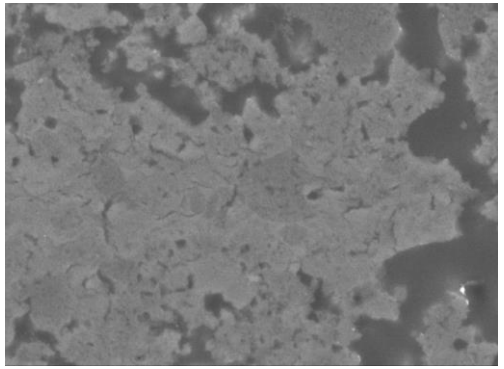
REINHOLD ENVIRONMENTAL ®

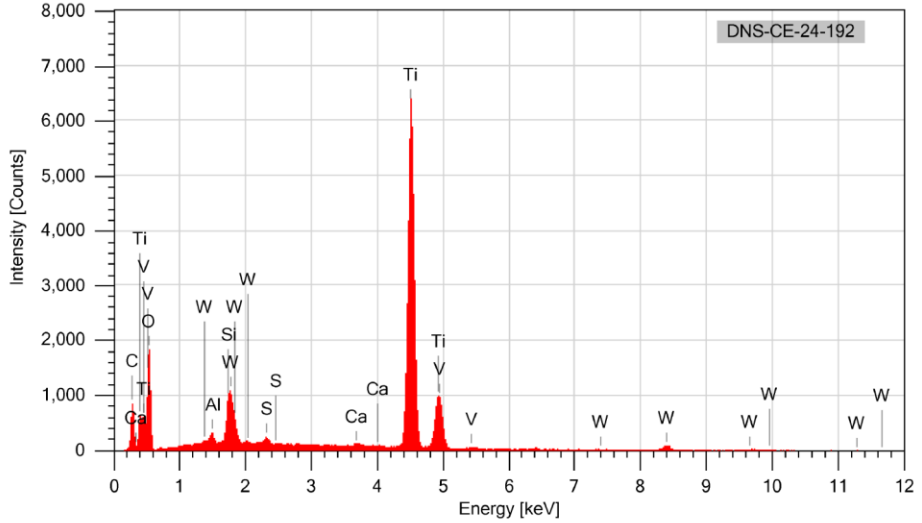
2024 Reinhold/PCUG Round Table Presentation

Hosted by LG&E/KU and Co-hosted by Southern Co. and TVA

in The Marriott Resort Lexington Griffin Gate Hotel, Lexington, KY on June 24-25, 2024

Methods of SCR/CO Catalyst Testing
Their Role in SCR Performance Investigations





Presented at:

June 24, 2024

Presented By:

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SCR/CO System Experts

Environex, Inc

Who We Are

- Industry consultants for the last 30+ years with SCR and Oxidation Catalyst Systems
- We specialize in SCR of all types of: Technologies, Systems, Catalyst, Fuel Types (Coal, Gas, Oil, MSW…)

What We Do

- SCR/CO Lifecycle Management
- Catalyst Testing
- SCR/CO Design Services
- AIG Tuning
- Consulting/Troubleshooting/ROI
- Training

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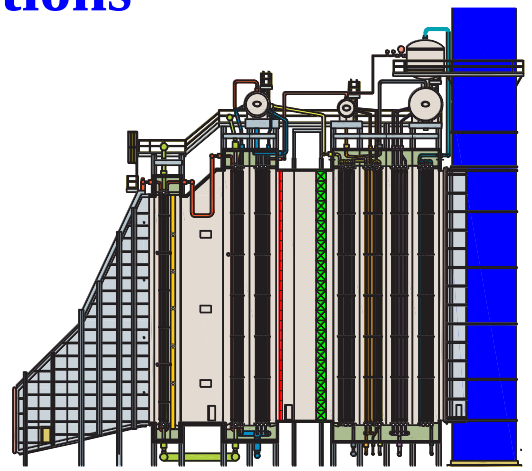
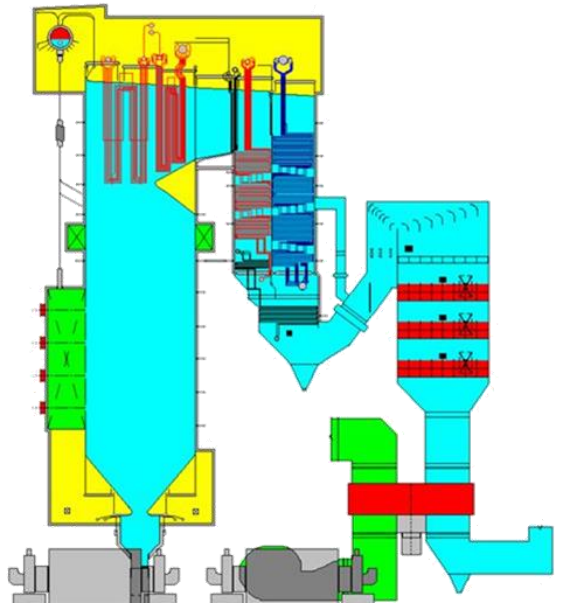
SCR Systems – Coal vs Natural Gas Applications

Variable/Parameter	Coal	Gas
Catalyst Volume	High/3 to 6 Layers	Low/1 or 2 Layers
Ammonia Injection	Further Upstream	Directly in front of catalyst
Ammonia Source	Anhydrous or Urea	Aqueous Ammonia
Dust	High Dust/Sandstorm	Minimal (but very fine)
NOx Removal Needed	Medium (60 to 90%)	High (70 to 95%)
Ammonia Slip	Less Important	Very Important
SO_2 to SO_3 Oxidation	Very Important	Less Important
Catalyst Suppliers	Few	Many
Catalyst Management	Manage many layers	Keep or Change
Onsite Labor Force	Significant (50 to 300)	Minimal (< 20)
Catalyst Poisons	Many in fuel (arsenic)	Few/None
Operation	Consistent	Variable
CO Oxidation Catalyst	No	Yes

Gas CT



Coal



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Types of Catalyst Tests Used for SCR/CO Systems

How Much?

Performance Testing

Common for SCR:
- NOx Removal Performance
- NH3 Oxidation
- NH3 Capacity
- SO2 Oxidation

Special Testing

Common for Oxidation Catalyst
- CO Removal Efficiency
- VOC Removal Efficiency
- NO to NO2 Oxidation
- SO2 Oxidation
- Formaldehyde Removal Efficiency
- Special Testing

Why?

Chemical Analysis

Surface Techniques
- SEM
- EDS
- XPS/ESCA
- PIXE

Bulk Techniques
- ICP
- XRF
- Dispersion/Microprobe

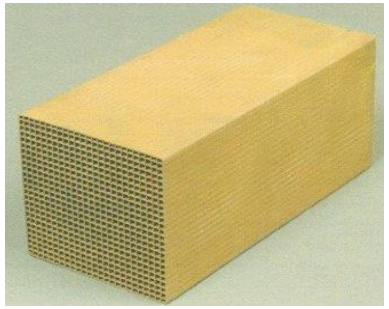
Physical Analysis

Common – Field Samples
- Pore Volume
- Pore Size
- Pore Surface Area (BET)
- XRD

Special Tests - Manufacturing
- Mercury Porosimetry
- Abrasion Testing
- Washcoat Adhesion Testing
- Strength Testing

Performance Testing Techniques - Micro Scale vs. Full Block

- **Two common test scales used in industry for SCR**
  - Full block typically a 6” x 6” cross section, up to 40” length reactor
  - Bench Scale reactor uses small core samples – 1” to 3” cross section



Full Block/Bench

- Plant conditions are replicated in pilot scale
- Thermal stability takes longer to achieve
- Common for Coal
- Used in Gas

Semi-Bench/Lab Scale

- Small scale is more economical for testing multiple samples and test conditions
- Used in Coal
- Common for Gas

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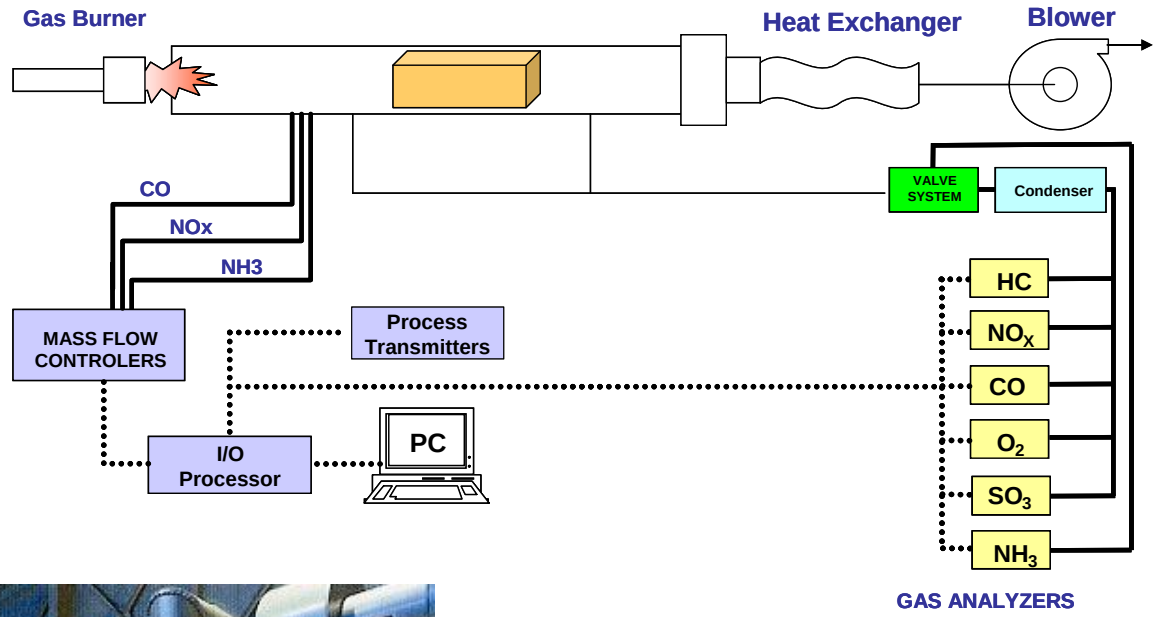
Full Block Testing

Pros:

- Sample trays can be used
- Sample can be reinstalled
- Meets VGB and EPRI guidelines

Cons:

- Fewer samples/$
- Limited test range
- Sample repeatability



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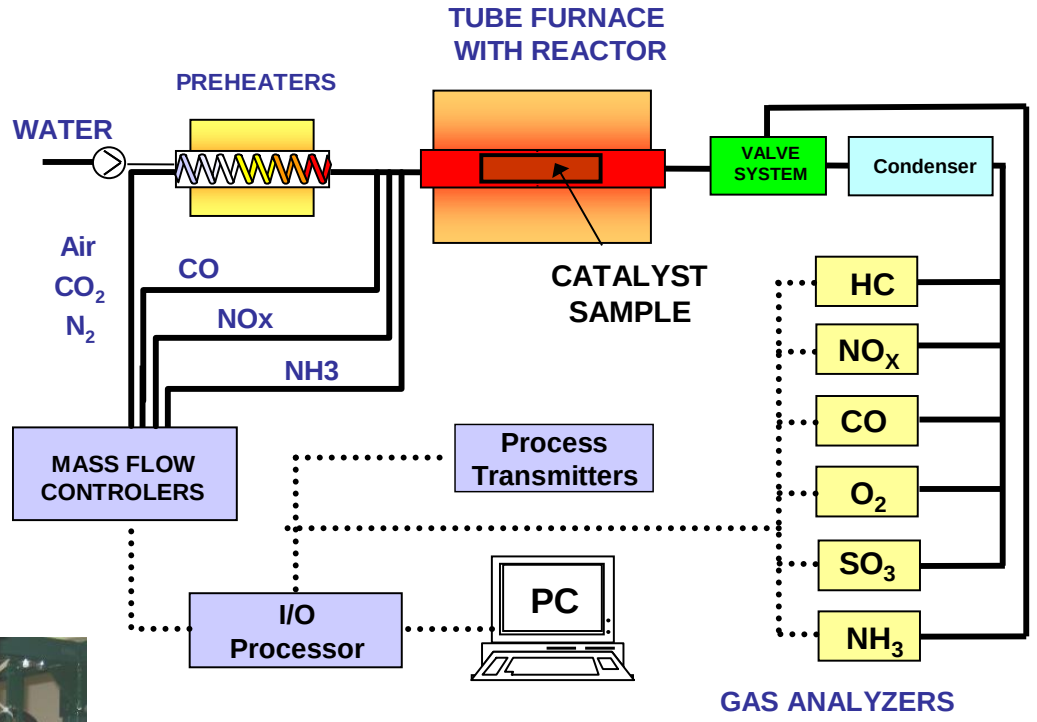
Lab Scale Testing – (Micro Testing)

Pros:

- Multiple samples
- Good repeatability
- Exact gas composition
- More Flexibility
- Less $/sample
- Meets VGB and EPRI Testing Guidelines

Cons:

- Linear velocity can be different
- Experienced test operator required



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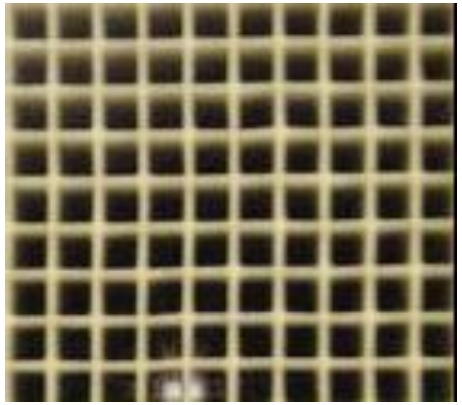
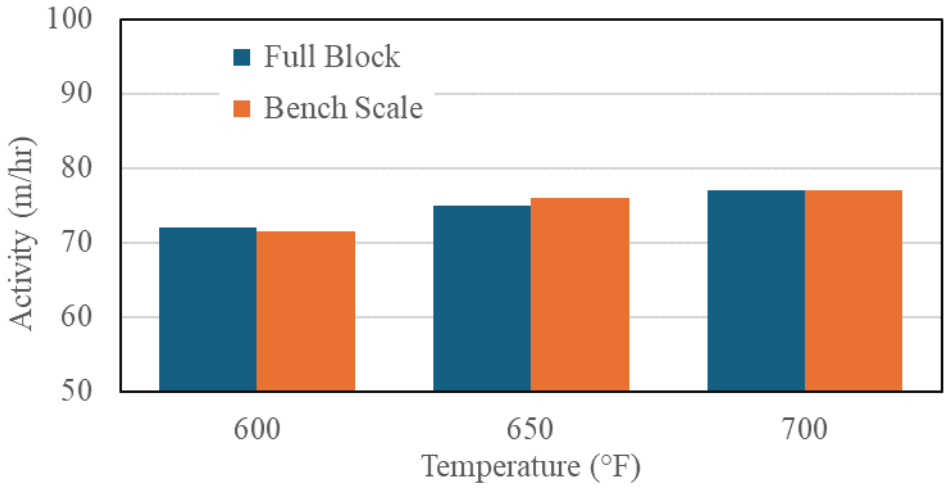
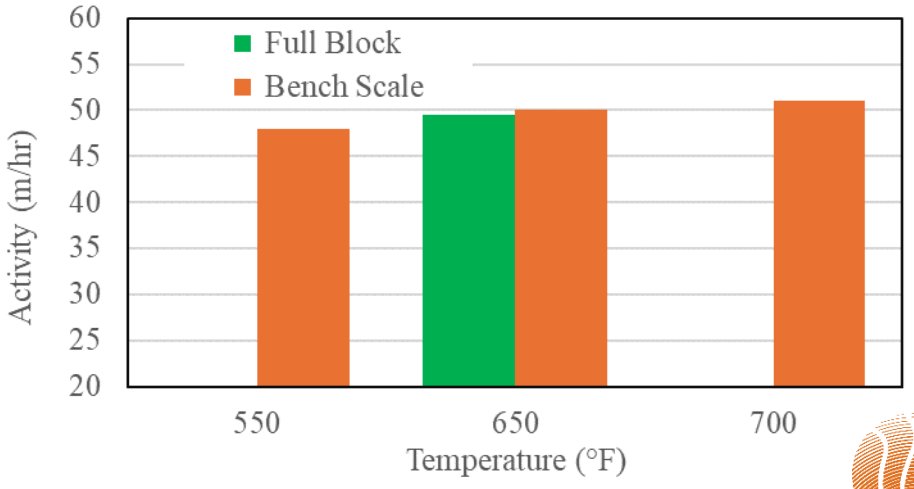
Comparison of Full Block vs. Lab Scale

- Comparison between full block and lab scale activity results investigated
- Good correlation between test methods found for both honeycomb and plate-type catalyst







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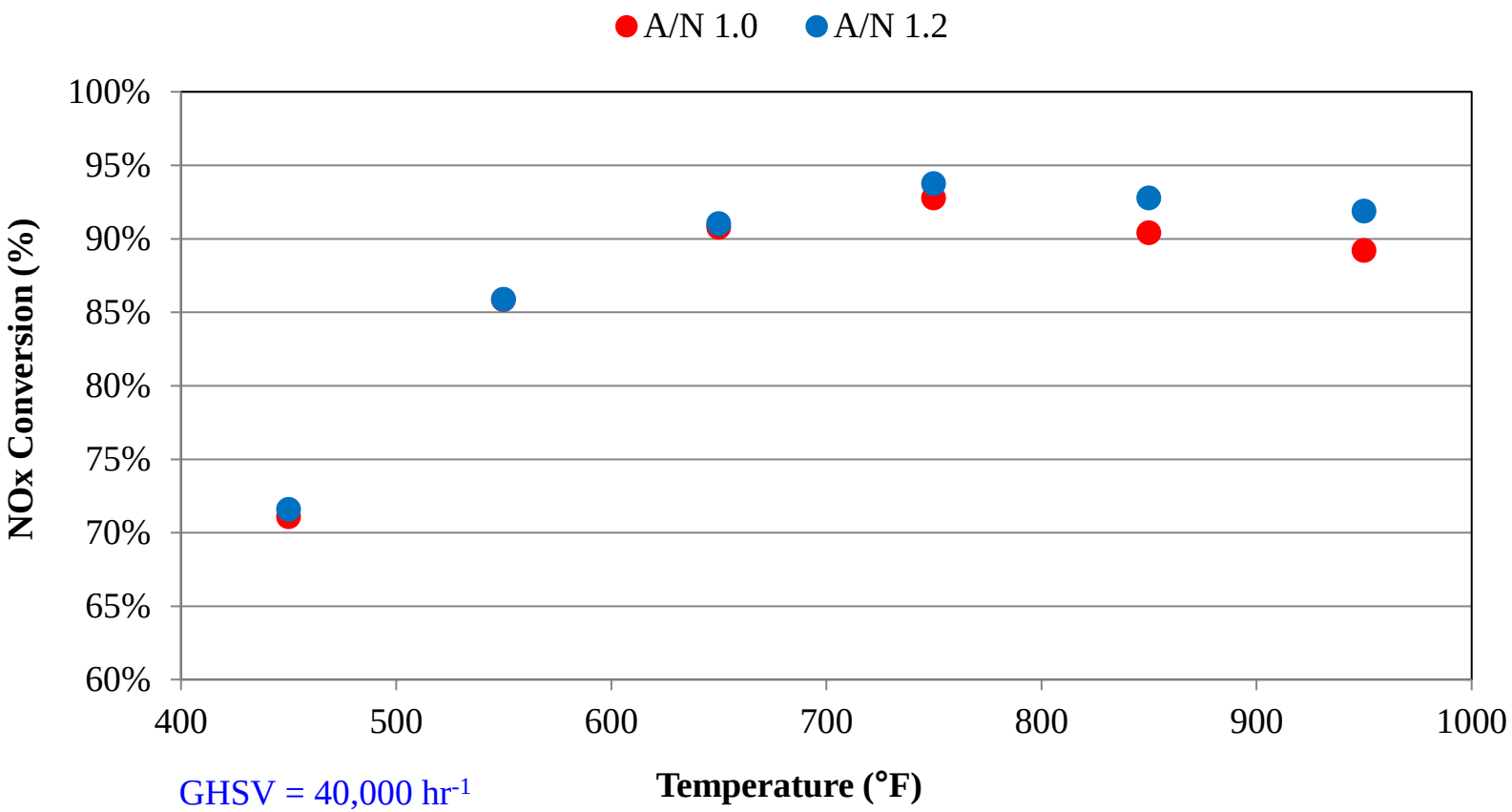
Performance Test Results – SCR Catalyst



GHSV = 40,000 hr^{-1}

2.7 mm pitch catalyst

Common Trends

- NOx Conversion increases with Ammonia-to-NOx (A/N) ratio
- NOx Conversion increases with Temperature to about 750°F
- Above 750 °F NOx Conversion Declines
- Catalyst Formulation can impact the temperature of peak performance

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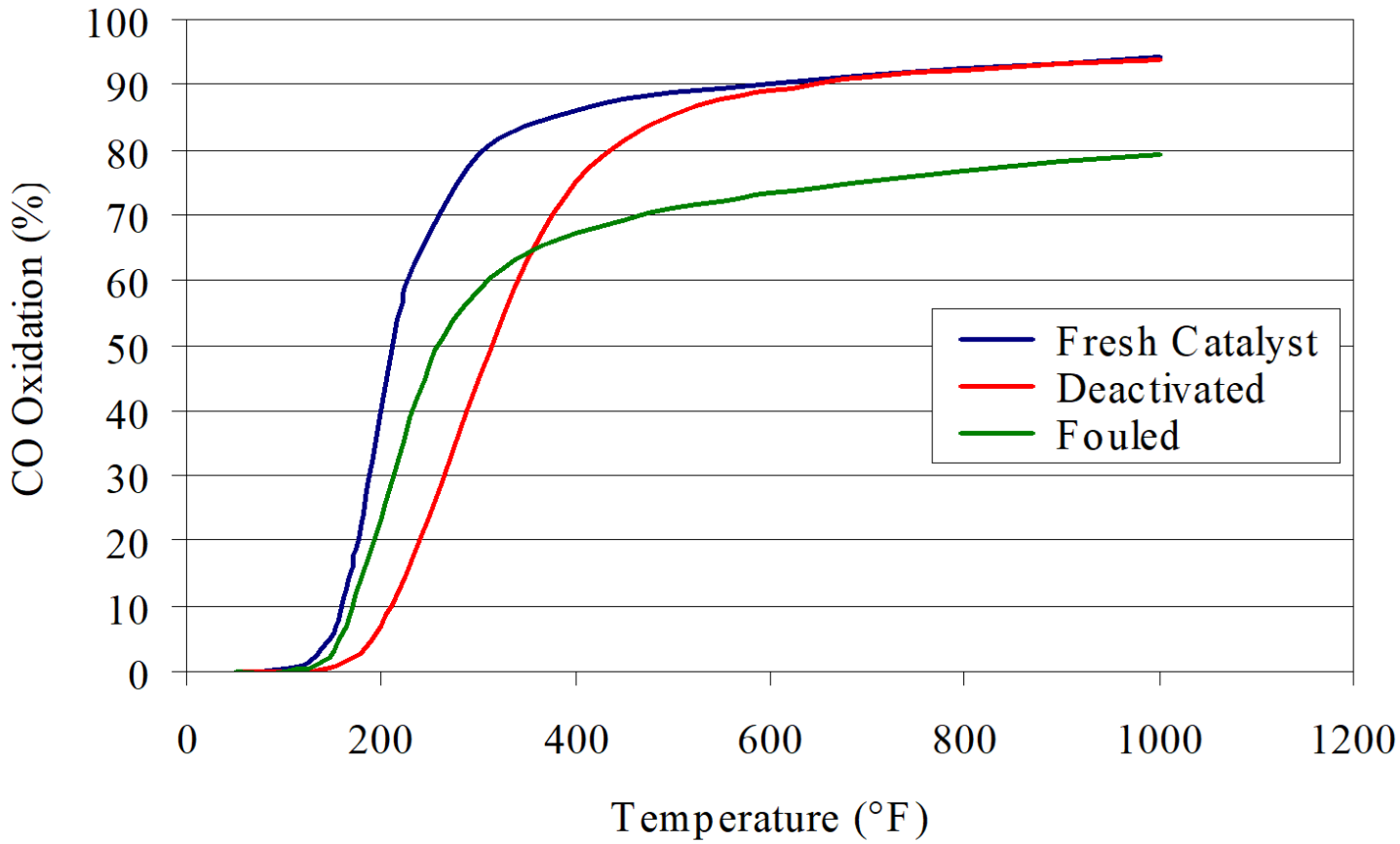
Performance Test Results – CO Catalyst



- CO oxidation "lights off" as temperature increases
- Fouling shifts the maximum potential CO oxidation downward
- Poisoning/deactivation increases the minimum temperature needed to achieve the design CO conversion

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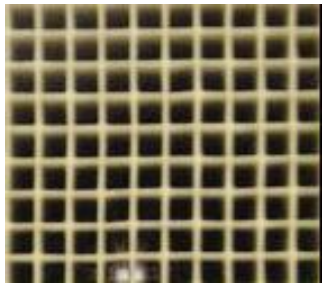
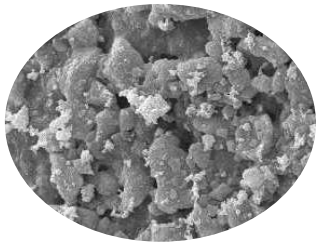
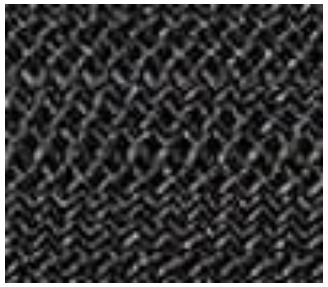
Catalyst Deactivation

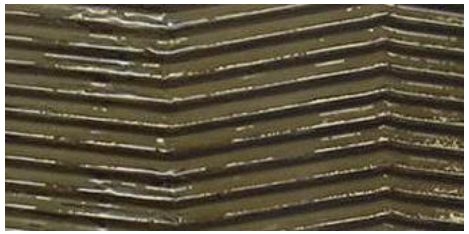
SCR

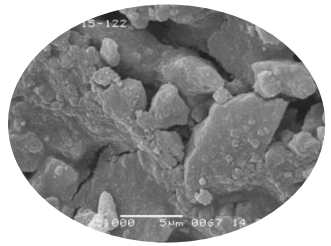


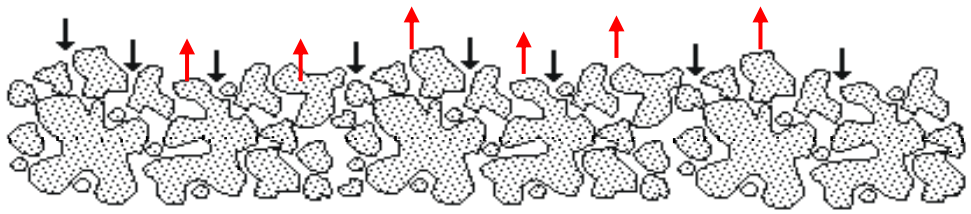


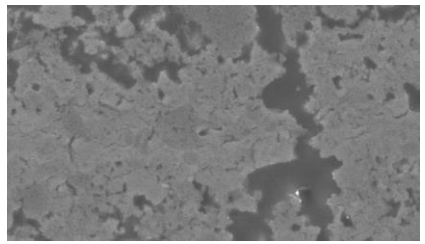
CO

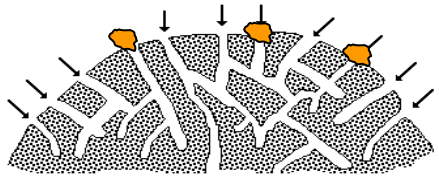




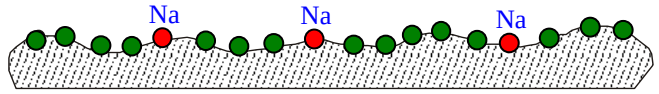








Fouling Blocks Mass Transfer



Poisoning Eliminates Active Sites

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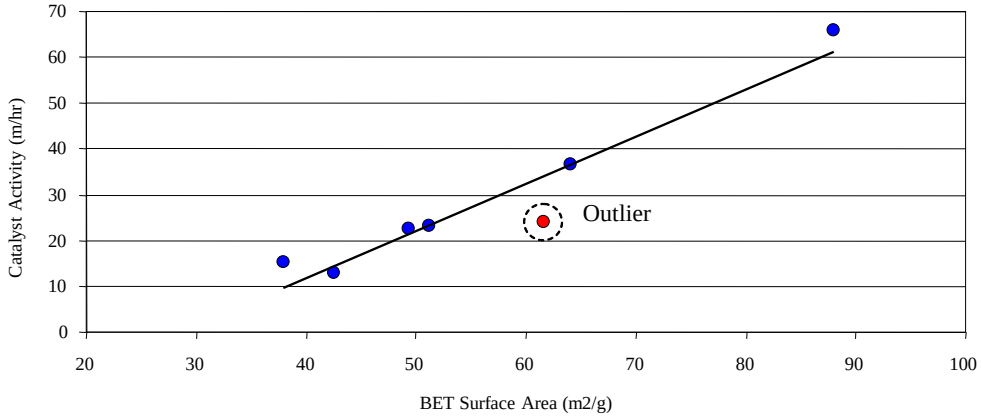
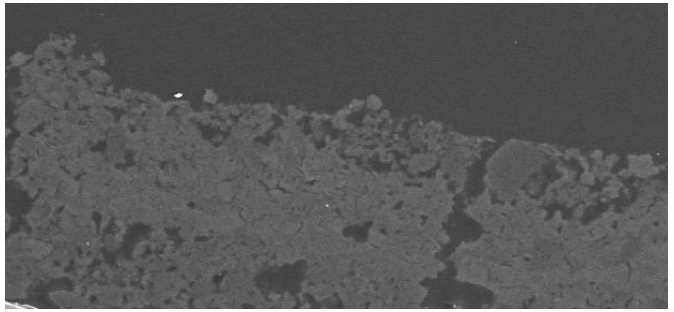
Physical Analysis Techniques

- **BET Surface Area Measurement**
  - NOx conversion proportional to surface area available for reaction when thermal damage or masking is the primary cause of performance loss



- **SEM Imaging**
  - **Used to examine** the physical condition of the catalyst surface. Masking and fouling are often visible



- **XRD – Crystalline Phase Analysis**
  - Used to determine presence and extent of thermal damage. Phase change from Anatase to Rutile Titania

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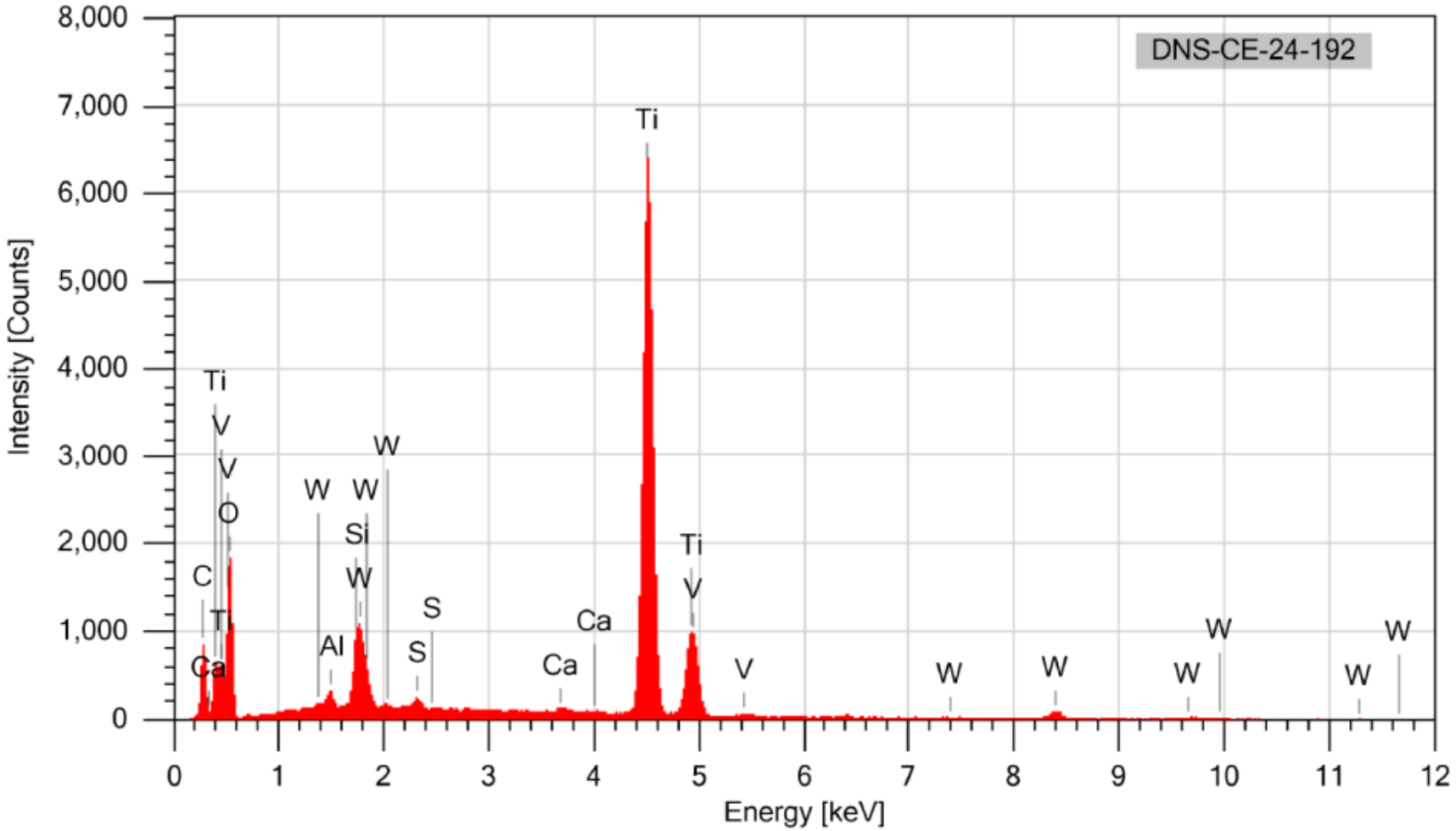
Common Chemical Analysis Techniques

- Surface Techniques
  - EDS (Energy Dispersive X-ray Spectroscopy)
    - Broad spectrum surface technique
    - Helpful in identifying surface contamination
  - ESCA/XPS – Electron Spectroscopy for Chemical Analysis
    - Broad spectrum
    - Thin film analysis (20-30 Angstrom)

- Bulk Techniques
  - ICP – Inductively Coupled Plasma Techniques
    - ICP-MS or AES used for quantitative analysis of bulk samples
  - XRF – X-ray Fluorescence
    - Quantitative, broad spectrum bulk analysis technique

Chemical Analysis Techniques – Example EDS



Mass (%)

Al	1.11%
Si	2.23%
S	0.62%
Ca	0.41%
Ti	80.36%
V	3.34%
W	11.94%

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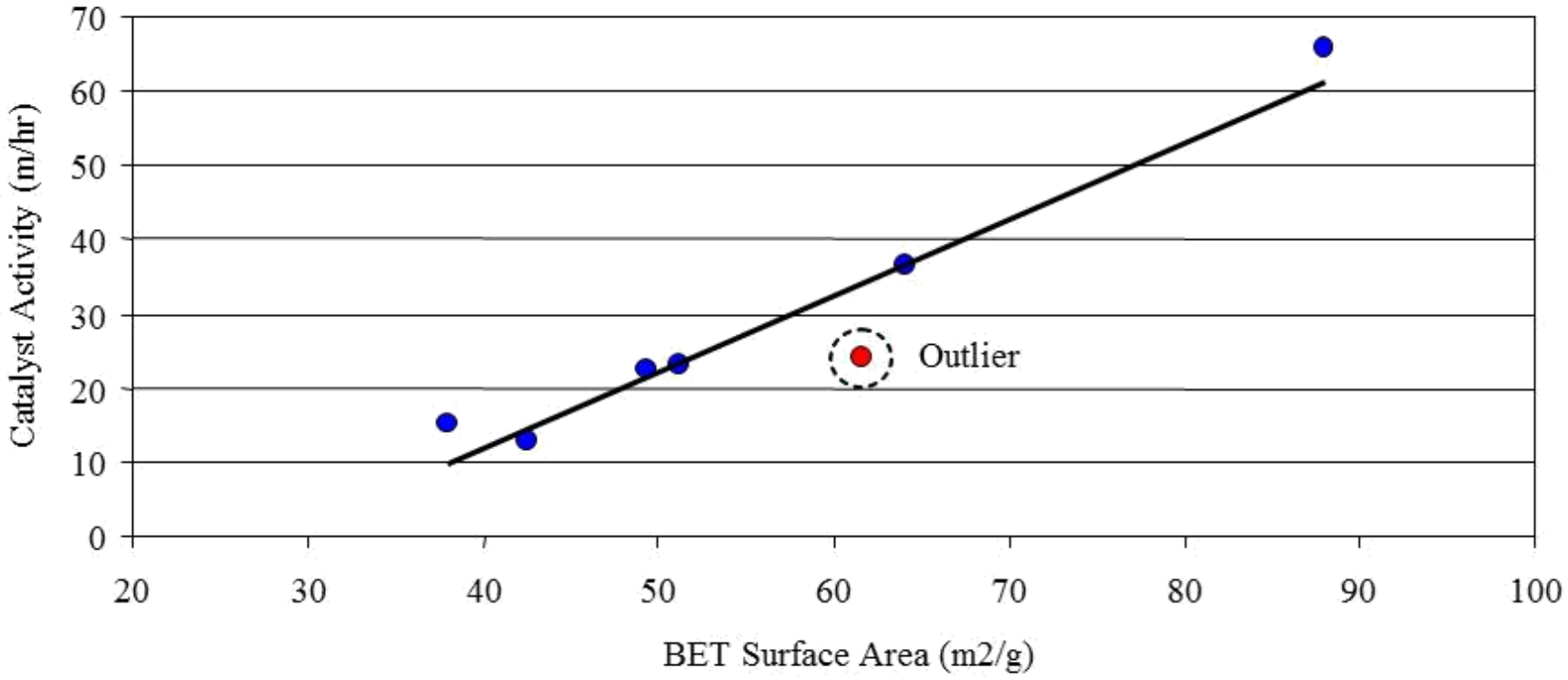
Determining the Primary Cause of Performance Loss



Fouling from dust and insulation is the #1 cause of performance loss

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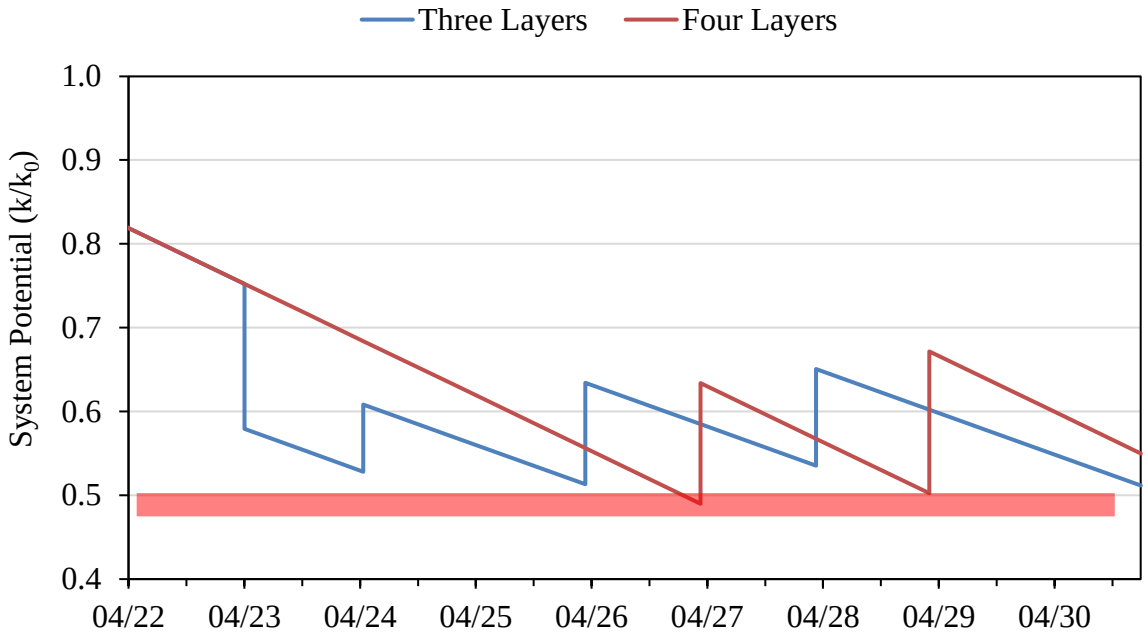
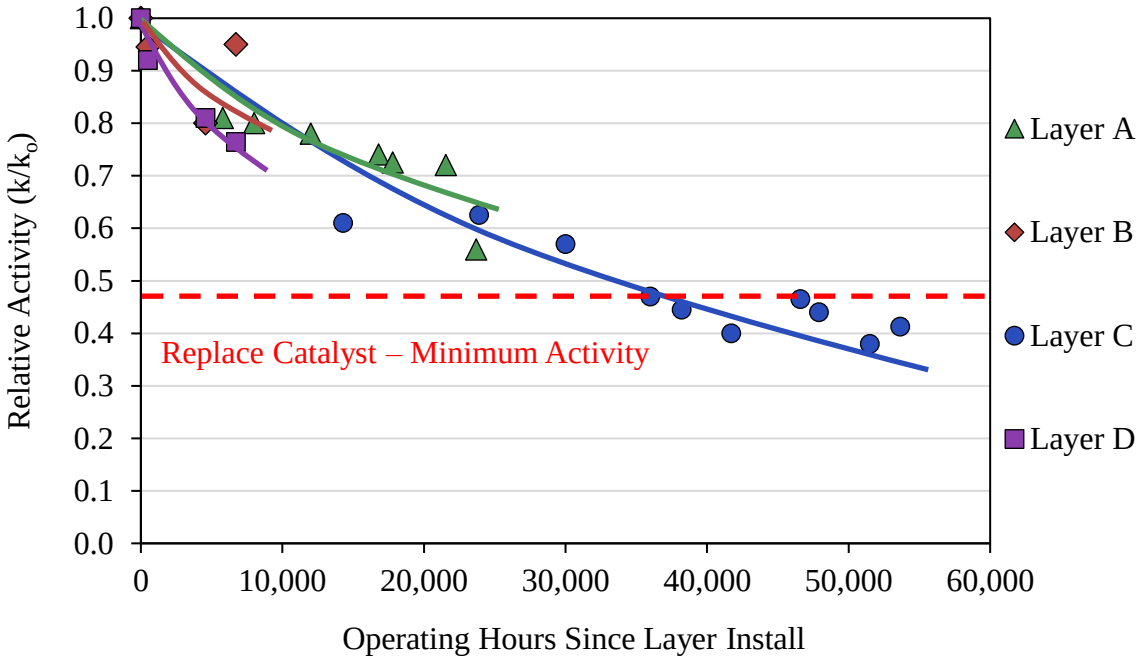
Life Cycle Analysis from Catalyst Testing





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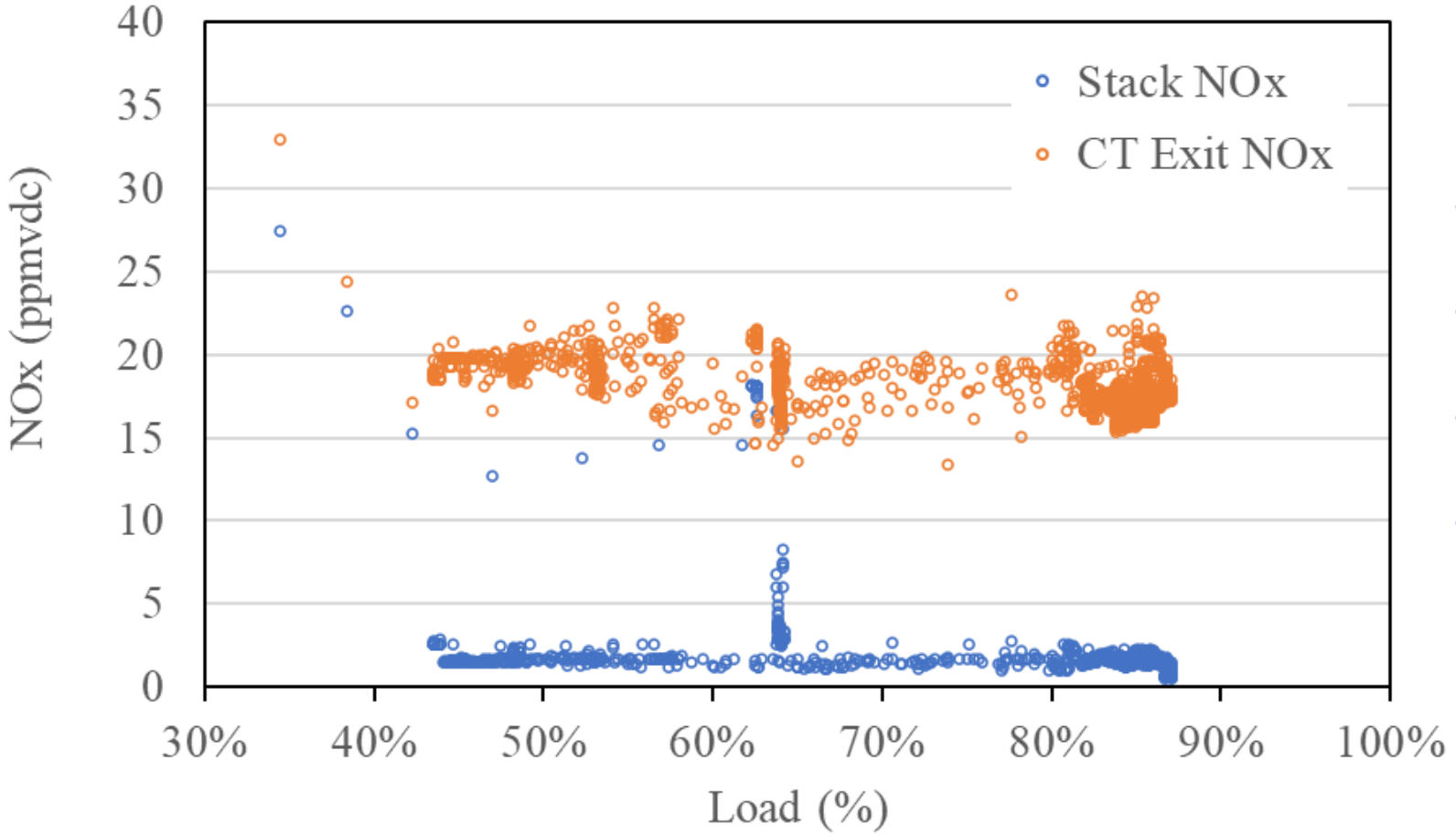
Case Study – Spikes in Stack NOx at Reduced Load



Spikes in Stack NOx at Reduced Load

- Not related to Ammonia Flow
- Periodic and “unpredictable”
- Always below 70% Load
- Does occur during start but not always related to transition

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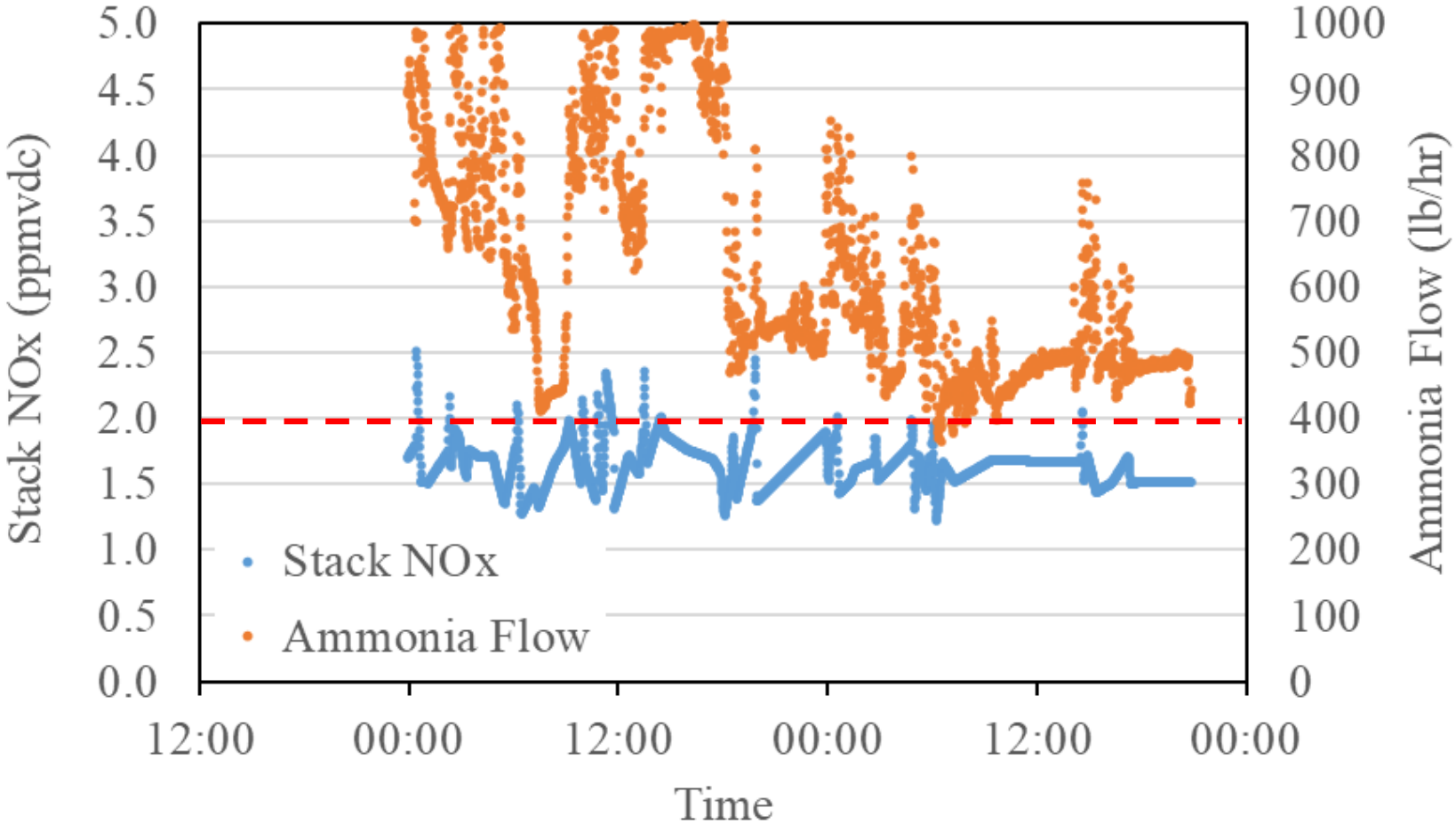
Case Study – Exceptionally High Variation on "Good" Days



Extreme Variations in Ammonia Flow and Stack NOx

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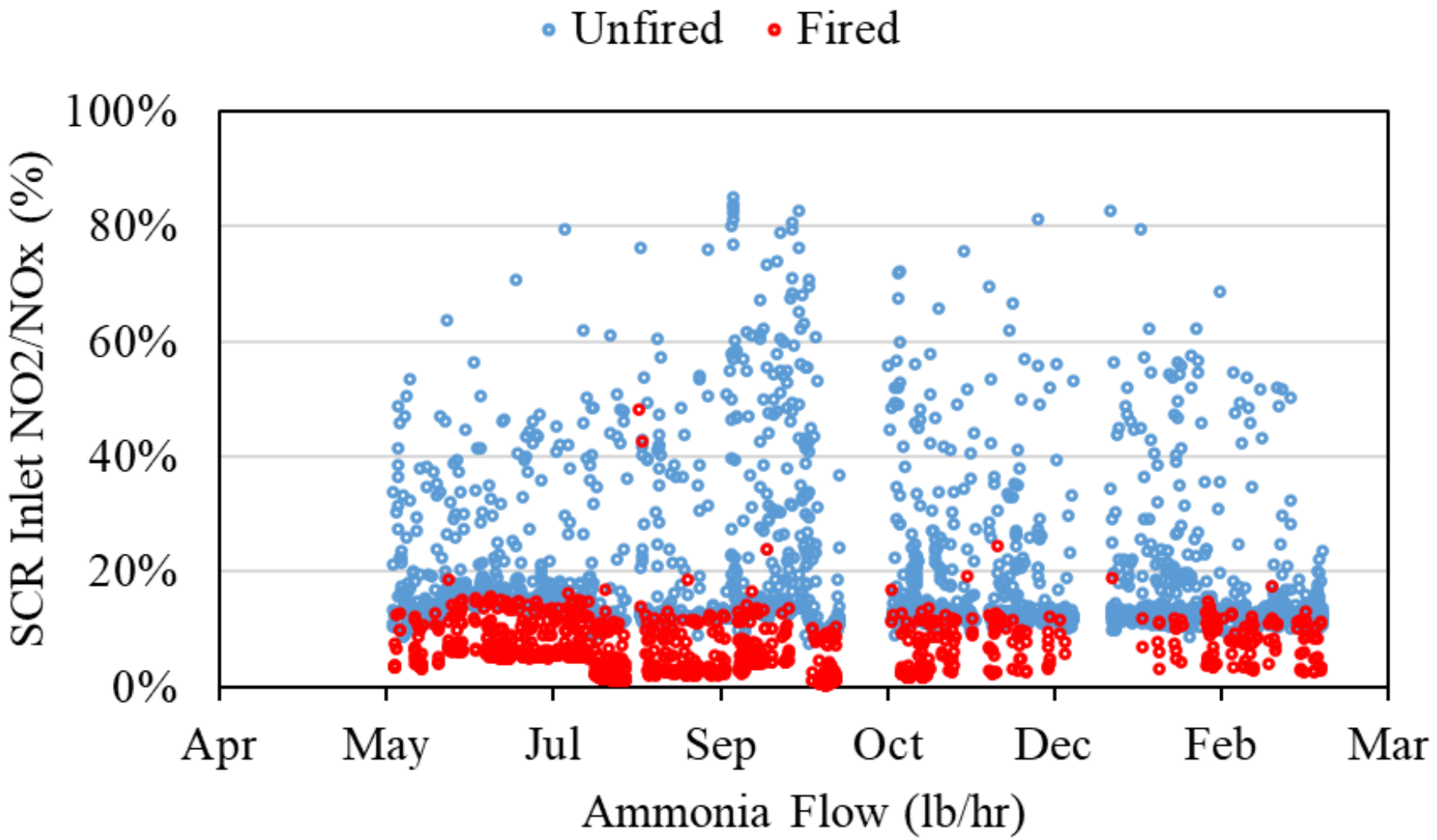
Case Study – Spikes Related to High NO2



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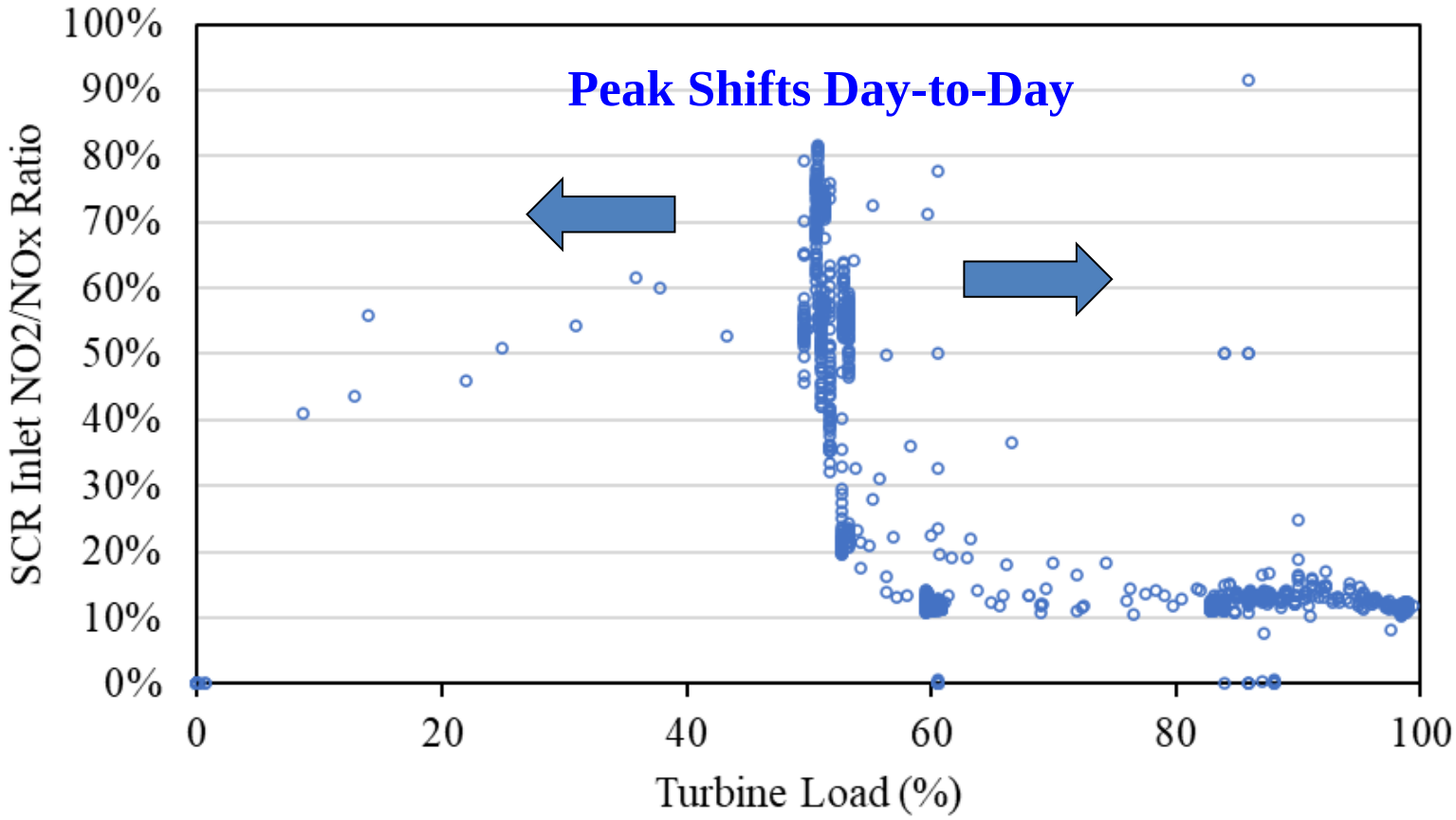

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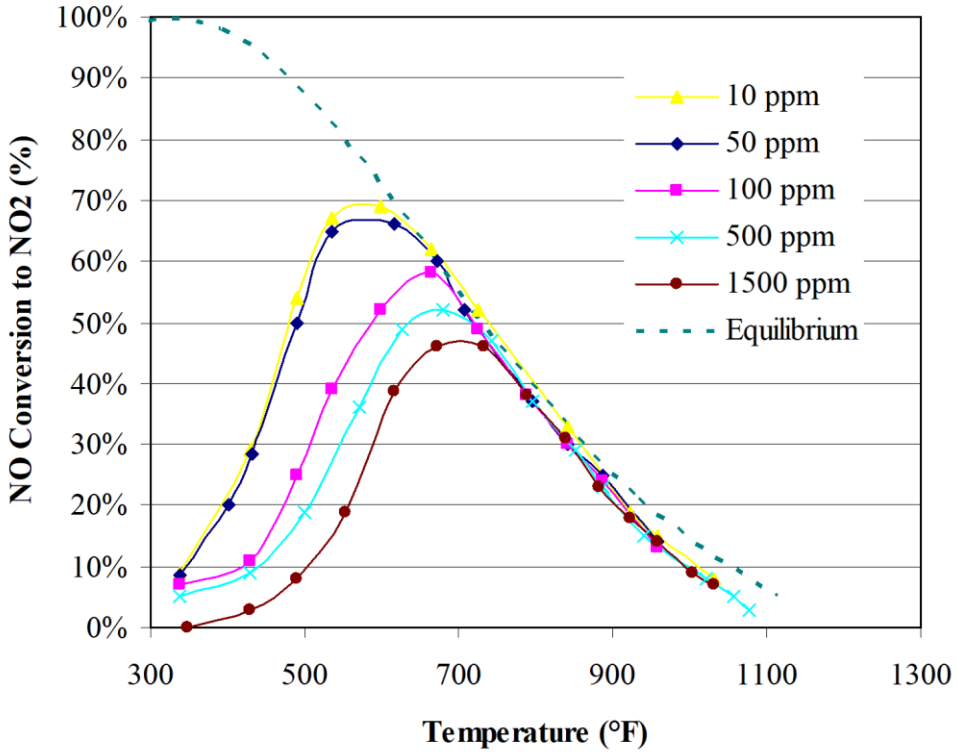

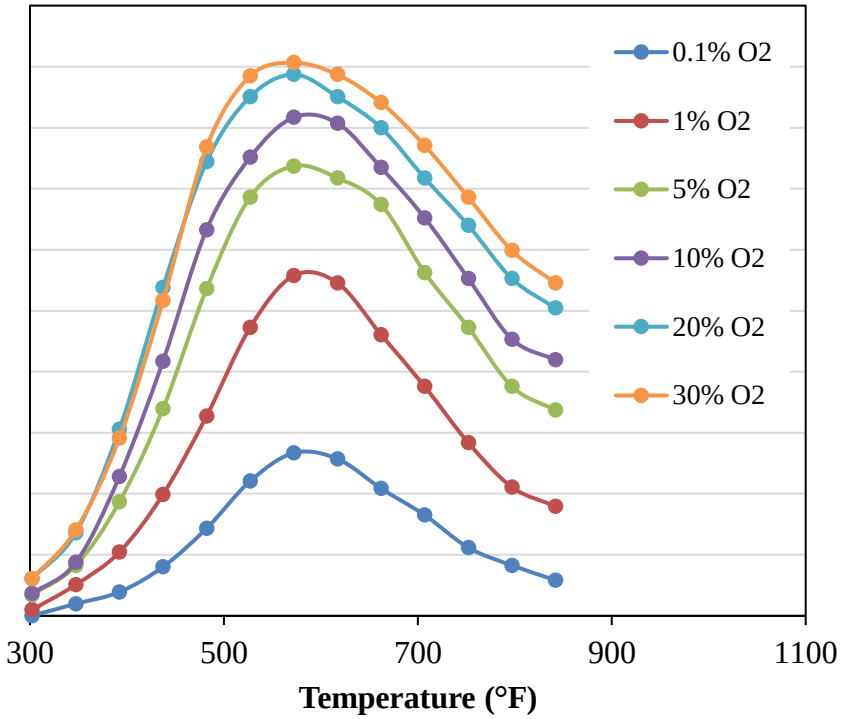

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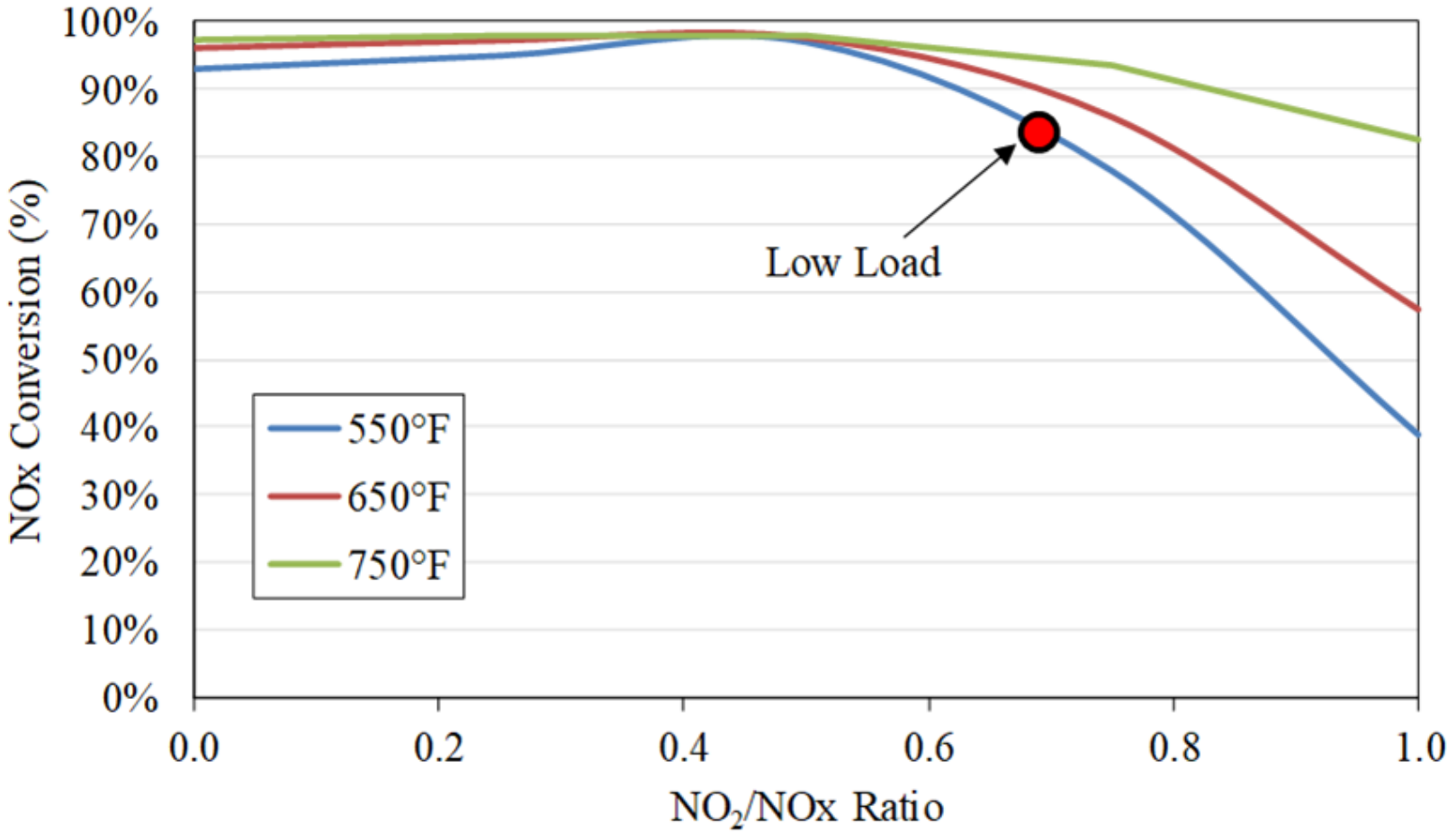
SCR Catalyst Performance With High NO_2



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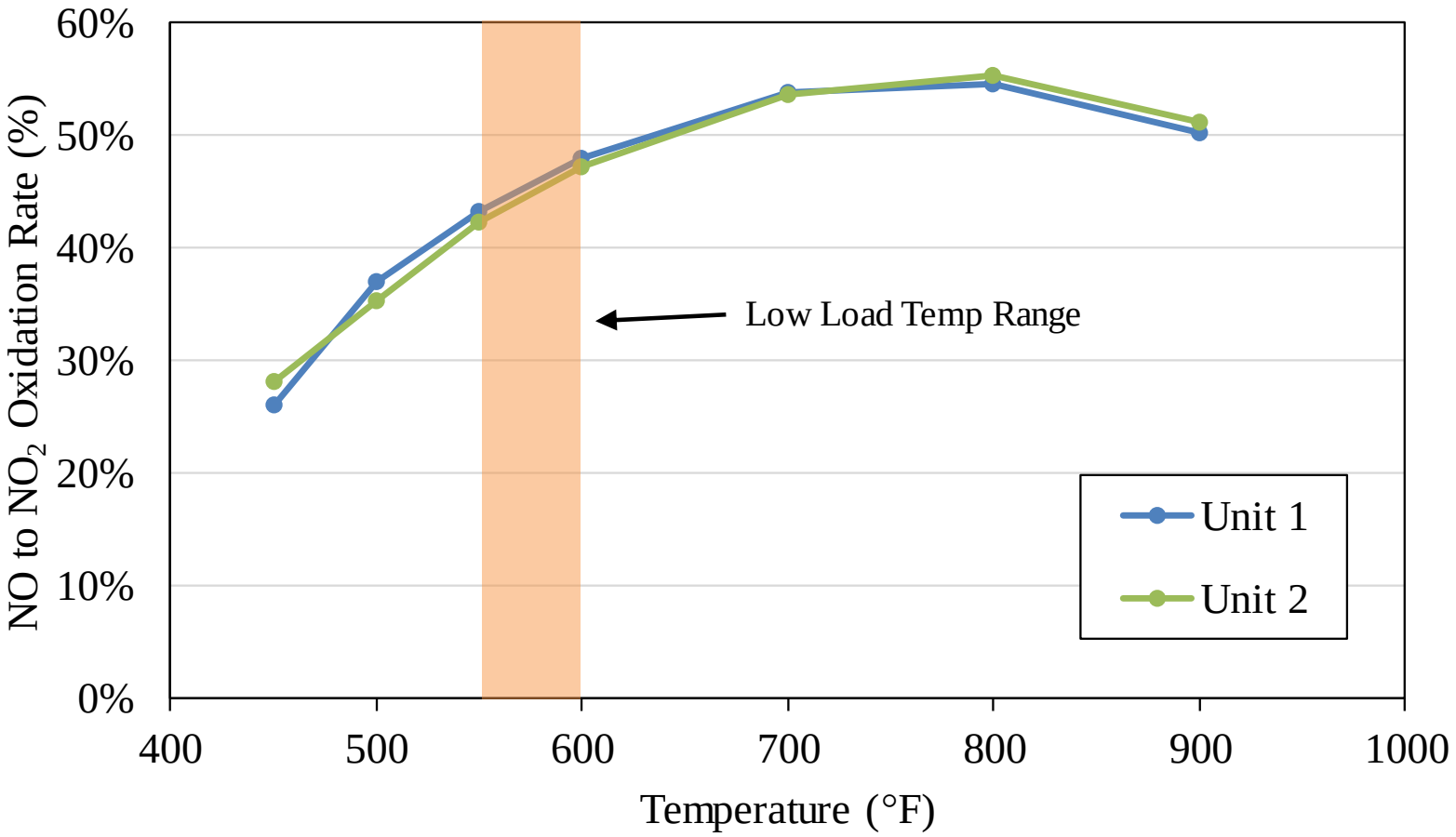
CO Catalyst Impact on NO2



The primary reaction across the CO catalyst is:

$$CO + \tfrac{1}{2} O_2 \rightarrow CO_2$$

Secondary Reactions :

$$NO + \tfrac{1}{2} O_2 \rightarrow NO_2$$

$$SO_2 + \tfrac{1}{2} O_2 \rightarrow SO_3$$

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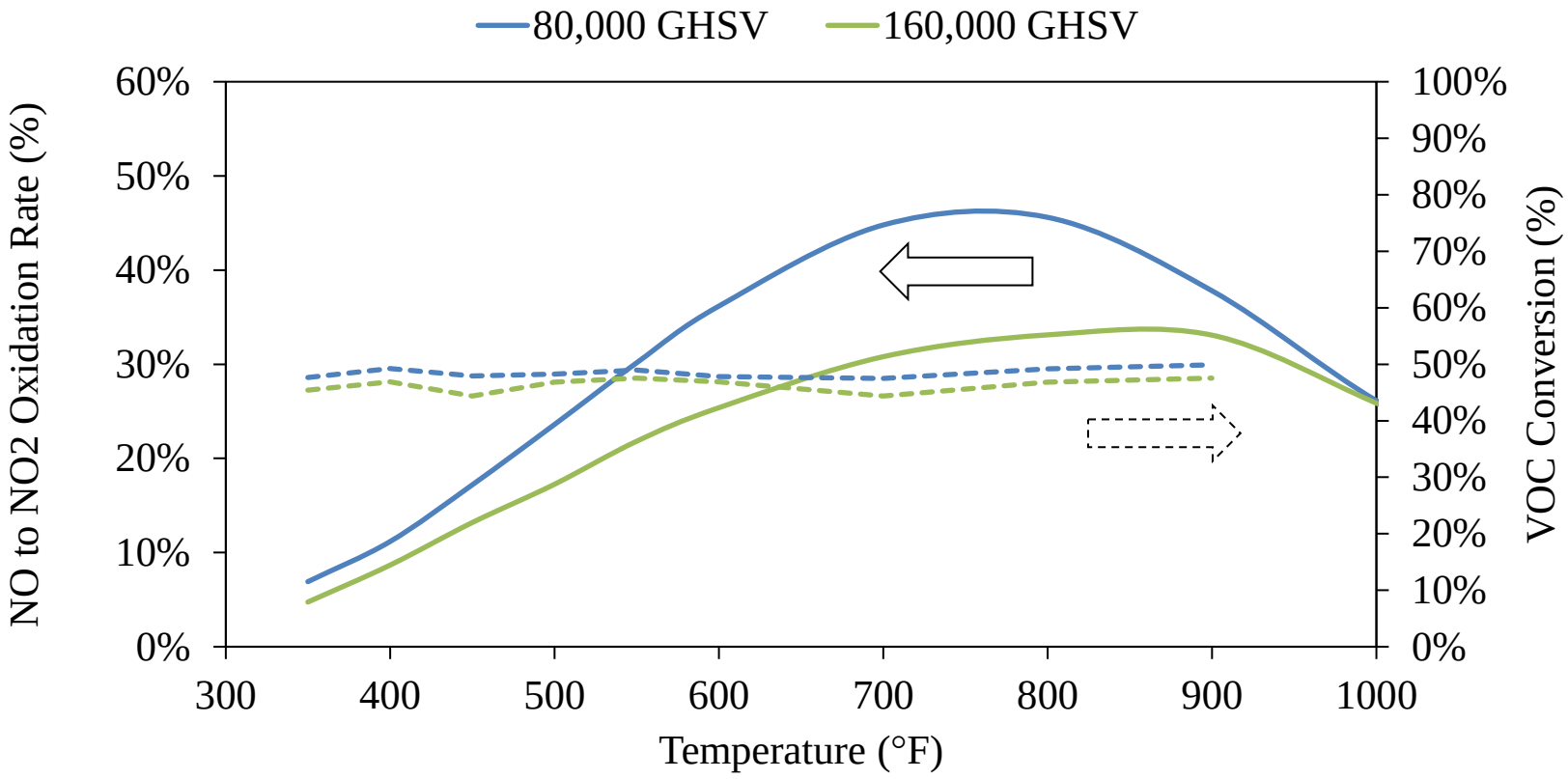
Using Performance Testing to Find/Test Solutions



VOC blend is 50% propane/50% butane

Can we reduce CO catalyst size to reduce how much NO2 is made?

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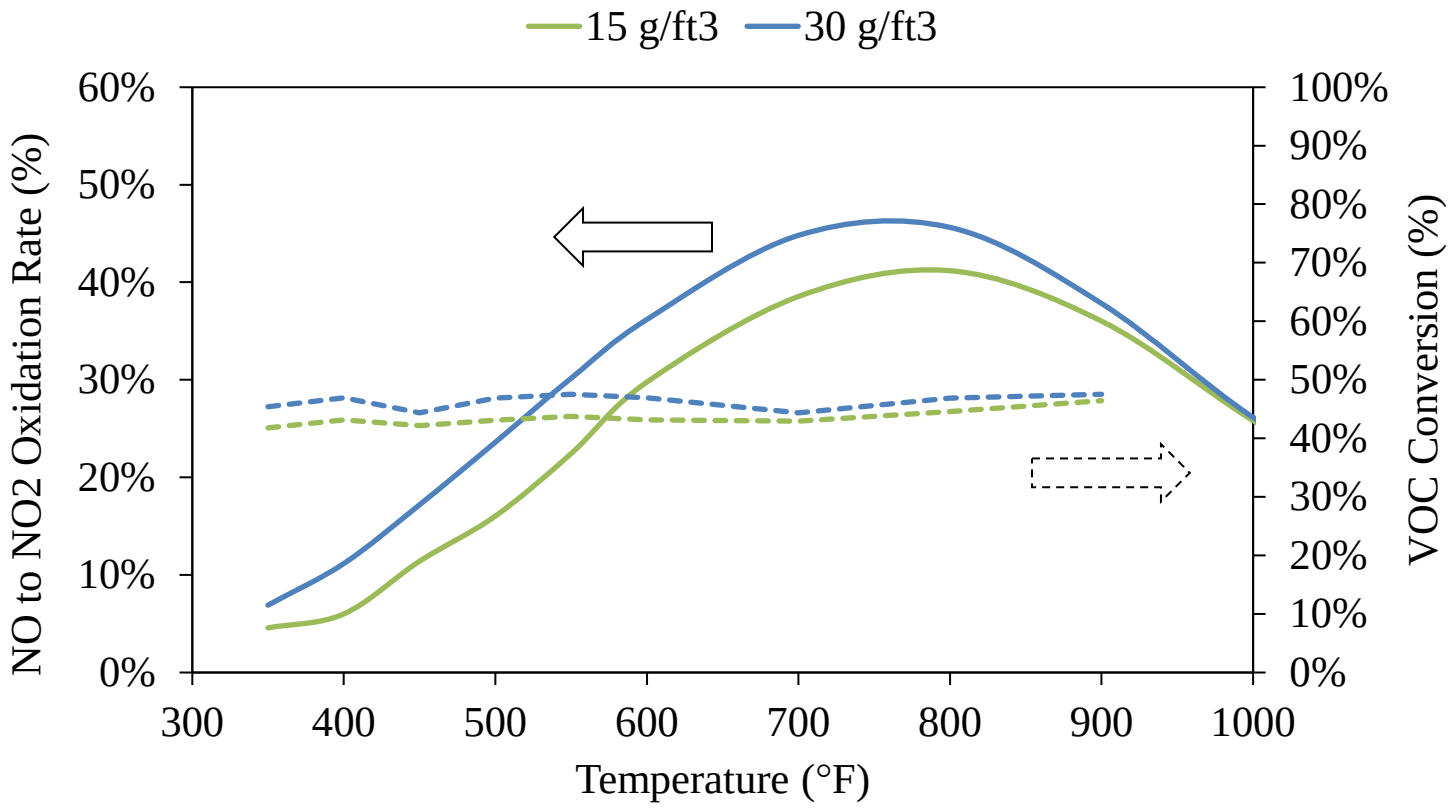
Using Performance Testing to Find/Test Solutions



VOC blend is 50% propane/50% butane

Can we reduce the CO catalyst platinum loading to reduce how much NO2 is made?

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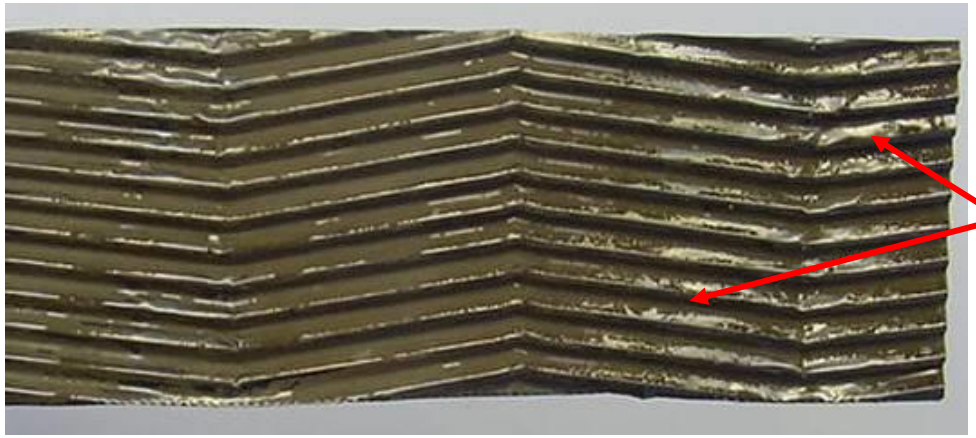
Platinum Migration from CO Catalyst to SCR



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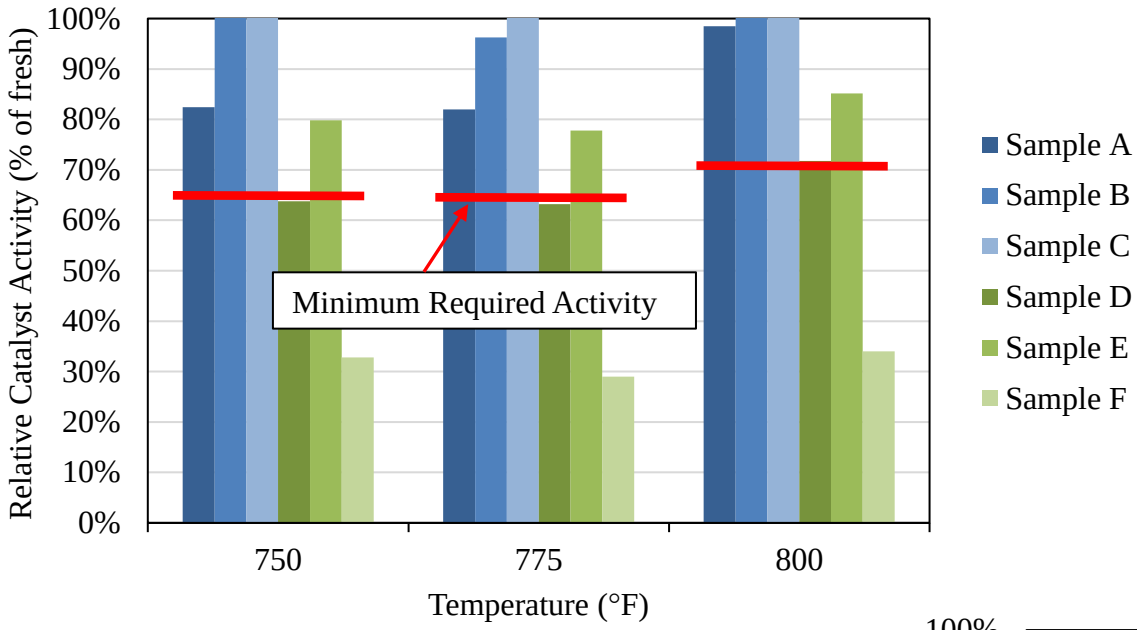
Testing for Platinum Migration



The primary reaction across the CO catalyst is:

$$CO + \tfrac{1}{2} O_2 \rightarrow CO_2$$

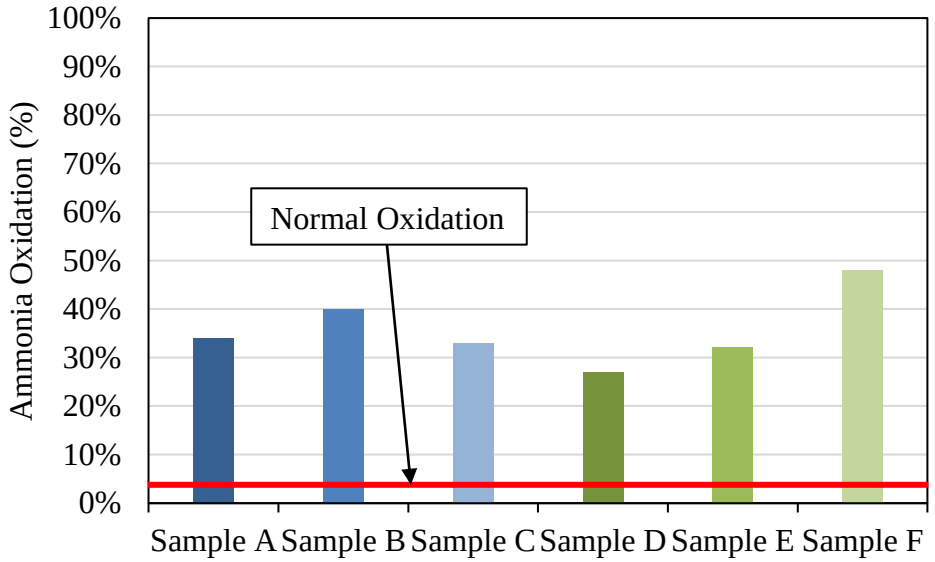
Secondary Reactions :

$$NO + \tfrac{1}{2} O_2 \rightarrow NO_2$$

$$SO_2 + \tfrac{1}{2} O_2 \rightarrow SO_3$$

If the CO Catalyst Migrates to the SCR Catalyst

$$4\ NH_3 + 5\ O_2 \rightarrow 4\ NO + 6\ H_2O$$



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Thank You !!

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Visit us in the Exhibit Hall

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