

REINHOLD ENVIRONMENTAL Ltd.



## **2014 NO<sub>x</sub>-Combustion Round Table & Expo Presentations**

February 10 & 11, 2014, in Charlotte, NC / Hosted by Duke Energy

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Reinhold Environmental  
2014 NOx-Combustion Round Table  
February 10, 2014

**SOUTHERN RESEARCH  
INSTITUTE**

## Bench-Scale SCR Catalyst Testing

Ken Jeffers

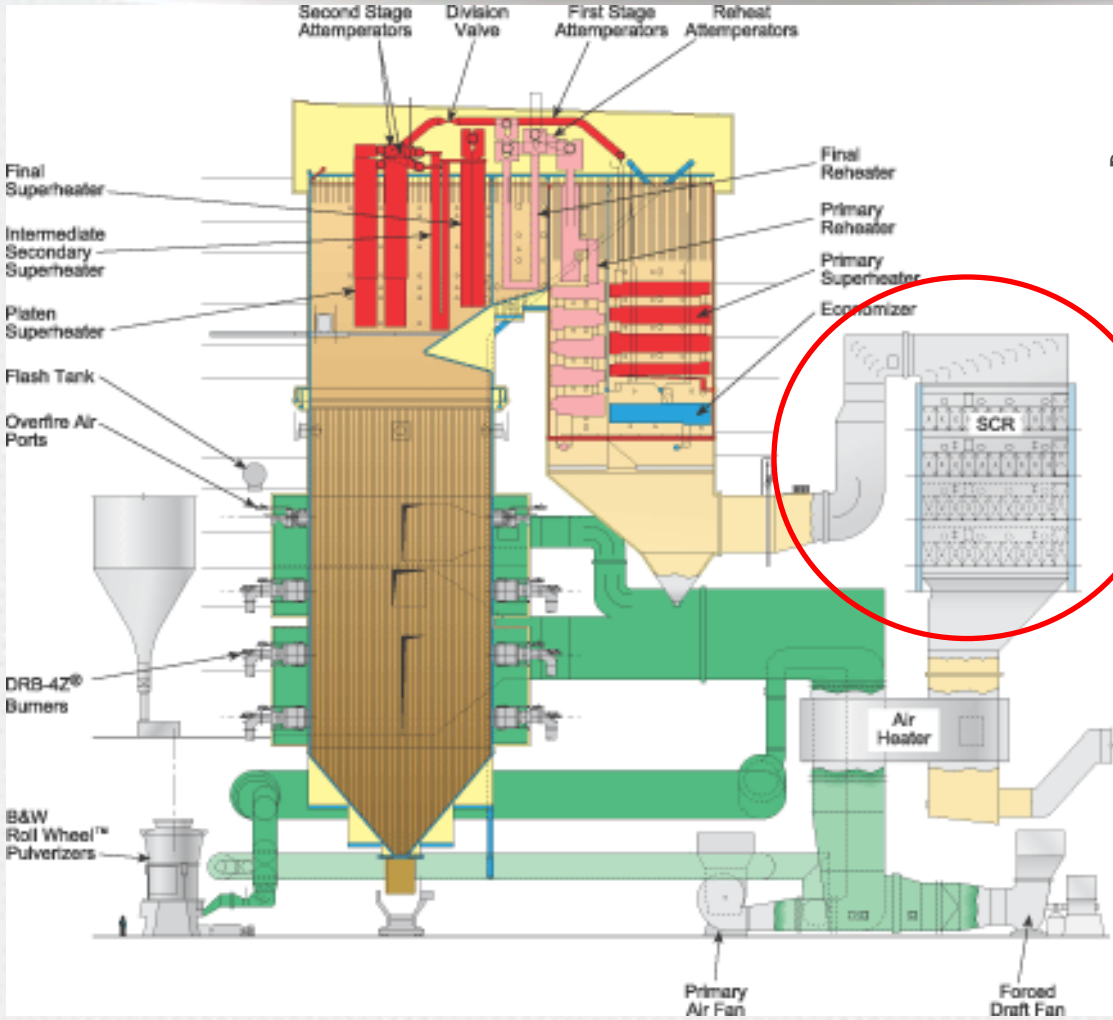
# Topics Covered

- Purpose of Testing
- Testing Systems
- Sampling
- Measurements Conducted
- Testing Procedures
- Interpreting Results
- Pitfalls, difficulties, complications, etc

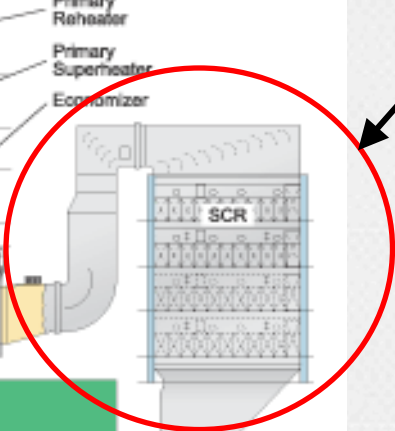
# Purposes of Testing

- Manufacturing QA/QC
- Product R&D
- Determine catalyst performance under varying conditions
- Verify performance guarantees
- Compare performance of fresh vs aged catalyst
- Determine deactivation trends
- Troubleshooting SCR performance problems

# Applications - Coal

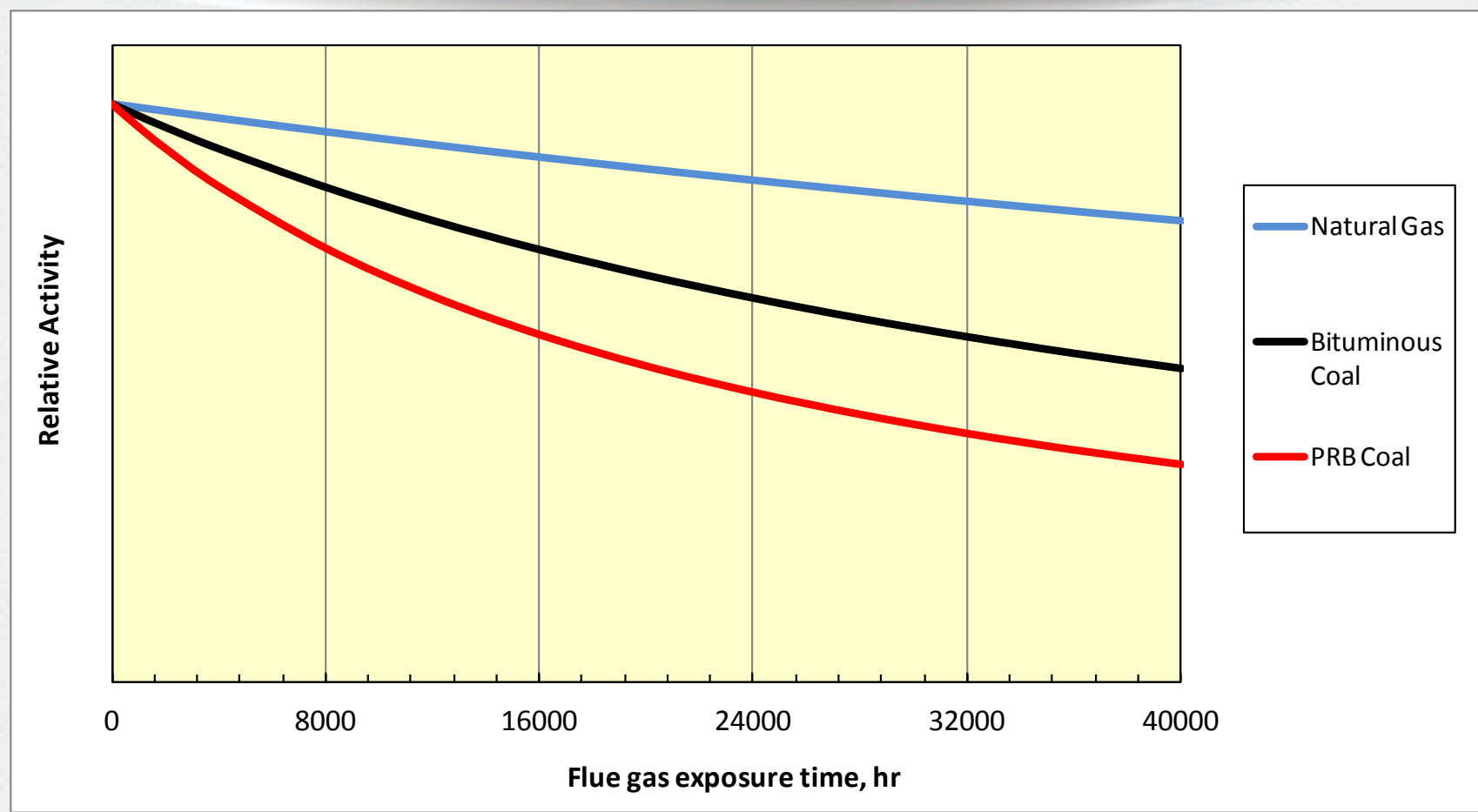


“High-dust” SCR





# Catalyst Deactivation by Application/Fuel



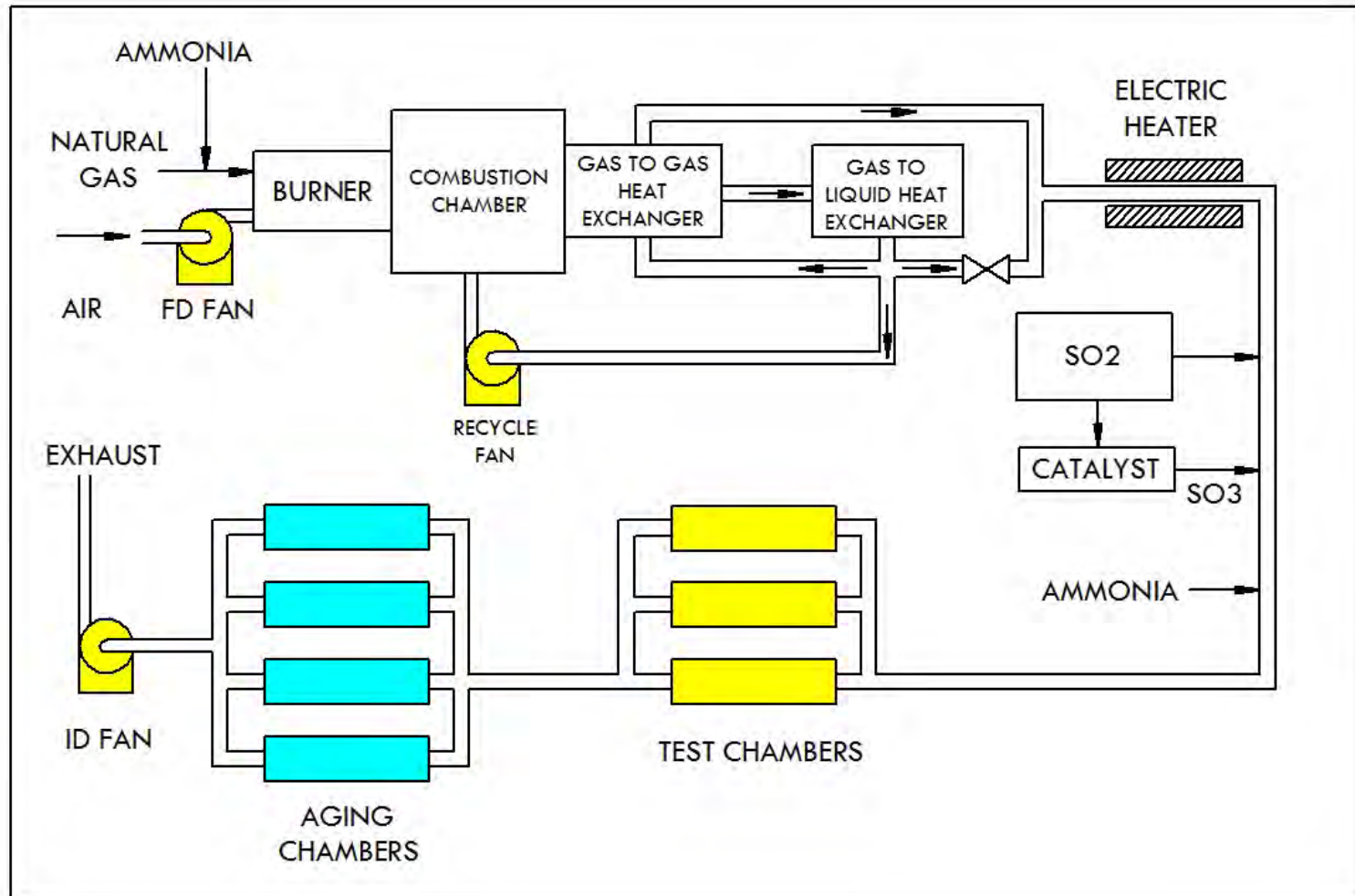
# Catalyst Deactivation Mechanisms

- Poisoning – chemical deactivation of active sites by
- Fouling – Surface deposits and pore structure plugging
- Thermal degradation/sintering – loss of pore structure and active site dispersion

# SCR Catalyst Testing Scales

- Bench-scale:  
test reactor sized for full-length sample elements  
150 mm x 150 mm (6" x 6") cross-section  
combustion based flue gas
- Micro-scale:  
test reactor holds smaller coupons cut from full size elements  
1" x 1" cross-section by 100 to 400 mm length  
Synthetic flue gas – fed by gas cylinders
- Semi-bench(?):  
test reactor cross-section between bench and micro-scales  
less than full length elements  
combustion based flue gas

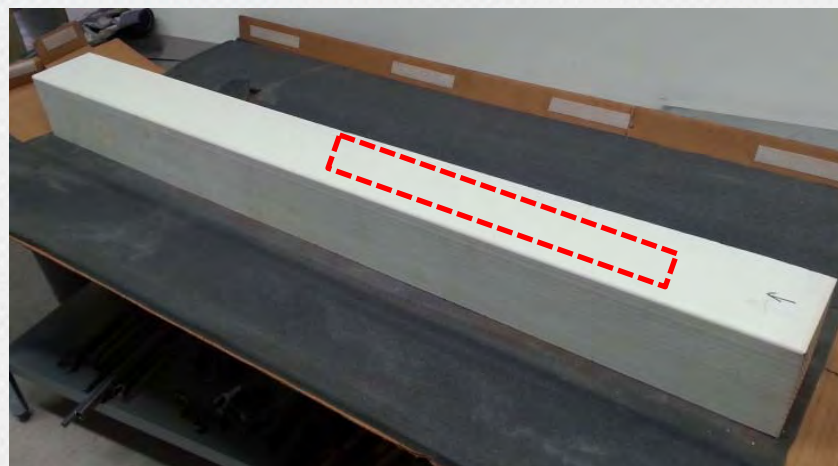
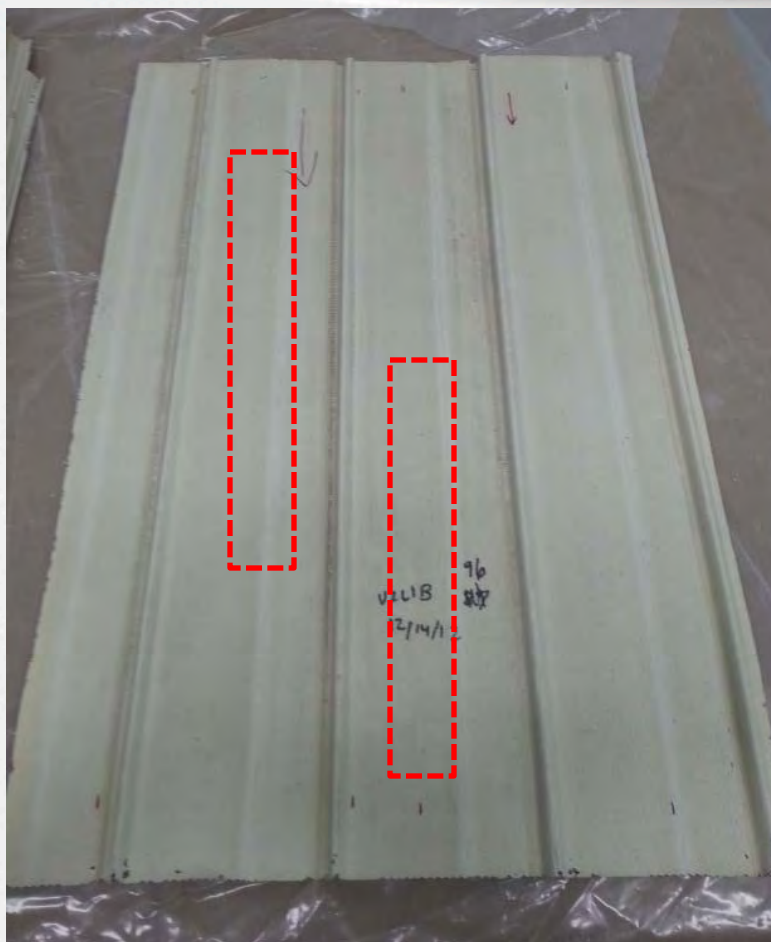
# Bench-Scale Test System



# Features of Bench-Scale Testing Systems

- Combustion based flue gas, with most flexible controls to mimic conditions of full-scale systems – temperature, flow, composition
- Accommodate full-size catalyst elements
- Preserve flow dynamics through the catalyst channels
- Preserve deactivation profile of a full-layer → reaction kinetics/diffusion properties

# Sample Coupons – Full Elements vs Micro-Scale



# SCR Catalyst Structures



Plate



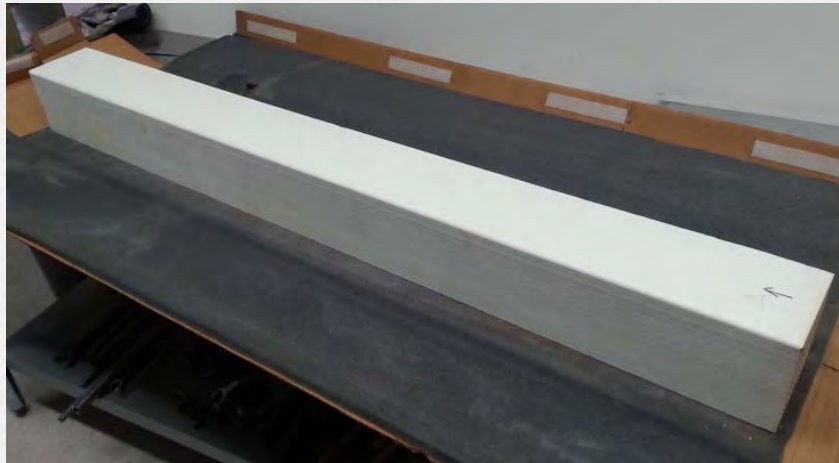
Honeycomb



Corrugated

# Catalyst Sampling – Honeycomb

- Sample size – 1 full block
- Cross-section: 150 mm x 150 mm
- Length: full block length, up to 1350 mm
- Field sampling – 1 block per layer per reactor
- Modules with removable/replaceable element(s)



# Honeycomb Test Elements



# Honeycomb Test Element



# Honeycomb Test Element



# Geometric Measurements - Honeycomb

- Cell Count
- Blocked Cells
- Element Length
- Cross-section
- Inner wall thickness
- Cell opening width

To Determine:

- Geometric Surface Area
- Linear Velocity in Channels



# Catalyst Sampling – Plate type

- Sample size – 150 mm x 150 mm test box with 22 – 26 coupons
- Coupons cut from full plates
- Length: 1 sub-layer, up to 750 mm
- Field sampling – 16 plates per layer per reactor, plates pulled in pairs from any module



# Plate Samples



# Plate Catalyst Sample Coupons



# Plate Samples - Damage



# Geometric Measurements - Plate

- Number of plates
- Coupon Length
- Coupon Width
- Inner box cross-section
- Plate thickness

To Determine:

- Geometric Surface Area
- Linear Velocity in Channels



# Catalyst Sampling – Corrugated



# Geometric Measurements - Corrugated

- Outer Element Dimensions:  
Face cross-section  
Length
- Rely on manufacturer for:  
Specific Surface Area  
Open Area, channel size

To Determine:

- Geometric Surface Area
- Linear Velocity in Channels



# Bench-scale Measurements

- deNO<sub>x</sub> activity,  $k_{\text{NOx}}$   
indicator of catalyst's ability to reduce NOx  
measure deNOx across catalyst, calculate  $k_{\text{NOx}}$   
initial, new/fresh activity –  $k_0$   
measurements after aging / flue gas exposure –  $k_t$   
relative activity =  $k_t/k_0$  indicator of deactivation, remaining lifetime
- SO<sub>2</sub> to SO<sub>3</sub> Conversion  
measure of undesired side reaction  
can vary over time with deposits from flue gas/fly ash
- Differential pressure

# Test Conditions

- Test element loaded in chamber and sealed with insulation
- Flue gas conditions set to closely match plant conditions:
  - Temperature
  - Volumetric flue gas flow rate set to match channel velocity
  - O<sub>2</sub> and H<sub>2</sub>O concentration at catalyst inlet
  - NO<sub>x</sub> and SO<sub>2</sub> at catalyst inlet
  - SO<sub>3</sub> typically not added at catalyst inlet, typical value ~0.5 ppm
- NH<sub>3</sub>/NO<sub>x</sub> ( $\alpha$ ):
  - $\alpha = 1.0$  for deNO<sub>x</sub>
  - $\alpha = 0.0$  for SO<sub>2</sub>-SO<sub>3</sub> conversion

# Sample Conditioning

- Period of exposing catalyst to flue gas at target temperature and SO<sub>2</sub> concentration before performance measurements
- Necessary for catalyst to reach equilibrium
- Complete when deNO<sub>x</sub> Activity and SO<sub>2</sub>-SO<sub>3</sub> stop trending
- Time duration requirements (some disagreement)  
New or Freshly regenerated catalyst: 72 hours  
Catalyst previously exposed to flue gas: 12 hours

# deNO<sub>x</sub> Activity, *k*

- NH<sub>3</sub>/NO<sub>x</sub>, = 1.0
- NO<sub>x</sub> conversion,  $\eta_{NOx}$

$$\eta_{NOx} = \frac{[NOx]_{in} - [NOx]_{out}}{[NOx]_{in}}$$

- deNO<sub>x</sub> activity,  $k_{NOx}$

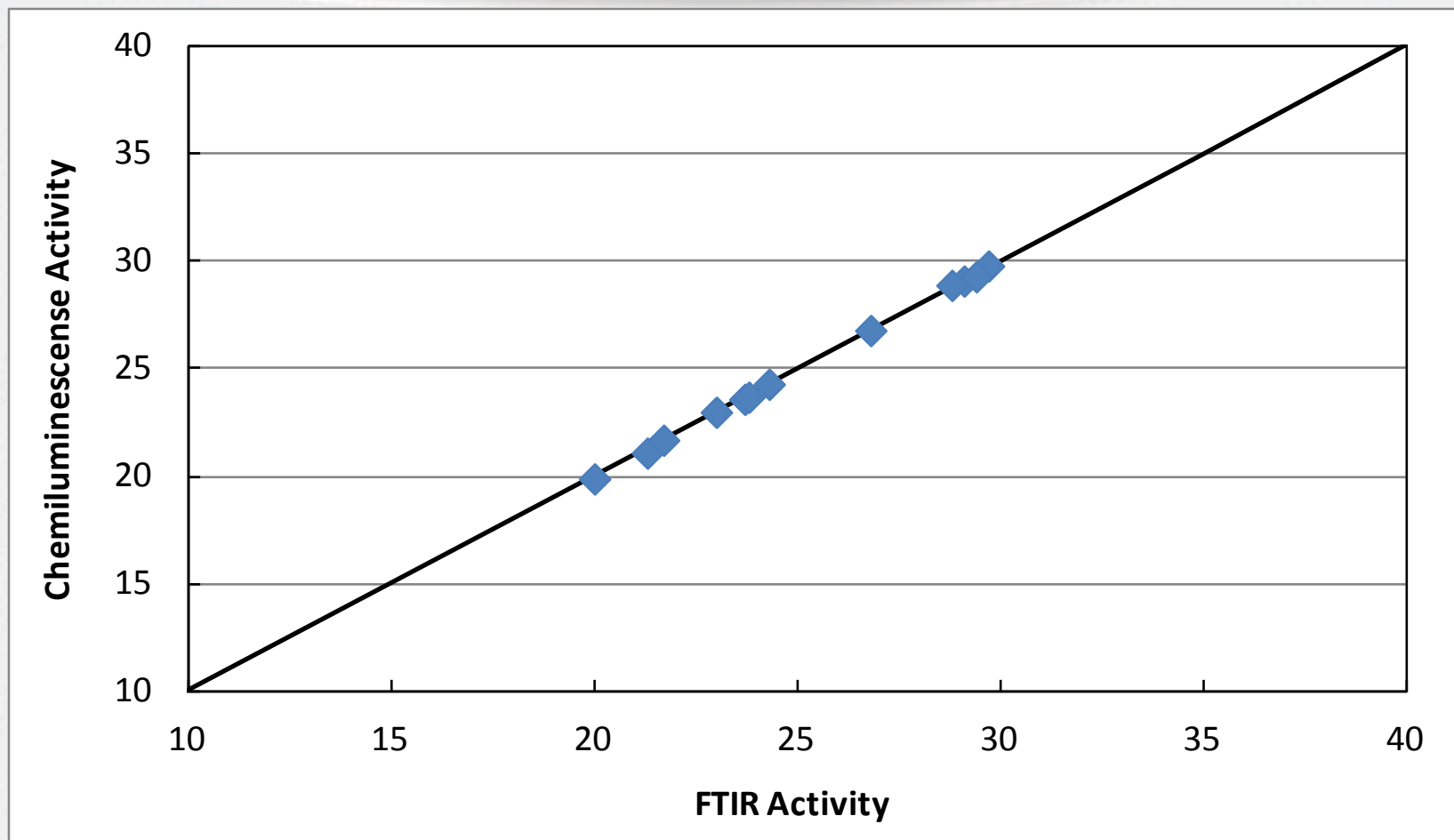
$$k_{NOx} = -AV \ln(1 - \eta_{NOx})$$

- Area Velocity, *AV*

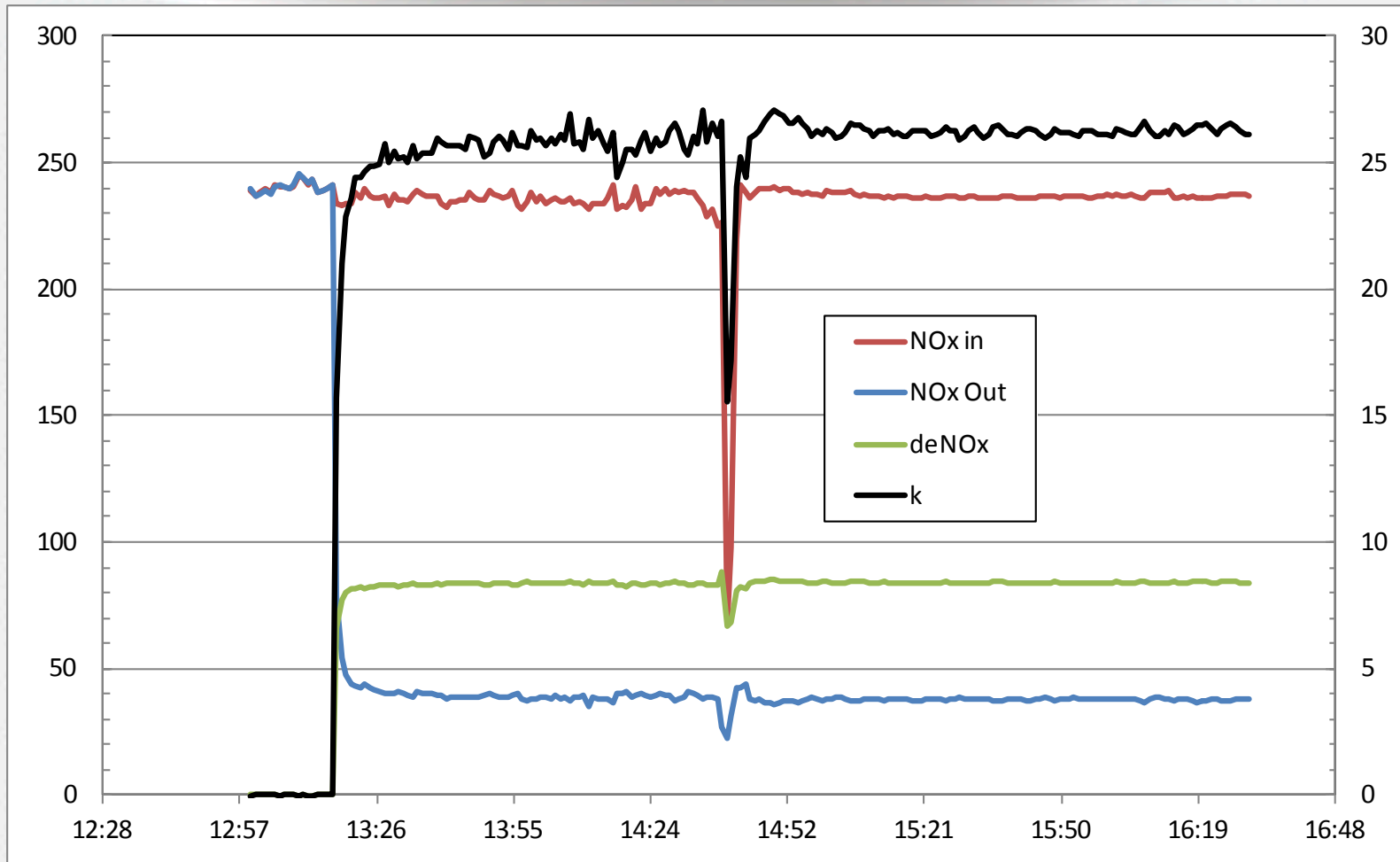
$$AV = \frac{\dot{V}_{fg}}{A_{gs}}$$

- NO<sub>x</sub> concentrations (NO & NO<sub>2</sub>) by FTIR, Chemiluminescence
- NH<sub>3</sub> concentration by FTIR  
IC, TKN (reference CTM-027)

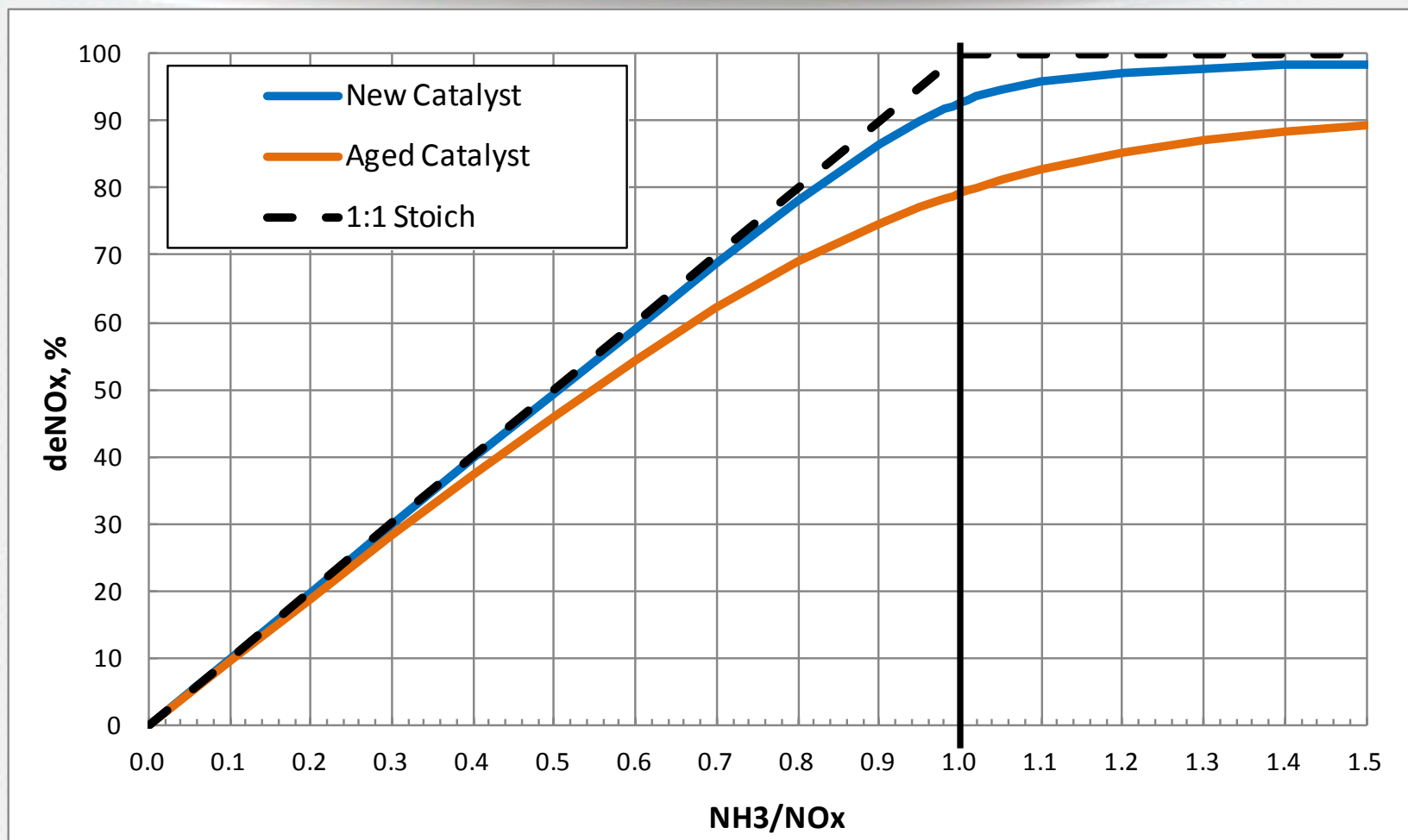
# Agreement in Measurements



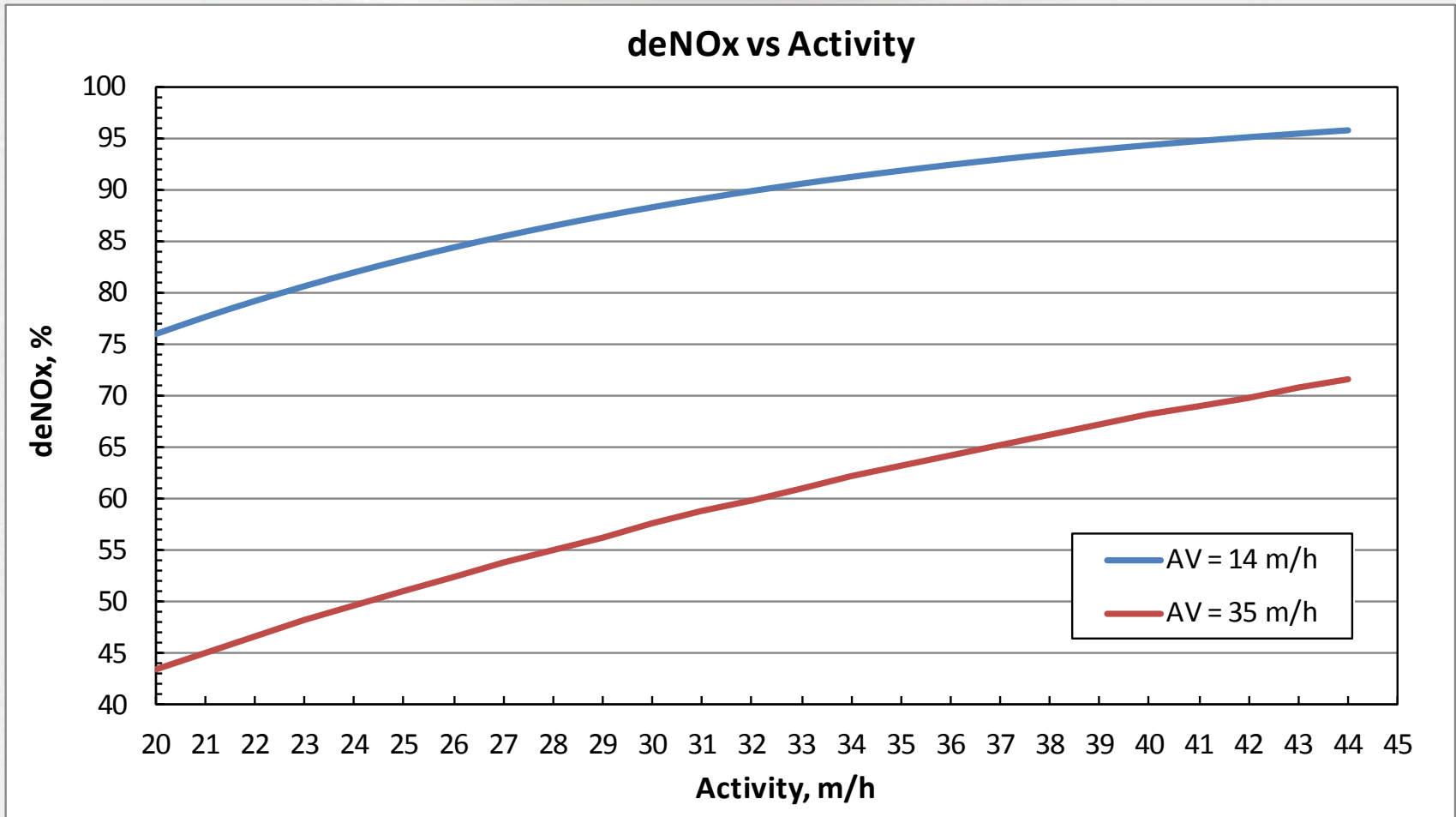
# deNOx Data



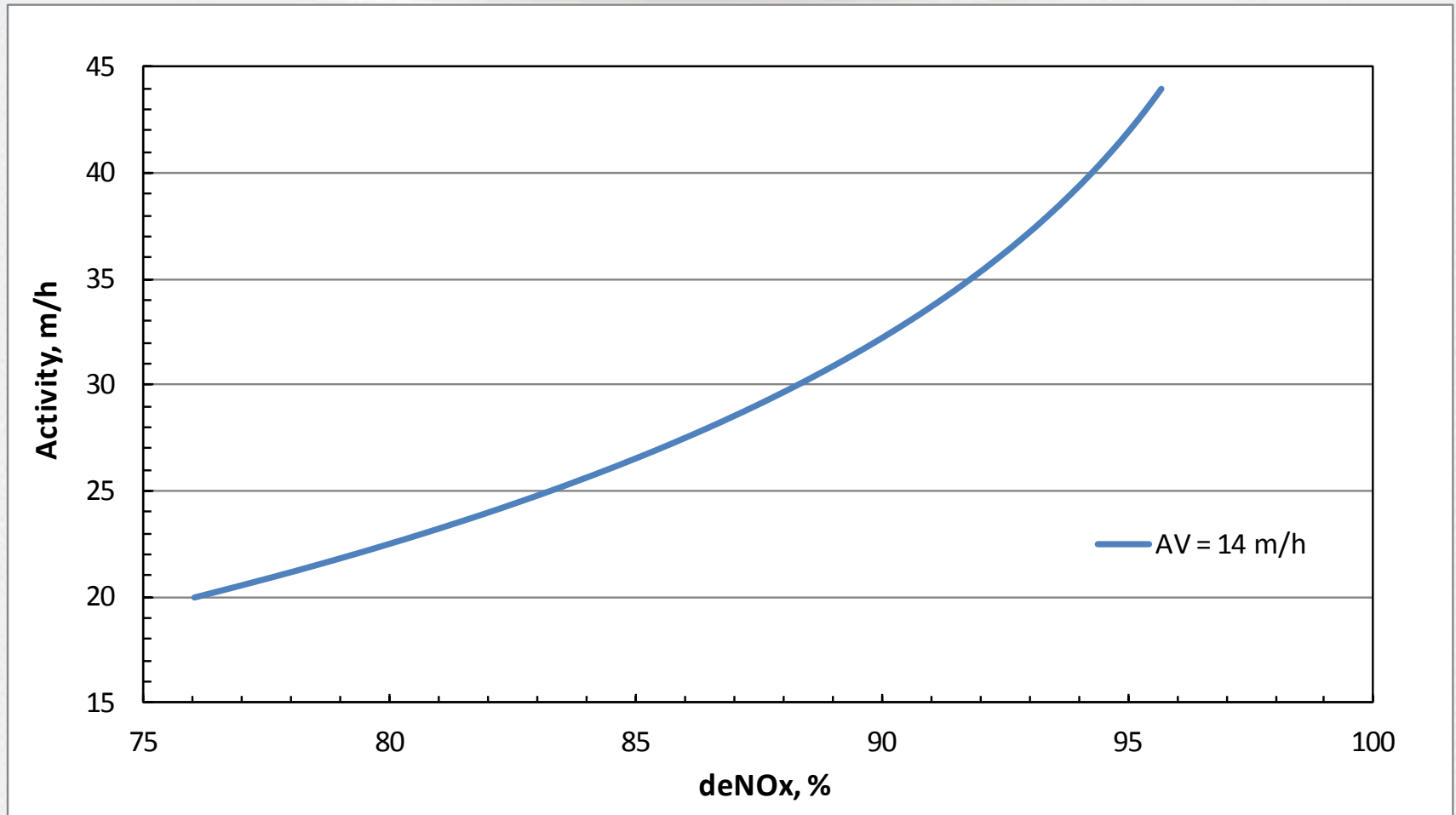
# deNO<sub>x</sub> vs NH<sub>3</sub>/NO<sub>x</sub>



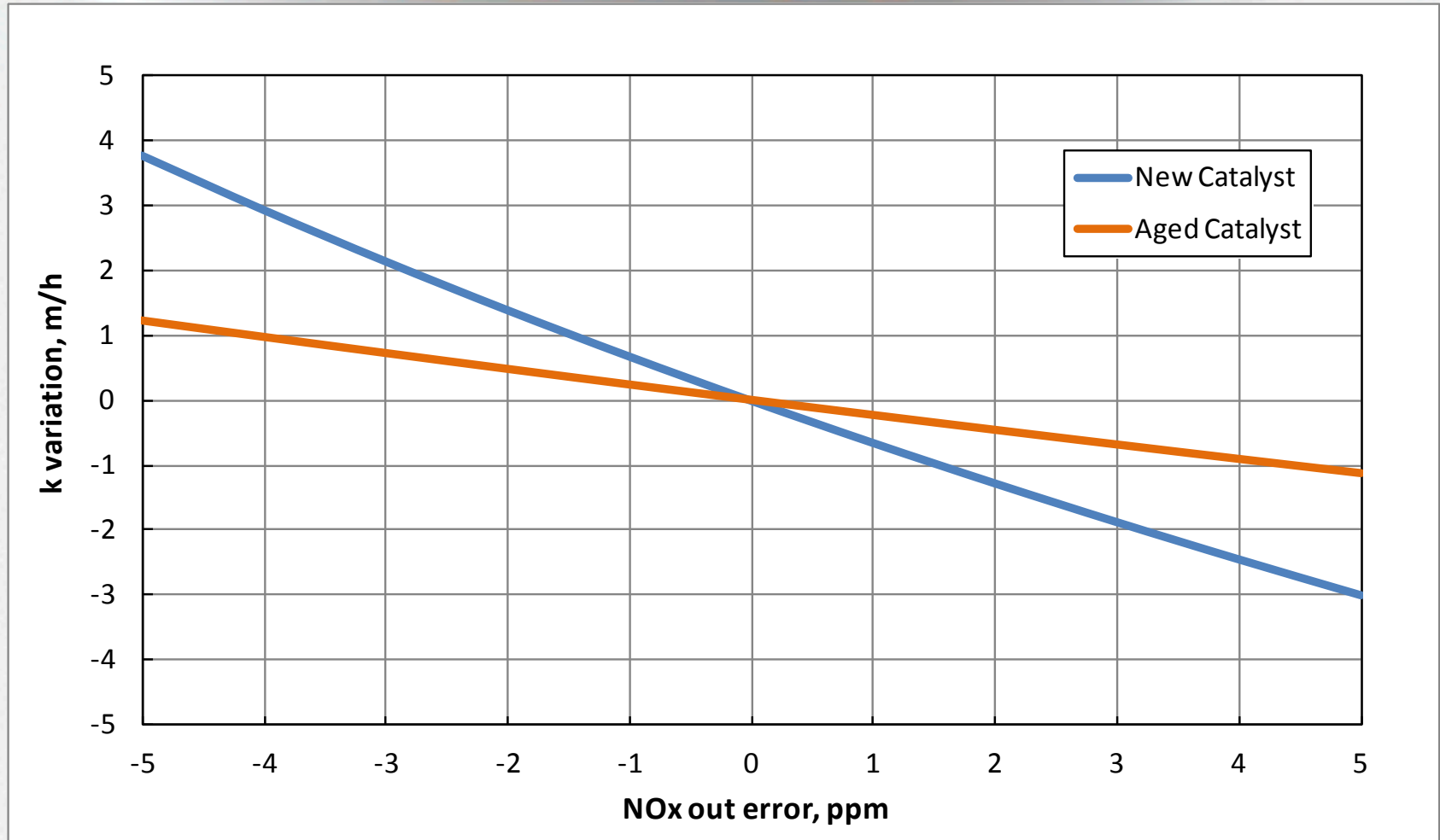
# deNOx Performance vs Area Velocity



# Activity vs deNOx



# Sensitivity – k variation vs NOx out variation



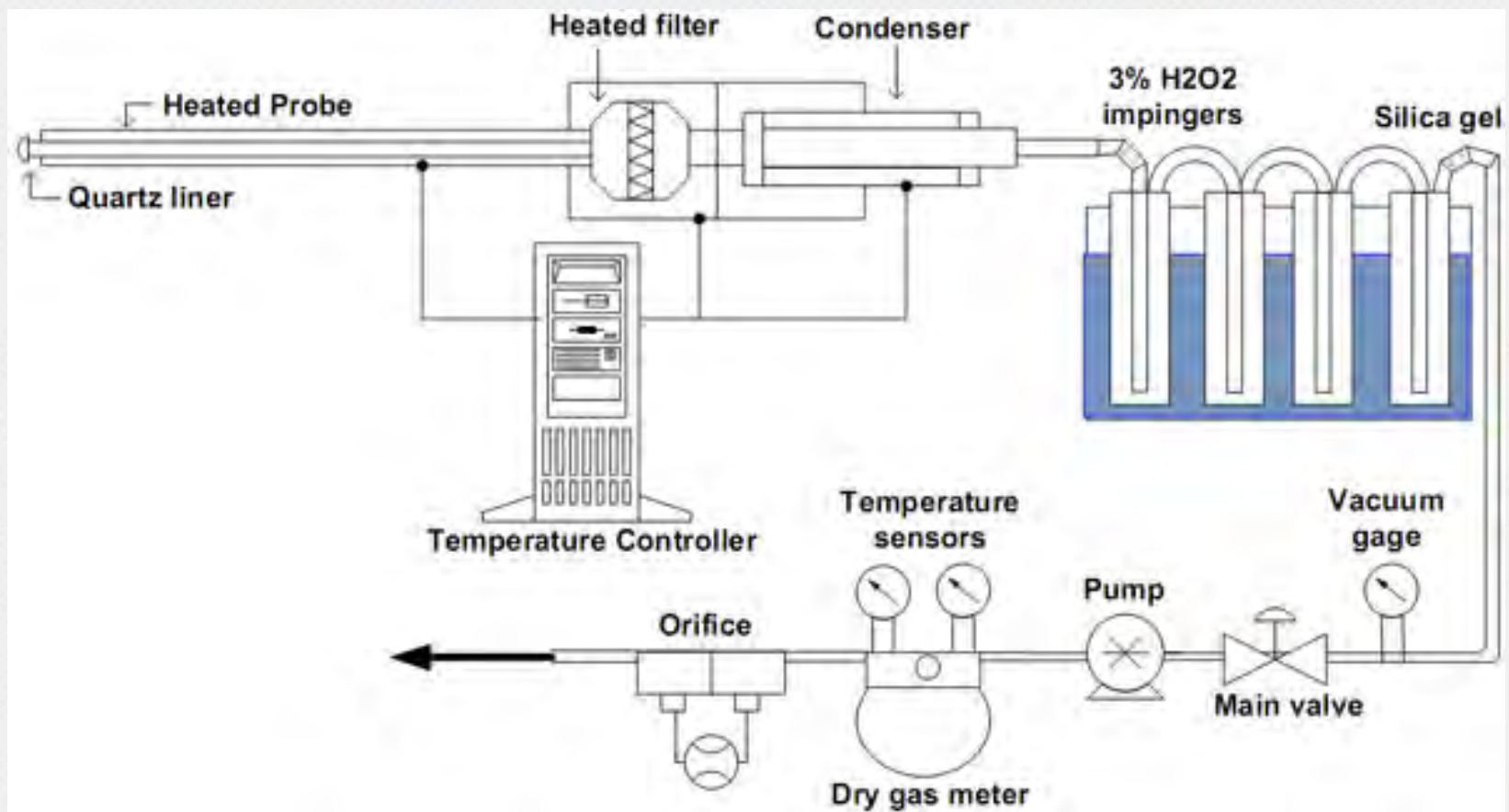
# SO<sub>2</sub> to SO<sub>3</sub> Conversion

- Calculation:

$$SO_2 \text{ Conversion} = 100 \times \left( \frac{[SO_3]_{out} - [SO_3]_{in}}{[SO_2]_{in}} \right)$$

- SO<sub>2</sub> concentration by FTIR, UV
- SO<sub>3</sub> concentrations by controlled condensation (ref Method 8A)

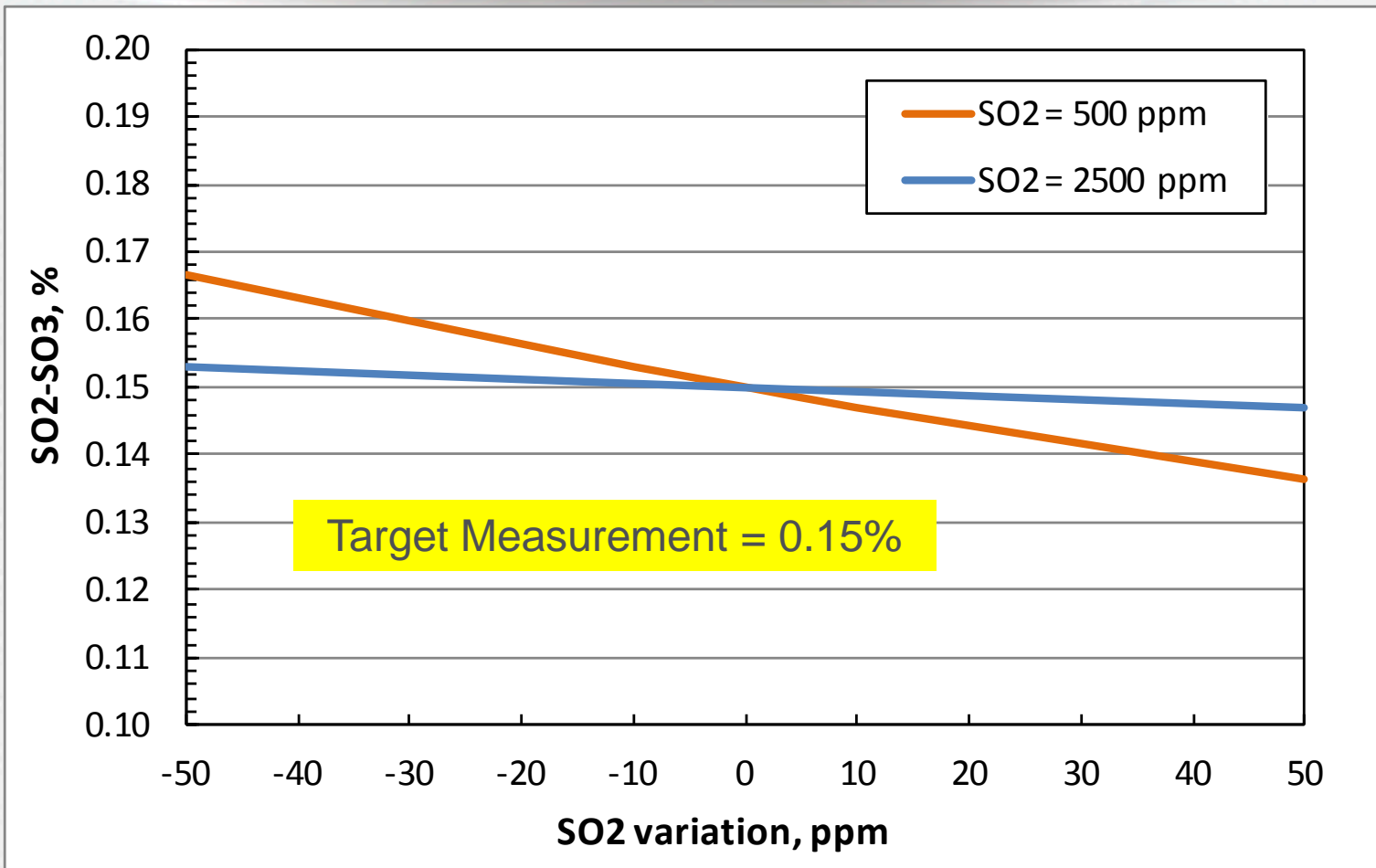
# Controlled Condensation for SO<sub>3</sub> Sampling



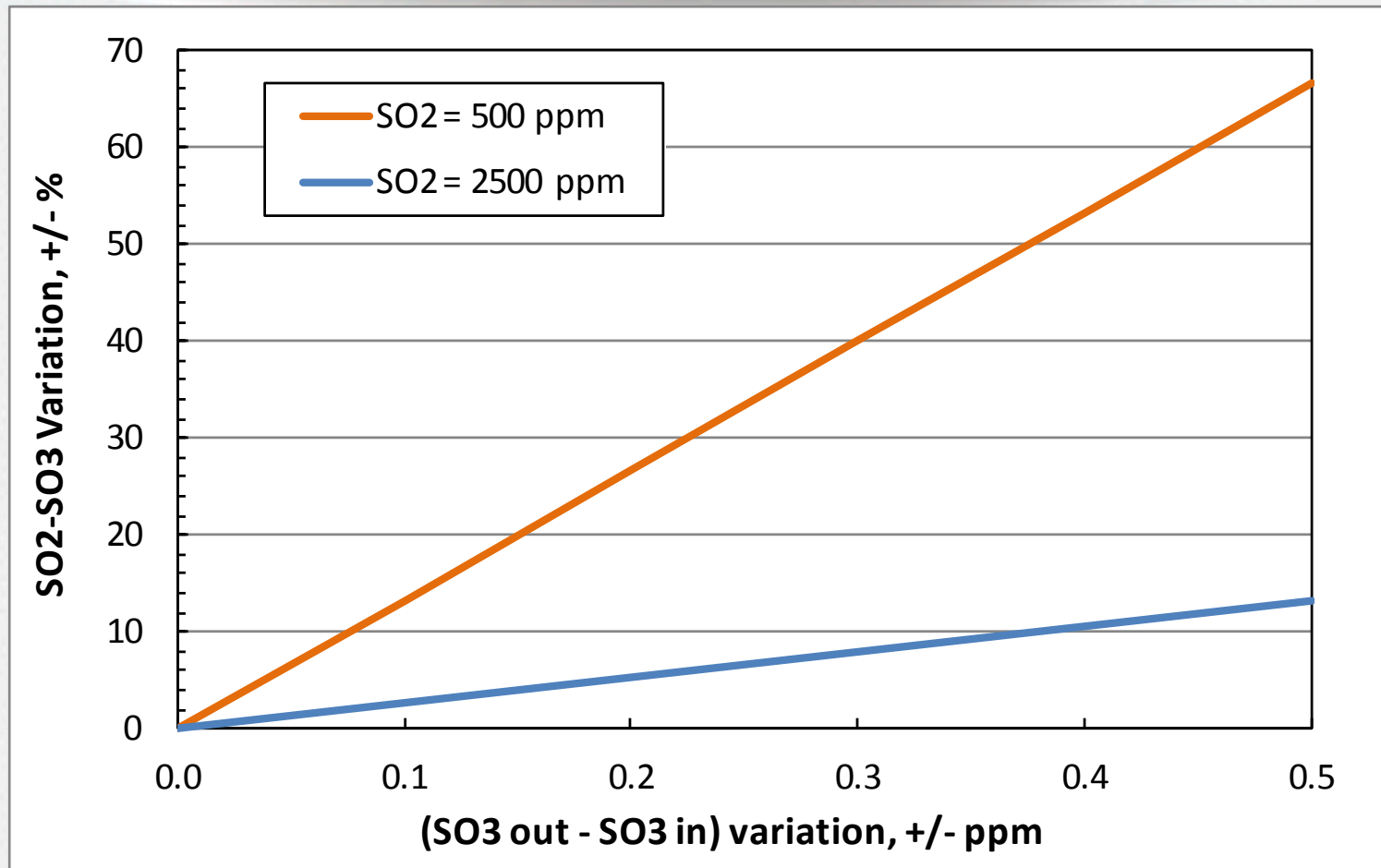
# SO<sub>2</sub>-SO<sub>3</sub> Measurement Challenges

- Low conversion measurements with low inlet SO<sub>2</sub> is difficult
- Some sensitivity to variation/error in SO<sub>2</sub> concentration
- Huge sensitivity to variation in SO<sub>3</sub> measurement

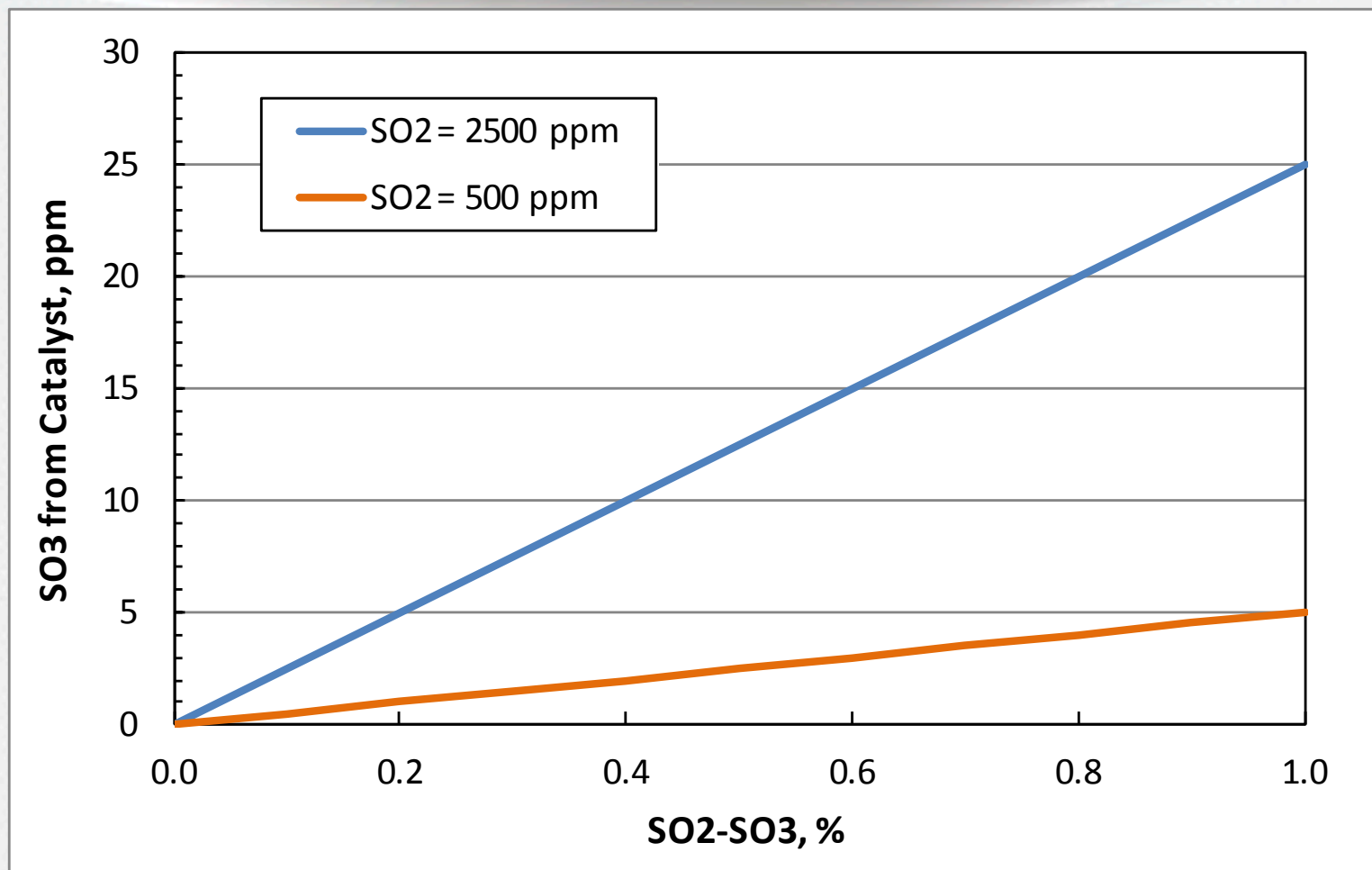
# SO<sub>2</sub>-SO<sub>3</sub> vs SO<sub>2</sub> Variation



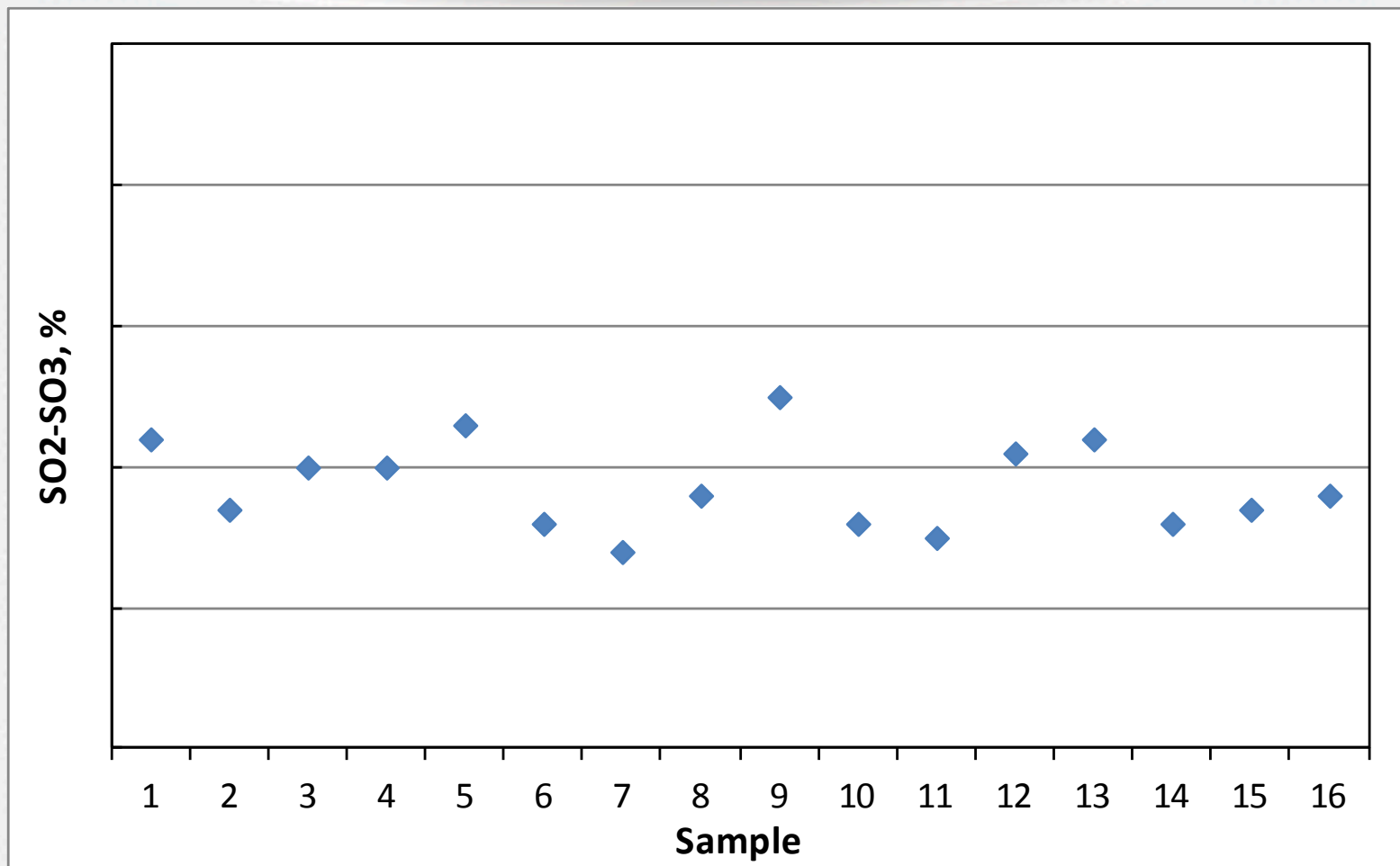
# SO<sub>2</sub>-SO<sub>3</sub> vs SO<sub>3</sub> Variation



# SO<sub>3</sub> Produced by Catalyst



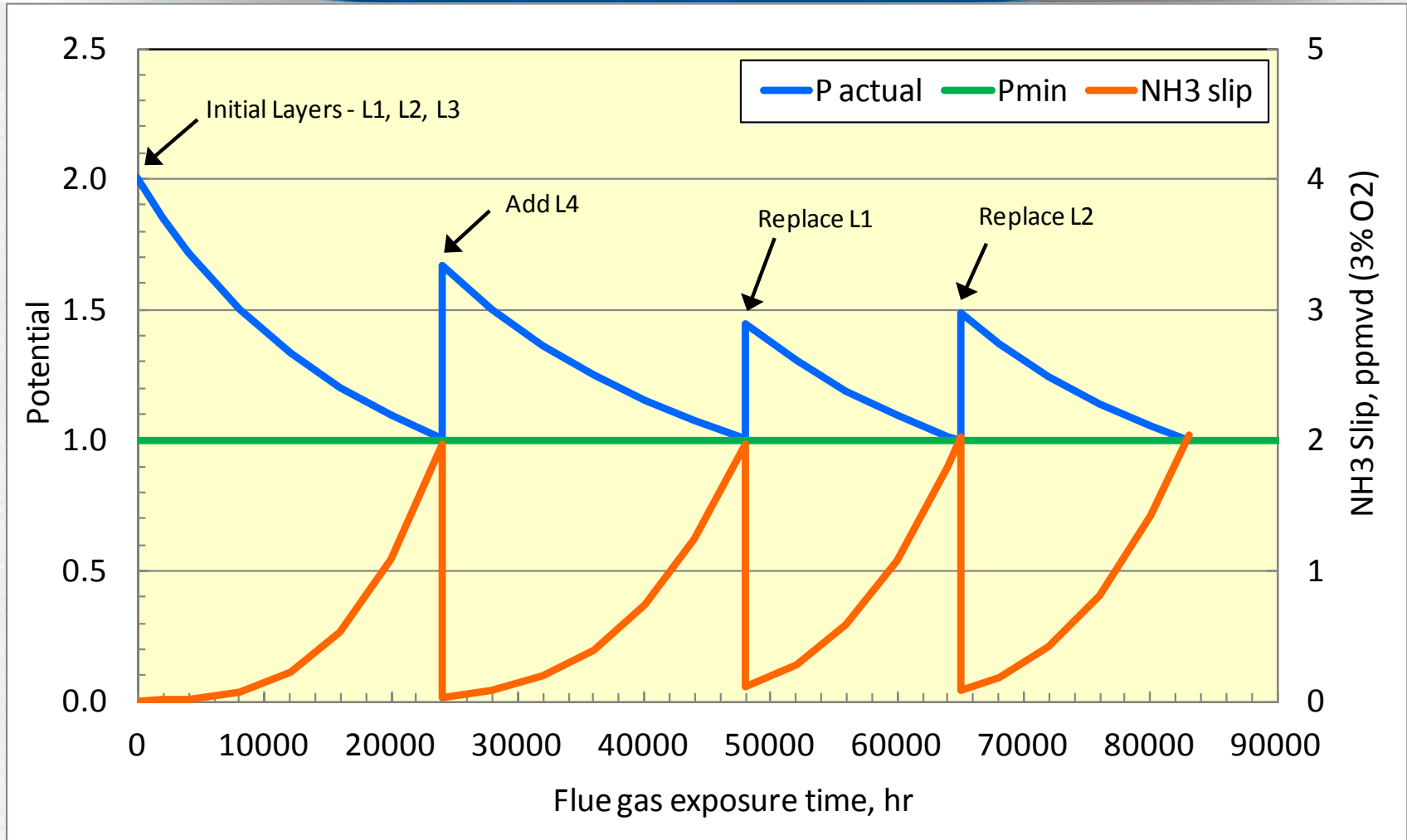
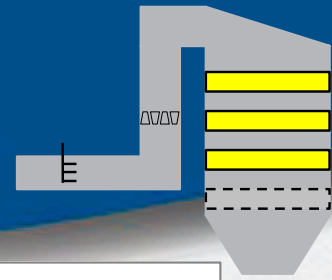
# SO<sub>2</sub>-SO<sub>3</sub>, Sample-to-Sample Variation



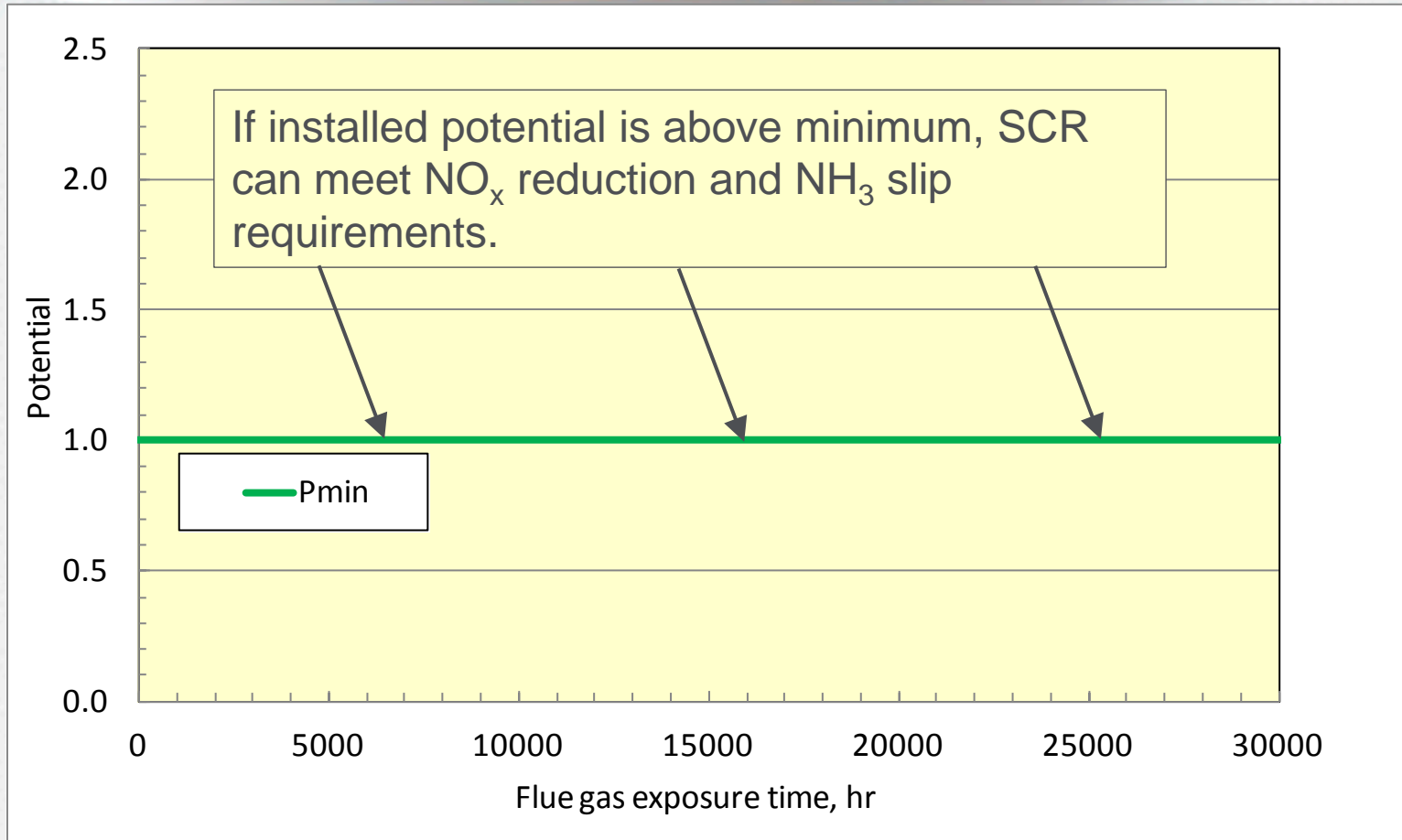
# Catalyst Management

- Maintaining SCR catalytic potential to achieve desired NO<sub>x</sub> reduction, ammonia slip limit . . . and Hg oxidation performance
- Determining deactivation trends and forecasting catalyst life based on sample activity measurements
- “What if . . .” projections for variation in operating conditions, changes in target NO<sub>x</sub> reduction performance, etc

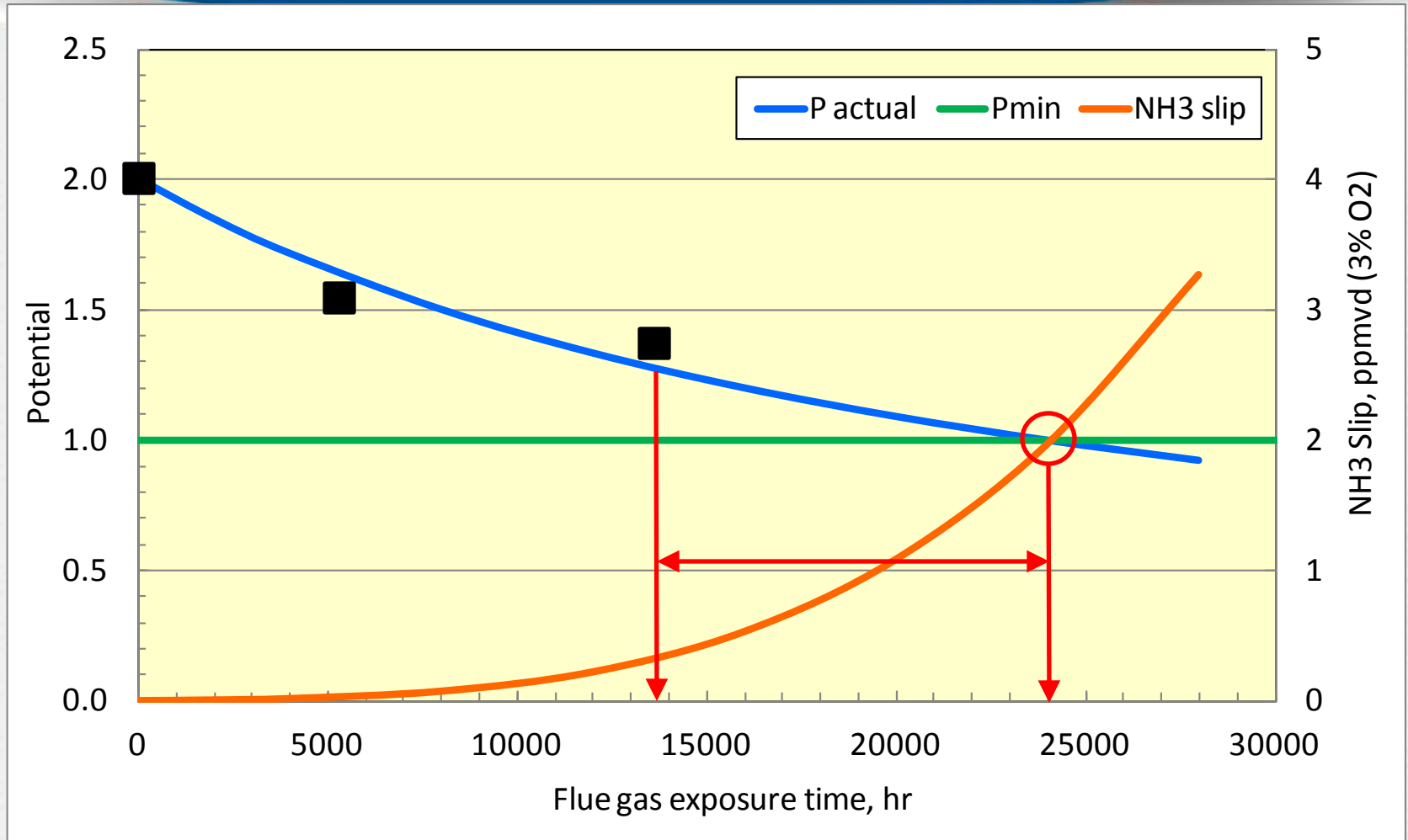
# Basic Catalyst Management Plan



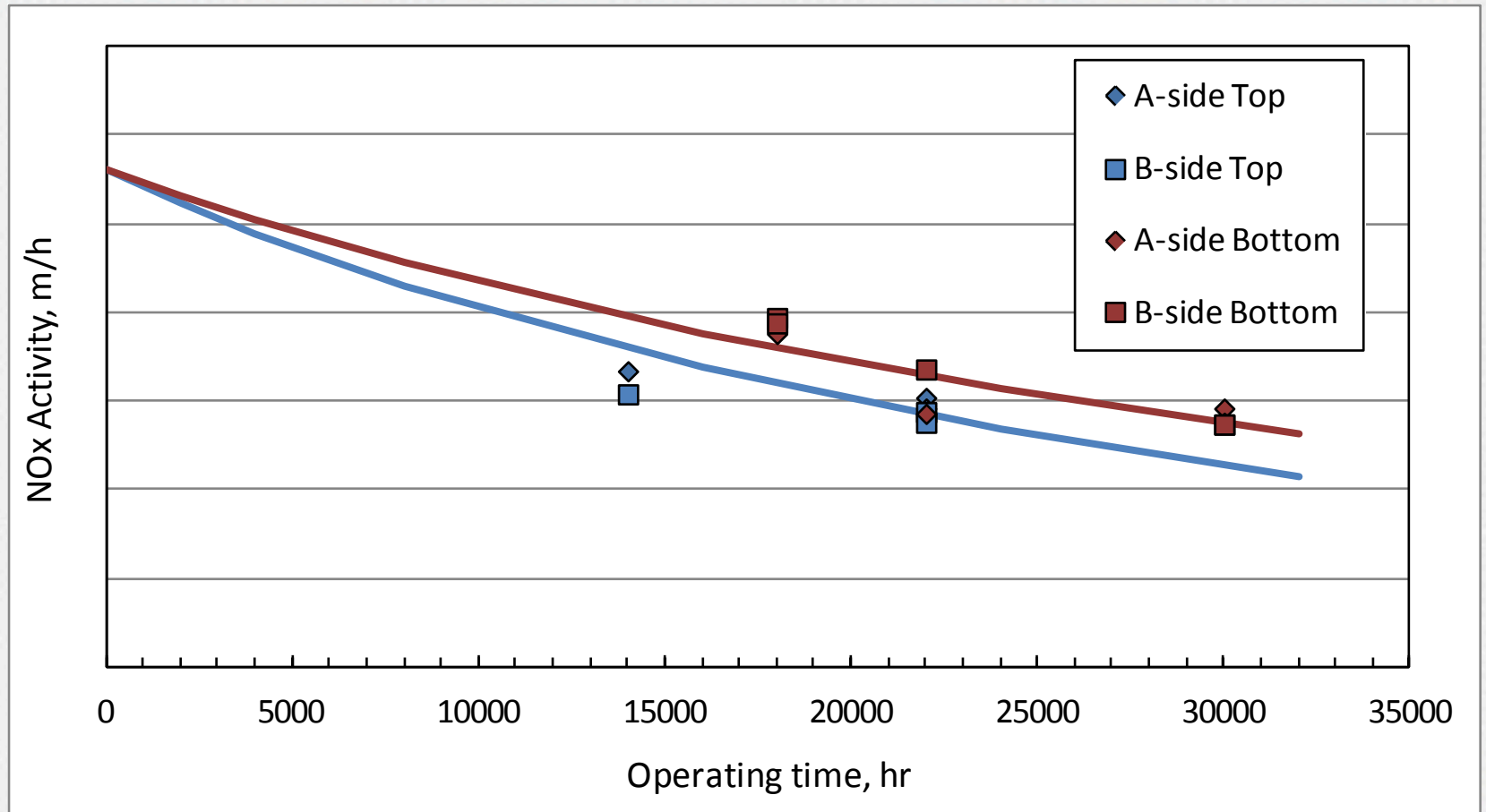
# Minimum Potential



# Catalyst Deactivation & Lifetime



# deNOx Activity History Data



# Summary

- SCR catalyst deactivates
- Bench-scale testing is a proven method for quantifying catalyst performance – especially individual layers
- Bench-scale testing data helps to optimize catalyst replacement strategy and scheduling

*Thank You!*

