

REINHOLD ENVIRONMENTAL Ltd.



2014 NO_x-Combustion Round Table & Expo Presentations

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

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Keeping the SCR Fit 2014 NO_x Roundtable

Philip Elliott
February 10, 2014

steag

Agenda

- **SCR and Catalyst Design**
- **During the Outage**
- **After the Outage**
- **Wrap Up and Conclusions**



SCR and Catalyst Design

Initial Design Considerations

Fuel Burned

PRB

Bituminous

Lignite

Natural Gas

Biomass

Flow Rate of Flue Gas

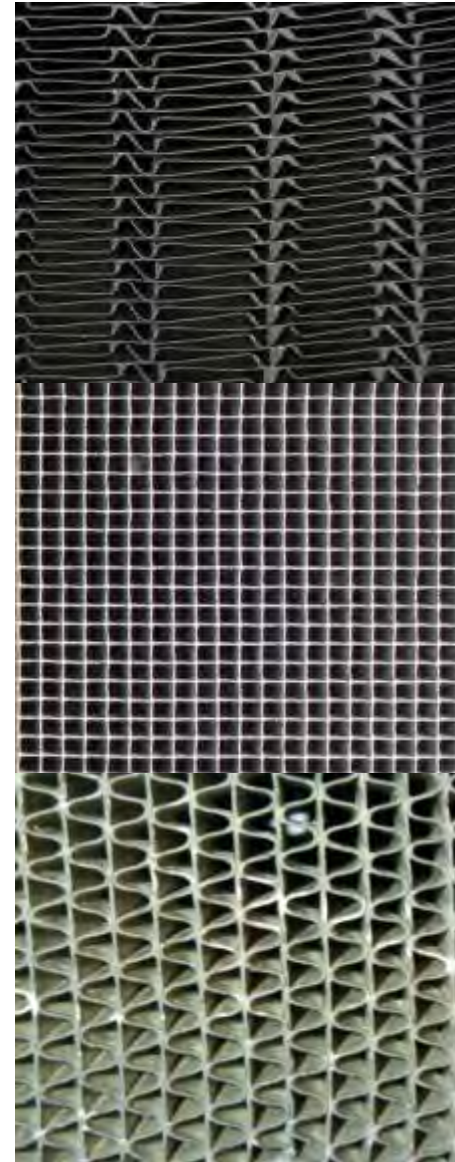
Want 13 – 15 feet per second

Reagent Use

Anhydrous Ammonia

Aqueous Ammonia

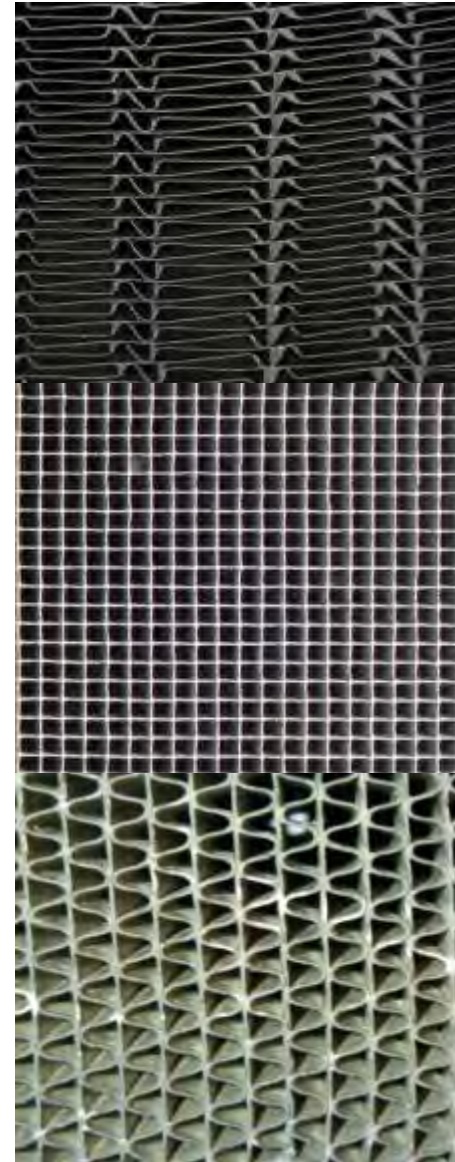
Urea



Initial Design Considerations

Location

- **Access to Catalyst Loading**
- **Catalyst Storage**
- **How will Catalyst be Exchanged during Outages**



Soot Blowers or Sonic Horns

- **Fuel Determination is Key!**
- **Sonic Horns Effective to about 20 – 25 foot depth to opposite wall. If greater than 20 – 25 feet, should considered sonic horns on both sides.**
- **For Catalyst with excess ash should consider Soot Blowers. To protect the catalyst from erosion, the height above the catalyst is critical! Combination of nozzle selection, air pressure and volume / type of ash to determine the correct height.**
- **Cleaning mechanism on the front wall should be considered if there is ash pile-up.**
- **Combination of sonic horns (with possible addition of air cannons and sootblower may be required.**



LPA Screens

Determine if Unit Needs LPA Screen

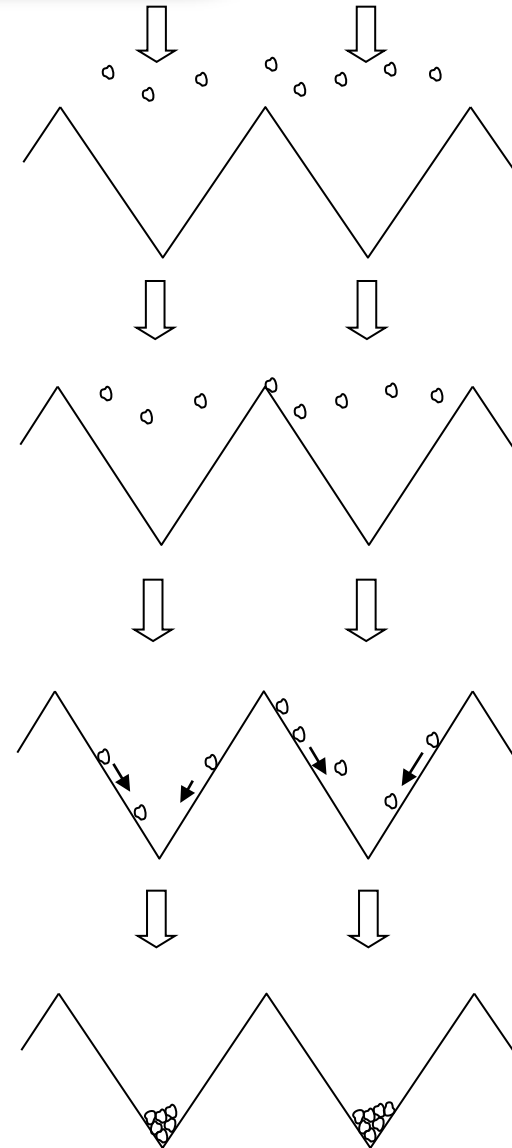
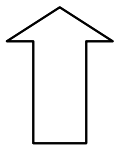
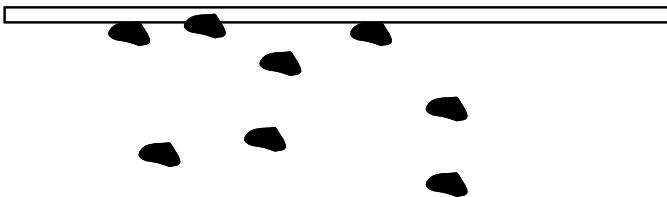
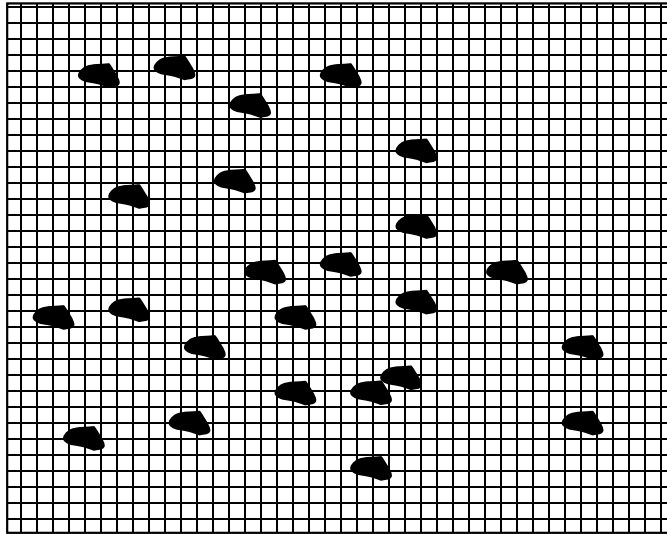
1. Ash in Hopper Can Provide Indication

What Type of Design

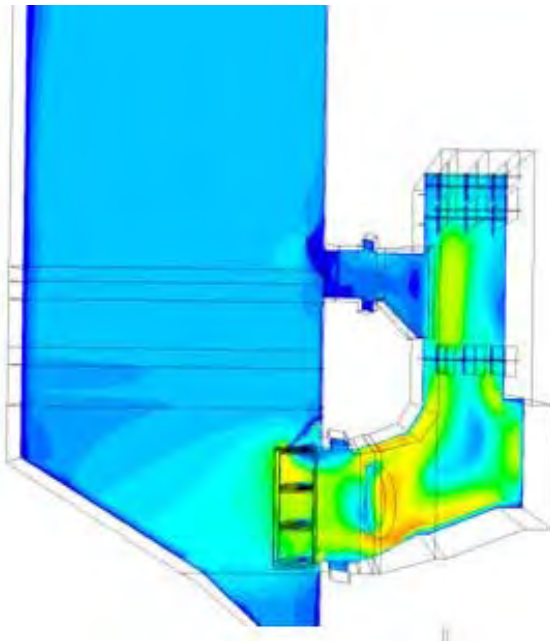
1. Pressure Drop
2. Erosion Across Screens
3. Ease of Maintenance



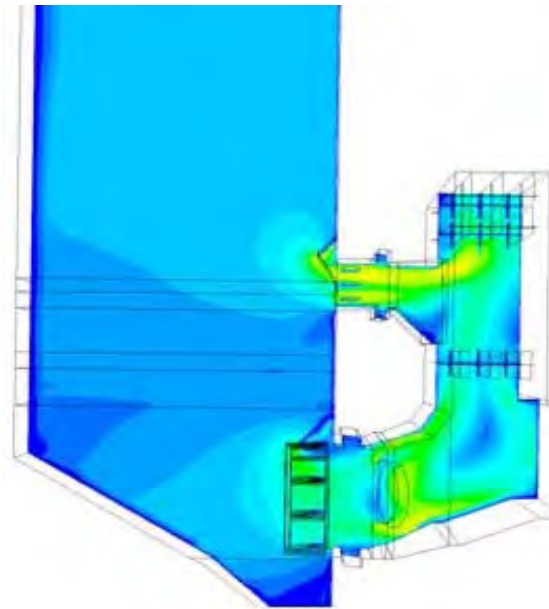
LPA Screen



Any SCR Design Should Go through CFD Modeling



Before



After

Catalyst Design and Types

What Type of Catalyst?

Honeycomb, Plate or Corrugated

Longevity – plate or honeycomb Catalyst

Catalyst Pitch Selection

Fuel Type is critical to the catalyst selection

PRB fuels – larger pitch catalyst (8.2m or 9.3mm)

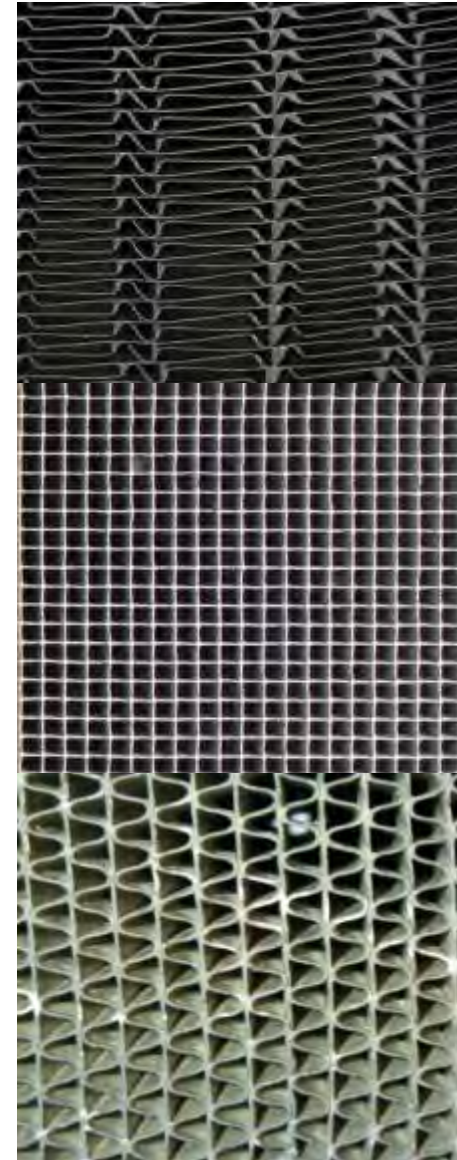
Bituminous – smaller pitch catalyst (7.1mm or 7.4mm)

Gas – smallest pitch (3 mm)

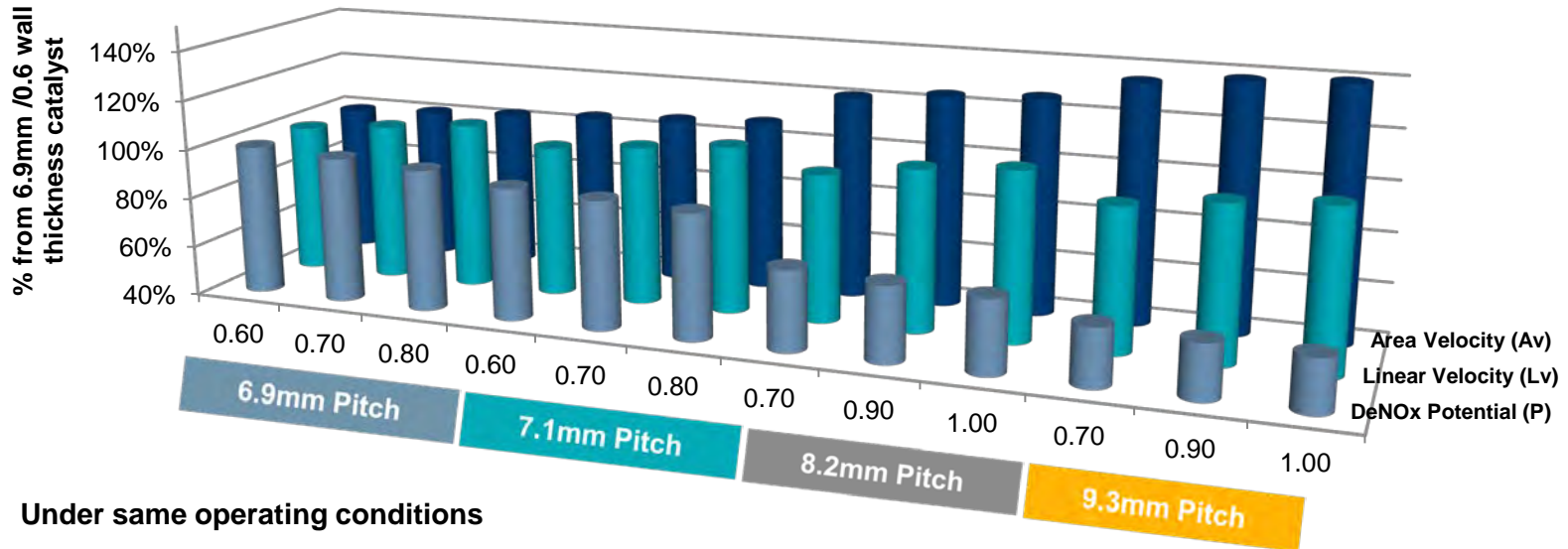
Catalyst wall thickness

The thicker the wall, the greater longevity of the catalyst.

Historically, 6.9mm pitch was installed moving to much larger pitch catalyst.



What do pitch and wall thickness really mean?



Under same operating conditions

Linear velocity stays somewhat constant with roughly a 10% deviation

Area velocity significantly increases.

Potential significantly decreases – nearly 40%.

Catalyst Design

SO₂ Oxidation in the SCR:

The SO₂ oxidation across an SCR reactor is a function of the:

- Total amount of catalyst installed
 - Catalyst mass
 - Catalyst wall thickness
 - V₂O₅ content
 - V₂O₅ distribution
- Temperature
- SO₂ concentration
- O₂ content
- SO₃ concentration at the SCR inlet

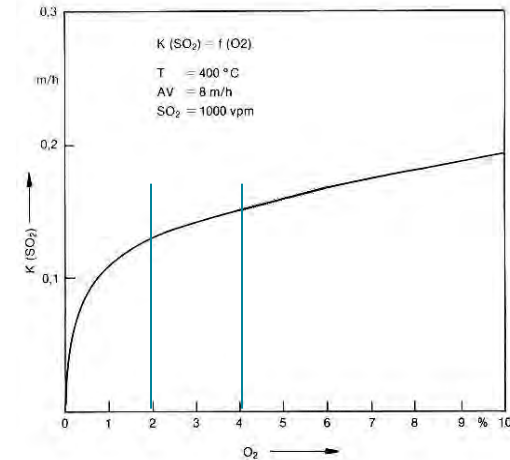
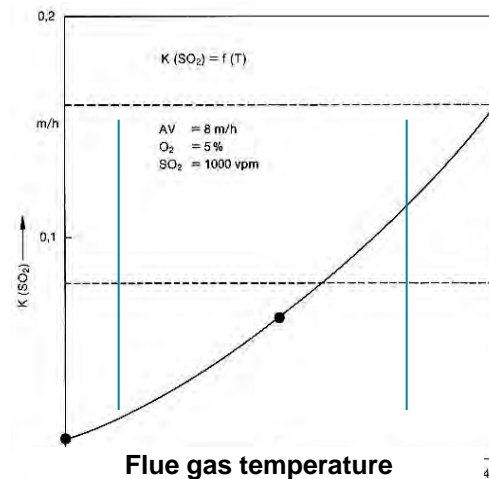
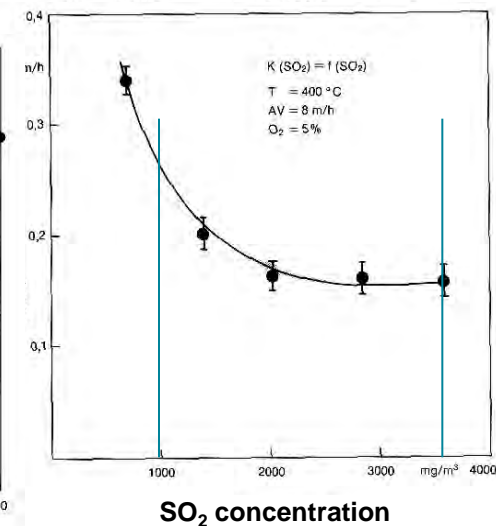


Figure 5



Effect of Temperature on SO₂ Conversion Constant



Effect of SO₂ Concentration on the Conversion Constant

Outage Time - SCR Inspections

SCR Inspections

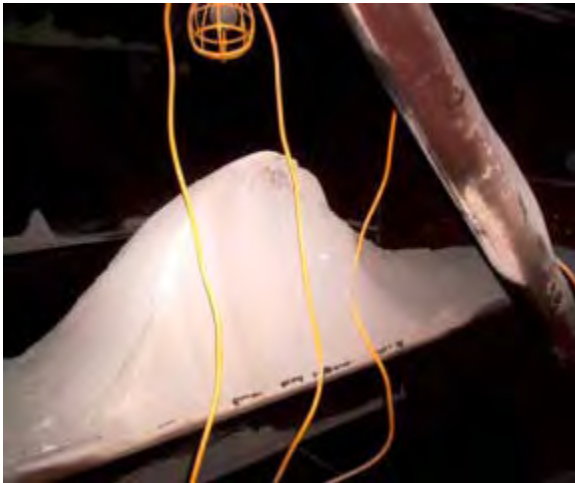
Inspections Should Cover:

- Ammonia Injection Grid
- SCR Ductwork, Insulation, and Lagging
- Turning Vanes
- Bypass Dampers and Expansion Joints
- Rectifier Hood
- Catalyst Layers



SCR Inspections

What Can Be Discovered!



SCR Inspections



**Different issues
found during
inspections**



Catalyst Samples

Plate Catalyst

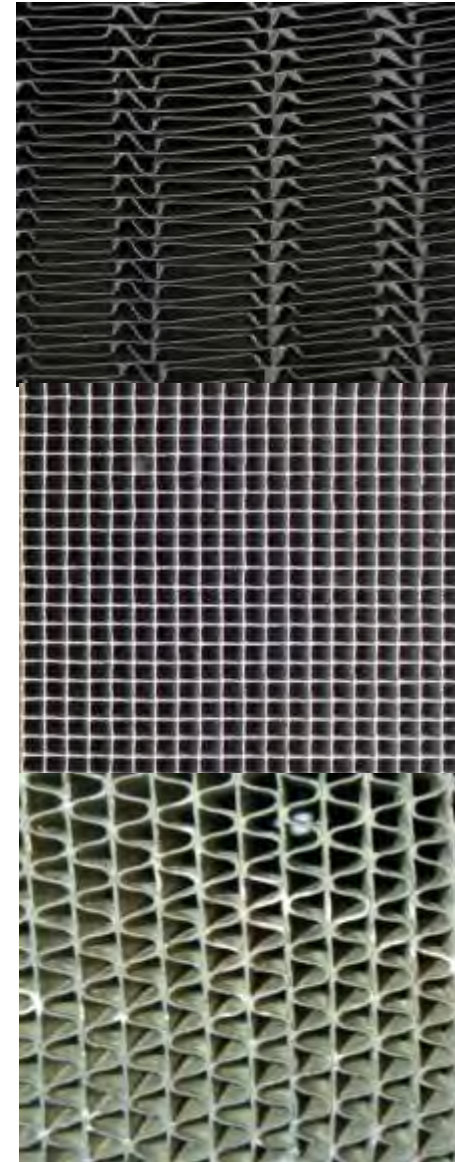
Need at least 6 pairs of plates in different locations

Honeycomb Catalyst

One Log per Reactor

Corrugated Catalyst

One Log per Reactor



Catalyst Samples

- **Samples send to Testing Facility**
 - **Packaging / marking of samples:**
 - **Mark the following on each plate or log:**
 - Unit #
 - Layer Number
 - Direction of Flow
 - Location where sample is taken
 - Packaging of samples
 - STEAG recommends wood crate

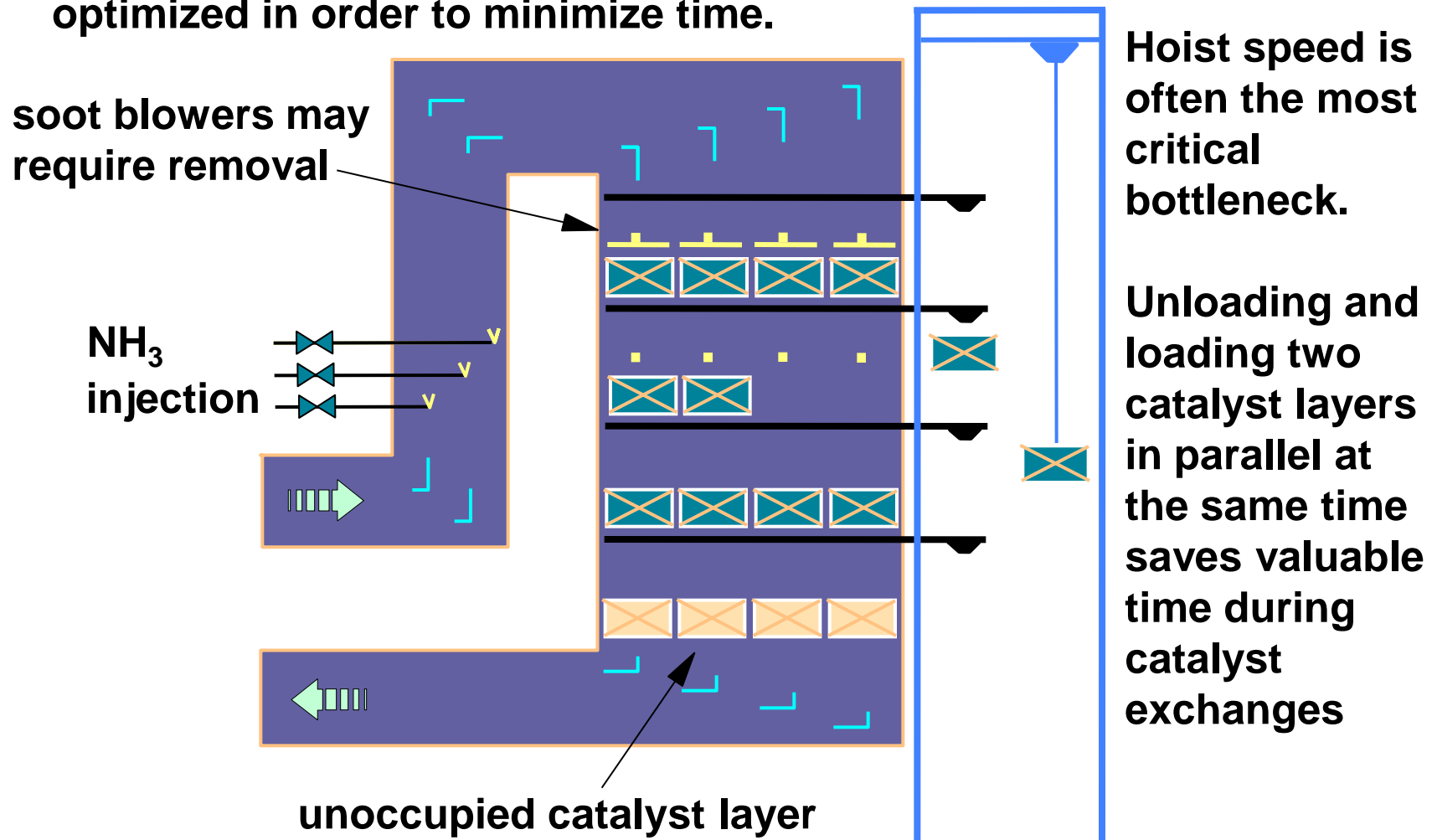


Outage Time – Catalyst Logistics

Catalyst Logistics

Catalyst Loading System:

Unloading and loading of catalyst modules must be logistically optimized in order to minimize time.



Planning for Exchange

Minimum 6 Months Planning

Where is Removed Catalyst Going?

- **Regeneration or Disposal**
- **If Regeneration – Dry Clean**

Where is Catalyst Stored During Outage?

Backup for Hoist

Type of Trucks



Catalyst Loading:



Effective catalyst exchange concepts require advanced logistical planning in order to eliminate critical bottlenecks and minimize unit downtime.

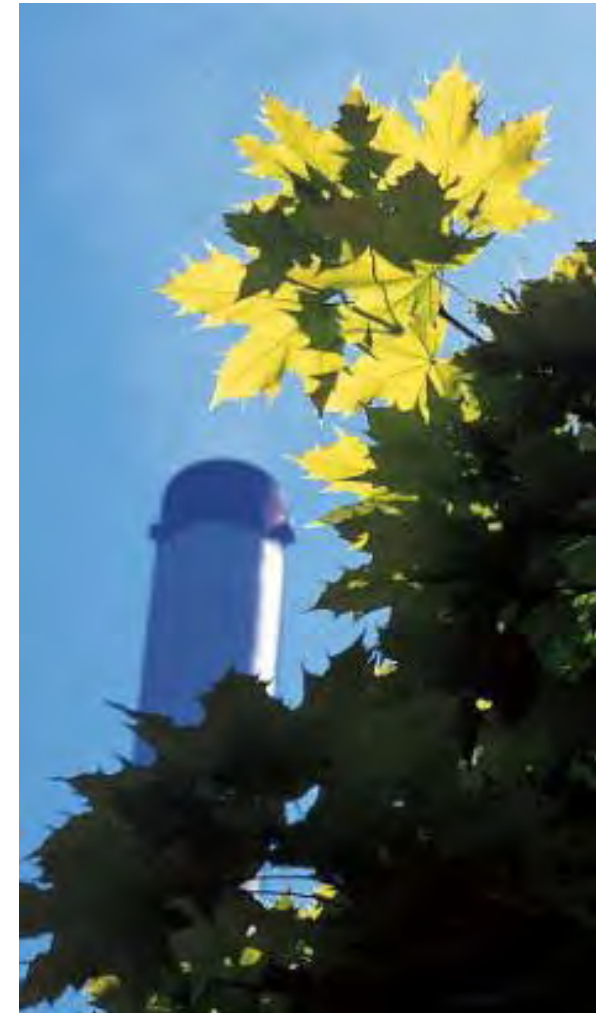


Catalyst Seals

Purpose is to Minimize Flue Gas Bypass

Make Easy to Install

Make to Use Again



Outage Time - Cleaning of Catalyst

The Effects of Catalyst Pluggage



Catalyst pluggage leads to:

- Flue gas maldistribution through the catalyst channels
- Loss of SCR performance through loss of available DeNO_x Potential
- Ammonia Slip (NH₃ slip)
- Excessive pressure drop
- Catalyst erosion damage

Cleaning in catalyst cells / channels

There are a variety of offerings:

High Pressure Washing

If all ash is not removed, it will be hardened.

Water will dissolve compounds which can be deposited on catalyst (deactivation and conversion rate issues can develop)

Weakening of catalyst.



Air Lancing

If catalyst is hardened in cells – this technology is not as effective.

Scraping & Poking

Mechanical damage can be massive.

Not effective if it is not a short plug.



Reactor Vibration

Installation of mechanical vibrators on support beams.

Minimal success has been achieved.

Issues with hardened ash.

STEAG Patented - Dry Ice Blasting

What is it?

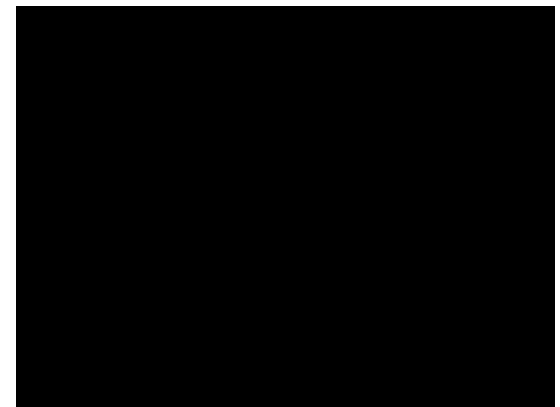
- In the reactor process for removing pluggage.
- Performed after the layers are vacuumed.
- A reactor can easily be cleaned in the outage.
- Can be used on both plate and honeycomb.

Why does the process work?

- There is compressed air force which will push the channel ash plug out of the catalyst.
- The Dry Ice temperature acts to contract the plug assisting the air force.

What is Dry Ice?

- Dry ice is the solid form of carbon dioxide Dry ice sublimates at $-78.5\text{ }^{\circ}\text{C}$ ($-109.3\text{ }^{\circ}\text{F}$) at atmospheric pressures.



STEAG US Patent # 8,268,743

STEAG Patented - Dry Ice Blasting

Is it Safe?

- Air Monitoring of reactors showed no increase in CO₂ from the dry ice.
- Appropriate PPE equipment is worn for protection from the flyash entrainment.

What about damage to the catalyst?

- STEAG has been developing for nearly 3 years this process.
- Catalyst samples have been removed and analyzed to detect any damage of the catalyst. No damage has been seen from the ice blasting process.
- The pluggage and blinding layers are removed.



STEAG US Patent # 8,268,743

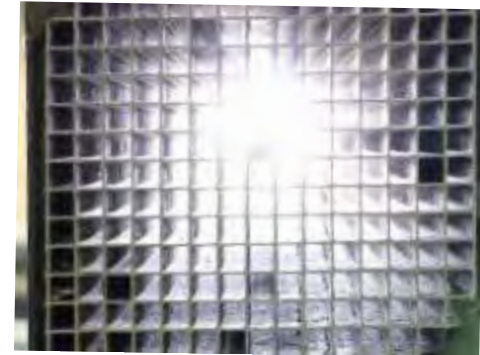
Comparison of Different Cleaning Techniques



Removal Systems	Benefits	Challenges
Vacuuming	Large ash removal	Top ash only, does not clean the channels.
Shakers	Large ash removal	Very labor intensive. Have to remove boxes for module.
High Pressure Wash	Large ash removal	On-site plate removal SO ₃ => H ₂ SO ₄ & Fe ₂ O ₃ deposition on catalyst – Higher conversion rate.
Air Lancing	Mechanical/light ash removal	Minimal pluggage removed. Will not remove the blinding layers.
Scraping / Poking	Mechanical/light ash removal	Damages catalyst which significantly weakens the catalyst & causes additional pluggage.
Dry Ice Blasting	Mechanical cleaning for all types of catalyst	No challenges. Positive results.

Different Types of Testing

- It can be done in an outage span.
- Catalyst does not need to be moved or shaken.
- Reactor can be cleaned to within 5% pluggage.
- Non-invasive process for pluggage removal
- All layers can be cleaned in an outage
- Selective cleaning can be performed.
- Potential prolonged life of the catalyst – deactivation rate decreased
- Catalyst pluggage results in increased system pressure loss and decreases SCR performance. This savings alone is \$150,000 to \$250,000 per year.



**Payback from STEAG Patented Process
can be realized with reduced pressure drop alone
within 6 to 8 months.**

After Outage - Catalyst Testing

Different Types of Testing

Micro-Bench Testing – very small portion of catalyst sample, typically 2 x 2 cells or 1 – 2 plate pieces

Size ~15 x 15 mm (0.6 x 0.6”), no longer than 100 mm (4”)

Standard conditions rather than actual plant conditions, $\alpha = 1.2$

Semi-Bench Testing – small portion of catalyst sample, typically 6 x 6 cells or 4 plate pieces

Size ~30 x 30 (1.2 x 1.2”), ~ 400 mm (16” long)

Standard conditions rather than actual plant conditions, $\alpha = 1.2$

Bench Testing – full size catalyst sample, typically 1 log or 18 – 30 plates

Size – 150 x 150mm (6 x 6”) – full actual log or plate length

Actual unit operating conditions, $\alpha = 1$



Bench Scale Catalyst Testing

Preparation of a single catalyst sample test element for bench scale testing requires:

Honeycomb and Corrugated Catalyst are assembled into “log” style canister. (150 mm square size)

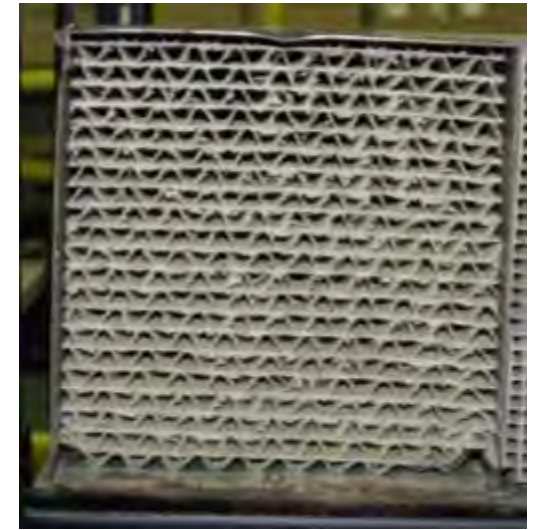
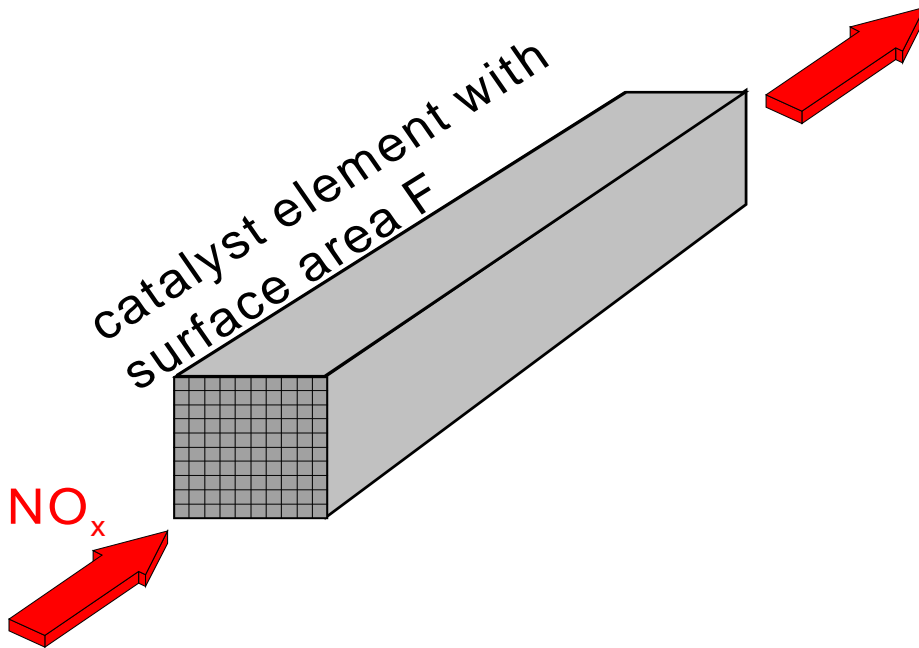


Plate Catalyst:

- The 12 plates per layer to be cut into 24 catalyst strips of approximately 145 mm in width.
- The 24 strips to be inserted into a sample holder with outer dimensions of 150 mm x 150mm.



Bench Scale Catalyst Testing



$$\eta = \frac{NO_{x,input} - NO_{x,output}}{NO_{x,input}}$$

$$K = - \frac{\dot{V}}{F} \times \ln(1-\eta)$$

η = NOx removal efficiency

\dot{V} = flue gas volume flow rate

F = catalyst surface area

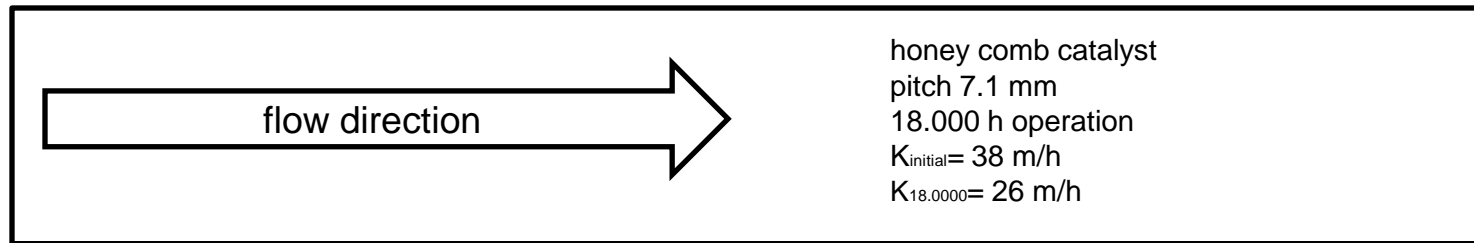
K = catalyst activity

Catalyst Testing Comparison

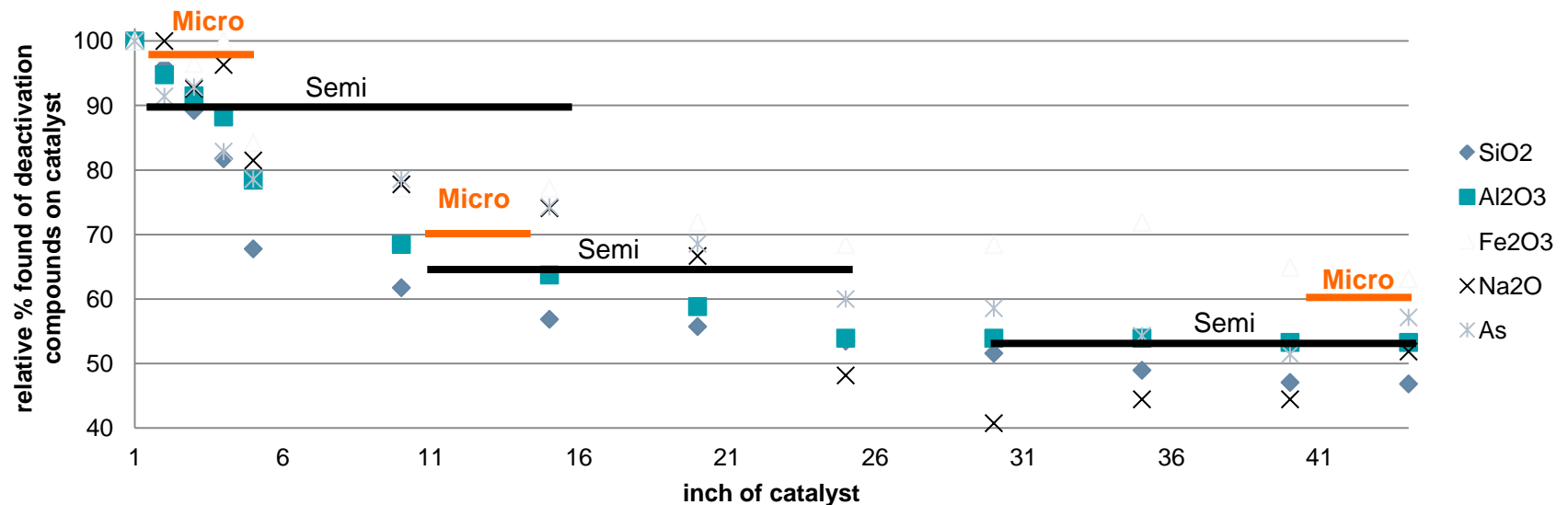
	Full Bench	Semi-Bench	Micro-Bench
Sample Length	Full Length	< 400 mm	<100 mm
Sample Face Size	150 x 150 mm	30 x 30 mm	15 x 15 mm
Flow Rate	Actual Plant Operating Conditions	Standard Conditions	Standard Conditions
Area Velocity	Actual Plant Operating Conditions	Standard Conditions, normally about 25 m/h	Standard Conditions, normally about 25 m/h
Temperature	Actual Plant Operating Conditions	Standard – normally 716 F	Standard – normally 716 F
NH ₃ (α) for K	1.0	1.2	1.2
NO _x	Actual Plant Operating Conditions	Standard Conditions, normally 200 ppmvd	Standard Conditions, normally 200 ppmvd
SO ₂	Actual Plant Operating Conditions	Standard Conditions, normally 500 ppmvd	Standard Conditions, normally 500 ppmvd
SO ₃	Actual Plant Operating Conditions	None	None
H ₂ O	Actual Plant Operating Conditions	Standard Conditions, normally 10 %vol.	Standard Conditions, normally 10 %vol.
O ₂	Actual Plant Operating Conditions	Standard Conditions, normally 2 %vol. dry	Standard Conditions, normally 2 %vol. dry
Testing Time	2 – 3 days w/ conditioning	3 – 4 hours	3 – 4 hours

Full Bench Vs. Semi-Bench Testing

Catalyst Deactivation Constituents Uptake in Catalyst.


















Catalyst deactivation versus length of catalyst



Coal-fired units do not have linear uptake unless full saturation is reached.

Impact of Catalyst Testing Parameters

- It is critically important to realize that variations of each catalyst testing parameter have a distinct influence on the result.

Parameter	Activity	Conversion
NO		
SO ₂		
SO ₃		
H ₂ O		
O ₂		
T	 	
V		

- Every catalyst behaves uniquely depending on the exact set of test conditions. Therefore, only bench scale testing at actual plant operating conditions provides absolute results directly applicable to the full size SCR of that plant on a coal unit.

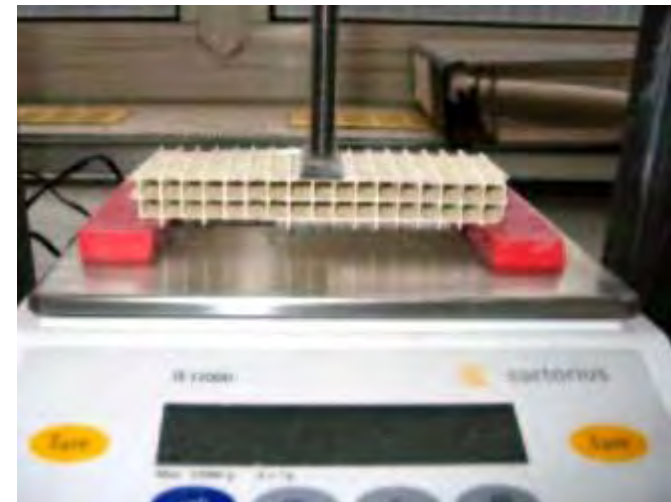
Mechanical Strength Testing

Mechanical strength of catalyst before and after regeneration is critical:

Compression strength – longitudinal stability in the direction of gas flow.

Bonding strength - transversal stability perpendicular to the direction of gas flow.

STEAG's mechanical strength testing procedure became the U.S. standard referenced in the EPRI Protocol.



X-Ray Fluorescence Testing (XRF)

Surface:

- The catalyst is being cut into the 1.5 inch diameter sized piece.
- Test only looks at the ceramic surface of the catalyst.



Bulk:

- A larger piece of catalyst is crushed into “catalyst powder”.
- 1.00g of catalyst powder and 10 g of flux make up a 1.5 inch diameter sized piece (so called “bead”).



X-Ray Fluorescence Testing (XRF)

Surface

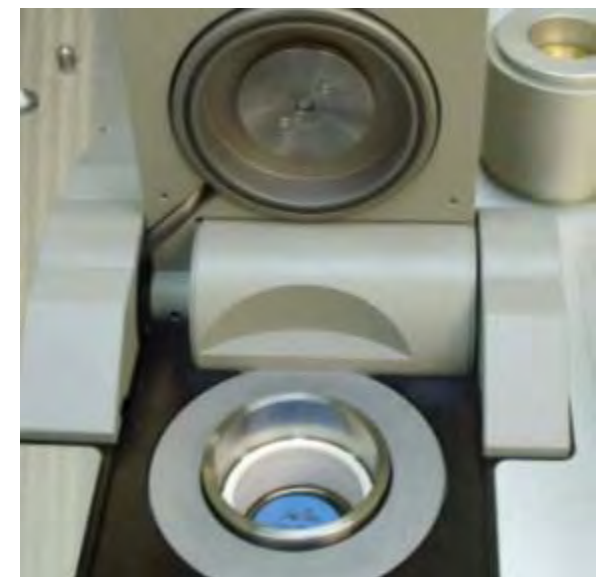
- Scanning the surface of the sample

Bulk

- The entire substrate of the catalyst.

Locations of samples – both the inlet and outlet

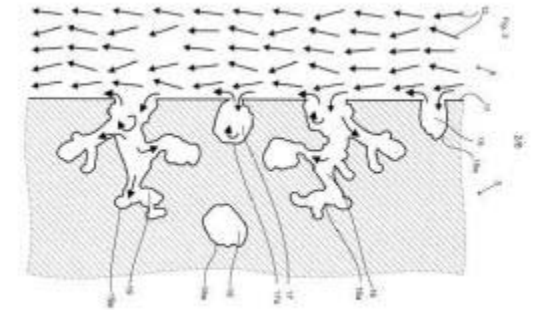
Total 4 samples



BET Surface and Pore Size Distribution

What is BET Surface and Pore Size Distribution Analysis?

- Measures the Inner Surface of a catalyst (one pound of catalyst equals the size of 7 football fields)
- Helps to explain how the catalyst deactivates



What Testing is Recommended and When? Coal and/or Biomass Applications



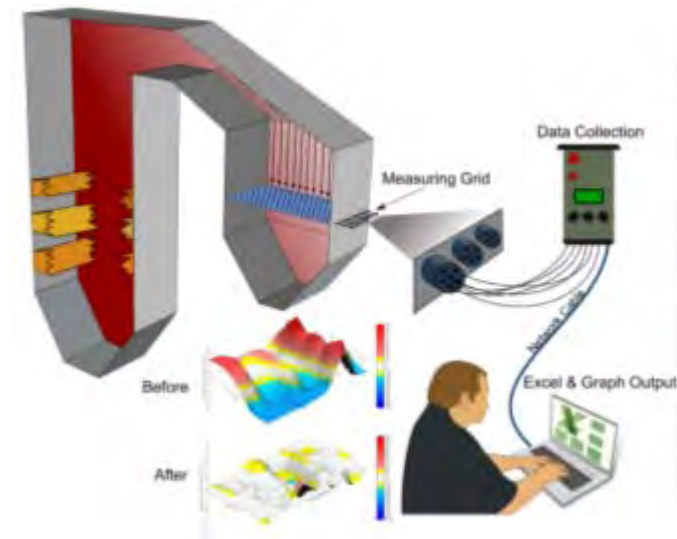
<u>Coal Applications</u>	Recommendations	Comments
Bench-Scale Testing	full Bench (both activity and SO₂/SO₃ conversion rate)	New, used and/or regenerated catalyst annually (each layer) for SCR Management purposes
Compressive / Bend / Bonding Strength Testing	before and after regeneration	Loss of bend strength in case of , Transportation is the issue!
XRF Analysis	inlet surface, outlet surface, inlet bulk, outlet bulk	New, used and/or regenerated catalyst annually (each layer) for SCR Management purposes
BET Testing	only in case of specific needs	New material, special deactivation mechanism
XRD Testing	only in case of specific needs	e.g. mineralogical composition of blinding layer
SEM Testing	only in case of specific needs	e.g. surface pore pluggage or R&D

- Every layer in each SCR reactor should be tested. Testing catalyst in series in a bench reactor (e.g. Cormetech) will reduce testing cost, but will NOT provide conclusive results as to what is happening with the catalyst.
- If cost is a concern, only 1 SO₂/ SO₃ conversion rate test of the lowest layer

After the Outage - AIG Tuning

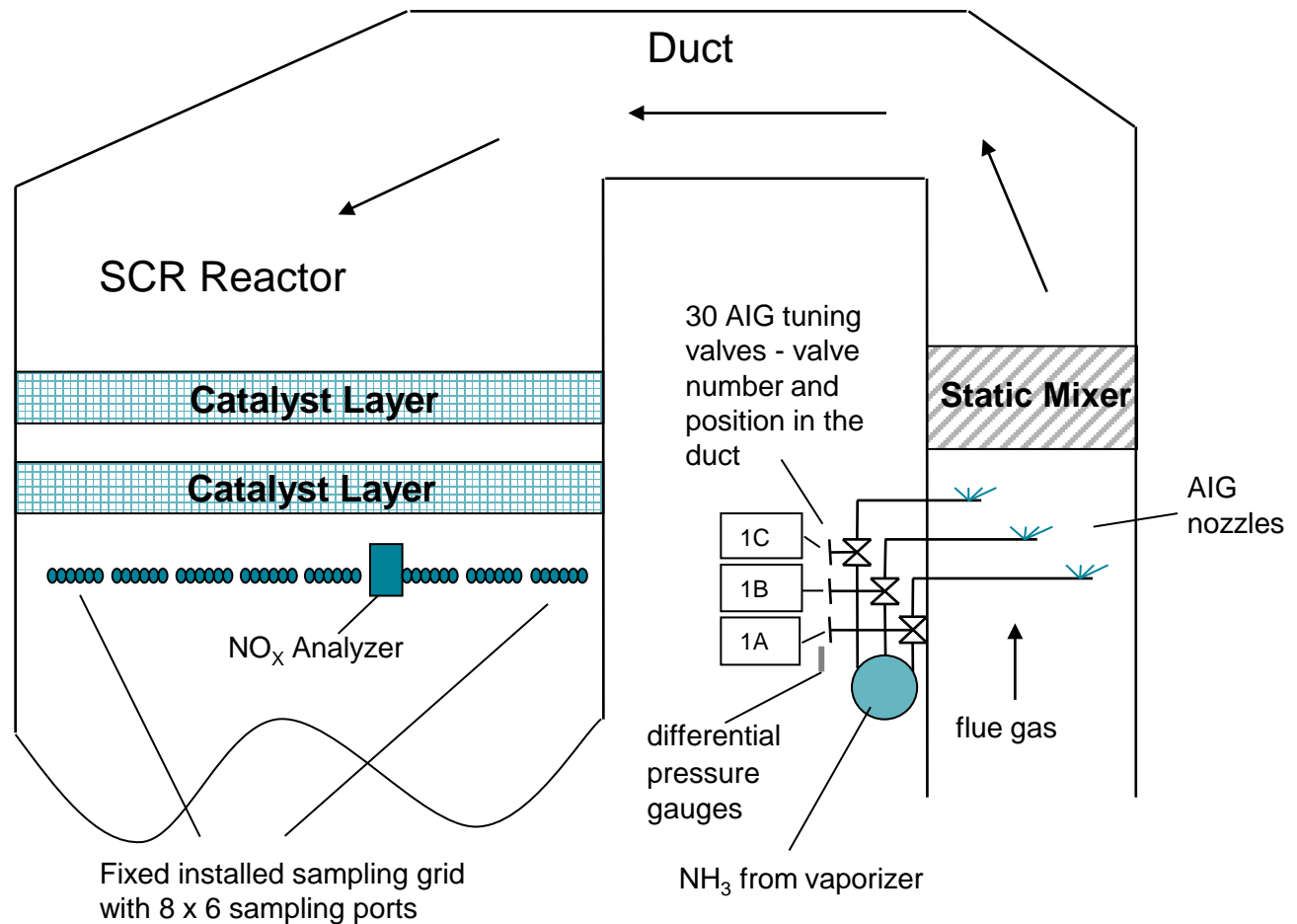
AIG Tuning – Part of Proper SCR Management

- **Why AIG Tune?**
 - **Maximizes NO_x removal efficiency**
 - **Optimizes SCR operation**
 - **Optimizes AIG system operation**
 - **Reduces NH₃ consumption**
 - **Minimizes ammonia (NH₃) slip**
 - **Reduces O & M costs**



Description of AIG Tuning

AIG Tuning:
Side view
example of
where valves
are located
with respect
to the reactor



AIG Tuning Preparations

- On-site inspection of the AIG system
- Review system information (drawings, diagrams, etc.)
 - SCR layout
 - Ammonia injection grid design
 - Sampling grid design
- Confirm there is a fixed installed sampling grid after the last catalyst layer
- Review AIG equipment availability
 - Are there differential pressure transmitters or gauges on the tuning valves (indicator of changes being made)?
 - Are the tuning valves frozen closed or locked?
 - Are the sampling lines unplugged?

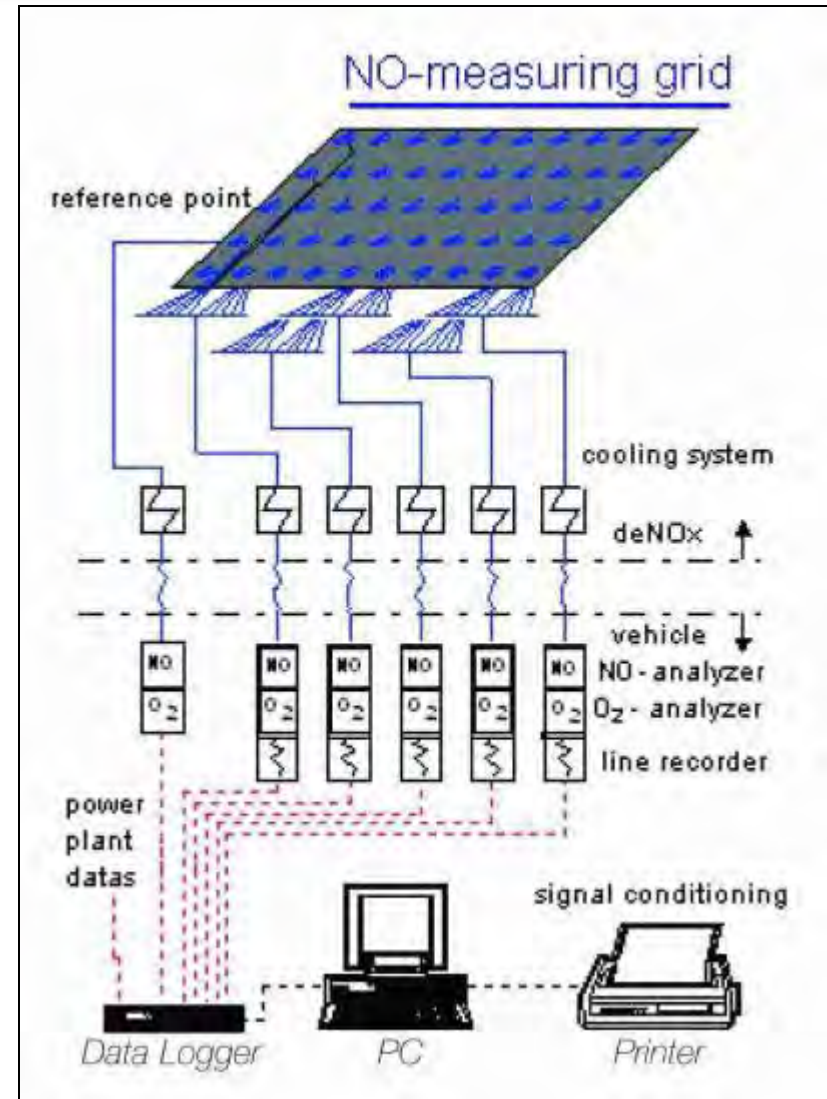


Multi-point NO_x/O₂
Analyzer Set-up

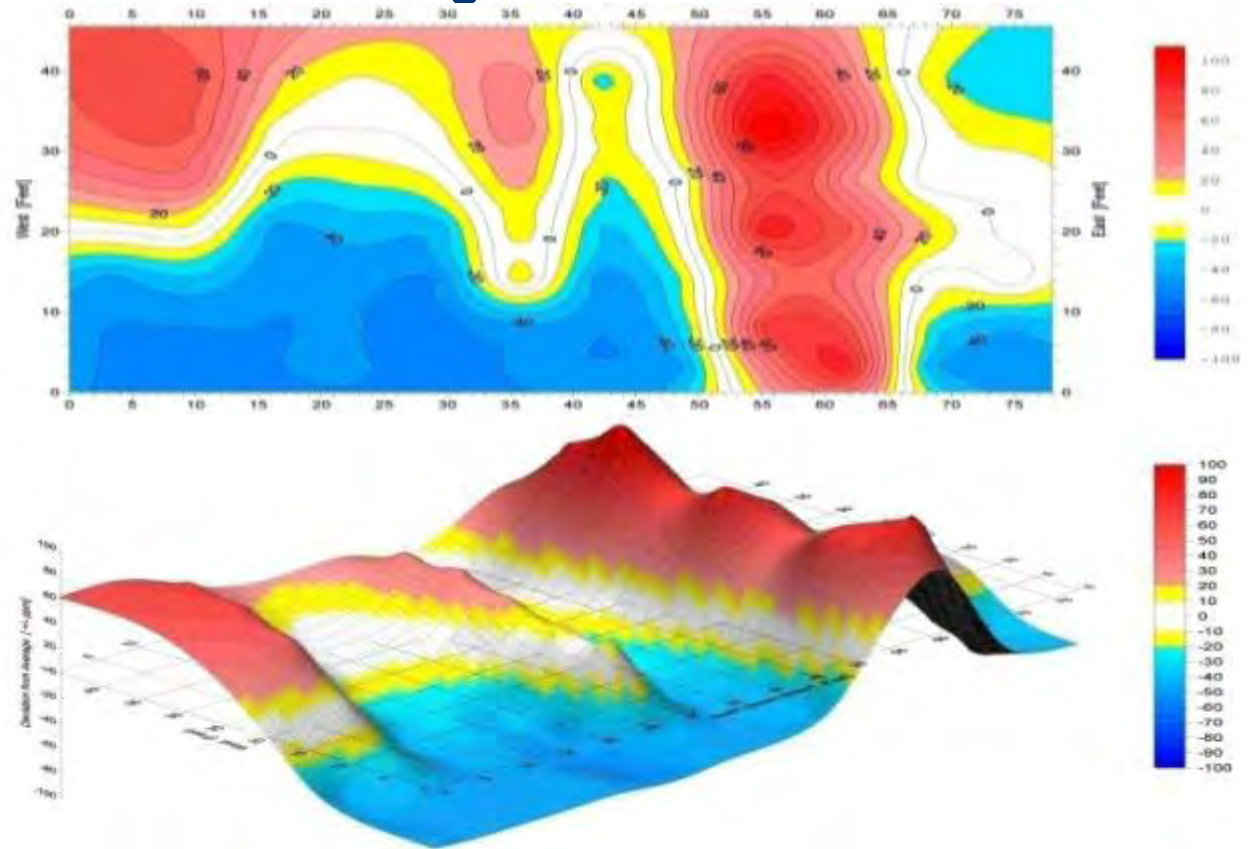
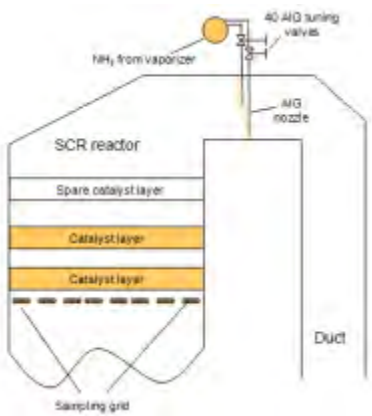
AIG Tuning

AIG Tuning allows for:

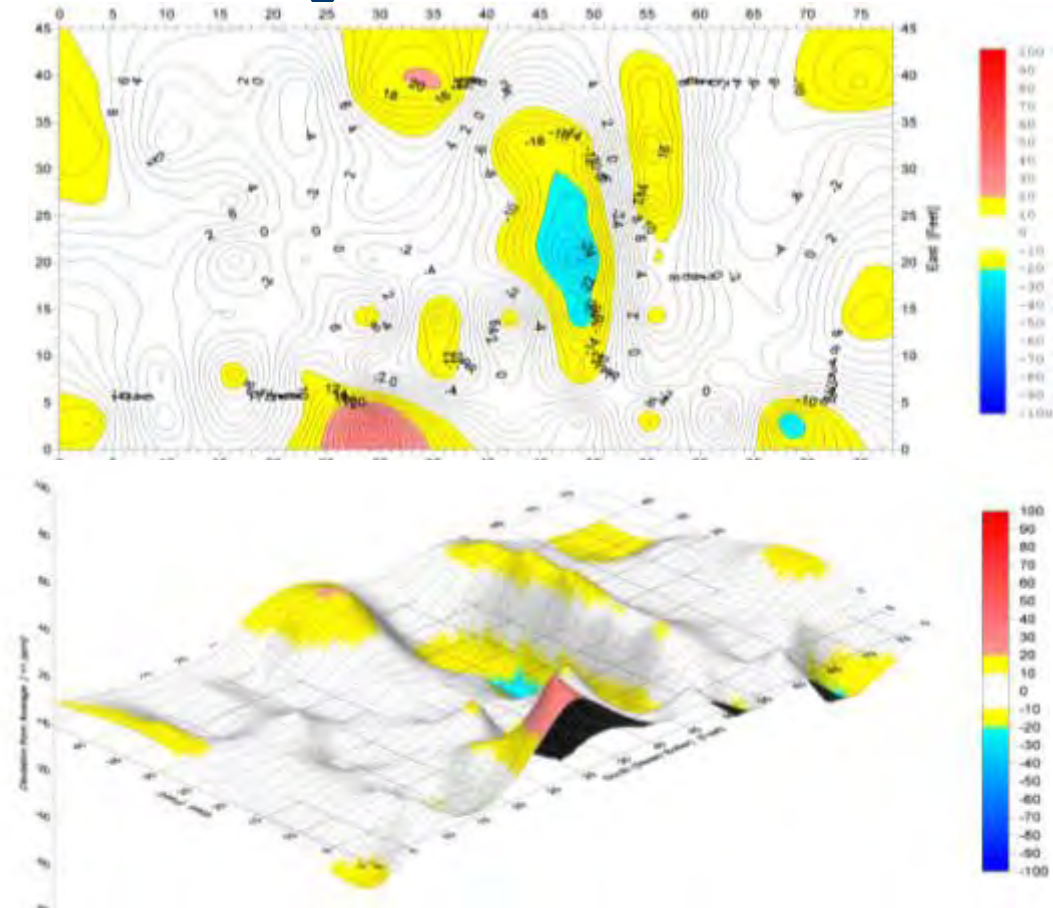
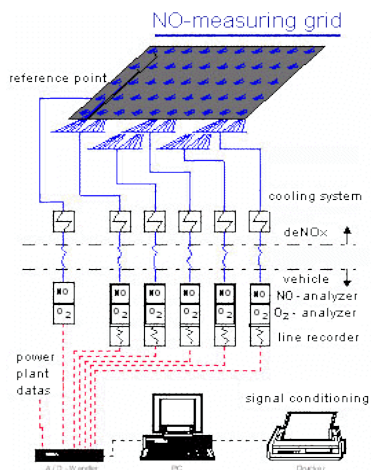
- Using up to multiple NO/O₂ analyzers in parallel.
- Generating a fully O₂ corrected 3-dimensional NO profile after the last catalyst layer for up to 100 sampling points in about 30 minutes.
- Tuning quality within about +/- 10 ppm NO after the last catalyst layer
- Handheld units do not create an optimal grid picture and does not account for boiler noise



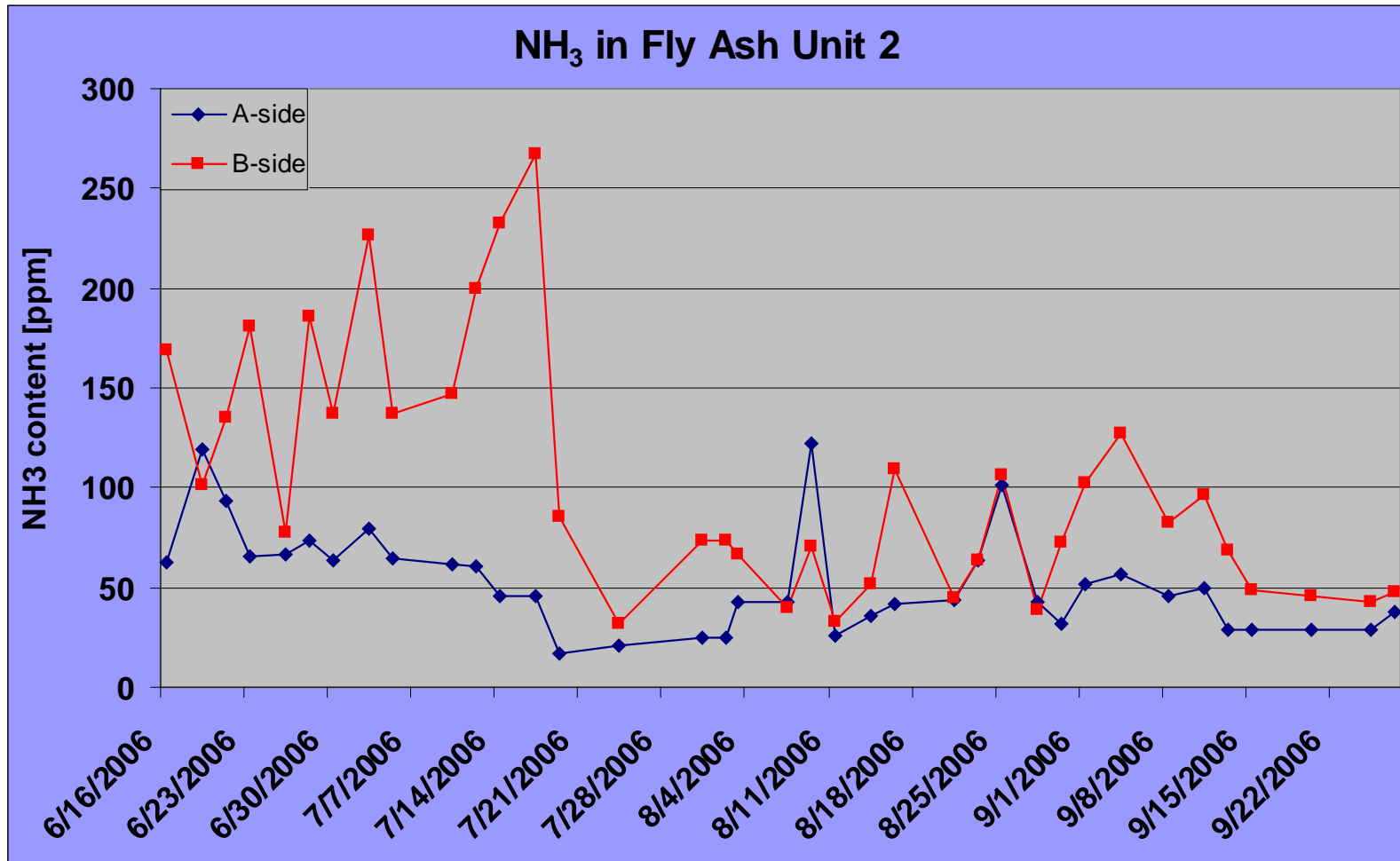
Outlet Grid Profile – Prior to Tuning



Outlet Grid Profile – After Tuning

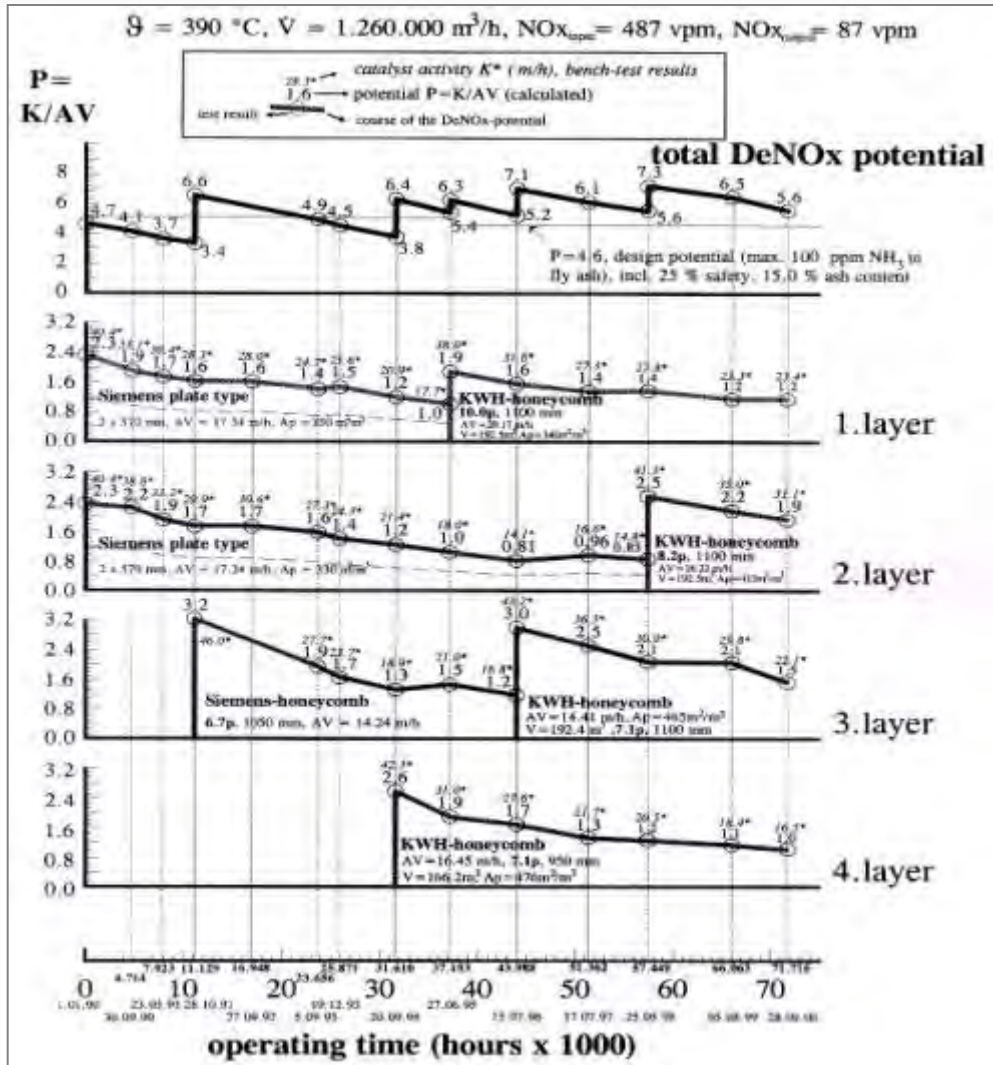


Ammonia in Fly Ash



After the Outage - Catalyst Forecasting

Catalyst Forecasting



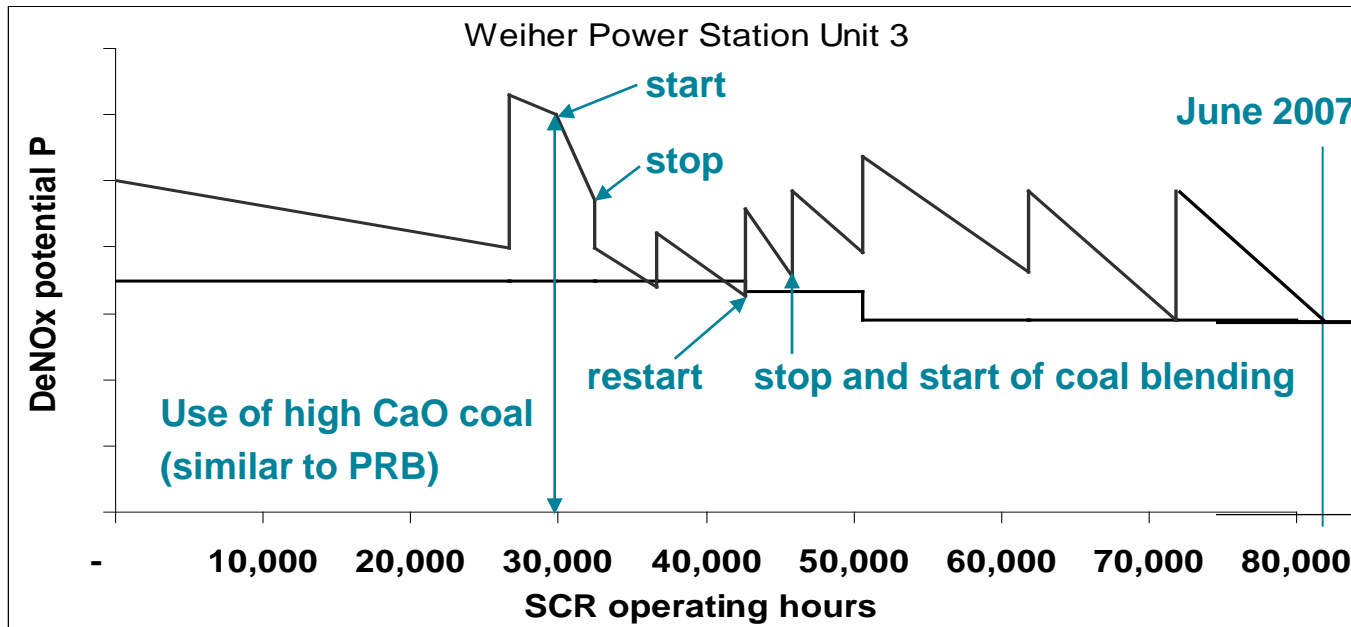
DeNO_x potential tracking and forecasting:

- Determining theoretical required potential P_{theo} .
- Calculating minimum needed and initially installed potentials P_{min} and P_{initial} from catalyst baseline test data.
- Determining initial catalyst design margin.
- Determining residual DeNO_x potential from actual catalyst activity.
- Accurately forecast SCR catalyst performance.

Catalyst Forecasting

Weiher Power Station Unit 1:

- 710 MW, PC T-fired dry bottom boiler,
- 15% ash coal, high CaO in the ash (~10%)
- High-Dust SCR commissioned in 1990
- As of 5/06 more than 81,000 SCR operating hours
- Reactor filled with 4 layers of honeycomb catalyst
- 2 new and 5 regenerated layers since 1990



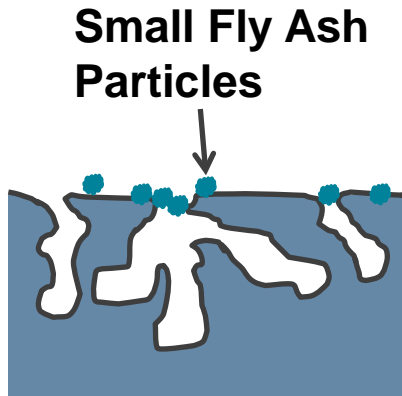
Catalyst Forecasting

- Use Potential for Reactor and Layers
- Use VGB Certified Bench Lab for Results
- When Conditions Change – Results Change
- Test Results Reflect Catalyst Only



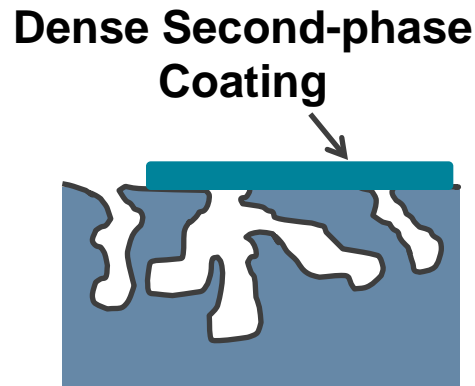
Catalyst Deactivation Mechanisms

Plugging:
Microscopic blockage
of catalyst pore
system by small fly
ash particles



i.e. Fly Ash

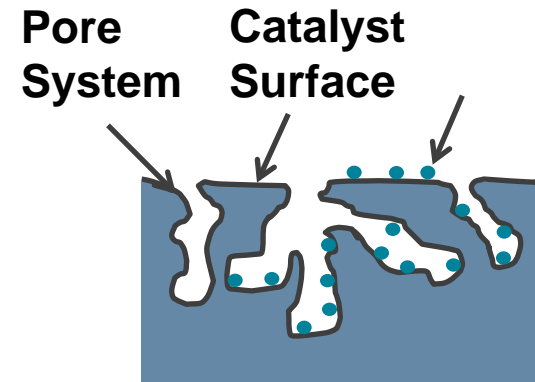
Masking:
Macroscopic blockage
of catalyst surface by
dense second-phase
coating



**i.e. Calcium,
Magnesium**

PRB

Poisoning:
Deactivation of active
catalyst sites by
chemical attack



**i.e. Arsenic,
Phosphorus,
Sodium,
Potassium**

Everyday Operation - Undesired SCR Reactions

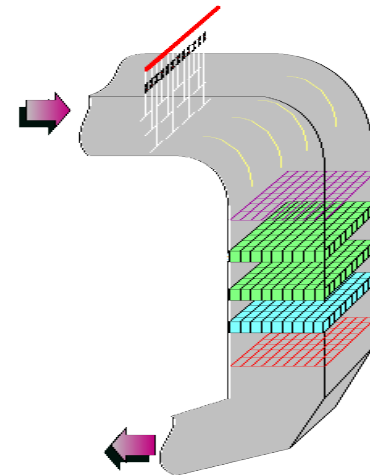
SCR Side Reactions

Undesired Side Reactions in the SCR:

- **SO₂ oxidation:** $2\text{SO}_2 + \text{O}_2 \rightarrow 2\text{SO}_3$
- **Ammonium bisulfate (ABS) formation:**
 $2\text{NH}_3 + \text{SO}_3 + \text{H}_2\text{O} \rightarrow (\text{NH}_4)_2\text{SO}_4$

Undesired Side Reactions in the Air Heater:

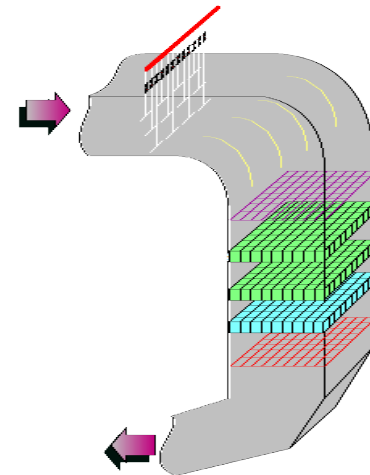
- **SO₃ condensation:** $\text{SO}_3 + \text{H}_2\text{O} + \text{O}_2 \rightarrow \text{H}_2\text{SO}_4$
- **Ammonium hydrogen sulfate (AHS) formation:**
 $\text{NH}_3 + \text{SO}_3 + \text{H}_2\text{O} \rightarrow \text{NH}_4\text{HSO}_4$



SCR Side Reactions

Controlling Undesired SCR Side Reactions:

- Ensuring optimized uniform NH_3 to NO_x distribution (diagnostic testing and regular AIG tuning required).
- Continuously tracking NH_3 slip by means of fly ash testing.
- Frequently tracking catalyst deactivation trend by means of bench scale catalyst testing.
- Ensuring a sufficiently high air heater outlet temperature and monitoring the air heater dp.
- Avoiding large variations in the SO_2 and SO_3 concentrations in the flue gas.
- Minimizing the impact of fuels, which contain significant amounts of promoters of SO_2 oxidation (e.g. vanadium in pet coke), by means of proper blending and balancing.

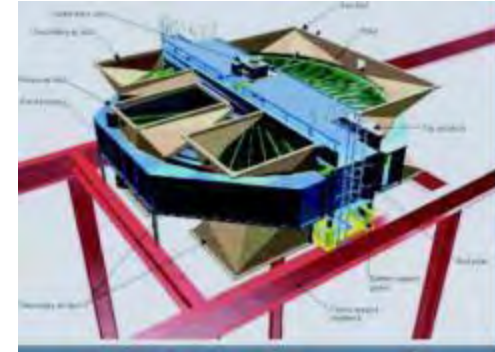


SCR Side Reactions

Controlling Undesired SCR Side Reactions:

These undesired reactions are controlled by appropriate system design and operation to minimize NH_3 slip (primarily) and SO_2 oxidation.

- SCR system design measures include:
- Ensuring uniform flue gas flow, velocity and temperature distribution across the catalyst.
- Proper selection of the catalyst activity and SO_2/SO_3 conversion rate.
- Minimization of the installed catalyst volume.
- Optimization of the SCR operating temperature.
- Optimization of the air heater outlet temperature.
- Installing enameled air heater baskets in lower layer and cold end sootblower or online washers.



Anytime – Ammonia Systems

Ammonia System Inspection

Basic Minimum Requirements

- Perform Maintenance per Manufacture's Specification
- Replace ALL Safety Valves Every 5 Years
- Outside Visual Inspection Each Year
- Ensure No Ammonia can Become Trapped

Must follow K61.1 and OSHA 1910.111 requirements



Ammonia System Inspection

- **Safety Features**

- => only flanged connections, easy and safe exchange of components

- => unloading Philosophy with compressor to entirely clean the fluid lines

- => instruments only on top of the tanks (gas-phase) not in the tank head (fluid phase)

- **Efficient Maintenance**

- => maintenance friendly arrangement of components on skids, accessibility by platform on tanks

- => system design parameters to achieve minimized components exchange (e.g. less responses of hydrostatic relief valves)

- **Preventing Material Stress by Design**

- => purge system for Nitrogen after maintenance/unloading (no stress corrosion through oxygen exposure)

- => built-in material friendly operation (designed to sustain under pressure during non operation for smooth re-commissioning)

Operating Temperature

Operating Temperature – What Criteria Are Used To Determine The Minimum Acceptable Vapor Temperature?

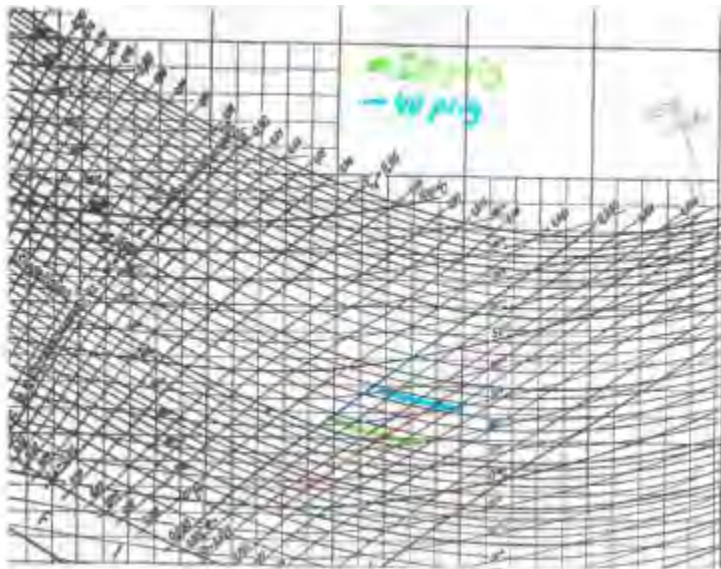
- **The minimum vapor temperature of NH_3 will be established from the condensation temperature of the NH_3 .**

Minimum temperature > condensation temperature

- **The H_2O concentration of up to 0.5% (USA) raises the condensation temperature also.**

Minimum Operating Temperature

Condensation of ammonia water in vapor lines



Dew point depends on pressure and water content:

0.5 % water

20 psig

80 degree F

40 psig

91 degree F

1.0 % water

20 psig

91 degree F

40 psig

104 degree F

Table of Recommended Maintenance

Activity	Frequency
SCR Inspection	Each Outage
Catalyst Testing – Each Layer	Each Outage
AIG Tuning	Once per Year or After Catalyst Installation
Ammonia System Inspection	Once per Year
Replacement of Safety Valves	No more than 5 years from Manufacture Date
Cleaning of Catalyst	Each Outage as Required
Catalyst Forecasting	Each Outage and Test Period
Catalyst Exchange	As Indicated by the Forecast Results
CFD Modeling	As Needed





Questions?

Philip.Elliott@steag.us

steag

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