REINHOLD ENVIRONMENTAL Ltd.

2019 NOx-Combustion-CCR Round Table Presentation

February 11 & 12, 2019, in Salt Lake City, Utah / Hosted by PacifiCorp

ONE SOURCE. MANY SOLUTIONS.

Determining O&M Savings for SCR Upgrades

Challenges Facing Utilities

- No longer base loaded design - more frequent and larger load swings
- Emissions maintained at steady state conditions but emissions swings noted during load transitions
- Lower minimum loads (and lower flue gas temperatures)
- More variability in fuel sourcing and fuel blends
- Tighter budgets for staff and O&M
- Less frequent/shorter outages
- Reduction in effluent discharge

Utility OEM Suppliers Provide Optimal Solutions

- Utility OEM suppliers provide engineering, equipment, solutions, and aftermarket support to the utility industry from chute-to-stack
- Utility OEM teaming up with sub-suppliers to provide an optimized solution for each customer that meets utility requirements
- Utility OEM provide aftermarket support

SCR Goals

- Maintain ash distribution across load range
- Eliminate high velocity zones
- Reduce ammonia slip across all loads
- Reduce ABS scaling and air heater pluggage
- Improve load following capabilities and low load operation
- Eliminate particulate buildup
- Optimize DSI performance
- Reduce catalyst minimum operating temperature

Agenda

- Improving Distribution to the SCR
- Reducing Catalyst Minimum Operating Temperature
- Dual-Fuel Firing Considerations
- Improving Access
- Combustion Optimization Post SCR
- Gas Fired SCRs

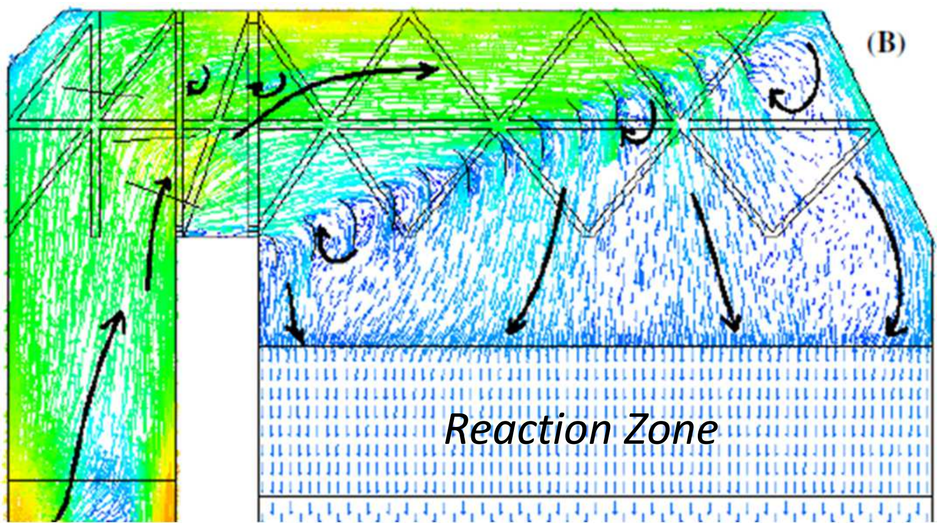
- **Improving Distribution to the SCR**
- Reducing Catalyst Minimum Operating Temperature
- Dual-Fuel Firing Considerations
- Improving Access
- Combustion Optimization Post SCR
- Gas Fired SCRs

Mixing Technology - SCR

Where does mixing need to take place?

Mixing and distribution has to be completed upstream of the reaction zone

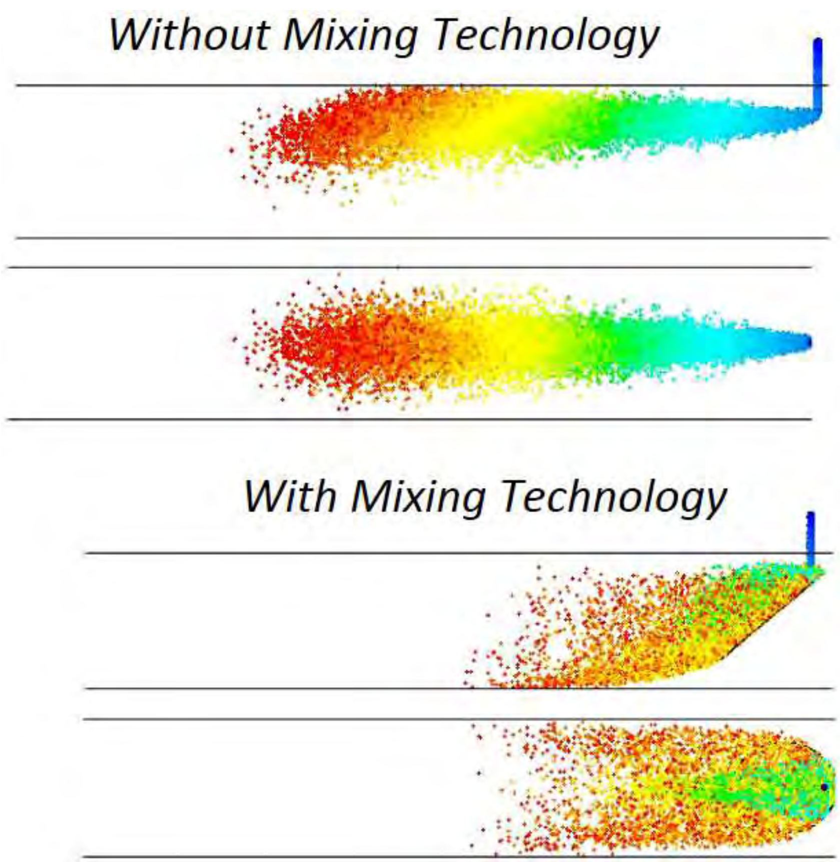
- No mixing in catalyst zone
- Minimize ammonia slip and ash buildup
- Maximize NOx removal
- Reduce catalyst minimum operating temperature

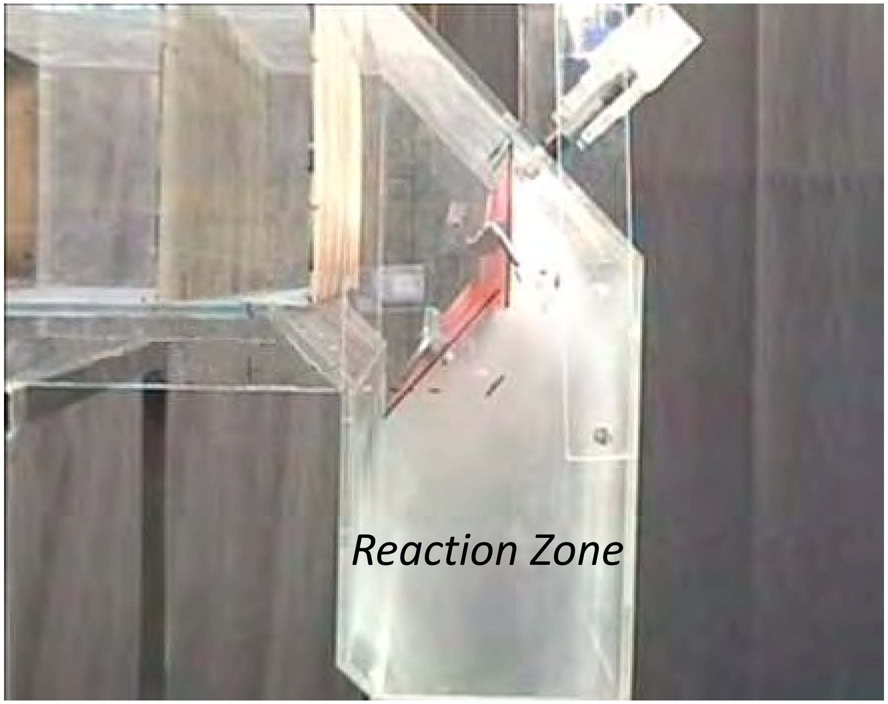


Mixing Technology - Continued

Mixing and distribution at the injection point

- Full mixing in short section of ductwork
- Improve removal and/or reduce ammonia/sorbent consumption





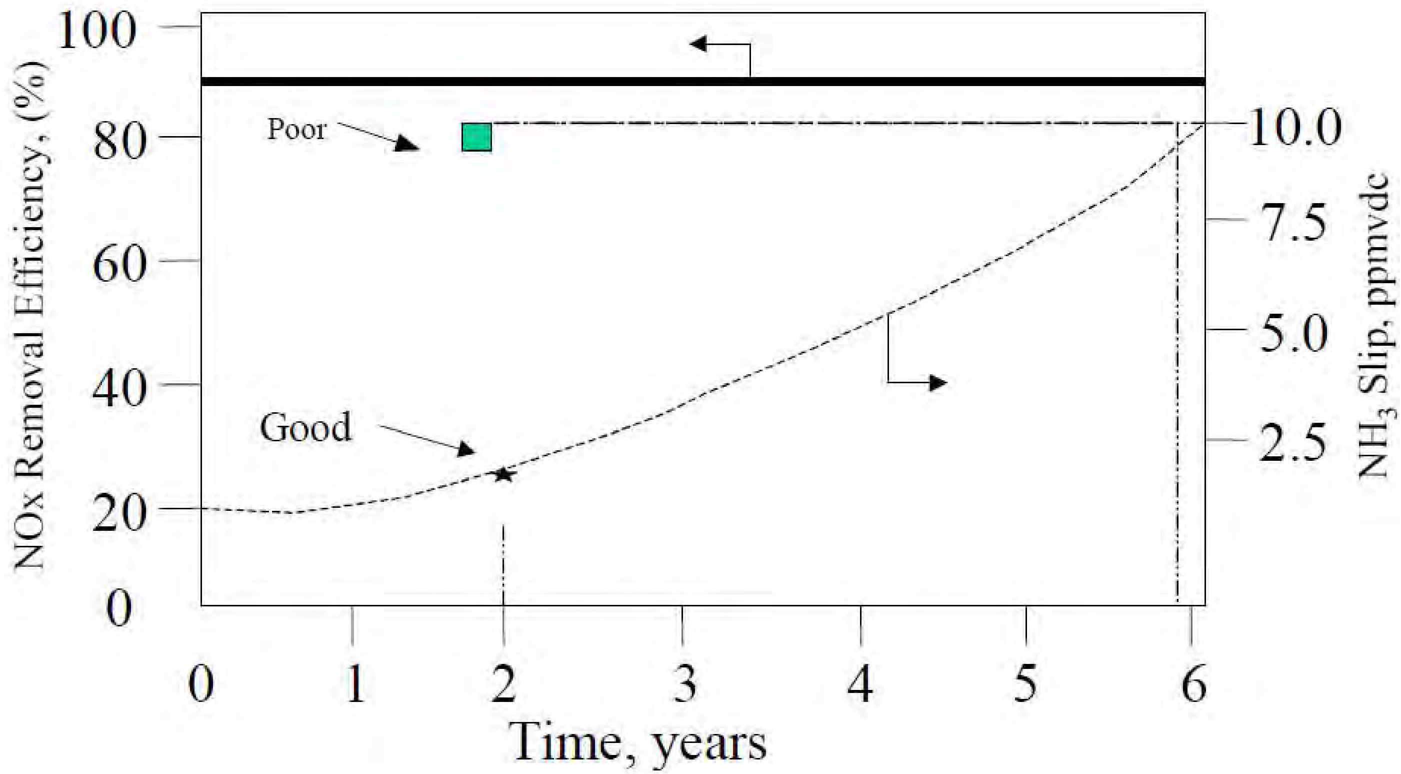
Evaluation to Determine Improvements and Savings

- Complete study
- Evaluate direct injection versus vaporization
- Determine improvement in distribution
- Estimate O&M savings
- Develop budgetary pricing
- Determine return on investment

Effect of Maldistribution on High Performance SCR

(Effective Catalyst Life)

Cormetech report: *SCR Catalyst Performance under Severe Operation Conditions*
by Scot G. Pritchard, Chris E. DiFrancesco, and T. Robert von Alten

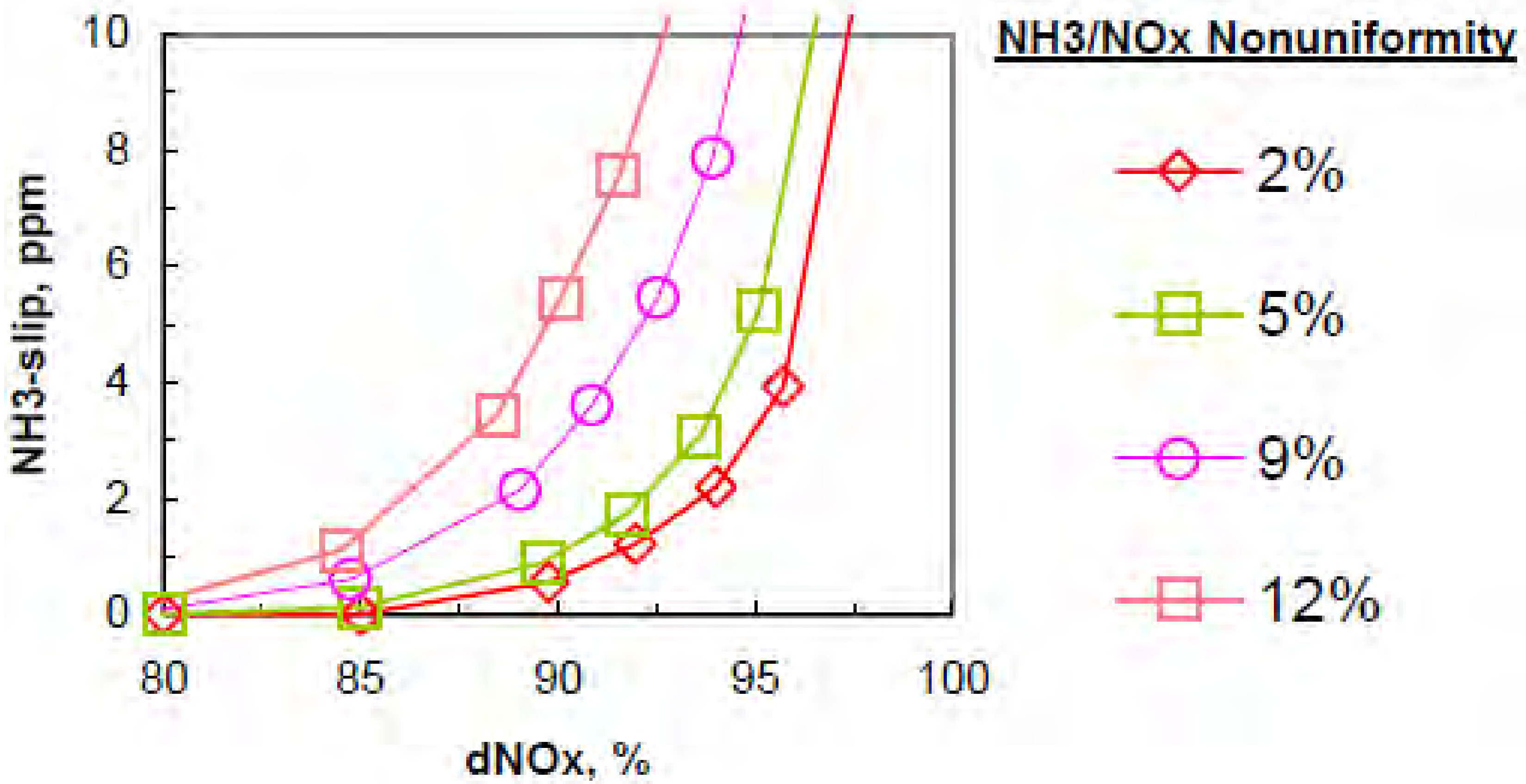


Other factors that impact catalyst life include:

- ABS formation
- Catalyst poisoning (i.e., As, P)
- Particulate buildup
- High velocity erosion

Effect of Mal-distribution on SCR Performance

High removal and minimal slip requires maintaining NH_3/NOx RMS distribution



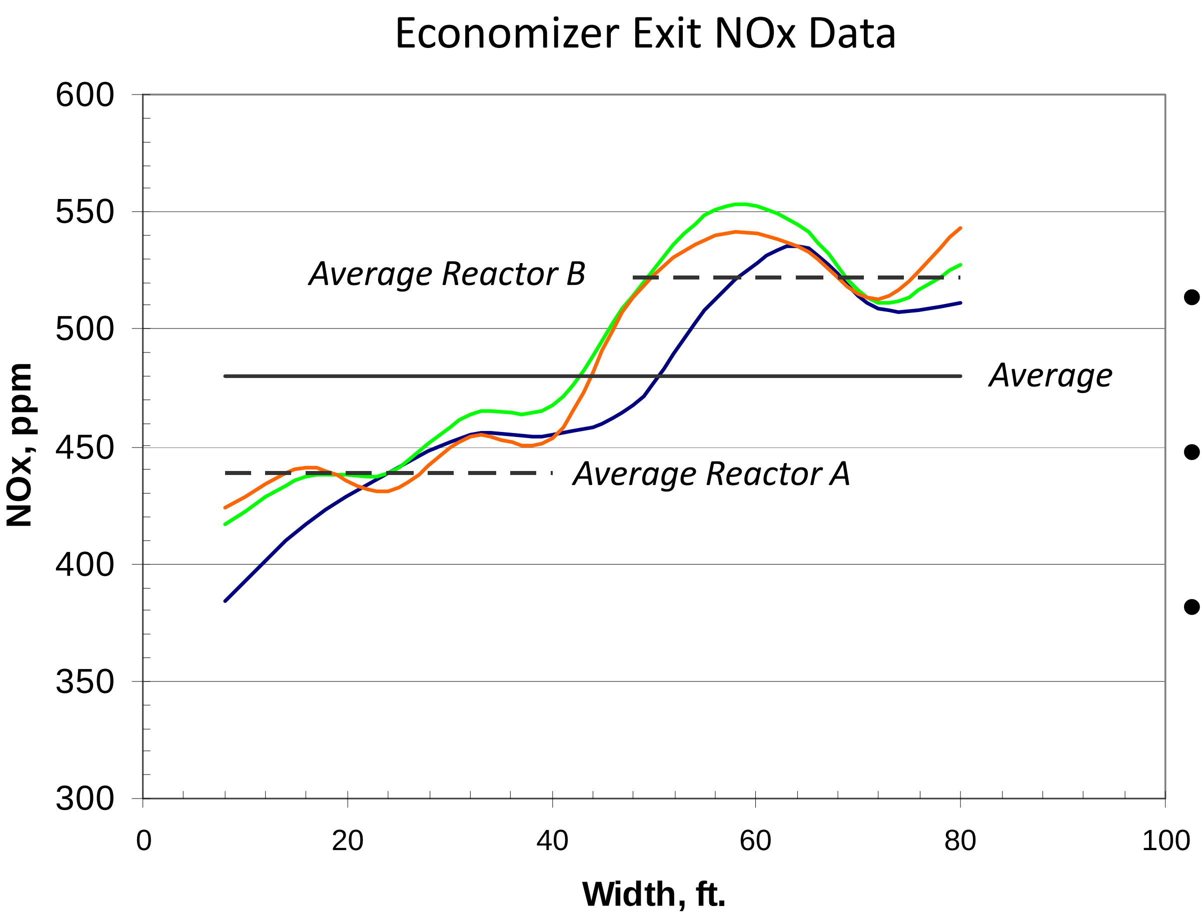
Source: Muzio, Smith, and Martinez, “New Tools for Diagnosing SCR Performance Issues”

Typical Ammonia and DSI Injection Grids




- Large number of adjustment valves & small diameter injection ports
- AIG does not result mixing issues upstream of ammonia injection
- Small diameter lances and multiple elevations for DSI
- Does not maintain mixing at reduced load operation

Removing Mal-distribution Upstream of SCR

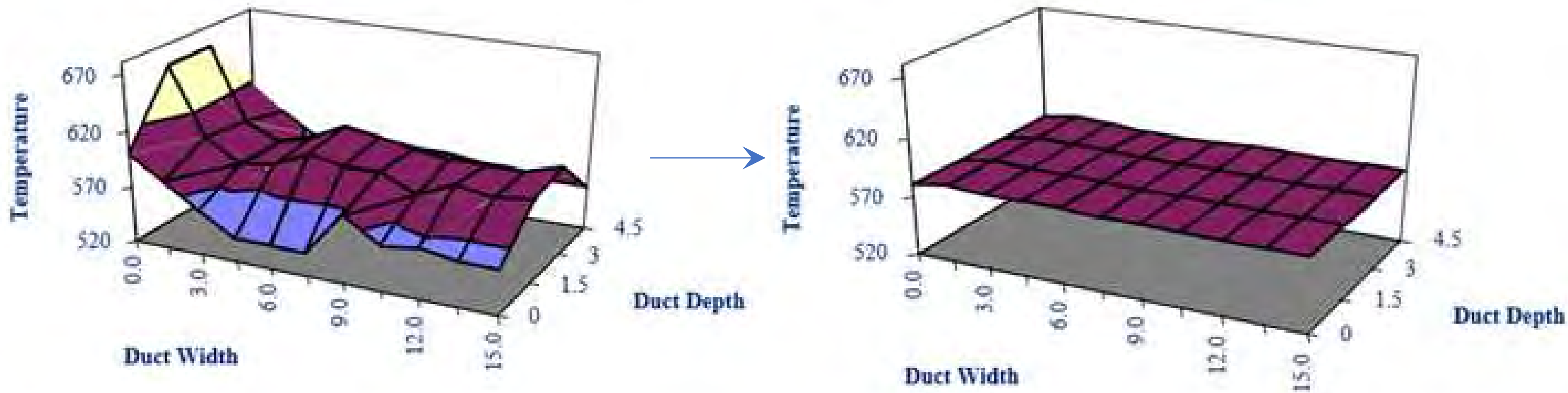


Firing and Draft System NOx Variations on a 1300 MW unit in West Virginia

- Inlet variations of flue gas composition
- Load and burner group dependent
- Mix prior to ammonia injection

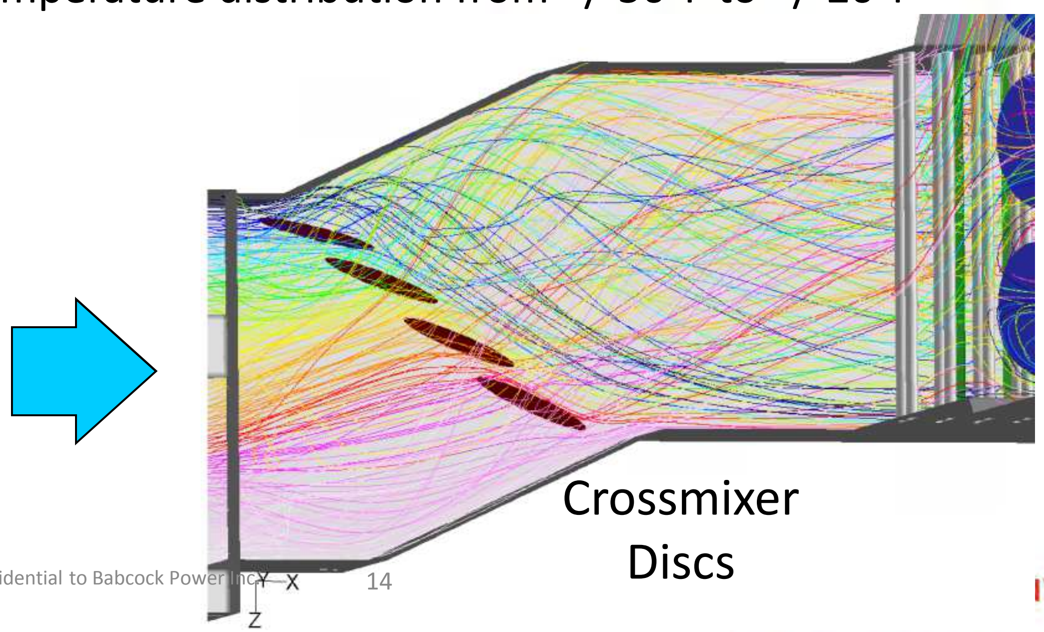
ONE SOURCE. MANY SOLUTIONS.

Upstream Mixers to Improve Temperature, NOx, and Particulate Distribution to Ammonia Injection



Reduce temperature distribution from +/-50°F to +/-20°F

Gas Flow from Boiler



IY SOLUTIONS.

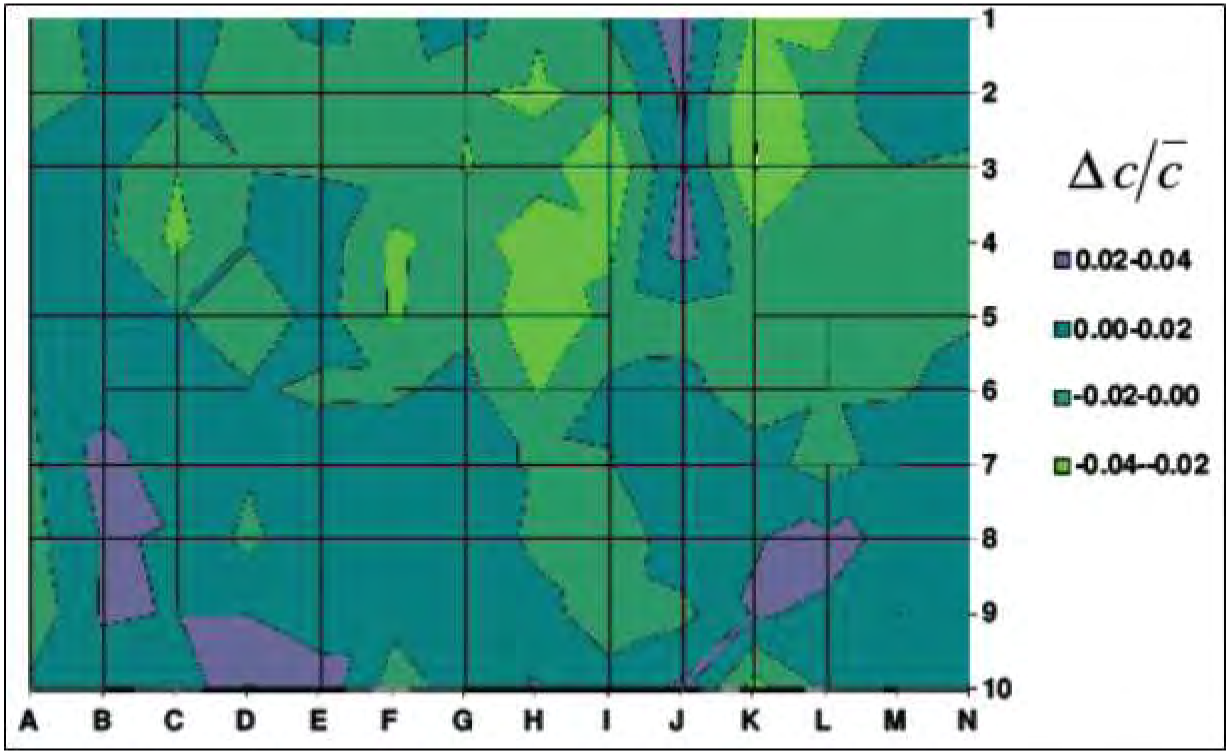
Flow Modeling – Mixing System Performance

- Model existing system
  - Reflect actual operation
  - Observe temperature and flow distribution
  - Observe ash buildup
  - Observe ash dropout at reduced loads
- Model proposed upgraded system
  - Reduce effects of unit firing & flow configurations
  - Homogenous flue gas and ash mixing at the catalyst face
  - Maintain ash entrainment and distribution
  - Maintain mixing at low load operation

SCR Flow Model Objectives

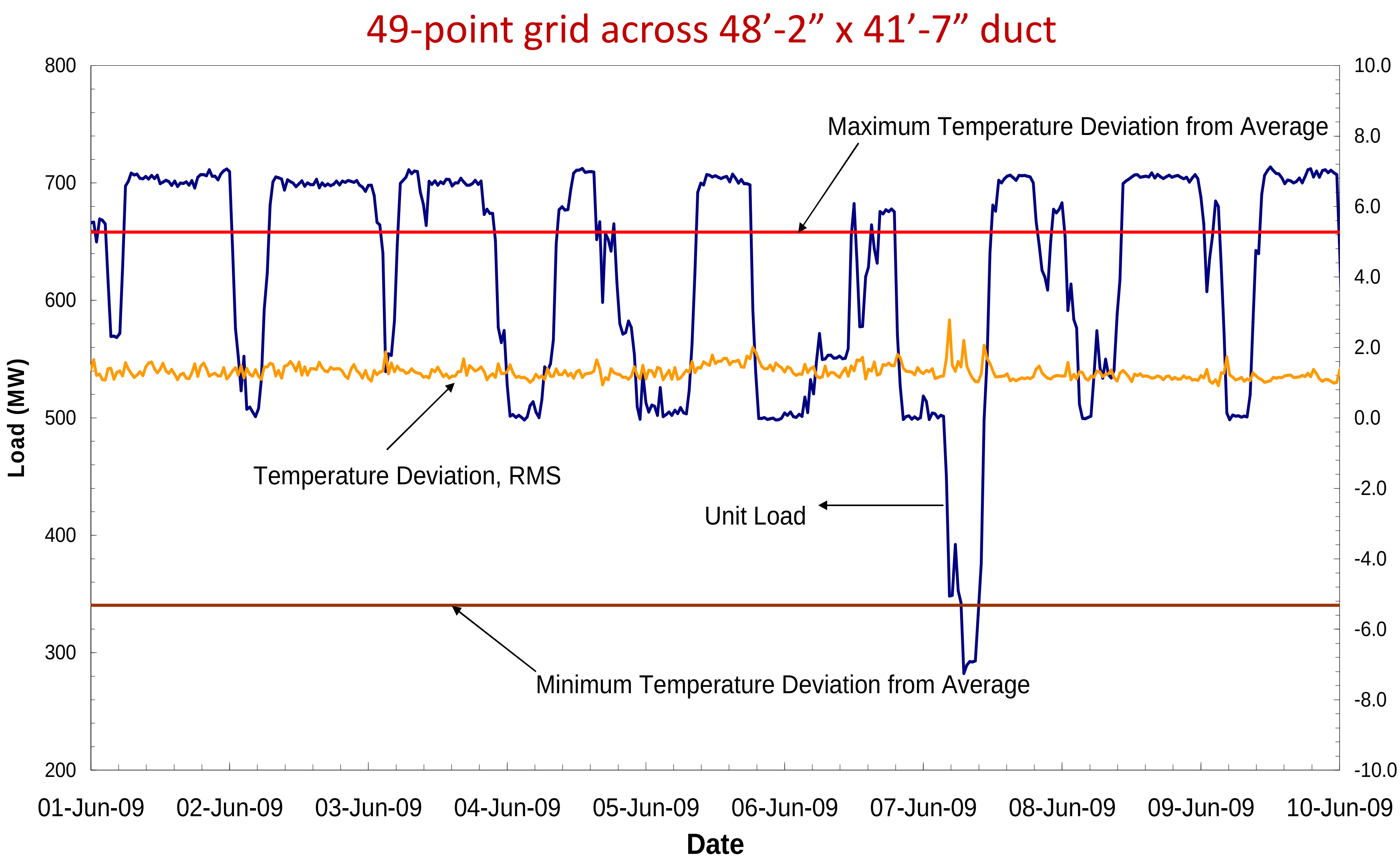
- NH_3/NO_X distribution @ 1st layer less than 3% RMS typical on new SCRs
- Gas velocity distribution
- Temperature distribution
- Gas flow angle @ 1st layer
- Dust distribution and layout
- System pressure loss

Ammonia to NOx Distribution = 1.5%



Check for Process Model to Full Scale Success

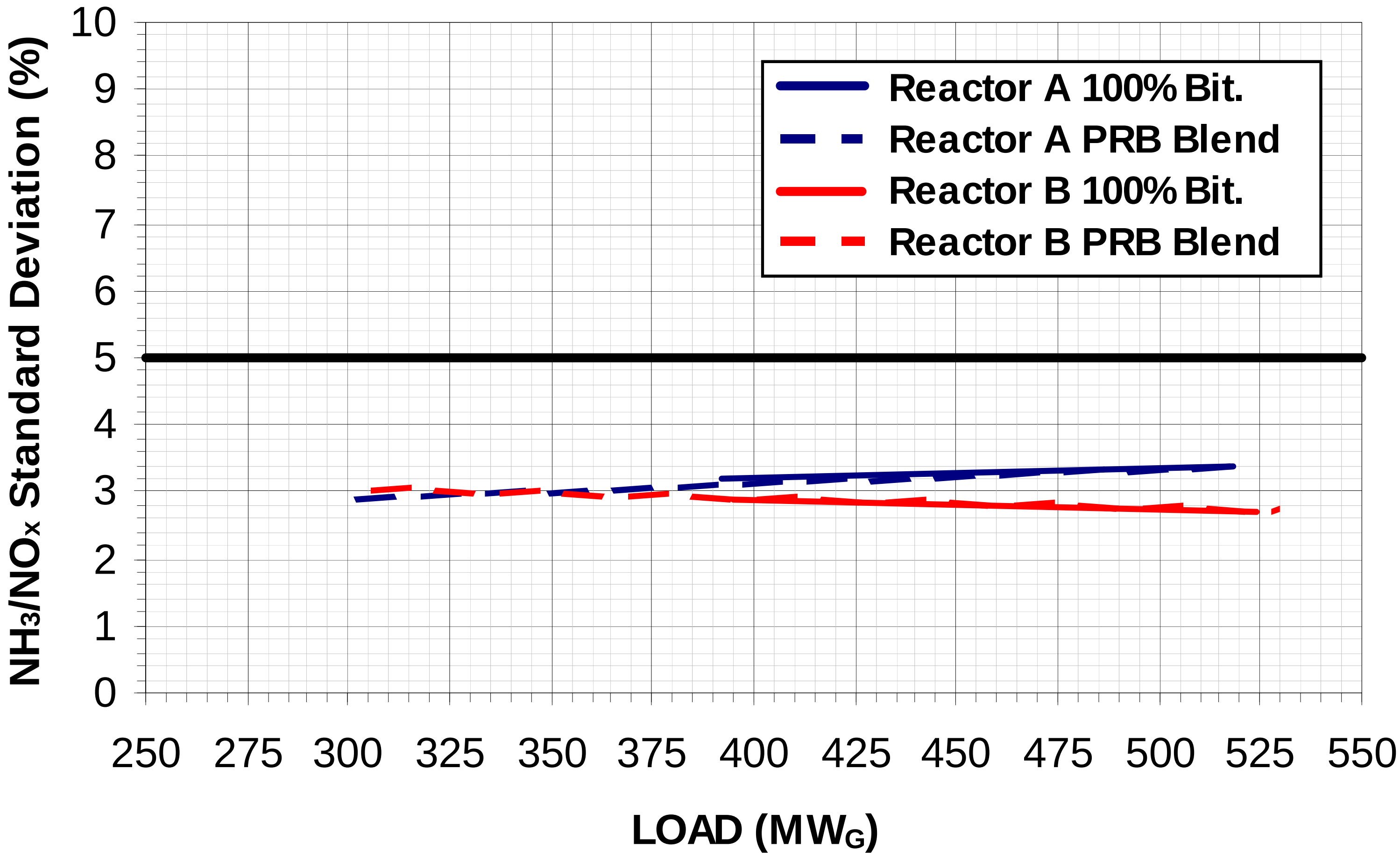
Temperature Distribution at Catalyst across Load



Temperature Distribution at Catalyst Face 48’-2” x 41’-7” during Load Swings on a Coal-Fired Unit in North Carolina

SCR Mixing Achieved with Variable Load

Important to maintain feed forward control to follow load



Homogenous Mixing with Bituminous Coal and Powder River Basin Coal Blends Across the Operating Load Range on a 550 MW Unit in Kentucky

Calculating Savings - Ammonia Injection Coupled with Static Mixers

- Reduce number of injection points reducing tuning requirements and duration to less than a week every other year – 56 valves (224 nozzles) to 12 valves (12 nozzles) for 936 MW unit
- Improve ammonia to NOx mixing reducing ammonia slip – reducing ammonia consumption 9% for 936 MW unit
- Reduce O&M associated with cleaning AIG - utility reported 20-40% pluggage of AIG each time unit was inspected during a short term outage
- Reduced pressure drop across air heater from ABS formation – utility reported 8-11 iwc reduction equivalent 6 MW on 936 MW unit (1.5 iwc increase from mixers)
- Reduced forced outages for air heater cleaning – utility reported $25K each outage
- Reduce soot blowing in air heaters improving basket life
- Increased catalyst life
- Utilize one set of mixers for ammonia and sorbent injection

Calculating Ammonia Slip from Ammonia in Ash

$$\text{Ammonia in fly ash, ppm weight basis} = \frac{\eta \times {}^{Ma}/_{M_f} \times S}{{}^{Y}/_{7000 \times \rho}}$$

Where:

- S - Ammonia Slip (ppm Volume Dry)
- Ma – Ammonia Molecular Weight (17.03)
- Mf – Flue-Gas Molecular Weight, Dry
- ρ - Flue-Gas Density (lb/dscf dry)
- Y – Ash Concentration (grains/dscf)
- η - Fraction of ammonia slip captured by flyash (0.7 – based on historical data)

Calculating Savings - Direct Injection vs Vaporization

- Eliminating dilution air – decrease total flue gas flow rate reducing fan power consumption
- Less reduction in flue gas temperature
- Less power consumption
- Eliminate steam consumption
- Less equipment and manpower to maintain

Direct Ammonia Injection Station

Power & Steam Savings for 936 MW Unit

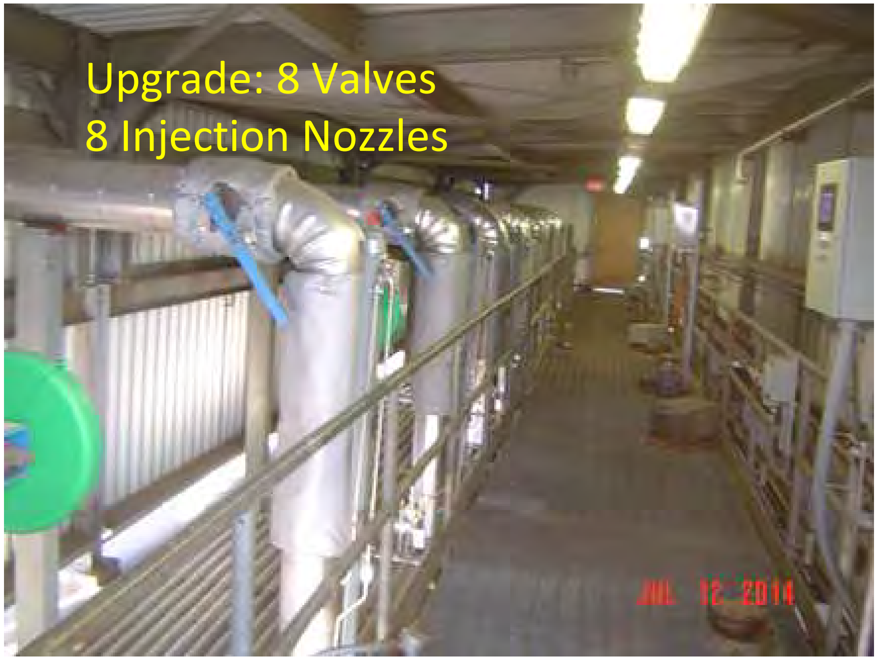
936 MW unit	Vaporization	Direct Injection
Capacity factor	70%	70%
Total blower + compressor power	134 kW	52 kW
Electric heater power		20 kW
Evaluated cost	$0.05/kWh	$0.05/kWh
Aux power cost	$40,946/yr	$22,130/yr
Steam consumption	8.4 Mbtu/hr	
Evaluated cost for steam	$2.0/MBtu	
Steam cost	$102,885/yr	
Power and Steam Savings	$121,701/yr	
Flue gas temperature change	-6 ^oF	-3 ^oF

Ammonia Vaporizer

SCR Upgrade Example

- Leaks from common ammonia vaporization system
- Plugging of nozzles with ash
- Fouling of tuning valves and piping with ammonia compounds
- Frequent tuning of AIG
- Load Limited

	Unit 1	**Unit 2**
NH_3/NOx, min/max		
Before Upgrade	-28/+21%	-29/+21%
After Upgrade	-10.5/+8.4%	-8.5/+7.9%
NH_3 Slip		
Before Upgrade	>10 ppmv	>10 ppmv
After Upgrade	0.13 ppmv	0.22 ppmv

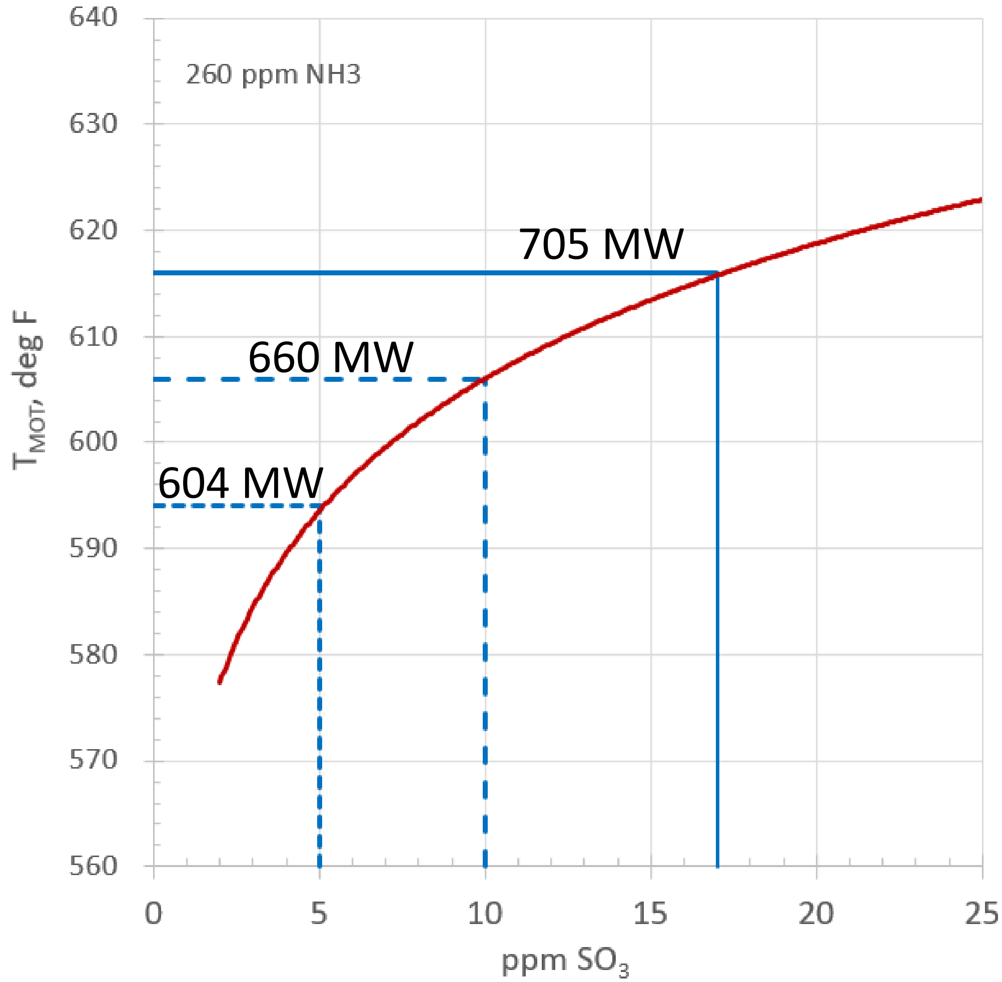


- Improving Distribution to the SCR
- **Reducing Catalyst Minimum Operating Temperature**
- Dual-Fuel Firing Considerations
- Improving Access
- Combustion Optimization Post SCR
- Gas Fired SCRs

DSI w/ Mixers Upstream of the SCR

- Reduce catalyst minimum operating temperature
- Lower load operation
- Increase sorbent residence time/reduce lime consumption
- Reduce ammonium bisulfate scaling
- Improve air heater efficiency
- Remove HCl upstream of the WFGD system

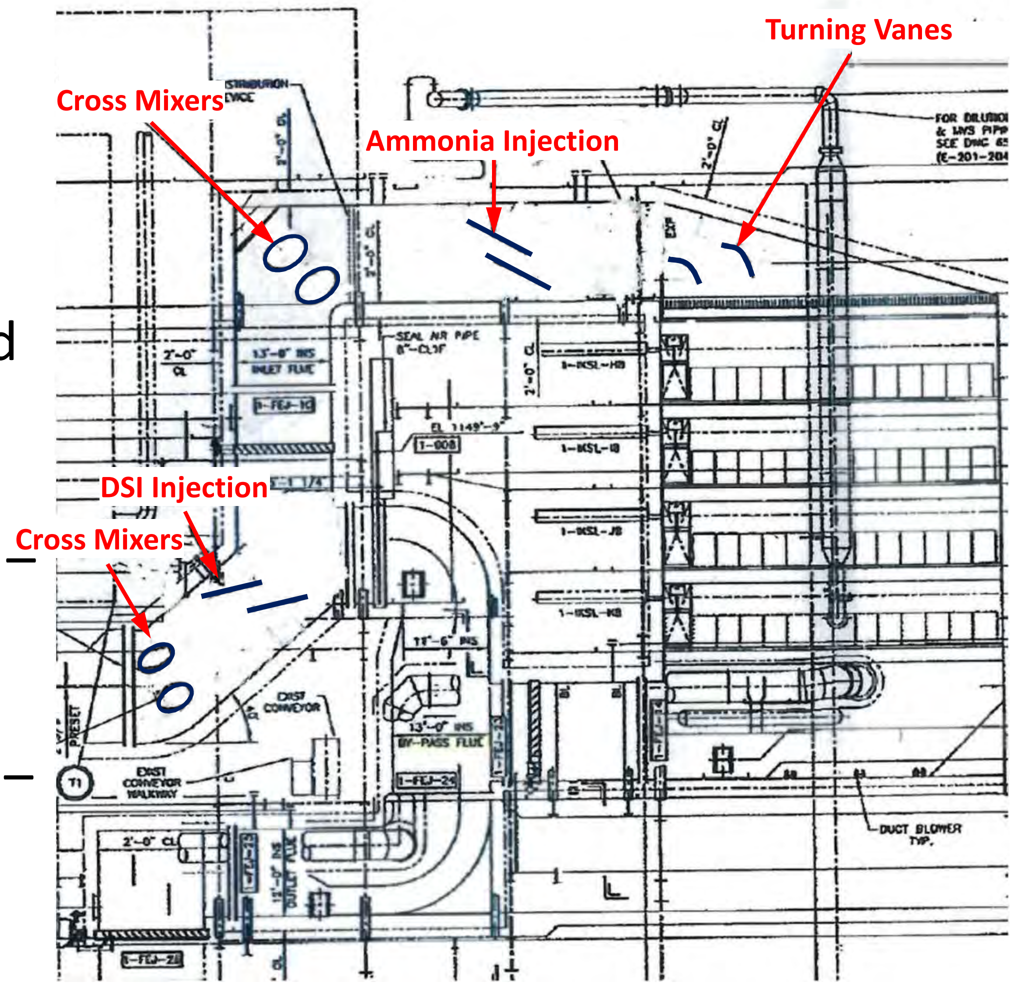
Catalyst Minimum Operating Temperature (MOT) vs. SO_3



Lowering Minimum Load

- Upstream DSI reducing SO_3 in flue gas stream – Reduced minimum load 101 MW on 936 MW unit
- Replacing vaporizer with direct injection – Reduced minimum load an additional 15 MW
- Reduce pressure drop across air heater by reducing ABS formation – Reduced minimum load an additional 6 MW
- Improve temperature distribution – to be quantified based on existing temperature distribution data

Proposed Mixer Locations



- Improving Distribution to the SCR
- Reducing Catalyst Minimum Operating Temperature
- **Dual-Fuel Firing Considerations**
- Improving Access
- Combustion Optimization Post SCR
- Gas Fired SCRs

Changes to Flue Gas Profile

Change in emissions leaving the boiler when firing 100% gas

- 1/3 the NO_x emissions of coal
- Lower CO (typically <50 ppm)
- Lower VOCs (typically <0.001 lb/MMBtu on a methane basis)
- Virtually no SO_x emissions (small amount of Sulphur added as odorant)
- Virtually no PM
- 50-80% less CO_2 than coal

Change in Flue gas

- Flue gas flow will typically decrease with natural gas by approximately 5-10% due to reduction in excess air requirements
- Flue gas temperature leaving the boiler bank will typically decrease slightly with natural gas firing due to increased heat absorption in the SH/RH sections from having a higher effectiveness due to no slag

Maintaining NOx Emissions

- Variable flue gas flow/temperature distribution to catalyst face
- Resize/Second ammonia feed control valve
- Analyze ammonia injection distribution
- Analyze catalyst minimum operating temperature for fuel mixes
- Reduce requirement of soot blowers/sonic horns/ash sweepers when firing gas

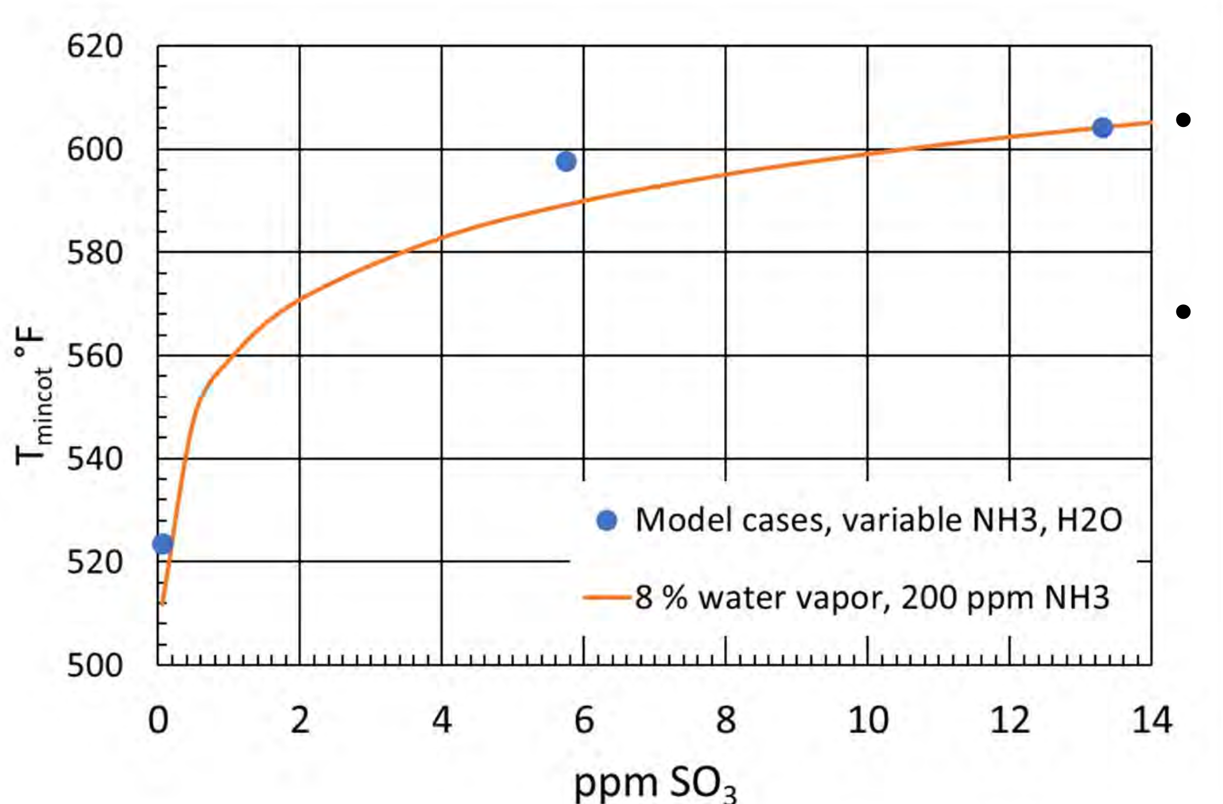
Catalyst Minimum Operating Temperature w/ Dual Fuel Firing

Example: 650 MW Unit firing 55% gas : 45% coal

- Reduced catalyst minimum operating temperature 6°F
- Minimum load limit for SCR operation reduced 20 MW

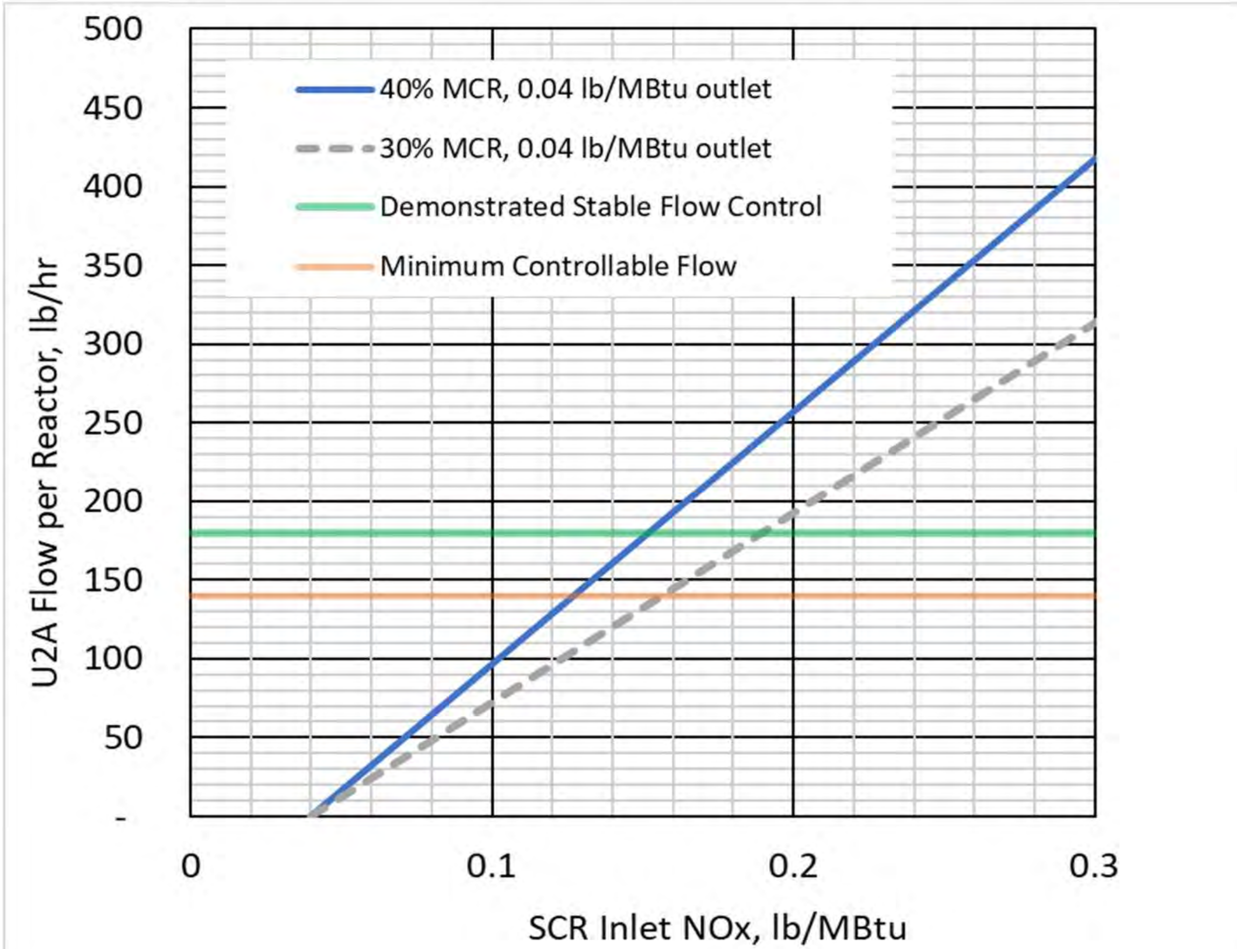
Example: Same 650 MW Unit firing 100% gas

- Reduced catalyst minimum operating temperature 70°F



- Need to quantify the potential for catalyst activity loss w/ gas firing
- With 100% gas, and no flue gas SO_2, the resulting desorption of sulfate from the catalyst can significantly reduce catalyst activity

Existing Ammonia Control Valve for 650 MW Unit



- The hydrolyzer is not limiting at the minimum injection rates required
- It may be necessary to adjust set points, re-tune steam control valves, and possibly modify valve trims for optimum operation
- Total flow meter covers the range – individual lance meters do not

Convert from Anhydrous Ammonia to Aqueous Ammonia

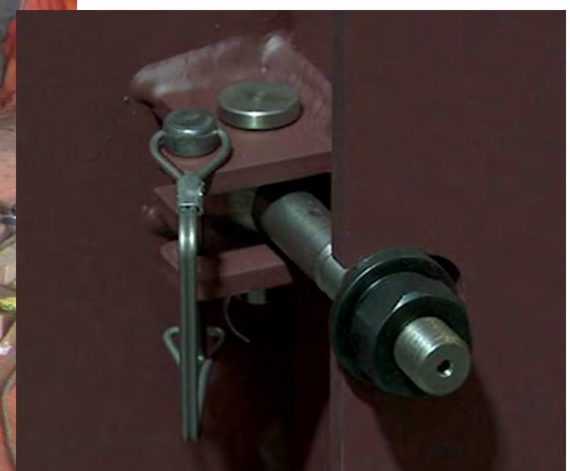
- If ammonia injection is reduced
  - Eliminate PSM program
  - Reutilize anhydrous tank farm and transfer system
- Utilize direct injection and eliminate vaporization system

- Improving Distribution to the SCR
- Reducing Catalyst Minimum Operating Temperature
- Dual-Fuel Firing Considerations
- **Improving Access**
- Combustion Optimization Post SCR
- Gas Fired SCRs

SCR Catalyst Module Removal Doors

Improves safety and time

Install of a Single Layer



Swing bolts for quick/safe access

SCR Catalyst Module Removal Doors

Laydown door opening with cart

Features to look for in quick release doors:

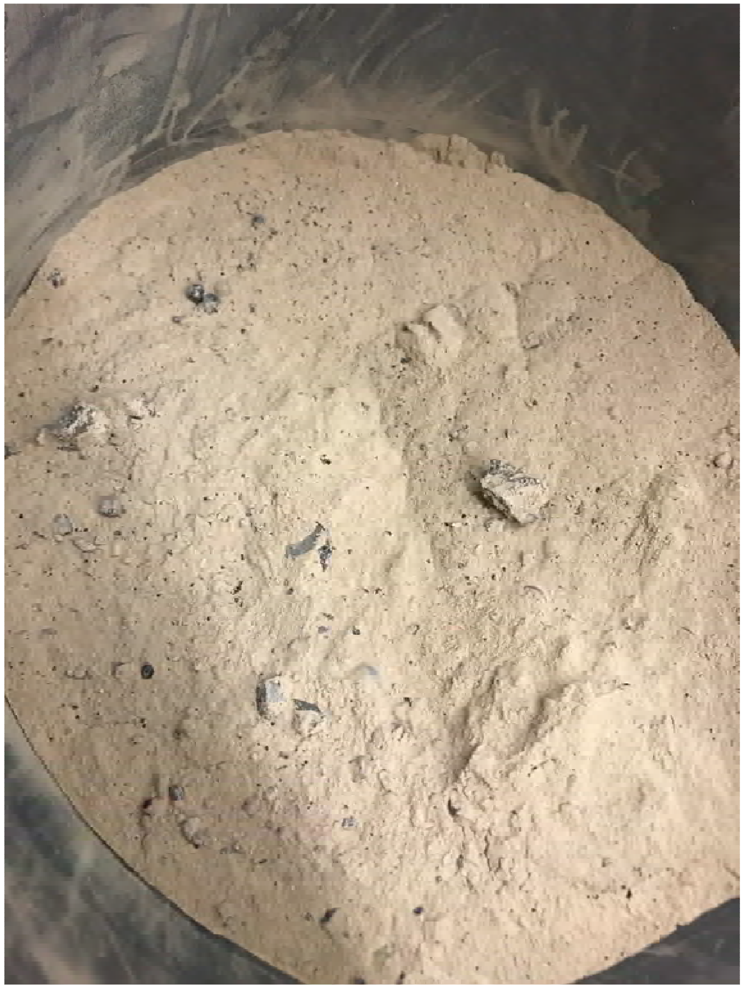
- Open & close without tools
- Adequate sizes for easy entry
- Safety latch prevents injury and entrapment
- Flush inside and outside - no material build-up
- Heavy, durable, dependable design

Payback Worksheet available

- Improving Distribution to the SCR
- Reducing Catalyst Minimum Operating Temperature
- Dual-Fuel Firing Considerations
- Improving Access
- **Combustion Optimization Post SCR**
- Gas Fired SCRs

Combustion Optimization Post-SCR

Low NOx Burner and Combustion Tuning

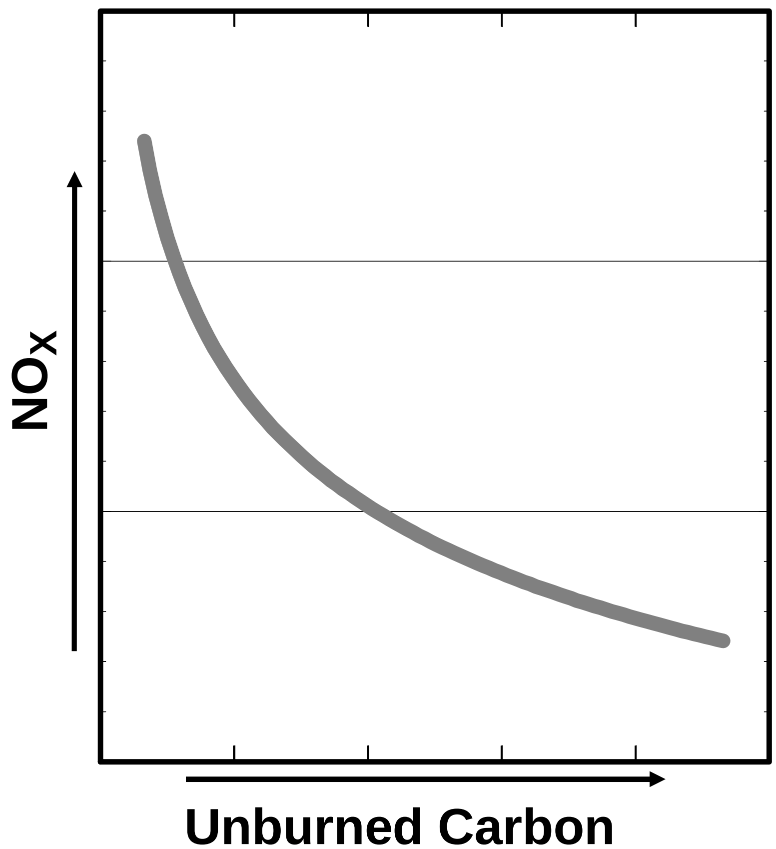


Goal: Reduce LOI level of bottom ash by optimizing combustion system

- Low NOx burners can have negative impacts on CO, UBC / LOI, flame length, and long term slagging
- Meet NOx guarantee while reducing LOI

UBC / LOI Control in Low NOx Operation

The Challenge

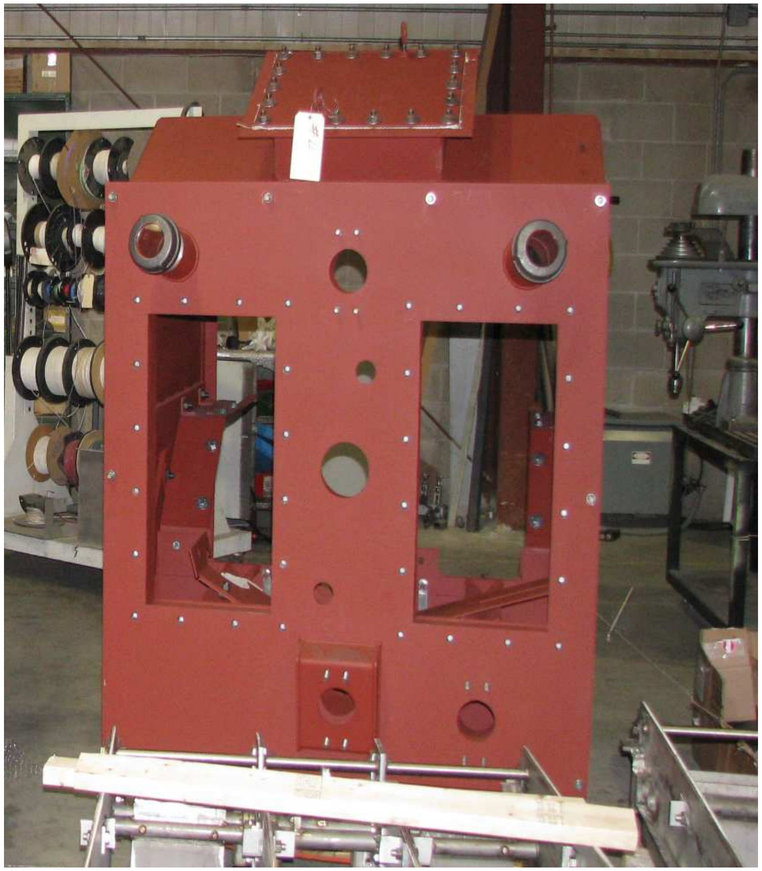


- Coal properties
  - Coal Rank
  - Coal Reactivity
  - FC/VM Ratio
  - Ash Content
- Coal fineness
- Operating conditions
  - Excess O_2
  - Burner Zone Stoichiometry
  - Boiler load

Impacts on Other Emission Control Equipment

- HG emissions increase as fly ash LOI decreases
- Increase SCR NOx removal reactor set points to keep NOx guarantee
  - Recalibrate ammonia injection
  - Review logic and tuning

Combustion Optimization Post-SCR



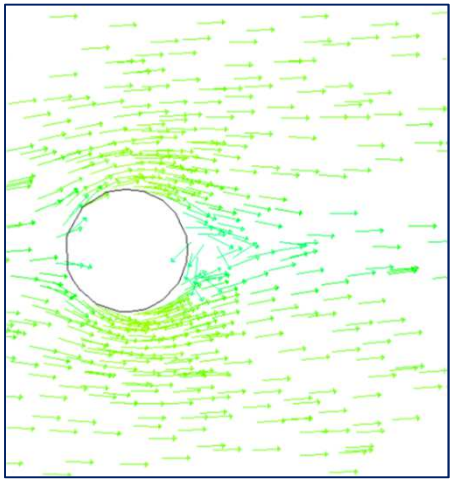
- Reduce LOI in bottom ash is achievable while maintaining NOx guarantee
- Can be optimized through minimizing air flow through OFA, UFA, and BA as well as identifying ideal burner directional vane, tilt, and SA damper settings

ONE SOURCE. MANY SOLUTIONS.

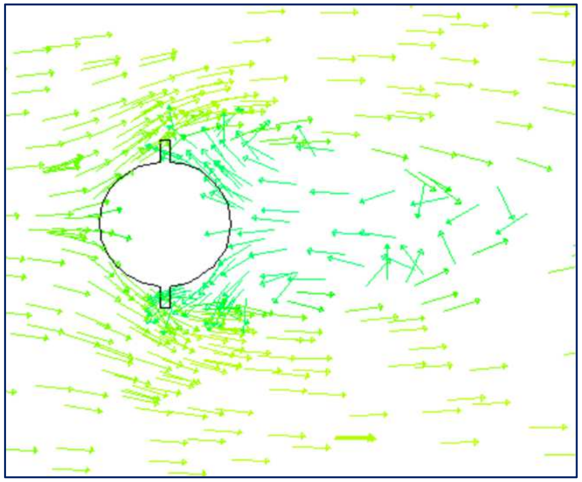
- Improving Distribution to the SCR
- Reducing Catalyst Minimum Operating Temperature
- Dual-Fuel Firing Considerations
- Improving Access
- Combustion Optimization Post SCR
- **Gas Fired SCRs**

Improving Ammonia Distribution to HRSG SCR

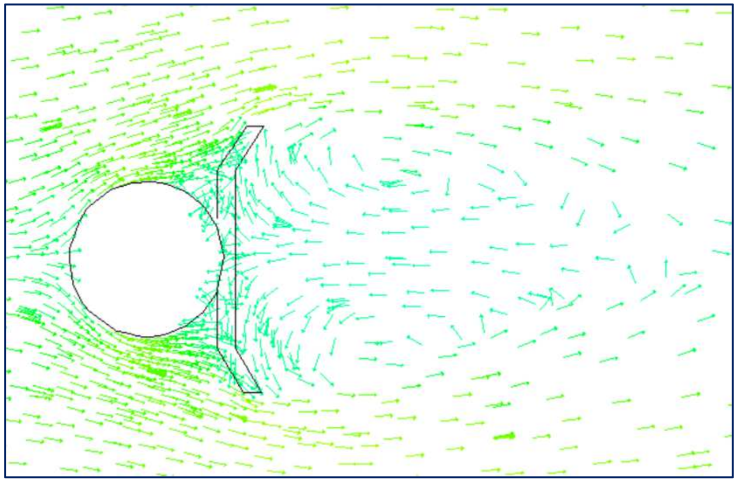
- Reduce ammonia slip
- Reduce tube fouling downstream of SCR



Velocity around lance without static mixer



Velocity around lance with bar static mixer

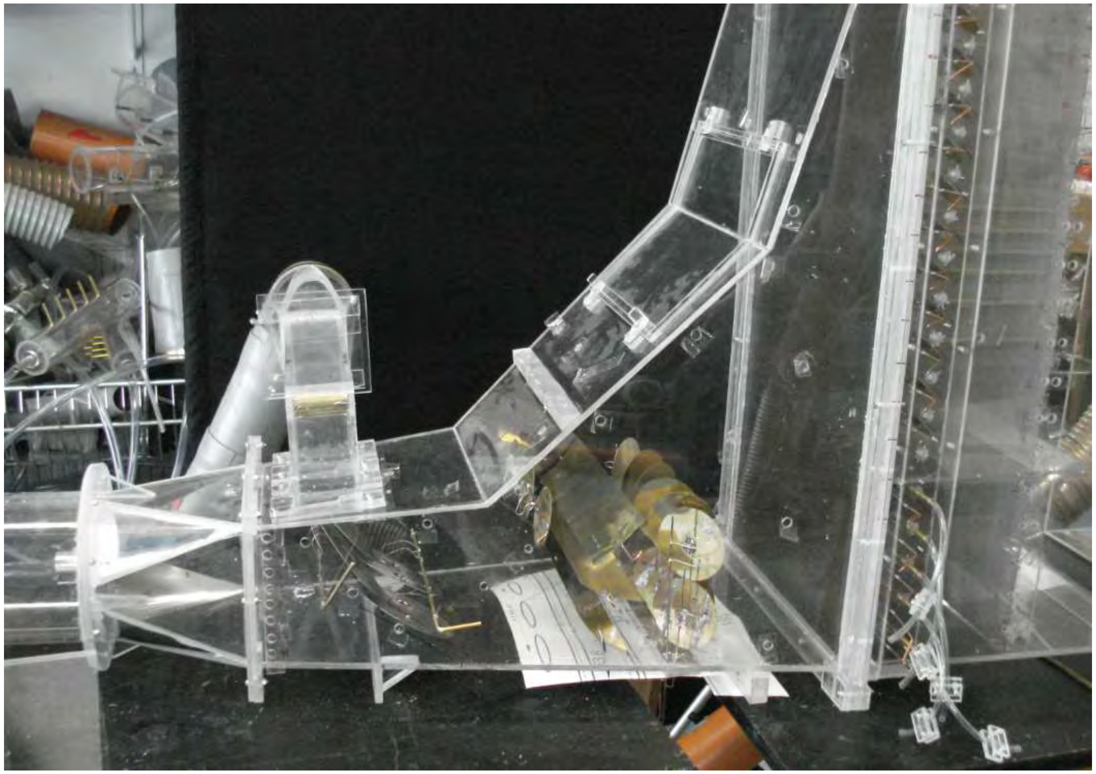


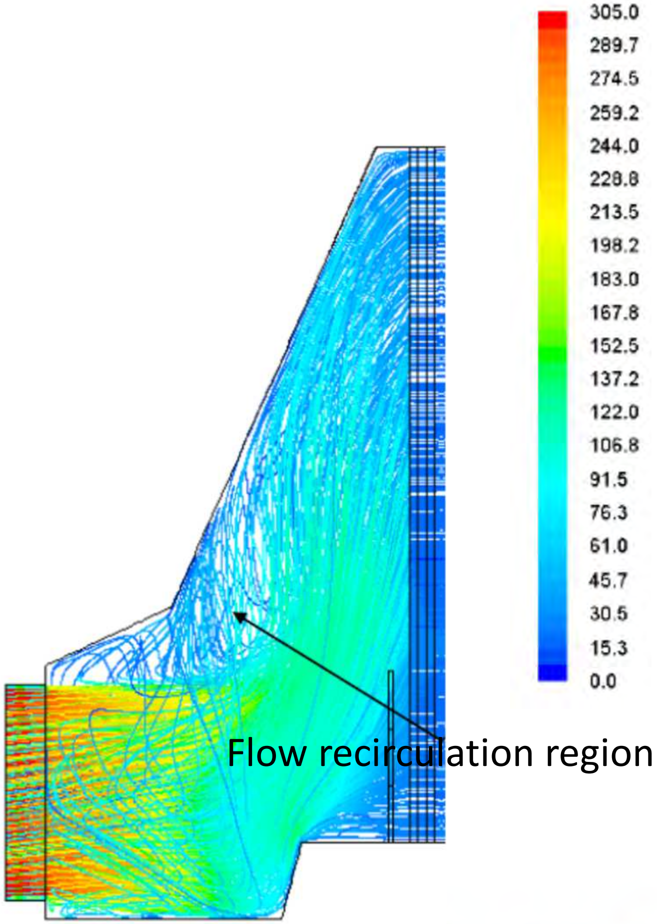
Velocity around lance with bat-wing static mixer

- Review catalyst sealing
- Review wall baffles (adding ammonia in dead spots not reacting with flue gas)
- Provide additional mixing at AIG

Improving Tempering Air Distribution for Simple Cycle Units

- Static mixers in lower velocity section to eliminate back pressure on turbine
- Reduce tempering air by improving distribution to the SCR catalyst
- Eliminate/minimize flow recirculation
- Eliminate hot and high velocity spots





Meeting SCR Goals

O&M Savings

- Reduce ash buildup
- Reduce ammonia consumption
- Reduce tuning requirements
- Reduce pluggage (reduce ammonia slip)

Optimize Performance

- Improve air heater performance (improve heat rate) and basket life
- Reduce pressure drop
- Improve turndown
- Increase catalyst life
- Reduce number of outages and eliminate forced outages

OEM to Optimize/Upgrade Systems

Original Equipment Manufactures provide the most cost effective, environmentally responsible generation solutions available today

- Supplied original technology and equipment based on condition at the time of installation
- Understand the design (i.e., materials of construction, stress analysis, installation issues)
- Understand the process and process impacts

Detailed specifications are not required for this type of work and tend to be difficult/expensive to develop
What is required is an OEM that understands the entire process and will partner in a collaboratively fashion with the owner. Working together to develop the solution from identification to installation that provides the best overall approach

Babcock Power

Suzette Puski
spuski@babcockpower.com
508-340-7836