REINHOLD ENVIRONMENTAL ®

2022 Reinhold/PCUG Round Table Presentation

Hosted by Duke Energy in the Charlotte Sheraton/Le Meridien Hotel, Charlotte, NC on June 27-28, 2022

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materials for a better life

Achieving Ultra High DeNOx & Low Ammonia Slip on Gas Turbines

2022 Reinhold Conference – Charlotte NC.

Agenda

- Ultra high NOx reduction
  - Design Considerations During Normal Unit Operation
  - Design Considerations During Start-up

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Design Considerations During Normal Unit Operation

Always Remember the Following!!!

If this is all you take away from this presentation!!!

High NOx removal is EASY

High NOx removal while controlling NH_3 slip is DIFFICULT

Controlling Ammonia Slip is the DRIVER

Main Drivers

“THE BIG THREE”

- **Sufficient reactor potential**
- **Very uniform ammonia to NOx distribution at the catalyst face**
- **Near “ZERO” flue gas bypassing the catalyst**

What is considered “ULTRA HIGH DeNOx”

- $\geq$ 93% - 94% DeNOx
- With required ammonia slip of ~ 5 ppmvdc
- $\geq$ 91% – 92%% DeNOx
- With required ammonia slip of $\leq$ 4 ppmvdc
- Current technology is limited to 95% - 96% at 5 ppmvdc ammonia slip
- **Remember the plant operator always has an outlet NOx setpoint of $\leq$ 1.8 ppmvdc**

FACTORS

Let's discuss each factor one by one

Reactor Potential

Think of catalyst as if it is electricity:

1. Voltage / (Activity)
2. Current / (Volume)

When combined you get the following:

Reactor “Potential” / (Power)

Sufficient “potential is required” based on “assumed” preconditions

Extra potential can makeup up for other deficiencies, but this is very limited

Ammonia to NOx Distribution

Preconditions

Primary Precondition (Generally is most important factor)

- WHY IS IT SO IMPORTANT?
  - Essential for the control of ammonia slip
  - Putting near equal number of ammonia molecules in the same location as the NOx molecules
  - Minimize areas across the catalyst face where the $NH_3/NO_x > 1.0$

Secondary Preconditions

- Velocity Distribution
- Temperature Distribution

Ammonia to NOx Distribution

How to achieve uniform NH_3 to NOx distribution?

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- Starts with a “High Resolution” CFD Model
  - AIG & interconnecting piping, turbine exit included and ammonia mixing
  - Consider physical model when ammonia mixing is critical.
- Multizone, tunable AIG design (generally $\geq$ 21 zones)
- Install “globe” AIG valves NOT butterfly valves. Include position locking device
- Permanent sample grid downstream of catalyst properly positioned relative to AIG zones. Locate outer probes 1.0 - 1.5 feet from each wall
- Tune AIG valves to reduce maldistribution. Be careful utilizing real-time ammonia measurement

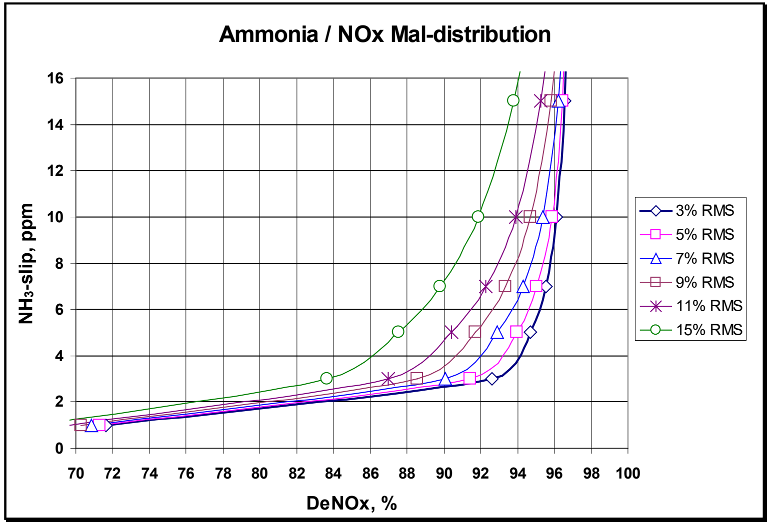
Ammonia to NOx Distribution

Catalyst potential only “goes so far”

As DeNOx approaches 94% - 96% distribution must be under 10% RMS.

Install 10 feet of catalyst at 15% RMS the slip will be high at SOR

Ammonia to NOx maldistribution was once the likely culprit now it is shifting to flue gas bypass



Flue Gas Bypass

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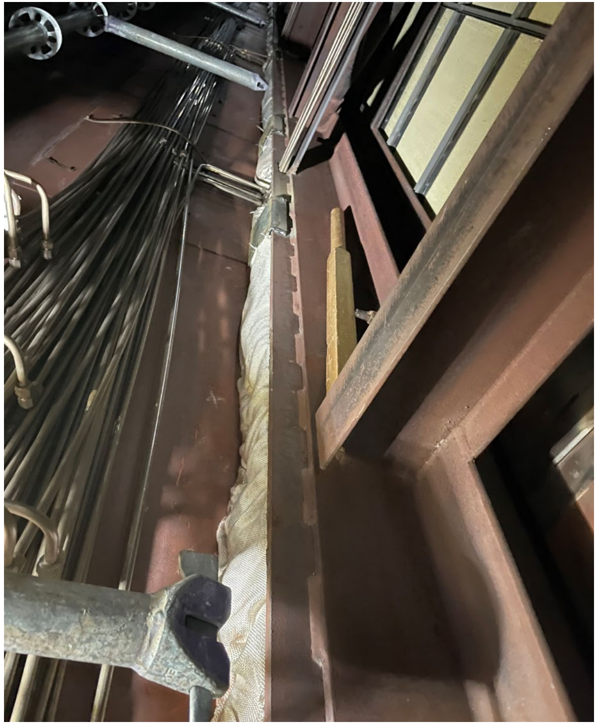
- On high DeNOx and low NH_3 slip applications bypass is becoming a “REAL” challenge
- Pure single mechanical seal technology may not be enough on some applications, secondary sealing system may be required
- Higher inlet NOx concentration from the CT is resulting in more impact from bypass
- Move to hydrogen-based fuels will increase NOx and further impact SCR performance

Flue Gas Bypass

Hi-Tech Mechanical Seals

Secondary Sealing Pillows



Flue Gas Bypass

What's Really Happening???

- On high DeNOx applications it's more than just the flue gas bypassing the catalyst
- The flue gas bypassing the catalyst results in both higher NOx and ammonia
- Subsequent increase in ammonia injection rate results in substantial increase in NH3 slip

Flue Gas Bypass

Real World Example

Design Conditions:

- Large CCGT with 40 ppmvdc outlet NOx requiring 95% DeNOx and $\leq$ 5.0 ppmvdc NH3 slip
- Since the operator uses an outlet setpoint of 1.8 ppmvdc the actual DeNOx is 95.5%
- Assume 1% flue gas bypass
- Assume 95% DeNOx and a designed NH3 to NOx distribution 10% RMS

Flue Gas Bypass

RESULTS: Appropriate catalyst design for 95% DeNOx and 5 ppm slip with 5-year guarantee

Design Type	Bypass %	NH_3/NOx Dist. %RMS	DeNOx %	NOx, ppmvdc	SOR NH_3, ppmvdc
Base 40ppmvdc – 2ppmvdc	0	10	95.0	40-2	3.0
Operator NOxout setpoint 1.8 ppmvdc	0	10	95.5	40-1.8	3.5
Operator NOxout setpoint 1.8 ppmvdc **Includes Bypass of NH_3**	1.0	10	95.5	40-1.8	3.9
Operator NOxout setpoint 1.8 ppmvdc **Includes Bypass by NOx**	1.0	10	96.5	40-1.4	4.9
Increase ATN Maldistribution	1.0	13	96.5	40-1.4	6.6

Let’s explore what can be done to minimize the impact of:

“THE BIG THREE”

Ammonia to NOx Distribution

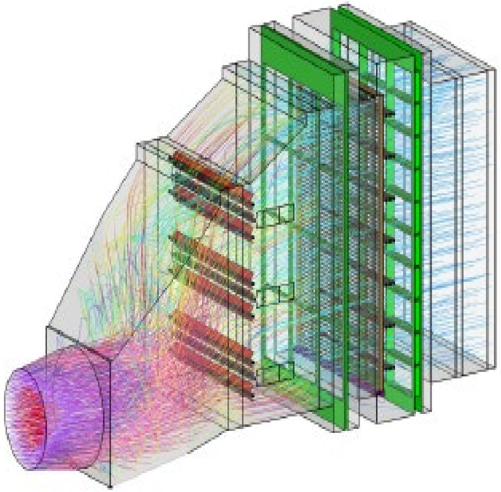
CFD Modeling and AIG Design

Modeling

- Model the entire HRSG from engine exit to catalyst face. High resolution grid / lots of cells. (Velocity uniformity & NH_3 mixing)
- Model the AIG interconnecting piping and lances to ensure uniform flow
- Consider mechanical mixers for NH3 mixing

Design

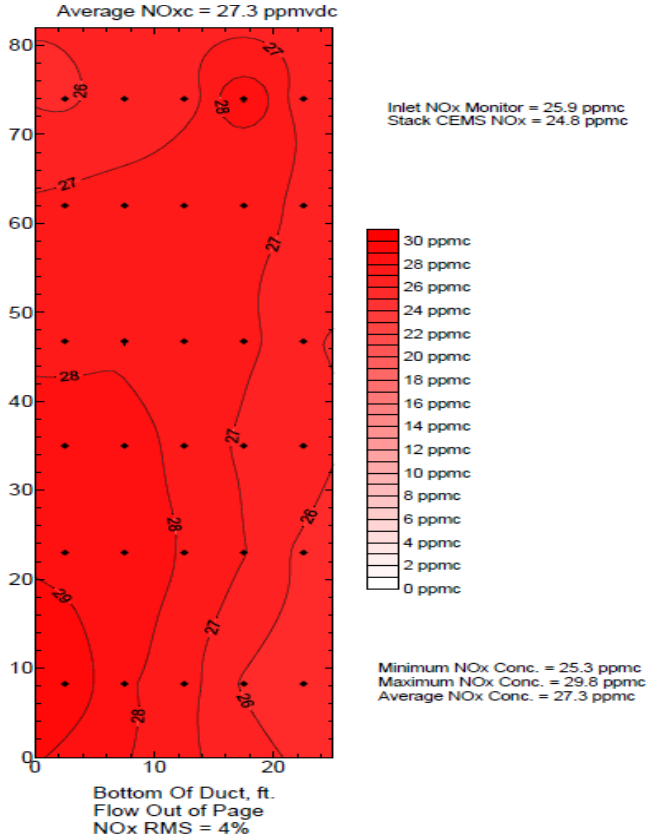
- Sufficient number of tunable zones
- Uniform flow through all nozzles
- Use of “Globe” AIG control valves
- Permanent probe grid to support optimization of AIG system



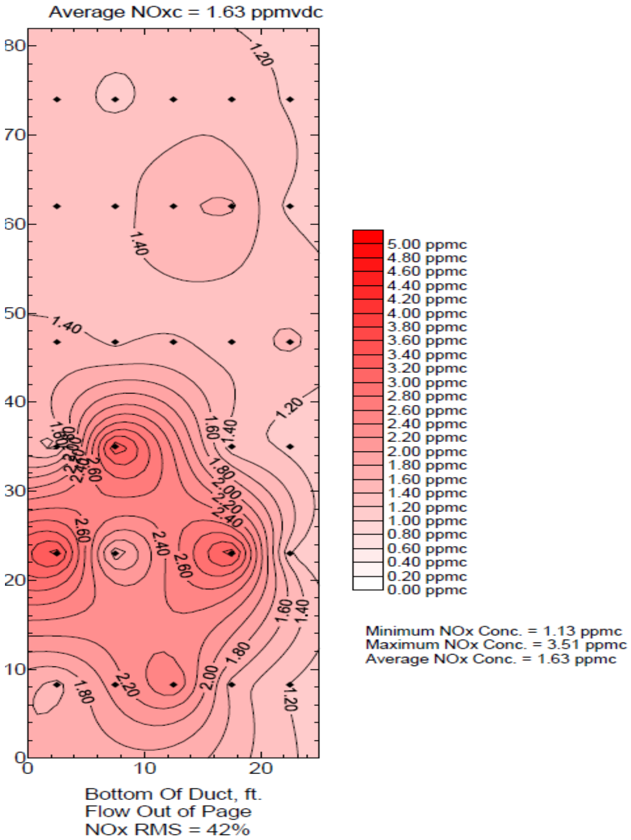
Ammonia to NOx Distribution

Added Impact of Velocity Maldistribution

Inlet NOx Dist.

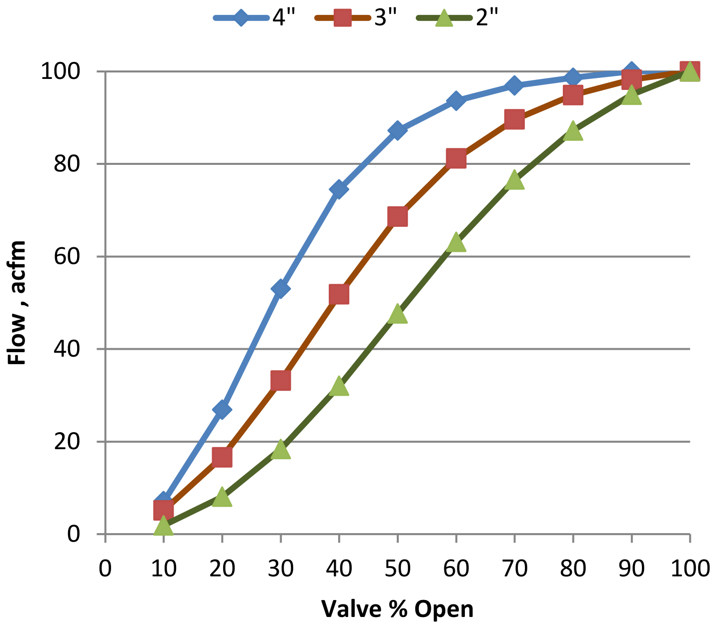


Outlet NOx Dist.



Ammonia to NOx Distribution

Controlling NH_3 Flow - Consider Globe valves or a smaller valve



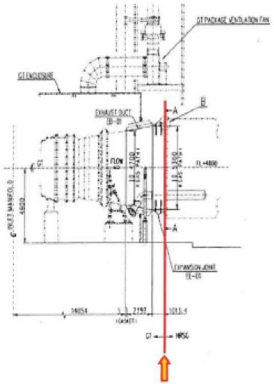
Ammonia to NOx Distribution

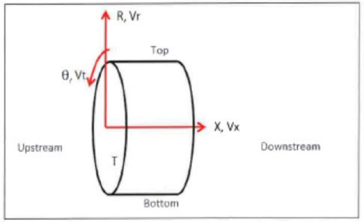
Include CT exit velocity profile

Exhaust Profile Summary

- Swirl velocities at 100% and 75% load are less than 15 m/s in magnitude.
- Swirl velocities at 50%, 25% and 0% load have swirl velocities of about 30 m/s near the centerline of the exhaust plane. These velocities are a significant fraction of axial velocity but are localized to center area.

Technical Specifications





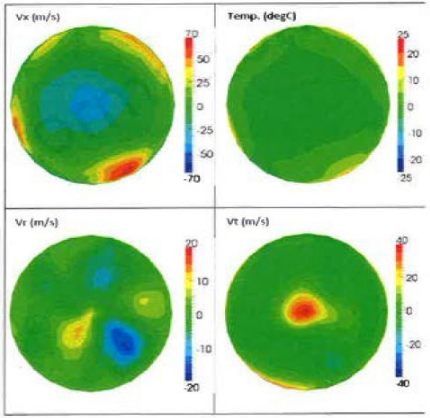
[NOTE REGARDING THE AVERAGE VALUES PROVIDED IN SUBSEQUENT SHEETS]
The Average values provided are based on Standard conditions and Supplier to refer to Project specific data as appropriate.
[Coordinates]

50% Load

[Average Values]

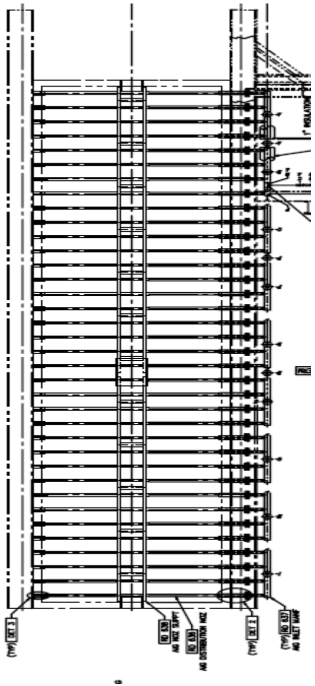
Exhaust Gas Flow	kg/s	471.1
Exhaust Gas Temperature	degC	537
Exhaust Gas Axial Velocity (Vx)	m/s	48.3
Exhaust Gas Radial Velocity (Vr)	m/s	-4.6
Exhaust Gas Tangential Velocity (Vt)	m/s	-43.7

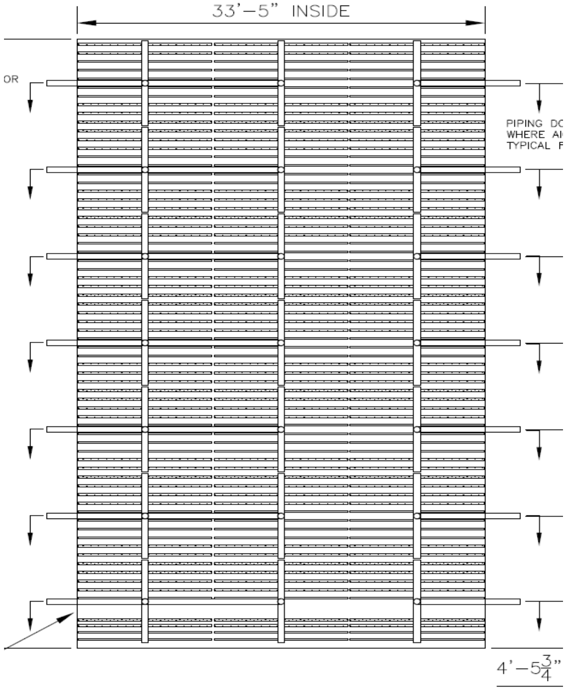
[Deviations from Average Values - Color Contour]



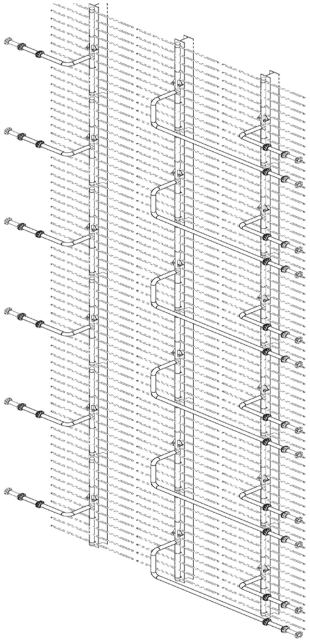
Ammonia to NOx Distribution

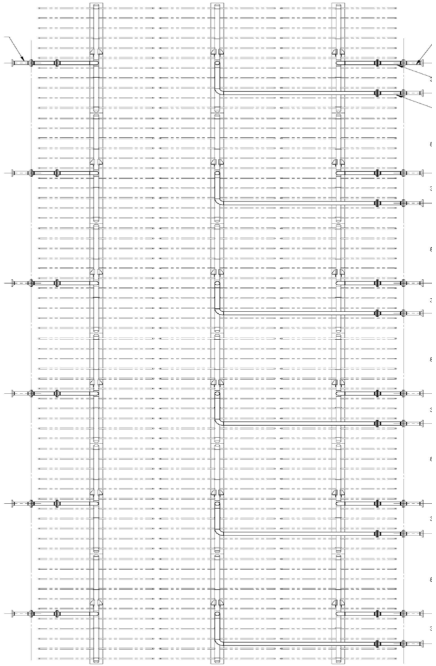
Multi-zone – Tuneable AIG Design





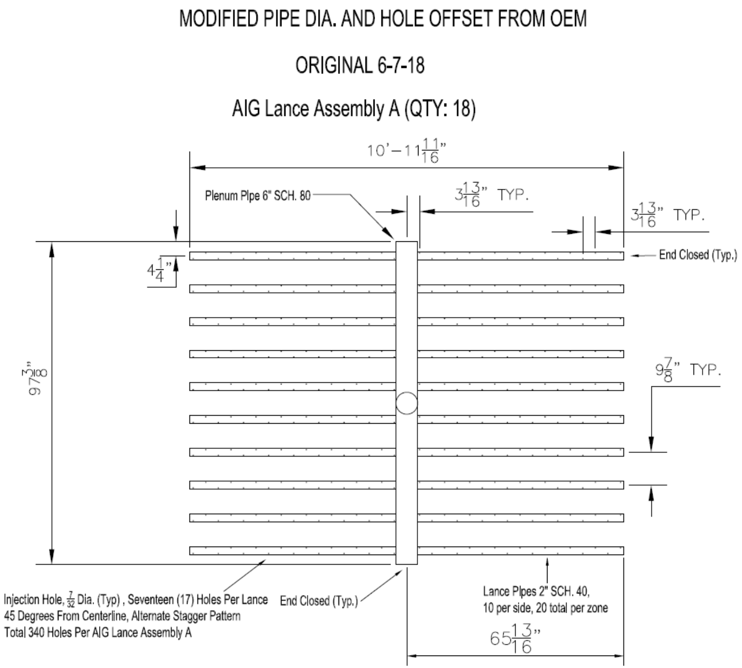
Ammonia to NOx Distribution





Ammonia to NOx Distribution

Multi-zone – Tuneable AIG Design



Ammonia to NOx Distribution

Modeling lances & Interconnecting Piping

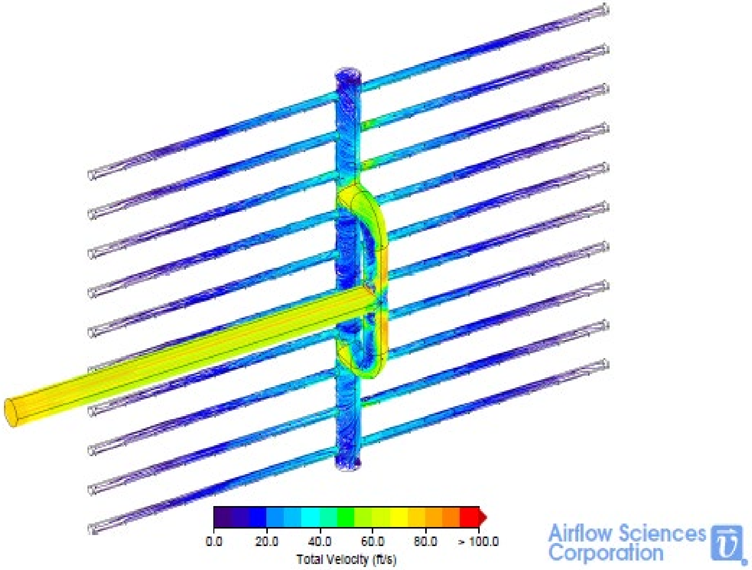
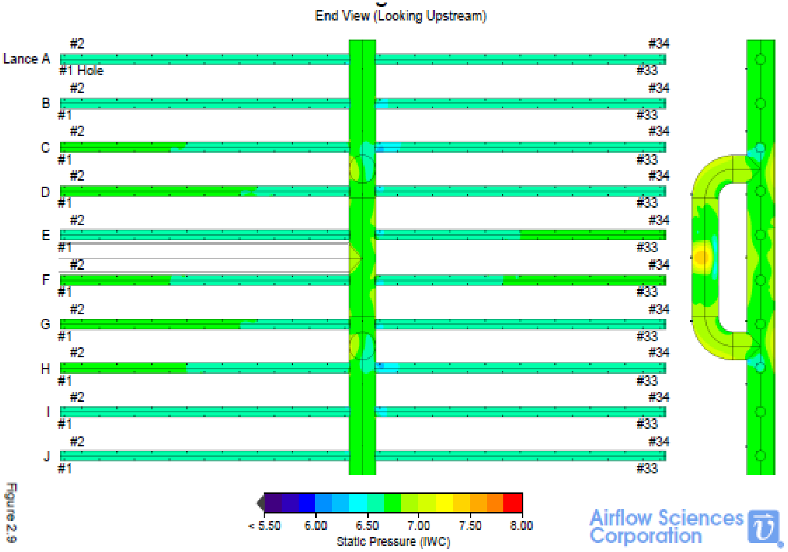
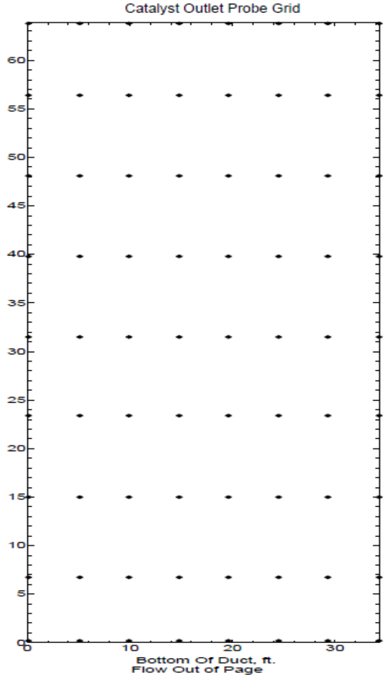


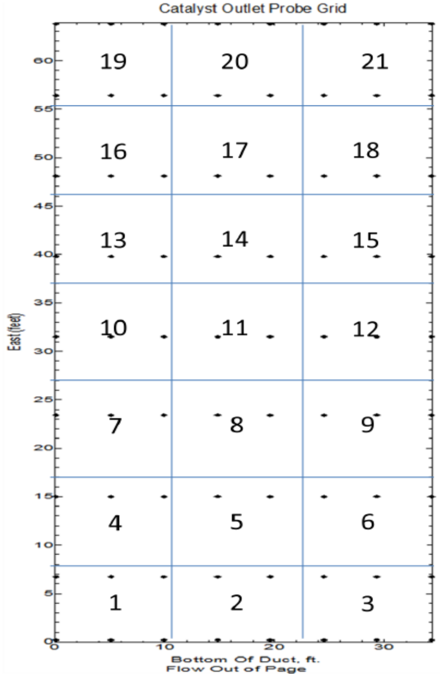
Figure 2.9



AIG Basis Design

Multi-zone with properly positioned sample probe grid
Optimizing Ammonia to NOx Distribution





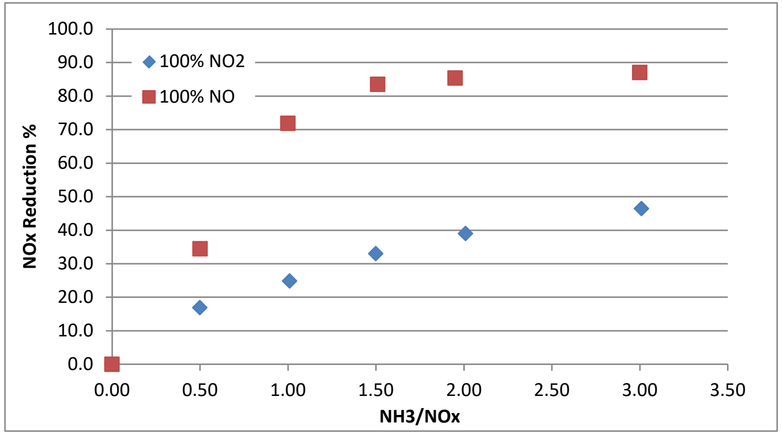
Additional Things Impacting Performance

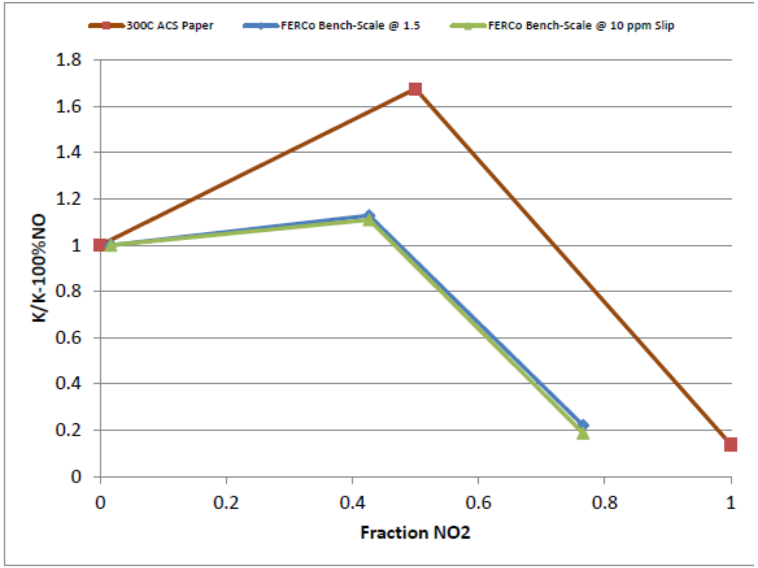
Optimizing SCR System Performance

- Place AIG valves and sample taps at grade. Run tubing inside reactor (**label correctly**)
- Install “globe valves” NOT “butterfly valves” for better control
- Consider using “mixers / bluff body” on or just upstream of AIG lances
- Locate fast acting NOx analyzers just upstream and downstream of catalyst layer
- Multi-probe CEMS at stack
- Utilize high performance mechanical seals around catalyst layer
- Add secondary sealing pillows to reduce flue gas bypass
- Ensure that NO_2/NOx ratio is always $\leq$ 0.5 at all loads
- Place outer sample probes 1.0 – 1.5 feet inboard from the reactor walls
- Catalyst cleanliness, liberated insulation fibers and rust.
- Minimum flue gas temperature at SCR catalyst of 625F at MECL
    - Split HP evaporator

Impact on SCR Performance & Design

Impact of high NO_2 on DeNOx Reaction ????





Umicore “Patent Pending” Process for CCGT’s

Achieves >97% DeNOx with low NH_3 Slip

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- Fits in existing HRSG reactor space
- Requires use of “dual function” catalyst
- Requires less uniform ATN distribution at catalyst face
- Flue gas bypass has less impact
- Controls ammonia slip below 5 ppmvdc
- Little or no change to pressure drop compared to traditional CO + SCR layer system
- Reduction in overall catalyst volume is likely
- Will be crucial as the industry transitions to hydrogen and much higher NOx
- Little or no change in overall system cost

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Design Considerations During Unit Startup

Design Considerations During Unit Startup

If I'm designing the emission control system

- Optimize flue gas temperature at the catalyst face
  - Increase flue gas temperature by splitting HP evaporator
  - Consider firing duct burners during startup

- Locate "quick acting" process NOx analyzers just upstream and downstream of catalyst
  - NOx feedback is far to slow during startup and high ramp rate operation
  - Multi-point in place of single-point

- Limit ammonia injection rate during startup to NH_3/NO_x ~ 1.0 - 1.2

Thank You!

Questions? Comments?

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