REINHOLD ENVIRONMENTAL ®

2023 Reinhold/PCUG Round Table Presentation

Cohosted by Duke Energy and Vistra in The Westin Hotel, Cincinnati, OH on June 26-27, 2023

Achieving Maximum DeNOx Performance on CCGT’s Using Current SCR Technology

“Controlling Ammonia Slip”

2023 Reinhold Conference – Cincinnati, OH

Agenda

- Controlling ammonia slip is by far “Single Most Important Component”
- Current Technology Has Reached/Past Its Performance Limit
- Craig Sharp to follow with news about a New Patented Technology

- How can we control/reduce ammonia slip?
  - Very uniform ammonia to NOx distribution at the catalyst face
  - Minimizing flue gas bypass
  - Install sufficient reactor potential (EASIEST)

- CONTROL OF AMMONIA SLIP IS THE BOTTOM LINE

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~~ FOUR”

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- **Sufficient reactor potential**
- **Very uniform ammonia to NOx distribution at the catalyst face**
- **Near “ZERO” flue gas bypassing the catalyst**
- **Higher NOx concentration due to H2 or H2 blends (NEW)**

What is considered “ULTRA HIGH DeNOx”

  - ≥ 92% DeNOx
  - With required ammonia slip of ~ 5 ppmvdc
  - ≥ 90% DeNOx
  - With required ammonia slip of ≤ 4 ppmvdc

- Current technology is limited to about 95% DeNOx at 5 ppmvdc ammonia slip
- Ammonia to NOx uniformity ≤10% RMS is required but very difficult
- **Remember the plant operator always has an outlet NOx setpoint of ≤ 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/Surface Area)

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

Impact of Reactor Potential on Ammonia Slip

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Design: 96% DeNOx (50ppmvdc – 2ppmvdc) @ 5ppm slip EOR, 650F, New Catalyst, No Bypass

Limit is a function of DeNOx % and inlet NOx concentration

Ammonia to NOx Distribution, % RMS	Flue Gas Bypass, %	DeNOx, %	Catalyst Depth, mm	SOR NH_3 Slip, ppmvdc
8.0	0	96.0	540	2.7
12.0	0	96.0	540	5.0
12.0	0	96.0	810	4.1
12.0	0	96.0	1080	4.1
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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 $NH_3/NO_x > 1.0$
  - Most difficult to achieve
  - Nearly impossible to accurately measure in an operating unit

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 or ball” 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

Flue Gas Bypass

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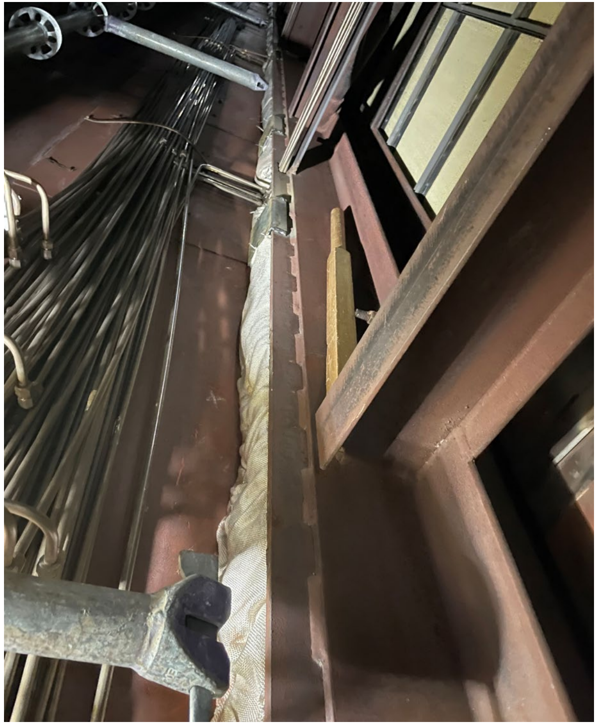
- On high DeNOx and low NH_3 slip applications bypass is becoming a “REAL” challenge
- Pure single mechanical seal technology may not be enough on some applications, secondary sealing system may be required
- Higher inlet NOx concentration from the CT is resulting in more impact from bypass
- Move to hydrogen-based fuels will increase NOx and NH_3 concentration 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 NH_3 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 NH_3 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 Slip, 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	12	96.5	40-1.4	**6.6**

Higher Inlet NOx (Hydrogen or H2 Blends)

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The direction we are headed - not a good one

- Consequences of higher NOx emission from the CT
  - Higher NOx in flue gas results in proportionally higher ammonia in flue gas stream
    - Same % flue gas bypass results in greater negative impact
    - Change in NOx concentration is proportional to impact at the stack

  - Higher NOx requires higher catalyst potential for the same % DeNOx removal rate
  - Higher NOx requires improved NH_3 to NOx uniformity
  - Higher NOx requires lower flue gas bypass

Impact on Ammonia slip with Increasing Inlet NOx

95% DeNOx, 650F, New Catalyst, $NH_3/NO_x \leq$ 10% RMS, No Bypass

Inlet NOx Concentration, ppmvdc	Bypass, %	NH3/NOx Dist. % RMS	DeNOx, %	SOR NH_3 Slip, ppmvdc	Addition cat. Vol to achieve 2.5 ppmvdc NH_3 Slip, %
25.0	0	10	95.0	2.5	0.0
75.0	0	10	95.0	7.1	Not Possible
100.0	0	10	95.0	9.5	Not Possible
125.0	0	10	95.0	11.5	Not Possible
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Let’s explore what can be done to ensure uniform

NH_3 to NOx distribution

Ammonia to NOx Distribution

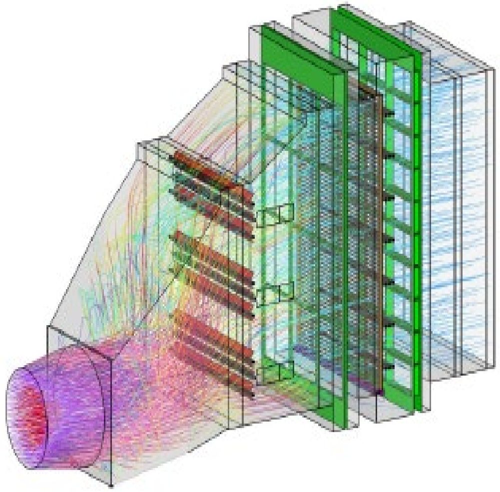
CFD Modeling and AIG Design

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 on AIG lances

Design

- Sufficient number of tunable zones
- Use of “Globe or Ball” AIG control valves
- Permanent probe grid to support optimization of AIG system. Wall probes 12” – 18” from wall.



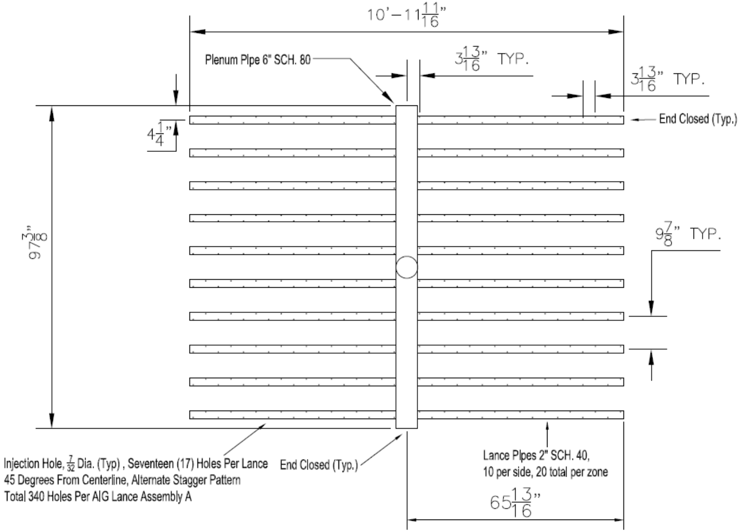
Ammonia to NOx Distribution

Multi-zone – Tuneable AIG Design

MODIFIED PIPE DIA. AND HOLE OFFSET FROM OEM

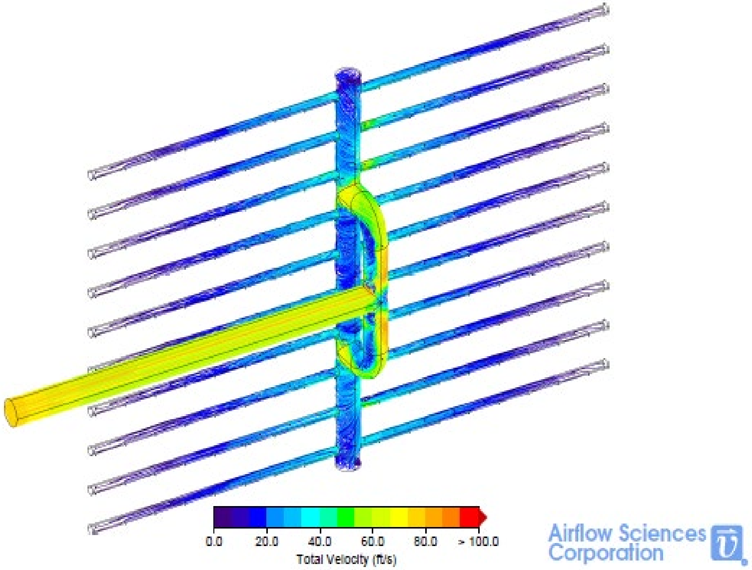
ORIGINAL 6-7-18

AIG Lance Assembly A (QTY: 18)



Ammonia to NOx Distribution

Modeling lances & Interconnecting Piping



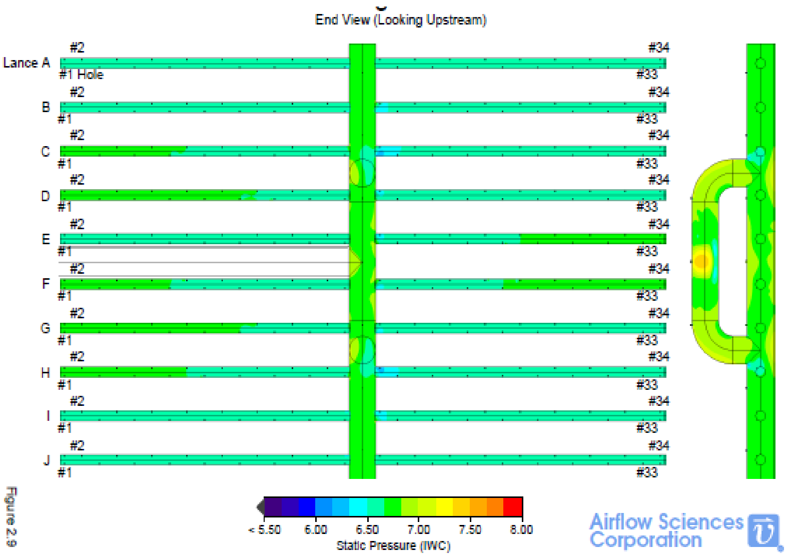
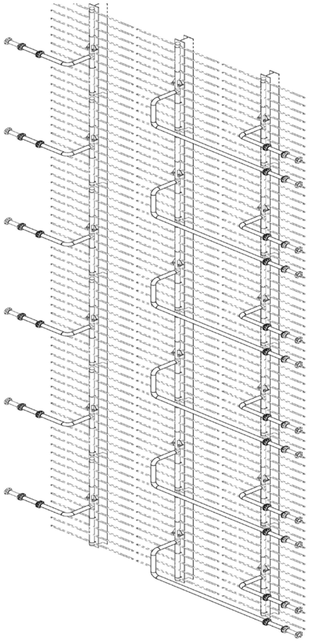
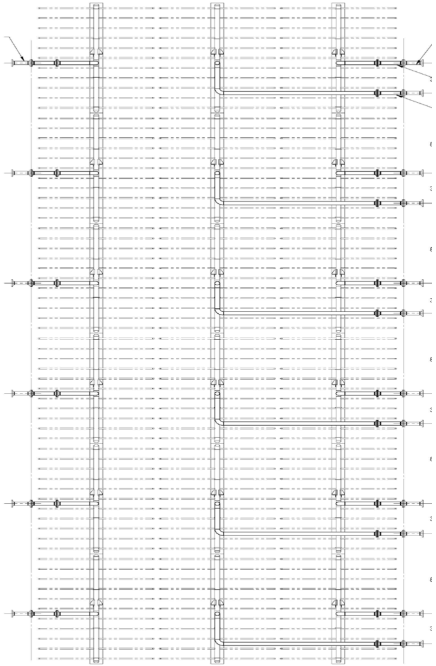


Figure 2.9

Ammonia to NOx Distribution

Multi-zone – Tuneable AIG Design





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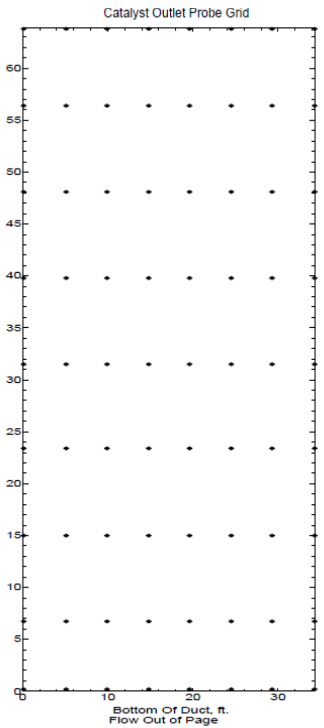
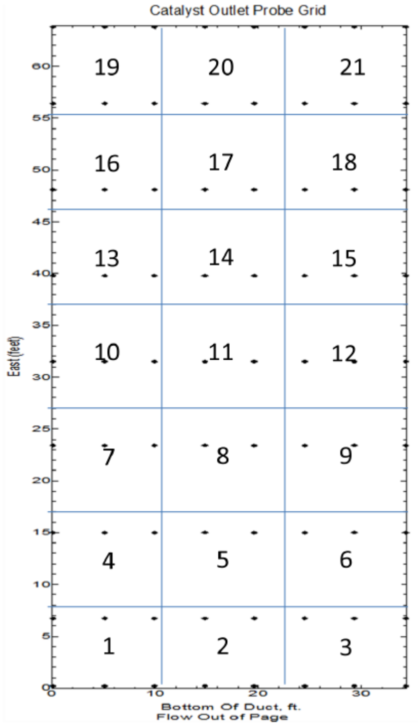
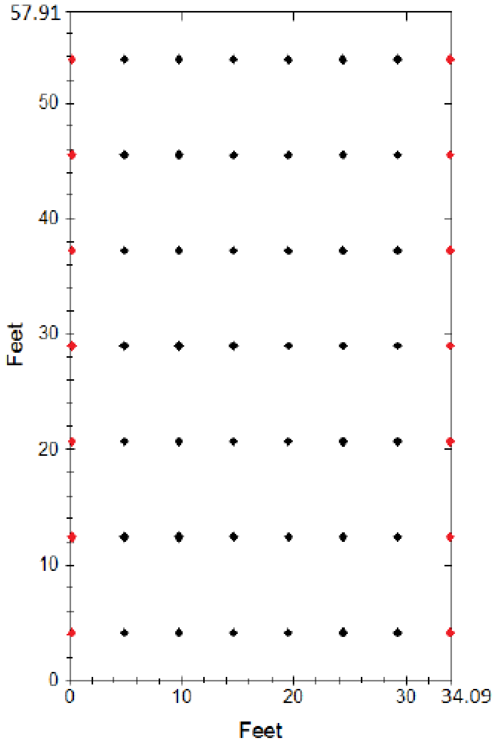
Ammonia to NOx Distribution

AIG Opimization - Multi Zone AIG with properly positioned “sample probe grid”

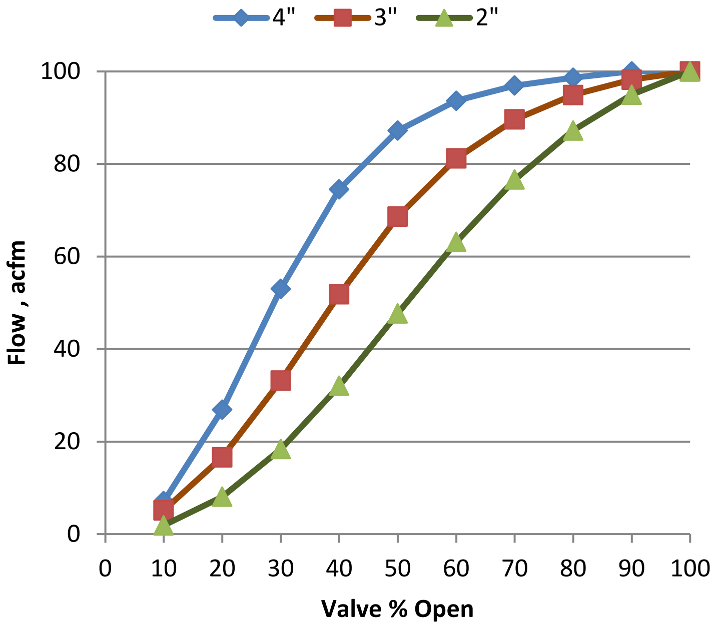






Ammonia to NOx Distribution

Controlling NH_3 Flow - Consider Globe or Ball valves or a smaller valve



Additional Things Impacting Performance

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Optimizing SCR System Performance

- Place AIG valves and sample taps at grade. Run tubing inside reactor (**label correctly**)
- Install "globe or ball 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 - 650F at MECL
  - Split HP evaporator

Umicore “Patented” Technology for CCGT’s

Achieves >97% DeNOx with Low NH Slip: Craig Sharp to Follow

- 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 5.0 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
- Current Technology has reached its performance limit

Thank You!

Questions? Comments?

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