Use of Field Testing and CFD Analysis to Improve Poor NH_3 Distribution and SCR Performance

for

HRSG Forum

June 2, 2021

HRSG FORUM WITH BOB ANDERSON

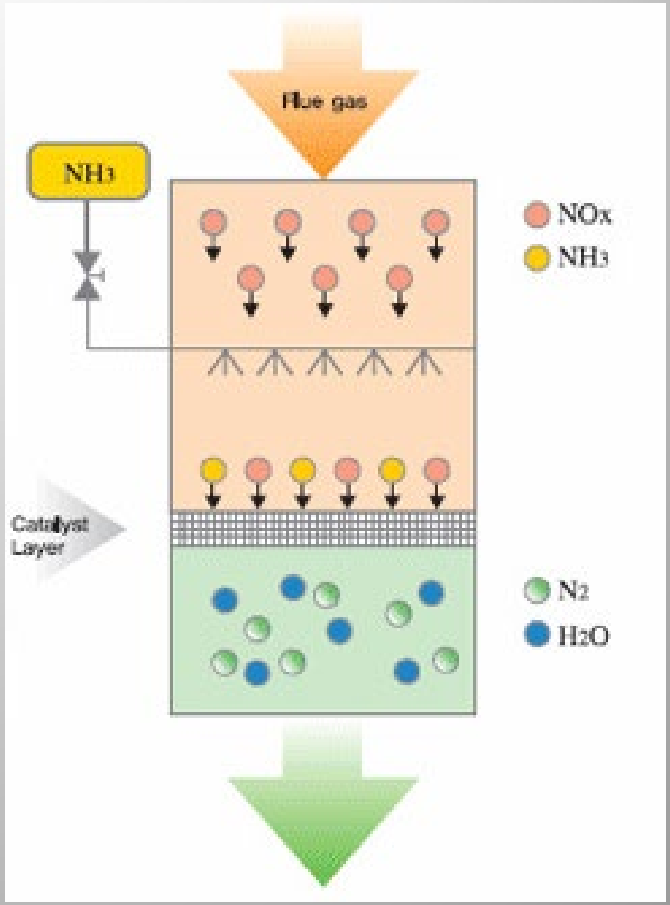
SCR SOLUTIONS, LLC
EXPERT EMISSION SOLUTIONS

Outline

- SCR Basics
- Key operating parameters and stack limits
- NOx Measurements and AIG Tuning
- Case Study #1
- Case Study #2
- Summary and Q & A

SCR Basics

- **S**elective **C**atalytic **R**eduction (SCR) is the process of removing NOx (NO and NO_2) out of the flue gas stream by injecting ammonia (NH_3) into the flue gas as a reagent.
- The flue gas passes over a fixed bed of catalyst installed in a reactor.
- Ammonia reacts with nitrous oxides on the catalyst surface to form safe and clean nitrogen and water.



$$4NO + 4NH_3 + O_2 \xrightarrow{\textit{Catalyst}} 4N_2 + 6H_2O$$

$$2NO + 2NO_2 + 4NH_3 \longrightarrow 4N_2 + 6H_2O$$

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Key Performance Parameters

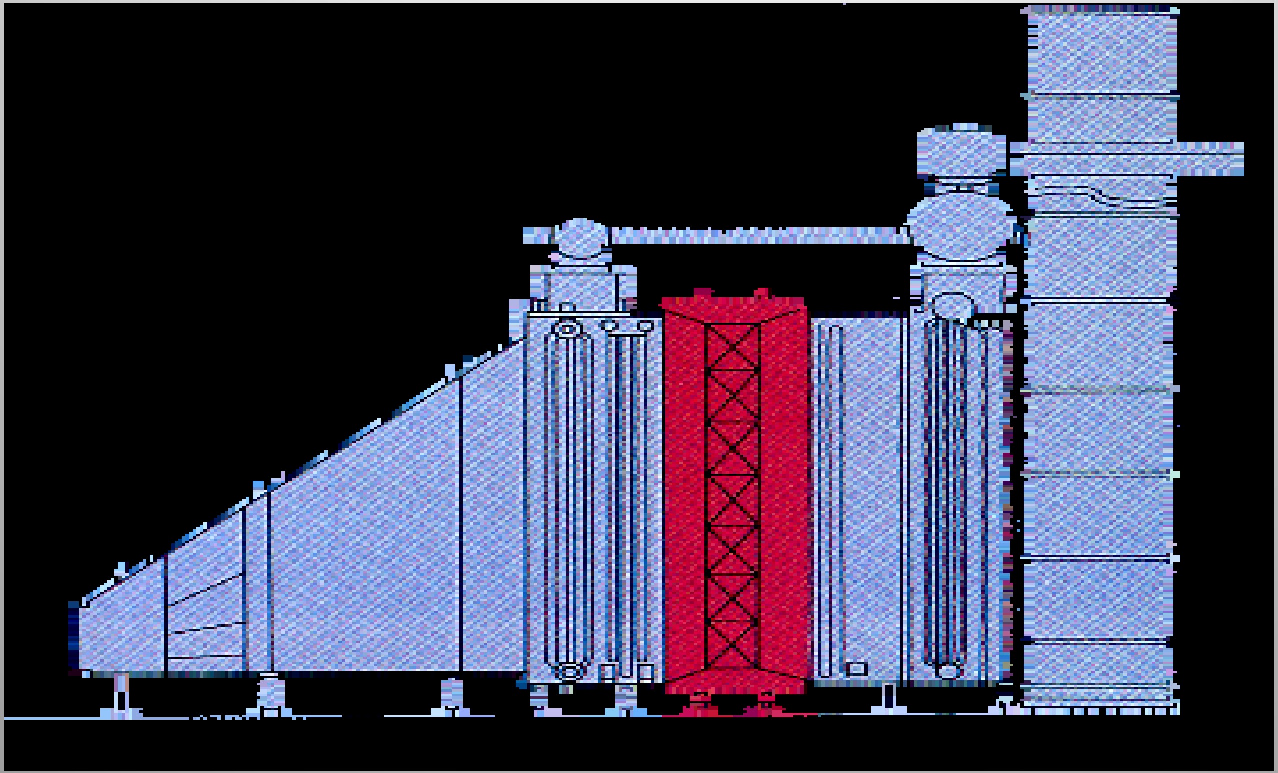
The “SCR” system usually consists of CO catalyst, in addition to the SCR system.

Typical Performance Parameters

Parameter	Units	Typical Range
Stack Requirements		
CO	ppmvd @ 15% O2	2 - 10
NOx	ppmvd @ 15% O2	2 - 5
Ammonia Slip	ppmvd @ 15% O2	2 - 10
VOC	ppmvd @ 15% O2	2 - 5
System Design Requirements		
CO Catalyst Pressure Drop	in. w.c.	1 - 2
SCR Catalyst Pressure Drop	in. w.c.	2 - 4
NH3/NOx Distribution	%RMS	5 - 10
Catalyst Life	Hours	8,000 - 50,000

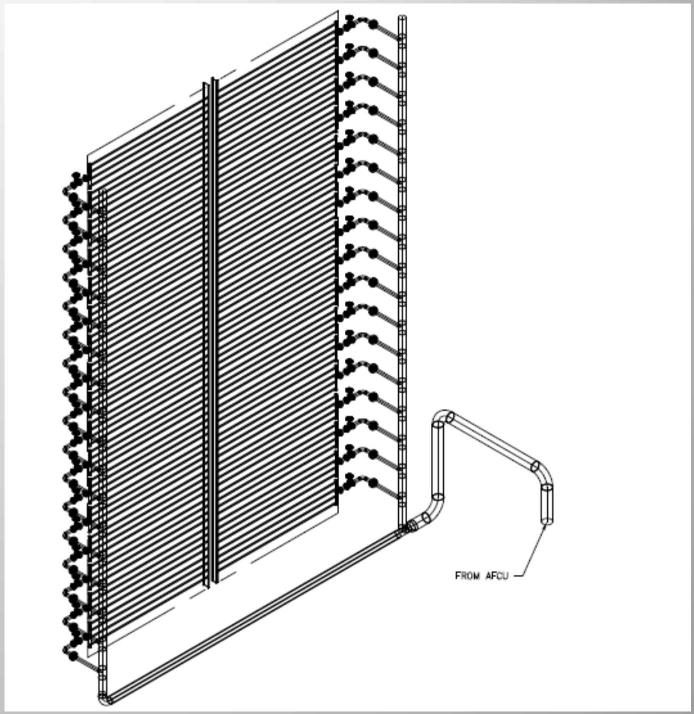
SCR Location in HRSG

- AIG and Catalyst typically located in HRSG where temperature is 550 - 750F



Ammonia Injection Grid

- AIG used to distribute ammonia/air mixture into exhaust flue, upstream of SCR catalyst
- Located downstream of CO catalyst
  - Otherwise CO catalyst would oxidize ammonia and convert to NOx
- AIG designed so that it can be tuned
  - Tuning should not be necessary if the system is properly design and modeled



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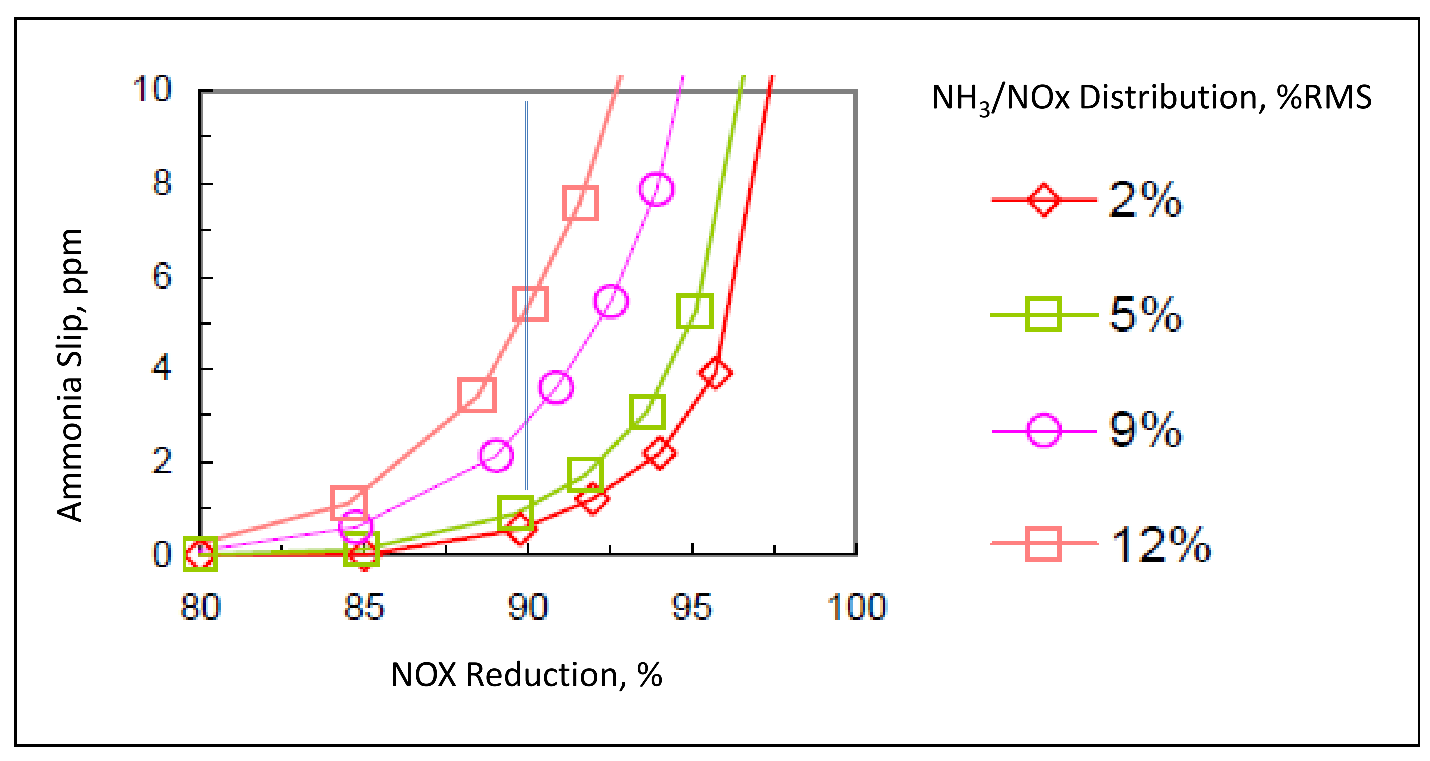
AIG Design – The need for good ammonia distribution

- Poor NH_3/NOx distribution can significantly impact NH_3 slip
- As shown, the better (lower %RMS) the NH_3/NOx distribution, the lower the overall ammonia slip (and ammonia usage)



Key Performance Parameters

Ammonia Slip…

- NOx and CO can be fairly straightforward to meet, but ammonia slip can be difficult to maintain
- "Overfeeding" ammonia can usually drive the NOx down to required limits, but ammonia slip will go up.
- Ammonia slip is either periodically tested, or continuously monitored.
- High ammonia slip can result in…
  - Ammonia emissions exceedances
  - High (wasted) ammonia usage
  - Downstream HRSG fouling
- Causes…
  - Poor NH_3/NOx and/or gas flow distribution
  - Bypass
  - Deactivated SCR catalyst

AIG Tuning

- Tuning performed by measuring NOx and O_2 at the inlet and outlet of SCR catalyst, as well as NH3 slip at the SCR catalyst outlet
- Can be done using a permanent test grid which are sometimes supplied in new units.

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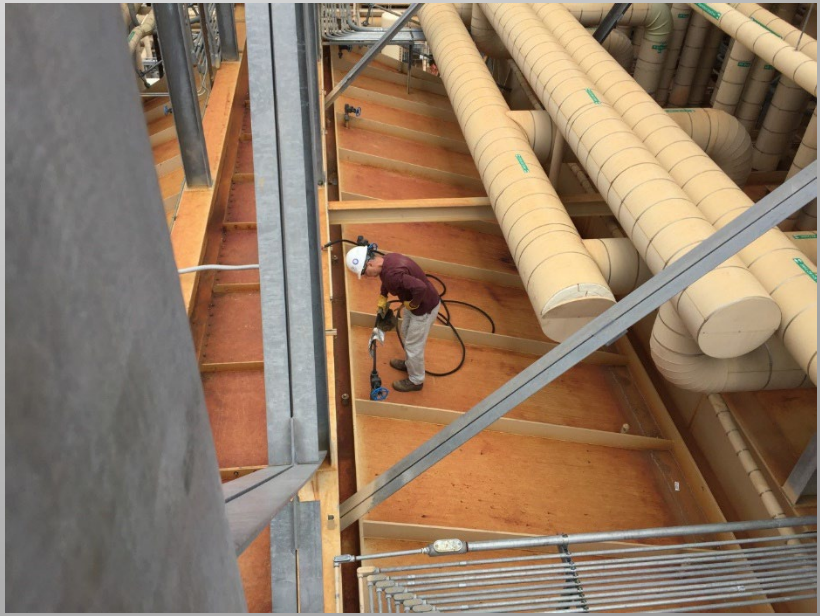
AIG Tuning – Top Traverse Test Method

- When a permanent test grid is not available, SCR Solutions utilizes a unique method to test using roof test ports or sky climber ports
- Flexible weighted probe is dropped down through the HRSG at specified elevations



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AIG Tuning – Top Traverse Method

Advantages

- Eliminates the need to add a costly permanent grid
  - Outage time
  - Materials
  - Scaffolding (inside and out)
- Full traverse (inlet and outlet) typically takes 3-4 hours
- Using FTIR (EPA Method 320), **ammonia slip** can be measured at any and all points
- Ideal for Combined Cycle Units

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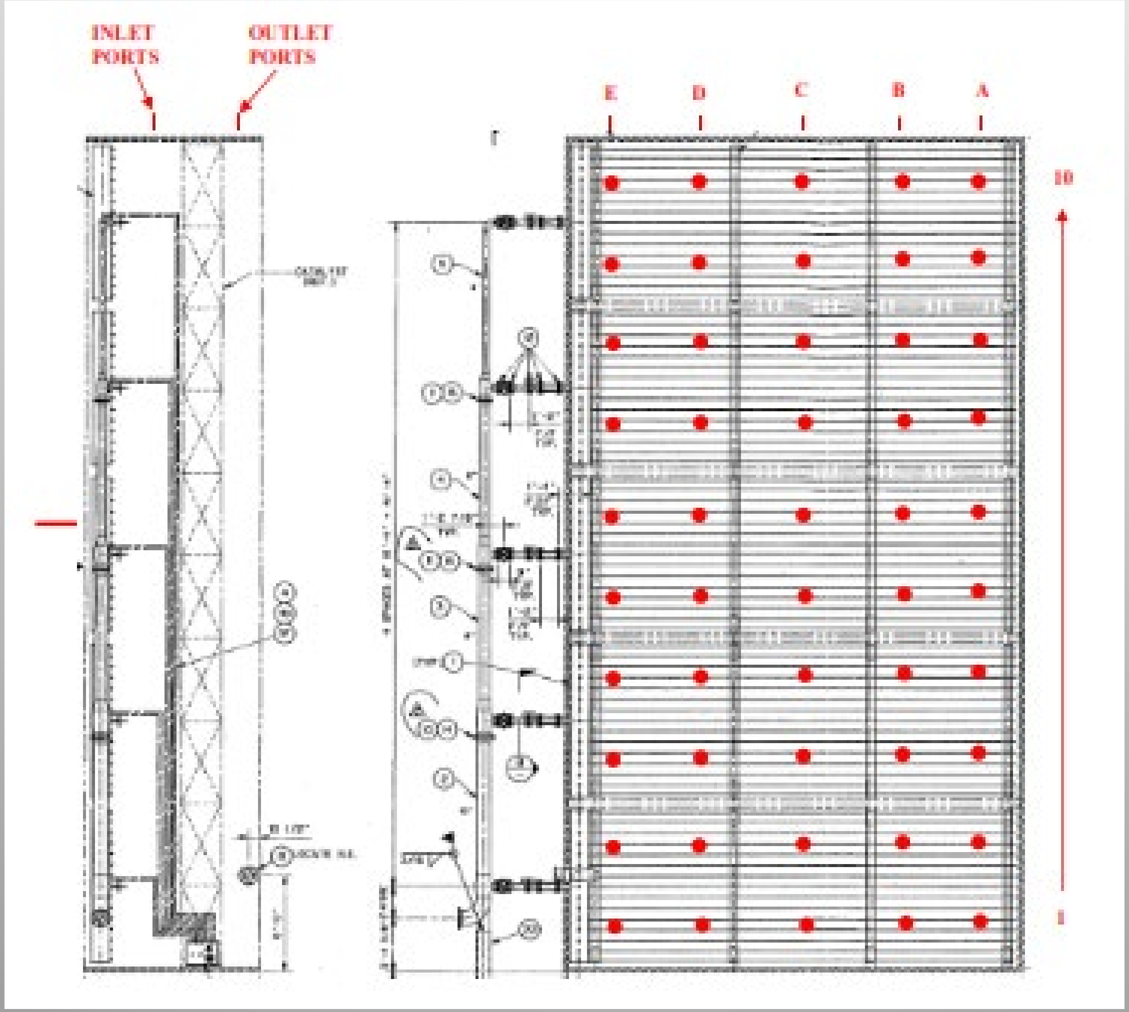
AIG Tuning – Top Traverse Method



CASE STUDY #1

A Southwest US plant consists of two Siemens 501F gas turbines in a 2 on 1 combined cycle configuration for a total plant output of 490MW.

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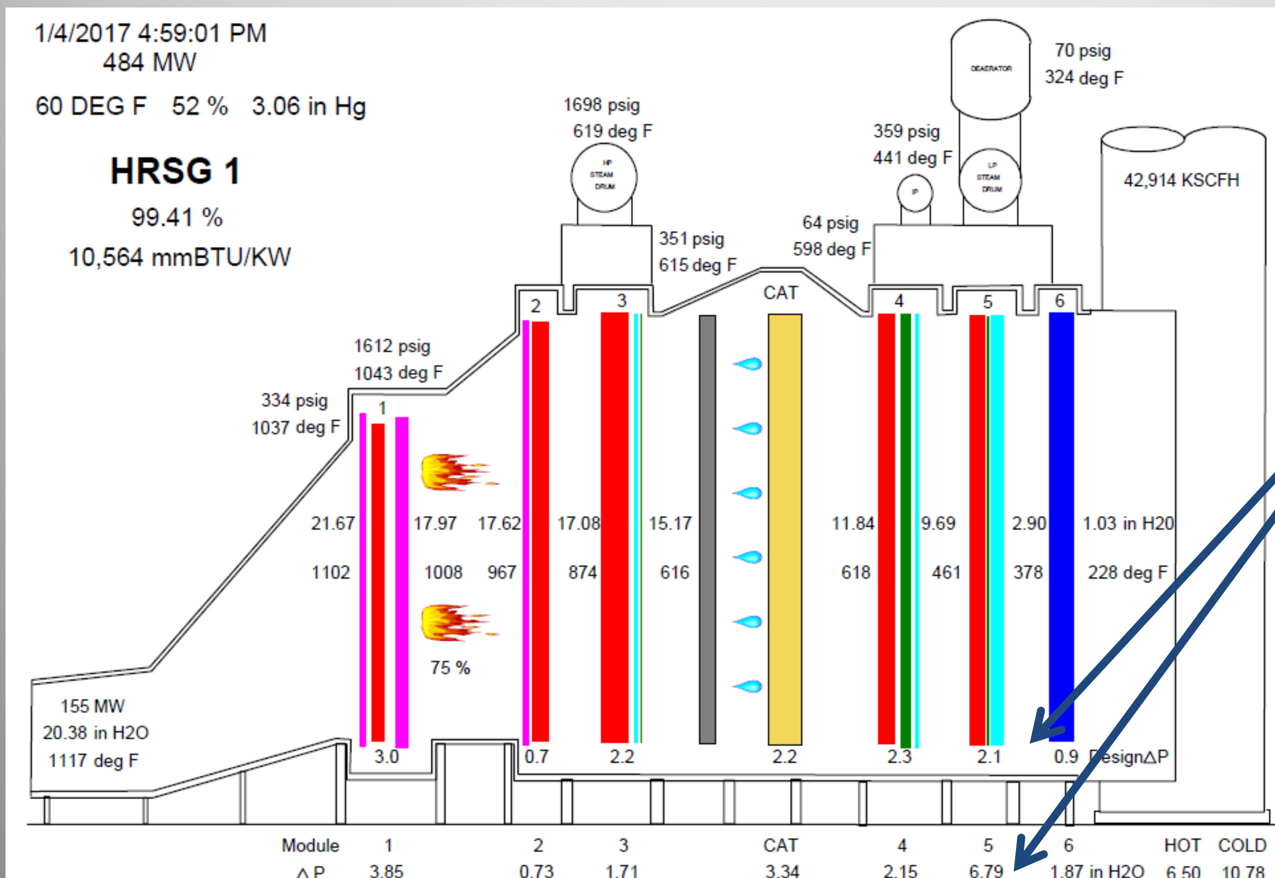
High Pressure Drop Downstream of SCR

Since startup in 2000, the HRSG's experienced high pressure drop in HP/IP Economizer tubes (Module #5).



Module #5

Design ΔP=2.1 in. w.c.

Actual ΔP>6.8 in. w.c.

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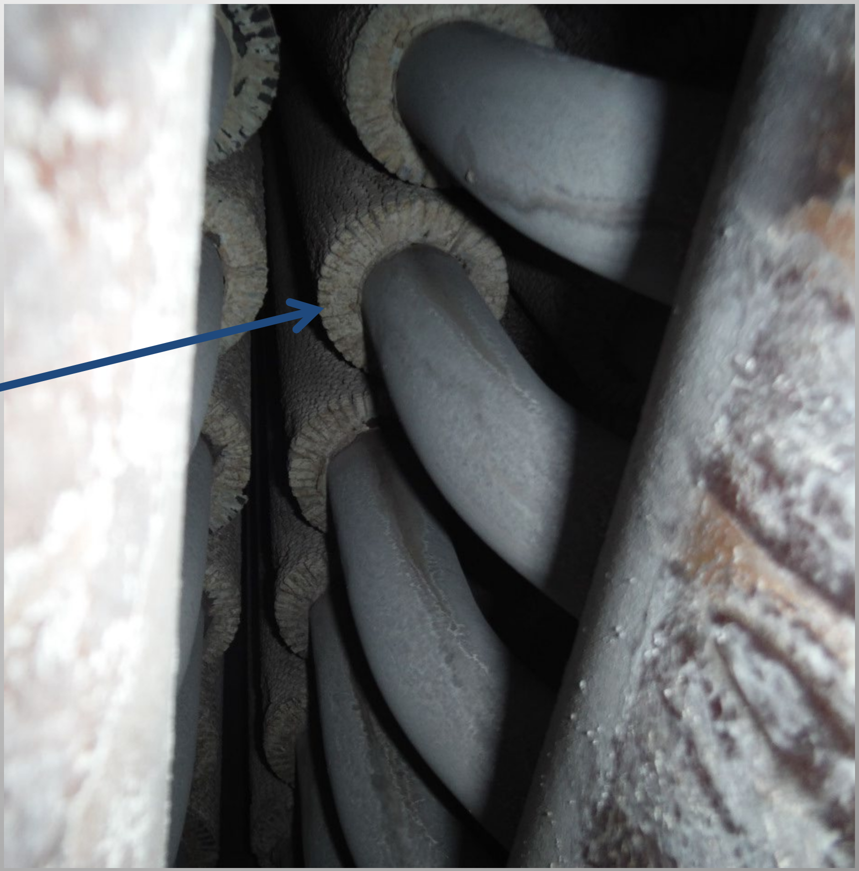
High Pressure Drop Downstream of SCR

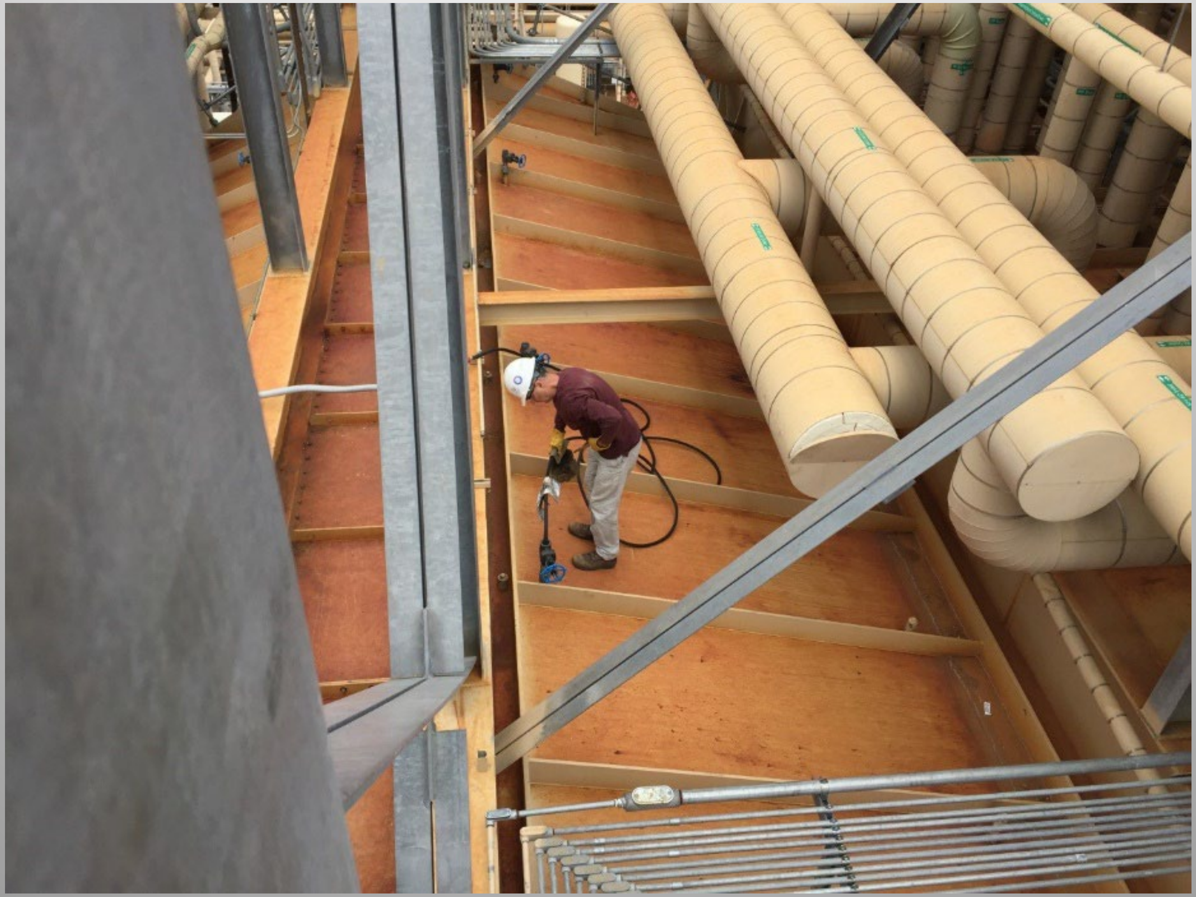
The cause of the high pressure drop was due to ammonium bisulfate (ABS) buildup within the tube bundle, due to high ammonia slip from the SCR. The units have to be cleaned annually, but the pressure drop always increased again after cleaning.

Heavy ABS Buildup on HP/IP Economizer tubes



AIG Tuning Performed

The customer contracted with SCR Solutions personnel to perform ammonia injection grid (AIG) tuning. The **Top Traverse Test Method** was used to measure NOx and ammonia distribution.



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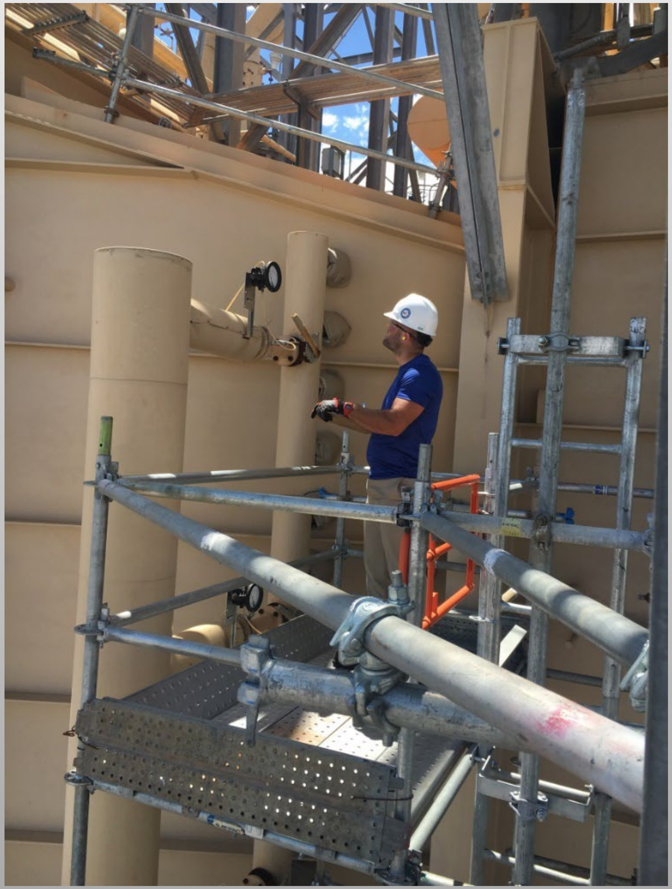
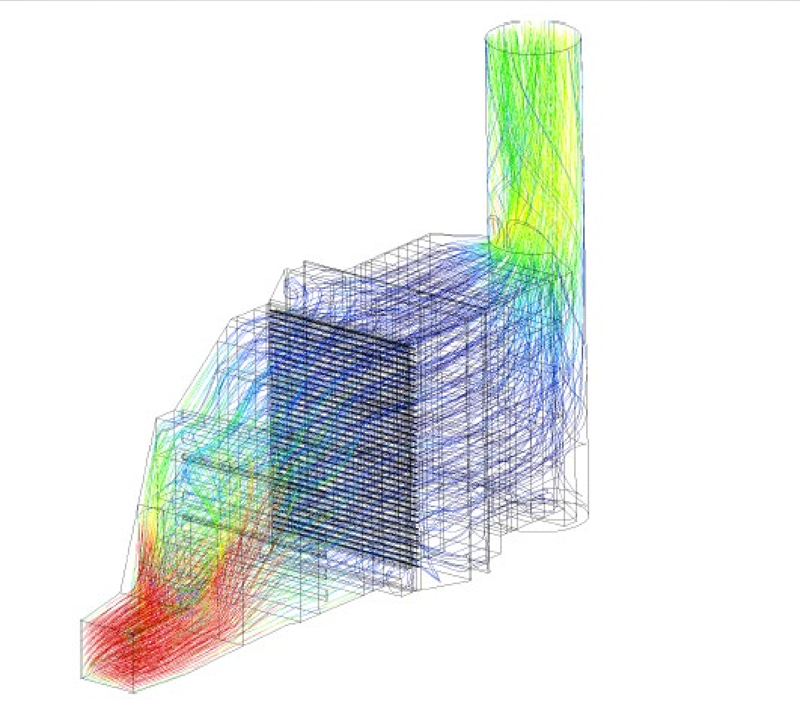
AIG Tuning Performed

AIG Tuning was attempted but improvements were only small. There was more to the problem….



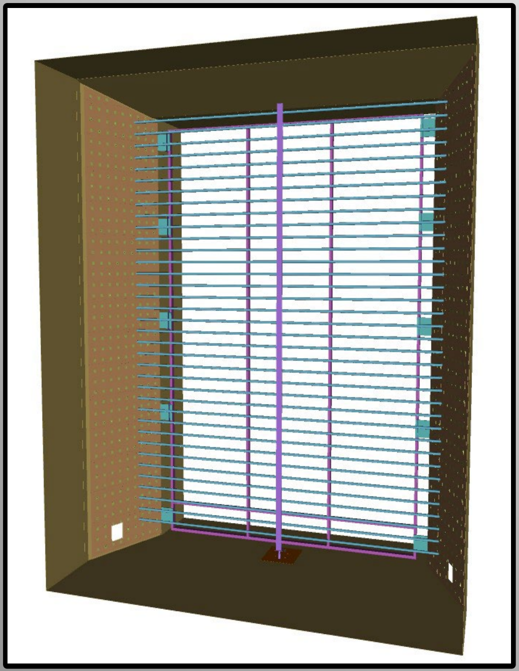
CFD Modeling

Based on our recommendations, the customer contracted with us to perform computational fluid dynamics (CFD) modeling to determine the cause of the poor distribution, and make changes to the system as required



AIG Design

The original AIG design was located 4 ft. downstream of CO catalyst, in an expanding section of the flue towards the SCR catalyst. There is also a large baffle at the base of the CO catalyst bed. CFD modeling confirmed that ammonia was concentrating heavily along the side walls, and top and bottom corners of the reactor.

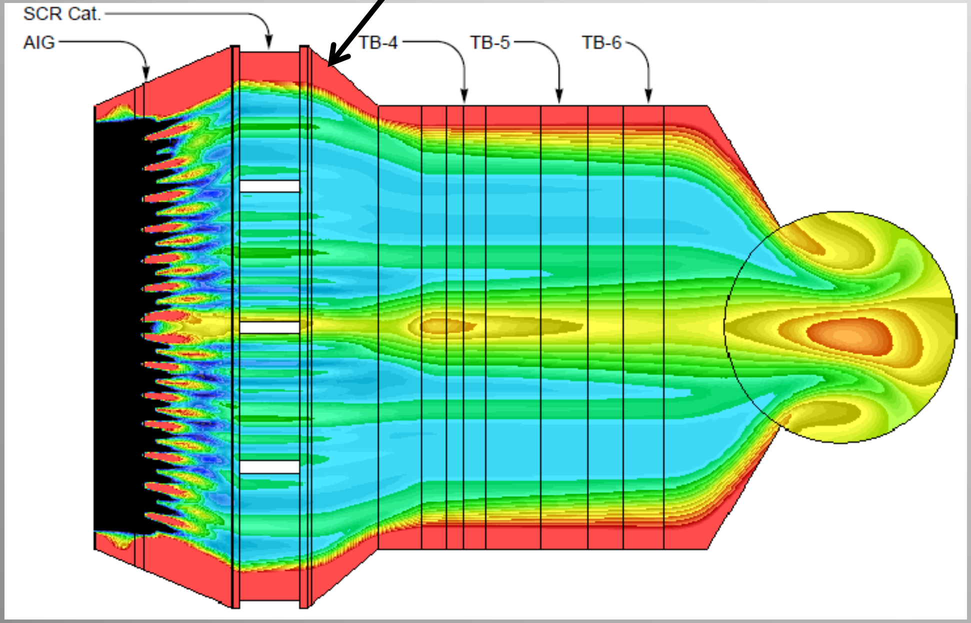


CFD Modeling

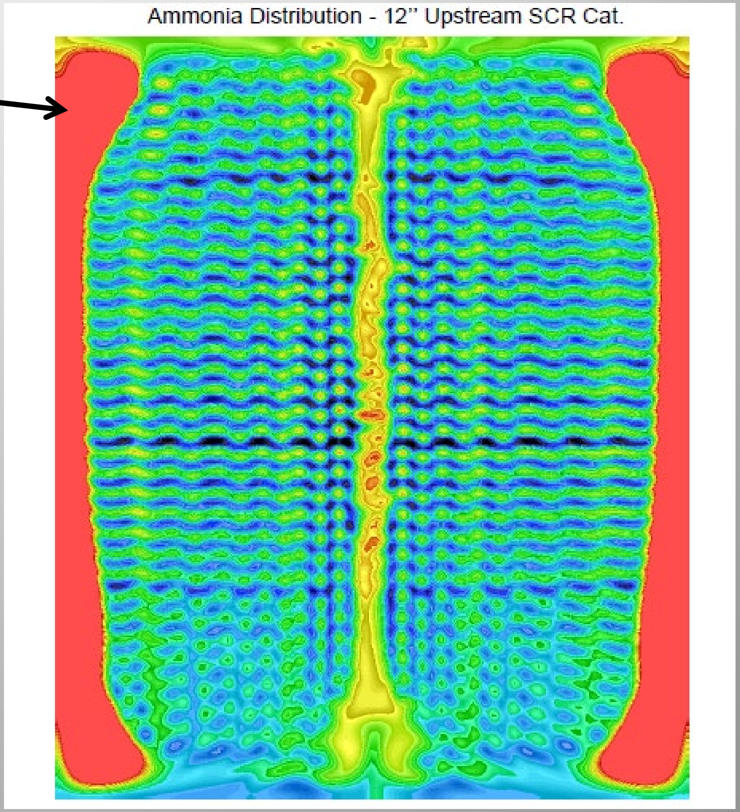
The CFD results confirmed the poor ammonia distribution measured in the field. It showed that the AIG design itself was creating the poor distribution with high concentrations along the sides of the catalyst bed.

RED Areas are high ammonia concentration

Flow →



Plan View



Front View, Facing SCR Catalyst

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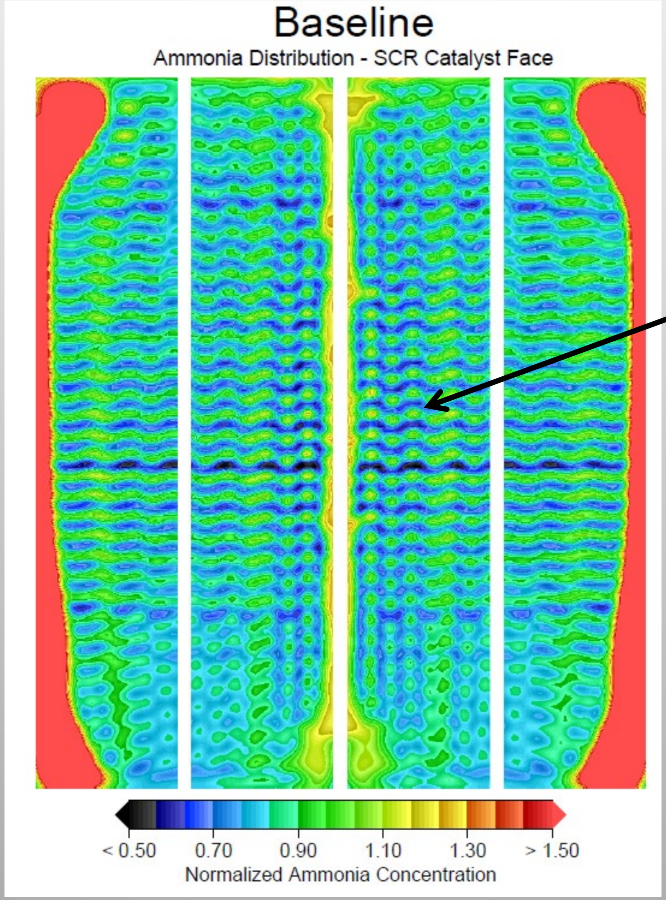
CFD Modeling

The CFD modeling also showed poor ammonia dispersion (mixing) across the face of the SCR



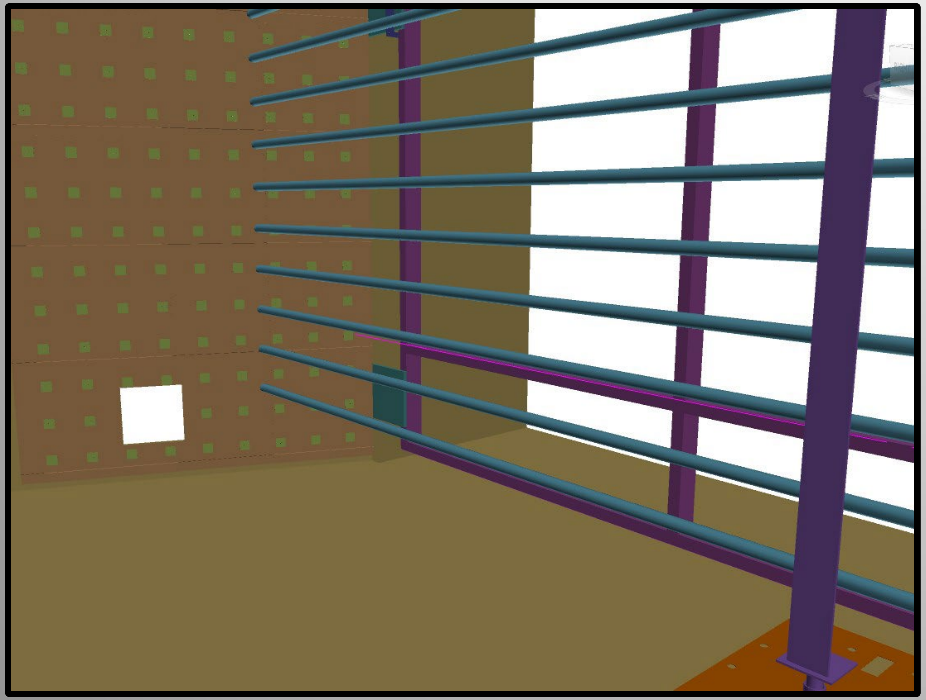
Front View, Facing SCR Catalyst

Note high and low ammonia concentrations, which are due to poor local mixing

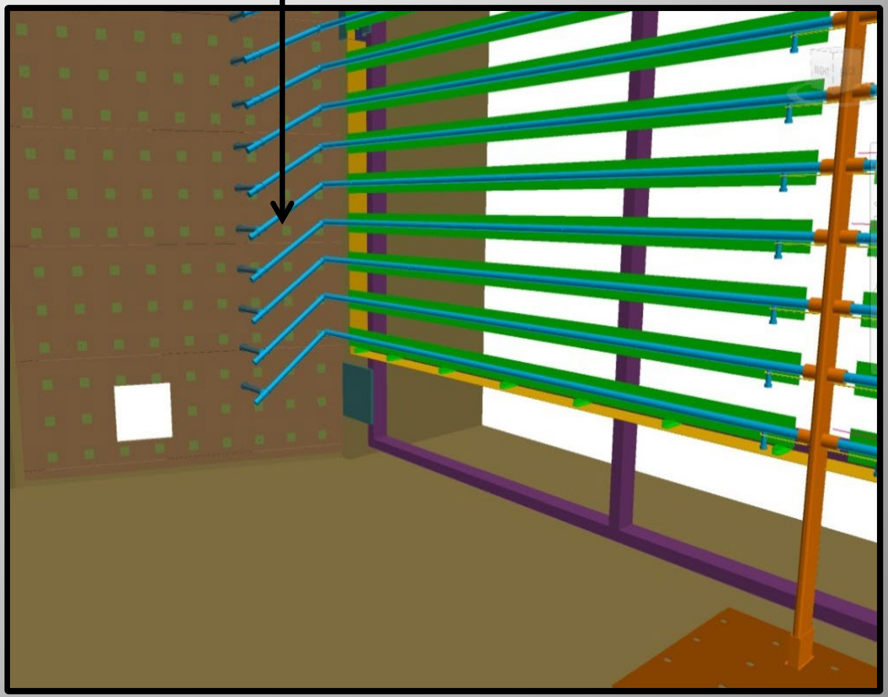
Revised AIG Design

CFD Modeling showed that the location of the AIG needed to be changed, and moved further upstream, closer to the CO catalyst

New AIG Moved Upstream 3 ft.



Existing AIG



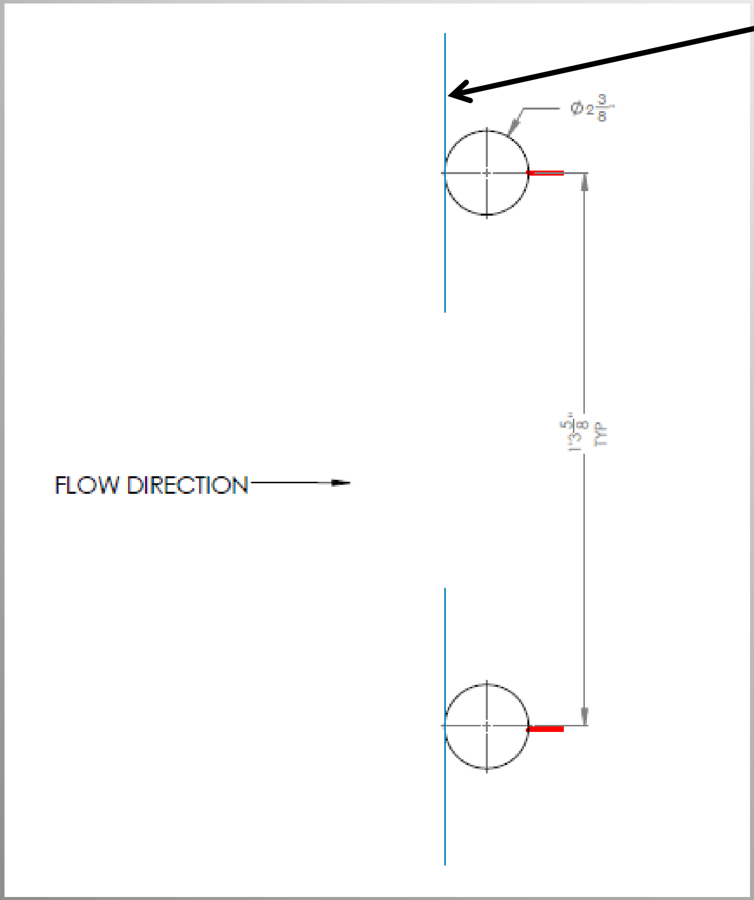
New AIG

Flow

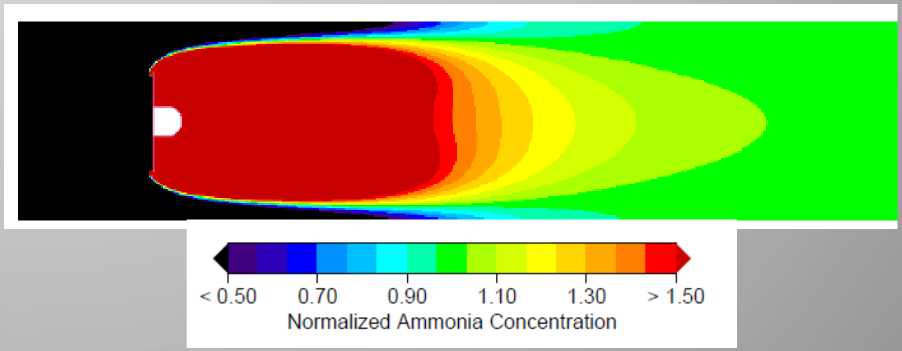
Revised AIG Design

CFD Modeling showed that adding a baffle to the upstream side of the newly located AIG greatly improved the local mixing

New Mixing Baffles



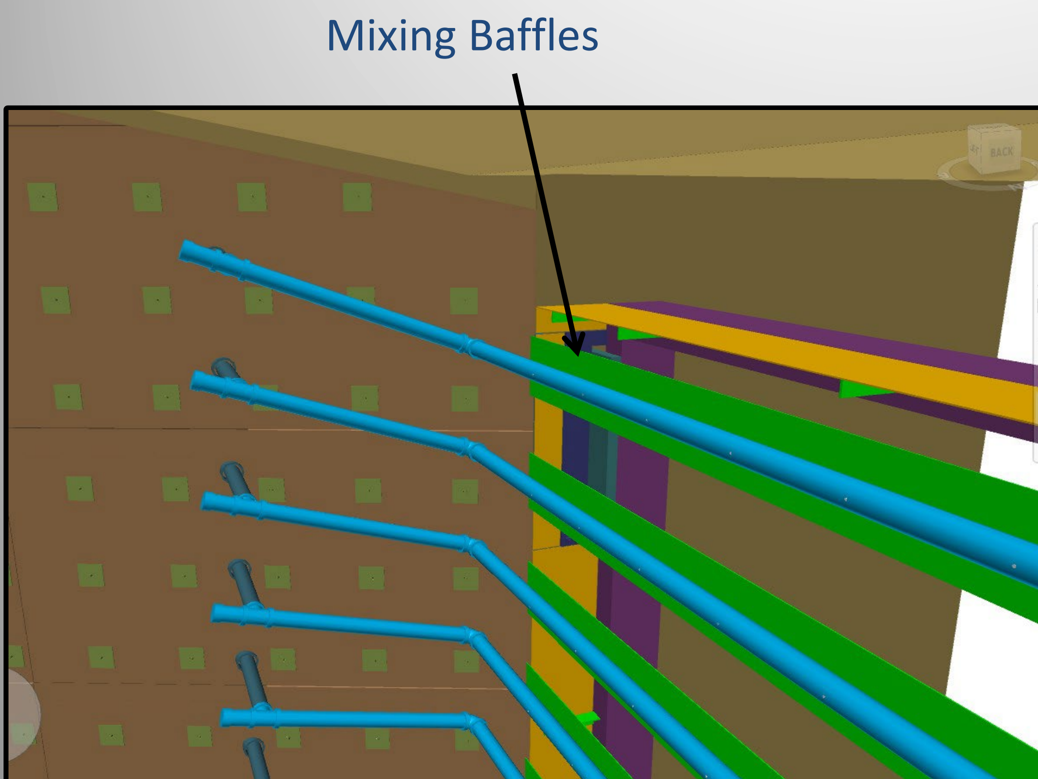
Flow →

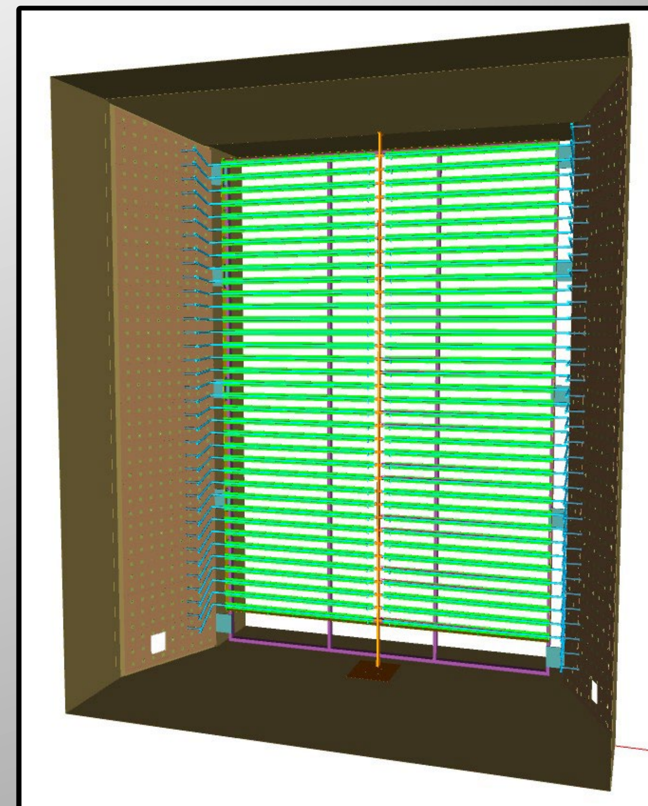


Improved Ammonia Mixing

Revised AIG Design

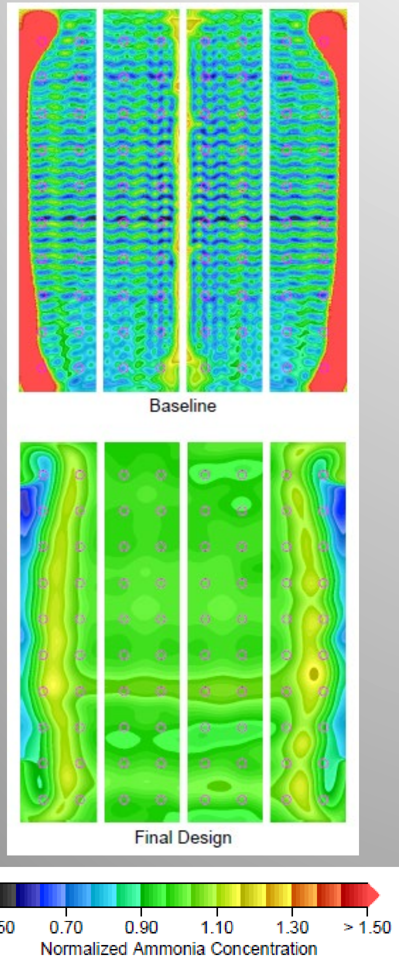
New AIG design, with mixing baffles, was finalized with CFD modeling





Final CFD Modeling Results

New AIG design, CFD model results showed **significant** improvement in ammonia distribution, with a minimal increase in pressure drop



Parameter	Units	Baseline AIG	Final (New) AIG
Ammonia Distribution	%RMS	70.2	5.8
Maximum Deviation from Avg.	%	+439	+13
Minimum Deviation from Avg.	%	-44	-21
Pressure Drop	in. w.c.	~0	0.2

AIG Retrofit

After CFD modeling was completed, we were awarded the design, supply and installation contract for removing the old AIG and installing the new design

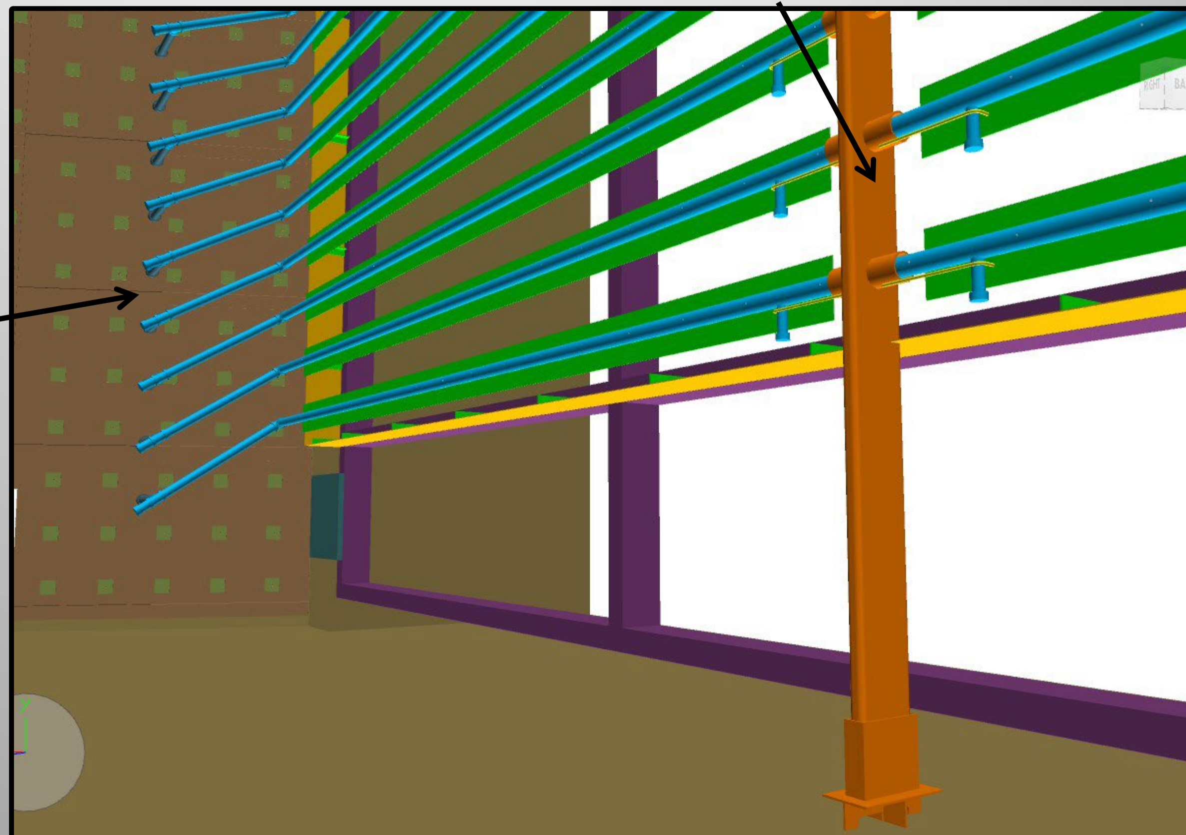
After the CFD modeling was completed, we had 4 weeks to…

- Design the new AIG
- Select a fabrication shop, procure materials and fabricate the new AIG
- Ship the new AIG to the jobsite
- Select and secure an installation contractor
- Mobilize labor to jobsite
- Complete both units in a two (2) week outage

AIG Design

Using 3D modeling, demolition of the old AIG was coordinated with the design of the new AIG

New center support column



Existing wall penetrations were reused, and new piping was added for new AIG

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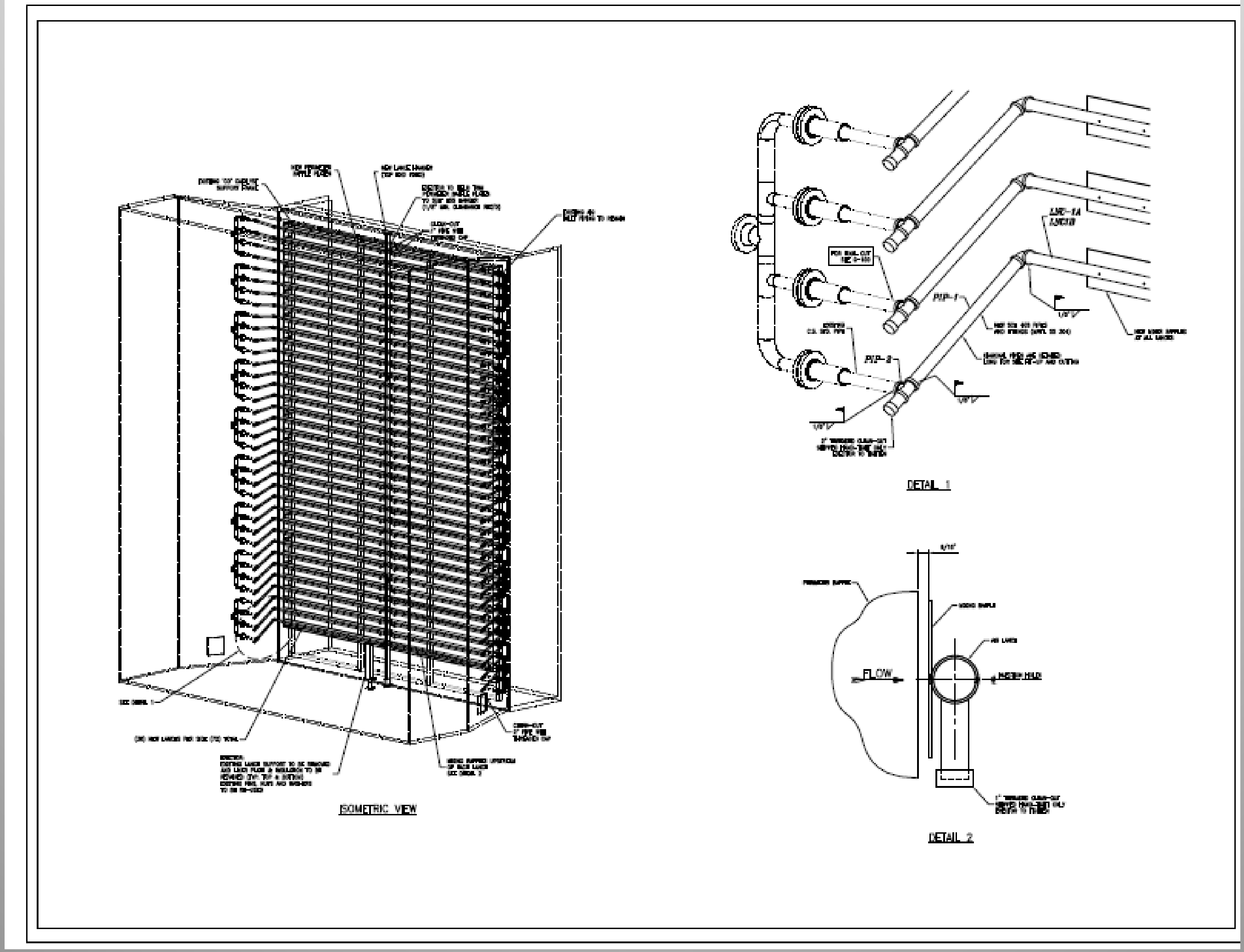
AIG Design

From the 3D model, fabrication drawings were generated



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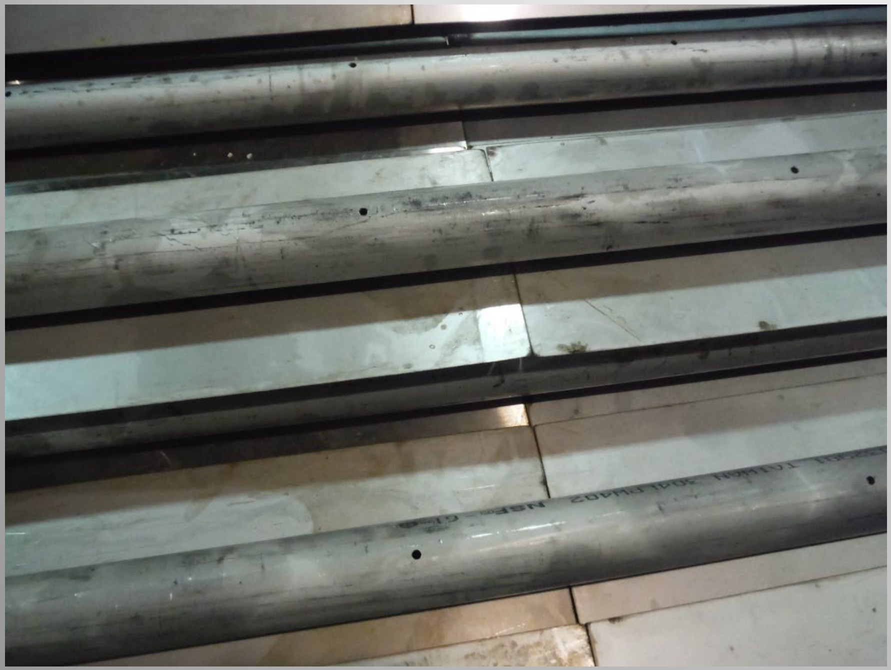
AIG Fabrication

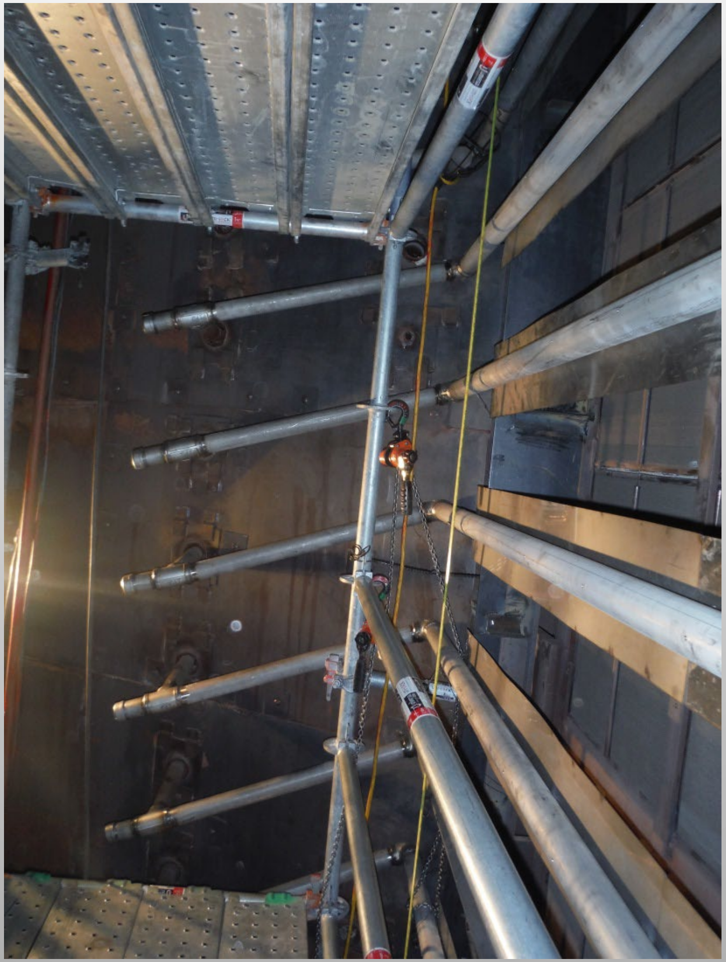
From the 3D model, fabrication drawings were generated and the new AIG and support members were fabricated



New AIG Lances

New Center Columns

AIG Installation



New SS AIG Pipes With Mixing Baffles Attached

AIG Installation

Installation Completed **one day ahead of schedule**

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Operating Data After Startup

After the outage was completed, initial startup data showed significant reduction in ammonia flow, indicating a reduction in ammonia slip.

Parameter	Units	Unit 1	Unit 2
Ammonia Flow Before Retrofit	lb/hr	161.2	164.9
Ammonia Flow After Retrofit	lb/hr	140.1	147.6
Reduction	lb/hr	21.1	17.3
Calculated NH_3 Slip Before Retrofit	ppmvd@15% O2	4.15	3.60
Calculated NH_3 Slip After Retrofit	ppmvd@15% O2	1.55	1.46
Reduction	ppmvd@15% O2	2.60	2.14

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Recent Customer Feedback

- *"New AIG looks great. No issues to note. "*
- *"NOx control has improved, and ammonia usage has decreased 15-25%, depending on load and other conditions."*
- *"Ammonia salt formation appears to have dropped off significantly. We cleaned the tubes this outage and removed less than half of the debris we typically encounter. We ran half of the last year without the new AIG, so this makes perfect sense. The cleaning crew recommended we either skip the next cleaning or reduce the scope next year. "*
- *"I again want to thank you for all of the work you put into our project and let you know that it appears to be a great success."*

CASE STUDY #2

A Northeast plant consists of one Siemens 501D gas turbine in a 1 on 1 combined cycle configuration

- Installed in 1994
- Total Plant Output 204MW
- HRSG with SCR
- Replacement Dual-Function Catalyst installed in 2019

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Plant Background

Due to other unit upgrades, the emissions requirements for the plant were ratcheted down to aggressive new levels…

Parameter	Units	Old Requirement	New Requirement
CO	ppmvd @ 15% O2	≤50	**≤2**
NOx	ppmvd @ 15% O2	≤9	**≤2**
Ammonia Slip	ppmvd @ 15% O2	≤10	**≤2**

- New dual-function catalyst was added in the Spring 2019 outage.
- Catalyst was designed for the above requirements.
- Not able to meet the new limits of the permit for NOx and ammonia slip for most operating cases.
- Since the catalyst was deemed sufficient to meet the requirements, the problems were considered system-related….

NH_3/NOx Distribution Testing

The **Top Traverse Test Method** was utilized using the sky climber ports on top of the HRSG, upstream and downstream from the SCR catalyst

Ports Used for Measurements

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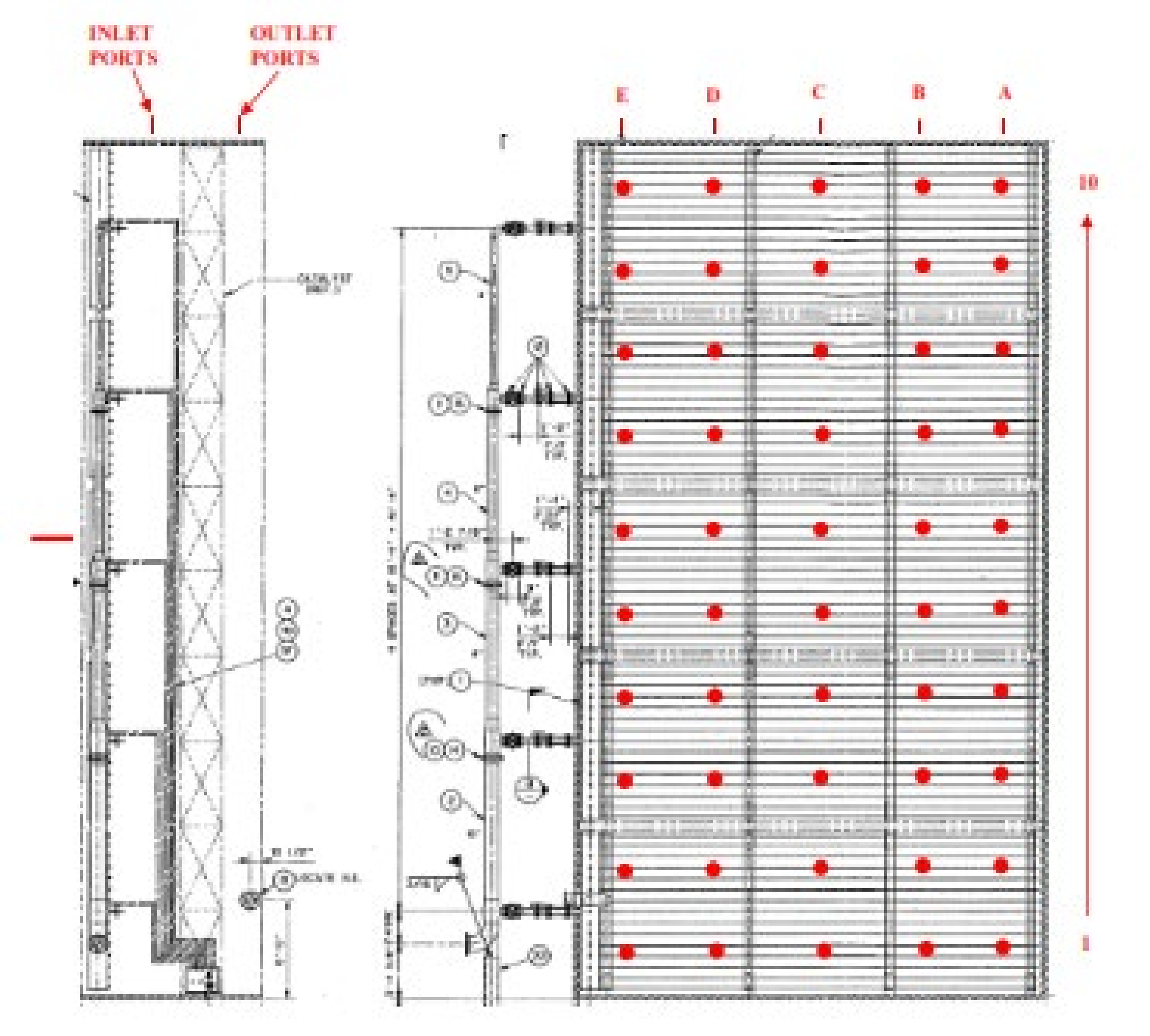
NH_3/NOx Distribution Testing

The first step in determining if the performance was system-related was to conduct a traverse at the SCR catalyst

- 5x10 array of points at inlet and outlet
- Measure NOx and O_2 at inlet and outlet
- Measure NH_3 at outlet



NH_3/NOx Distribution Testing Results

Baseline (Existing) Field Testing Results showed poor NH_3/NOx distribution at the SCR catalyst

RMS=19.13%

AIG tuning was attempted, but results unsuccessful

Based on these results, an internal inspection was recommended…

CALCULATED NH3/NOx Ratio - ELEVATION VIEW

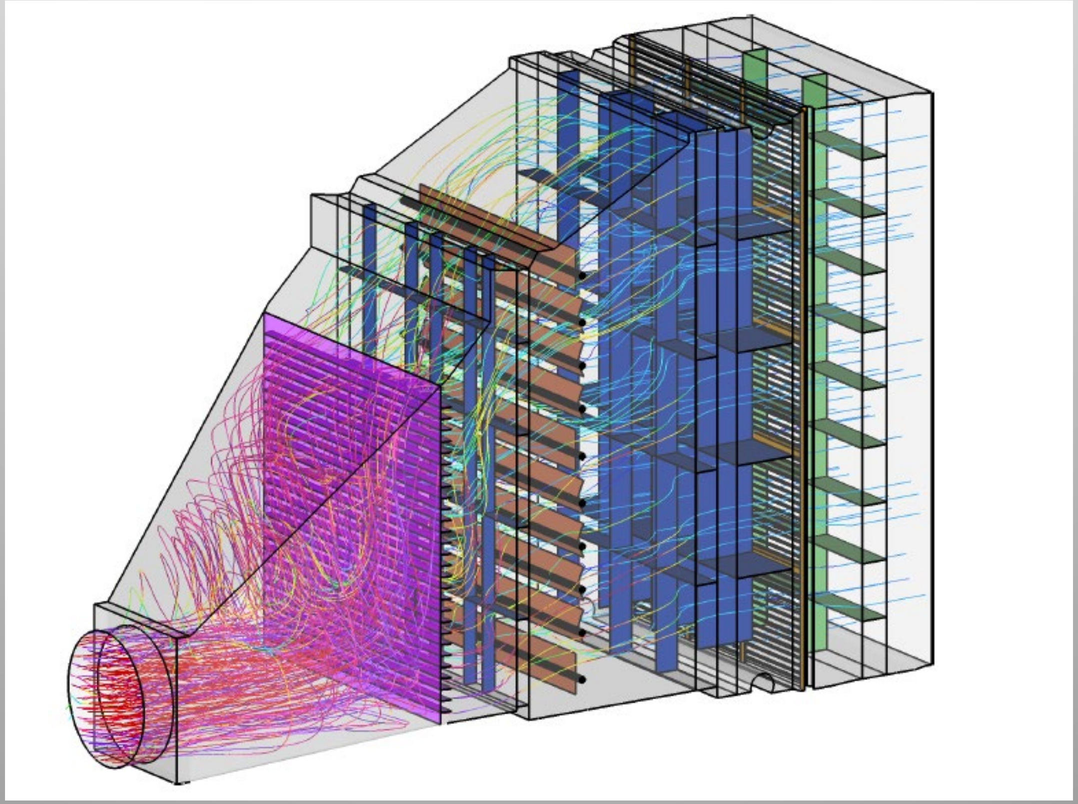
Gas Flow Into Page

Top	A	B	C	D	E	Avg	Zone Avg
10	1.026	0.869	0.883	1.028	0.884	0.95	0.98
9	1.034	1.086	1.006	1.034	0.962	1.04	
8	1.022	1.097	1.012	1.040	0.970	1.04	0.98
7	1.037	1.003	1.003	1.000	0.617	1.01	
6	0.687	0.962	0.638	0.758	0.615	0.76	0.74
5	0.702	0.970	0.602	0.794	0.643	0.77	
4	0.947	1.070	0.834	0.913	0.704	0.94	0.92
3	1.066	1.105	0.897	0.977	0.687	1.01	
2	1.216	1.190	1.201	1.136	0.940	1.19	1.18
1	1.275	1.272	1.263	1.142	1.146	1.24	
Averages	1.00	1.06	0.93	0.98	0.82		

Average=	0.96
Std Dev=	0.18
% RMS=	19.13

CFD Modeling

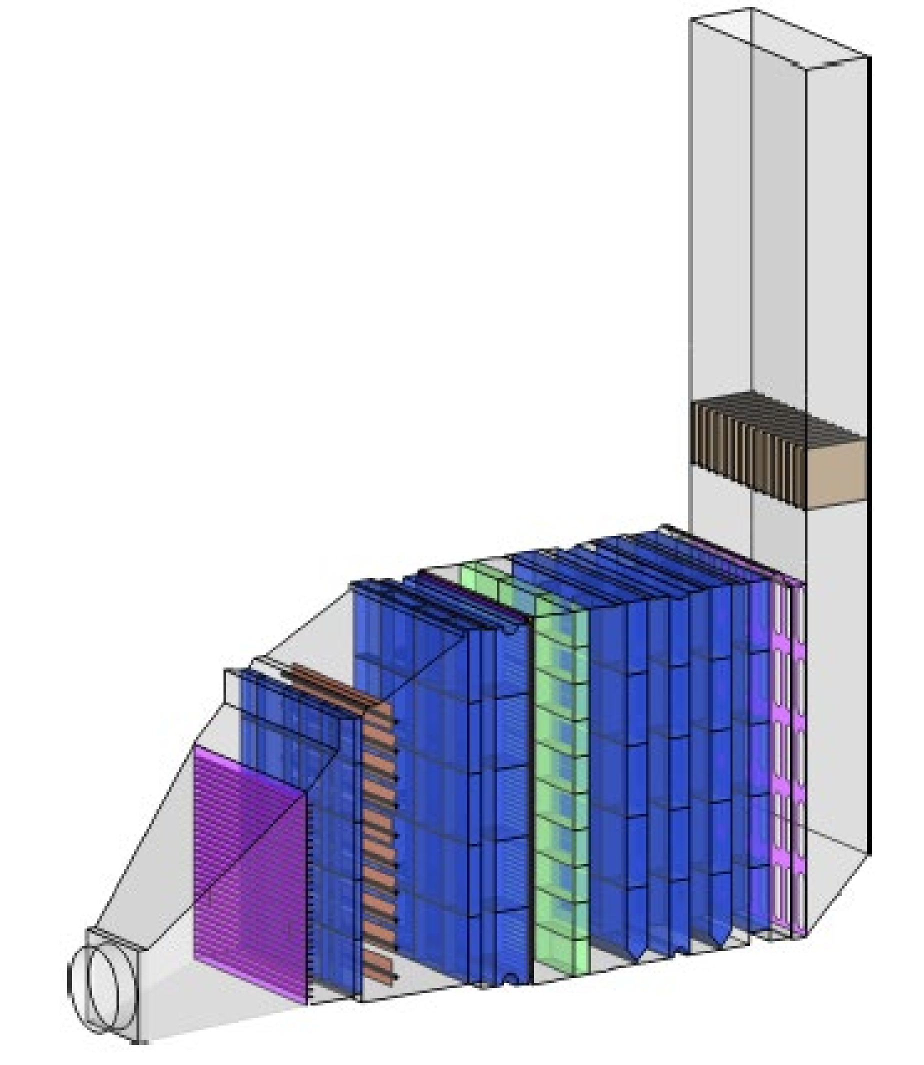
Based on the NH_3/NOx distribution testing and the internal inspection, the client elected to go with CFD modeling of the system to address poor NH_3/NOx distribution.



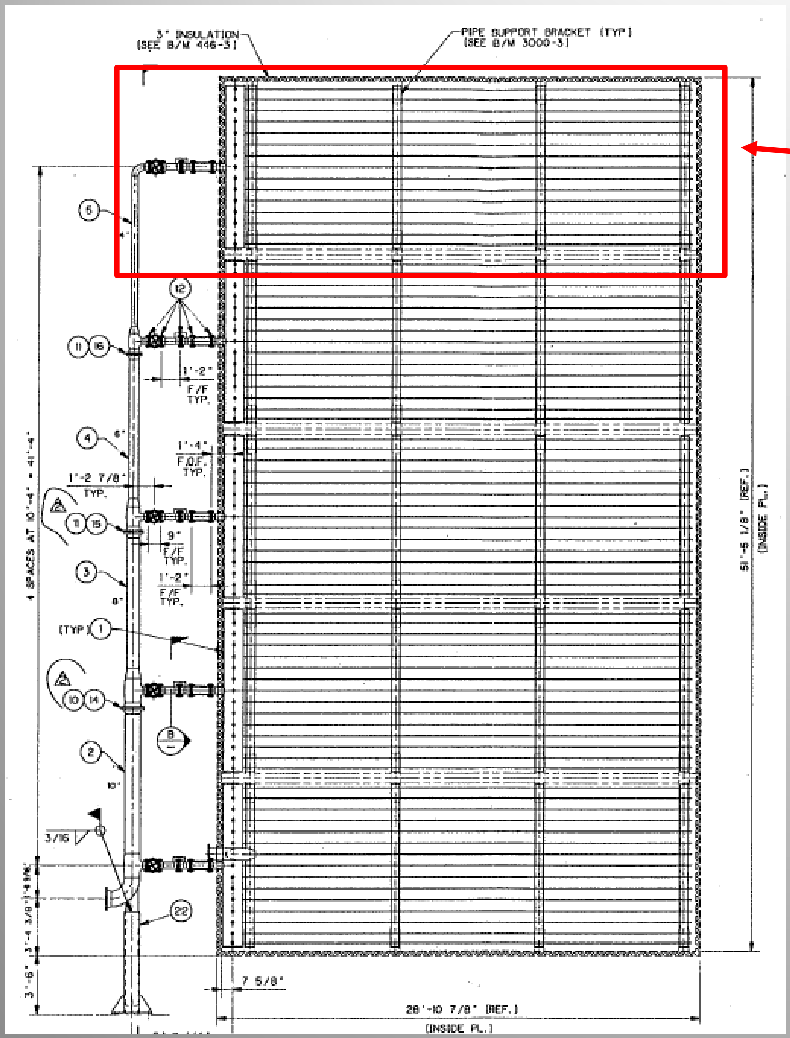
CFD Modeling

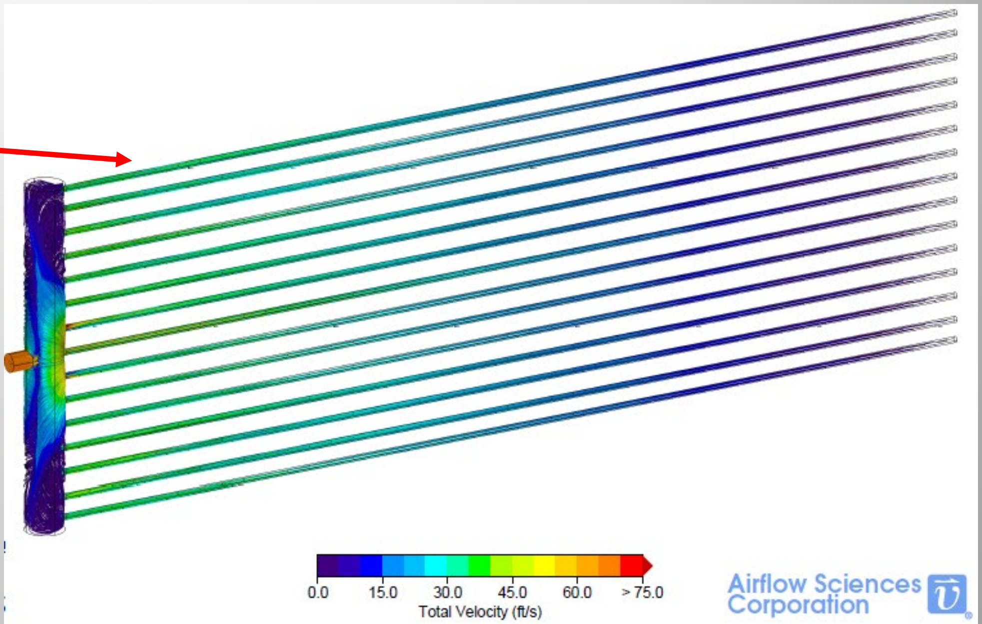
Detailed model included:

- Simulated 501D exhaust profile
- All tube banks and pressure drops
- Perforated plate
- Duct Burners
- Existing AIG and catalyst



CFD Modeling



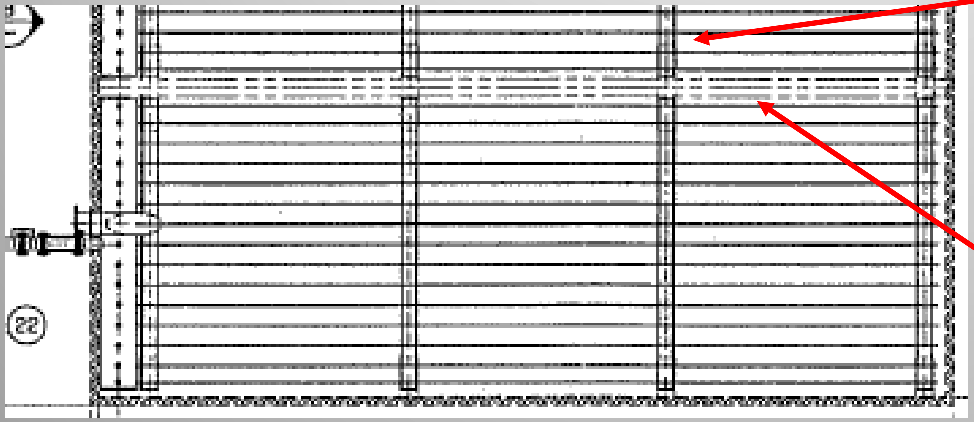


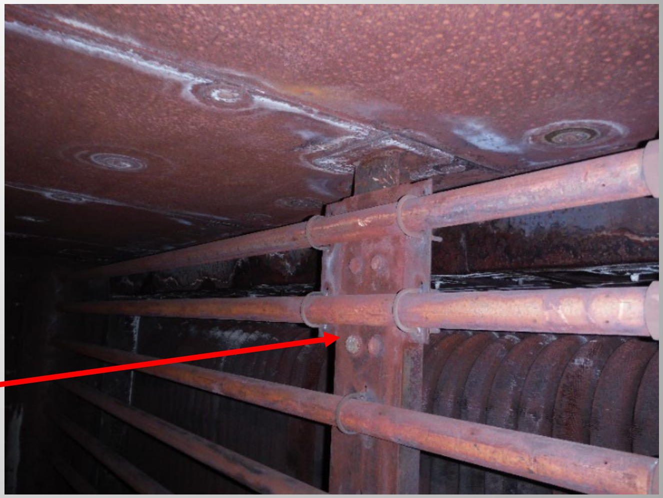
Detailed model of AIG branch

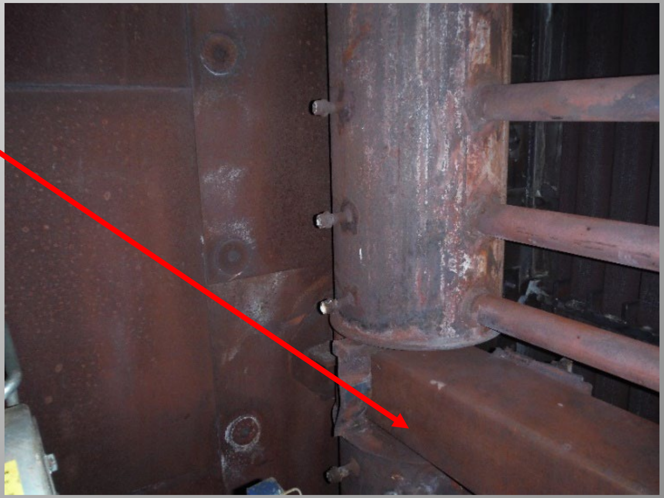
CFD Modeling

AIG Support System had significant blockage

- Vertical C-Channels
- Horizontal tube steel







Blockages added to poor NH_3 distribution at catalyst…

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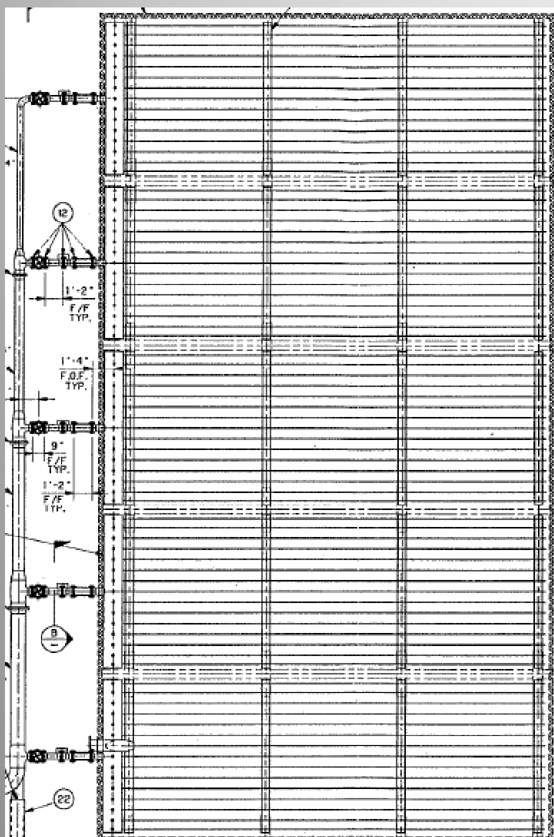
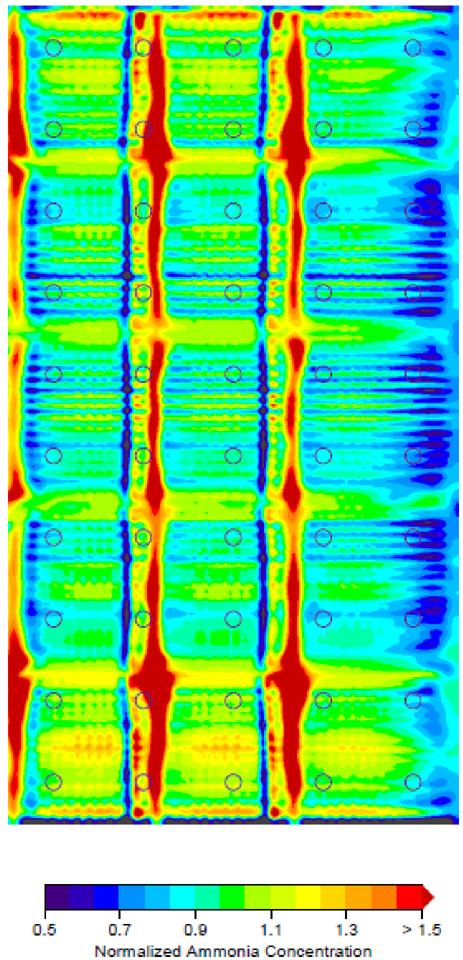
CFD Modeling

NH_3/NOx Distribution: 26.4% RMS (all CFD points)



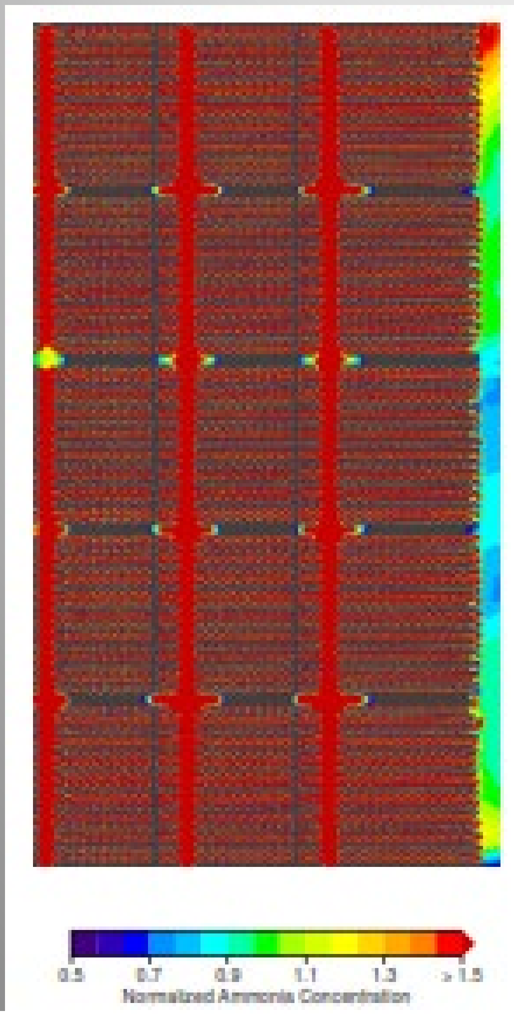


Causes of poor distribution:

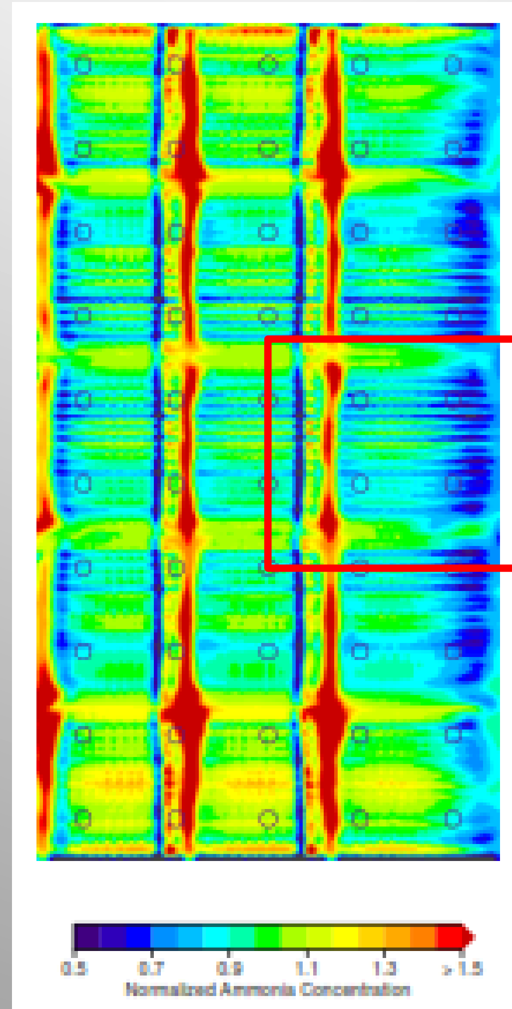
1. Vertical support members (C-channels)
2. Horizontal tube steel
3. Poor distribution within each lance (inlet to outlet)
4. Proximity of AIG to catalyst
5. Poor local mixing…

CFD Modeling

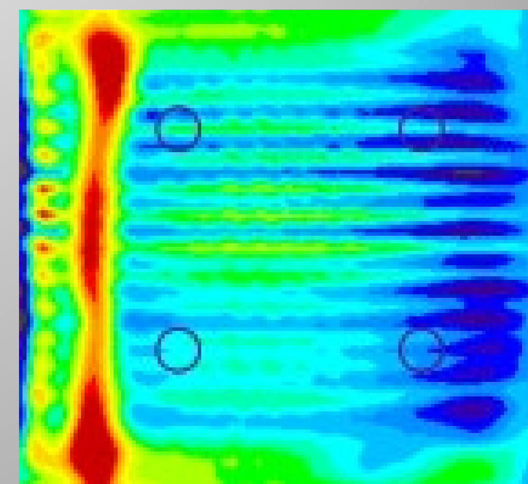
8" Downstream of AIG



SCR Catalyst Inlet Face
(5' Downstream of AIG)



Note "stripes" of ammonia which still remain at catalyst, indicating lack of mixing



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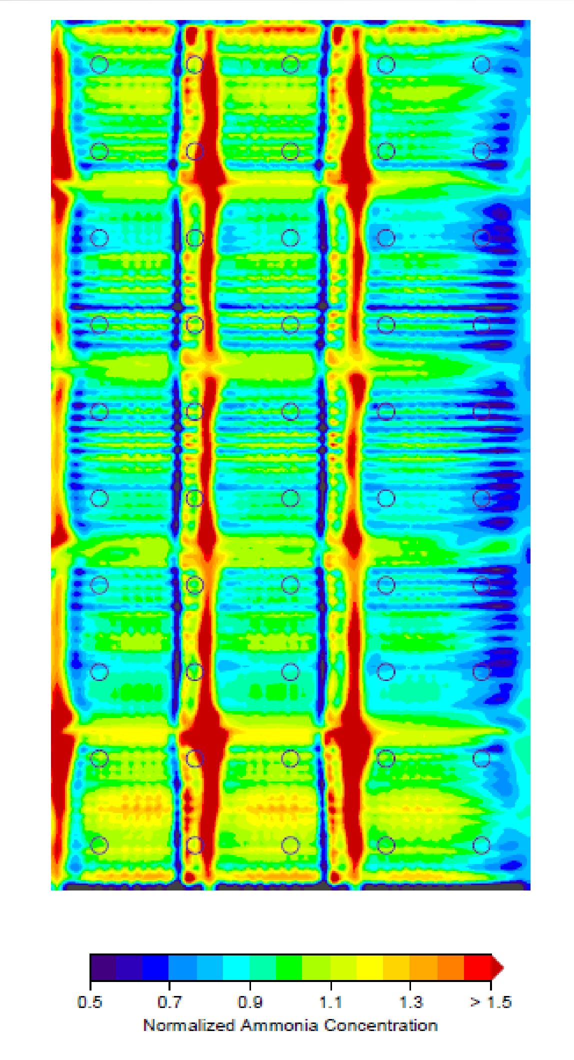
CFD Modeling vs Field Test Data



CFD NH_3/NOx Distribution:

- All CFD Points: 26.4% RMS
- **50 Points: 18.2% RMS**

Field Test NH_3/NOx Distribution:

- **50 Points: 19.1 % RMS**

CFD modeling provides thousands of data points that helps better diagnose problems!

HRSG FORUM WITH BOB ANDERSON

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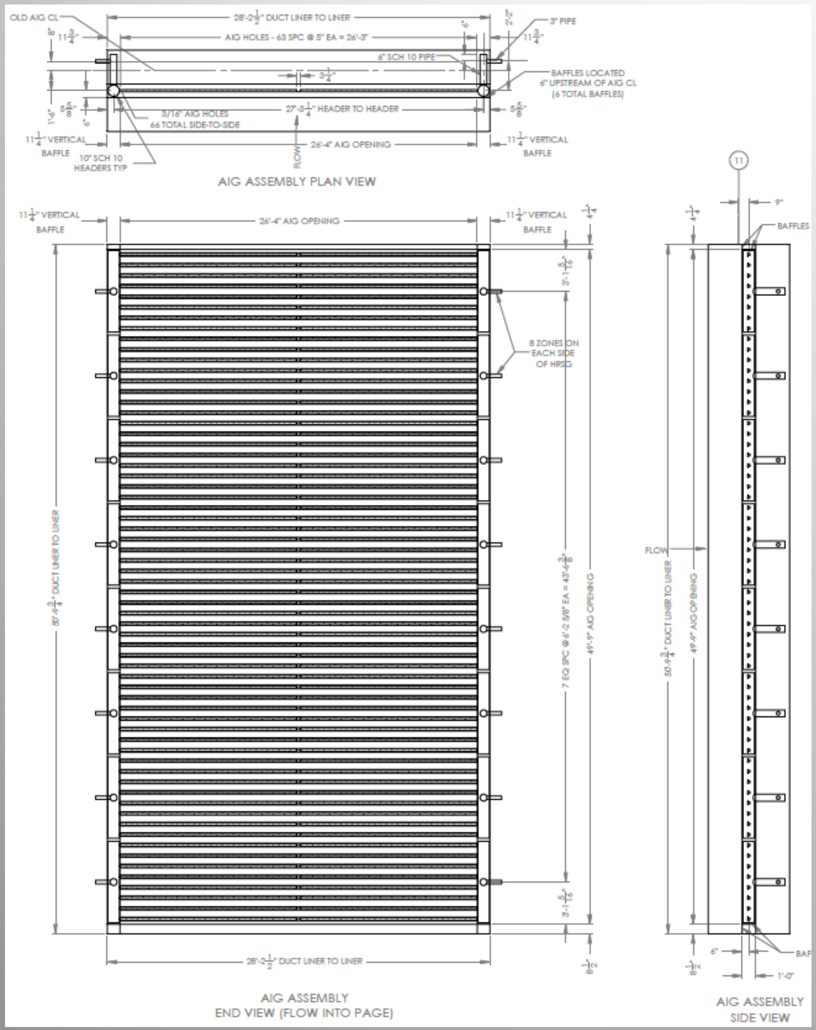
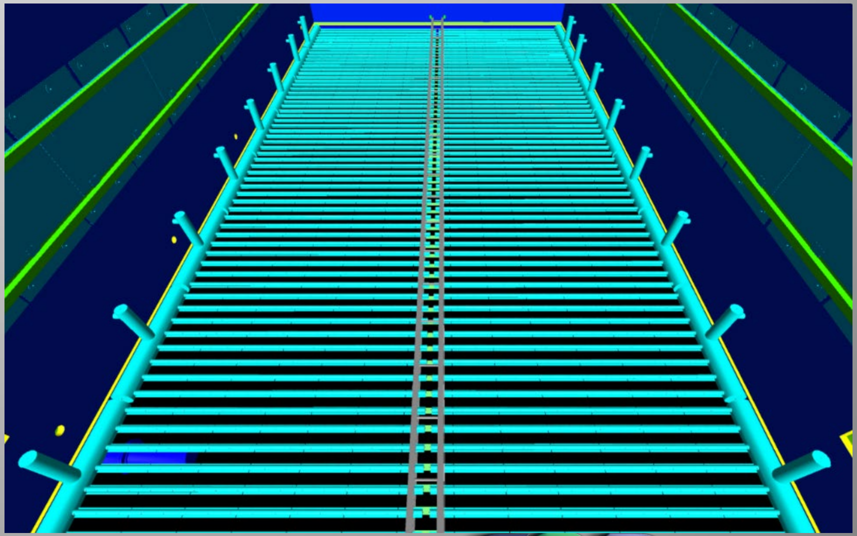
CFD Modeling for New Design



New AIG Design

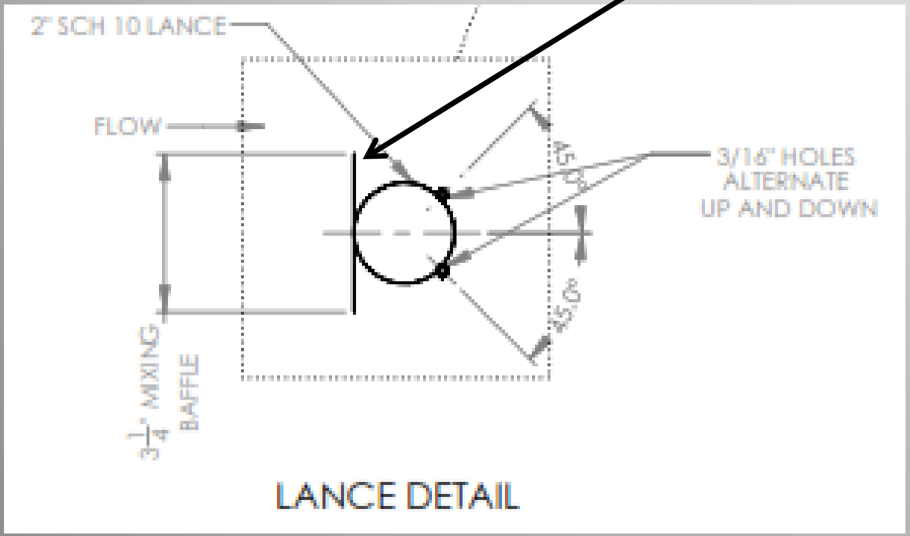
1. Enters from both sides of unit (16 zones)
2. No major structural supports
3. Improved lance/hole design
4. Move 18” upstream from existing AIG
5. Better local mixing



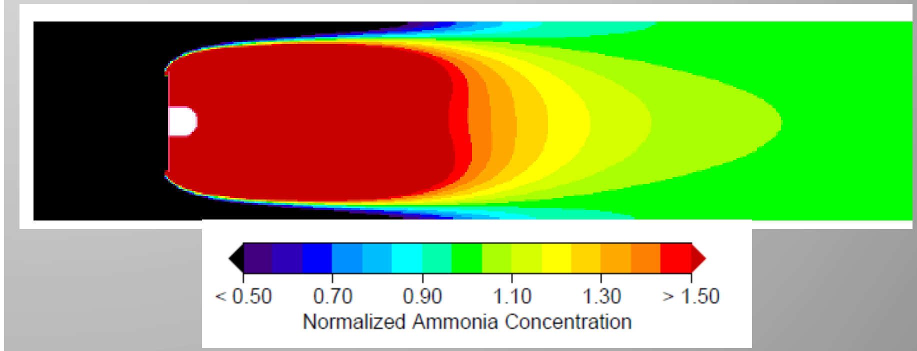
CFD Modeling for New Design

CFD Modeling showed that adding a baffle to the upstream side of the newly located AIG greatly improved the local mixing

New Mixing Baffles

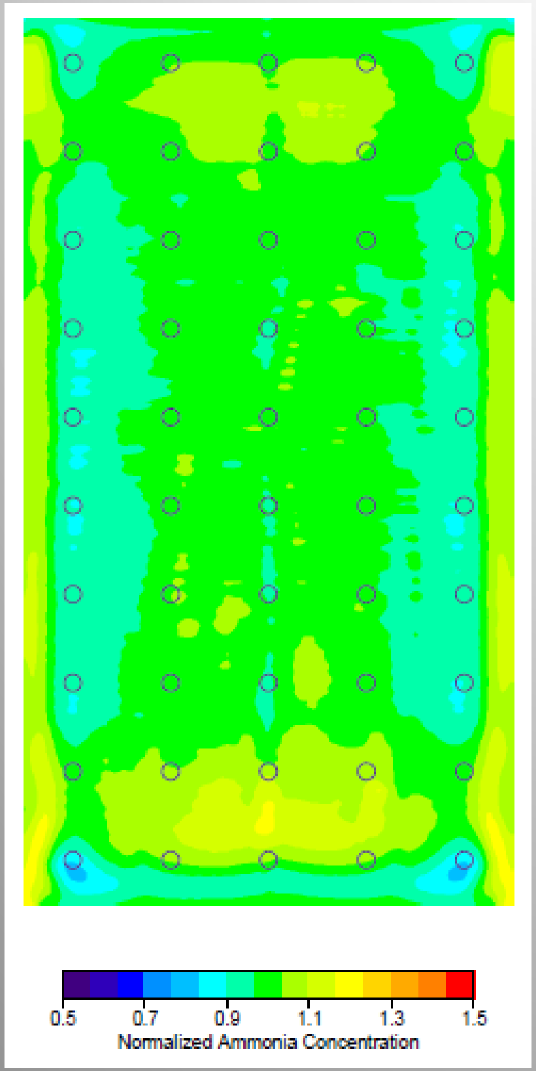


Flow →



Improved Ammonia Mixing

CFD Modeling for New Design



CFD NH_3/NOx Distribution:

- All CFD Points: 5.7% RMS
- 50 Points: 5.8% RMS

Results were excellent and well below the target of 10% RMS

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Turnkey Retrofit – Installation

SCR Solutions worked with SVI Dynamics for the new AIG installation…

Scope of supply:

- Demolition of old exterior AIG piping
- Removal of SCR catalyst modules
- Demolition of old AIG and catalyst support structure
- Installation of new catalyst support structure and seals
- Installation of new AIG and center support
- Installation of new external piping and supports
- Replacement of SCR catalyst modules

- All work performed in 15-day outage, working 2x 12-hours shifts per day

Turnkey Retrofit – Installation

New AIG

Post-Retrofit Test Results

The following post-retrofit Control Room results were obtained (based on CEM's)

Parameter	Units	Requirement	Results
CO	ppmvd @ 15% O2	2	~0.5
NOx	ppmvd @ 15% O2	2	~1.7
Ammonia Slip	ppmvd @ 15% O2	2	~0.8

- All guaranteed results easily achieved
- Comfortable margins for operational changes (higher GT NOx, Load Changes, etc.)

NH_3/NOx Distribution Testing Results

Post-retrofit Field Testing Results showed excellent NH_3/NOx distribution at the SCR catalyst

RMS=6.06%

AIG tuning was not required

CALCULATED NH3/NOx Ratio - ELEVATION VIEW

Gas Flow Into Page

Top	A	B	C	D	E	Avg	Zone Avg
10	0.921	1.003	0.991	0.961	1.006	0.97	0.97
9	0.921	1.018	1.024	0.966	0.914	0.98	
8	0.855	0.991	1.042	1.042	0.942	0.98	0.97
7	0.831	1.021	1.023	1.006	0.948	0.97	
6	0.850	1.015	1.023	1.003	0.911	0.97	0.95
5	0.858	0.997	0.983	0.970	0.912	0.95	
4	0.878	0.986	0.983	0.930	0.900	0.94	0.93
3	0.855	0.997	0.989	0.925	0.881	0.94	
2	0.883	1.003	0.992	0.923	0.907	0.95	0.95
1	0.903	1.020	1.011	0.952	0.921	0.97	
Averages	0.88	1.01	1.01	0.97	0.92		

Average=	0.96
Std Dev=	0.06
% RMS=	6.06

Comparison of CFD and Field Results

Excellent agreement between CFD and field results

CALCULATED NH3/NOx Ratio - ELEVATION VIEW
Gas Flow Into Page

Top	A	B	C	D	E	Avg	Zone Avg
10	0.921	1.003	0.991	0.961	1.006	0.97	0.97
9	0.921	1.018	1.024	0.966	0.914	0.98	
8	0.855	0.991	1.042	1.042	0.942	0.98	0.97
7	0.831	1.021	1.023	1.006	0.948	0.97	
6	0.850	1.015	1.023	1.003	0.911	0.97	0.95
5	0.858	0.997	0.983	0.970	0.912	0.95	
4	0.878	0.986	0.983	0.930	0.900	0.94	0.93
3	0.855	0.997	0.989	0.925	0.881	0.94	
2	0.883	1.003	0.992	0.923	0.907	0.95	0.95
1	0.903	1.020	1.011	0.952	0.921	0.97	
Averages	0.88	1.01	1.01	0.97	0.92		

Average=	0.96
Std Dev=	0.06
% RMS=	6.06

Field Test Results - April 3, 2020

CFD RESULTS NH3/NOx Ratio - ELEVATION VIEW
Gas Flow Into Page

Top	A	B	C	D	E	Avg	Zone Avg
10	0.912	1.013	0.991	1.033	0.909	0.99	0.98
9	0.984	0.991	1.007	1.015	0.977	1.00	
8	0.903	0.964	1.013	0.967	0.905	0.96	0.95
7	0.920	0.983	0.941	0.982	0.900	0.96	
6	0.889	0.961	0.995	0.969	0.896	0.95	0.94
5	0.880	0.988	0.940	0.972	0.889	0.94	
4	0.923	1.016	0.936	0.998	0.902	0.97	0.94
3	0.891	0.991	0.939	0.971	0.883	0.95	
2	0.991	1.023	1.056	1.053	0.990	1.03	0.99
1	0.833	1.027	1.029	1.029	0.831	0.98	
Averages	0.91	1.00	0.98	1.00	0.91		

Average=	0.96
Std Dev=	0.06
% RMS=	5.82

CFD Results - Final Design

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Thank You!!

SCR Solutions LLC

Clinton, NJ USA

www.scr-nox.com

- Combined Cycle/Simple Cycle SCR Optimization
- Coal-Fired Boiler SCR Optimization
- AIG Tuning
- NH_3/NOx Distribution Testing
- SCR System Inspections
- CO and SCR Catalyst Management and Testing
- Gas Flow Modeling (CFD and Physical)
- SCR Maintenance/Catalyst Replacements
- Ammonia System Design and Upgrades (aqueous, anhydrous, urea)
- Full Design, Supply and Installation Services
- System Commissioning
- Specification Development