REINHOLD ENVIRONMENTAL Ltd.

2019 NOx-Combustion-CCR Round Table Presentation

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CC – Multi-Pollutant Catalyst Performance & Experience

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Field Tuning & Data by: D.Davis, TVA Perf. Engr (TVA Test Crew Lead)

Rev 0 – 2/11/19 Initial Issue for Reinhold 2019 NOx-Combustion-CCR Round Table

Everything* You Need to Know About Retrofitting a CC Multi-Pollutant Catalyst

- Why Did TVA Install a Multi-Pollutant CC Catalyst?
  - Installation Drivers

- How Did the Performance Compare w/ Targets?
  - NOx/CO/VOC Performance

- What Embarrassing Lessons Learned Can Be Shared?
  - Experience / Lessons-Learned

* (Almost)

Unit 2 Stats – Start of Project

- Frame: Westinghouse W501G
- HRSG: Nooter/Erikson, Inc. 2X1 Configuration w/ Duct Burners
- Fuel: Natural Gas
- Load: 250 MegaWatt
- CO Catalyst: None
- NOx Catalyst: (2) Layers Plate Catalyst
- Startup: 2007

Installation Drivers

- Sample – Service Time Threshold Crossed w/ Some Elevated Ammonia Slip
- Hi differential Pressure = CT + HRSG Load Loss
  - Structural Integrity Issues of Plate Catalyst
  - U/S Duct Liner Insulation
- Load Curtailment Risk from Annual Permit CO Emissions / Generation Plan
- Additional Project Goals

Additional Project Goals

- Install Inlet & Outlet Sample Test Grids
- Carbon Steel AIG Annubars to SS dP Gauges
- Carbon Steel AIG Balancing Valves to SS Butterfly's
- New Modules Fit Thru Top Hatch
- New Modules Fit Into 3 Wide X 10 Tall Existing Support Frame

New Multi-Pollutant Catalyst

- 1.4mm Pitch, Honeycomb Catalyst

New Multi-Pollutant Catalyst

- (12) Point Outlet Sampling Grid
- Design to Correspond to (12) AIG Headers

New Multi-Pollutant Catalyst

- Relocated Frame's Jacking Bolt Channel to Match Module

Performance vs. Targets

Parameter	Actual Plate Catalyst	Multi-Pollutant Catalyst	Multi-Pollutant Design Spec or Target
CT Load (MW)	~230	~240	N/A
SCR dP (in-w.c.)	~ 6	~2.2	1.9
NOx% Removal		~94%	88% to 3.0 ppmvdc
NOx Outlet (ppmvdc)	2.5	2.5	3.0
CO% Removal	None	~98%	80% Reduction to 4.5 ppmvdc
VOC% Removal	None	Not Tested	25% Reduction to 3.0 ppmvdc
NH_3 Slip (ppmvdc)	~5	~8 to 12	10 @ End of Life

Lessons Learned

- Undersized Catalyst
- Differential Pressure Recovery
- AIG Work Rust Scale Findings
- Outlet Sample Grid Installed Per Drawing
- Tuning

Specification Resulted in Undersized Catalyst

- Utilized Original CT Design Guarantee Case:
  - Design Flue Gas Flow @ 4.9M lb/hr
  - Inlet NOx @ 25ppmvdc / Outlet NOx @ 3.0ppmvdc

- Actuals Closer to:
  - Flue Gas Flow 6.2M lb/hr
  - Inlet NOx @ 32ppmvdc

- Probably Why That Second Layer of Plate Catalyst was Added by Original CC Owner…

Differential Recovery

- Predicted Total Load Recovery from Differential Pressure Recovery+Thermal Improvements: 5MW
- Plant Maximized Recovery with Shockwave Cleaning of HRSG During Outage
- CT Load Recovery ~ 10MW

AIG Findings

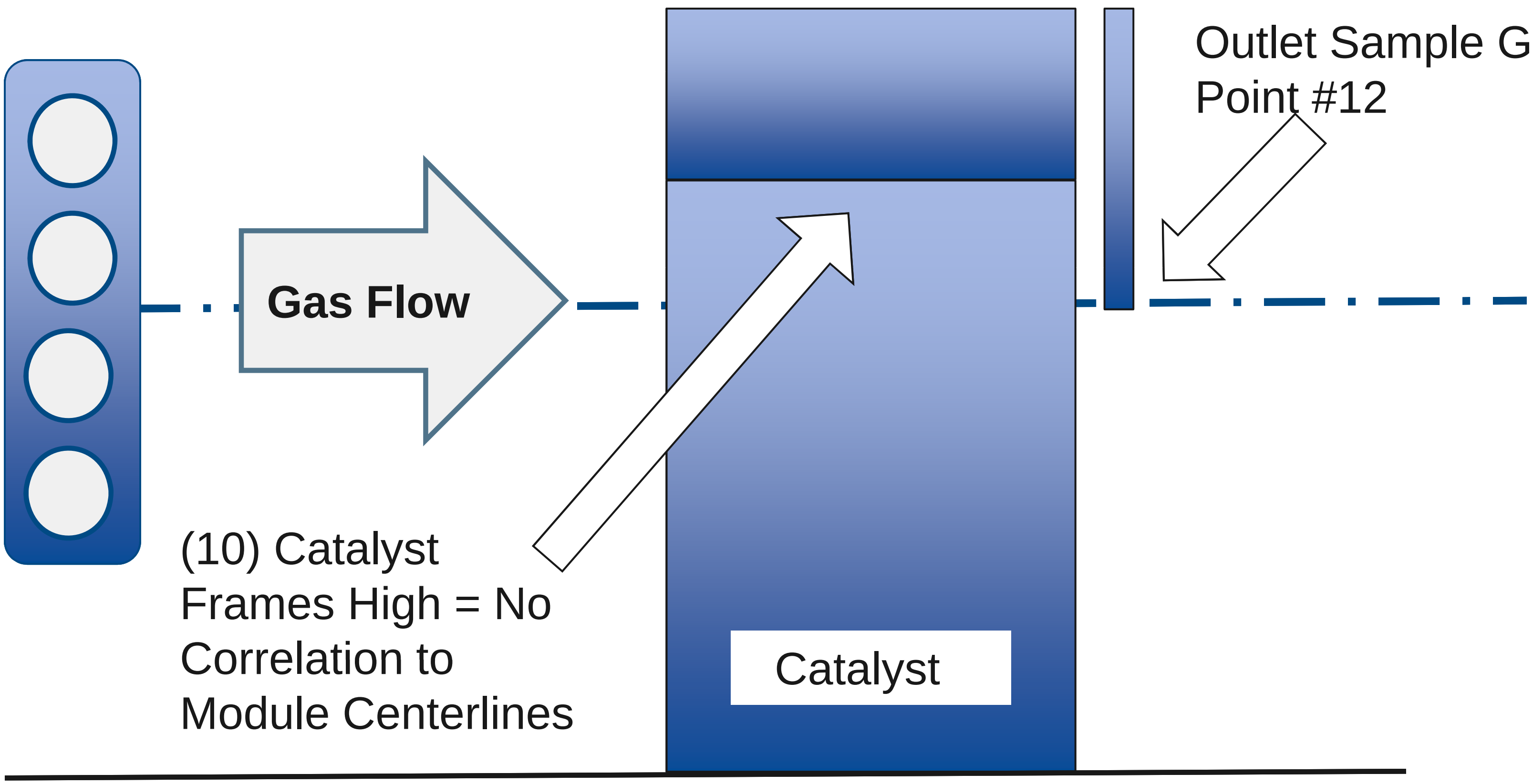
- AIG Valve & Annubar Replacement Yielded a Stop When Unsure Moment w/ AIG Rust Scale

AIG Findings

- AIG Header Internal Borescope Picture
- Vacuumed All AIGs Prior to AIG Hardware Reinstall

Sampling Grid Installation

- Concept: (1) Outlet Sample Point per ea of (12) AIG Headers
- Would Allow AIG Valve-to-Sample Point Correlation



Inlet NOx Distribution Uniform

SCR Inlet

	East		West	
Zone A1	32.4	NO_X,@15% O2	32.2	Zone B1
Zone A2	33.7	NO_X,@15% O2	34.1	Zone B2
Zone A3	33.9	NO_X,@15% O2	33.1	Zone B3
Zone A4	34.3	NO_X,@15% O2	32.4	Zone B4
Zone A5	31.4	NO_X,@15% O2	32.6	Zone B5
Zone A6	31.9	NO_X,@15% O2	31.9	Zone B6

	Avg.	Min.	Max.	St dev.	
NOX,@15%	32.8	31.4	34.3	1.0	

Outlet NOx Distribution

SCR Outlet

East | West

Zone D1	2.2	NO_X,@15% O2	3.5	Zone C1
Zone D2	1.9	NO_X,@15% O2	0.7	Zone C2
Zone D3	1.0	NO_X,@15% O2	5.8	Zone C3
Zone D4	0.6	NO_X,@15% O2	3.1	Zone C4
Zone D5	1.2	NO_X,@15% O2	0.5	Zone C5
Zone D6	1.4	NO_X,@15% O2	1.7	Zone C6
Zone D7	1.3	NO_X,@15% O2	0.8	Zone C7
Zone D8	1.4	NO_X,@15% O2	0.9	Zone C8
Zone D9	1.6	NO_X,@15% O2	1.1	Zone C9
Zone D10	1.1	NO_X,@15% O2	0.6	Zone C10
Zone D11	1.8	NO_X,@15% O2	1.2	Zone C11
Zone D12	8.9	NO_X,@15% O2	3.8	Zone C12

	Avg.	Min.	Max.	St dev.	
NOX,@15% O2	1.9	0.5	8.9	1.9	

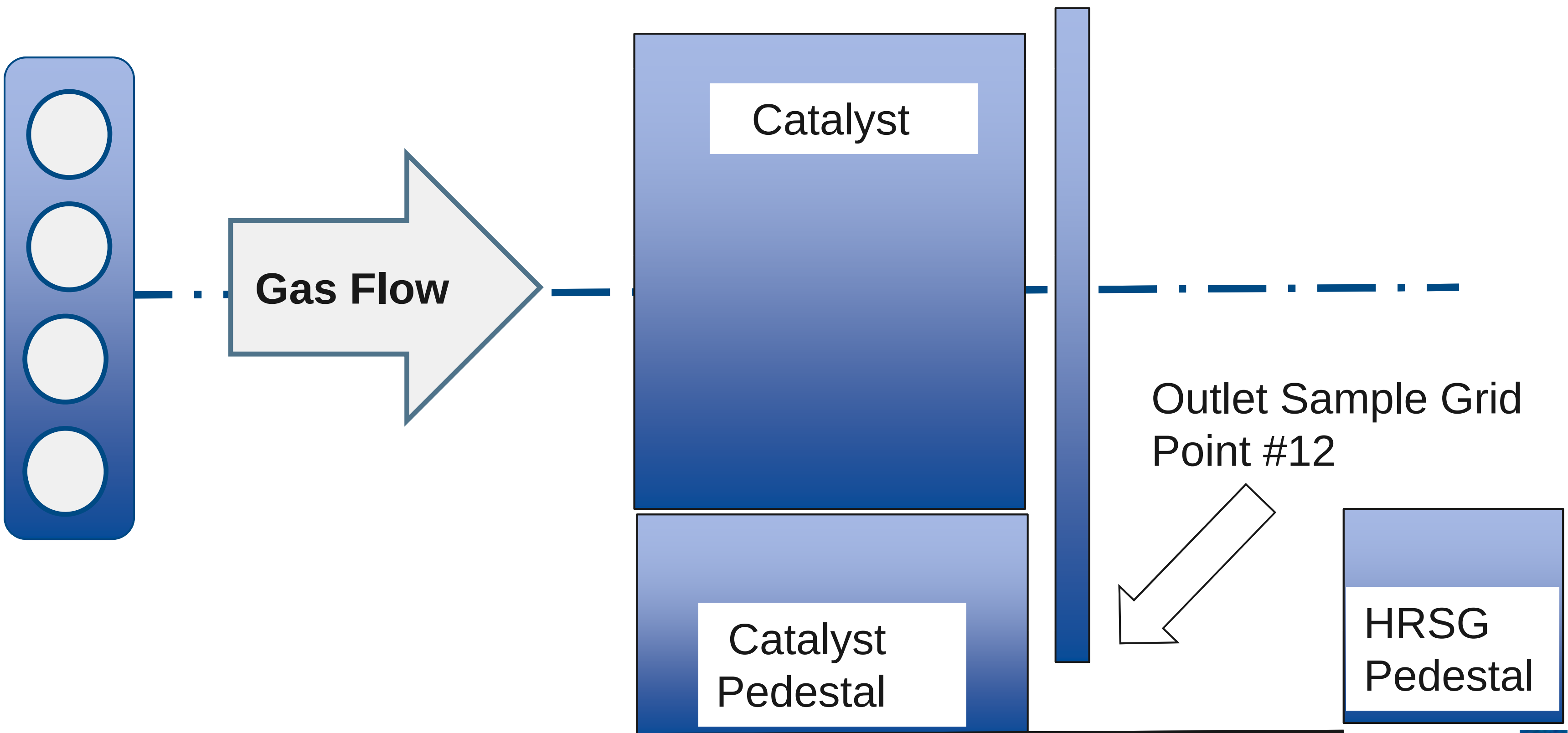
Outlet RMS (Skewed w/ Hi NH_3 Slip)

Avg. removal (deNOx)		93.9
standard deviation		5.94
	rms	6.33

DeNO$_X$ @ 15 %02			
	East	**West**	
zone D1	**93.2**	**89.2**	zone C1
zone D2	**94.2**	**97.8**	zone C2
zone D3	**97.0**	**82.8**	zone C3
zone D4	**98.4**	**90.8**	zone C4
zone D5	**96.5**	**98.4**	zone C5
zone D6	**95.9**	**95.0**	zone C6
zone D7	**96.1**	**97.6**	zone C7
zone D8	**95.9**	**97.4**	zone C8
zone D9	**95.0**	**96.7**	zone C9
zone D10	**96.5**	**98.1**	zone C10
zone D11	**94.4**	**96.3**	zone C11
zone D12	**72.1**	**88.0**	zone C12
Avg.	93.8	94.0	

Sampling Grid Installation

- Installed per Design: All Measurements off Duct Floor
- Design Did Not Account for Catalyst on Pedestal
- Removed Point #12 From Tuning



Revised Outlets Improved

Avg. removal (deNOx)		95.1
standard deviation		3.59
	rms	3.77

DeNO$_X$ @ 15 %02			
	East	**West**	
zone D1	93.2	89.2	zone C1
zone D2	94.2	97.8	zone C2
zone D3	97.0	82.8	zone C3
zone D4	98.4	90.8	zone C4
zone D5	96.5	98.4	zone C5
zone D6	95.9	95.0	zone C6
zone D7	96.1	97.6	zone C7
zone D8	95.9	97.4	zone C8
zone D9	95.0	96.7	zone C9
zone D10	96.5	98.1	zone C10
zone D11	94.4	96.3	zone C11
zone D12			zone C12
Avg.	95.7	94.5	

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