REINHOLD ENVIRONMENTAL Ltd.

2019 NOx-Combustion-CCR Round Table Presentation

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

Boiler Combustion Optimization to Reduce Superheat Tube Metal Temperatures and Creep

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Reinhold 2019 NO_x-Combustion Round Table
February 11, 2019
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FERCo

MP312

Problem Statement

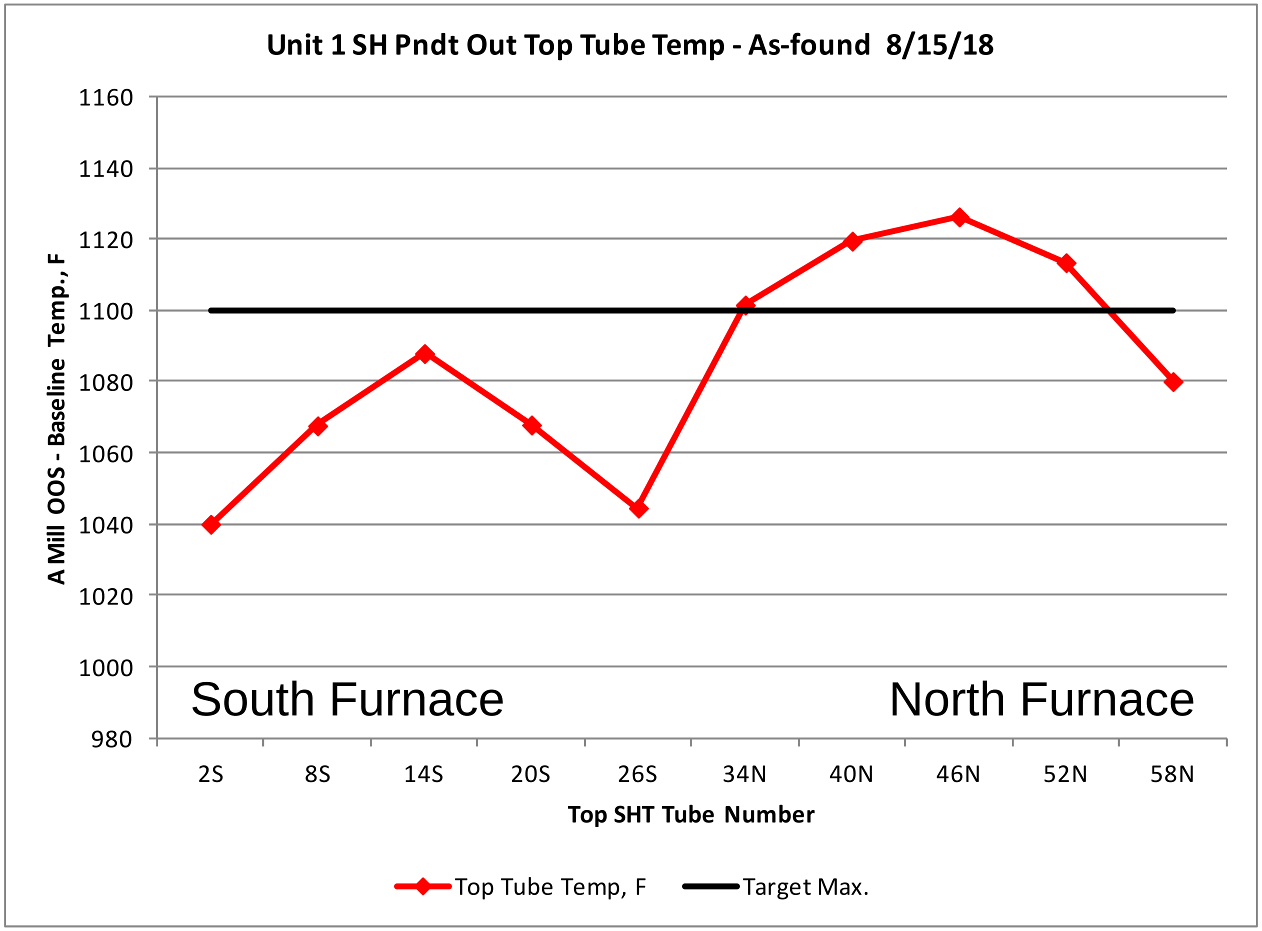
- **A 260 MW_{net} T-fired Unit Equipped with an Alstom TFS-2000 Low NO_x Firing System was Derated Due to High Superheat Pendant Tube Metal Temperatures**
- **Full-load Local Peak Tube Metal Temperatures Reached 1,135°F, Substantially Above the 1,100°F Maximum Target**
- **Potential Tube Metal Temperature Creep, Shortened Tube Life, and Increased Tube Failures were Major Concerns**
- **The Unit Operates with a High Degree of Overfire Air (OFA) Staged Combustion to Meet NO_x Regulations without an SCR System**
- **The Unit Burns a Low Sulfur Powder River Basin (PRB) Western Coal**

Problem Statement (continued)

- **The Highest Tube Metal Temperatures Occurred at Full-load but High Temperatures were Noted Across the Entire Load Range**
- **The Unit was Well Maintained and had a Major Maintenance Overhaul Less than 9 Months Prior to the Combustion Diagnostic Test Program**
- **Preliminary Testing Indicated that the Peak Temperatures Located in the North Furnace Were Related to Fuel-rich Incomplete Combustion**

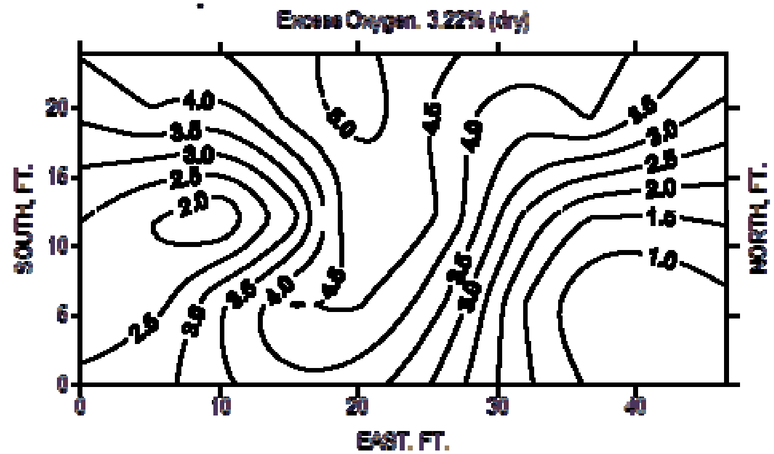
Problem Statement (continued)

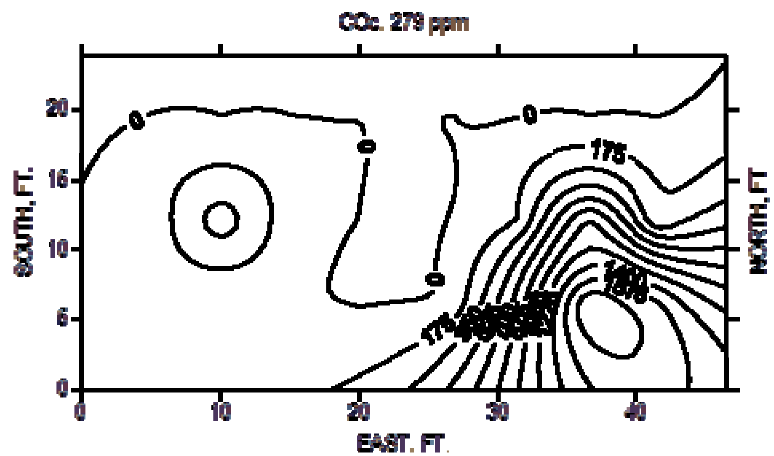
- **Baseline "As-found" Full-load Superheat Pendant Tube Metal Temperature Profile with the Top A Mill OOS**



Problem Statement (continued)

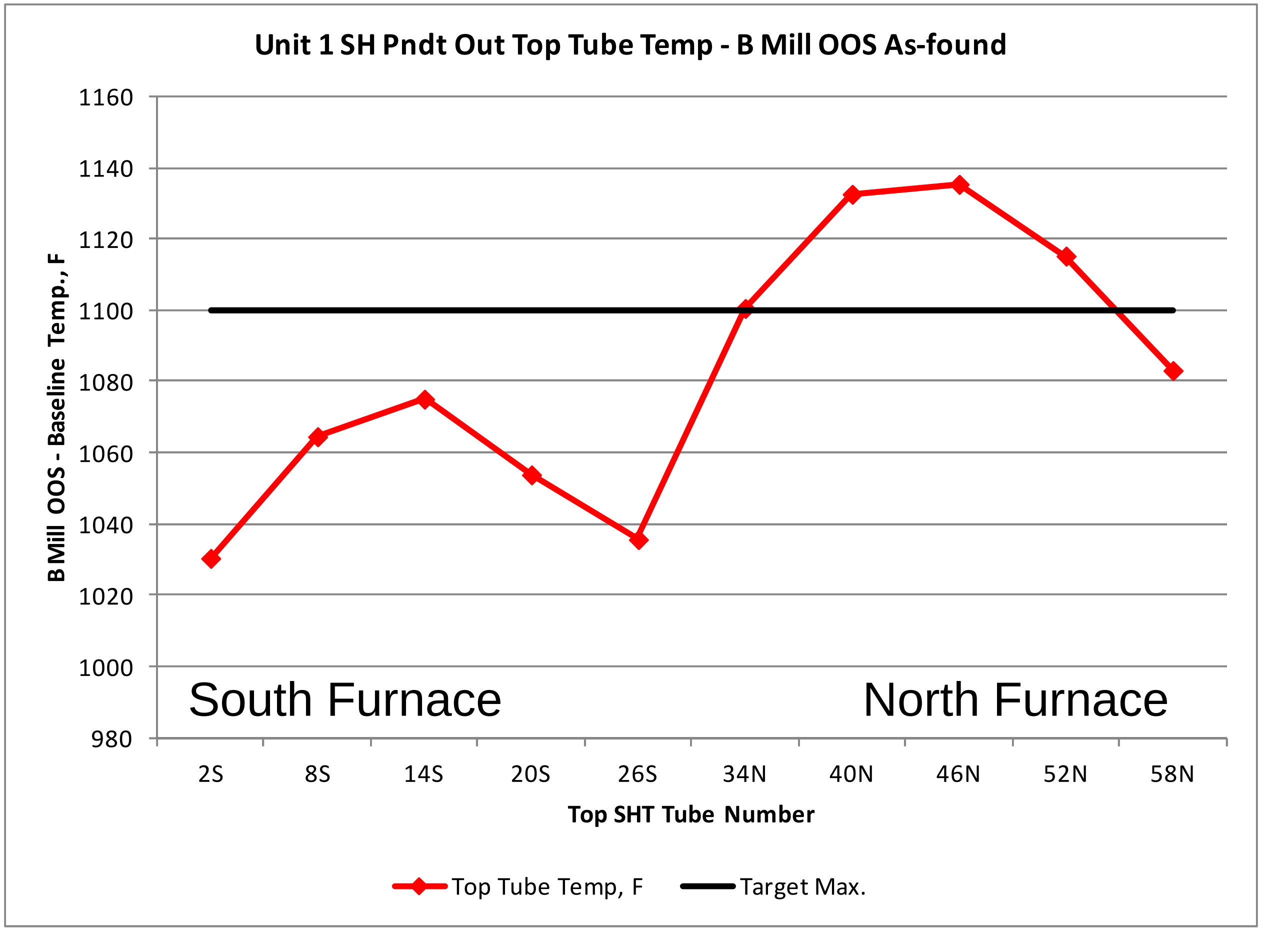
- **Baseline Economizer Exit Duct Oxygen and CO Profiles with Top Mill OOS ("As-found", 8/15/18)**





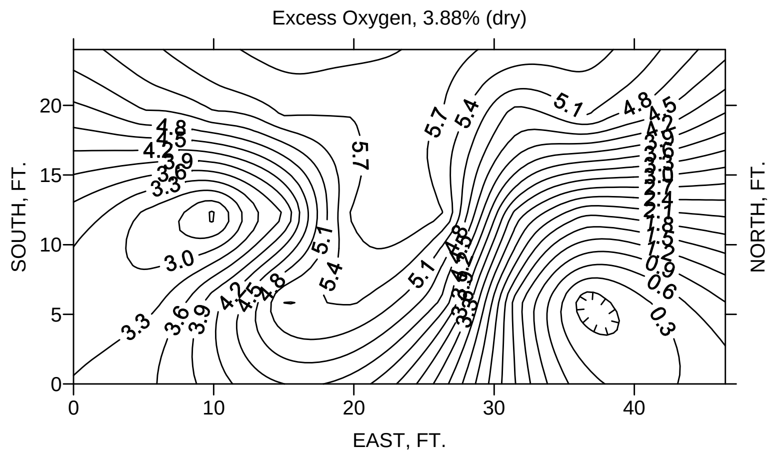
Problem Statement (continued)

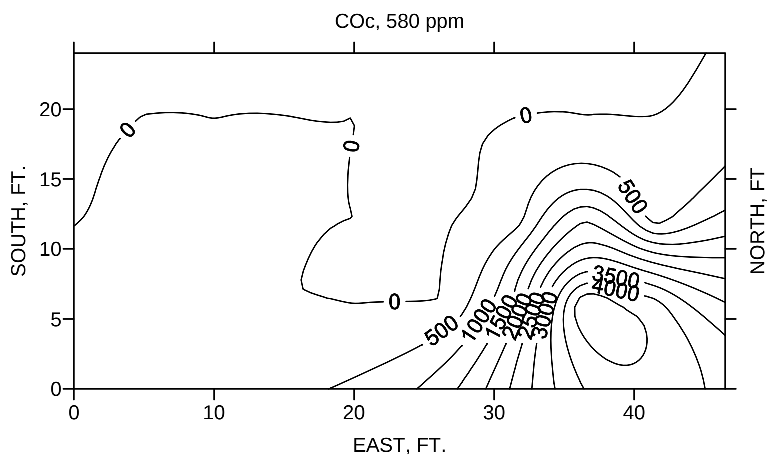
- **Baseline "As-found" Full-load Superheat Pendant Tube Metal Temperature Profile with the B Mill OOS**



Problem Statement (continued)

- **Baseline Economizer Exit Duct Oxygen and CO Profiles with B Mill OOS ("As-found", 8/18/18)**





Project Objectives

- **Identify the Cause of the Localized High Superheat Tube Metal Temperatures at Full-load for Common Boiler Firing Configurations**
- **Develop a Diagnostic Test Methodology Specifically for Adjusting the Boiler Combustion Control Settings to Reduce Peak Tube Temperatures**
- **If Possible, Reduce All Superheat Pendant Tube Metal Temperatures Below the 1100°F Maximum Target Using Operational Modifications Only (No Maintenance or Capital Equipment Expenditures at this time)**
- **Demonstrate the Reduced Tube Metal Temperature Benefits of Using Boiler Tuning to Improve Combustion Uniformity and CO Burnout**

Project Objectives (continued)

- **Recommend a Reduced Tube Metal Temperature Boiler Firing Practice Across the Load Range Based on the Most Desirable Combustion Controls Settings Established During the Boiler Tuning Test Program**

Technical Approach

Q: What is the Fastest and Most Cost-effective Way to Solve the Derated Load Problem?

A: Use a Boiler Combustion Tuning Technical Approach Similar to NO_x Emissions Optimization but Focus on Improving the Furnace-wide Combustion Uniformity Entering the Superheat Pendants

- Take advantage of a high speed digital multipoint combustion diagnostics analyzer (MCDA) that can simultaneously measure O_2 and CO at 12 individual probes at 6 second intervals

Key Boiler Operating Parameters

- **Load (firing rate)**
- **Firing Configuration (Mill Out-of-Service (OOS) and location)**
- **O_2 Set Point (%)**
- **OFA Flow and Distribution**
  - CCOFA and SOFA Damper Positions/Bias
- **Mill Feeder Bias (if any)**
- **North/South Auxiliary Air (AA) Damper Bias**
- **Burner Tilt Position (degrees)**
- **OFA Tilt Position (degrees)**
- **SOFA Yaw Angle (degrees)**
- **Sootblowing Frequency/Strategy**

Alternative Options Considered – Time Consuming & Costly

- **Balance the Coal Flow to Each Burner Corner by Elevation**
  - Replace the riffles
  - Install adjustable riffles to balance the coal flow

- **Install Real-time Coal Flow Measurement Instrumentation and Bias AA Dampers by Corner to Offset Coal Flow**

- **Install a Neural Network Combustion Optimizer on an Older Legacy Unit Scheduled for Retirement**

Test Program Relevancy

Q: How are the Test Results from This Project Relevant to Other Units?

A: High Boiler Tube Metal Temperatures, Creep, and Tube Failures Have Become Much More Common Because:

- Duty cycles have changed and former base load units are now load following
- Frequent and rapid load ramps on units without properly tuned combustion controls can result in temperature overshoot & tube failures

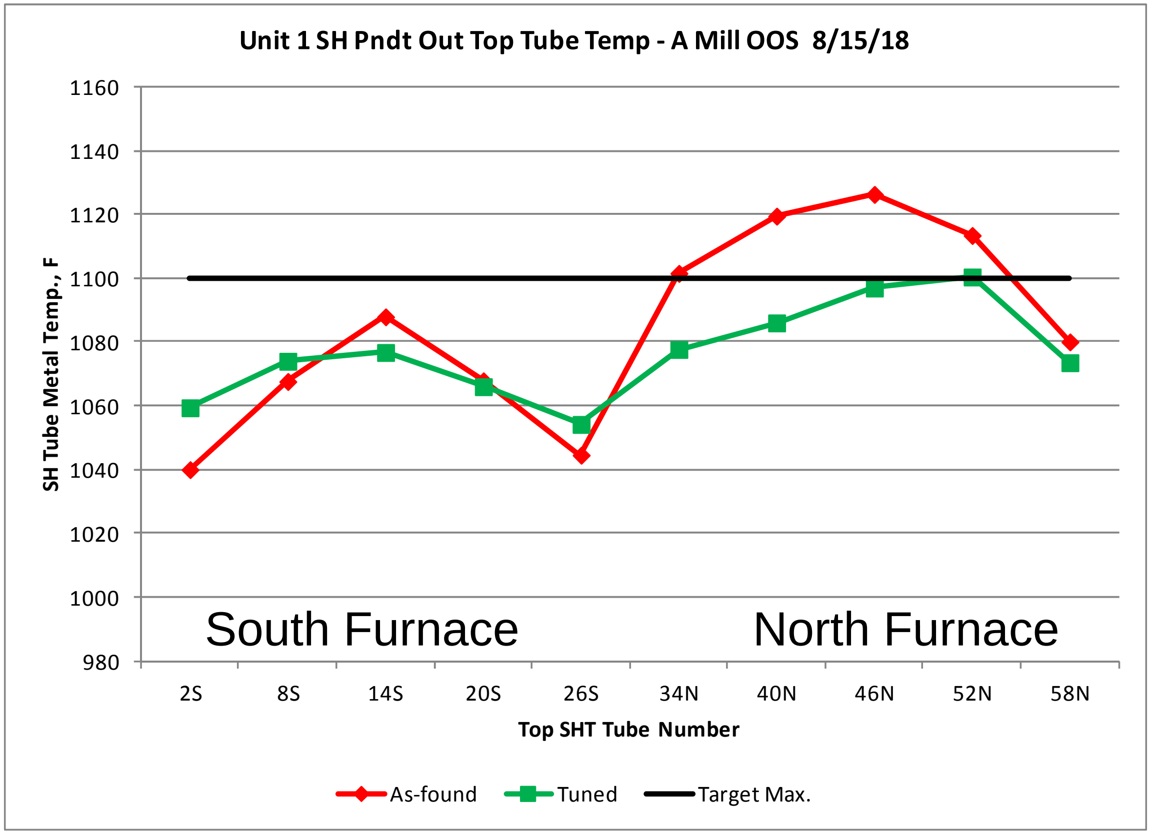
A: Plant Management Needs and Deserves a Proven Quick Response Solution to a Load Derate Problem

Combustion Diagnostic Test Methodology

- **Conduct an Extensive Off-site Pre-test Program Analysis of Prior DCS Data to Characterize the Problem**
- **Develop Quantitative Statistical Data Analysis Techniques for Quickly Assessing the Progress and Benefits of Combustion Tuning**
- **Establish a Baseline "As-found" Reference Test Condition that Best Characterizes the Magnitude of the Tube Metal Temperature Problem and Associated Combustion for the Test Series**
- **Apply Process Combustion Uniformity Optimization Techniques in a Prioritized Sequence to Document the Relative Tube Temperature Reduction Benefits**
- **Apply the Most Promising Temperature Reduction Boiler Combustion Controls Adjustments to Other Boiler Firing Configurations Across the Load Range**

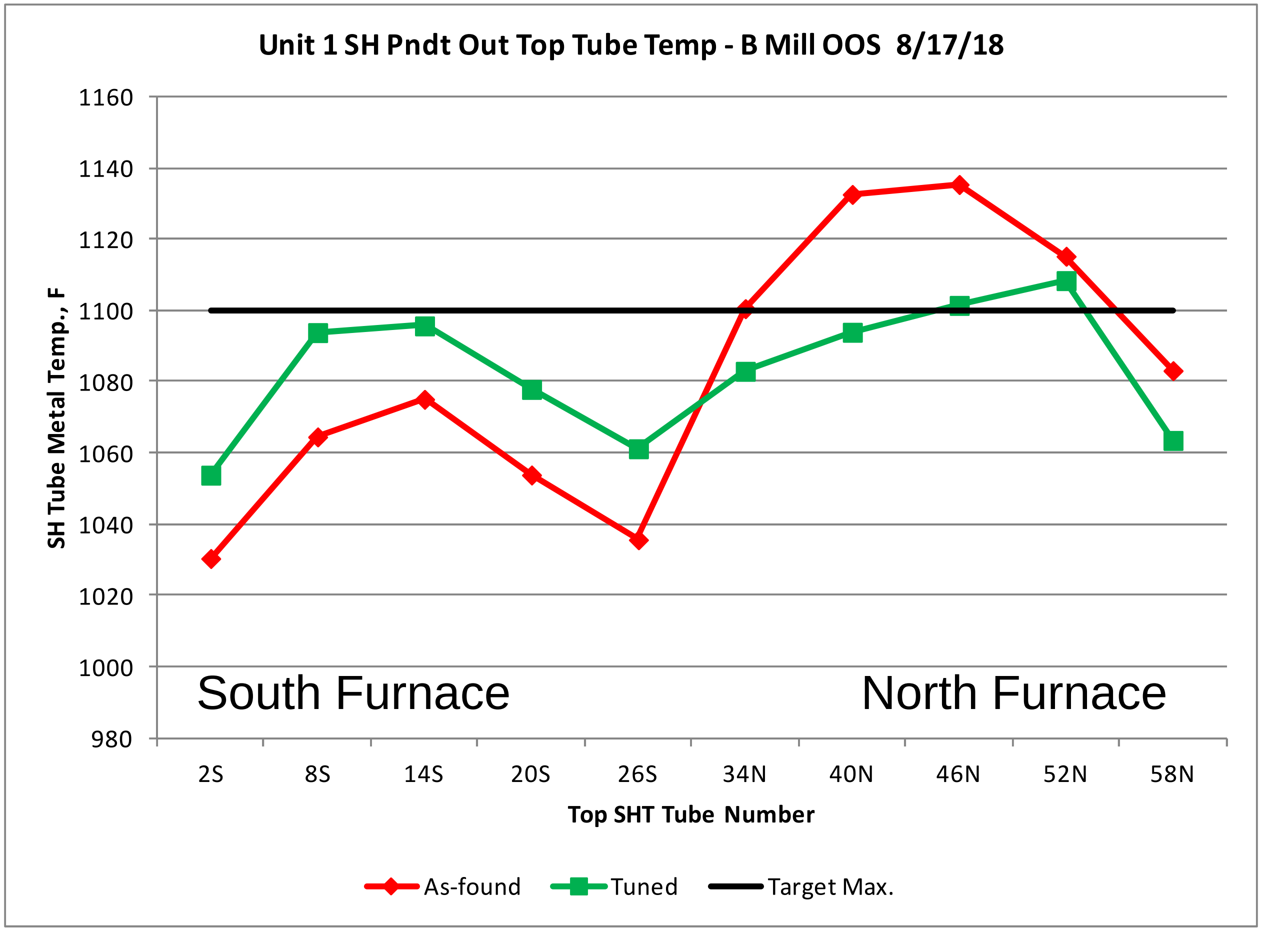
Full-load Combustion Diagnostic Test Results

- **The Benefits of Combustion Tuning to Reduce Tube Metal Temperatures during the First Day with the A Mill OOS**



Maximum Tube Metal Temperature was Reduced by 26°F

B Mill OOS Combustion Diagnostic Test Results

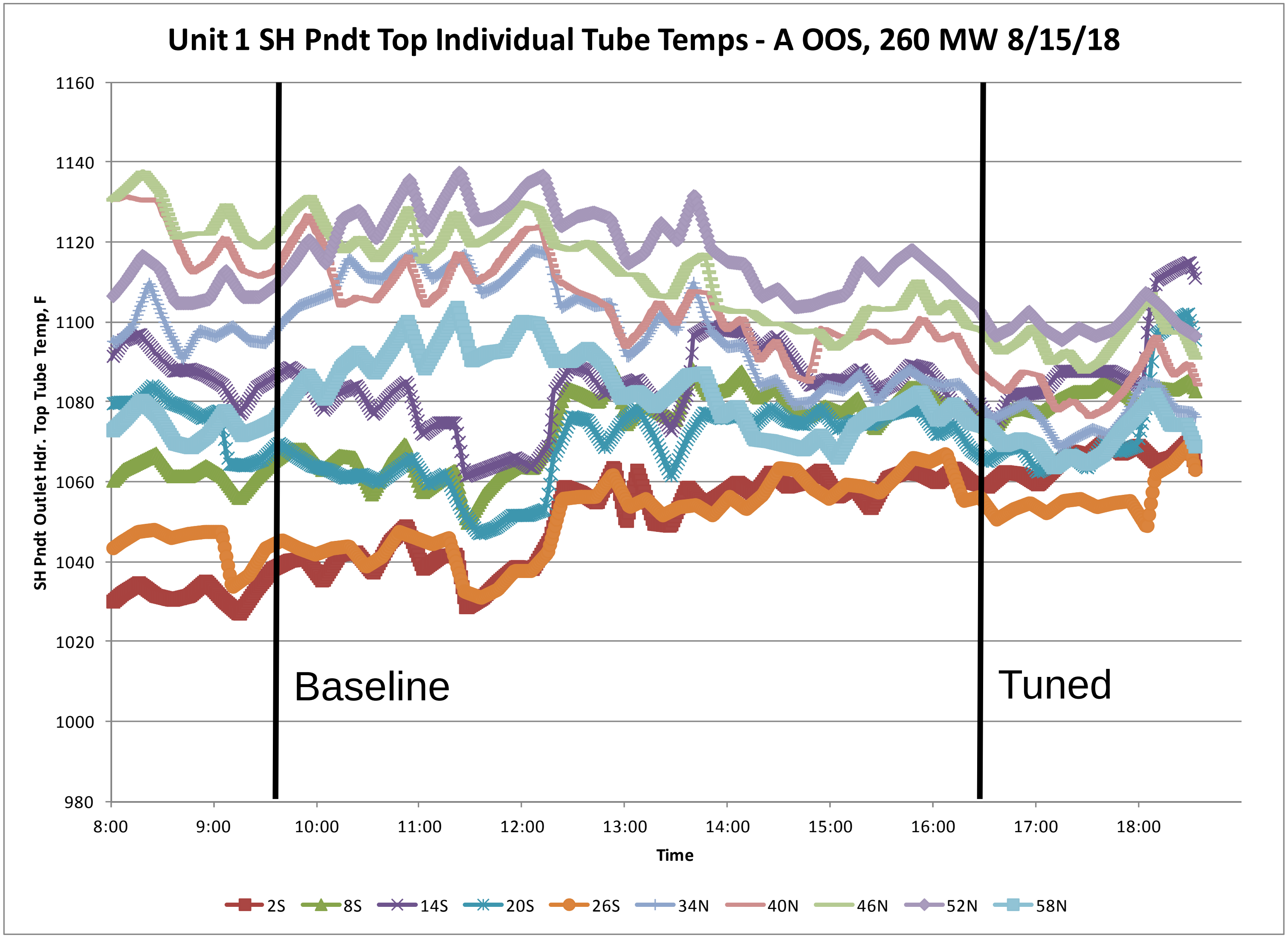


Maximum Tube Metal Temperature was Reduced by 27°F

Tube Metal Temperature Tuning & Data Analysis Strategy

- **Trend the *Individual* Tube Temperatures Throughout the Test Day**
- **Adjust Key Combustion Control Settings to Improve Combustion Uniformity**
  - CCOFA and SOFA flow to improve penetration and mixing
  - O_2 bias to improve CO burnout without exceeding NO_x limits
  - Burner auxiliary air (AA) damper bias
  - Burner tilt position
  - SOFA tilt position
  - SOFA yaw angle for CO burnout
  - Mill bias to explore coal flow sensitivity
  - Boiler control operator feedback (prior experience)
- **Monitor Secondary Impact of Sootblowing Strategy on Temperature Variations**

SH Pendant Individual Tube Temperature Trends – A Mill OOS



Boiler Combustion Tuning Involves Complex Tradeoffs

- **Older Units with Retrofit LNB/OFA NO_x Controls are Particularly Sensitive to OFA Tuning**
  - Deeply staged combustion (> 30% OFA) is used to limit NO_x formation but flame carryover into the pendants can be a problem
  - Delayed combustion can result in longer flames with reduced heat absorption in the lower furnace walls
  - Various combinations of OFA flow and O_2 set point exist that can meet the NO_x emissions constraint depending upon the shape of the emissions curve
  - The elevation of the OFA injection and the jet penetration velocity can affect the mixing and CO burnout
  - Combustion optimization is sensitive to the coal flow distribution from the mills to individual burners and which mills are in service
  - Combustion tuning must be performed across the load range for common firing configurations and DCS control curves modified to achieve optimum combustion

OFA Combustion Tuning Can Be Counterintuitive

- **A Logical Initial Diagnostic Testing Approach Would be to *Reduce* the OFA to Decrease the Staging, Improve the CO Burnout and Reduce the Flame Carryover**
- **Moving the Primary Combustion Zone Lower in the Furnace Away from the Superheat Pendant Tubes Would Also Allow More Heat to be Absorbed in the Furnace Walls**
- **However, the Associated Increase in NO_x Emissions Can Exceed Regulatory Limits**
- **An Uncommon but Quite Often Effective Approach Can be to *Increase* the OFA Flow (if carefully applied in combination with other measures)**

OFA Combustion Tuning Can Be Counterintuitive
(continued)

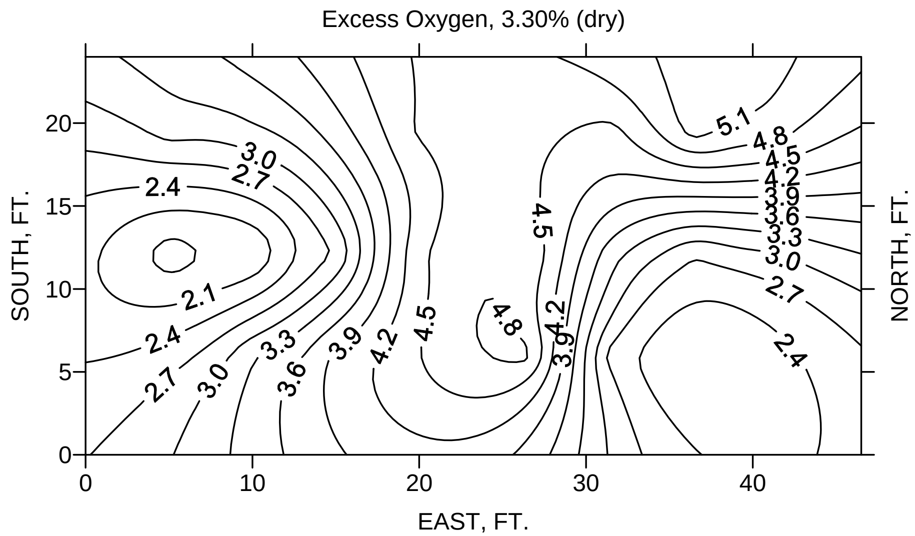
- **Improved Upper Furnace OFA Penetration and Mixing Can Significantly Improve CO Burnout and Combustion Uniformity**

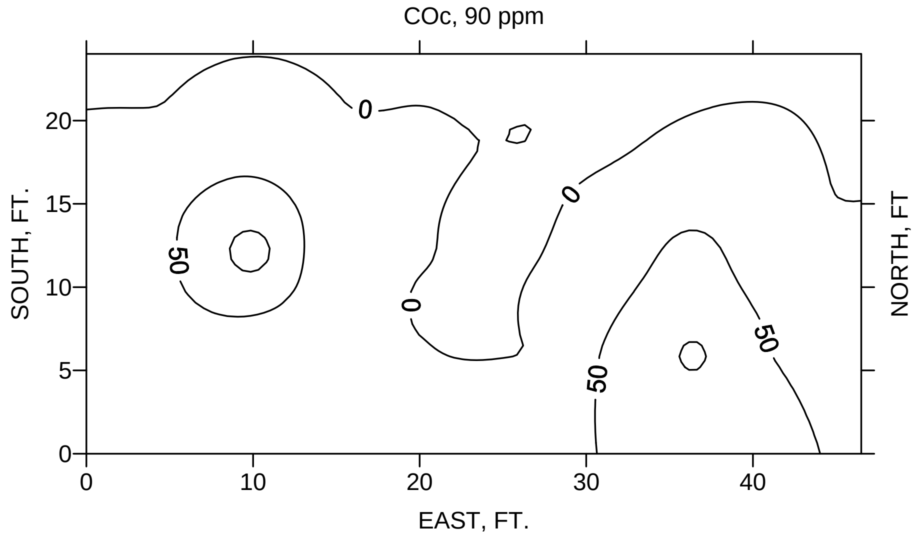
- **Complementary Burner Auxiliary Air (AA) Damper Biasing Can be Effectively Monitored with a Real-time Multipoint Combustion Diagnostic Analyzer (MCDA)**

Full-load Boiler Firing Configuration is Very Important

- **Operation with a Top Burner Elevation OOS or with Coal Flow Biased to Lower Elevations is a Popular Low NO_x Firing Configuration**
- **Uniform Coal Flow Distribution from the Mills to the Individual Burner Corners is Critical**
- **Operation with the Top Mill OOS on a Five Elevation Boiler Pushes 25% More Coal thru the Burners on the Lower Elevations**
- **The Increased Coal Flow to the Lower Elevations Can Exacerbate Poor Combustion on High Coal Flow Burners Leading to Flame Carryover to the Superheat Pendants**
- **What are the Combustion Uniformity Benefits of Operation with all Five Mills in Service?**

Combustion Profiles with All 5 Mills In Service





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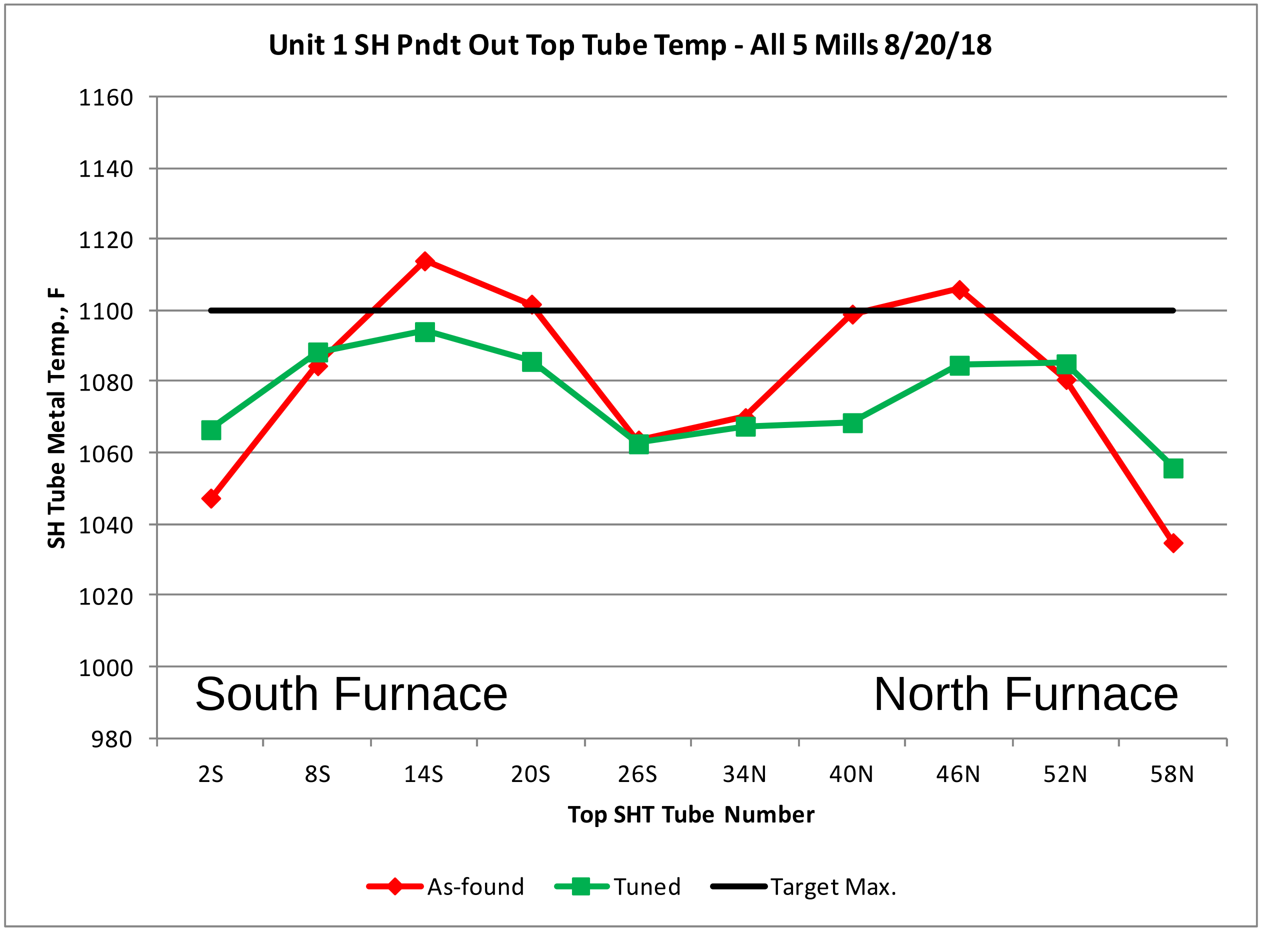
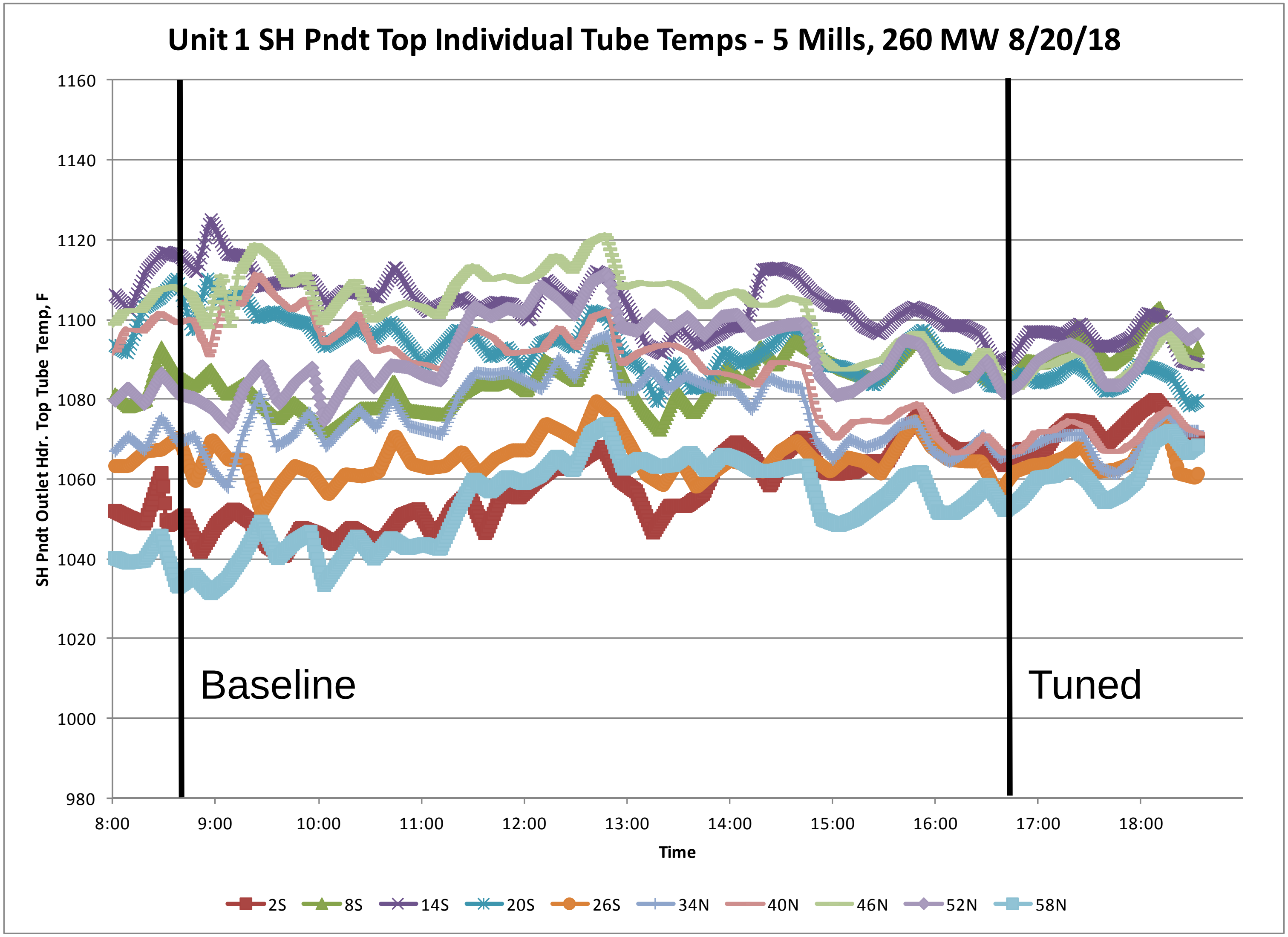
All 5 Mills Combustion Diagnostic Test Results



Although the Maximum Tube Metal Temperature with 5 Mills was only 1114°F, it was Still Possible to Reduce it by 20°F

SH Pendant Individual Tube Temperature Trends – 5 Mills In Service



Advantages of 5 Mill In Service Operation

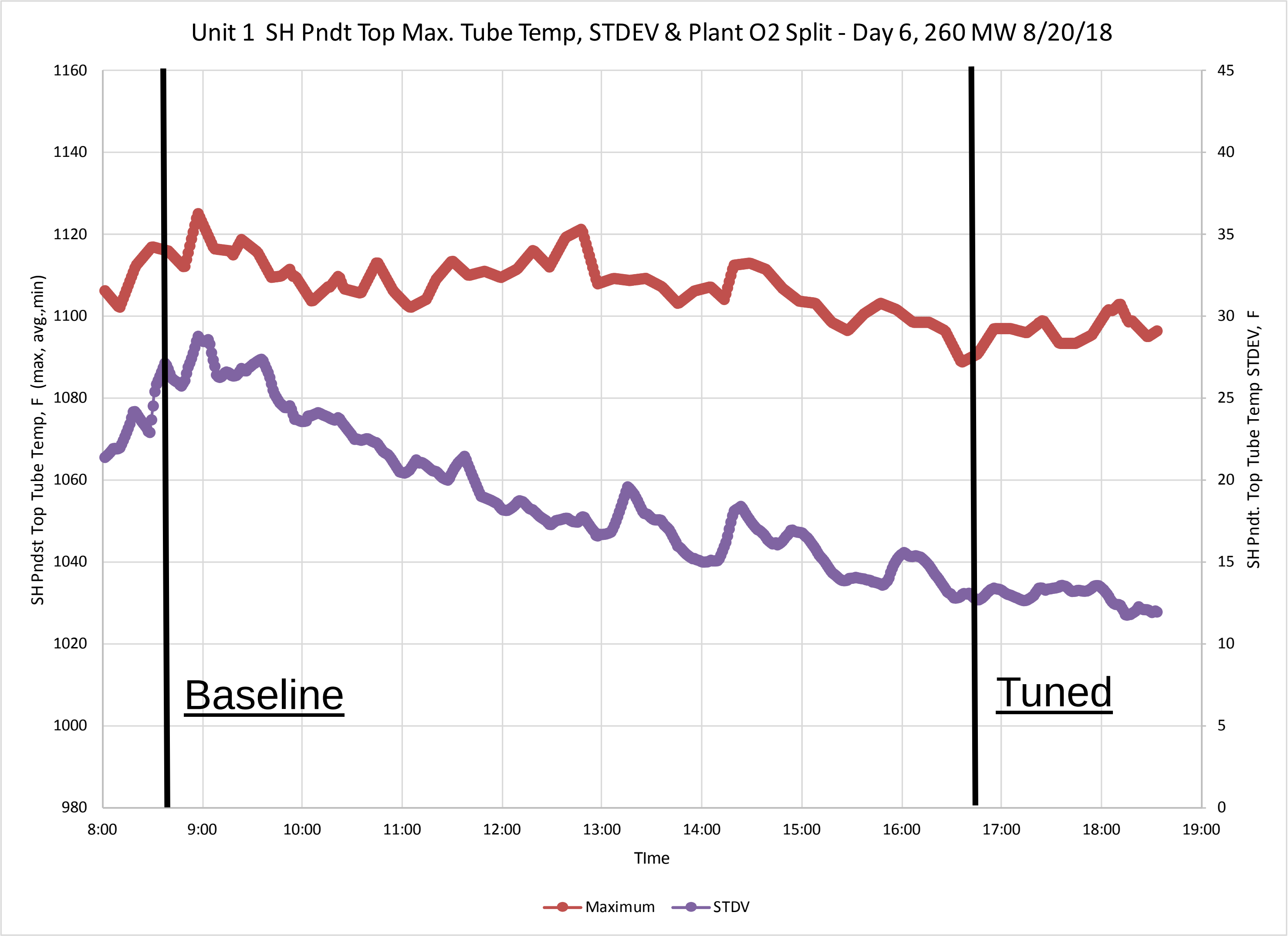
- **Higher Probability of Homogenous Combustion and Burnout in a 25% Larger Burner Zone Combustion Volume**
- **Increased Furnace Water Wall Heat Absorption with Full-load Heat Release Spread Over Five Burner Elevations (not four)**
- **Avoiding the Adverse Combustion Conditions of a “Hole in the Fires” with a Split Firing Configuration**
- **Reduced Potential for Burner Flame Impingement on Furnace Walls and Deposits Associated with Furnace Water Wall Corrosion**
- **Reduced Potential for Locally Fuel Rich “High CO” Corners Compared to Firing with Only Four Mills In Service**

Combustion Tuning Benefits with 5 Mill Operation

- **Although 5 Mill Operation Combustion Uniformity was the Best Full-load Firing Configuration, Tuning Still Reduced Tube Temperatures**

- **The Maximum Tube Metal Temperature Dropped 20°F to 1094°F and the STDEV Among the Individual Tube Temperatures Dropped from 27°F to 13°F**

Combustion Tuning Benefits with 5 Mill Operation



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Summary of Full-Load Boiler Tuning Test Results

Load, MWn	Date	Test #	Test Condition	Max Tube Temp, °F	Min Tube Temp, °F	STDEV °F	Reduction in Max Tube Temp, °F
260	8/15	T324	A OOS Baseline	1126	1040	30	26
		T329	A OOS Tuned	1100	1059	15	
260	8/17	T337	B OOS Baseline	1135	1030	38	27
		T367	B OOS Tuned	1108	1054	22	
260	8/20	T355	5 Mills Baseline	1114	1035	27	20
		T360	5 Mills Tuned	1094	1056	13	

- **Reductions in Maximum Tube Metal Temperature Ranged from 20°F to 27°F**
- **All Superheat Tube Metal Temperatures Post-tuning were Less than 1100°F with A Mill OOS and 5 Mills Operation**
- **Only Two Tube Metal Temperatures were Above the 1100°F After Tuning with the Worst Case B Mill OOS**
- **The Post-tuning Standard Deviation in Tube Metal Temperatures Dropped by Almost 50%**

Combustion Diagnostics and Boiler Tuning at Reduced Loads

Load, MWn	Date	Test #	Test Condition	Max Tube Temp, °F	Min Tube Temp, °F	STDEV °F	Reduction in Max Tube Temp, °F
180	8/18	T341	A OOS Baseline	1123	1029	27	14
		T344	A OOS Tuned	1109	1043	23	
160	8/19	T351	A & E OOS Baseline	1117	1022	34	17
		T354	A & E OOS Tuned	1100	1026	22	
100	8/19	T349	A & E OOS Baseline	1120	991	45	22
		T350	A & E OOS Tuned	1098	1000	32	

- **Boiler Tuning at Reduced Loads Down to 100 MW_n were Conducted with Either the A Mill or the A & E Mills OOS**
- **Although Reductions in Maximum Tube Metal Temperatures Ranging from 14°F to 22°F were Achieved, It was a Challenge to Try to Reach the 1100°F Maximum Tube Temperature Target at 180 MW_n**

Recommended Interim Boiler Firing Practice

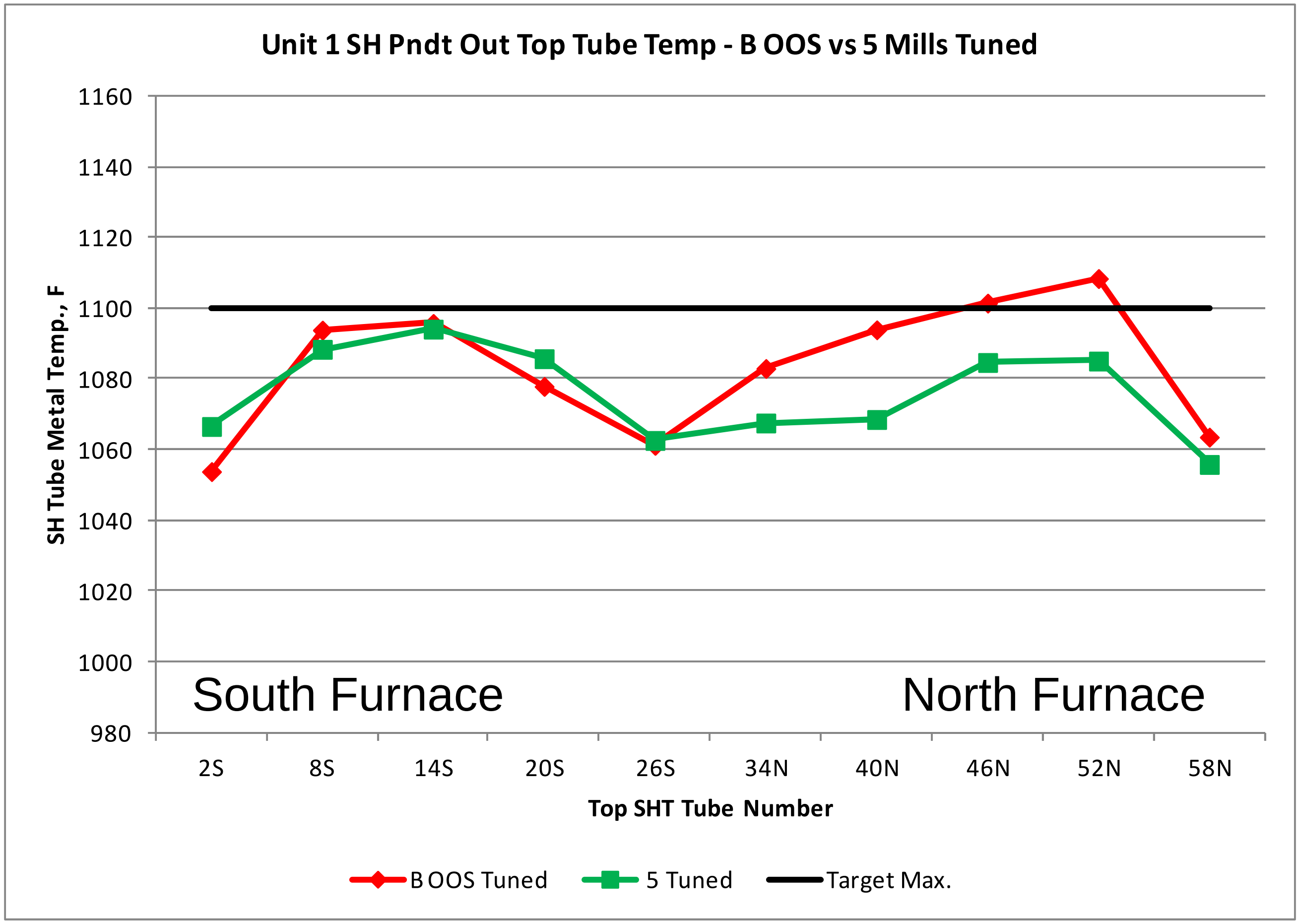
- **Operate with All 5 Mills In Service to Control Tube Metal Temperatures during High Load Operation**
- **Modify the DCS SOFA 4 and SOFA 5 Damper Curves so they are both 100% Open Above 55% Load to Improve Upper Furnace OFA Penetration and Mixing**
- **Modify the DCS O_2 Curve to Increase the Full-load Set Point by Roughly 0.4%**
- **Bias the Burner Auxiliary Air N/S Master to Increase Combustion Air Flow to the Furnace with Elevated Tube Temperatures**
- **Monitor the Individual Tube Metal Temperature Trends During Tuning to Gauge the Improvement in Combustion Uniformity**

Recommended Interim Boiler Firing Practice
(continued)

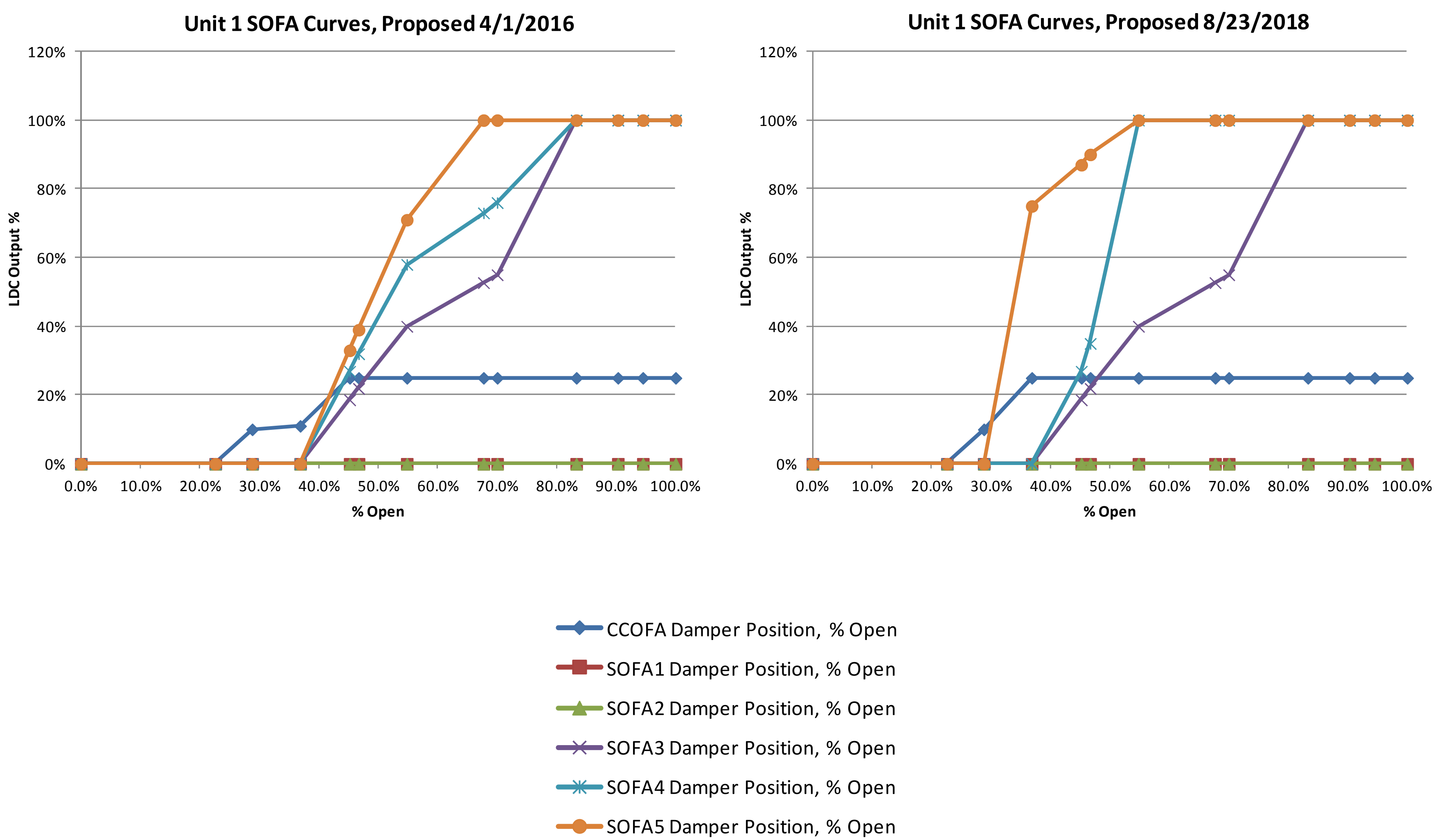
- **Implement a More Proactive Approach to Convective Section Sootblowing in Advance of the Tube Metal Temperatures Reaching their Alarm Point**
  - If possible, blow sensitive IK's at lower loads rather than at full-load

- **Evaluate the Potential Benefits of Reducing the Load Ramp Rate Near Full-load from 3 MW/min to 2 MW/min Until the O_2 Combustion Controls and FD Fan Controls are Tuned**

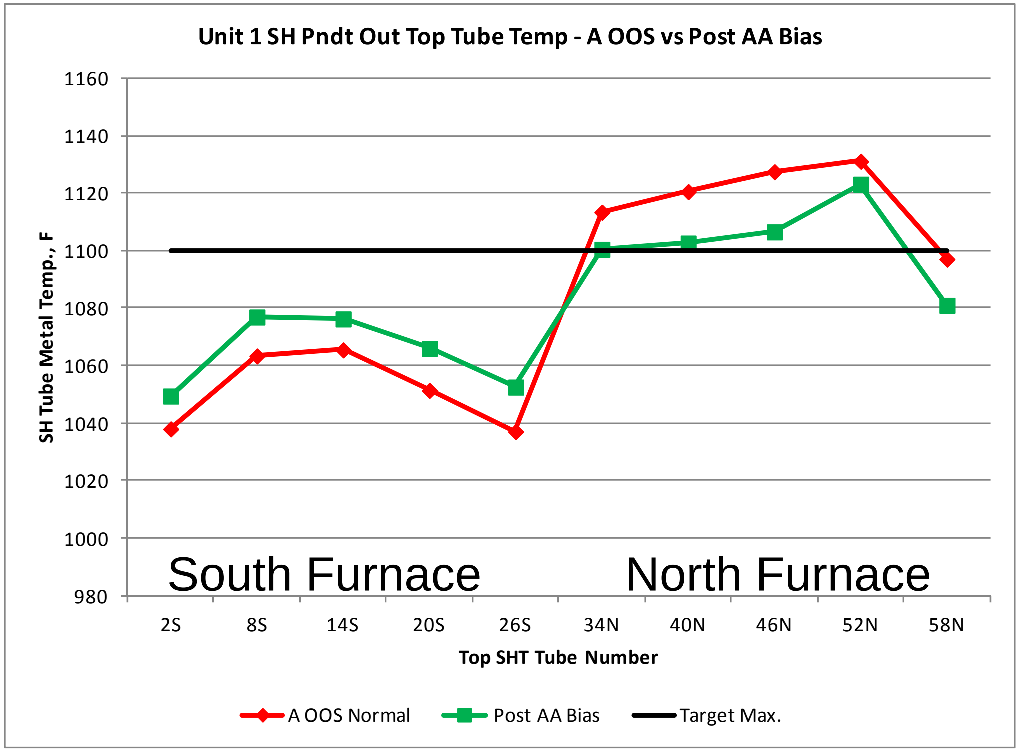
Tube Metal Temperature Benefits of 5 Mills Tuned Operation



OFA Combustion Tuning Recommendations



How Effective is the Burner N/S Auxiliary Air Master Bias



N/S AA Bias	North O_2, %	South O_2, %	North FEGT, °F	South FEGT, °F
Normal = 0.0	2.6	3.8	1836	1747
Biased - 6.6%	3.3	3.5	1790	1757

Summary of Boiler Combustion Tuning Benefits

- **Reductions in Maximum Tube Metal Temperature Ranged from 20°F to 27°F**
- **All Superheat Tube Metal Temperatures Post-tuning were Less than 1100°F with A Mill OOS and 5 Mills Operation**

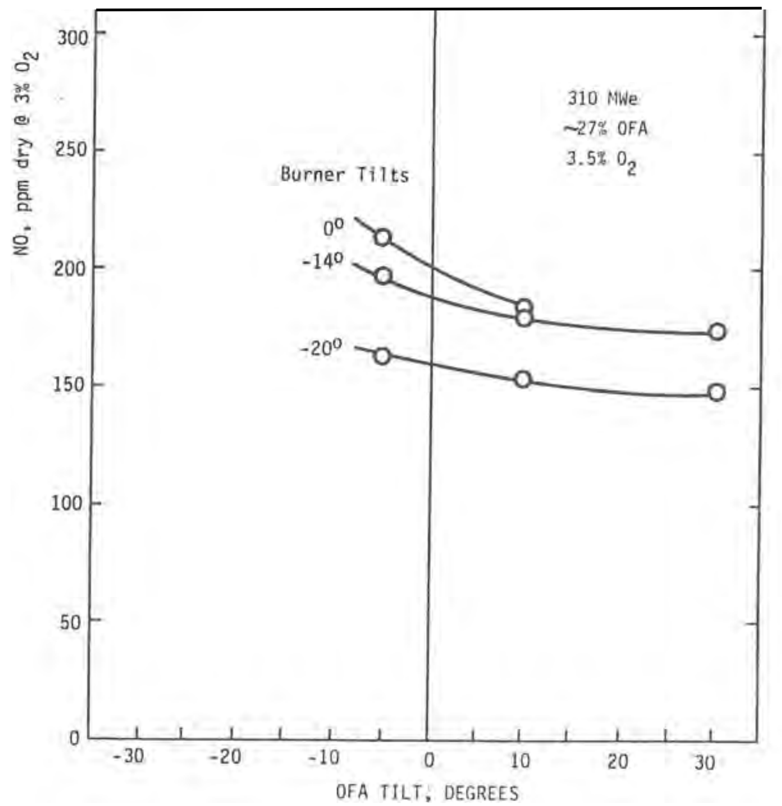
Load, MWn	Test Condition	Max Tube Temp, °F	Reduction in Max Tube Temp, °F	Tube Life Extension Multiplier
260	A OOS	1126	26	2.0
260	B OOS	1135	27	2.0
260	5 Mills	1114	20	1.7

- **A 25°F Reduction in Maximum Tube Temperature for a Tube with a 5 Year Remaining Life Would Extend it to 10 Years**
- **If Just One Forced Outage, Caused by a Superheat Tube Failure Could be Avoided, The Estimated Cost Savings are $595,000**

Successful Boiler Tuning Requirements

- **Pre-test Preparation and Understanding of the Key Elements of the Problem**
- **Utilize Advanced Combustion Diagnostic Test Instrumentation to Track Dynamic Process Changes in Real-time with Digital Playback Capability**
- **Custom Designed Multipoint Combustion Diagnostic Analyzer System (MCDA) in a Portable Configuration that can be Easily Shipped to US and International Destinations**
- **An Open Mind and Willingness to Explore Potential Solutions that may be Counterintuitive**
- **A Desire to Work Closely with the Clients Technical Staff and Share Test Experiences to Improve Operating Practices**
- **Tuning Experience**

NO Dependence on OFA and Burner Tilt – Circa 1988

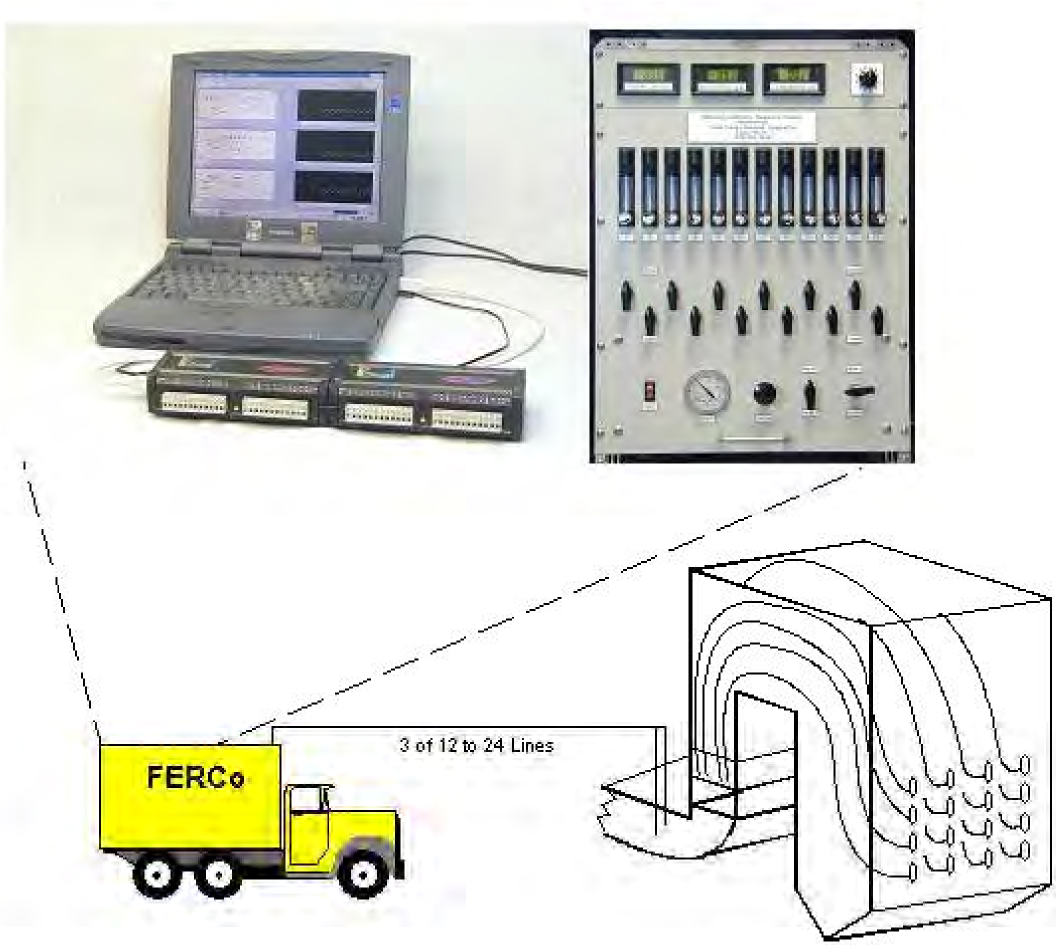


NO_x Emissions Results for a Low-NO_x PM Burner Retrofit

Presented at

JOINT EPRI/EPA SYMPOSIUM ON NO_x CONTROL
San Francisco, California
March 1988

Typical Multipoint NO, O_2, CO Analyzer (MCDA) Installation



Analyzer Features and Benefits

- **Simultaneous Emissions Measurement from 12 Individual Sample Probes**
- **NO, O_2, CO – 12 Channels Each (36 Total)**
- **Displays Real-time Trends of Gas Concentrations with Digital Recording**
- **Identify Non-Uniform Combustion and Air Inleakage**
- **Burner and OFA Tuning in Interactive Mode**

Advanced Multipoint Combustion Diagnostics Analyzer

Problem Solving in an Era of Tight Budgets

- **The Latest Trends in Providing Consulting Services and Professional Technical Support Involves the Industrial Internet of Things (IIoT)**
- **Very Cost-effective Problem Solving Can be Provided Remotely via the Internet and Wireless Communications Avoiding Airfare and Hotel Expenses**
- **FERCo has Provided Real-time Remote Combustion Diagnostics Since 2009**

First Verizon MiFi 2200 Intelligent Wireless Hotspot 2009

Remote Technical Support During This Boiler Tuning Project

- **Extensive Pre-test Program Off-site Combustion Diagnostic Data Analysis and Test Methodology Support Provided Prior to the August 2018 Test Program**
- **Large Data Files Efficiently Transferred Using a Secure File Transfer Method such as Secure File Transfer Protocol (.SFTP) or (.FTPS) to Secure Dedicated Space on the FERCo Server**
- **Defined Combustion Diagnostic Test Methodology Used During Brief 8 Day Onsite Testing with Informal Training of New Group Member**
- **All Post-test Data Analysis and Reporting Conducted Offsite by Internet Communications**
- **Additional Post-test Technical Support Related to Coal Quality Issues also Provided via Internet**

Questions?

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