Reinhold Environmental Ltd.

2009 NOx-Combustion Round Table & Expo Presentation

February 9 & 10, 2009, Cleveland, OH

Workshop I

Tuning LNB's and OFA Systems

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2009 Reinhold NO_x Roundtable

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REQUIREMENTS FOR EFFECTIVE NO_X OPTIMIZATION

- **Comprehensive Diagnostic Evaluation of Factors Affecting NO_x Emissions:**
  - Coal Property Variability
  - Burner Pipe Coal Flow Distribution
  - Combustion Uniformity (Individual Burner and OFA Settings)
  - Post-Combustion NO_x Control (SCR/SNCR Grid Tuning)
  - Plant Combustion Controls and Process Instrumentation
  - SCR Catalyst Performance Degradation and Catalyst Replacement Management

ROLE OF ADVANCED INSTRUMENTATION IN OPTIMIZATION

- **Expedient Cost Effective NO_x Emissions Diagnostics and Tuning**
  - Real-Time Burner Pipe Coal Flow Distribution Measurement
  - Real-Time Economizer Exit O_2,CO, NO Profiles for Interactive Burner/OFA Tuning Using Multipoint Emissions Analyzer
  - Quick Turnaround Fly Ash LOI Analysis (Hot Foil Analyzer)
  - Rapid Cost Effective SCR/SNCR Tuning Using Real-Time Multipoint Emissions Analyzer
  - Periodic SCR Catalyst Activity Measurement Using *In situ* KnoxCheck Advanced Instrumentation System
- **FERCo Uses Custom Proprietary Instrumentation in its NO_x Emissions Diagnostics and Process Control Optimization**

COMBUSTION DIAGNOSTICS AND TUNING

BOILER/BURNER COMBUSTION TUNING

- Measure Primary Air and Coal Flow Distribution to Burners
- Optimize Mill Performance and Coal Fineness
- Balance Coal Flow to Individual Burners
- Characterize/Reduce Air Inleakage Between Furnace and Economizer Exit
- Adjust Secondary Air Flow to Burners for Uniform Combustion
- Improve Instrumentation/Placement
- Modify Boiler Firing Practice Over Load Range

BOILER OFA TUNING

- **Characterize the Emissions and Profiles for Varying Levels of OFA**
- **Establish Tradeoffs Between OFA Flow, NO_x, CO, LOI and Operating O_2 Level**
- **Evaluate the Potential Non-Uniformity in OFA Distribution to the OFA Ports**
- **Bias the OFA Flow, if Necessary, to Achieve Uniform Combustion**
- **Evaluate OFA Settings and Combustion Uniformity over the Load Range**

IMPACT OF NON-UNIFORM COMBUSTION

- **Local Air-Rich Zones - High NO_x Emissions**
- **Local Fuel-Rich Zones - High Ash Carbon Levels, CO, Slagging/Fouling**
- **Overall O_2 Level Dictated by Lowest O_2 Region**
- **Average O_2 is Higher than Necessary**

BENEFITS OF UNIFORM COMBUSTION

- **Lowest Overall LOI and NO_x Emissions at Uniform Low O_2 Level**

- **Improved Boiler Efficiency**
  - Reduced Dry Gas Loss
  - Reduced Combustible Loss

- **Emission Control Equipment Performance may Improve**

COMMON CAUSES OF NON-UNIFORM COMBUSTION

- **Uneven Coal Flow Distribution**
  - Coal Pipe Orifices
  - Riffle Box Configuration
  - Coal Feeder Calibration or Bias

- **Uneven Air Flow Distribution**
  - Air Register/Damper Settings
  - Windbox Design, FD Fan Placement
  - Air Register/Drive Motor Malfunction
  - OFA Ductwork Configuration

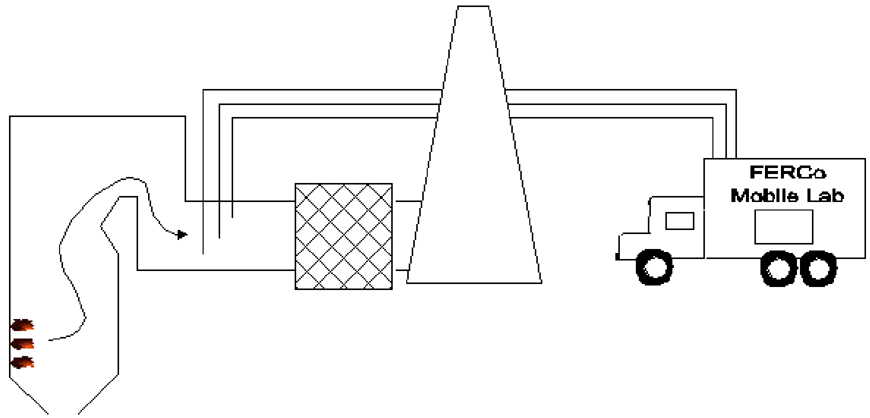
- **Air Heater – Seal Leakage or Partial Pluggage**

- **Furnace Air Inleakage Before O_2 Probes**

LIMITATIONS OF STACK (CEM) DATA

- **Boiler Average Emissions Only, No Indication of Burner Zone Gradients**
- **No Direct O_2 or CO Measurement**
- **Typically Not Real-Time Data to Allow Interactive Burner and OFA Tuning**
- **Difficult to Evaluate Combustion Uniformity Downstream of the Air Heater**

MULTIPOINT COMBUSTION DIAGNOSTICS ANALYZER (MCDA)



ANALYZER FEATURES AND BENEFITS

- **Simultaneous Measurement at 12 Sample Points**
- **NO, O_2, CO - 12 Channels Each (36 Total)**
- **Real-Time Contour Plots of Gas Concentrations**
- **Identify Non-Uniform Combustion and Air Inleakage**
- **Burner and OFA Tuning in Interactive Mode**

BOILER TUNING CASE HISTORY

- **Boiler Configuration**
  - 165 MW Combustion Engineering, T-Fired Divided Furnace
  - 16 OEM Burners, 2 Elevations
  - Fixed Coal Pipe Orifices

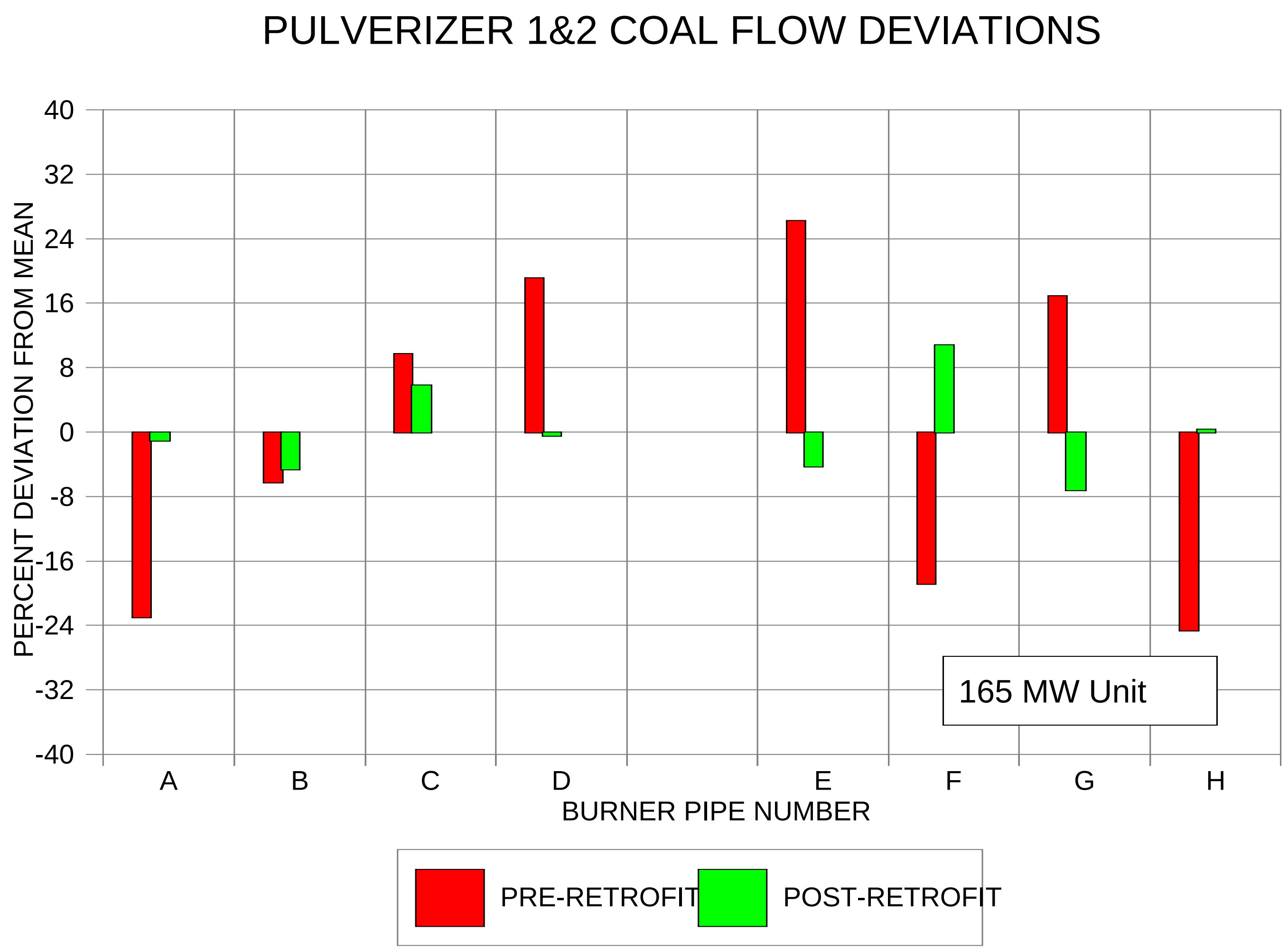
- **Test Coal**
  - Blended Eastern and PRB

- **NO_x Controls**
  - Candidate for Retrofit LNB and OFA

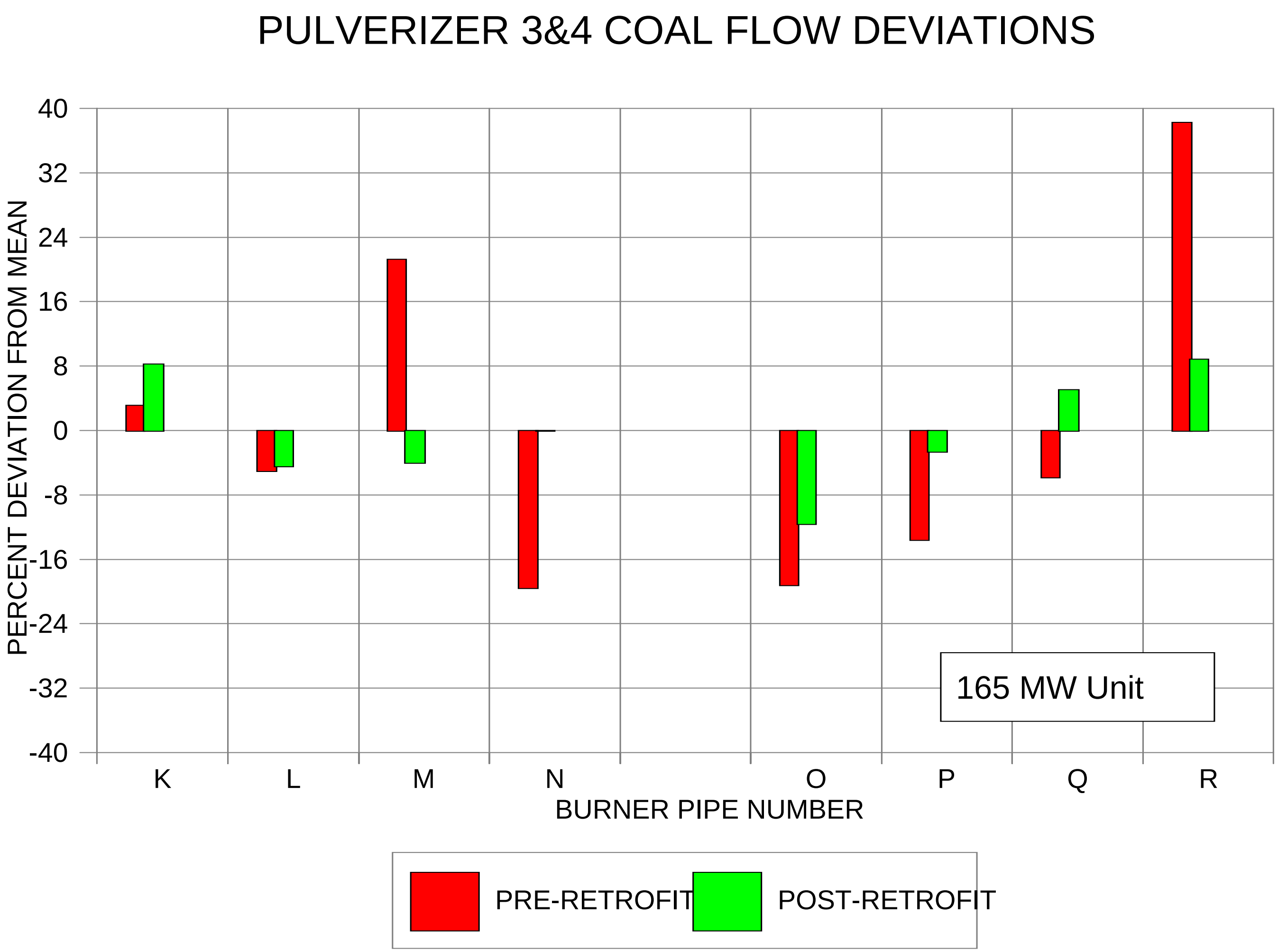
WHY BALANCE THE COAL FLOW TO BURNERS?

- **Fuel Rich Burners are a Source of High CO and LOI**
- **Fuel Rich Burners Can also Cause Furnace Ash Deposits, Waterwall Corrosion, and Fouling in the Convective Section**
- **Furnace Wall Cleanliness is a Key Issue in Low-NO_x Firing with PRB Coals (Derates and Outages can Occur)**
- **Air Rich Burners Produce NO_x and Contribute to Boiler Efficiency Losses**
- **Low-NO_x Burner Vendors Typically Require the Coal Flow Variation Between Burners Not Exceed ±10% for Each Pulverizer**

TYPICAL IMPROVEMENT WITH ORIFICE MODIFICATIONS



TYPICAL IMPROVEMENT WITH ORIFICE MODIFICATIONS (cont'd)



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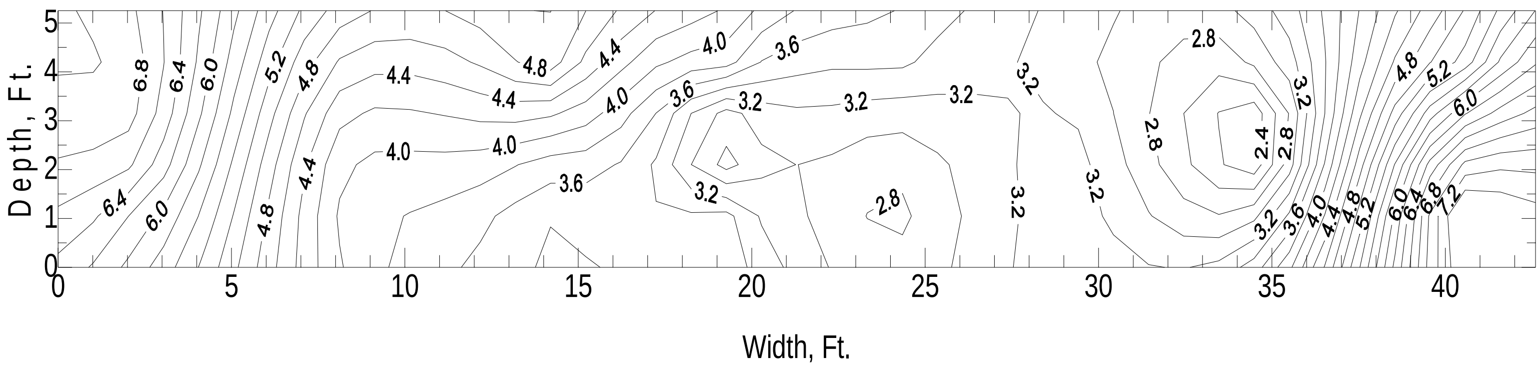
BENEFITS OF REPLACEMENT COAL PIPE ORIFICES

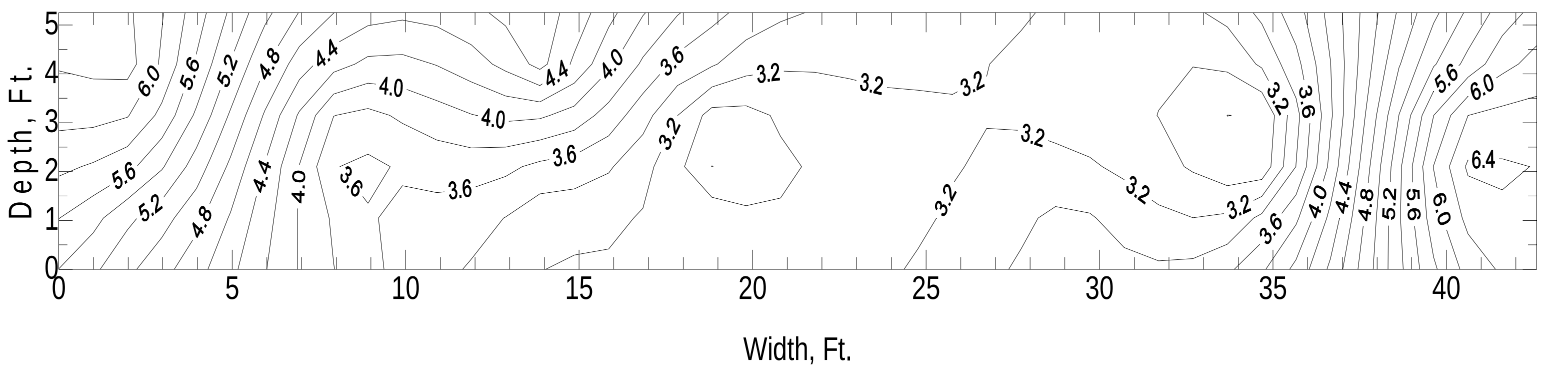
Pulverizer Type	Initial Coal Flow Deviation	Final Coal Flow Deviation	Orifice Type	Location
F-W	± 11.7%	± 1.5%	Fixed	IL
B&W	± 29.2%	± 4.3%	Fixed	OH
C-E	± 25.4%	± 3.2%	Adjustable	CT
C-E	± 28.3%	± 9.6%	Adjustable	CT
B&W	± 16.1%	± 4.1%	Fixed	CT
C-E	± 32.4%	± 4.4%	Adjustable	CT
C-E	± 38.0%	± 7.7%	Fixed	OH
C-E	± 38.2%	± 8.3%	Fixed	MI
B&W	± 22.8%	± 4.9%	Fixed	OH
C-E	± 39.3%	± 11.3%	Fixed	OH
F-W	± 31.5%	± 4.8%	Fixed	CT
F-W	± 12.3%	± 3.6%	Fixed	CT

TYPICAL IMPROVEMENT IN COMBUSTION UNIFORMITY

BASELINE ECONOMIZER EXIT O_2 (%) PROFILE

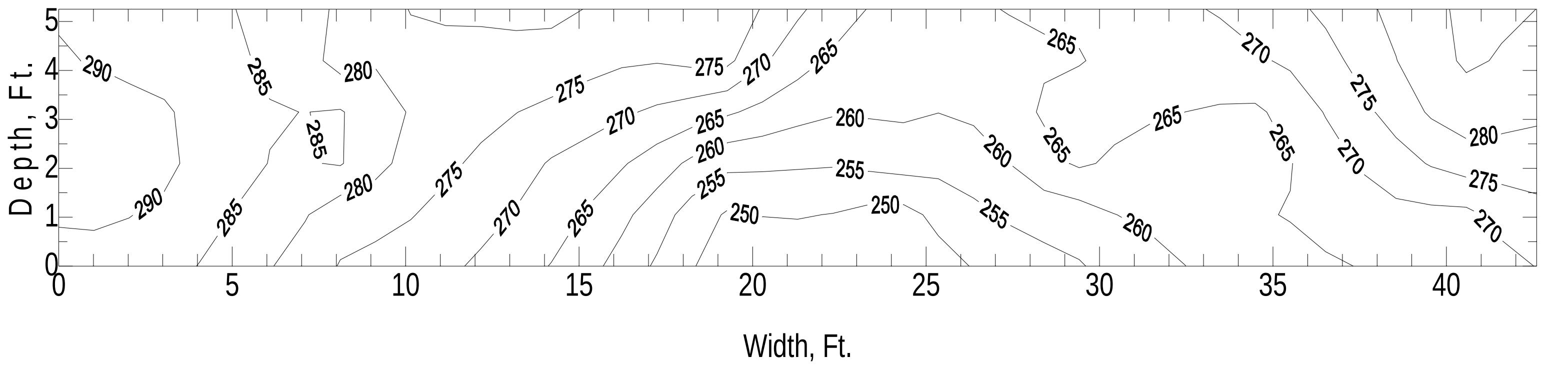


POST ORIFICE REPLACEMENT O_2 (%) PROFILE

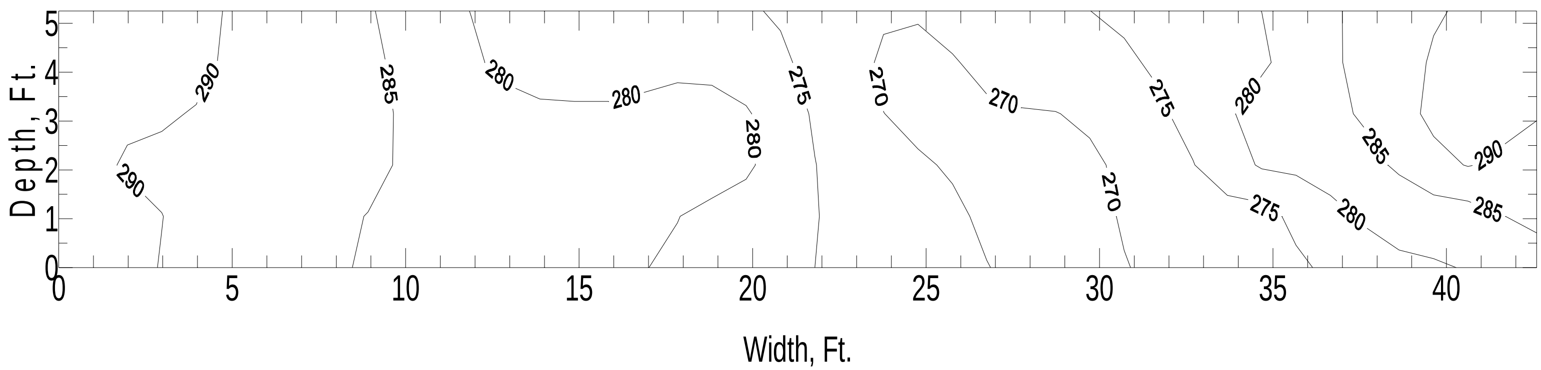


TYPICAL IMPROVEMENT IN COMBUSTION UNIFORMITY (continued)

BASELINE NO_c (ppm @ 3% O_2) PROFILE



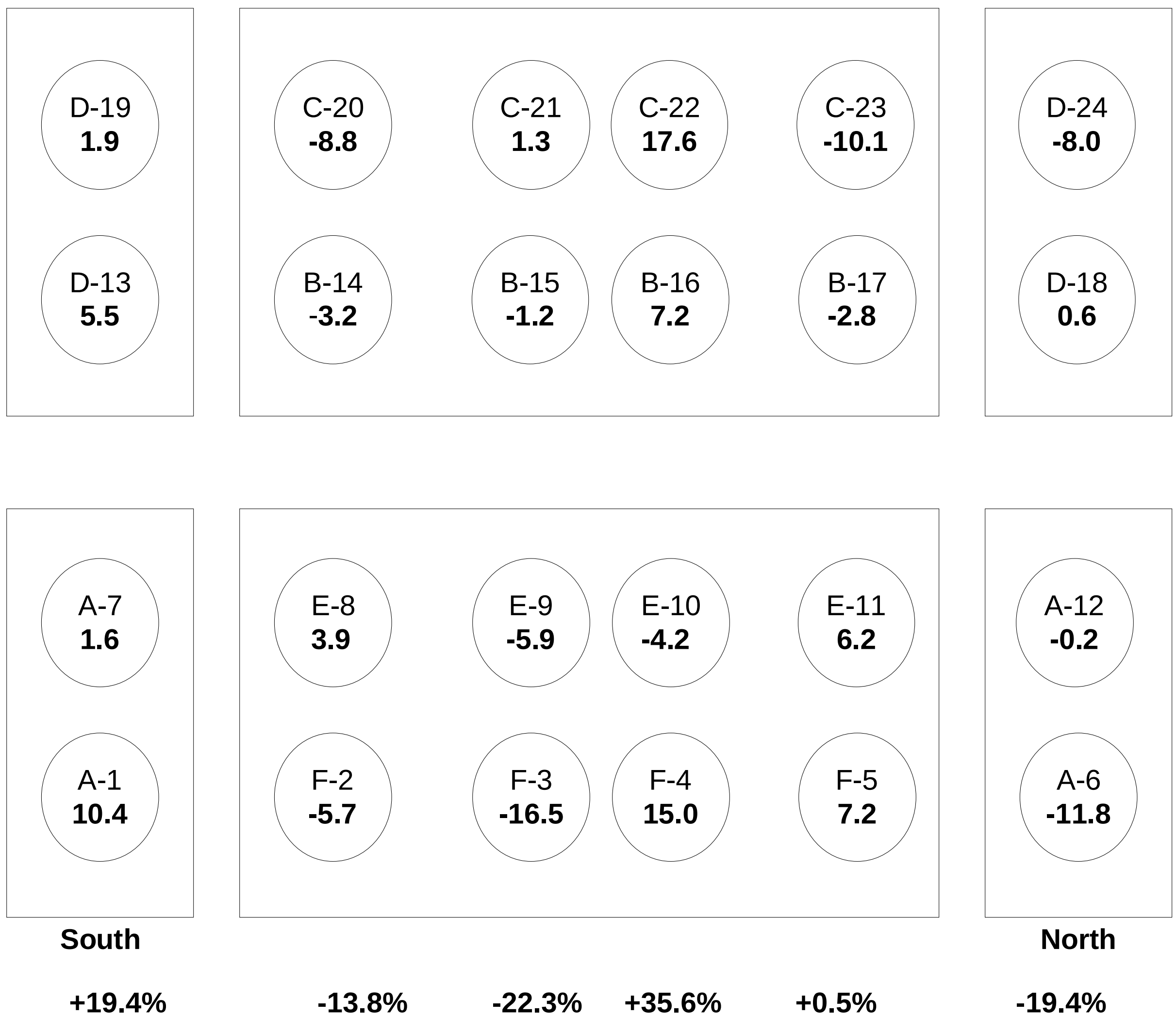
POST ORIFICE REPLACEMENT NO_c (ppm @ 3% O_2) PROFILE



BOILER TUNING CASE HISTORY

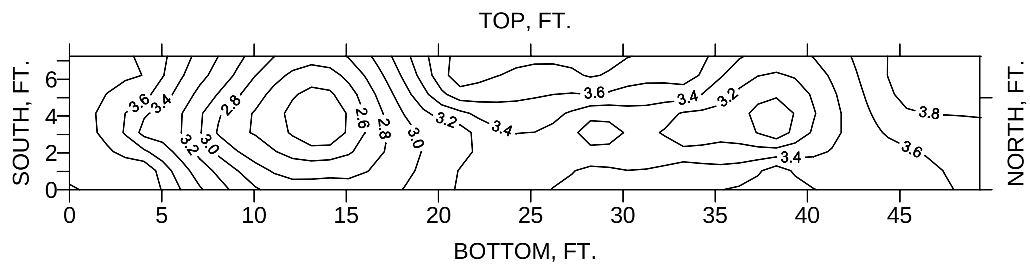
- **Boiler Configuration**
  - 260 MW Babcock & Wilcox, Front Wall-Fired
  - 24 Low-NO_x Burners (4 x 6), 6 Overfire Air Ports
  - Adjustable Coal Pipe Orifices, Dynamic Classifiers
- **Test Coal**
  - Blended Eastern and PRB
- **Post-Combustion NO_x Control**
  - Babcock & Wilcox SCR

BURNER FRONT COAL FLOW DISTRIBUTION

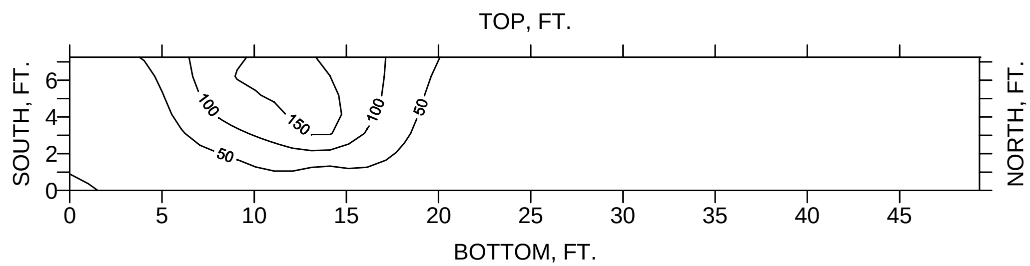


BASELINE BOILER EXIT EMISSIONS PROFILES

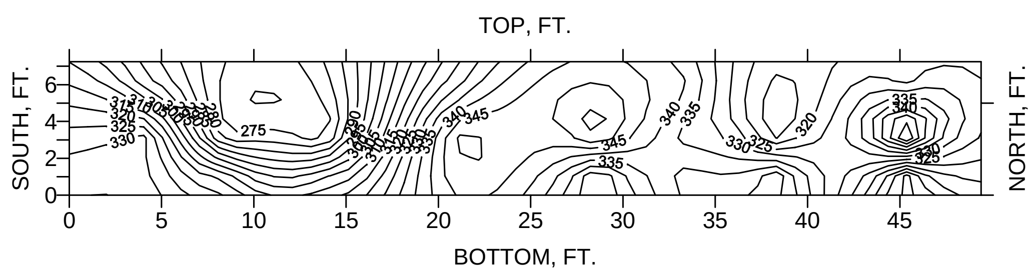
UNIT 2 - ECON. O2 CONTOURS
TEST MT01 - 277 MW, ALL MILLS, NORMAL O2 & SOFA



UNIT 2 - ECON. CO CONTOURS
TEST MT01 - 277 MW, ALL MILLS, NORMAL O2 & SOFA

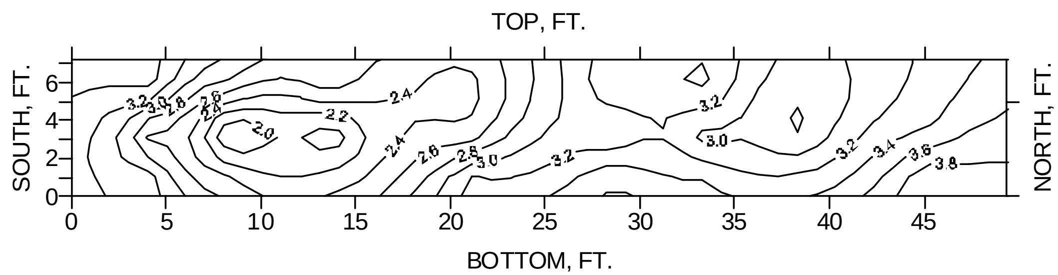


UNIT 2 - ECON. NO CONTOURS
TEST MT01- 277 MW. ALL MILLS, NORMAL O2 & SOFA

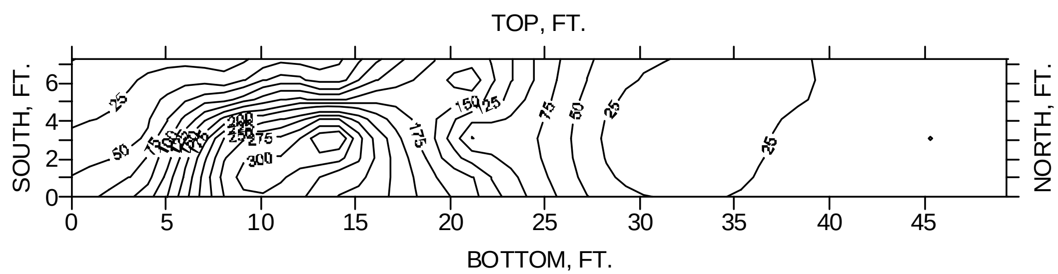


POST-TUNING BOILER EXIT EMISSIONS PROFILES

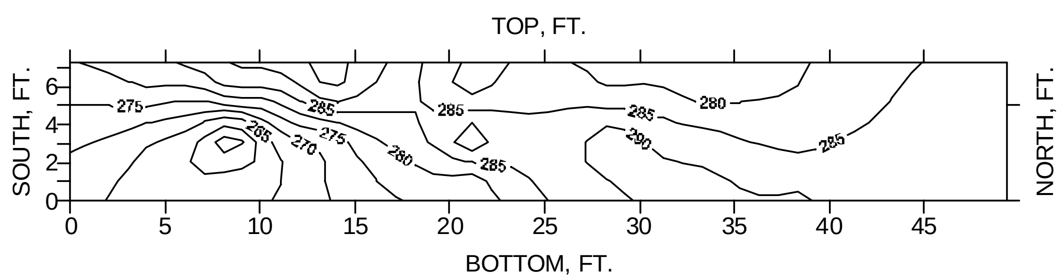
UNIT 2 - ECON. O2 CONTOURS APRIL 12th
TEST S21 - 265 MW, NORMAL O2 & SOFA, SCR BASELINE NO NH3



UNIT 2 - ECON. CO CONTOURS APRIL 12th
TEST S21 - 265 MW, NORMAL O2 & SOFA, SCR BASELINE NO NH3



UNIT 2 - ECON. NO CONTOURS APRIL 12th
TEST S21 - 265 MW, NORMAL O2 & SOFA, SCR BASELINE NO NH3



BOILER TUNING BENEFITS

- **NO_x Emissions**
  - "As-Found" NO_x = 0.44 lb/MMBtu
  - Post-Tuning NO_x = 0.38 lb/MMBtu
  - NO_x Reduction = 13.6%
  - Estimated NH_3 Flow Reduction = 16%

- **SCR Inlet NO_x Uniformity**
  - "As-Found" NO_x RMS = 9.2%
  - Post-Tuning NO_x RMS = 4.2%

BOILER TUNING BENEFITS (continued)

- **Boiler Efficiency**
  - "As-Found" Operating O_2 Level = 3.3%
  - Post-Tuning Operating O_2 Level = 2.9%
  - Fly Ash LOI Decrease from 10 to 15 percent to 7 percent
  - Approximate Boiler Efficiency Improvement = 1%

- **Boiler Operational Performance**
  - Reduced Ash Deposition, Less Frequent Sootblowing
  - Reduced Spray Flows, Larger Attemperation Margin
  - Improved Tube Metal Temperatures

BOILER TUNING BENEFITS (continued)

- **Lower Inlet NO_x to SCR**
  - Increased Compliance Margin with NO_x Regulations
  - Reduced Reagent Consumption, Cost
  - Potential to Accrue Valuable NO_x Credits
  - NH_3 Slip Less Sensitive to NH_3/NO_x Maldistributions
- **More Uniform Inlet NO_x Profile to SCR**
  - Inlet NO_x Probe Data More Representative
  - Less Impact of Mill Performance on NO_x Profile at AIG
- **Improved Boiler Performance**
  - Lower Operating O_2 Level, Increased Boiler Efficiency
  - Better Burner Air/Fuel Ratio, Reduced Slagging/Fouling, Lower LOI
  - Reduced Fuel Consumption and Secondary Emissions

OVERFIRE AIR (OFA) TUNING

- **Tangentially-Fired Boilers**
- **Wall-Fired Boilers**
- **Cyclone Boilers**
- **Other Designs**

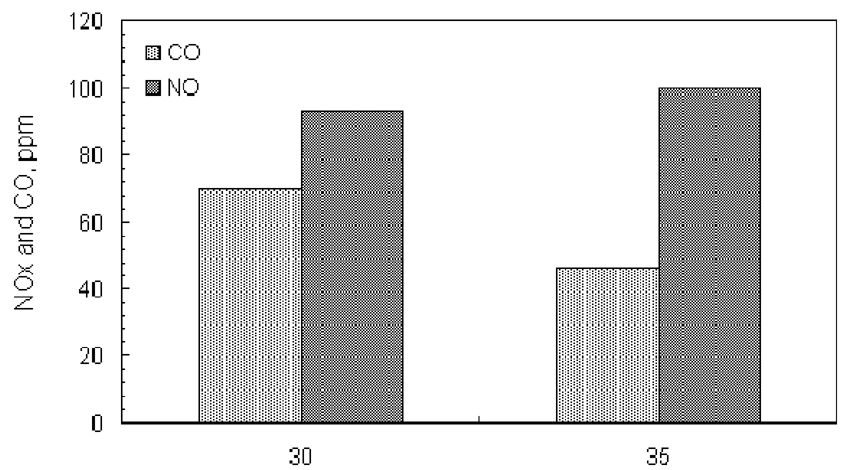
OFA INFLUENCE FACTORS (T-FIRED)

- **OFA Flow Rate**
- **CCOFA/SOFA Configuration**
- **SOFA Yaw Angle**
- **SOFA Bias (Between Levels and Corner-to-Corner)**
- **SOFA Flow Distribution to Corners**
- **SOFA Damper Schedule Over Load Range**
- **SOFA Tilt vs. Burner Tilt (included angle)**

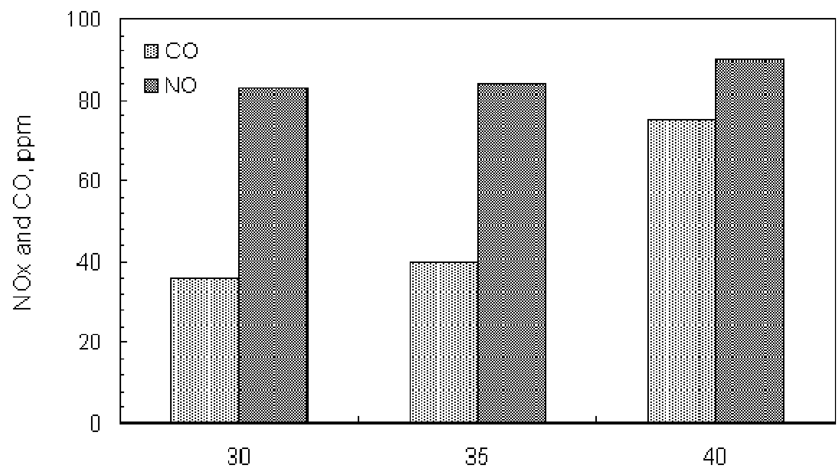
OFA TUNING CASE HISTORY

- **Boiler Configuration**
  - 240 MW Combustion Engineering, Twin Furnace
  - 32 Low-NO_x Burners, 16 each Furnace (4 Elevations)
  - Separated OFA, Two Levels
- **Test Coal**
  - 100% PRB

OFA MIXING AFFECTS CO, NO EMISSIONS

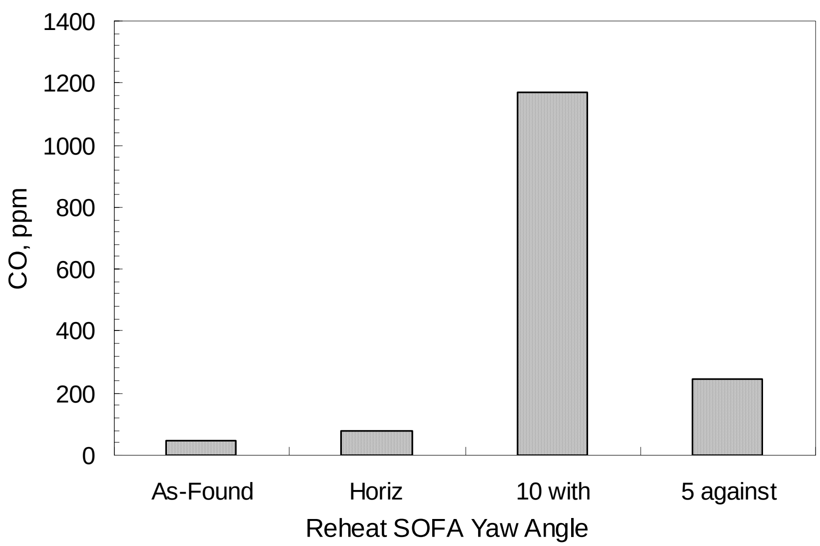


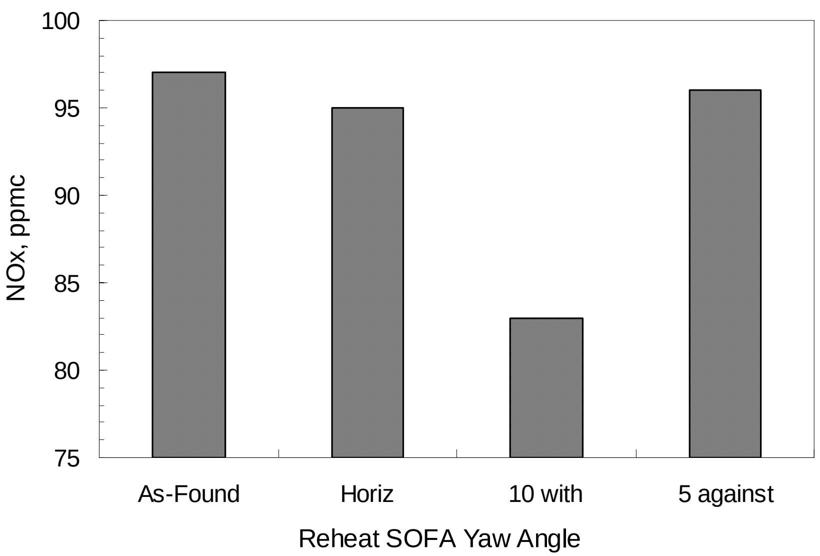
Reheat SOFA Dampers, %



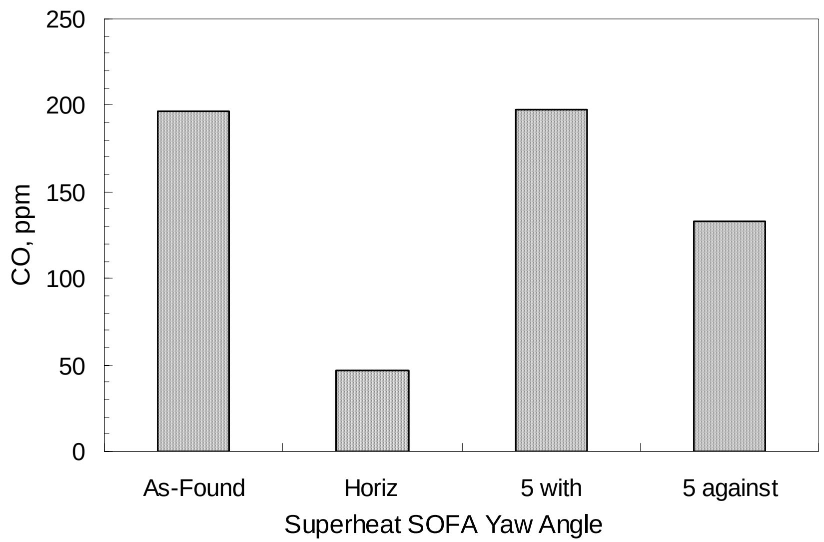
Superheat SOFA Dampers, %

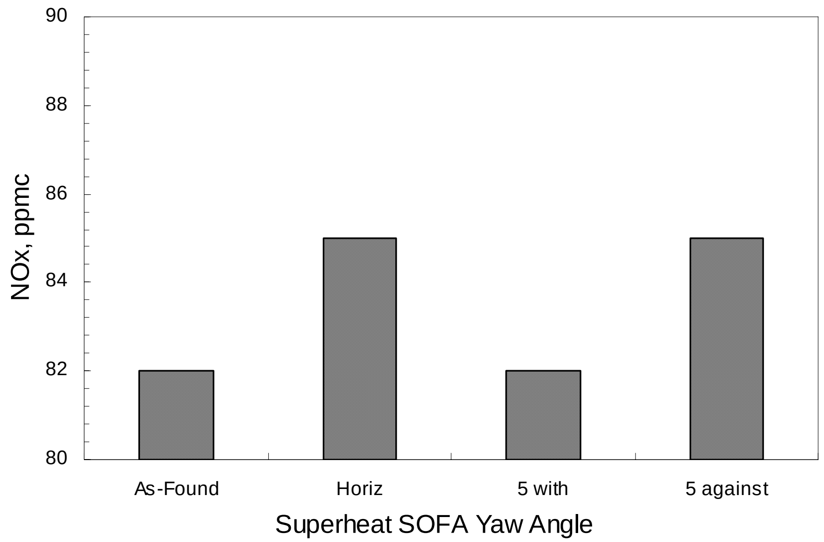
SOFA YAW ANGLE IMPACT ON CO EMISSIONS





FINE TUNING SOFA YAW ANGLE – PRB COALS





OFA TUNING CASE HISTORY

- **Boiler Configuration**
  - 155 MW Combustion Engineering, Divided Furnace
  - 24 Low-NO_x Burners, Three Elevations, 12 per Furnace
  - Advanced OFA, Four Compartments, Highly Staged
- **Test Coal**
  - 100% PRB
- **Instrumentation**
  - Direct Measurement of OFA Flow to Each Elevation and Each Corner

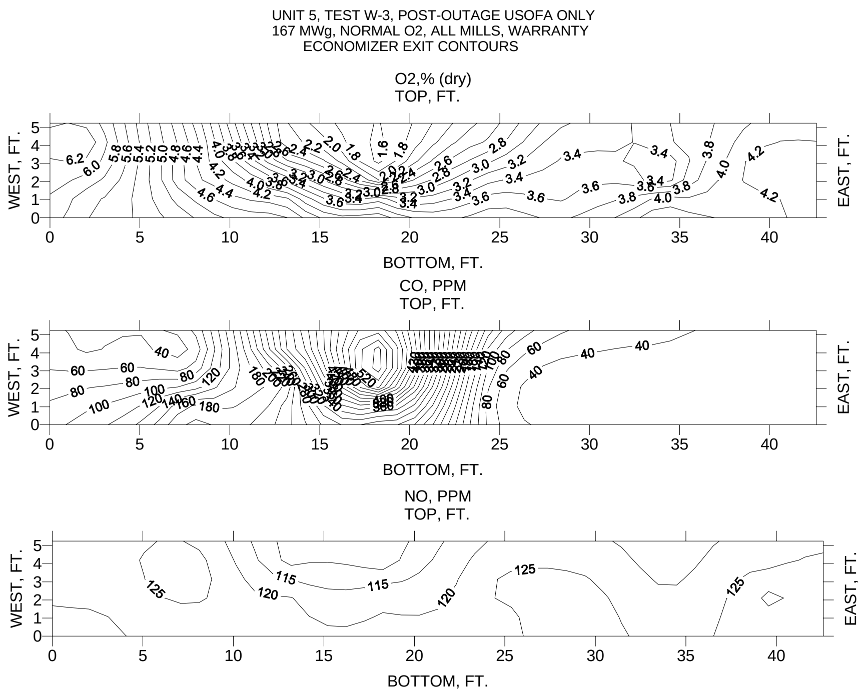
INITIAL COMBUSTION DIAGNOSTICS

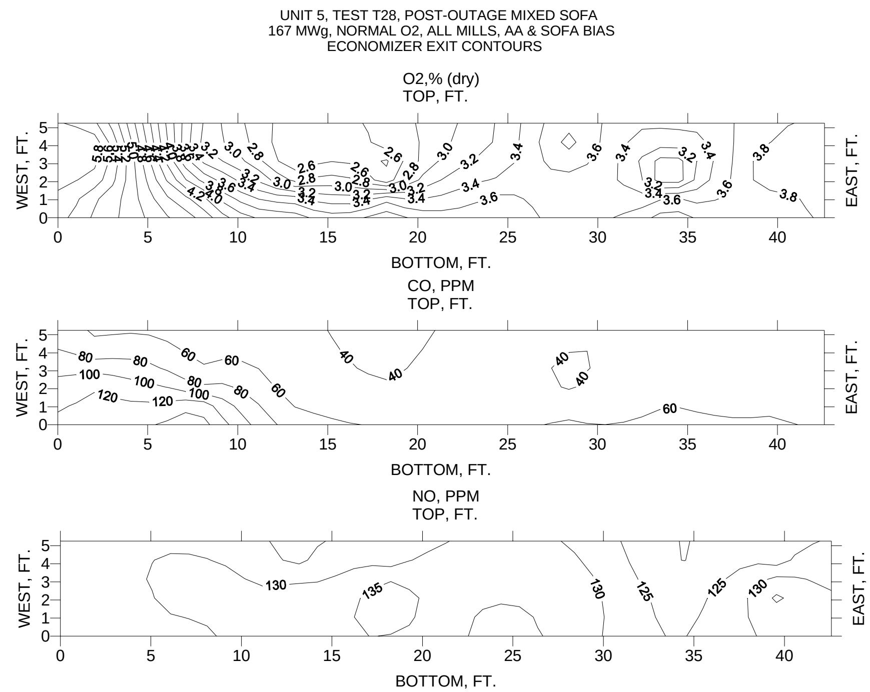
- **Inspection of OFA Dampers/Controls Indicated Proper Operation**
- **Economizer Profiles – Non-Uniform with High CO**
- **MCDA Combustion Profiles Indicated Stuck Damper – Corner #8**
- **OFA Damper Bias Tests Confirmed Non-Uniform OFA Flow**

INITIAL COMBUSTION DIAGNOSTICS (CONTINUED)

- **Balanced OFA to Each Furnace**
- **CO Dropped by 60%; LOI by 2 points**
- **Plant O_2 Probes in West Furnace Increased (1.5% to 2.5%)**
- **NO_x Emissions were Unchanged**

IMPACT OF STUCK OFA DAMPER

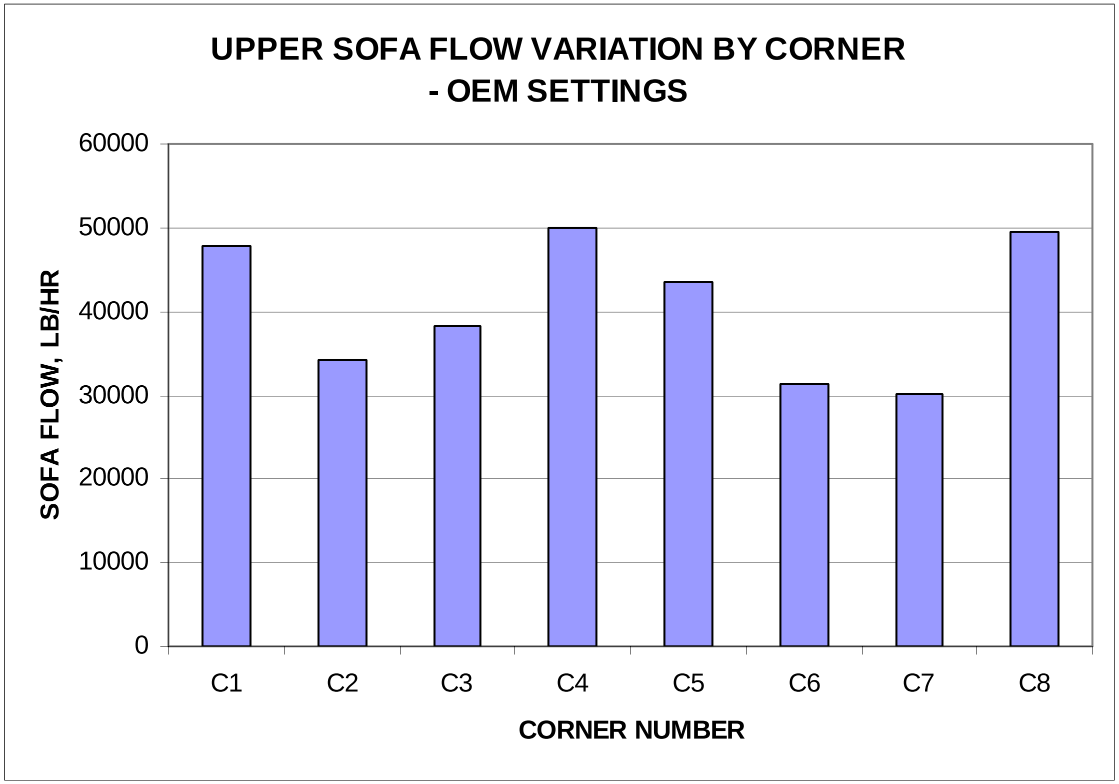




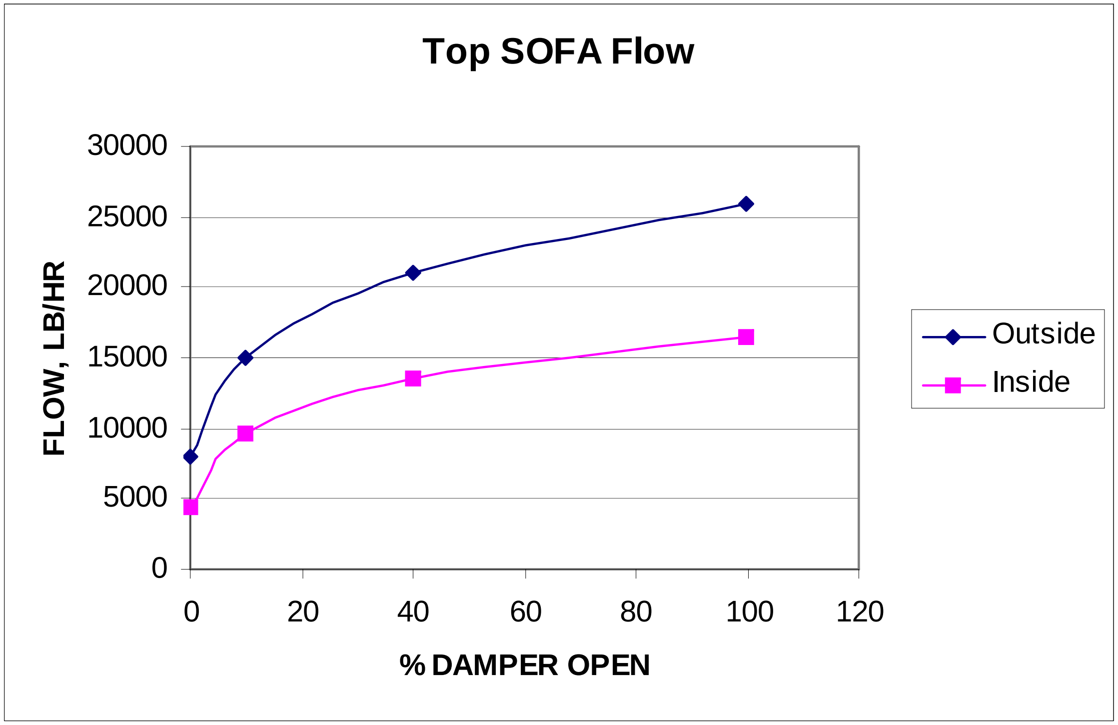
OBSERVATIONS FROM HIGH OFA DIAGNOSTIC TESTS

- **Distribution of OFA to Furnace Corners often is Uneven on Retrofit OFA Systems**
- **Direct Measurement of OFA Flow to Corners is Valuable in Tuning OFA Systems**
- **“Inside” Corners on T-Fired Divided Furnace Designs May Get Less OFA Flow than “Outside” Corners**
- **OFA Flow and Windbox Pressure Should be Monitored Over the Load Range to Confirm Desired Staging**
- **Modification to Plant O_2 Probe Locations May be Necessary**
- **Calculations and Display of OFA Staging on DCS is Recommended (not just damper position)**

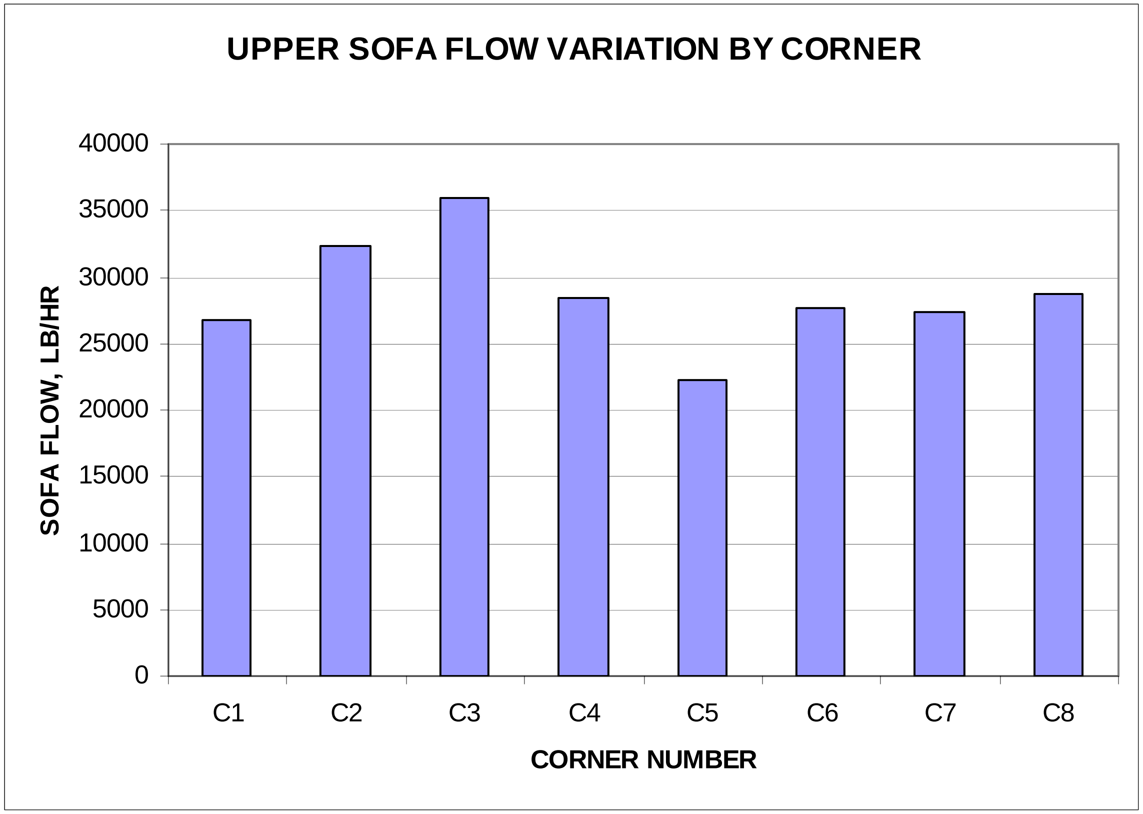
SOFA FLOW DISTRIBUTION OFTEN NOT EVEN



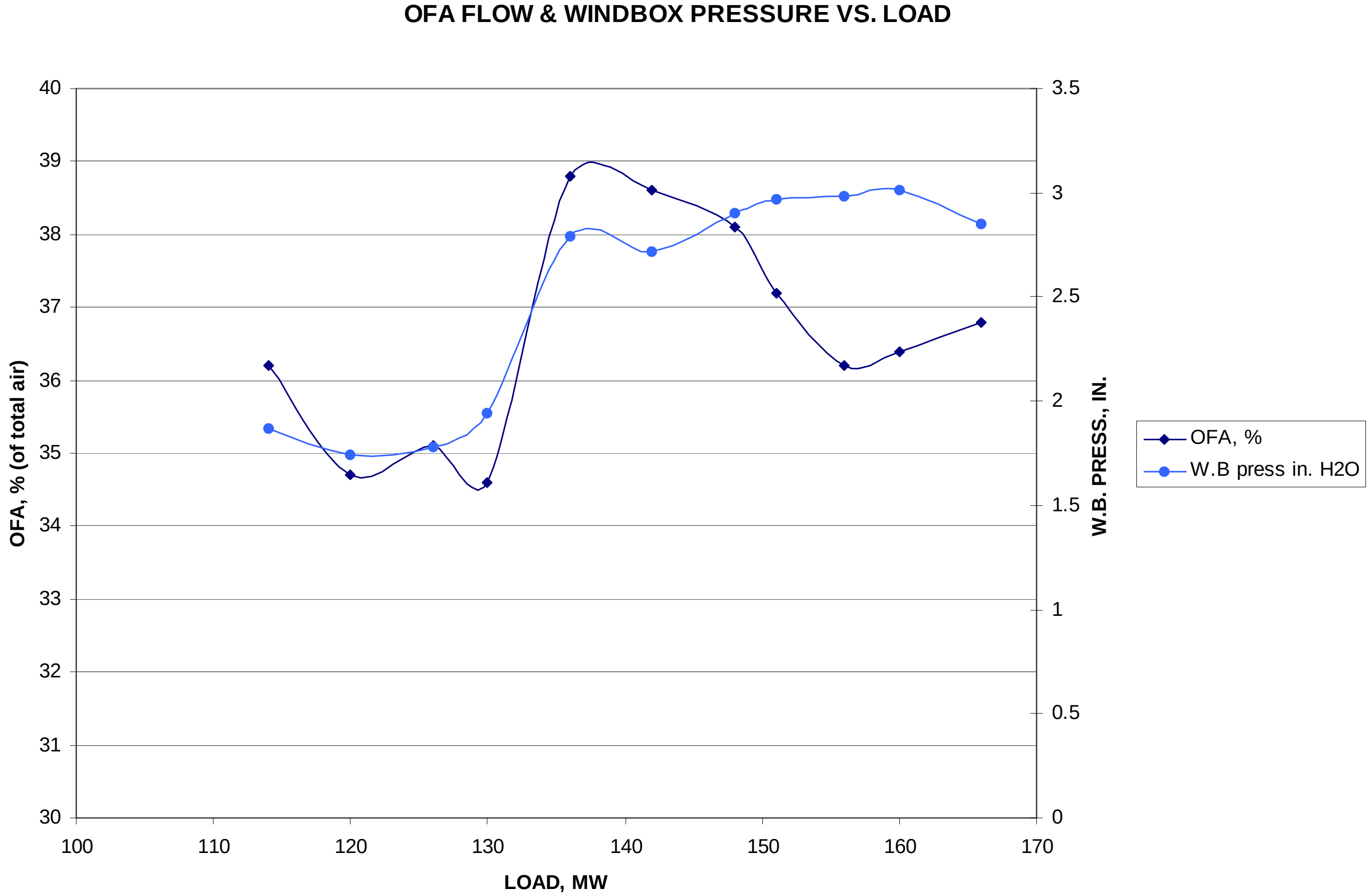
INSIDE CORNERS OF DIVIDED FURNACE STARVED



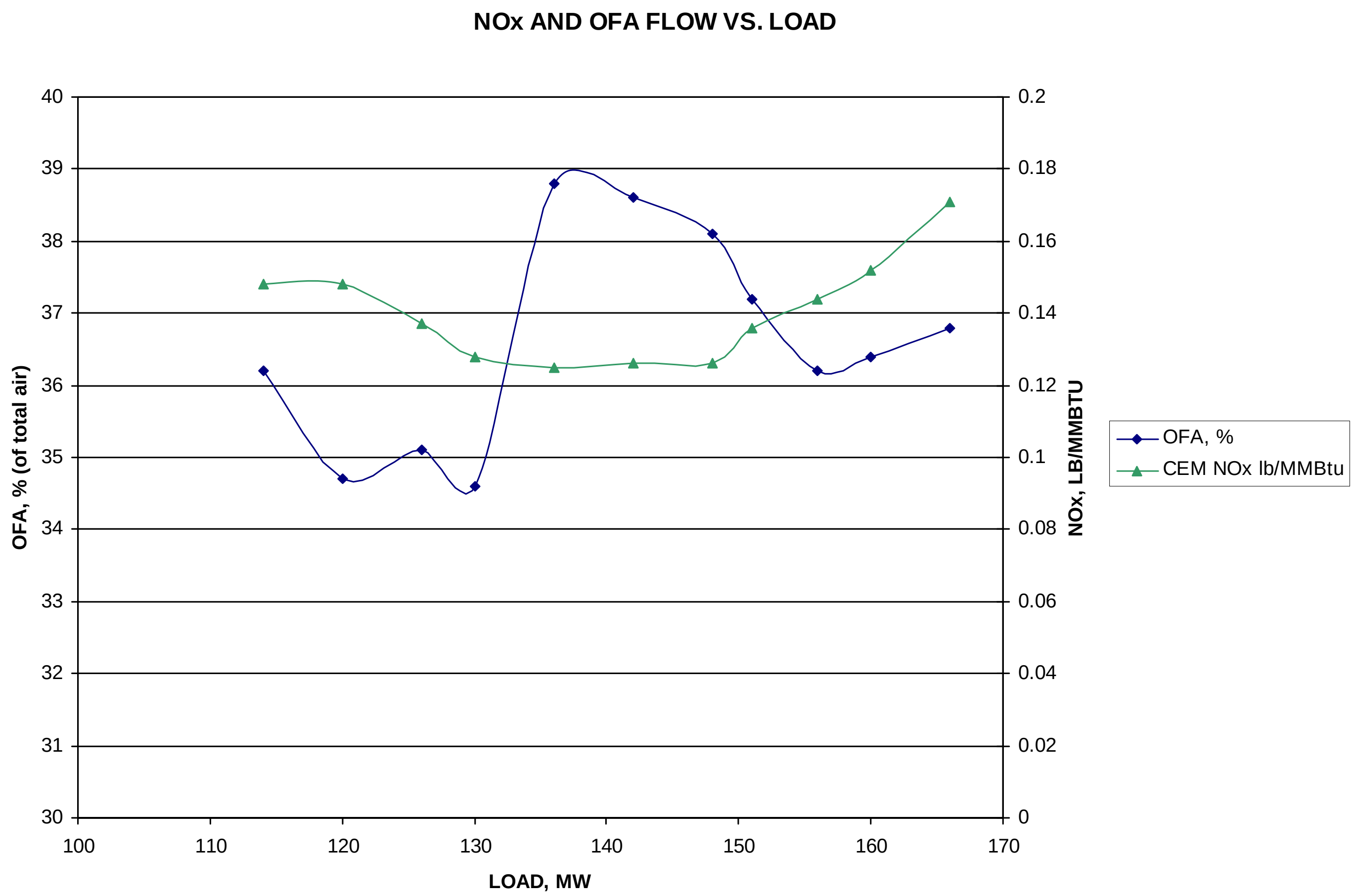
SOFA DAMPER BIAS REQUIRED FOR IMPROVED COMBUSTION



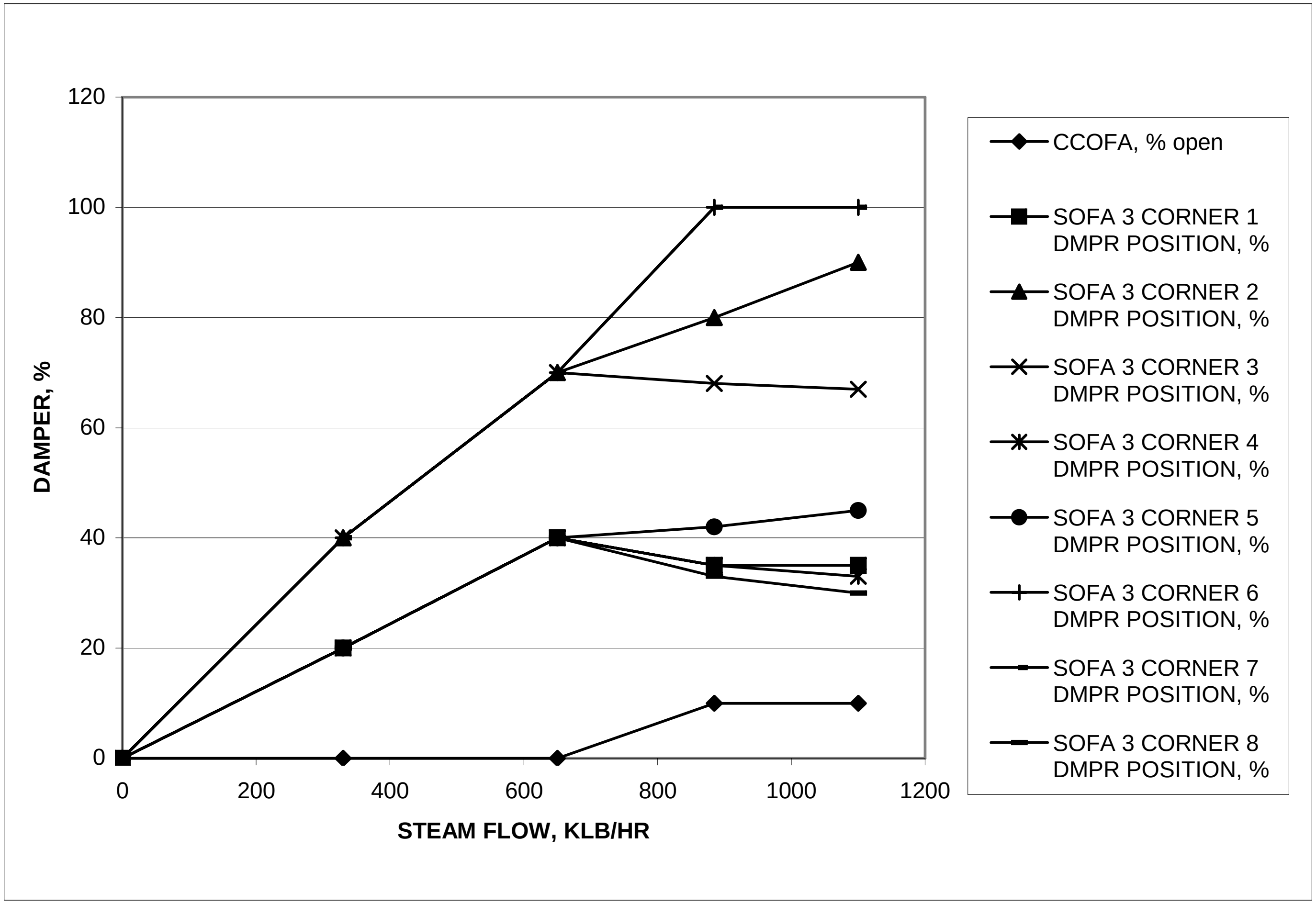
VARIATIONS IN OFA AND WINDBOX PRESSURE WITH LOAD



NO_x VARIATIONS WITH OFA FLOW AND LOAD



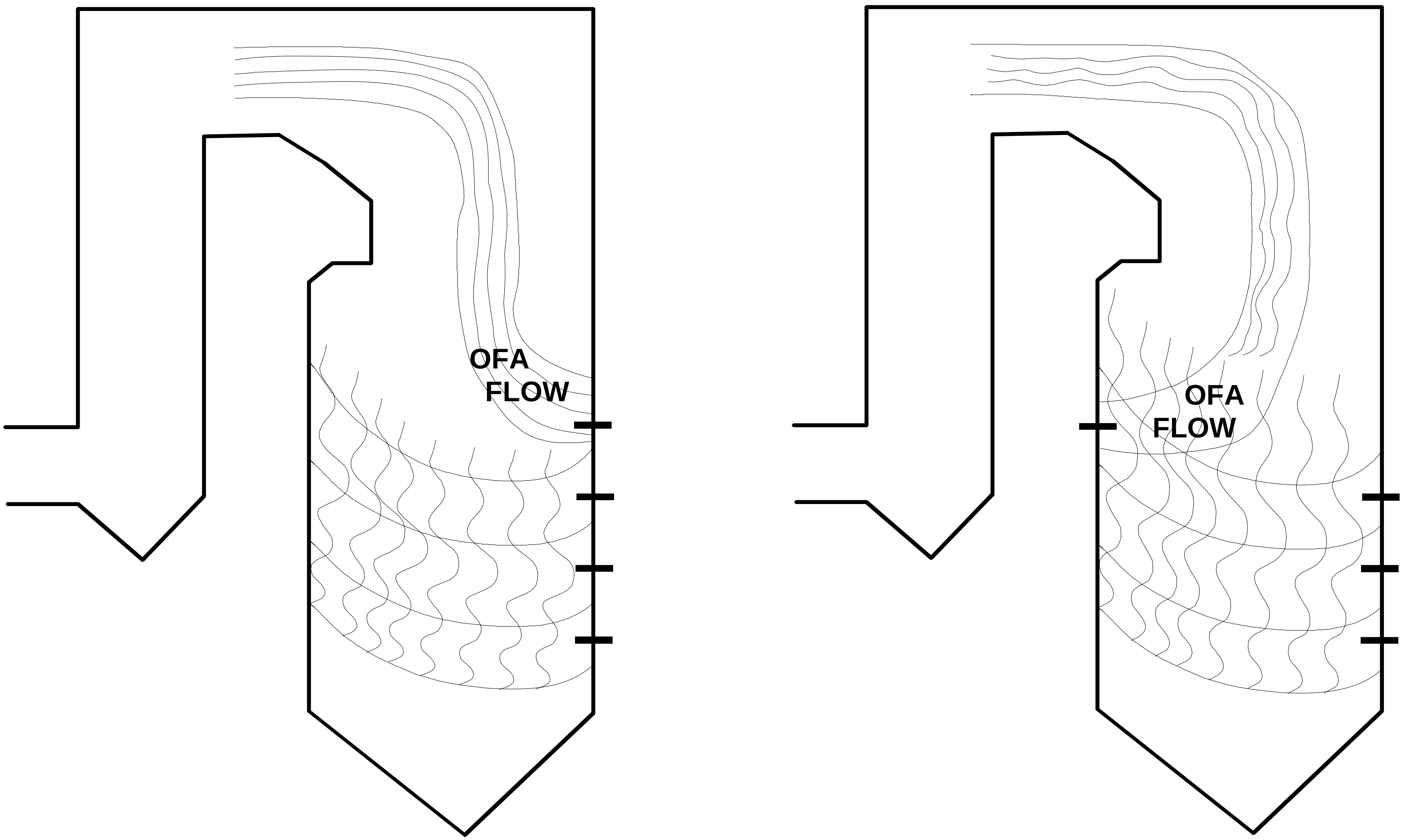
SEPARATE SOFA DAMPER SCHEDULES BY CORNER



OFA INFLUENCE FACTORS (WALL-FIRED)

- **OFA Flow Rate/Measurement**
- **Burner to OFA Spacing**
- **OFA Configuration**
  - Multiple Level
  - Location
  - Service Pattern
  - Wing Ports
- **OFA Port Swirl and Penetration Control**
- **Ash Deposits**

OFA OPTIONS FOR FRONT WALL-FIRED BOILERS



OFA TUNING – WALL-FIRED CASE HISTORY

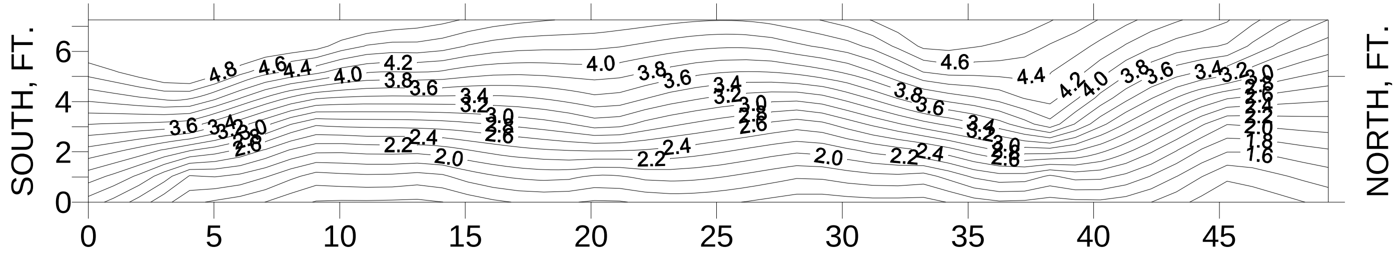
- B&W 225 MW – Front Wall-Fired
- 24 Low-NO_x Burners (4 rows x 6 wide)
- OFA Ports on Rear Wall for Improved Mixing
- OFA Ports Equipped with Manual Controls for Sleeve Damper Opening, Core Air Damper Position, and Spin Vane Setting
- Sleeve Damper Settings Used to Distribute OFA Flow. Core Air Damper and Spin Vanes Used to Control OFA Penetration and Mixing

PRELIMINARY OFA COMBUSTION DIAGNOSTIS

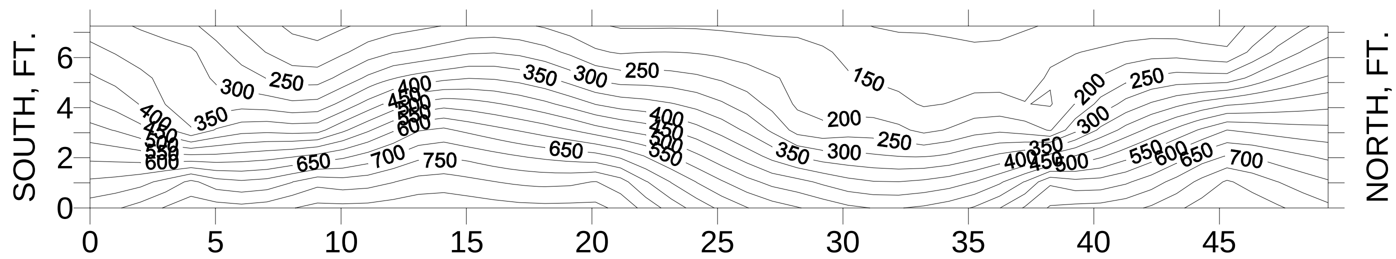
- **LNB's Tend to Have Longer Flames Than Original Burners**
- **Gas Flow from Lower Burner Rows "Hugs" Rear Wall of Furnace**
- **Economizer Emissions Profiles with Minimum SOFA Spin Show Large O_2, CO, and NO Gradients**
- **High SOFA Spin Provides Improved Mixing and Reduced CO Gradients**

EMISSION CONTOURS WITH MINIMAL SOFA SPIN

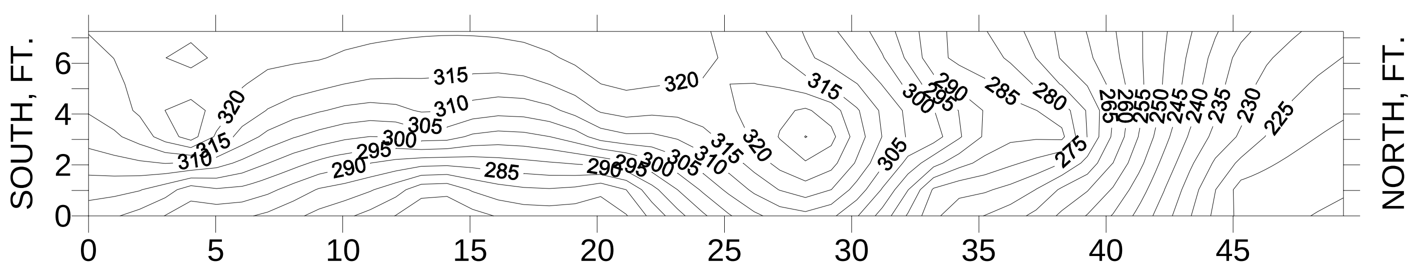
O2, CONTOURS, %



CO CONTOURS, PPM

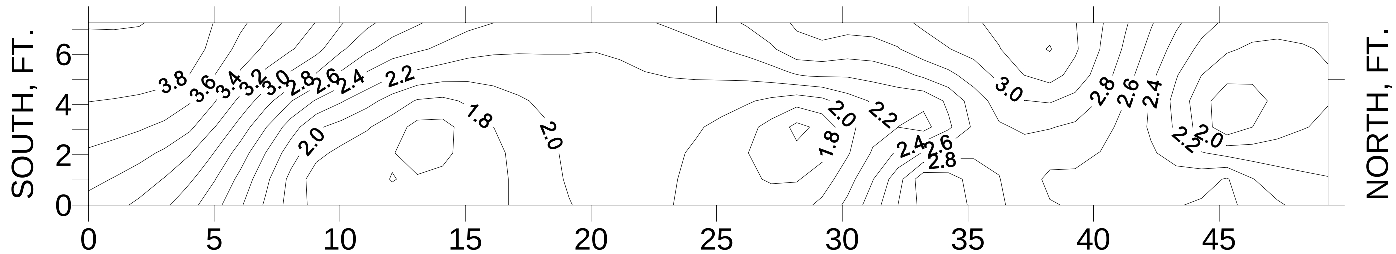


NO CONTOURS, PPM

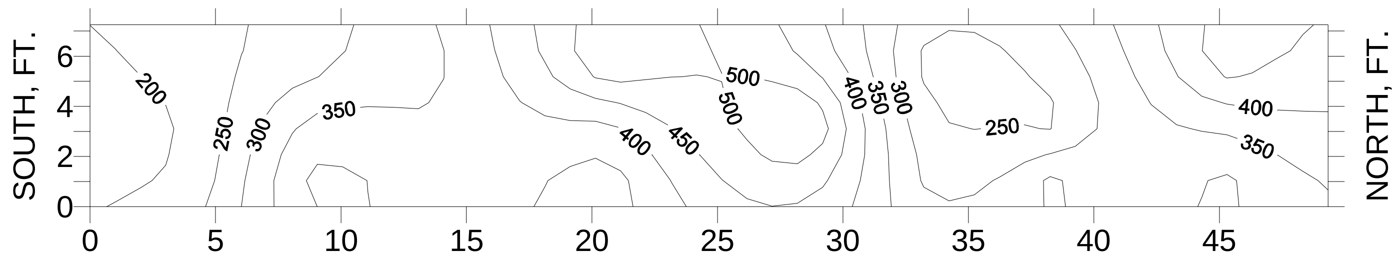


EMISSION CONTOURS WITH HIGH SOFA SPIN

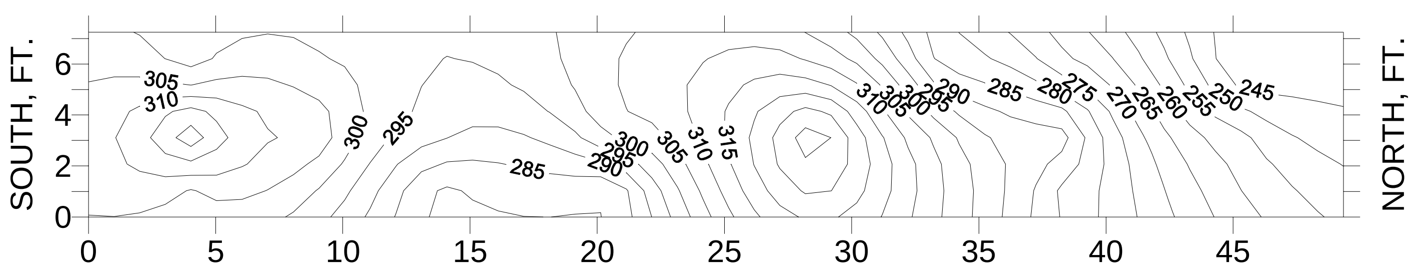
O2, CONTOURS, %



CO CONTOURS, PPM



NO CONTOURS, PPM



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RESULTS OF ADDITIONAL SOFA TUNING TESTS

- **Full-Load SOFA Parameter Range:**

SOFA Sleeve Position:	50% to 100% Open
SOFA Disk Position:	2 to 6 Inches
SOFA Spin Setting:	30 to 90 Degrees

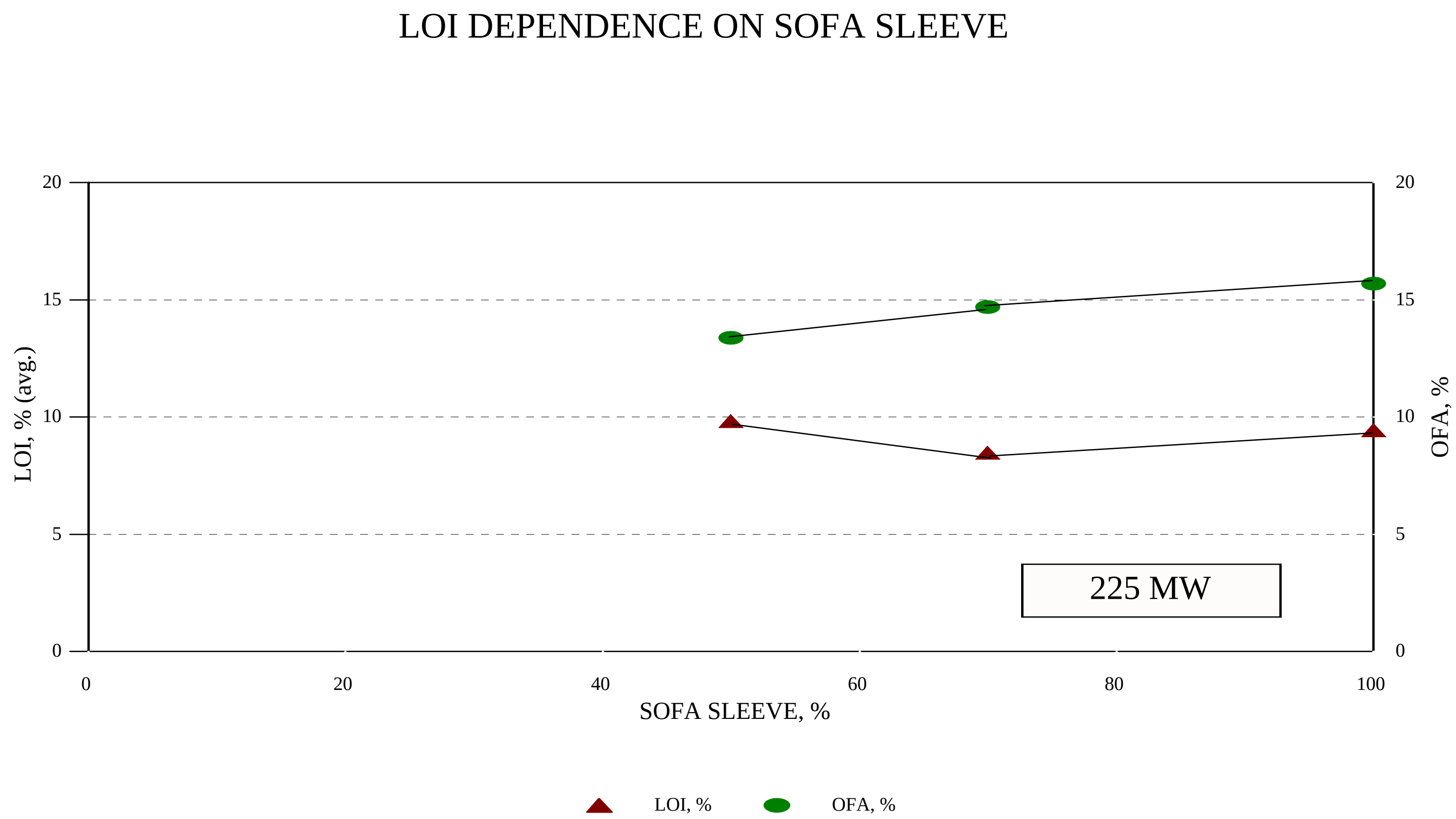
- **Reduced OFA Flow Reduced Penetration and Mixing Into Fuel Rich Burner Flow Up Rear Wall**

- **LOI Increased Due to Reduced Mixing, NO Increased Due to Reduced Staging**

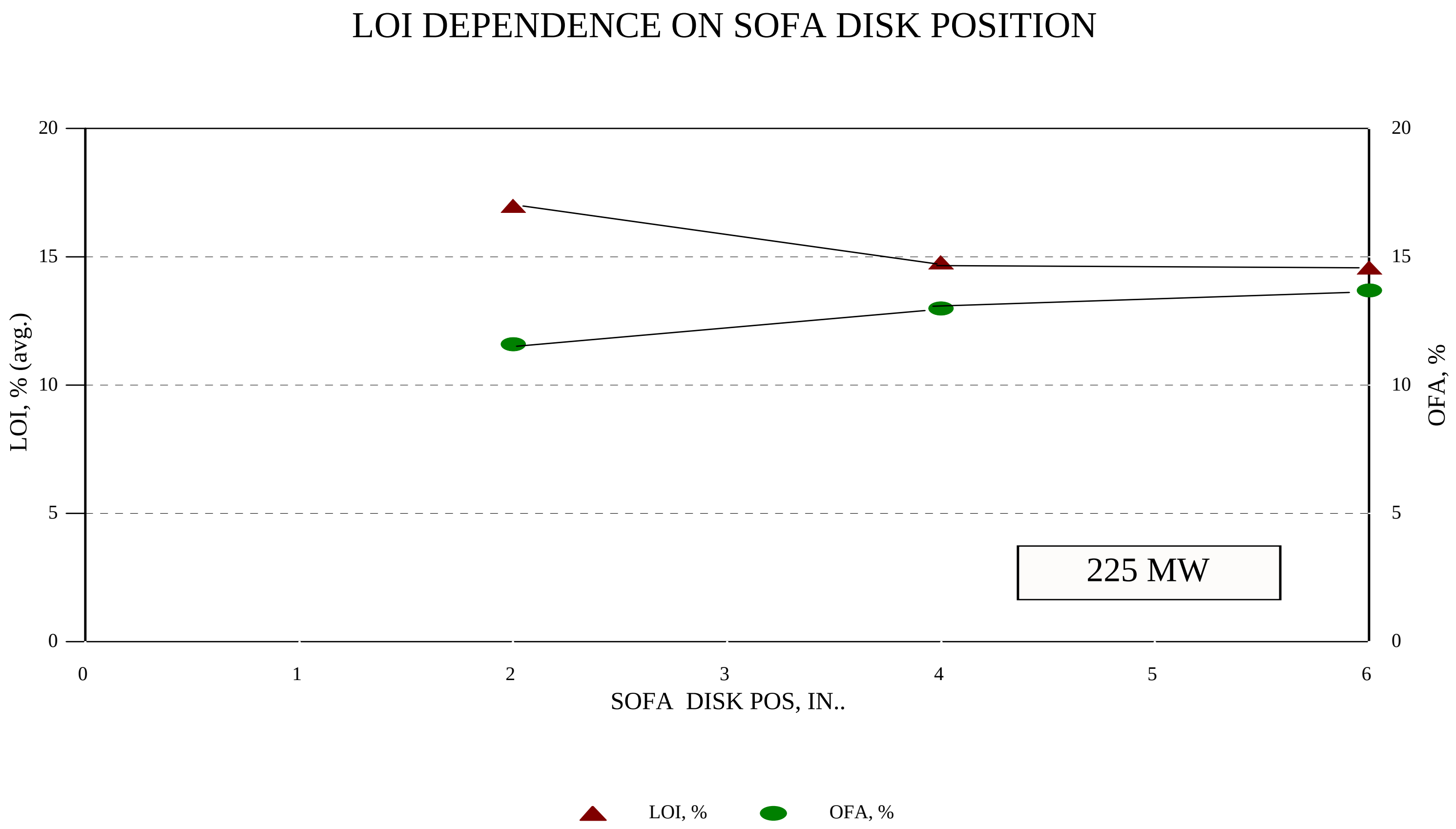
- **High OFA Spin Improves Mixing, Lowers CO, Allowing Lower O_2 Operation**

- **“Scrubbing Action” of High OFA Flow Benefits LOI In Spite of More Fuel Rich Lower Furnace**

LOI DEPENDENCE ON SOFA SLEEVE POSITION

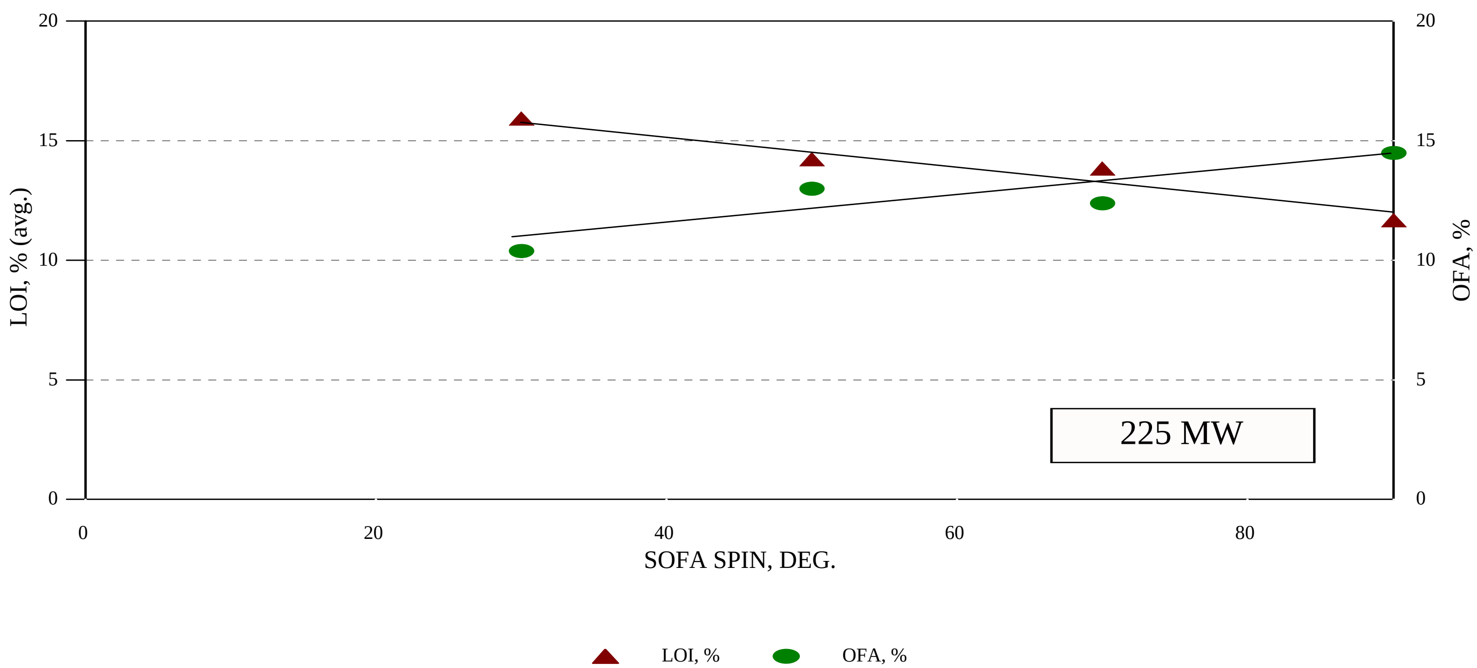


LOI DEPENDENCE ON SOFA DISK POSITION

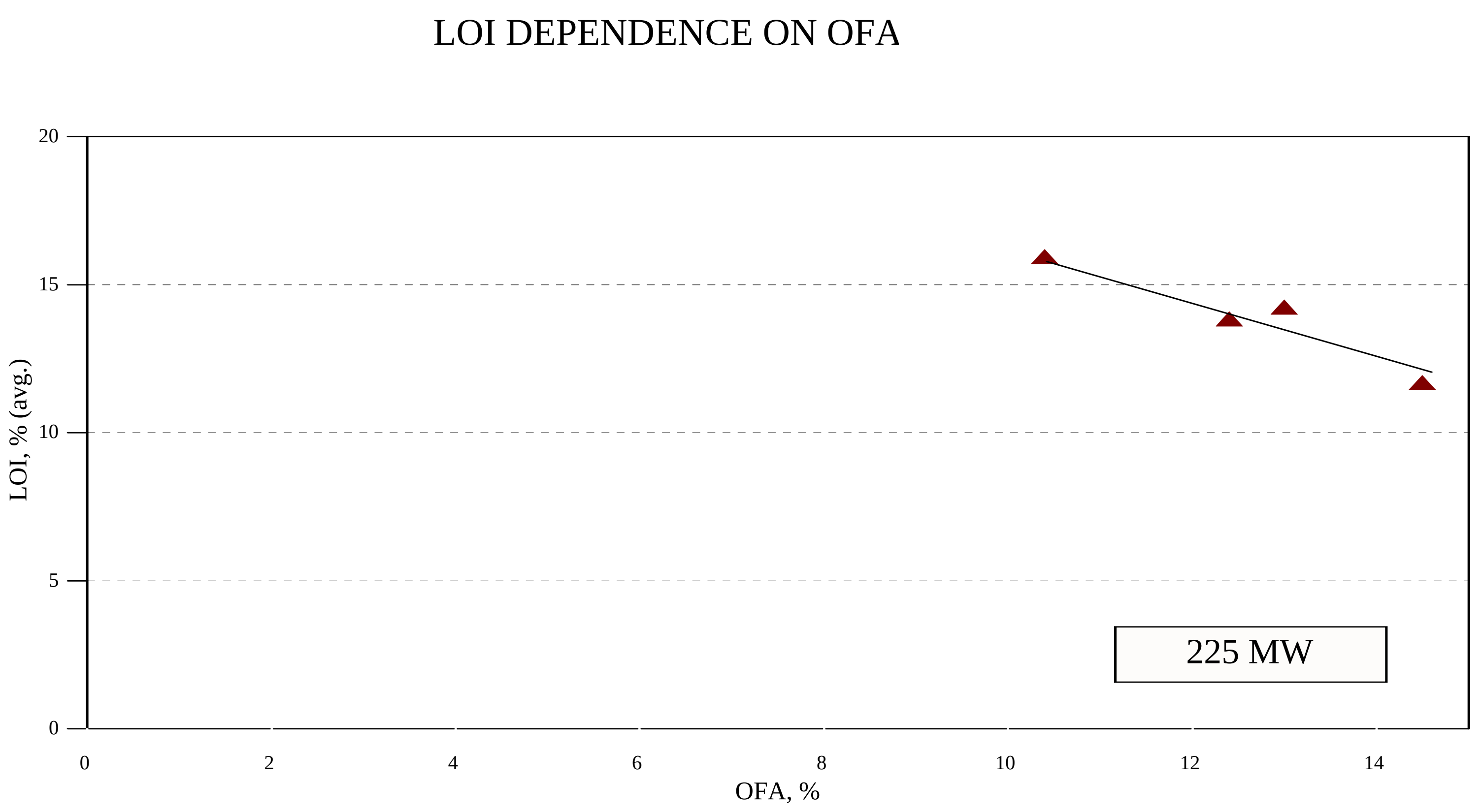


LOI DEPENDENCE ON SOFA SPIN

LOI DEPENDENCE ON SOFA SPIN



LOI DEPENDENCE ON OFA (VARIOUS SPIN COMBINATIONS)

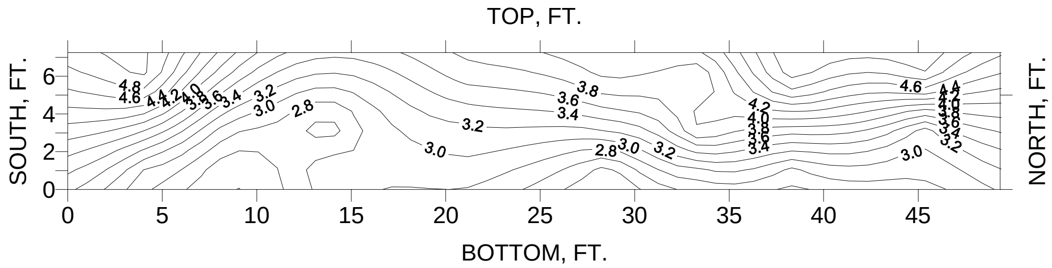


ASSOCIATED OFA TUNING CONSIDERATIONS

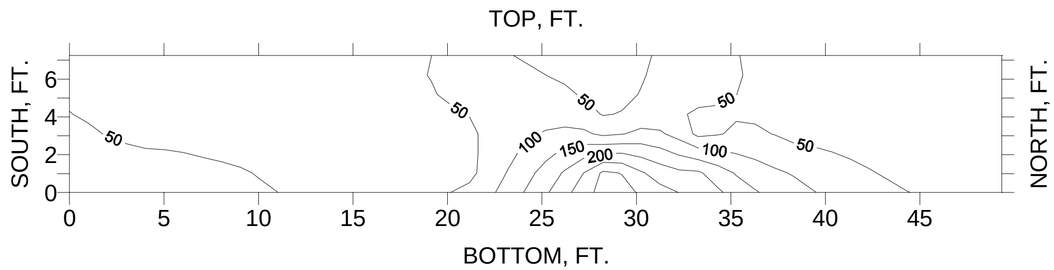
- **High Spin Vane Settings Do Benefit CO Reduction but Increased Back Pressure Restricts OFA Flow and Penetration**
- **Reduced OFA Penetration and Mixing Inhibits Carbon Burnout**
- **OFA Ports Adjustments to Minimize CO Do Not Simultaneously Reduce LOI As One Might Expect**
- **Tradeoffs Between OFA Settings, CO, LOI, and Operating O_2 Level are Likely Fuel Blend Dependent**
- **Test Coal Blend was 45% Western/55% Eastern**

FINAL TUNED SOFA CONTOURS

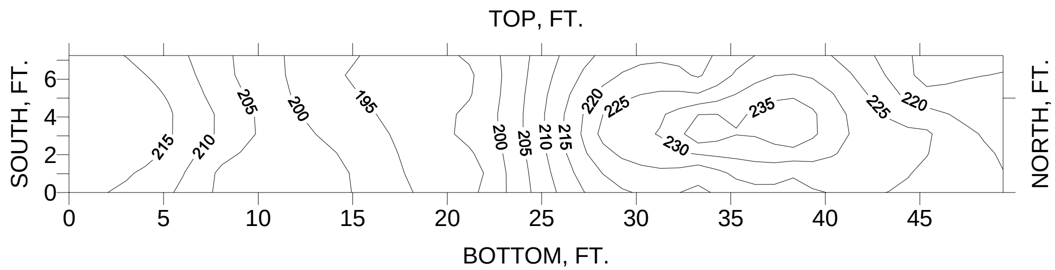
ECON. O2 CONTOURS
TEST T35 - 260 MW, ALL MILLS, SOFA=100%, TUNED



ECON. CO CONTOURS
TEST T35 - 260 MW, ALL MILLS, SOFA=100%, TUNED



ECON. NO CONTOURS
TEST T35 - 260 MW, ALL MILLS, SOFA=100%, TUNED



FERCo

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OTHER OFA TUNING ISSUES

- **Large Opposed Wall-Fired Boilers**
  - Two Elevations of OFA Better than One
  - "Checkerboard" Pattern Enhances Mixing

- **Calibrated OFA Flow Measurement to each Elevation is Important**

- **"Compartmentalized OFA Windbox" Designs Can Provide Added Flexibility**

- **Resolve Burner Pipe Coal Flow Balance Issues Before Tuning OFA**

CONCLUSIONS

- Balancing the Coal Flow Distribution to the Burners is an Important Prerequisite to Burner Tuning
- Fuel Rich Burners can Create "Hot Spots" of Incomplete Combustion, Ash Deposits, Slagging/Fouling and Corrosion
- Uniform Combustion is a Key Element in Efficient Low-NO_x Firing with Low-NO_x Burners and OFA Systems
- The Distribution of OFA Flow to the SOFA Ports is Frequently Not Even on Retrofit OFA Systems

CONCLUSIONS (continued)

- OFA Tuning is Often More Time Consuming Then Burner Tuning to Achieve Optimum Combustion
- Boiler and OFA Tuning Frequently Involves Adjustments to Equipment that is Not Automatically Controlled
- A Real-Time Multipoint Combustion Diagnostics Analyzer can Reduce Boiler Tuning Test Time by a Factor of Three to Five