Workshop I

Tuning LNB’s and OFA Systems

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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\textsubscript{x} Emissions Diagnostics and Tuning
  - Real-Time Burner Pipe Coal Flow Distribution Measurement
  - Real-Time Economizer Exit O\textsubscript{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 \textit{In situ} KnoxCheck Advanced Instrumentation System

- FERCo Uses Custom Proprietary Instrumentation in its NO\textsubscript{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\textsubscript{x}, CO, LOI and Operating O\textsubscript{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\textsubscript{x} Emissions
- Local Fuel-Rich Zones - High Ash Carbon Levels, CO, Slagging/Fouling
- Overall O\textsubscript{2} Level Dictated by Lowest O\textsubscript{2} Region
- Average O\textsubscript{2} is Higher than Necessary
BENEFITS OF UNIFORM COMBUSTION

- Lowest Overall LOI and NO\textsubscript{x} Emissions at Uniform Low O\textsubscript{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 O₂ 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, O₂, 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\textsubscript{x} Firing with PRB Coals (Derates and Outages can Occur)
- Air Rich Burners Produce NO\textsubscript{x} and Contribute to Boiler Efficiency Losses
- Low-NO\textsubscript{x} Burner Vendors Typically Require the Coal Flow Variation Between Burners Not Exceed ±10% for Each Pulverizer
TYPICAL IMPROVEMENT WITH ORIFICE MODIFICATIONS

PULVERIZER 1&2 COAL FLOW DEVIATIONS

165 MW Unit

BURNER PIPE NUMBER

PRE-RETROFIT

POST-RETROFIT
TYPICAL IMPROVEMENT WITH ORIFICE MODIFICATIONS (cont’d)

PULVERIZER 3&4 COAL FLOW DEVIATIONS

BURNER PIPE NUMBER

PRE-RETROFIT
POST-RETROFIT

165 MW Unit
## BENEFITS OF REPLACEMENT COAL PIPE ORIFICES

<table>
<thead>
<tr>
<th>Pulverizer Type</th>
<th>Initial Coal Flow Deviation</th>
<th>Final Coal Flow Deviation</th>
<th>Orifice Type</th>
<th>Location</th>
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<tr>
<td>B&amp;W F-W</td>
<td>± 11.7%</td>
<td>± 1.5%</td>
<td>Fixed</td>
<td>IL</td>
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<tr>
<td>B&amp;W C-E</td>
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<td>± 4.3%</td>
<td>Fixed</td>
<td>OH</td>
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<td>C-E B&amp;W</td>
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<td>± 3.2%</td>
<td>Adjustable</td>
<td>CT</td>
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<td>± 9.6%</td>
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<td>CT</td>
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<td>C-E B&amp;W</td>
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<td>± 4.1%</td>
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<td>CT</td>
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<tr>
<td>C-E C-E</td>
<td>± 32.4%</td>
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<td>CT</td>
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<tr>
<td>C-E C-E</td>
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<td>± 7.7%</td>
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<tr>
<td>C-E C-E</td>
<td>± 38.2%</td>
<td>± 8.3%</td>
<td>Fixed</td>
<td>MI</td>
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<td>B&amp;W B&amp;W</td>
<td>± 22.8%</td>
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<td>OH</td>
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<td>± 11.3%</td>
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<td>OH</td>
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<td>F-W F-W</td>
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<td>± 4.8%</td>
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<td>CT</td>
</tr>
<tr>
<td>F-W C-E</td>
<td>± 12.3%</td>
<td>± 3.6%</td>
<td>Fixed</td>
<td>CT</td>
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</table>
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

D-19 1.9
D-13 5.5
C-20 -8.8
C-21 1.3
C-22 17.6
C-23 -10.1
B-14 -3.2
B-15 -1.2
B-16 7.2
B-17 -2.8
D-24 -8.0
D-18 0.6

A-7 1.6
A-1 10.4
E-8 3.9
E-9 -5.9
E-10 -4.2
E-11 6.2
F-2 -5.7
F-3 -16.5
F-4 15.0
F-5 7.2
A-12 -0.2
A-6 -11.8

North

South

+19.4% -13.8% -22.3% +35.6% +0.5%

-19.4%
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
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\textsubscript{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

- CO emissions:
  - As-Found: Low
  - Horiz: Low
  - 10 with 5 against: Low

- NOx emissions:
  - As-Found: High
  - Horiz: High
  - 10 with 5 against: Low
FINE TUNING SOFA YAW ANGLE – PRB COALS

CO, ppm

NOx, ppmc

As-Found  Horiz  5 with  5 against

Superheat SOFA Yaw Angle
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

UNIT 5, TEST WI-3, POST-OUTAGE USOFA ONLY
167 MW, NORMAL O2, ALL MILLS, WARRANTY
ECONOMIZER EXIT CONTOURS

UNIT 5, TEST T28, POST-OUTAGE MIXED SOFA
167 MW, NORMAL O2, ALL MILLS, AA & SOFA BIAS
ECONOMIZER EXIT CONTOURS
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

UPPER SOFA FLOW VARIATION BY CORNER
- OEM SETTINGS

SOFa FLOW, LB/HR

CORNER NUMBER

C1 C2 C3 C4 C5 C6 C7 C8
INSIDE CORNERS OF DIVIDED FURNACE STARVED

Top SOFA Flow

FLOW, LB/HR

% DAMPER OPEN

Outside

Inside

FLOW, LB/HR

% DAMPER OPEN

0

20

40

60

80

100

120

0

5000

10000

15000

20000

25000

30000
SOFA DAMPER BIAS REQUIRED FOR IMPROVED COMBUSTION

UPPER SOFA FLOW VARIATION BY CORNER

<table>
<thead>
<tr>
<th>CORNER NUMBER</th>
<th>SOFA FLOW, LB/HR</th>
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</thead>
<tbody>
<tr>
<td>C1</td>
<td>25000</td>
</tr>
<tr>
<td>C2</td>
<td>30000</td>
</tr>
<tr>
<td>C3</td>
<td>40000</td>
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<tr>
<td>C4</td>
<td>35000</td>
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<tr>
<td>C5</td>
<td>30000</td>
</tr>
<tr>
<td>C6</td>
<td>25000</td>
</tr>
<tr>
<td>C7</td>
<td>20000</td>
</tr>
<tr>
<td>C8</td>
<td>15000</td>
</tr>
</tbody>
</table>
VARIATIONS IN OFA AND WINDBOX PRESSURE WITH LOAD

OFA FLOW & WINDBOX PRESSURE VS. LOAD

LOAD, MW

OFA, % (of total air)

W.B. PRESS., IN.

OFA, %

W.B press in. H2O

LOAD, MW
NO\textsubscript{x} VARIATIONS WITH OFA FLOW AND LOAD

![Graph showing NO\textsubscript{x} and OFA flow vs. load.](image)

- **X-axis**: LOAD, MW
- **Y-axis**: OFA, % (of total air)
- **Legend**:
  - OFA, %
  - CEM NO\textsubscript{x} lb/MMBtu

**Key Observations**:
- The graph illustrates the variations in NO\textsubscript{x} and OFA flow with respect to load.
- There are distinct peaks and troughs indicating changes in NO\textsubscript{x} and OFA flow at different load levels.

*Note: Detailed analysis and interpretation of the data points would require additional context from the source document.*
SEPARATE SOFA DAMPER SCHEDULES BY CORNER

![Graph showing steam flow and damper positions for different SOFA corners.]

- CCOFA, % open
- SOFA 3 CORNER 1 DMPR POSITION, %
- SOFA 3 CORNER 2 DMPR POSITION, %
- SOFA 3 CORNER 3 DMPR POSITION, %
- SOFA 3 CORNER 4 DMPR POSITION, %
- SOFA 3 CORNER 5 DMPR POSITION, %
- SOFA 3 CORNER 6 DMPR POSITION, %
- SOFA 3 CORNER 7 DMPR POSITION, %
- SOFA 3 CORNER 8 DMPR POSITION, %
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 TUNING – WALL-FIRED CASE HISTORY

- B&W 225 MW – Front Wall-Fired

- 24 Low-$\text{NO}_x$ 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
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
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

LOI DEPENDENCE ON SOFA SLEEVE POSITION

D.E. KARN UNIT 2 - TUNE (2/2000)

225 MW
LOI DEPENDENCE ON SOFA DISK POSITION

- LOI, % (avg.)
- OFA, %
- SOFA DISK POS, IN.

LOI DEPENDENCE ON SOFA DISK POSITION

D.E. KARN UNIT 2 - TUNE (2/2000)

225 MW
LOI DEPENDENCE ON SOFA SPIN

LOI DEPENDENCE ON SOFA SPIN

225 MW
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 O₂ 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
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 Than 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