REINHOLD ENVIRONMENTAL Ltd.

2011 NOx-Combustion Round Table & Expo Presentation

February 7-8, 2011, in Birmingham, AL / Hosted by Southern Company

Mill System Effects

Mill System – Key Parameters Effecting Low NO_X Combustion

- Primary Air (PA) Flow Balance to burners
- Coal Flow Balance to burners
- Coal Fineness
- Primary Air to Fuel Ratio
- Mills in or out of service
- Effects on CO and UBC are more pronounced than NO_X emissions

Importance of PA Flow Measurement in Mill System

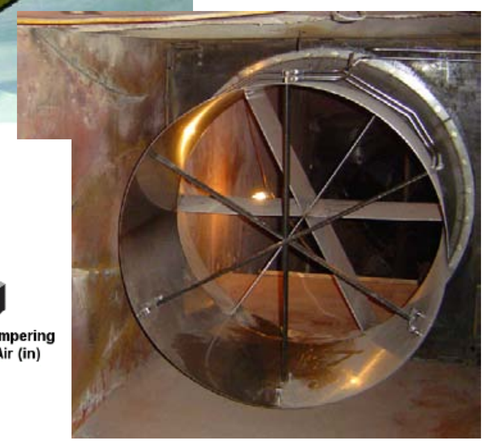
- Implement proper PA flow characterization
- Integrated with LNB design
- Optimize the Primary Air / Coal Ratio throughout boiler load range
- Input for PA flow control
- Diagnosis for abnormal mill operation
  - Pluggage
  - burner line layout
  - erosion

Approaches of PA Flow Measurement

- Clean Air Basis
  - Coal pipe traverses with std. pitot probe and Mill Off Line
  - Primary Air Duct traverse with a s-type probe with the mill in operation
  - Airflow measuring devices such as Venturi, Pitot Array, ETC.
- Dirty Air Basis
  - Coal pipe traverses using dirty air probe with mill operating
  - On-line permanent/semi-permanent probe system
- LNB Requirements
  - Typically ±15% or less

PA Flow Measurement on line and real-time

- Clean air basis measurement in PA duct
  - Straightening device may be required to evenly profile airflow and temperature distribution
  - CFD modeling may be required to design and locate Straightening device for complex PA duct configurations
  - An array of probes with differential pressure lines separately manifolded for fully averaged and representative airflow sampling
- Burner coal flow can be "matched" with airflow adjustment .
  - Primary air has to be adjusted / set to accommodate the heaviest burner line.
  - With adjusted burner lines, primary airflow can optimized.



Addressing Coal Flow Balance

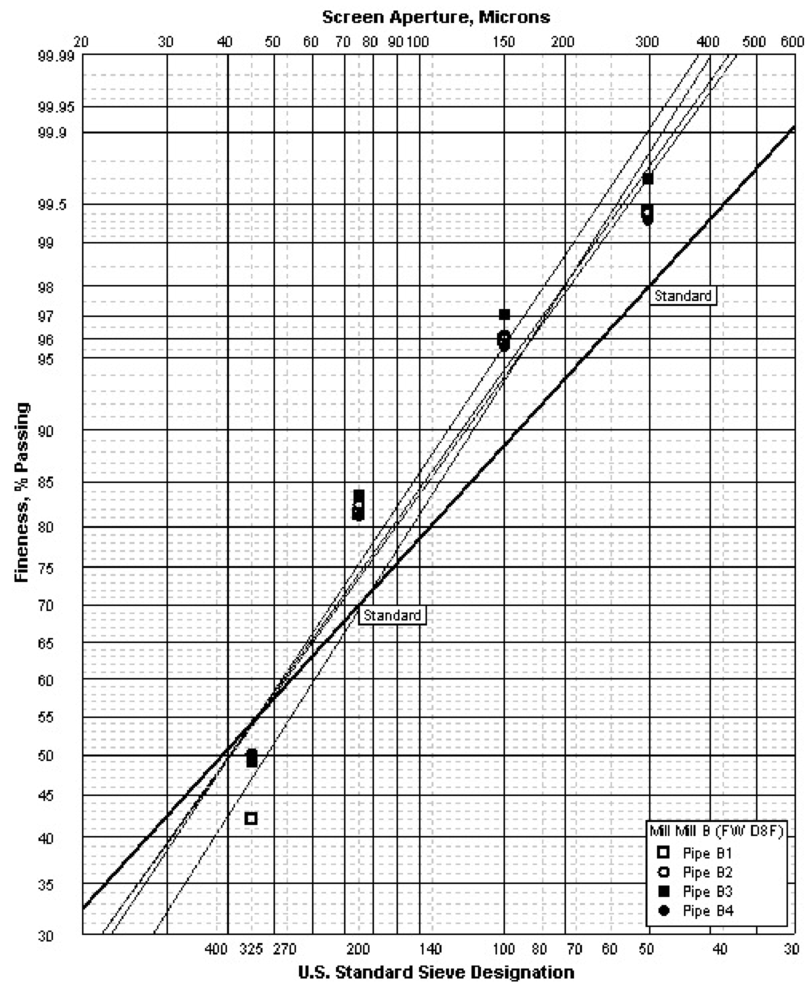
- Characterize the system performance
- Determine the amount of imbalance present
- Utilize coal balancing devices with on-line adjustment
  - Variable orifices
  - Coal Flow distributors
  - Classifier Adjustments
  - Classifier Inlet or Outlet distribution devices
  - Dynamic Classifiers
- Re-Characterize the system balance

Coal Line Balancing Impacts on Emissions

- Pre NSPS burners could maintain good repeatable performance with variations of ±20%
- LNB typically require a coal pipe-to-pipe distribution of ±15% or less
- To achieve the best possible combustion emissions less than ±5% deviation pipe-to-pipe coal flow is ideal

Coal Fineness Basics

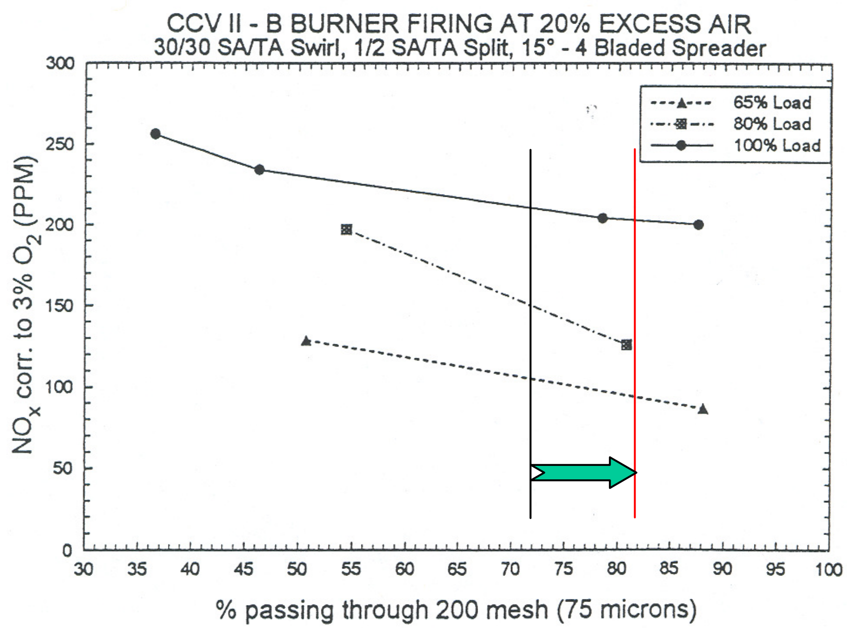
- Rosin-Rambler Plots
- Minimum fineness requirement
  - 98% passing 50 mesh
  - 70% passing 200 mesh
- Average Mill Fineness versus Coal Pipe fineness
- One coal pipe with poor fineness can have an effect on emissions

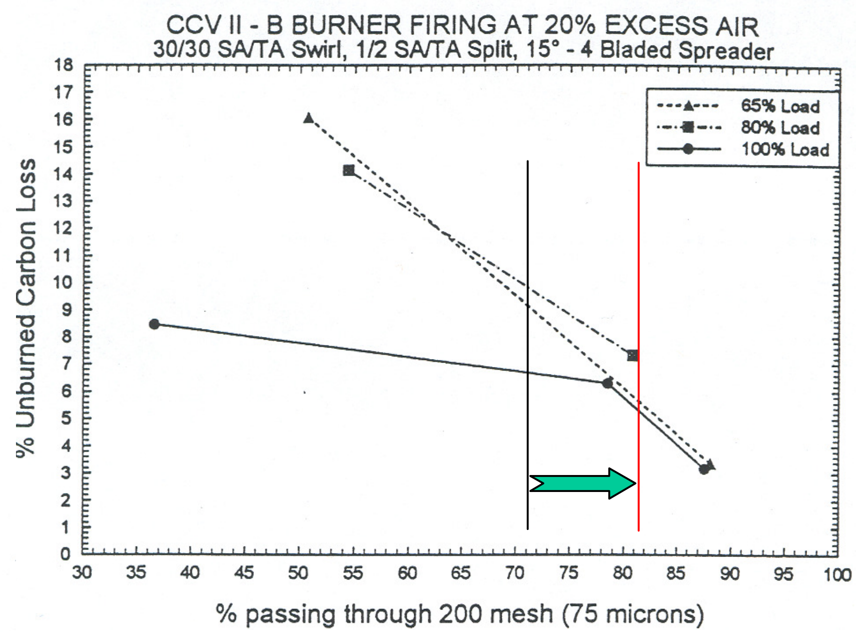


Coal Fineness for Low NOx

- Maintaining the coal fineness over time is critical
- Coal particle size distribution directly effects emissions (more bit. Coal than PRB)

Effect of coal fineness on NO_X and Unburned Carbon





Laboratory Data @ 100 MBtu/hr
1996 Test Facility Data

Coal Feed Balance

- Typically mill to mill coal flows should be maintained within ± 5%
- The raw coal size entering the mill must be maintained to ensure proper and steady throughput.
- Mill and Feeder maintenance is essential to ensuring peak performance.

Maintaining the Mill System

- Establish a list of critical inspection points within the mill system which effect the performance of the mill
- Inspect the mills during each outage
- Use inspections to track the dimensions/wear to forecast future repair and replacement requirements

Example List for Ball Tube Mill System

Component	Original Dimension /Setting	Year 2	Year 4	Minimum Before Replacement
Mill Liner Profile Depth	3.25″ peak to peak	3.0″ peak to peak	2.7″ peak to peak	1.75″ Peak to Peak
PA Flow Pitot	100,000 KPPH ± 5,000	100,000 KPPH ± 6,000	100,000 KPPH ± 6,000	± 10,000 Recalibrate or Replace probe
Classifier Vane Length x Width	6″ x 9″	5.5″ x 8″	5″ x 7″	75% of the length or 50% of the Width
Classifier Inverted Cone	24″ @ Base x 18″ H x 1/4″ th	23.25″ x 17.75″ x 3/16″	23″ x 17″ x 1/8″ with one hole	No holes

- Vertical Roller Mill – Critical wear components are the rollers and nozzle ring
- Atrita Pulverizers – Critical wear components are the Hammers, Pegs, Clips & rejector arms

Low NO_X Burner Effects

Combustion and the Burner

- Burner supplies and directs a specified amount of fuel to the furnace
- Burner supplies and directs the air necessary for combustion
- Produces mixing of the fuel and air
- Provides ignition source with heat sufficient to start and sustain the combustion process

Combustion & Low NO_X Burners

- Burner reduces formation of NO_X by:
  - Lowering peak flame temperatures
  - Controlling amount of O_2 in combustion zone (i.e. mixing)
    - PA/ SA/ TA flow splits
    - Swirl/ turbulence

- Results in a longer and extended flame pattern

- Burner must control fuel and air flow and air flow must be controllable and balanced burner to burner

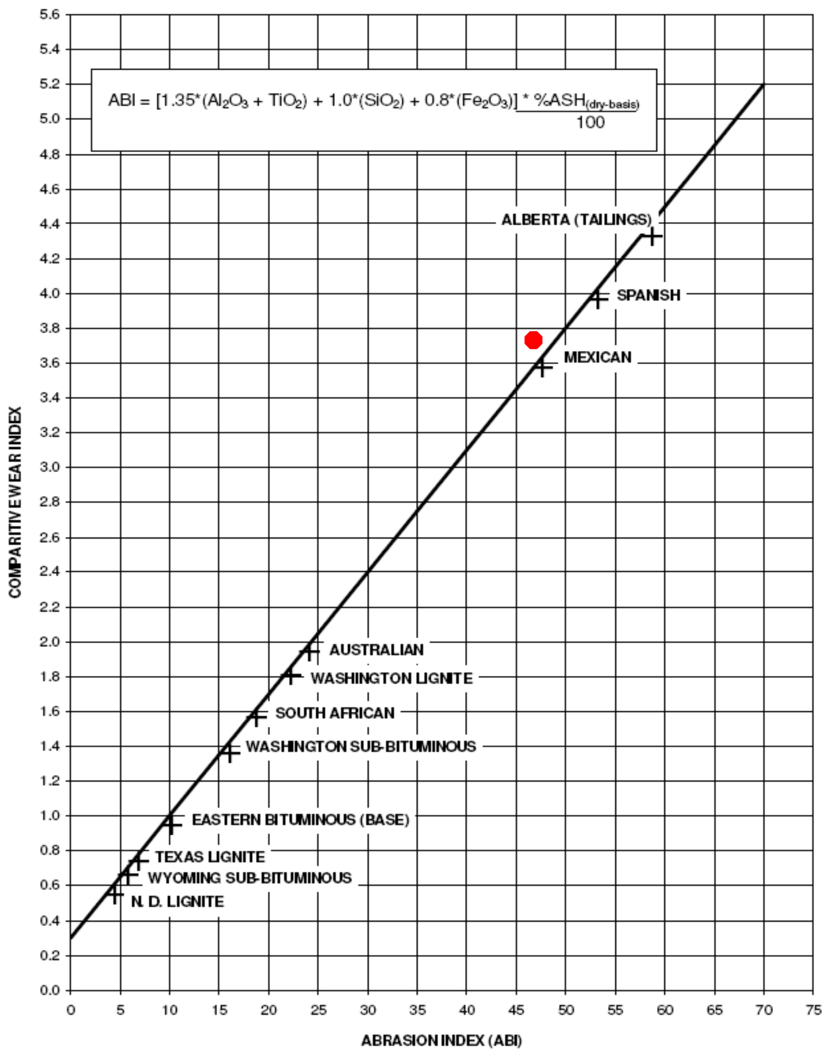
Challenges of a Successful LNB Project

- Compatibility with existing mill operation and limitations
- Wide range of fuel properties – utilities purchase coal on spot market
- Fit within existing furnace geometry with minimal respacing or pressure part reconfiguration
- Minimizing UBC & CO while optimizing NO_X performance
- Operation up to four or more years between major outages

Erosion Factors for Coal Burners

- Fuel ash chemistry
- Ash percentage by weight
- Velocity
  - In the coal pipe
  - Through the Primary side of the burner
- Ash Concentration in the secondary air stream

Coal Abrasiveness



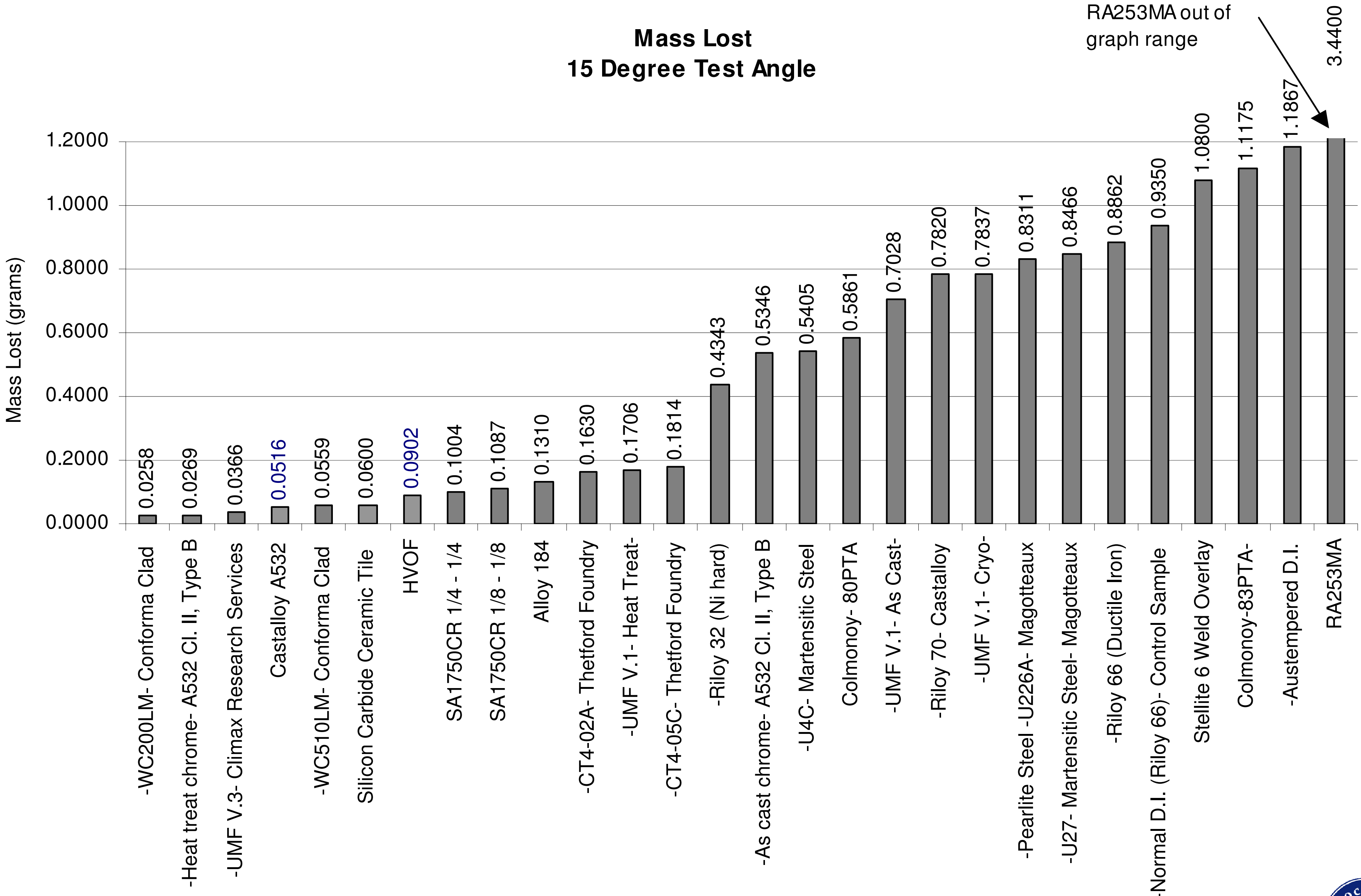
ABRASIVE INDEX CALCULATION

ABI = (1.35(Al2O3 + TiO2) + 1.0(SiO2) + 0.8(Fe2O3)) * (% $ash_{(dry\text{-}basis)}$) / 100

coal type	Indian Coal 1	Indian Coal 2
% $ash_{(as\text{-}received)}$	43	43.5
% moisture	12	12
% $ash_{(dry\text{-}basis)}$	48.9	49.4
Al_2O_3 wt%	27.36	27.36
TiO_2 wt%	1.84	1.84
SiO_2 wt%	61.85	61.85
Fe_2O_3 wt%	5.18	5.18
ABI	51.5	52.1

Advanced Material Selection for Critical LNB Components

- Maintain the geometry of key LNB components
- Reduced maintenance outage requirements
- Reduced spare parts inventory requirements


Mass Lost
15 Degree Test Angle
RA253MA out of graph range
Mass Lost (grams)
1.2000
1.0000
0.8000
0.6000
0.4000
0.2000
0.0000
0.0258
0.0269
0.0366
0.0516
0.0559
0.0600
0.0902
0.1004
0.1087
0.1310
0.1630
0.1706
0.1814
0.4343
0.5346
0.5405
0.5861
0.7028
0.7820
0.7837
0.8311
0.8466
0.8862
0.9350
1.0800
1.1175
1.1867
3.4400
-WC200LM- Conforma Clad
-Heat treat chrome- A532 Cl. II, Type B
-UMF V.3- Climax Research Services
Castalloy A532
-WC510LM- Conforma Clad
Silicon Carbide Ceramic Tile
HVOF
SA1750CR 1/4 - 1/4
SA1750CR 1/8 - 1/8
Alloy 184
-CT4-02A- Thetford Foundry
-UMF V.1- Heat Treat-
-CT4-05C- Thetford Foundry
-Riloy 32 (Ni hard)
-As cast chrome- A532 Cl. II, Type B
-U4C- Martensitic Steel
Colmonoy- 80PTA
-UMF V.1- As Cast-
-Riloy 70- Castalloy
-UMF V.1- Cryo-
-Pearlite Steel -U226A- Magotteaux
-U27- Martensitic Steel- Magotteaux
-Riloy 66 (Ductile Iron)
-Normal D.I. (Riloy 66)- Control Sample
Stellite 6 Weld Overlay
Colmonoy-83PTA-
-Austempered D.I.
RA253MA

Establishing Primary Side Burner Component Life as a Function of ABI

Component	Low Cost Material ABI < 15	Estimated Wear Life (Years)	Upgraded Materials ABI < 15	Estimated Wear Life (Years)
Coal Head	Carbon Steel	3	CS with Ceramics	> 8
Protective Liner	Hardened Steel	> 2	CS with Ceramics	> 8
Bluff Body in Coal Nozzle*	Carbon Steel Stainless Steel	> 2	CS or SS with Tungsten Cladding	> 8
Coal Nozzle Tip/Body	Stainless Steel	3	SS with Tungsten Cladding	> 7
Straightening/Distributor	Carbon Steel	> 2	Hardened Plate	> 4

* Base material is dependent on the location of the body and the local out of Service temperature

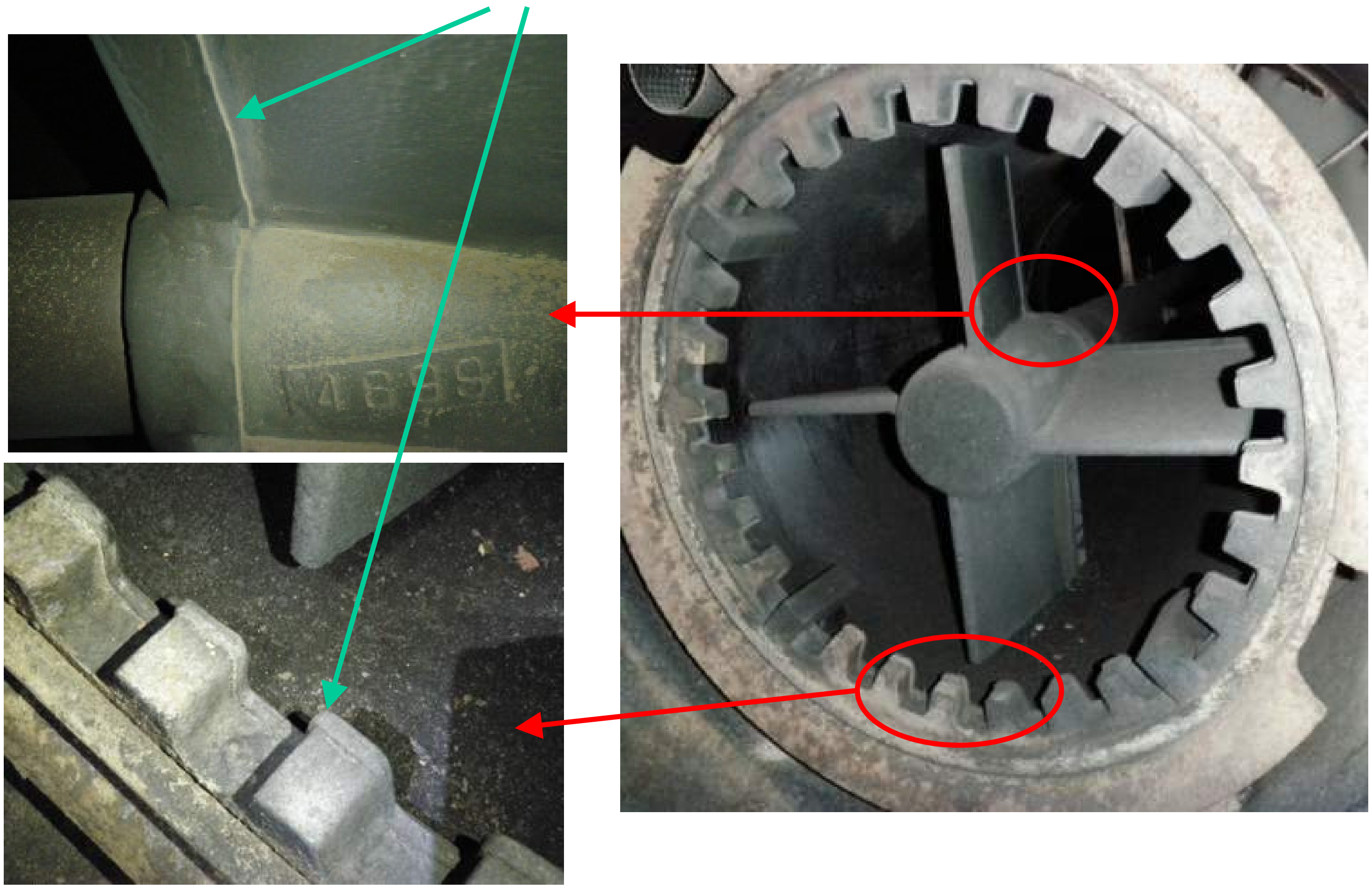
Establish Replacement / Repair Criteria for Critical Primary Side LNB Components

Component	Repair/Replacement Criteria
Bluff Body Component	>50% (in) Note 2 typ Loss of original length
Nozzle Tip	≥1/2 inch of increase in internal diameter
Ceramic Tiles	≥50% (in) loss of thickness and no missing or detached tiles NOTE 1
Protective Lining Tiles	≥50% (in) loss of thickness and no missing or detached tiles NOTE 1
Coal Head Lining Tile	Detached tiles NOTE 1

Note 1: Broken or detached tiles that are the result of improper pulverizer operation (e.g., pulverizer explosions/puffs, tramp metal processing, etc.) are not covered under this Criteria.

Note 2: Actual Dimensions to be filled in during contract design phase.

Flame Stabilizer Ring & Coal Spreader
Both have ConformaClad in “like new” condition

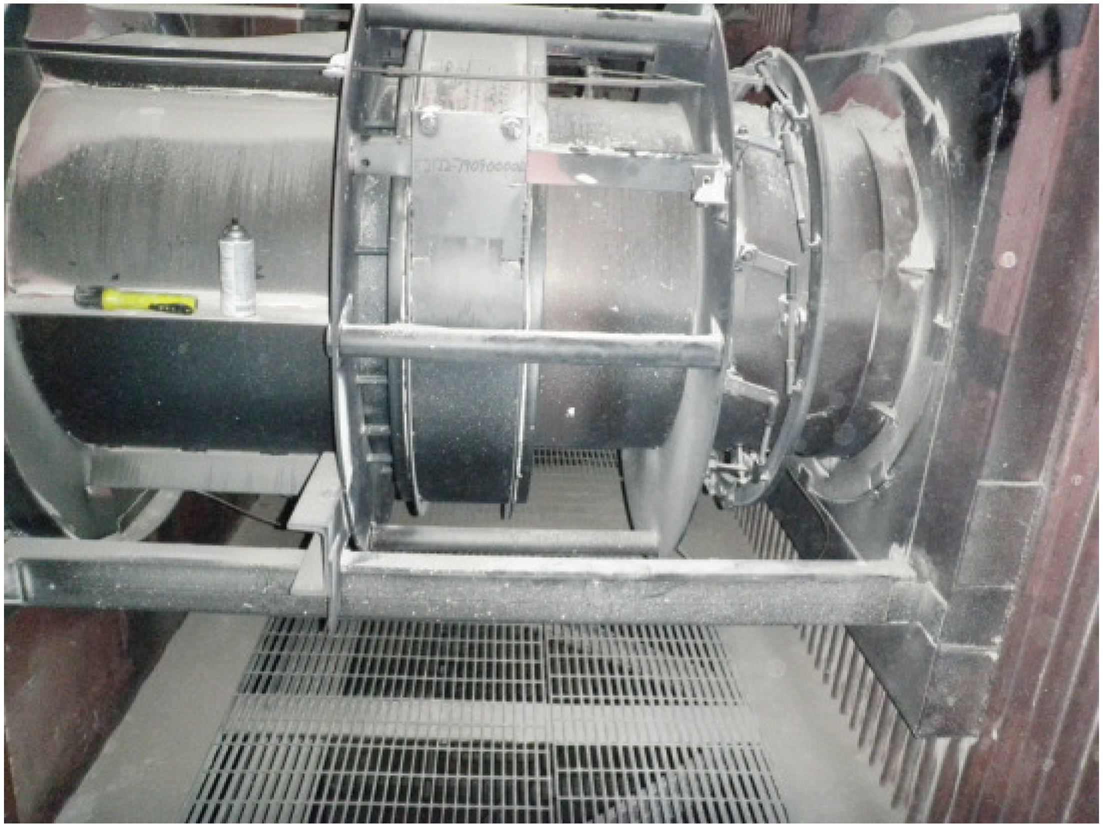


Maintaining Functionality of the Air Register of the LNB

- The operating functions of the Air Register are important to maintaining good low NO_X emissions
  - Controls the airflow balance from burner to burner
  - Directs the secondary air entering the furnace and mixing (spin/swirl) with the coal.
  - Controls the total secondary air to the burner
  - Controls the w/f dP
- Swirl vanes need to be functional to support optimization for significant fuel variations over time
- Air modulation control is important to ensuring local burner zone stoichiometry can be controlled

Example Air Register

Fully Functional After 3 Years in Service



Effects of Boiler System Conditions

Effects of Heat Absorption on Low NO_X Combustion

- Low heat absorption in the burner zone increases the local temperature and raises NOx
- Reduced heat absorption in the radiant pendants increases fouling potential which can affect emissions
- Use of wallblowers and sootblowers are important to maintaining the furnace conditions for controlling peak temperatures - especially on PRB coal firing

Effects of Operation Parameters on Low NO_X Combustion

- Secondary (Combustion) Airflow Balance
  - Good Airflow balance starting with FD Fans & windbox
  - Flue Gas temperature balance

- Furnace Pressure

- O_2 Levels at the economizer outlet
  - Balance from Left to Right and Front to Rear
  - Average level consistent with fuel and burner requirements to maintain design velocities

Effects of Operation Parameters (Con.'t)

- Maintaining fuel firing rates within the design range
  - Coal quality can effect the feed rate
  - Low economizer inlet water temperature can increase the firing rate
  - Consistent coal feed to the mill can effect the firing rate and unit fluctuations

Re – Tuning of Low NOx Burners

Detailed Planned Approach

- Understand the goals of the testing
  - Is lowest NOx emissions the goal?
  - Is lower UBC or CO emissions the goal?
  - Is furnace conditioning the goal?
- Prioritize the goals for success
- Schedule req'd. unit loads for testing
- Schedule testing times but be aware of potential delays

Detailed Planned Approach (con.'t)

- A Test Matrix with a logical progression of tests designed to achieve the goals of the testing.
- Emissions sampling location and grid equipment
  - Portable analyzers versus a test truck
  - Test time versus cost

Example of Low NOx Test Plan & Matrix

<table>
<tr><th>Test #</th><th>Unit Load)</th><th>Windbox Dampers (°closed)</th><th>Swirl Vane (°)</th><th>BRN Air Balnce</th><th>% O_2 wet</th><th>OFA Damper Bias</th><th>Flame Length Adj</th><th>Data and Samples Required [1]</th></tr>
<tr><td>1</td><td>MCR</td><td>As Found</td><td rowspan="4">20</td><td rowspan="7">As Found</td><td rowspan="8">3.1</td><td rowspan="10">100/100</td><td rowspan="11">1</td><td>BR, B, FO, G</td></tr>
<tr><td>2</td><td></td><td rowspan="3">Bias per [2] 2.1</td><td>BR, B, FO, G</td></tr>
<tr><td>3</td><td></td><td>BR, B, FO, G</td></tr>
<tr><td>4</td><td></td><td>BR, B, FO, G</td></tr>
<tr><td>5</td><td></td><td rowspan="11">OPT</td><td>30</td><td>BR, B, FO, G</td></tr>
<tr><td>6</td><td></td><td>35</td><td></td></tr>
<tr><td>7</td><td></td><td>40</td><td></td></tr>
<tr><td>8</td><td></td><td rowspan="8">OPT</td><td>Bias per 2.3</td><td>BR, B, FO, G</td></tr>
<tr><td>9</td><td></td><td rowspan="7">OPT</td><td>2.7</td><td>BR, B, FO, G</td></tr>
<tr><td>10</td><td></td><td>2.6</td><td>BR, B, FO, G</td></tr>
<tr><td>13</td><td></td><td rowspan="5"></td><td>Balance</td><td>BR, B, FO, G</td></tr>
<tr><td>14</td><td></td><td rowspan="4">OPT</td><td>2.5 [3]</td><td>BR, B, FO, G</td></tr>
<tr><td>15</td><td></td><td>4</td><td>BR, B, FO, G</td></tr>
<tr><td>16</td><td>INT</td><td rowspan="2">OPT</td><td>ALL</td></tr>
<tr><td>17</td><td>LOW</td><td>ALL</td></tr>
</table>

Boiler Operation/Tuning for Low NOx

- Reduce the amount of excess air to the furnace as much as possible to achieve lowest NOx while maintaining low CO and % UBC.
- Windbox to Furnace Differential Pressure should be optimized according to furnace and burner type and fuel being fired (~4.0 – 4.5” W/F dP seems best)
- Coal flow distribution to the furnace should be balanced to ±15%, PA distribution to ±10%.
- Balance air distribution to burners

Optimization Strategies

- Primary Airflow Balance
  - Mill testing to determine the current airflow balance and identify any deficiencies
  - Install balancing devices as required to correct the airflow within +/- 10%
  - Confirm balance with testing on the mill
  - Good primary airflow balance can help minimize CO while achieving low NOx emissions

Optimization Strategies

- Coal Flow Balance
  - Coal flow out of the mill should be within +/- 15% of the mean on a weight basis
  - Correcting pipe to pipe balance can be difficult
  - Coal particle sizes is important to achieving low LOI/UBC
  - Coal distribution within the burner nozzle

Optimization Strategies

- Secondary Airflow Balance
  - SA balance begins at the FD Fan
  - Varying approaches can be utilized to improve the balance entering the burner
    - Divided windbox versus common windbox designs
    - Individual burner air balancing
    - Airflow measurement devices for assisting with balancing
    - CFD modeling of windbox and upstream ductwork
  - Economizer outlet grid O_2 measurement
  - Good Air distribution improves furnace conditions, decreases CO and NOx emissions and lowers UBC

Optimization Strategies

- Overfire Airflow Balance
  - Overfire Air system designs vary, but have some similarities
    - From the Windbox
    - From the Main Secondary Air Feed
    - From Booster Fans
  - Balance from port – to – port improves overall furnace distribution
    - biasing may be required depending on the furnace conditions
    - CFD modeling of the WB & Furnace for distribution and mixing
  - Balancing the low NOx Burners first with OFA closed can better isolate the OFA tuning.

Test Support and Personnel

- Plant participation is critical to ensure success
  - Operational assistance and involvement improves the effectiveness of the tuning process
  - Test coordination for unit load conditions and sample procurement
  - Availability of key personnel to assist with system controls, settings and issues can reduce the optimization time required
- The OEM of the low NOx equipment must have trained well seasoned service personnel to conduct the optimization
  - Knowledge of total boiler & fuel systems operation is an asset
  - Knowledge of the equipment and tuning process is essential

Test Support and Personnel

- Third Party Test Teams
  - Utilizing a test company with a mobile gas sampling system can shorten the test duration by decreasing the gas sample collection time.
  - Utilizing a test crew for mill testing can minimize the time required to review and reset the mill characterization curve.
  - Cost is a concern when deciding to use any test company.
  - If the plant has the personnel available and trained then testing at the economizer outlet grid and for the mill can be completed without a 3rd party test company.

Summary

- Maintain mill system at or near design conditions (PA & Coal Distribution, fineness, A/C)
- Maintain the low NO_X burner on both the primary and secondary sides to ensure reliable long term performance
- Characterize and operate the boiler within the known design ranges whenever possible

Summary

- If re-tuning is needed, a well defined plan improves the process of optimization / tuning
- Low NOx burners are one part of the combustion system. Optimizing the mill and boiler system is also part of a good tuning strategy.
- Air and Fuel Balancing is key to any low NOx burner optimization program.
- Documentation of the optimization testing is critical to reducing test time for any future testing.

THANK YOU !

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