REINHOLD ENVIRONMENTAL Ltd.

2014 NOx-Combustion Round Table & Expo Presentations

February 10 & 11, 2014, in Charlotte, NC / Hosted by Duke Energy

SIEMENS

Getting the Most From Combustion System Tuning

WPCA NO_x–Combustion Roundtable

February 10, 2014

Alan Paschedag
Manager, Engineering
Environmental Systems and Services
Advanced Burner Technologies Product Line
3040 US Highway 22 West
Branchburg, NJ 08876
908-947-3805

SIEMENS

Determine Combustion System Tuning Goals

For combustion system tuning to be the most effective, it must be clear what performance parameters are important. Without defined goals, tuning is nothing more than a random exercise in collecting data.

Operation of the furnace and boiler result in many potential outcomes. The relative importance of each of these will shape the goals and thus the focus of the tuning effort.

This must always be step one of any tuning as the goals ultimately impact; scope, schedule, cost, manpower, equipment required, etc of the tuning process.

Determine Combustion System Tuning Goals

Some typical goals that ultimately affect the cost of electricity production are:

Goal	Goals/Benefits
Minimize NO_x	Reduce emission fines, sell NO_x credits
Reduce Slagging	Minimize spray flows, minimize deslagging efforts
Reduce UBC	Ability to sell flyash, increase combustion efficiency
Flame Stability	Increase turndown, minimize auxiliary fuel use, reduce unit cycling

SIEMENS

Firing Configuration

When determining the goals for tuning, the firing configuration (mills in service, plays a big role.

Does the plant prefer to operate with all mills in service or with one mill out of service?

Very often there is a preference for a mill out of service to minimize auxiliary power in the plant.

Top rows of burners out of service tend to minimize NO_x production.

Since various mill combinations produce different results, is it important to identify the ranges of boiler operation?

Preparation for Combustion System Tuning

Once the goal(s) have been set, it is time to start to prepare for tuning.

Preparing for combustion tuning requires attention to detail in order to produce the best results.

Proper preparation = Best performance/results

Preparation for Combustion System Tuning

Proper preparation is the most important step for combustion system tuning.

Burner tuning is a relatively straightforward process. Much of the tuning process is based on what has been learned from all previous tuning.

Thus, for the best outcome during burner tuning, complete and diligent preparation most likely accounts for 90% of the success of the tuning effort.

Preparation for Combustion System Tuning - Schedule

SCHEDULE

Schedule is probably the most important part of preparation. The schedule not only includes dates but also the tasks that must be completed before, during and after tuning.

The schedule should include:

- Name of activity
- Due date of activity
- Duration of activity
- Responsible person for activity

One person should be in charge of tuning and make sure the activities are completed on time. Short meetings help keep all involved aware of how their activities affect others.

Preparation for Combustion System Tuning - Schedule

Scheduling starts well in advance of the tuning effort. Typical pre-tuning schedule items would include:

- ✓ Obtaining desired test coal
- ✓ Instrument calibration
- ✓ Test grid (if required)
- ✓ Schedule/hire third party (if required)
- ✓ Manpower planning (vacations, shifts, etc.)
- ✓ Repairs (if required)
- ✓ Review of past tuning data
- ✓ Dispatch of boiler loads required

Preparation for Combustion System Tuning - Schedule

Why are pre-tuning activities important?

Any preparation items not completed prior to tuning will affect not only the efficiency of the tuning process but it can also impact the value of the information gathered during tuning.

Uncalibrated instruments may provide inaccurate data.

Missing or inoperable equipment may eliminate useful data from the results.

If specific loads must be scheduled with dispatch, any delay or change to schedule may eliminate some elements of tuning or rescheduling will be required.

Preparation for Combustion System Tuning – Test Plan

There must be a test plan. This is a specific set of tests designed to best define operation of the units under the desired scenarios.

The test plan would include:

- ✓Duration of test
- ✓Coal burned
- ✓Load
- ✓Desired operating conditions (O_2, OFA flow, etc.)
- ✓Mills in service
- ✓All data to be collected
  - ✓How is each point collected
  - ✓If necessary, manual data sheets must be prepared
  - ✓Identify expected outcomes
  - ✓Time intervals, if appropriate

- ✓Test order, if important

Data Recording

Any tuning effort includes the collection of a significant amount of data.

Where and how this data is collected and recorded should be known prior to starting any tuning effort.

Today the most common method of collection boiler data is through the plant’s data acquisition system.

The most effective method of tuning a multi burner combustion system is by measuring the properties of the flue gas at the economizer outlet.

Since the fuel affects the outcome, plans for analysis and recording of coal properties is important.

Data Recording – Plant Data

Plant data is typically collected in the data acquisition system. This system includes hundreds of data points, all collected in specoified time intervals 24 hours a day.

Tuning and the affects of tuning do not involve all of these points.

Typically a “report” can be generated that will collect only the data for the pre-selected data points. This “report” should be saved for use in future tuning efforts.

Data collected this way is very useful in evaluating the results. The data can be imported into spreadsheets and reduced.

Averages over time can be determined, since large amounts of data are generated. Bad data points can be identified and removed.

SIEMENS

Data Recording – Plant Data

As an important part of tuning is to make sure the unit is operating optimally, comparison to expectations and past data is necessary.

Part of the preparation for tuning should have been to identify both the results of the last tuning effort and the expected operating conditions.

Graphs are useful ways to visually review data. Upper and lower limits can be shown for the range of expected results. Curves from past tuning efforts should be included.

Changes in operating conditions of the boiler can be noted by changing trends in the family of historic curves for a particular parameter.

Why is Preparation Important?
Why Should Plants Invest in Combustion System Tuning?

Increasing Boiler Efficiency

Unburned Carbon in Flyash	-Direct loss of efficiency -Affects the ability to sell flyash (potentially a significant cost)
Slagging	-Reduces the heat transfer from the combustion gases to the waterwalls, more heat input is required to produce the required amount of steam. -Spray flows and resulting heat rate will increase
Excess Air	- Higher excess air causes increased heat loss leaving the boiler.

SIEMENS

Combustion Tuning Conflicts

Combustion tuning is at best a compromise.

One of the main combustion tuning parameters is excess air. The compromise is to minimize the excess air while having the least effect on the combustion products that reduce efficiency.

Reducing Excess Air Will:	
Decrease NO_x	Increase CO
Decrease wet gas loss	Increase UBC
	Increase slagging
	Increase corrosion

Combustion Tuning Conflicts

Tuning low NO_x burners to reduce the NO_x levels in a furnace interacts with other performance conditions of the furnace/boiler.

Therefore, achieving the lowest possible NO_x levels is a compromise between lowering NO_x while balancing the effects on the related furnace/boiler performance conditions.

Attempting to achieve the lowest NO_x levels at any cost can cause a significant impact to the furnace and boiler performance.

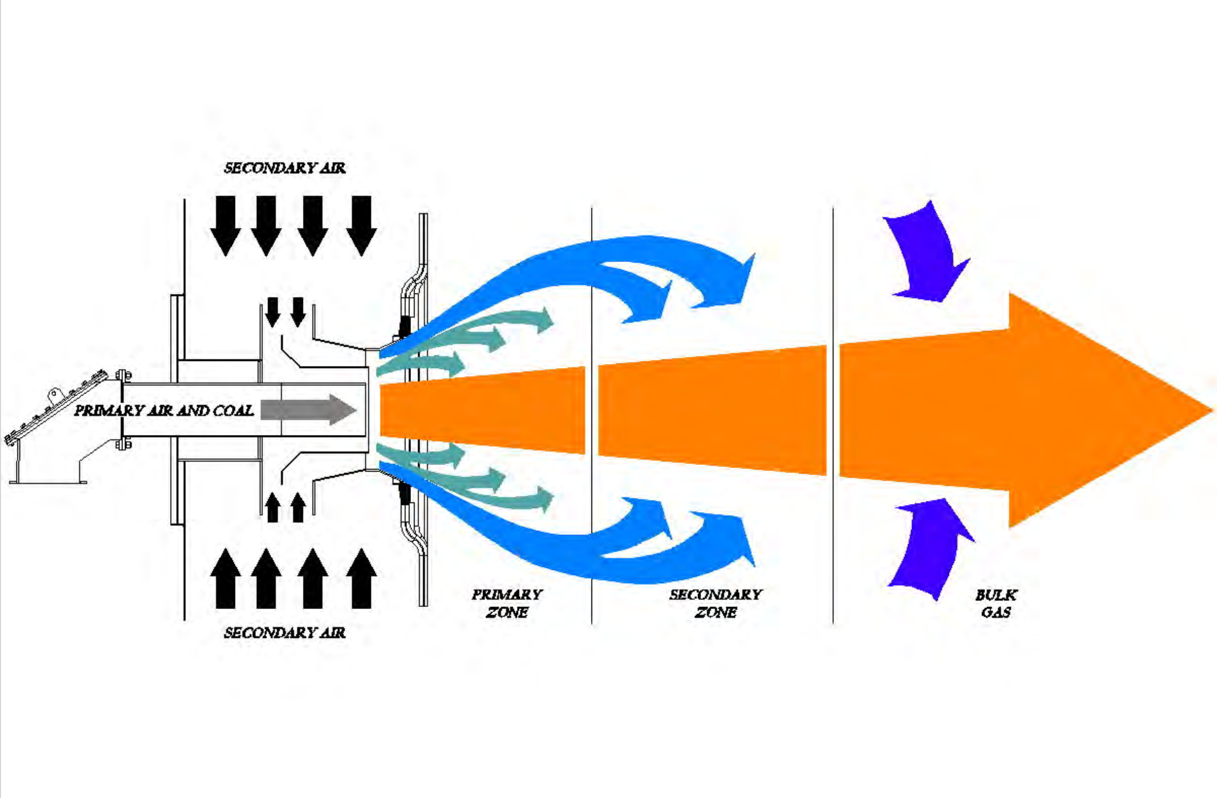
SIEMENS

Proper Preparation + Diligent Tuning = Optimum Performance

Proper preparation and diligent tuning will insure that each of the operational conditions affected by the combustion system will be optimized.

- Combustion efficiency (maximize)
- UBC effects (minimize)
- Flame stability (maximize)
- Flame impingement (minimize/eliminate)
- Waterwall slagging (minimize)
- Waterwall corrosion (minimize)
- Heat transfer (maintain design conditions)
- Boiler operation (maintain proper conditions)
- Steam temperatures (maintain steam temps/spray flows)

Air and Coal Mixing in a Low NO_x Burner



The mixing of the combustion air and coal in a low NO_x burner is achieved in a staged process throughout the flame and with the addition of overfire air, throughout the furnace. The goal is to make this mixing process as effective and efficient as possible.

SECONDARY AIR FLOW

TUNING CONDITIONS

Secondary Air Flow

Secondary air flow is the major emphasis of any tuning effort. Primary air and coal flow issues require mill outages and are not easily accomplished during a normal tuning program.

There are many ways that the combustion process is affected by how the secondary air is delivered to and used in the burners, overfire air ports and any other air injection to the furnace.

Secondary Air Flow Issues

There are a number of issues that can affect the ability to operate the combustion system at the optimum performance of NO_x, UBC, CO, slagging, etc. Some of these issues are as follows:

- ✓ Poor air flow distribution in the burner windboxes
- ✓ High pressure drop in the secondary air ducts reducing the available pressure to the burner and overfire air windboxes
- ✓ Plugged air heater baskets reducing the available pressure to the burner and overfire air windboxes
- ✓ Random plugged air heater baskets causing continuously fluctuating windbox pressures

Poor Air Flow Distribution in the Burner Windboxes Effect On NO_x

Low NO_x burners and the combustion created by them is defined by the design conditions of the burners. With poor air flow distribution, each of the burners is operating at different air flow and stoichiometric conditions. In addition, poor air flow can cause poorly distributed air flow, with one side of the burner having too much air and the other not enough.

SIEMENS

Secondary Air Flow and Burner Stoichiometry

When the stoichiometry in the burner zone is below 100%, this creates a reducing (oxygen deficient) zone. The following negative impacts on the operation of the boiler are created in a reducing atmosphere:

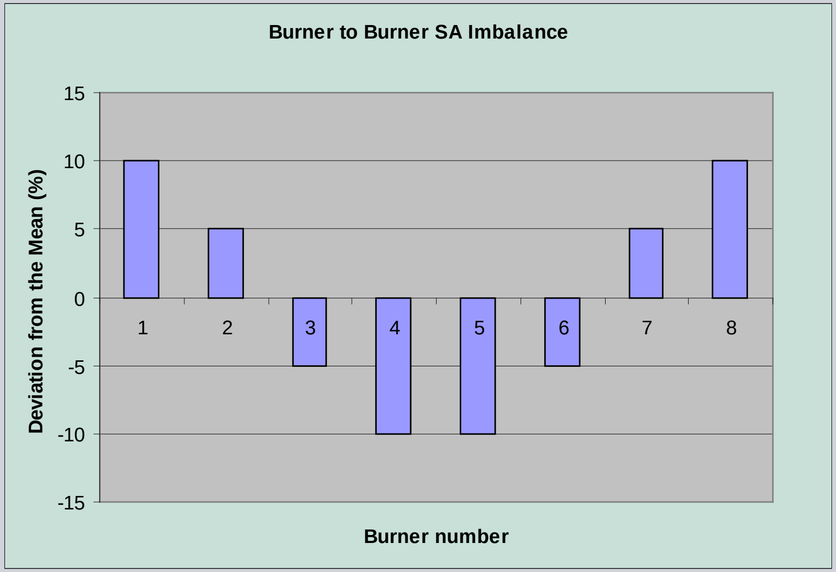
- Potential increases in corrosion due to sulfur in the fuel forming H_2S
- Potential increases in slagging rates in the furnace
- Increased CO levels
- Increased unburned carbon levels

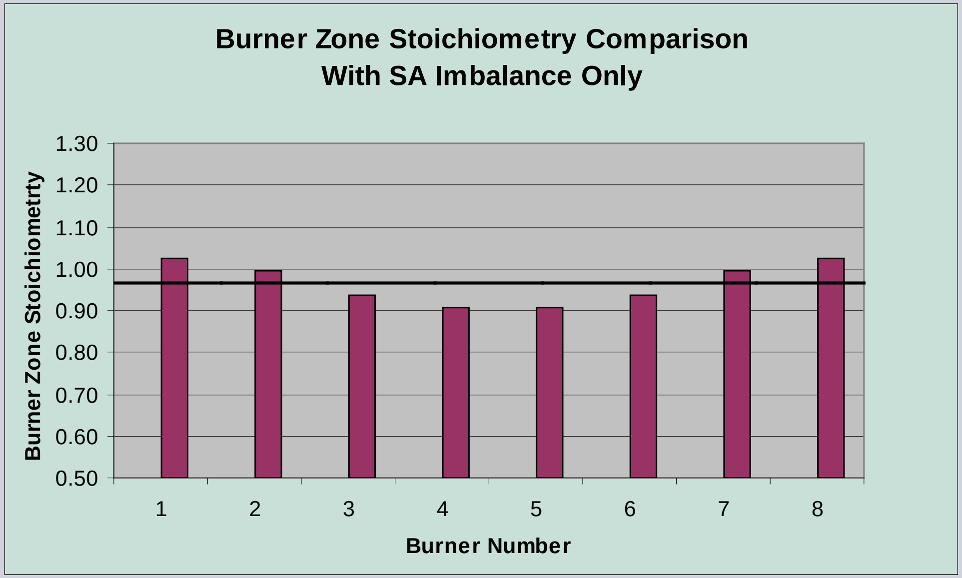
When the stoichiometry in the burner zone is above 100%, this creates an oxidizing (oxygen rich) zone. The following negative impacts on the operation of the boiler are created in an oxidizing atmosphere:

- Potential increases in NO_x levels

Poor Air Flow Distribution in the Burner Windboxes Effect On NO_x

SIEMENS





The chart on the left shows a secondary air flow imbalance with more air flow to the outboard burners, typical of a side fed windbox.

The chart on the right shows the variation in the stoichiometric ratio between burners, assuming an equal coal flow to all burners.

When combined with coal flow imbalances, the effect is much greater.

Poor Air Flow Distribution in the Burner Windboxes
Remedy

SIEMENS

A secondary air flow model of the windboxes and subsequent design, fabrication and installation of flow correcting turning vanes and baffles can correct poor windbox flow patterns.

This is obviously not something to be taken on during tuning.

Some of the observations made during tuning that may indicate a need for windbox modeling and improvements to the windbox are:

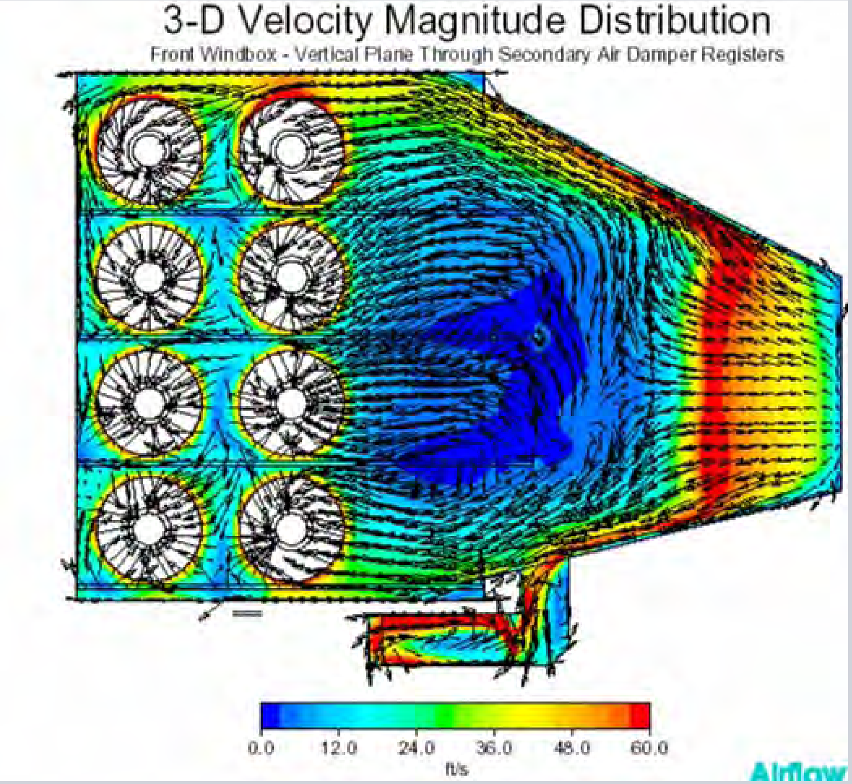
- ✓ Areas of widely different O_2/CO concentrations throughout the furnace
- ✓ Higher than expected UBC levels
- ✓ Visual differences in flames between burners
- ✓ O2 imbalance from side to side of the furnace
- ✓ Random slagging patterns

Improving Secondary Air Distribution Utilizing CFD Modeling

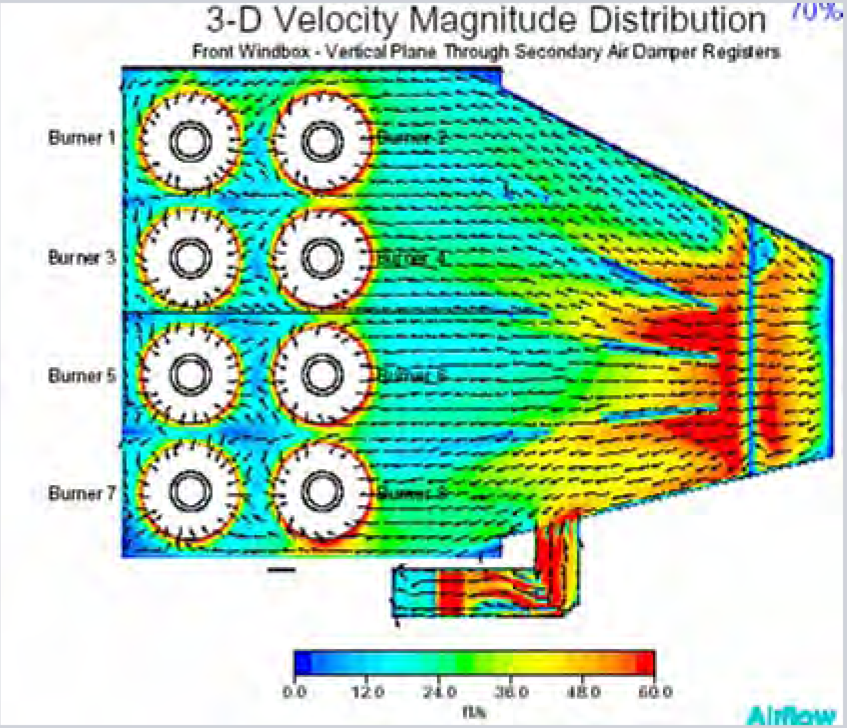
SIEMENS

700 MW Unit with 7 Mills and 28 Burners

Windbox Modification



As- Found Condition



Siemens Remedy

Baffles and turning vanes have been added to correct flow distribution.

Secondary Air Flow Issue:
Plugged Air Heater Baskets

SIEMENS

Plugged air heater baskets reduce the available pressure to the burner and overfire air windboxes.

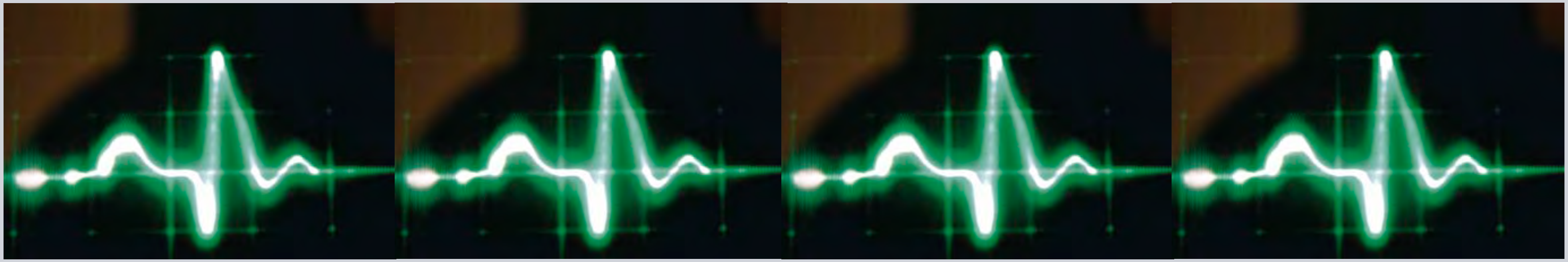
Effect on NO_x, UBC, CO, slagging:

There is no direct effect, however, the indirect effect is the reduced available windbox pressures for the burners and overfire air. This reduced available pressure may affect the ability to balance and tune the burners properly. In addition, the reduced pressure restricts the ability to “force” more air into the overfire air system for maximum and efficient NO_x reduction.

Remedy:

Clean or replace air heater baskets.

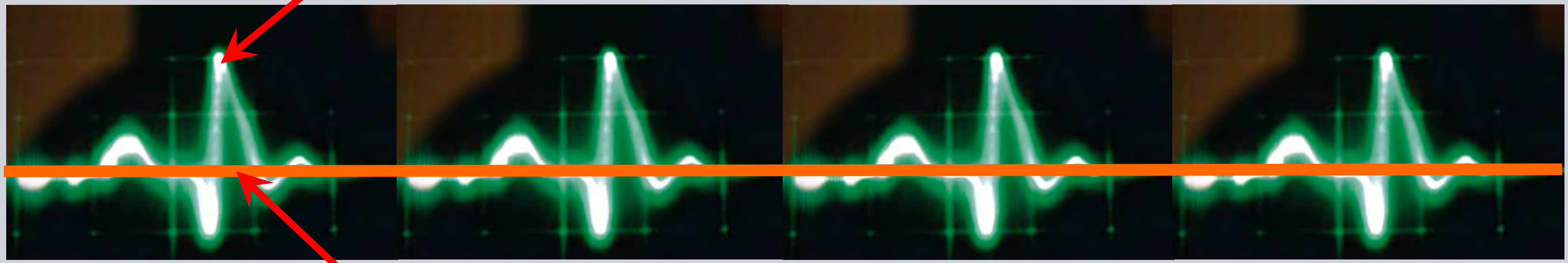
What do a heartbeat and secondary air flow control have in common?



NOTHING

Good heartbeat

Bad secondary air flow control



Bad heartbeat

Good secondary air flow control

Random Plugged Air Heater Baskets Effect on NO_x

SIEMENS

Since any combustion process is most effective in a steady state condition, significant fluctuation in the secondary air flow causes constant fluctuation in the stoichiometry at each of the burners. Randomly plugged air heater baskets causes continuously fluctuating windbox pressures.

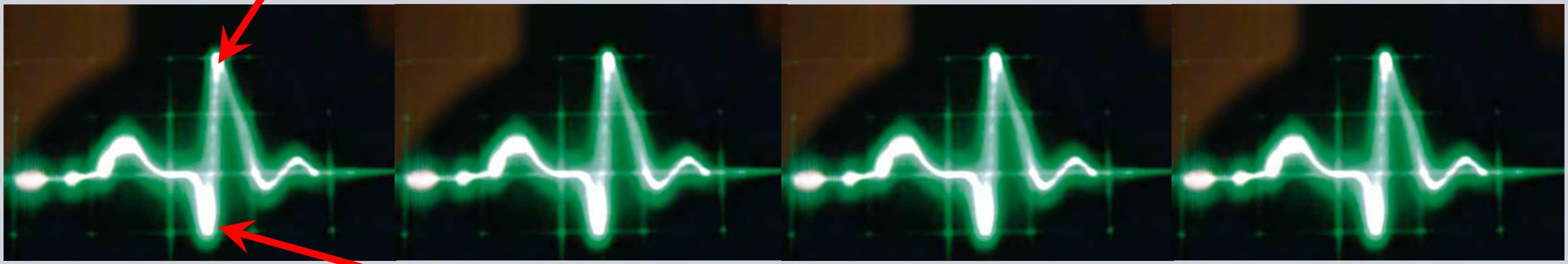
This would be equivalent to the change in gas mileage from using cruise control and constantly changing the gas pedal position.

In addition, NO_x is optimized as a compromise with CO, unburned carbon, corrosion and slagging rates.

Random Plugged Air Heater Baskets
Effect on NO_x

SIEMENS

<u>High secondary air flow:</u>
Higher NO_x levels
Lower CO levels
Lower UBC levels
Lower potential corrosion rates
Lower potential slagging rates



<u>Low secondary air flow:</u>
Lower NO_x levels
Higher CO levels
Higher UBC levels
Higher potential corrosion rates
Higher potential slagging rates

Random Plugged Air Heater Baskets
Remedy

Clean or replace plugged air heater baskets.

Boiler Air In Leakage

All boilers have some level of ambient air in leakage to the boiler (except pressurized furnaces).

This air enters the boiler after the burners and does not participate in the combustion process. It is not preheated and uses furnace gas heat to raise its temperature. In the end it leaves the boiler as a loss of efficiency.

It is important to note that the excess oxygen levels measured by plant/test instrumentation includes this air.

Since the air in leakage is included in the excess air, the actual excess air at the burners is lower than indicated by instrumentation and may be the cause of noted combustion problems.

SIEMENS

Reporting

Once the tuning plan is complete, organize, evaluate and create a report to document the findings.

Too often, the value of tuning efforts are not realized due to the lack of evaluation and follow-up.

By creating a report of the tuning effort, the operating conditions will be organized and available for the next tuning effort.

This becomes particularly valuable when plant operation changes (alternate fuels, equipment upgrades, etc.)

SIEMENS

Reporting

The report will contain not just raw data but much more useful information.

Typical contents are:

- ✓Tuning plan and description of tests performed
- ✓Raw data
- ✓Processed data
- ✓Recorded observations during tuning
- ✓Summary of past results
- ✓Comparison of current and past results
- ✓Discussion of any noted deficiencies
- ✓Plan for any identified changes/corrections/improvements

COAL FLOW BALANCING

TUNING CONDITIONS

If All Else Fails – Look Elsewhere

If tuning with secondary air does not produce the expected results, it will be necessary to assess the coal and primary air systems.

This would be done if the tuning results were significantly deteriorated from past tuning results.

Coal Fineness

Typical fineness guidelines:

70% thru 200 mesh

99% thru 50 mesh

The percent of the coal passing the 50 mesh screen is of most importance to the unburned carbon levels in the ash with low NO_x burners.

Coal fineness has a minimal impact on the NO_x levels. However, as has been repeated, NO_x is optimized as a compromise with unburned carbon levels. The percent passing through the 50 mesh screen has the largest impact on the UBC levels. Thus, the better the fineness, the more tuning flexibiity there is to make adjustments for NO_x optimization.

Coal Fineness Optimization

Achieving the best possible coal fineness levels involves adjustments and/or maintenance to the mills.

The simplest method of increasing the fineness to acceptable levels is by adjusting the classifier on the mill.

Some mill have static classifiers built in to the mills. These require a mill outage to be adjusted.

Relatively few mills have dynamic classifiers. These classifiers can be adjusted with the mill on line. The adjustment is typically changing the speed of the rotating element in the classifier.

SIEMENS

Coal Flow Balance

Typical coal flow balance between coal pipes on each mill are ± 10%.

In some cases one mill may be out by a bit more than this.

It is also relatively important to have all mills operating at similar coal flow levels to each other.

Biasing of the coal flow between mills can raise or lower the overall NO_x in the furnace (depending on which mills have more or less coal flow). In addition, it is then also important to bias the secondary air flow to maintain the proper stoichiometry at all of the burners. This condition also limits the operational flexibility of the unit.

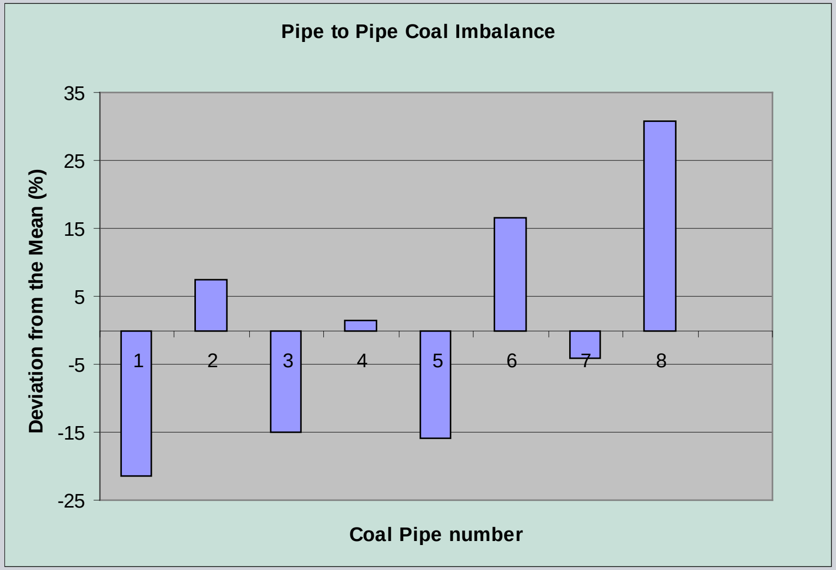
Coal Flow Balance Optimization

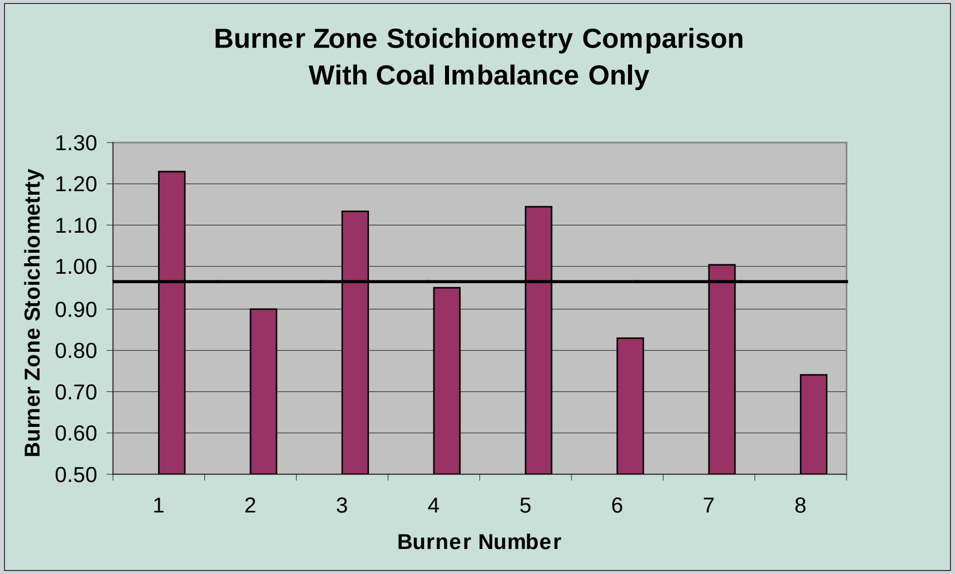
There are a number of things that affect the coal flow balance between coal pipes on a mill. Coal flow imbalances are somewhat influenced by imbalanced primary air flows (but not always). The following are potential sources of coal flow imbalances in the coal pipes:

- Length and geometry (bends) of the individual coal pipes
- Coal pipe velocities
- Condition of any existing coal flow devices (orifices, etc.)
- Air flow maldistribution in the mills
- Coal Roping at mill outlets and in coal pipes

Coal Flow Imbalance Effect On NO_x

SIEMENS



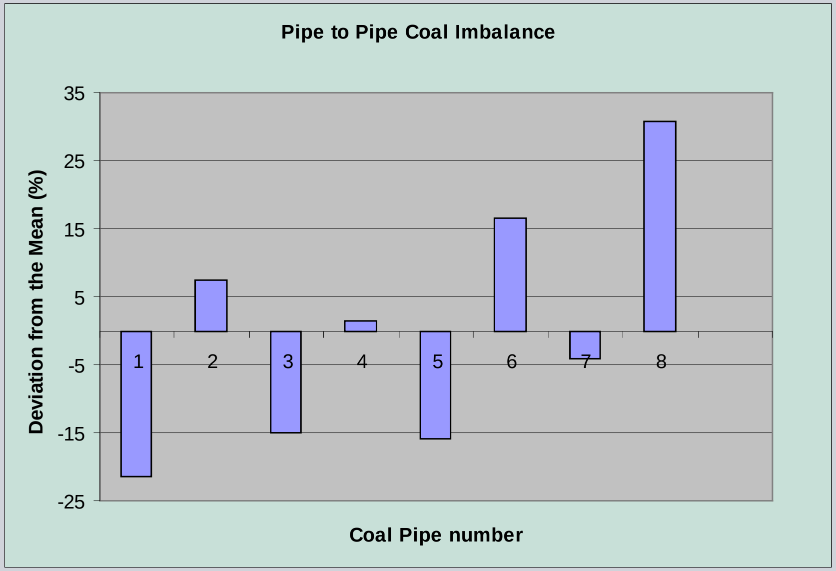


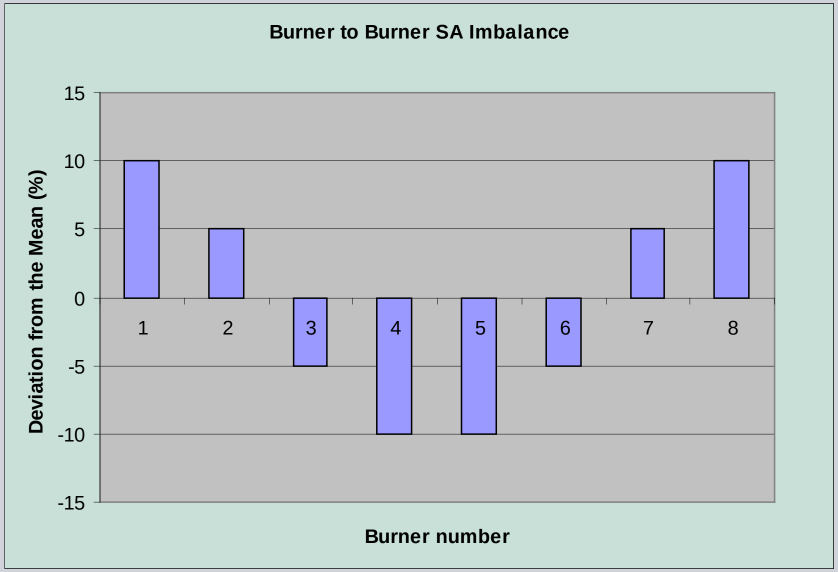
The chart on the left shows a test case burner to burner coal flow imbalance.

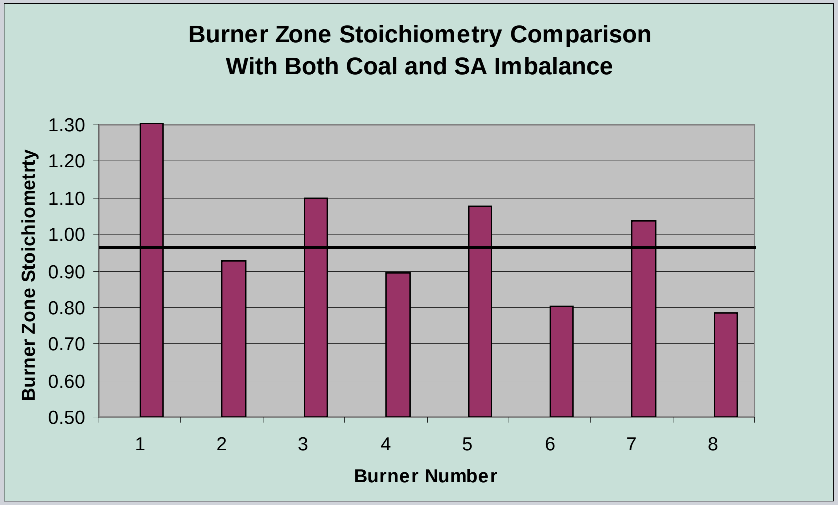
The chart on the right shows the variation in the stoichiometric ratio between burners, asssuming an equal secondary air flow to all burners.

When combined with secondary air flow imbalances, the effect is much greater.

Coal and Secondary Air Flow Imbalance Effect On NO_x







The charts above show burner to burner coal and secondary air flow imbalance.

The chart on the left shows the variation in the stoichiometric ratio between burners, based on the above imbalances.

SIEMENS

Coal Flow Balance Optimization Remedy

Coal (and primary air) balancing can be achieved through the installation of fixed orifices or adjustable coal balancing valves. These devices essentially equalize all of the coal pipes, to account for the length and geometrical differences between pipes.

It must be noted that the ability to balance the coal (and primary air) flow may be limited by conditions within the mill itself.

One important note is that the application of balancing devices is limited by the coal pipe velocities.

When the coal pipe velocities are very low, near which the coal settles out of the flow, it is not possible to use these devices as the velocity will become so low and coal will settle out. In addition, if a specific pipe has high coal flow and low air velocity, this cannot be corrected.

SIEMENS

Coal Flow Balance Optimization Remedy

Coal

Balancing

Valve

One remedy for coal flow imbalances between coal pipes is an externally adjustable coal balancing valve. This offers the ability to balance coal flow between pipes without taking the mill out of service.

Coal Flow Imbalance and Fineness Optimization Remedy

In some cases it is not possible to correct coal fineness or coal flow imbalance issues with devices external to the mills.

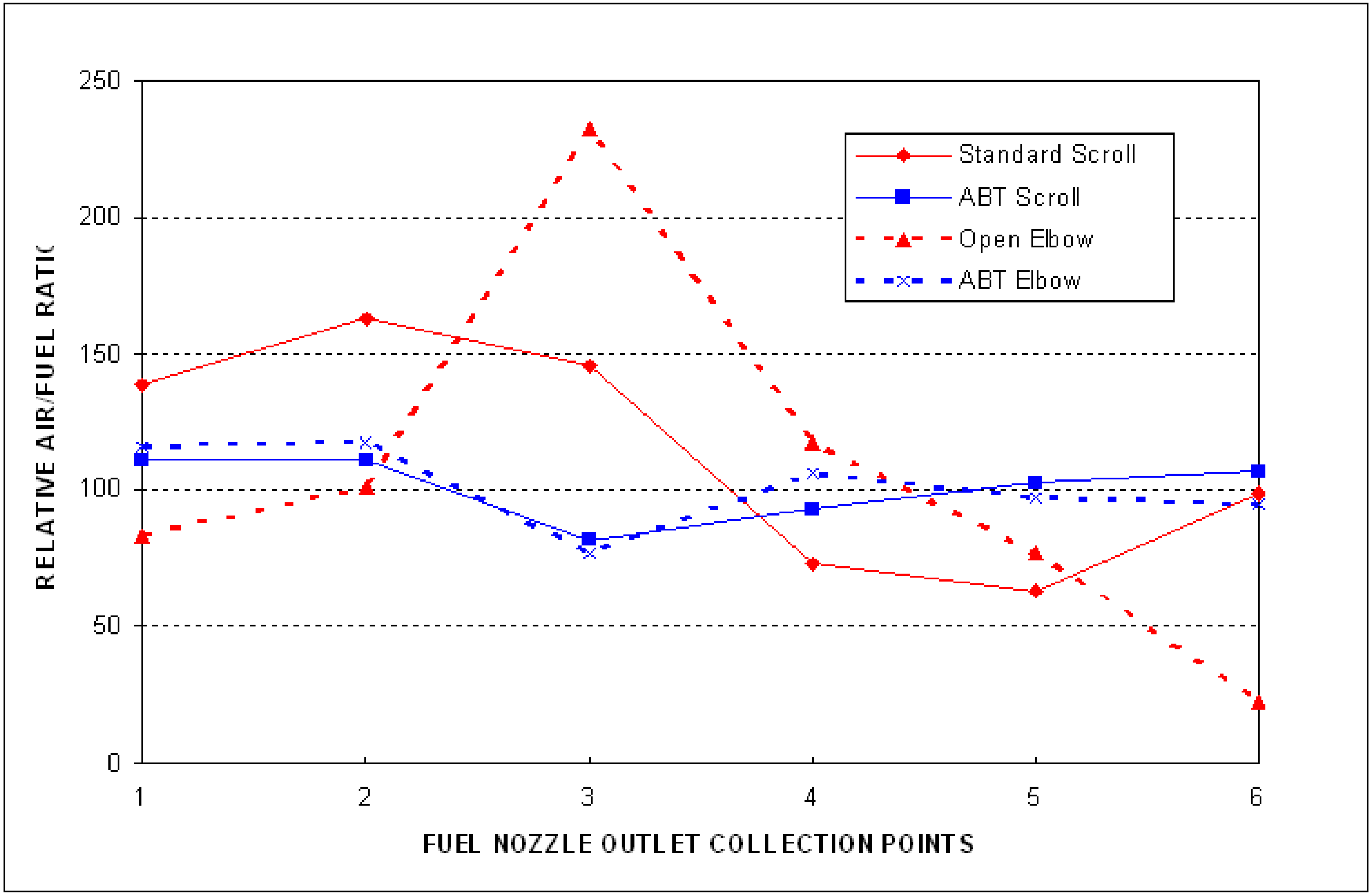
In this case, adjustments or maintenance must be performed on the mills. Some adjustments can be made without major maintenance (adjusting spring tensions, ball charge, adjusting fixed vane classifiers, etc.).

In other cases, it is necessary to perform maintenance on the mills. This would include items such as; replacing mill tires, repairing mill tables, replacing an entire ball charge, etc.

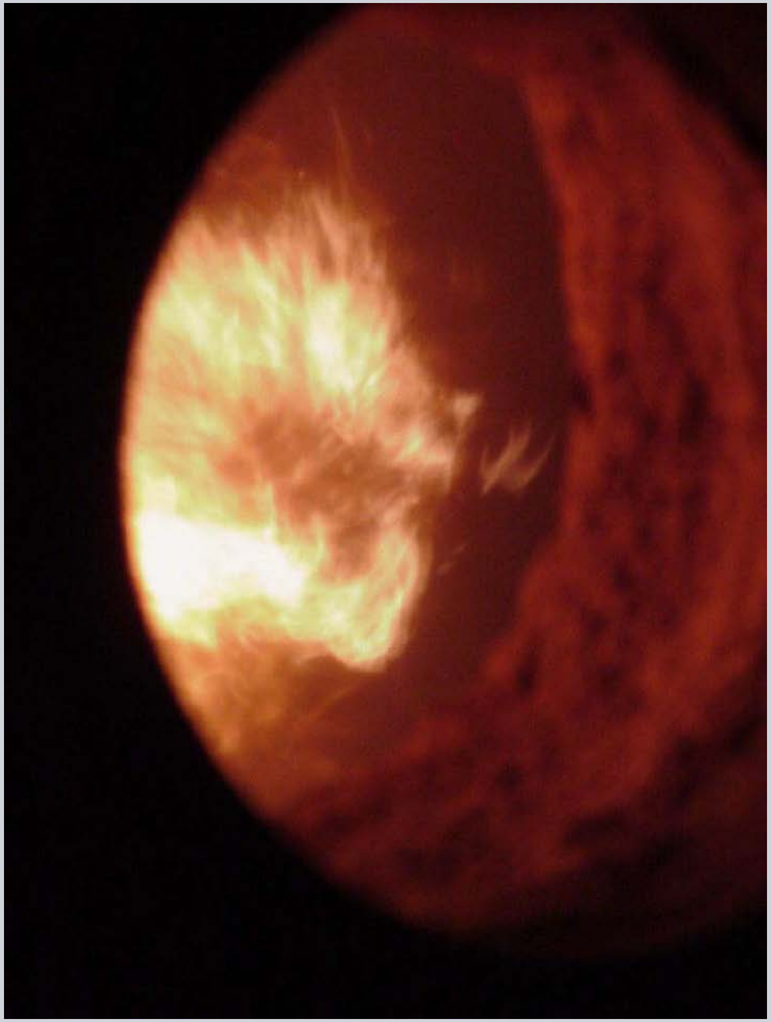
BURNER TIP

COAL FLOW DISTRIBUTION

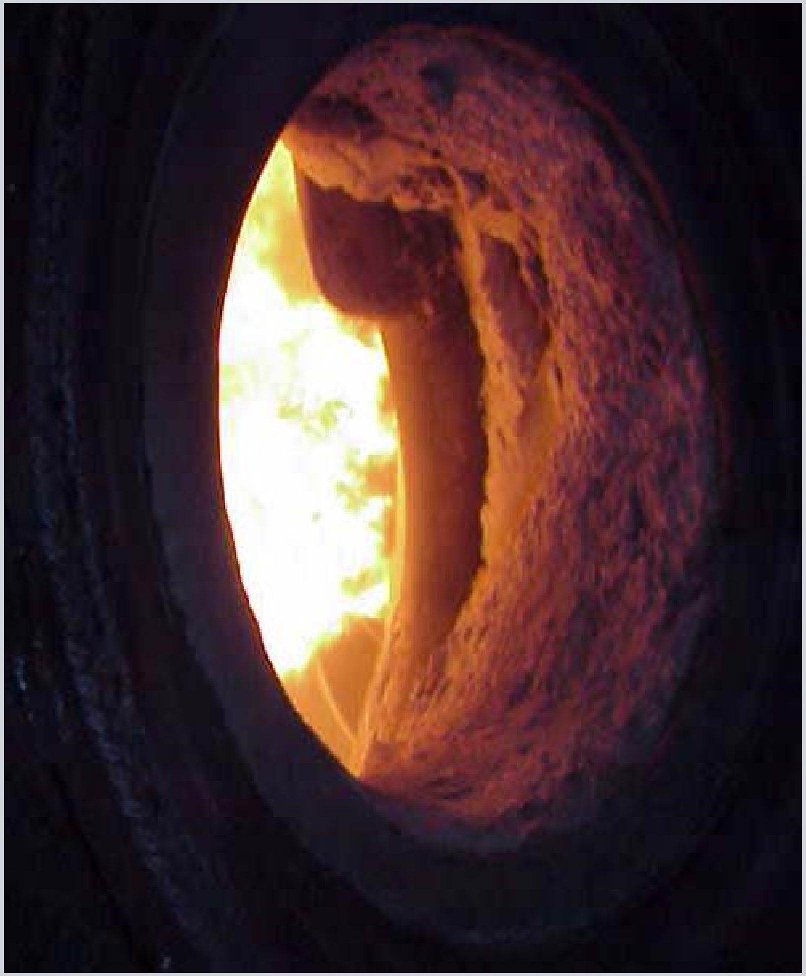
Burner Nozzle Coal Flow Distribution



Burner Flame Shape Generated From Poor Burner Nozzle Fuel Distribution



Burner Flame Shape Generated With Good Burner Nozzle Fuel Distribution



PRIMARY AIR FLOW

TUNING CONDITIONS

Primary Air Flow Issues

There are a number of issues that can affect the ability to operate the combustion system at the lowest possible NO_x levels. Some of these issues are as follows:

- Poor air flow distribution in the coal pipes
- Poor air flow distribution through the mill
- Incorrect air flow indication

Poor Air Flow Distribution in the Coal Pipes

Poor air flow distribution in the coal pipes is caused by some of the following conditions:

- Length and geometry (bends) of the individual coal pipes
- Coal pipe velocities
- Condition of any existing coal flow devices (orifices, etc.)

SIEMENS

Incorrect Air Flow Indication

Probably the most common cause of primary air flows that deviate from the design conditions of the burners is incorrect primary air flow indication.

There are two basic causes of incorrect primary air flow indication. They are as follows:

- Incorrect calibration of the existing flow measuring devices/control system factors

- Poor locations for the flow measuring devices.

SIEMENS

Effect of Incorrect Primary Air Flow

All burners are nothing more than flow device “orifices”. As such, they operate best at the design air flow and associated pressure drop.

Pressure drop is known to vary as the square of the velocity.

To illustrate how increased primary air flow affects the pressure drop, the following two examples are offered:

Primary air flow 10% high

Pressure drop = $(1.10)^2 = 1.21$

Primary air flow 15% high

Pressure drop = $(1.15)^2 = 1.32$

SIEMENS

Effect of Primary Air Flow Due To Fuel Change

As previously stated, pressure drop is known to vary as the square of the velocity.

Increased primary air flow due to a fuel change will affect the pressure drop in the fuel injector.

As an example, if a fuel change from bituminous coal to PRB is made, the coal flow and associated primary air flow would change.

Bituminous coal HHV = 10,500 Btu/lb, PRB HHV = 8,800 Btu/lb

For the same heat input per burner, the coal and associated air flow would increase by 10,500/8,800 = 1.19

Primary air flow 19% high

Pressure drop = $(1.19)^2 = 1.42$ or an increase in ΔP of 42%

Incorrect Air Flow Indication
Incorrect Calibration

SIEMENS

Most often the primary air flows indicated by the control system deviates from the actual primary air flow.

Most cases involve situations where the documentation suggests that the calibration is correct. However, upon testing the two do not match.

The actual versus the indicated primary air flows should be periodically checked and recalibrated as necessary.

Where the operational conditions of the mills dictate that the primary air flows must be higher than the design curves, this presents operational issues with the burners. There is no remedy for existing burrners. When specifying new burners, it is imperative that the actual (by test, not indication) primary air flows are provided for the design of the burners.

SIEMENS

TUNING

IS IT WORTH IT?

SIEMENS

Tuning Is Worth It

Fuel is the largest operating cost to producing electricity.

Small improvements in efficiency result in large fuel savings.

Properly planned and executed tuning reduces tuning cost and maximizes the benefits derived from tuning.

Tuning should include a review of the fuel fired to be sure it meets the specifications and the needs of the boiler. This is a very useful task, as coals tend to vary depending on the part of the mine it comes from.

Tuning is worth the effort when performed well and is performed in line with achieving predetermined goals.

Tuning Is Worth It
Maintaining Plant Operating Emission Limits

Local, state and federal limits on the production of NO_x must be continuously met.

Excedances, even for a short period of time, result in fines to the plant. Thus, if operating margins can be maintained or increased, the possibility of meeting the required limits are high.

As a side effect of the regulations, NO_x credits are financial “incentives” to reduce NO_x. These credits can either be sold as a revenue stream or banked to offset future expenditures by the utility in the event NO_x credits are needed for the operation of one or more units. The value of these credits is widely debated.

Tuning Is Worth It

The value of tuning must be shared by every employee.

Management must support tuning by providing the resources required to perform tuning.

Operators must make every effort to operate the unit to perform as required to evaluate its performance.

Lab technicians must collect coal and ash samples by the best methods and perform proper analyses.

Instrument technicians must make sure instruments are calibrates and in good working order.

All assigned to taking data must take collect the data as diligently as possible.

SIEMENS

Tuning Is Worth It When…

- ✓Goals are set
- ✓Proper preparation is performed
- ✓A test plan is prepared
- ✓All equipment is operating properly
- ✓Past tuning results are reviewed
- ✓A record with comparison of results and recommendations is made
- ✓All parties share the value of tuning

QUESTIONS??

SIEMENS