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COAL FIRED BOILER PERFORMANCE IMPROVEMENT THROUGH COMBUSTION OPTIMIZATION

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ABSTRACT

This paper presents an outline of boiler performance improvement by the implementation of a methodical approach. This method of testing and empirically derived design changes has resulted in immediate improvements in the flyash carbon loss content and unit heat rate.

The authors' experience, when working with a number of utilities, has been that heat rate improvements can be realized in the magnitude of 200 BTU/KwHr and greater. This is by the combined process of combustion improvements and plant operations and maintenance personnel awareness of performance factors that often are accepted as constants. The usual motivating factor to implement a combustion improvement program is to reduce flyash carbon loss. This paper will describe how testing and performance aimed at flyash carbon loss improvement can lead to additional unit efficiency improvements.

1.0 PREREQUISITES FOR OPTIMUM COMBUSTION

Combustion improvement testing and retrofit modifications to burners and pulverizer systems have been the primary interest of the authors for the last ten years or so. Pulverized coal boilers that are front wall fired, rear wall fired, opposed fired, down fired, corner fired, wet bottom and dry bottom, have been tested and evaluated. Based on these experiences, there are some common factors which are deemed to be optimum combustion prerequisites. The primary factors which have been identified are:

A. Furnace exit excess oxygen content shall be no less than 3% at any one point as measured by a water-cooled probe at the superheater inlet (furnace exit).

B. Pulverized fuel fineness shall be no less than 72% passing a 200 mesh screen, and with 1% maximum remaining on a 50 mesh screen.

C. Secondary air flow to the burners shall be balanced within about ± 10% of the mean flow.

D. Primary air flow should be balanced to within ± 2% of the mean on each pulverizer by the clean air method.

E. Pulverizer primary air flows should be balanced to within ± 10% or better from pulverizer to pulverizer.

F. Fuel flow balancing to the pulverizers should be controllable and balanced to within ± 10% of the mean.

G. Fuel flow from each fuel pipe should be balanced to within ± 10% of the mean.

H. Secondary air flow velocity should exceed primary air flow velocity by a factor of about 1.5 or 2.0 to 1.0. Secondary air velocity through the burner throats is optimum at about 7,000 fpm. Primary air/coal mixture velocity about 3,500 fpm - at full pulverizer and/or boiler load.

I. The optimum primary air/fuel ratio should be in the range of 1.5 to 2.0 pounds of air per pound of fuel for adequate coal drying in the pulverizer at full load, and preferably not exceed 3.0 pounds of air per pound of fuel at intermediate or low pulverizer loads.

J. Fuel line velocities at intermediate and low loads should not drop below 3,000 fpm.

K. Fuel feed rate should be constant, with smooth flow rate changes during load changes.

Most of the authors' experience has been on boilers firing Eastern Bituminous coal. However, some testing and experience has been obtained on Western Lignite fuels with moisture above 35% and as received, heating values in the range of 4,000 to 7,000 BTU/Lb.

Optimum combustion of these Western fuels has required many of the same prerequisites as Eastern fuels, with the exception of fuel fineness and the primary air/fuel ratios. That is, the minimum fineness of 72% passing a 200 mesh screen has not been, in our experience, as important on Lignite fuel as with Eastern Bituminous fuel.

The number one prerequisite for optimum combustion remains furnace exit excess oxygen balance, and a range of 3 to 3.8%. This measurement by use of a water-cooled HVT probe, as shown on Figure 1, is the first priority when beginning a combustion improvement program. Many balanced draft boilers have been found to have the total excess oxygen amount added to the flue gases by setting air in-leakage. This is difficult for many engineers to accept. However, after dozens of units have been found with zero excess oxygen at the nose arch area, and many corrected and retested, we know that this in-leakage situation is one of the primary causes of high unburned carbon content in older (say twenty-year old or greater) balanced draft boilers.

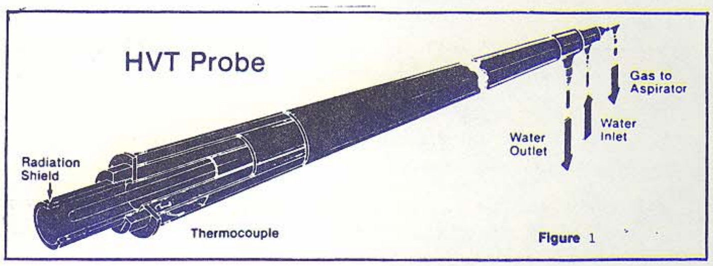


Figure 1

FIGURE 1: HVT PROBE

The HVT probe is most useful for combustion tuning when it is used to measure the furnace exit excess oxygen. The usual test points are shown on Figure 2.

H.V.T. TEST LOCATIONS

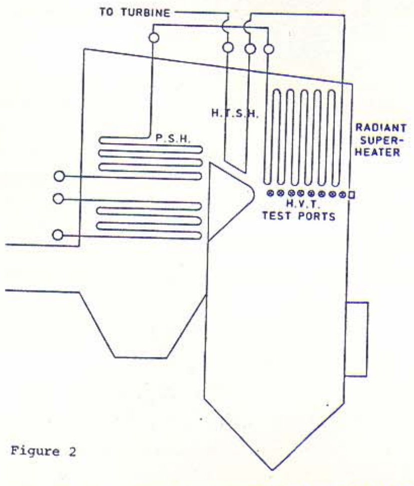


Figure 2

FIGURE 2: BOILER SECTIONAL ELEVATION DRAWING WITH HVT TEST POINTS SHOWN

Figure 3 shows a typical furnace exit excess oxygen profile. The furnace exit usually measures between 1,800°F and 2,200°F with the excess oxygen in the range of 3 to 3.8%. When the furnace exit is starved for air, and operating below 2% excess oxygen, it is common to find single points that exceed 2,700°F. This can lead to furnace exit slagging, fluid ash corrosion, and overheated superheater and reheater tubes.

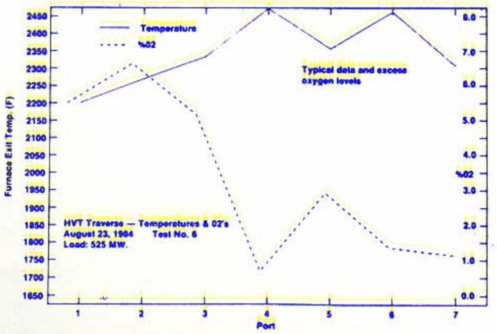


Figure 3 Typical HVT Data Plot at the Furnace Exit Corner Fired Boiler

FIGURE 3: HVT - DATA PLOT OF A TYPICAL FURNACE EXIT

Interestingly, when the furnace exit is very high in temperature (due to secondary combustion) and low in excess oxygen, the boiler exit gas temperature is usually only slightly increased.

Furnace exit excess oxygen levels and balance are important because the flue gas velocity at this point rapidly accelerates to the range of 35 to 60 fps. The fuel volatile is consumed in the lower furnace, and virtually the only combustible remaining in the fuel particles at the furnace exit is elemental carbon char. This requires a temperature of about 1,500°F to complete combustion. Therefore, as the furnace exit is approached, if the air and fuel have not thoroughly mixed at that point, then there is insufficient time to complete combustion before the flue gases are quenched below the ignition temperature of the carbon. Thus, any carbon remaining in the ash at the furnace exit is likely to remain unburned when it is collected in the particulate removal devices.

2.0 OPERATIONS AND MAINTENANCE CONTROLLED VARIABLES

Heat rate improvements of 200 BTU/KwHr or above were mentioned, and it is easily understood that if flyash unburned carbon loss is reduced from say 8% to 3%, that this would only represent a heat rate improvement of about 50 BTU/Lb. So a very logical question would be, how can we say that a combustion improvement program can result in unit heat rate improvements of 200 BTU/KwHr and above?

The experiences that the authors have obtained, through the cooperative efforts of many electric utilities, are that there are at least ten controllable heat rate variables, that once a program is begun, are identified and improved. Ten items are listed below. Nine out of ten of these items are controllable, at least to a certain extent, at the boiler.

The most accepted method of measuring boiler efficiency is the "heat loss" method. Most Eastern Bituminous coal fired utility boilers are capable of around 90% efficiency. It should be pointed out that 90% boiler efficiency can be maintained - yet unit heat rate penalties experienced at that given time may represent more than 2% - or about 200 BTU/KwHr.

This is because controllable heat rate factors such as steam temperatures, turbine initial pressure, fan and pulverizer auxiliary horsepower, and desuperheating spray water flow rates are controllable at the boiler, but are not factored into boiler efficiency calculations. These factors, especially on single and double stages of reheat units, can become very significant.

2.1 Ten Controllable Heat Rate Variables

2.1.1 Superheater outlet steam temperature.

2.1.2 Desuperheating water flow rate (superheat and reheat).

2.1.3 Reheater outlet steam temperature.

2.1.4 Auxiliary equipment horsepower.

2.1.5 Turbine throttle pressure.

2.1.6 Air heater outlet gas temperature.

2.1.7 Flyash loss on ignition.

2.1.8 Air heater leakage.

2.1.9 Boiler outlet excess oxygen.

2.1.10 Pulverizer coal dribble from pyrites.

Deviations from optimum on any of these individual items can lead to a cumulative effect that totals the range of 200 BTU/KwHr or more.

A typical example is shown below for a unit with two sets of data -- optimized and non-optimized. This example is based on a typical 400 Mw unit, designed for 2,400 psi operation with 1005°F main steam, and one stage of reheat to 1005°F.

Table 1

Item	Optimum	Non-Optimum	Approx. Heat Rate Change in BTU/KwHr.
Superheater Outlet	1005 F	980 F	+ 30
Reheater Outlet	1005 F	970 F	+ 45
Steam Turbine Throttle	2520	2350	+ 40
Air Heater Outlet Gas Temp. (on a No-Leakage Basis)	300	330	+ 90
Flyash Unburned Carbon	3%	7%	+ 40
Air Heater Leakage	7%	12%	+ 2
Coal Pulverizer Dribble	50 Lb./Day Max./Pulv.	500 Lb./Day/ Pulverizer	+ 90
Auxiliary Horsepower for Fans and Pulverizers	11 Mw	13 Mw	+ 50
			+ 387

This example of key parameters is typical of many operating units which we have seen operated. When a combustion improvement program is embarked upon, many of these non-optimum data can with very little trouble be corrected, through such simple changes as, say for the low steam temperatures, by reducing the number of cycles that the waterwall deslaggers are operated, and thus permit furnace wall fouling to reduce the furnace heat absorption, and raise the furnace exit gas temperature such that the steam temperatures are restored to the design level of 1005°F.

Other items such as reducing air heater leakage, and reducing air heater exit gas temperatures, will usually require an outage.

The points which should be made here are:

(1) The data points and heat rate changes, as in Table 1, are very approximate, but they are also realistic.

(2) Most operating units with which we have experience are capable of around 9,800 BTU/KwHr heat rate, by design.

(3) Few of these units operate much below 10,000 BTU/KwHr.

(4) These variables are controllable at the boiler.

Therefore, if the deviations listed in Table 1 are typical, then it is deviations such as these that could explain heat rates that are above those obtainable under ideal conditions.

Graphs of heat rate and boiler efficiency variations are shown on Figures 4 through 10. These graphs are simplified approximations of the effects of these seven heat rate variables. These graphs are based on calculated, or turbine manufacturers correction curves for a modern 2,400 psi 1000°F superheat, 1000°F reheat, 400 Mw pulverized coal fired unit.

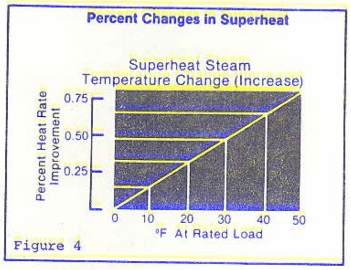


Figure 4

FIGURE 4: HEAT RATE CHANGE FOR SUPERHEAT TEMPERATURE DEVIATIONS FROM DESIGN

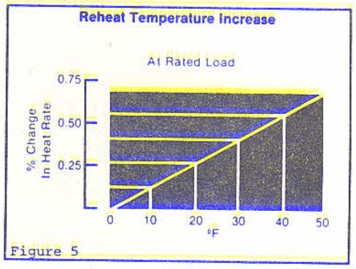


Figure 5

FIGURE 5: HEAT RATE CHANGE FOR REHEAT TEMPERATURE DEVIATIONS FROM DESIGN

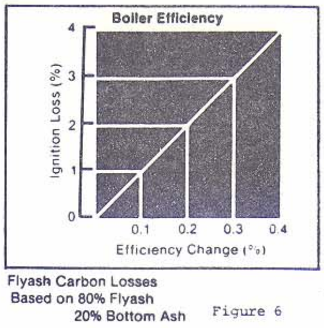


Figure 6

FIGURE 6: BOILER EFFICIENCY CHANGES WITH FLYASH CARBON LOSS VARIATIONS

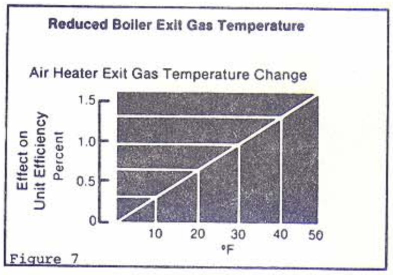


Figure 7

FIGURE 7: BOILER EXIT GAS TEMPERATURE CHANGES IN BOILER EFFICIENCY

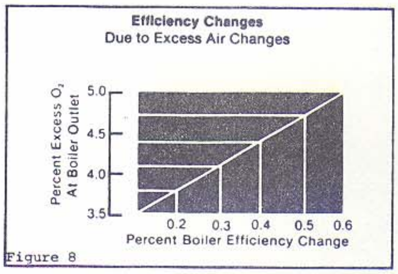


Figure 8

FIGURE 8: BOILER EFFICIENCY CHANGES DUE TO EXCESS AIR CHANGES

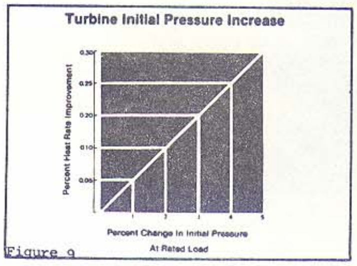


Figure 9

FIGURE 9: TURBINE INITIAL PRESSURE CHANGE IN HEAT RATE

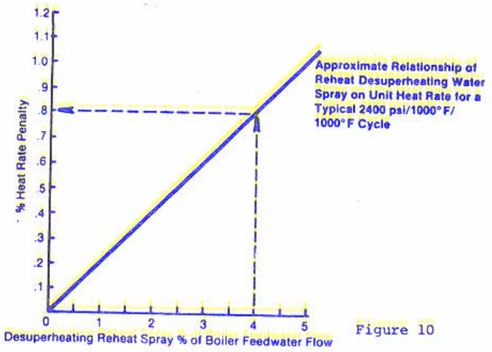


Figure 10

FIGURE 10: RELATIONSHIP OF REHEAT DESUPERHEATING SPRAY WATER FLOW ON UNIT HEAT RATE

3.0 DIAGNOSTIC TESTING TO QUANTIFY OPPORTUNITIES FOR IMPROVEMENT

3.1 Some Reasons for Local Test Instrumentation

Some of the controllable heat rate variables which have been discussed here can be measured with good accuracy from the control room instrumentation. That is such parameters as:

1. Superheater outlet steam temperature.
2. Reheater outlet steam temperature.
3. Turbine throttle pressure.
4. Desuperheating spray water flows.
5. Auxiliary equipment horsepower.

It has been our experience that the remaining five controllable heat rate variables either cannot be measured accurately by permanent instrumentation, or the instrumentation to do so is frequently not representative.

Let's take as an example flyash unburned carbon content, and air heater leakage; it is simply not possible to provide an instantaneous measurement of these parameters. Two other important factors, air heater exit gas temperature and boiler exit excess air, are frequently found to be in error. The most common reason found by the authors has been non-representative measuring points. A compounding factor for the air heater exit gas temperature measurement has been the influence of increasing air heater leakage causes a reduction in air heater exit gas temperature.

When a satisfactory temperature grid is utilized for air heater exit gas temperature measurement, the temperature should be corrected to a no-leakage basis. High air heater leakage of say 15%, when corrected to a no-leakage basis, will result in an exit gas temperature about 30°F higher than the measured amount. Thus, it can be seen that unidentified air heater leakage can provide a misleading unit efficiency indication even by accurate control room instrumentation.

3.2 Diagnostic Test Parameters and Equipment

Combustion optimization changes require quantification of certain data, such as:

1. Furnace exit gas temperatures and excess oxygen profiles.
2. Windbox secondary air flow balance.
3. Primary air flow measurement.
4. Representative flyash sampling.
5. Excess oxygen rise from the furnace to the economizer.
6. Pulverized fuel fineness.
7. Fuel flow balance.

3.2.1 Furnace Exit Measurements with the HVT Probe

Section 1.0 of this paper, and Figures 1, 2, and 3 describe the use of a water-cooled HVT probe for use in measurement of the furnace outlet gas temperature and excess oxygen profiles. This is, in the authors' experience, the single most important piece of test equipment for identifying whether combustion optimization is justified, and to what extent.

The furnace exit should be an oxidizing environment across the full width and depth, and for flyash unburned carbon content in the range of 2 to 3%, the excess oxygen should not measure below 3% at any single point. The excess oxygen rise from the furnace to the economizer outlet is determined by measurements at both locations--the furnace exit and the economizer exit. Ideally, the setting will be gas and air tight enough that no increase in excess oxygen is measured between the furnace and the economizer outlet.

3.2.2 Windbox Secondary Air Flow Measurements

Measurement of secondary air flows require that test connections be installed in the ductwork to permit a satisfactory measurement grid of each test plane. The authors utilize our own version of a forward-reverse pitot tube called a Stormshiebe probe. This is shown on Figure 11. The combustion air flow balancing between front and rear windboxes, between corners, and burner to burner are usually found to vary considerably.

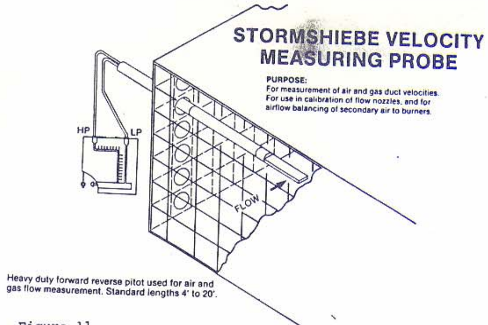


Figure 11

FIGURE 11: STORMSHIEBE FORWARD-REVERSE PITOT TUBE

For example, on wall fired units, the front to rear imbalance may be 60% - 40%; on corner fired units, the imbalance may be as much as 50% deviations from a high air flow corner to a low air flow corner. Laminar flow type burners at one level may have burner to burner air flow deviations that exceed 50%.

Once these flow imbalances are identified and quantified, corrective action can be initiated, such as the installation of turning vanes or splitter dampers. Figure 12 shows typical secondary air flow distribution to the four corners of a corner fired boiler.

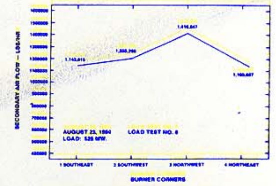


Figure 12 Secondary Air Flow Traverse

FIGURE 12: SECONDARY AIR FLOW GRAPH

3.2.3 Primary Air Flow Measurement

The primary air flow quantity is important for at least four reasons:

1. Optimum combustion is usually dependent on proper burner primary air velocities.
2. The primary air/fuel ratio should be in the proper range - usually about 1.5 to 2.0 pounds of air per pound of fuel to permit satisfactory moisture removal in the pulverizer.
3. Satisfactory pulverizer velocities are necessary for consistent fuel fineness, and to provide minimum coal rejects or dribble.
4. Primary air/fuel mixture trajectory into the furnace, in our experience, is important for optimization of heat release and carbon burn out.

The best measurement of primary air flow, in the authors' experience, is to install permanent flow nozzles or venturis. Often this is not practical, so test connections are installed to measure the primary air entering the pulverizers. For pulverizers with ambient air intakes, a measuring box is installed such as that shown on Figure 13.

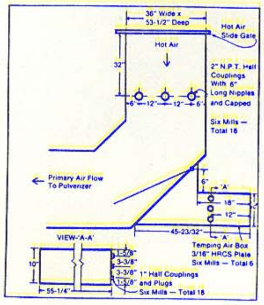
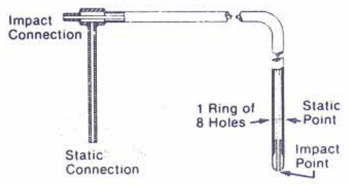


Figure 13 Hot Primary and Tempering Air Test Ports

FIGURE 13: PRIMARY AIR FLOW MEASUREMENT AT THE PULVERIZER INLET

For measurement of the pulverizer hot and tempering air flows, either a standard pitot tube (Figure 14), or a Stormshiebe probe is used.

Figure 14 Pitot-Static Tube



K factor = 1.0

FIGURE 14: STANDARD PITOT TUBE

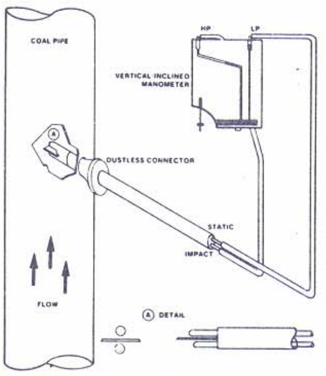
3.2.4 Fuel Line Balancing and Pulverized Coal Sampling

Fuel line balancing is imperative for optimum combustion. The authors have used three techniques for determining fuel line balancing:

1. Clean air testing of velocities.
2. Dirty air velocity testing.
3. Air/fuel ratio sampling.

Clean air testing is accomplished by use of a standard pitot tube. The coal pipes are traversed, usually through at least ten points in two axis, 90° apart to calculate flow rate. All coal pipes are traversed from each pulverizer at a constant primary air flow, with no coal flow, thus the term clean air test. Fuel lines are then orificed to obtain velocity balance.

The dirty air method utilizes a probe, as shown on Figure 15, to measure the coal pipe velocity of the flowing primary air pulverized coal mixture. The advantage of this probe and method is that actual fuel line velocities can be measured with the coal pulverizers in normal service. Further, it is a check on the primary air flow measurements at the pulverizer inlet.



COAL PIPE "DIRTY AIR" VELOCITY MEASURING PROBE FOR DETERMINING IN SERVICE COAL/AIR MIXTURE VELOCITIES

Figure 15 Dirty Air Probe

FIGURE 15: DIRTY AIR PROBE

Sometimes the coal line velocity profiles as measured by the clean air method and the dirty air method agree very well, such as on Figures 16 and 17. This clean air - dirty air agreement is attributed to balanced air/fuel ratios to all coal pipes.

Figure 16 Dirty Air Burner Line Velocity — A Mill

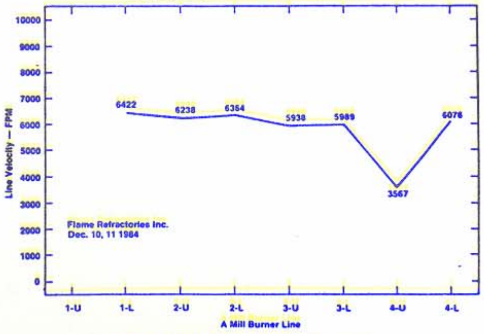
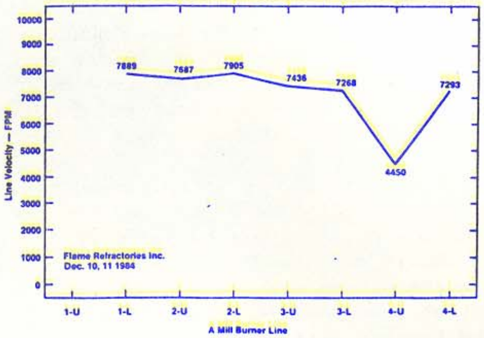


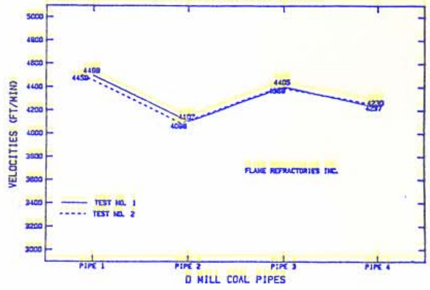
Figure 17 Clean Air Burner Line Velocities — A Mill



FIGURES 16 and 17: CLEAN AIR/DIRTY AIR VELOCITY GRAPHS

Then sometimes, as shown on Figure 18, the clean air method and the dirty air method velocity measurements do not result in the same indicated fuel line distributions of velocity.

Figure 18 CLEAN AIR VELOCITIES



DIRTY AIR VELOCITIES

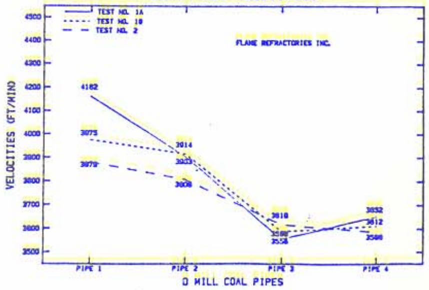


FIGURE 18: CLEAN AIR/DIRTY AIR VELOCITY BALANCE

This difference is attributed to fuel stratifications, with the pipes that receive heavier fuel feed resulting in lower dirty air velocities as a result of the necessary energy needed to accelerate the greater quantity of pulverized coal. Sometimes the dirty air velocity profiles are not constant due to uneven pulverized coal discharge from the pulverizers or classifiers.

For these reasons, the authors prefer to utilize both the clean air and dirty air methods.

The air/fuel ratio sampler has been developed by the authors as a tool to measure the air/fuel ratio in each fuel pipe. This device is shown on Figure 19. The probe and cyclone collector portions of the air/fuel ratio sampler are similar to the ASME Performance Test Code No. 4.2 device parameters.

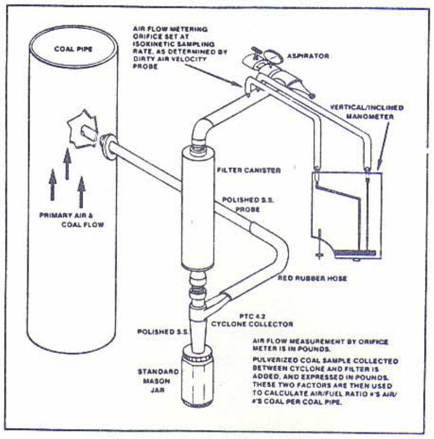


Figure 19. **Flame Air/Fuel Sampler**

FIGURE 19: AIR/FUEL RATIO SAMPLER

The authors have added the filter canister and air flow metering orifice portions. The air/fuel ratio sampler is an isokinetic coal sampler.

The dirty air velocity traverses and the air/fuel ratio sampler extracted coal samples should be removed through test penetrations installed on vertical straight runs of coal pipes, in as long a run as possible. Some pulverizer exhausters have test connections mounted at the exhauster discharge. This is a highly stratified zone, with coal particle size classifications favoring larger particles to one side. Please see Figure 20.

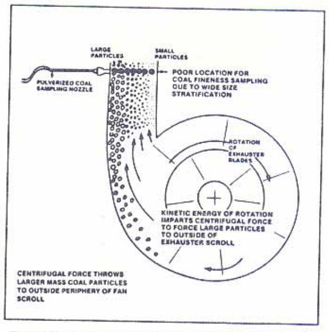
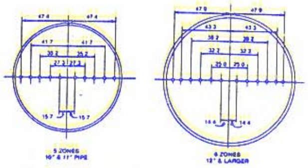


Figure 20 **Sampling Pulverized Coal at the Outlet of an Exhauster Can Cause Non-Representative Coal Fineness Sampling**

FIGURE 20: PULVERIZED COAL SAMPLING AT THE OUTLET OF AN EXHAUSTER

Straight pipe sampling locations should be through ten to twelve points across the pipe diameters, and at least two diameters. Please see Figure 21 for test point layout.

Figure 21



SAMPLING DIRECT-FIRED PULVERIZED COAL-SAMPLING STATIONS
DIMENSIONS ARE "PERCENT OF PIPE DIA."

FIGURE 21: LAYOUT OF POINTS FOR SAMPLING EQUAL AREAS OF COAL PIPES

The fuel line velocity is determined with the dirty air probe, Figure 15, and then the air/fuel ratio sampler flow rate is adjusted by the aspirating air pressure to withdraw pulverized coal and primary air from the coal pipes at an isokinetic rate. This isokinetic sample removal results in improved plotting of fuel fineness on the Rosin and Rammler chart, as shown on Figure 22. The preferred pulverized coal fineness is plotted on Figure 22--specifically, less than 1% remaining on a 50 mesh screen, and a minimum of 72% passing a 200 mesh screen.

Figure 22 **Pulverized Coal Sampling Chart With Typical Coal Fineness Sample Plotted**

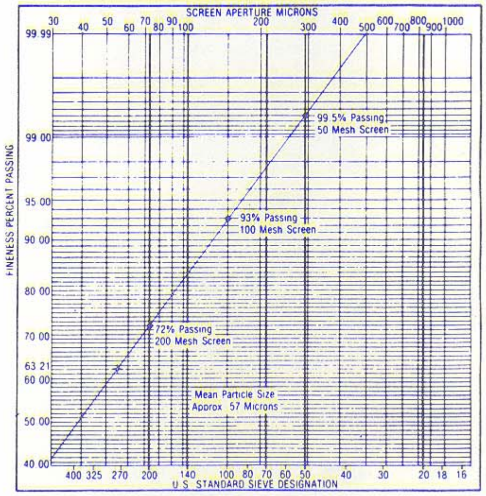


FIGURE 22: COAL FINENESS PLOTTED ON ROSIN AND RAMMLER CHART

Fuel balancing and some methods to accomplish same, is a subject that, treated in depth, would require more space than permitted in this paper. Fuel balancing is important, and these three methods of clean air testing, dirty air testing, and the air/fuel ratio sampler all have their part in the identification of fuel imbalance, and to what extent. This data is then used for corrective action which includes fuel pipe reorificing, pulverizer classifier modifications, and pulverizer modifications.

3.2.5 Flyash Sampling

Representative flyash sampling is important to obtain flyash samples that are representative of the pulverizer, burner, and furnace conditions that are measured at nearly the same time.

The most straightforward method to obtain representative flyash samples, which the authors have used, is to use a flue inserted flyash sampler as shown on Figures 23 and 24. The flyash which is collected in either the isokinetic or high volume type samplers is sieved through a 200 mesh screen, and then analyzed for combustibles loss or carbon content. A large fraction of carbon content in the ash remaining on a 200 mesh screen suggests pulverizer fineness as a major contributor. Carbon contents exceeding 2% of the fine particles suggests one of the following:

1. A furnace reducing atmosphere (insufficient oxygen in the furnace for complete combustion).
2. Non-optimum mixing of the fuel and air in the burners due to burner part damage.
3. Primary air flow rates too high.
4. Fuel line imbalances.
5. Secondary air flow imbalances.

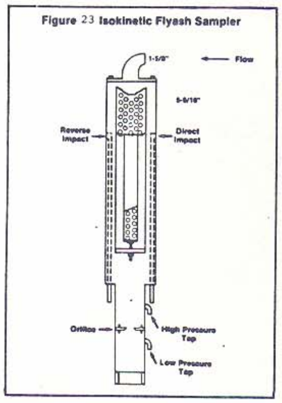
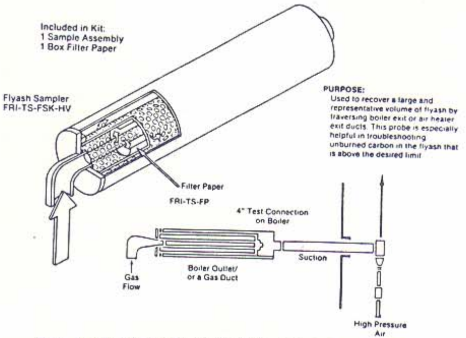


Figure 23 **Isokinetic Flyash Sampler**

FIGURE 23: ISOKINETIC FLYASH SAMPLER



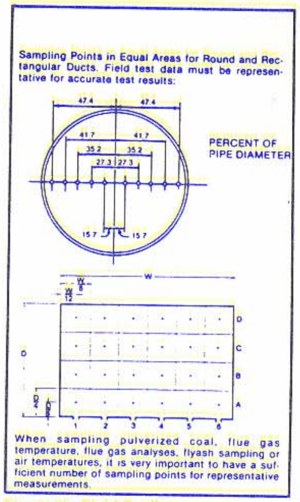
PURPOSE:
Used to recover a large and representative volume of flyash by traversing boiler exit or air heater exit ducts. This probe is especially helpful in troubleshooting unburned carbon in the flyash that is above the desired limit.

FRI HIGH VOLUME FLYASH SAMPLER
(Flue Inserted Type)

Figure 24

FIGURE 24: HIGH VOLUME FLYASH SAMPLER

The flyash sampler should be used in a sample grid of the ductwork of one sampling point for each 9 $Ft.^2$ of duct cross-sectional area. Please refer to Figure 25.


Sampling Points in Equal Areas for Round and Rectangular Ducts. Field test data must be representative for accurate test results:

When sampling pulverized coal, flue gas temperature, flue gas analyses, flyash sampling or air temperatures, it is very important to have a sufficient number of sampling points for representative measurements.

Figure 25 **Field Testing — Sample Points**

FIGURE 25: FLYASH SAMPLING GRID

3.2.6 Air Heater Performance Measurements

Nearly every plant results group performs air heater inlet and outlet gas analyses and temperature measurements. This remains an important component of diagnostic testing. Use of this data with the furnace exit HVT probe data is useful not only for identifying oxygen rise across the boiler convection pass, but also to compare single point stratifications--that is, the oxygen and temperature measurements at individual points in the measuring grid. Typical data plots of air heater inlet and outlet gas analyses and temperatures are plotted on Figures 26 and 27.

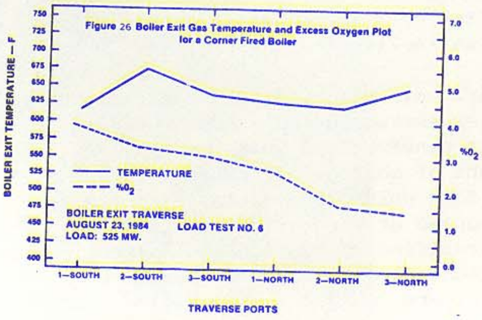


Figure 26 **Boiler Exit Gas Temperature and Excess Oxygen Plot for a Corner Fired Boiler**

FIGURE 26: BOILER OUTLET GAS AND TEMPERATURE MEASUREMENT GRAPHICAL PLOT

Figure 27 **Airheater Exit Gas Analysis and Temperatures for a Corner Fired Boiler**

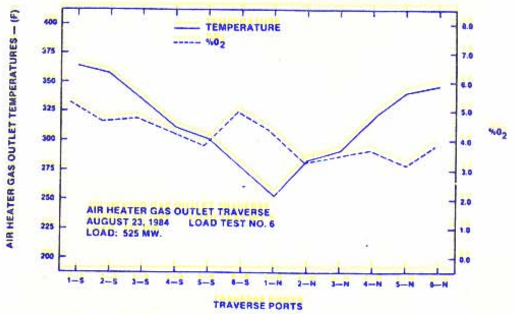


FIGURE 27: AIR HEATER EXIT GAS DUCT GAS ANALYSES AND TEMPERATURE GRAPHICAL PLOT

3.3 Diagnostic Testing -- Personnel

Testing as described in the foregoing is most helpful from a diagnostic standpoint when it is performed as close as practical to simultaneously, and at steady state boiler load conditions. The testing is then repeated for a number of loads (sometimes referred to as "load tests") to ascertain the performance trends, steam temperature characteristics, flyash unburned carbon content at varied loads, and other factors. Obviously, to do this a large test team is required.

The experience gained by the authors has been with the utilization of test personnel from plant results, operations, maintenance, engineering, and a small number of consultants. A typical test team is outlined here by the test stations:

Furnace exit HVT	6
Air heater gas and temperature traverses	2
Flyash sampling	2
Pulverizer primary air	2
Pulverizer air/fuel samplers	6 (two teams)
Control room data	1
Windbox velocity traverses	3
Roving test technical director/supervisor	1
Total Personnel	23

Often, due to limitations of personnel, the pulverizer testing is completed as a separate item, and this reduces the personnel listed above by six persons, for a total boiler test crew of 17. This number of personnel exceeds most results testing groups in the plants which we have worked. The personnel do not all have to be test engineers, and in fact, there are added benefits in not using all test engineers. The side benefits are that operations, maintenance, and engineering personnel can function on the effort together, with a common goal of improved performance.

By working together on a program such as this, the operators, for example, can actually see and participate in measuring the furnace exit flue gas temperatures. This is data that the operators would rarely see on control room instrumentation. Further, if changes were made to improve the excess oxygen balance at the furnace exit, by moving splitter dampers or changing pulverizer primary air flows, then there is more valid feedback to the operating staff by actual personal experience and word of mouth, rather than by written procedures.

Similarly, if velocity measurements are taken in the combustion air ducts by a group including plant mechanics, and it is found that turning vanes or splitter dampers are required to balance the flows, then the installation of those devices later at a scheduled outage is more thoroughly understood by the men who are issued the work orders to install the changes.

There are disadvantages to using non-test experienced personnel also. It is suggested that this be handled in two ways:

1. Provide one experienced test person at each test location. The above example has six test locations, five if the pulverizer fineness and air/fuel ratio samples are taken separately.
2. Plan on replicate tests to ensure that definite trends are identified. Three tests at each load point should be considered.

It is highly likely that much of the data outlined here has never been measured on many boilers. These measurements open opportunities for improvement by identifying performance improvements that can be prioritized.

4.0 WALL FIRED BOILER -- BURNER CHANGES

There are a number of prerequisites that should be addressed when undertaking a combustion improvement program. Some items seem obvious, but because of their importance, we shall list them:

4.0.1 Coal nozzles must be centered in burner throats within ± 1/4".

4.0.2 Scroll type burners should have nozzles and tertiary air tubes centered with ± 1/4" of the same center as the burner throats.

4.0.3 Coal impellers or spreaders should be centered in the coal nozzles to within ± 1/4" of coal nozzle centerline.

4.0.4 Coal spreaders or impellers that impart a spin on the primary air, coal mixture, and scroll type burners should spin in the same rotation on each respective burner. Usually, adjacent burners rotate in opposite directions. This, in our experience, is satisfactory, and in fact means little. The secondary air and primary air, though, must spin in the same rotation on each burner.

4.0.5 The air register blades should open symmetrically around the register for uniform air flow through the burner throat.

4.0.6 Coal nozzle depths should be similar with respect to burner throats contours.

4.0.7 Coal nozzles should be perpendicular to the furnace walls - not tilted up or down.

Please refer to Figure 28, which highlights many of these critical dimensions. Now, these dimensions are correct, and some may call this "blueprinting" or simply restoring the dimensions to brand new tolerances.

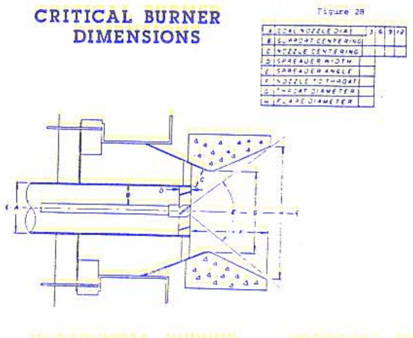


FIGURE 28: HORIZONTAL BURNER -- CRITICAL MEASUREMENTS AND VELOCITIES

4.1 Burner Changes to Achieve Optimum Combustion

It is likely that the desired 3% range flyash unburned carbon loss may not be achieved with restoring critical dimensions to like-new tolerances. The parameters that should be changed to reach optimum combustion are:

4.1.1 Reduce burner throats for a secondary air velocity of 7,000 to 7,500 fpm at full load.

4.1.2 Shroud the air registers to increase velocity over the register blades. The open area of the shrouded register periphery should be about two times the burner throat diameter.

4.1.3 Balance fuel line velocities to within ± 2% of mean by clean air velocity traverses.

4.1.4 Balance secondary air flow to front and rear windboxes, and as much as practical to equal distribution to all burners.

4.1.5 Balance fuel flow to all burners to within ± 10% by a combination of classifier, riffle, pulverizer, and fuel line orifice changes.

4.1.6 Install burner coal nozzle spreader/spinners that swirl the fuel into the burner throats for uniform diffusion, heat release, and symmetrical burning.

4.2 Performance Expectations with the Changes Outlined

It is possible to obtain flyash carbon loss levels as low as 2% when the preceding parameters are applied. This is including the very important prerequisites that 3% minimum excess oxygen is available at every single point of the furnace exit, and specified fuel fineness of 72% passing 200 mesh screen with a maximum of 1% on a 50 mesh screen.

Again, it is worth stating the importance of the water-cooled HVT probe measurements at the furnace exit. These are the measurements that prove that all items in the aforementioned 4.0 and 4.1 Sections are effective and successful.

5.0 CORNER FIRED BOILER BURNER CHANGES

Just as the wall fired boiler burners have certain prerequisites, so do corner fired boiler burners. Among those:

1. Tilts must be timed within ± 5°.
2. Auxiliary air and fuel air dampers must be in serviceable condition, and damper shafts accurately marked for damper positions monitoring when the boiler is in operation.
3. Fuel line balancing should be accomplished just as wall fired boilers; that is, balanced by clean air and then by dirty air and air/fuel ratio traverses and changes.
4. Fuel fineness should be measured in straight coal pipes, and the pulverizers primary air flow and classifiers "tuned" to achieve the same desired coal fineness of 72% passing 200 mesh, and 1% maximum remaining on a 50 mesh screen.

5.1 Burner Changes to Achieve Optimum Combustion on Corner Fired Boilers

5.1.1 Secondary air flow balancing to the corners is accomplished after determining which corners are starved for air by use of splitter dampers and/or turning vanes.

5.1.2 The installation of perforated plate in the windbox corners, designed for two to four inches of water pressure drop, permits maintenance of a higher windbox to furnace differential with wider opening of the auxiliary and fuel air dampers. This wider average opening provides less chance for unbalanced air flows to the various levels, or different corners.

Those boilers which have had perforated plate installed for a modest pressure drop have tended to operate with more uniform combustion, lower flyash unburned carbon content, and other reliability factors relating to slagging, waterwall wastage, and waterwall overheating.

5.2 Performance Expectations with the Changes Outlined for Corner Fired Boilers

Flyash unburned carbon content almost always is reduced with tilting burners angled downward, as compared to angled up. Therefore, changes that result in more superheater and reheater heat absorption tend to contribute to improved flyash carbon loss, as the tilts are angled downward to compensate for the improved superheater or reheater absorptions.

Some pulverized coal fueled corner fired boilers have been equipped with flue gas recirculation fans. Operation of the gas recirculation fans with the tilts down, to compensate for the increased flue gas mass flow, has resulted in a carbon loss reduction from the range of 4 to 5% to the range of 2 to 3%, with other factors remaining constant.

The authors' experience regarding corner fired boilers has been that combustion is improved as more balance of primary air flows, secondary air flows, and fuel flows is achieved.

6.0 PULVERIZER SYSTEM PERFORMANCE FACTORS

Optimum combustion depends on balanced fuel flow distribution, as well as balanced combustion air flow distribution. The coal pulverizers are key components in preparing and distributing fuel to the burners.

The prerequisites for combustion, with which this paper began, included parameters that must be achieved at the pulverizers. These are:

6.0.1 Pulverized fuel fineness of a minimum of 72% passing a 200 mesh screen, and 1% maximum remaining on a 50 mesh screen.

6.0.2 Primary air flow should be balanced to within ± 10% of the mean from pulverizer to pulverizer.

6.0.3 Fuel flow to each burner should be balanced to within ± 10% of the mean.

6.0.4 The primary air/fuel ratio mixture should be adequate to remove the moisture from the fuel by creating sufficient heat input. Usually this requires an air/fuel ratio of between 1.5 and 2.0 to 1.0.

6.0.5 Medium speed Roll and Race, or Bowl type pulverizers should have a primary air throat velocity above 6,500 fpm to minimize coal dribble.

6.0.6 Primary air velocities should be controllable to permit smooth load changes without fuel slugging or coal line settling.

6.0.7 Primary air flow quantities should be consistent for optimum pulverizer performance as well as optimum combustion in the burner belt zone of the furnace.

6.1 Pulverizer Performance Improvement Changes

6.1.1 Precise primary air flow control is achieved by installing accurate primary air flow measuring flow nozzles or venturis. Please see Figure 29.

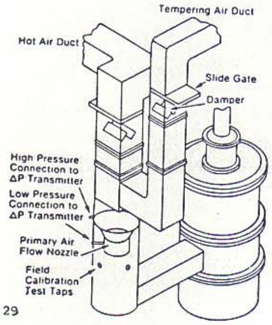


Figure 29

FIGURE 29: PRIMARY AIR FLOW MEASURING VENTURI

6.1.2 Coal dribble is minimized by adjusting the pulverizer throat opening to yield a 6,500 fpm velocity minimum. This velocity has been empirically derived, and is a calculated value based on the throat area and the measured primary air flow quantity. A rotating interfuser has been developed by Flame for use in shallow Bowl Mill type pulverizers. Data on the performance of a number 823 Bowl Mill is included on Table 2.

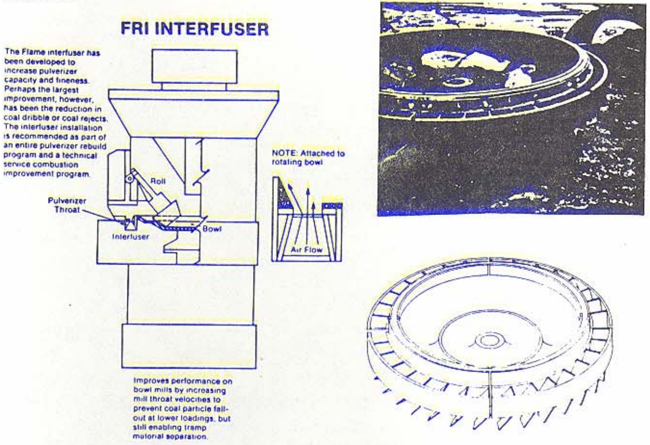
Table 2

"B" MILL (823 PULVERIZER)

	Before Modifications Full Mill Load	After Modifications at Same Load	After Modifications at Full Load
(Kw)	584	540	640
Feeder Speed	70%	70%	85%
Bowl Diff.	7.15	6.2	7.9
Coal Flow Lb/Hr.	86,076	91,795	107,095 Lb/Hr.
Hardgrove Grindability	63.5	66.0	61.0
Time Taken to Fill Pyrite Tank	45 Mins.	No coal dribble within 8 Hrs.	No coal dribble within 8 Hrs.

This Bowl has been retrofitted with a primary air flow measuring flow nozzle, an exhauster inlet cone, and an interfuser. The interfuser is described on Figure 30. Sufficient throat velocity is designed into this device to minimize coal dribble. The rotation of the angular vanes creates a mixing action to improve pulverizer circulation, which enhances fines production and uniform loading of the grinding surfaces.

Figure 30



The Flame interfuser has been developed to increase pulverizer capacity and fineness. Perhaps the largest improvement, however, has been the reduction in coal dribble or coal rejects. The interfuser installation is recommended as part of an entire pulverizer rebuild program and a technical service combustion improvement program.

Improves performance on bowl mills by increasing mill throat velocities to prevent coal particle fall-out at lower loadings, but still enabling tramp mutorial seperation.

FIGURE 30: INTERFUSER FOR INSTALLATION IN SHALLOW BOWL MILL TYPE PULVERIZERS

6.1.3 Pulverized fuel balance to each of the coal lines must sometimes be corrected with pulverizer and/or classifier changes. For centrifugal classifier equipped pulverizers, the authors' experience has been very favorable in introducing changes which promote spin--substitution of curved classifier blades with straight blades, as one example.

Other changes include classifier internal skirt length changes and classifier blade extensions to enhance the mixing (by swirling) effect.

6.1.4 Ball tube mill pulverizers have perhaps the greatest opportunities for imporvement because of their large power consumption. Some typical changes to ball tube mill pulverizer systems are:

6.1.4.1 Substitution of smaller grinding balls for more grinding surface area, and less drive motor horsepower.

6.1.4.2 Ball mill inlet/outlet baffle seal changes and open area adjustments.

6.1.4.3 Primary air flow measurement by flow nozzles or venturis, and classifier changes similar to the medium speed pulverizer classifier modifications.

6.2 Performance Improvement Expectations Following the Changes Described

The usual changes are increased pulverizer fineness and capacity for a given input horsepower. This combination then contributes to reduced flyash carbon loss and, in general, improved combustion. The pulverizer throat reductions which have been implemented were crucial for a number of factors. The plant operators will typically operate at high enough primary air flow to counteract coal dribble. That is, if coal dribble is a problem at optimum primary air flow rates from a combustion consideration, then to eliminate the dribble, the primary air flow is increased for optimum "dribble" (coal rejects), but compromised combustion. Let's look at this example:

A boiler is equipped with four Roll and Race type pulverizers, and any time the primary air flow is dropped below 2.2 pounds of air per pound of fuel, coal dribble is excessive--in the magnitude of hundreds of pounds per hour. Compensation is done by the operators to operate the oversized primary air fans at about 2.5 pounds of air per pound of fuel. This works out satisfactorily enough that full boiler load can be achieved, and the boilers acceptance test is passed. This situation is common, and here are some opportunities for heat rate improvement. These improvements will become possible in this situation, because accurate flow nozzles have already been installed, and only one change is required--reduce the pulverizer throat area.

The improvements are as follows.

A. Primary air fan horsepower is reduced.

B. Flyash carbon loss is reduced from the range of 6% to about 4%.

C. The boiler dry gas loss (air heater exit gas temperature) is slightly improved because the quantity of tempering air that bypasses the air heater is reduced.

D. Low load flame stability is improved.

E. Fewer superheater tube metal thermocouple temperatures are into alarm, due to the more balanced furnace heat release.

F. Greater pulverizer turn-down is achieved without ignitor flame support, due to the more favorable (lower) primary air - coal mixture velocities.

G. Fuel fineness improved due to less tendency of the larger coal particles to break out of the classifier spinning action.

All of these factors are the result of simply sizing the pulverizer throats for optimum primary air flows. Figure 31 shows this relationship.

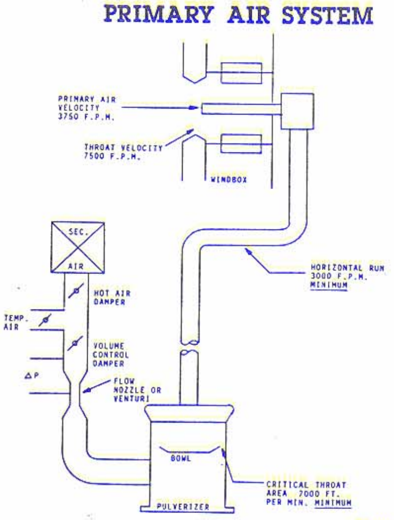


Figure 31

FIGURE 31: PRIMARY AIR FLOW CONSIDERATIONS

7.0 PERFORMANCE IMPROVEMENT RESULTS

Tables of pertinent data from four units which have been tested and optimized are shown in Tables 3, 4, 5, and 6. The improvements to these units were initiated in the interest of combustion improvement. The end result was unit heat rate improvements that more than exceeded the flyash unburned carbon loss improvements.

Table 3

CORNER FIRED UNIT

	Phase A	Phase B	Phase C
Mw	378	370	340
"4A" F.D. Fan	130	150	143
"4B" F.D. Fan	130	150	137
Reheat	951	970	997
Left Superheat	966	995	1000
Right Superheat	978	992	1000
Left Excess O_2	1.9	1.9	3.5
Right Excess O_2	2.1	4.6	3.5
LOI	21.1	4.01	3.5

Phase A: Pre-Outage Test

Phase B: Added Flow Nozzles and Perforated Plate

Phase C: Installed Refractory Baffle Wall at Nose Arch

Table 4

WET BOTTOM TURBO

	Phase A	Phase B	Phase C	Phase D
Mw	340	388	395	400
Exit Gas Temp.	340	311	310	314
F.D. Fan Amps	363	320	370	362
Reheat Spray	62	0	0	20
Superheat Spray	63	0	9	23
Final Reheat	968	992	990	1000
Final Superheat	992	995	990	1000
Main Pass Damper	50	65	86	100
Bypass Damper	100	100	74	50
Excess O_2	3.6	3.1	2.4	2.3
Flyash Comb.	6.9	5.3	2.6	2.6

Phase A: Burner Nozzle Modifications to Remove Spreaders

Phase B: Balanced Coal Pipes
Balanced Secondary Air
Burner Modifications to Increase Secondary Air Velocity
Interior Modifications

Phase C: Permanent Burner Modifications
Extended Convection Pass Division
Baffle Wall to above PSH Tubes

Phase D: Post Modifications

Table 5

CORNER FIRED UNIT

	Phase 1	Phase 2	Phase 3
Mw	530	525	530
Reheat (°F)	985	999	996
Furnace Temp. (°F)	2387	2389	2209
Economizer Exit Gas Temp. (°F)	627	575	623
Air Heater Exit Temp. (°F)	294	244	288
Excess O_2	0%	1.3%	3.2%
Unburned Carbon Loss	10.5%	7.95%	3.7%

Phase 1: Pre-Outage Benchmark Test

Phase 2: Installation of:

- A) Flow Nozzles In Primary Air Ducts
- B) Refractory Kicker Wall at Nose Arch
- C) Perforated Kicker Wall Prior to Horizontal Tubes
- D) Perforated Plate in Burner Corners
- E) FRI Air Flow Interfuser
- F) I.D. Fan Anti-Spin Baffles

Phase 3: Balance Secondary Air Flow
Close Oil Air Dampers

Table 6

370 Mw Front and Rear Wall Fired Unit

	Before Changes	After Changes
Load Capability	370 Mw	370 Mw
Auxiliary Power for Fans & Pulv.'s	13.4 Mw	12.4 Mw
Superheat Spray Flow	382,000 #/Hr.	212,000 #/Hr.
Reheat Spray Flow	98,000 #/Hr.	64,000 #/Hr.
Flyash Unburned Carbon Loss (%)	6.25%	3.7%

Changes:

1. Balanced secondary air flow to four compartments.
2. Installed primary air flow measuring flow nozzles for accurate primary air flow measurement and control.
3. Installed pre-spin vanes in primary air fans (which were oversized) to limit unneeded primary air fan motor horsepower input.
4. Reduced pulverizer throat areas to permit reduced primary air flow with minimal coal dribble.
5. Centered coal nozzles, and precisely stroked air registers.
6. Installed I.D. fan and P.A. fan, seal strips to reduce fan wheel air/gas circulation.