2367 LAKESIDE DRIVE, SUITE A-1 BIRMINGHAM, AL 35244
PHONE (205) 453-0236 FACSIMILE (205) 453-0239
www.innovativecombustion.com

Innovative Combustion Technologies, Inc.

A SUMMARY OF EXPERIENCES RELATED TO ACHIEVING OPTIMUM PULVERIZER PERFORMANCE AND FUEL LINE BALANCE

Modern utility and industrial burners utilize many independent coal burners to deliver fuel to the furnace for combustion. The number of burners a boiler is equipped with depends on the number of pulverizers and furnace configuration. Typical burner configurations include single wall firing, opposed wall firing and tangential firing. Modern boilers of electric utility size are usually equipped with (18) to (88) separate coal burners. To achieve optimum and efficient combustion of coal, equal quantities of fuel must be delivered to each of the separate burners.

An overwhelming majority of coal fired boilers utilize a pulverized coal firing system. These systems utilize a pulverizer or mill to grind coal to a desired fineness and subsequently transport the coal to the burners using air as a transport medium. Air utilized to transport coal to the burners is considered “Primary Air”. Primary air serves two purposes, these are:

- Transportation of pulverized coal from the pulverizer to the burner.
- Provides the necessary heat requirement to facilitate evaporation of surface and inherent moisture in the coal.

After coal and air is mixed at the pulverizer the resulting mixture of air/coal is typically called dirty airflow. The use of air to transport coal to burner requires equal airflow through each fuel conduit supplying the burners. Imbalances in airflow through the fuel conduits can affect the quantity of fuel delivered to each burner.

Burners from each pulverizer are usually grouped or paired for combustion stability in the furnace. A majority of pulverizers have (3) to (8) fuel conduits per pulverizer. Usually burners of given elevation or group originate from a single pulverizer. This enables “biasing” of total fuel to a given elevation to control steam temperatures and furnace combustion characteristics. Each pulverizer is an independent system that delivers fuel to the burners originating from the given pulverizer. For this reason, the balance of fuel and air is typically addressed on an individual pulverizer basis. That is, fuel and air is balanced between all burner lines leaving a specific pulverizer. This will result in uniform air to fuel ratios for all burners. This is critical for combustion performance and control of emissions.

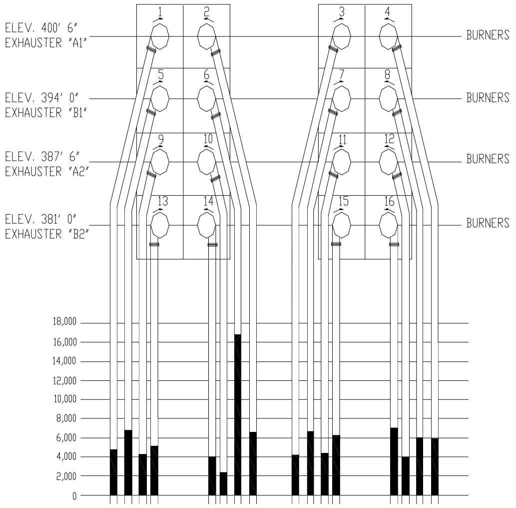
Tolerances for fuel and air balance which have been accepted as industry standards are as follows:

- ±5% balance in dirty airflow between each pulverizer’s separate fuel lines.
- ±10% balance in fuel between each *pulverizer’s separate fuel lines.*

Maintaining optimum fuel and air balance is critical to the following items:

- Obtaining acceptable levels on unburned Carbon in Flyash.
- Uniform release and absorption of heat across of the furnace.
- Reduction in furnace slagging and fouling propensities.
- Maintaining furnace and boiler exit gas temperatures within design tolerances.
- Prevention of water-wall wastage and tube metal overheating.

The figure below illustrates actual test data that indicates gross imbalances in fuel to burners. Poor fuel balance such as this is commonly observed on utility boilers. One of the primary reasons for this is the difficulty in balancing two phase mixtures. Another is gaining the experience and testing equipment to determine fuel balance at plant facilities. Many utility operators have assumed that fuel was balanced or was not critical in the past. The reduced emphasis on fuel and air balancing at the burners has been promoted in the past by boiler manufacturers that depended on mixing by the furnace. Since the Clean Air Act Amendment, the importance of air and fuel balance at individual pulverizers and burners has been increased.



Numerous controllable variables affect the distribution of air and fuel between a pulverizer’s separate fuel lines. These variables are as follows:

- Size of pulverizer coal particles leaving the pulverizer *(Fineness).*
- System resistance of each individual fuel conduit.
- Total airflow through the pulverizer that is controlled on a ratio of weight of air to fuel.
- Velocity of air/coal mixture passing through each burner line.
- Maintenance of critical components such as classifiers, classifier cones riffles, orifices and burner components.

Coal Fineness and Fuel Balance

Coal fineness is ascertained by collecting a representative coal sample from each burner line and shaking the sample through a series of sieves. Coal fineness samples should be collected from all fuel lines of a specific pulverizer. The pulverizer fineness is considered the weighted average of all fineness samples collected. To obtain a representative coal sample an Isokinetic sampler must be utilized. The Air/Fuel Sampler or Rotorprobe®.are two types of samplers that have been successfully utilized.

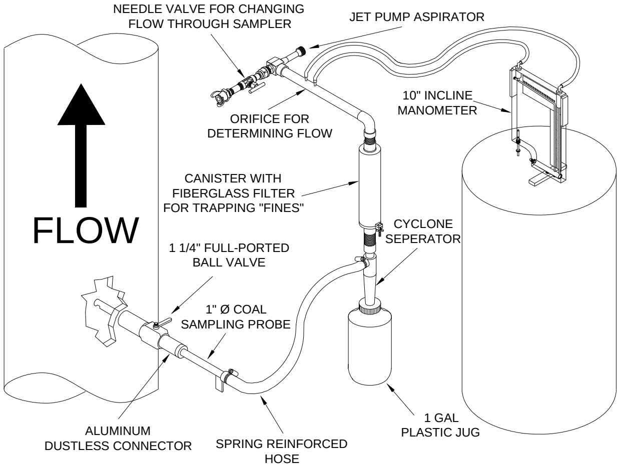


Figure 1 - Air/Fuel Sampling

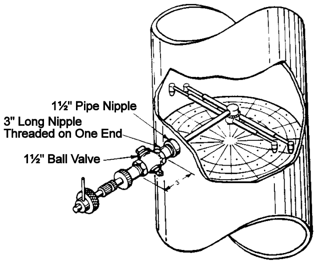


Figure 2 - Rotorprobe® Coal Sampler

The dirty air probe is used in conjunction with the air/fuel sampler and the Rotorprobe® to measure fuel line airflow and to determine Isokinetic sampling rates.

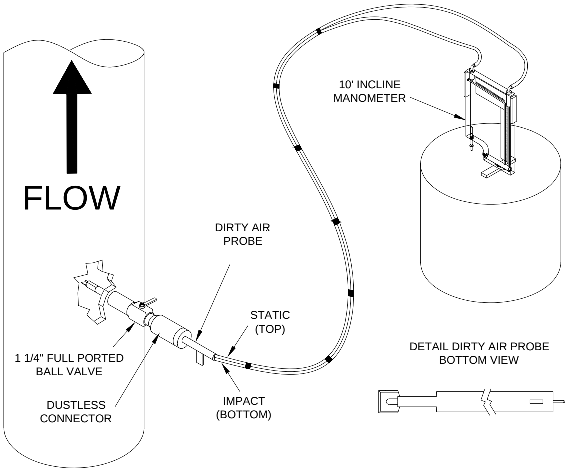
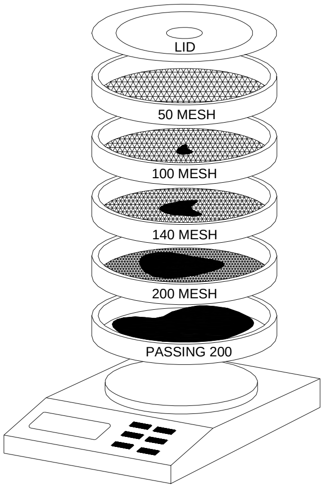


Figure 3 - Dirty Air Probe

The quantity of coal passing each sieve is used to determine coal particle sizing. Sieves utilized are ASTM 50, 100, 140 and 200 Mesh.



PLACE 50 GRAMS OF COAL ON STACKED 50, 100, 140 AND 200 MESH SIEVES AND SHAKE FOR 20 MINUTES

Figure 4 - Arrangement of Coal Sieves for Sieving

The numeric designation on ASTM sieves specifies the number of openings in screen or mesh per linear inch. For example, a 200 Mesh sieve would have 200 openings per linear inch. Coal fineness levels of 75% passing 200 Mesh and 99.5% passing 50 Mesh are generally considered acceptable. Boiler manufacturers *(OEM)* have typically specified coal fineness to be no less than 70% passing 200 Mesh with 99% passing 50 Mesh.

Coal Fineness and Fuel Balance

The OEM fineness specification was determined in the 1960's when boiler furnace designs were very conservative and based on single stage combustion theory. A majority of boilers in operation today are subject to the new Clean Air Act Amendment *(CAAA)* that the limits Nitrous Oxide *(NOx)*, Sulfurous Oxide and particulate emissions. 1960's vintage boilers have required modifications to reduce Nitrous Oxide emissions. NOx emissions are usually reduced by staging combustion to lower the air/fuel stoichiometry in the burner zones where temperatures are sufficient to facilitate formation of Nitrous Oxides. Reducing air/fuel stoichiometry reduces available air to fully combust carbon in the fuel. Due to this, a higher degree of precision in delivery of fuel and air to the furnace is required. To compensate for imbalances in fuel and air and lower exposure time of fuel carbon to free Oxygen at temperatures above ignition points, the OEM coal fineness standard required reevaluation. Low NOx firing configurations require no less than 75% passing 200 Mesh with 99.9% passing 50 Mesh. Coal fineness is not always required for acceptable NOx emissions, as some burners have performed with compliance NOx levels and poor coal fineness. However, when optimum combustion and flyash of ≤6% unburned Carbon is desired, then improved fineness is required. Fineness levels of 75% passing 200 Mesh and 99.9% passing 200 Mesh improves fuel distribution as well as unburned Carbon in flyash.

After coal fineness is determined by sieving, fineness data should by plotted against the Rosin and Rammler formula. This plot is utilized to verify the representativeness of the coal sample and sieving. A representative sample will plot as a straight line on a Rosin and Rammler chart.

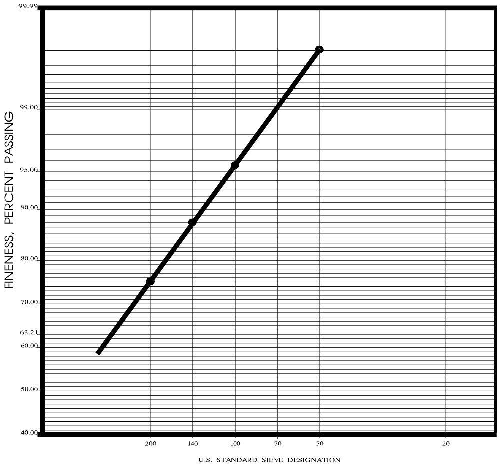


Figure 5 - Plot of coal fineness on Rosin and Rammler

As fineness increases *(reduction in coal particle sizing)*, fuel balance improves. The finer the coal, the more the two-phase mixture (coal and air) behaves like a fluid than a solid in suspension. The more homogenous mixture of air and coal results in more even distribution between the separate burner lines. Pulverizers usually utilize classifiers, which employ the principles of centrifugal separation to reject coarse coal particles back to the pulverizer for regrinding. The "Swirl" imparted by centrifugal classification facilities separation of coarse and fine particles. Poor fineness results in a very stratified mixture leaving the classifier due to wide variation in particle sizing. The more massive coal particles (lower fineness) have more momentum when entrained in air at a certain velocity and are more easily stratified than finer coal particles that have less mass, thus lower momentum. After coarse and fine coal particles are separated fuel and air balance is further aggravated by imbalances in airflow. Typically, burner lines that receive the largest quantity of coarse coal particles have the lowest air velocities.

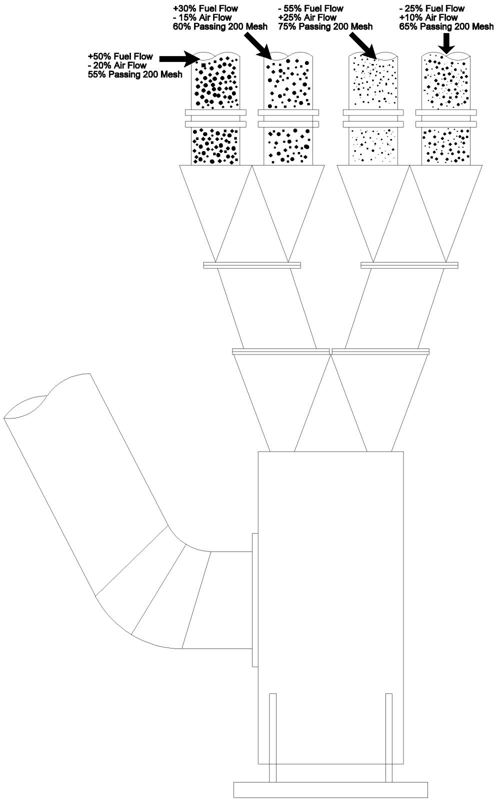


Figure 6 - Fuel & Air Balance Relationship

Coal Fineness and Fuel Balance

Several mechanical factors effect coal fineness. Some of these factors are the condition and geometry of grinding elements, critical clearances, spring tensions. A short overview of critical tolerances to achieving optimum coal fineness on different types of pulverizers are as follows:

- Pulverizer throat clearances
- Roll to bowl or tire clearances and roll pressures are critical on Raymond Bowl mills and MPS mills.
- Grinding ring geometry, ball size, number of balls and spring compression's on EL pulverizers.
- Cabbage cutter clearances and classifier cone condition.
- Ball charge, size of balls, inlet/outlet baffle and trunion seal plates on ball tube mills.

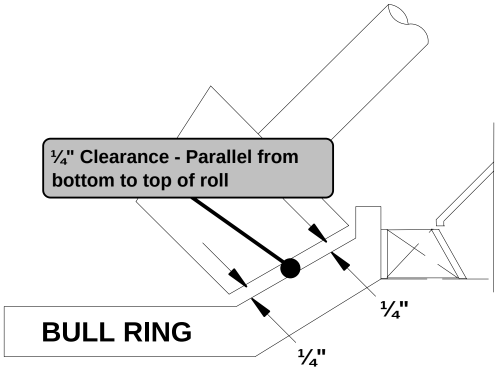
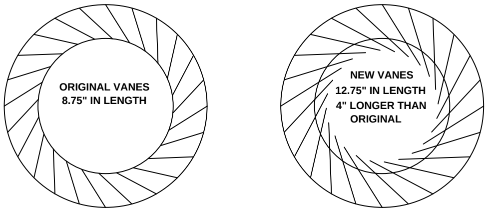


Figure 7 - Proper Roll to Bowl Clearance on Raymond Bowl Mill Pulverizer

Less than desired mill performance after all mechanical and maintenance variables are addressed may be due to marginal pulverizer capacity or coal quality different from the pulverizer capability or design. Pulverizer modification is sometimes required to achieve desired fineness and fuel balance.

Common Pulverizer Modifications

- Replacement of curved classifier vanes with straight vanes on Raymond Bowl mills. Raymond bowl mills utilize classifier blades that are curved on the trailing edge. This Curve arrests the "swirl" imparted by vanes that facilitates separation of coarse and fine coal particles. Straight classifier blades increase "swirl", improving fineness and homogenization of the two phase mixture.
- Extended classifier blades. Increased blade length increases swirl that rejects more coarse particles and improves fuel distribution. Classifier blade extensions have been completed on all pulverizers utilizing centrifugal type classifiers. Extended classifier blades can improve fineness between 5% and 15% passing 200 Mesh. The figure below illustrates typical classifier blade extensions for an EL pulverizer and improvement in fuel distribution.



PRE-MODIFICATION TESTING			POST-MODIFICATION TESTING	
DIRTY AIR VELOCITIES	RECOVERED SAMPLE (g)		DIRTY AIR VELOCITIES	RECOVERED SAMPLE (g)
+8.27%	+13.2%	MAXIMUM DEVIATION	+1.55%	+5.45%
-6.07%	-18.3%	MINIMUM DEVIATION	-2.33%	-6.05%

DEVIATIONS ARE %DEVIATION FROM MEAN VELOCITY OR RECOVERY WEIGHT

Figure 7 - Improvement in Fuel Balance with Extended Classifier Blades

- Installation of angled classifier blades that change the diameter of the swirl. Blades are angled further towards the outside of the mill and the back of other classifier blades. Larger coal particles, which are accelerated more than fines due to higher momentum, collide with classifier blades and are rejected. Angled classifier blades are intended for pulverizers with fixed classifier blades such as the EL and MPS pulverizers. Classifier blades on Raymond bowl mills are on a rotating axle that allows varying angles.

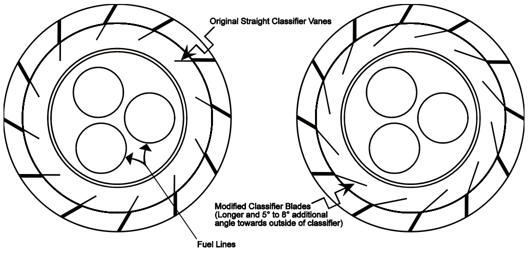


Figure 8 - Angled classifier blades for MPS or EL Type Pulverizers

Common Pulverizer Modifications

- Extension of classifier outlet skirts or deflector rings. This is performed to change the direction of the coal particles in a downward direction towards the classifier reject area. The increased downward momentum and 180° turn of the particles with higher mass allows less of these large particles to be carried to the fuel lines. This modification is applicable to all pulverizers utilizing centrifugal classifiers. A 1" extension of the outlet skirt below the bottom of the classifier blades *(Bowl mills, also called deflector ring)* or the inverted top hat *(EL pulverizers)* is usually sufficient.

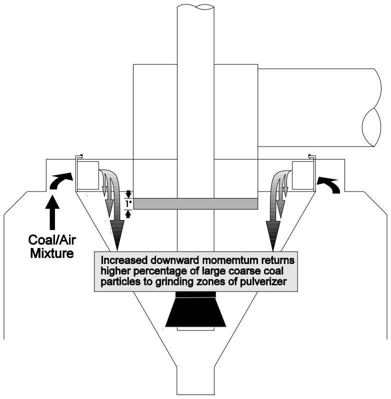


Figure 9 - Classifier Outlet Skirt Extension

- Installation of raw coal deflectors on EL pulverizers. If raw coal deflectors are not installed on EL pulverizers, raw coal is dumped on the outside of the grinding ring. Coal must pass from the inside of the grinding rings to the outside by passing through balls for efficient pulverization. The raw coal deflector insures this. The Figure below illustrates a typical raw coal deflector installed in an EL Pulverizer.

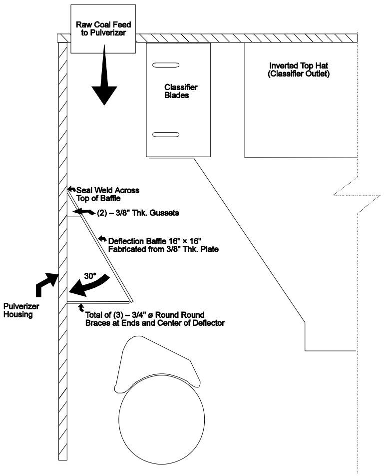


Figure 10 - Raw Coal Deflector for EL Pulverizers

Clean Air Balancing

Balancing system resistance of fuel lines on clean air is the first step of an empirically derived approach to balancing pulverizer fuel and air. Clean air balance is defined as balance of airflow between a pulverizer's fuel lines in the absence of fuel. This is achieved by forcing air through the pulverizer at normal operating mill outlet temperatures with primary air fans or exhausters while the feeder remains off-line. Clean air balance is determined by measuring the velocity of air flowing through each individual fuel line with a standard Pitot tube.

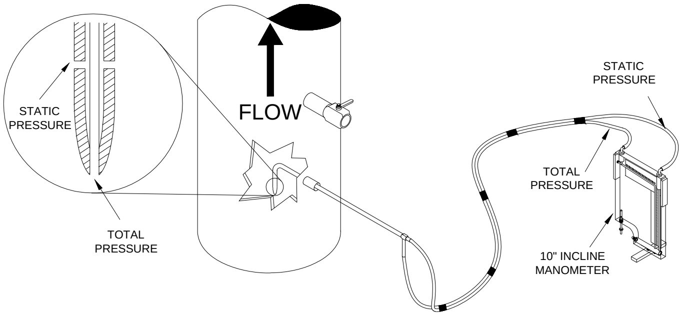


Figure 11 - Standard Pitot Tube and Incline Manometer

Optimization of pulverizer airflow will be discussed later in this report. In most cases, primary airflow is higher than desired and will be reduced to optimize performance. Prior to optimization of primary airflow it is prudent to perform clean air balancing. This will insure minimum fuel line velocities are maintained after optimization of primary airflow. Air velocity in all fuel lines must exceed 3,300 feet/minute *(Fpm)*. Fuel line velocities above 3,300 Fpm are to insure coal entrainment in primary air. Air velocities below 3,000 Fpm allow coal to fall out, accumulate or "dune" in horizontal runs of fuel lines. The 3,300 Fpm minimum velocity includes a 10% safety margin above the absolute minimum line velocity of 3,000 Fpm. Coal line accumulations may cause burner pulsation's, flame instabilities and possible stoppages. Fuel lines are balanced by an iterative process utilizing 10 Gauge carbon steel trial orifices. Clean air balance with a maximum of ±2% deviation from the mean between all fuel lines on a pulverizer must be achieved. After optimum orifice configuration is determined, permanent hardened 400 Series stainless orifices are installed. Computer modeling is sometimes performed to determine orifice sizing. Following installation of orifices, clean air balance should always been verified by Pitot traverse of fuel lines. Clean air tests by Pitot traverse is also required to ascertain if any fuel line resistance's not shown by drawings are present.

Clean Air Balancing

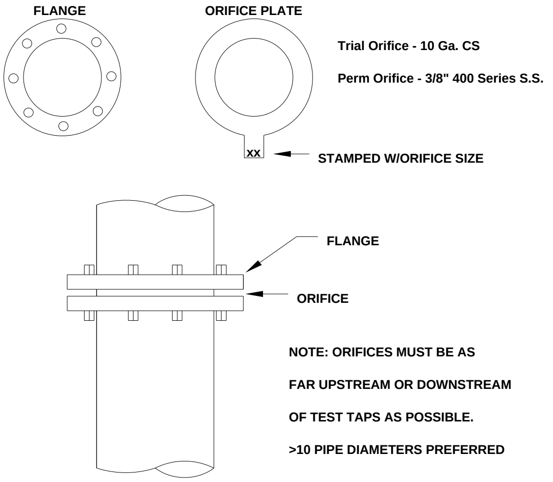


Figure 12 - Typical Coal Lines Orifices

Pulverizer Airflow

High primary airflow can cause poor coal fineness as well as poor fuel balance. Optimum primary airflow depends on the type of pulverizer. Primary airflow should be ramped or ratioed against fuel flow. Optimum pulverizer airflow in most cases is as follows:

Pulverizer Type	*Lbs. Air per Lb. Coal*
MPS and EL Mills	1.5 to 1.8
Raymond Bowl Mills	1.8 to 2.0
Ball Tube Mills	1.1 to 1.3
Attrita Mills	1.2 to 1.6

The graph below illustrates a typical air to fuel relationship for a MPS, EL or Raymond bowl pulverizer. To characterize primary airflow, accurate control and measurement of primary air and fuel must be facilitated. Load cell gravametric feeders is the preferred method of fuel flow control.

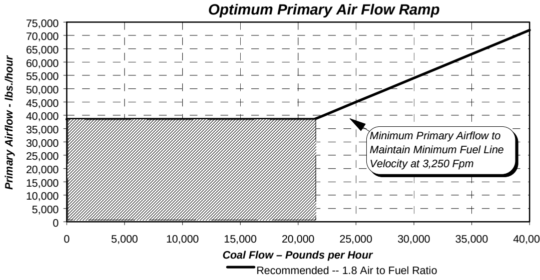


Figure 13 - Typical Primary Airflow Ramp

Flow nozzles or venturis usually provide the most accurate and reliable means to measure and control primary airflow. The figures below illustrate the venturi and flow nozzle that are frequently recommended by ICT.

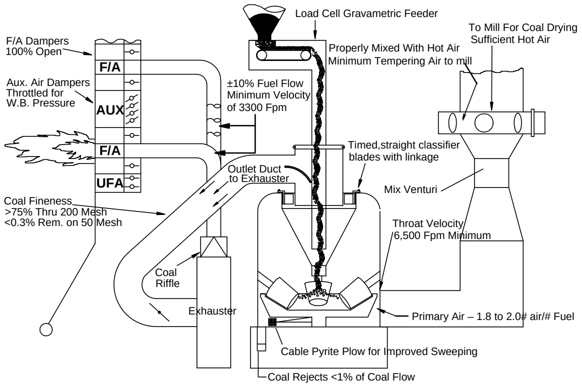


Figure 14 - Mix Venturi on a Raymond Bowl Mill

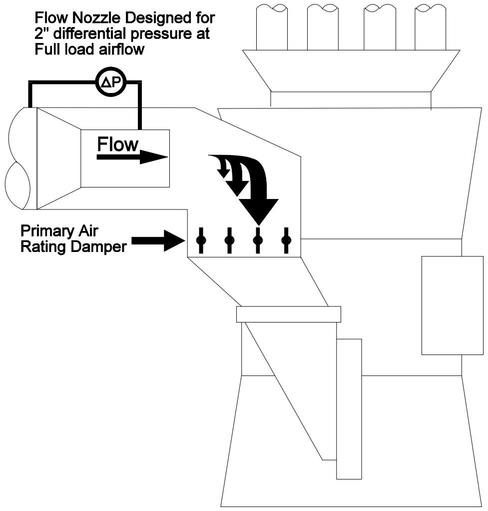


Figure 15 - Flow Nozzle on a MPS-89 Pulverizer

Pulverizer Airflow

High primary airflow contributes to poor coal fineness by increasing air velocities in the classifier and reducing overall retention time of coal in the grinding zones. Increases in primary airflow correlate to an increase in velocities at the classifier outlet of the pulverizer. Higher velocity air at the classifier outlet has sufficient energy to entrap larger more massive coal particles. Lower velocities allow larger particles to be returned to the grinding zones. Inverted cone clearances, if so equipped, must be correct before optimizing primary airflow. Non-optimum inverted cone clearance can result in pulverizer swings that can cause high motor amperage trips and poor 50 Mesh fineness.

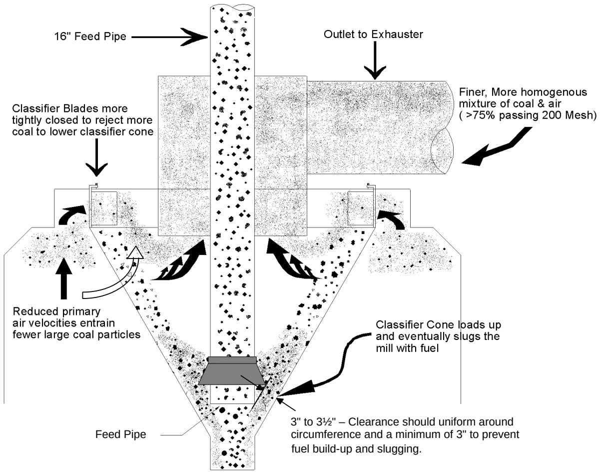


Figure 16 - Entrapment of large coal particles by high P.A. Flow and inverted cone clearance.

High primary airflow causes poor fuel balance by increasing separation of coarse and fine coal particles. Higher velocities result in higher kinetic energy or momentum of coal particles increasing stratification when centrifugal forces or direction changes are imparted on coal particles.

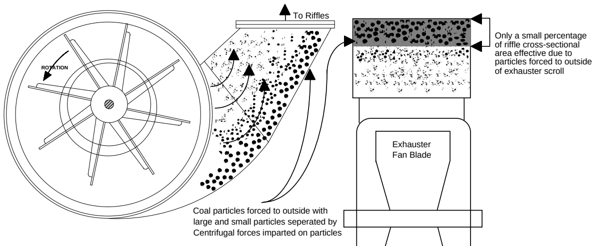


Figure 17 - Increased stratification and reduced coal riffle effectiveness cause by high primary airflow.

<u>Note:</u> Riffles, when installed above an exhauster should be mounted 90° to the exhauster shaft for uniform splitting of coal particles.

Additional adverse effects of high primary airflow on unit performance are as follows:

- Poor flame stability at lower loads and flame ignition points unattached to burner nozzles. Optimized primary airflow (1.8 pounds Air per pound of Fuel) will maintain velocities at the coal nozzle tip within the best range of flame propagation speed for flame stability and improved combustion efficiency.
- Increased air heater exit gas temperatures. Higher dry gas losses are the result of increased tempering air usage. Higher air to fuel ratios require lower temperature at the pulverizer inlet to maintain pulverizer outlet temperature, decreasing the quantity of hot air from the air preheaters. Additional dry gas losses are incurred by heat loss to heat additional ambient (tempering) air after injection into the boiler “boundary."
- Increased furnace exit gas temperatures. High primary airflow increases the differential in velocity between the primary air/fuel mixture and the secondary (combustion) air. This stages or delays combustion that allows a large percentage of heat to be released above the burner belt zone. Lower heat release in the burner belt zone results in less heat absorption by the waterwalls and the subsequent elevation of the furnace exit gas temperature.
- Higher proclivity towards mill fires or explosions.
- Higher slagging or fouling propensity.
- Increased wear of coal lines, burner nozzles and exhauster components.
- Slight increase in auxiliary power, due to the increased horsepower demand of the exhauster required to convey additional primary airflow.
- Increased Nitrous Oxide emissions. Increased Nitrous Oxide emissions is facilitated by injecting more of the total air, for a given excess air, as primary air in the high temperature root of the burner flame rather than secondary air.

Pulverizer Airflow

Pulverizer throat clearances must be verified prior to optimization of primary airflow. Pulverizer throats that are not properly sized or have been enlarged by wear may result in serious coal dribble or spillage. Coal dribble is raw coal that is rejected through the pulverizer's pyrite discharge. This is caused when the velocity across the pulverizer throat is too low to maintain suspension of coal. Air velocities through the pulverizer throat should be between 6,500 and 7,500 Fpm when calculated on a free jet basis. Air at velocities above 7,000 Fpm will have sufficient energy to prevent coal from falling through the throat and will carry coal to the classifier.

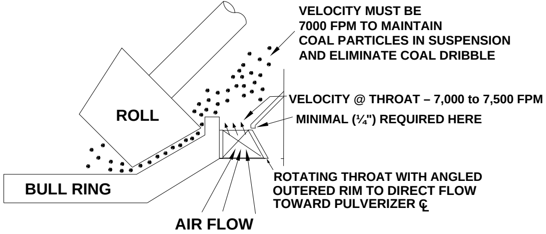


Figure 18 - Proper pulverizer throat velocities

Pulverizer Outlet Temperature

Maintaining optimum mill outlet temperature is required to insure fuel moisture is evaporated and for proper ignition of coal at the burners. Pulverizer outlet temperature should be no less than 155°F on MPS, EL and ball tube pulverizers. Attrita pulverizers should be maintained at 200°F to 225°F. Temperatures less than 155°F will not promote complete evaporation of fuel moisture. Low pulverizer outlet temperature can lead to coal accumulations on fuel line pipe walls, poor combustion and poor fineness. The ability of a pulverizer to grind coal to fines is debilitated by fuel moisture. Pulverizer outlet temperature on Raymond bowl pulverizers is often measured at the exhauster outlet. If pulverizer outlet temperature is measured at this point, mill outlet temperature should be maintained at 180°F. Temperatures at the exhauster outlet are usually 15° to 30°F higher than at the classifier outlet. This temperature differential is caused by the additional heat introduced by the dynamic inefficiency of the radial bladed exhauster fan, which has typical efficiencies of 40% to 50%. Maintaining low pulverizer outlet temperature is also a heat rate penalty. While lower pulverizer outlet temperatures are maintained, a higher percentage of total primary airflow is tempering airflow rather than hot air. Tempering air is at ambient temperature and is introduced through atmospheric damper or ducting from the forced draft fans. Tempering air, which has not been heated by the air heater, is injected into the boiler boundary resulting in higher dry gas losses. This also facilitates less air passing across the air heater, which in turn results in a slight increase in air heater exit gas temperature.

Summary

Achieving optimum pulverizer performance is of paramount importance to heat rate, boiler reliability, emissions compliance and flyash combustibles. To summarize the following items are required to achieve optimized pulverizer performance:

- Pipe to pipe clean air balance within ±2% of the mean pipe velocity.
- Pipe to pipe fuel balance within ±10% of the pulverizer's mean pipe fuel flow.
- Pipe to pipe dirty air velocity balance within ±5% of the pulverizer's mean pipe dirty air velocity.
- Air to fuel ratio of 1.8 pounds of air per pound of fuel on MPS, EL and Raymond Bowl pulverizers.
- Minimum coal fineness level of 75% passing 200 Mesh and less than 0.1% remaining on 50 Mesh.
- Pulverizer to pulverizer mass air and fuel balance within ±5%.
- Pulverizer outlet temperature of 155°F or higher.
- Minimum fuel line velocity of 3,300 Fpm.
- Pulverizer throat velocity of 6,500 to 7,500 Fpm calculated on a free jet basis.
- Optimum mechanical tolerances.
  (i.e. spring pressures, grinding element condition, ball sizes, etc.)

Written by: Richard Paul Storm

For Further Information or Questions Contact:

Innovative Combustion Technologies, Inc.
Richard P. Storm - President
H.F. (Mac) McNeill - Vice President

- **Comprehensive Boiler Testing**
- **Combustion Improvement**
- **Boiler Inspections**
- **Air Flow Measurement Calibrations**
- **Pulverizer Performance Improvement**
- **Testing Equipment**
- **Fan Capacity Improvements**
- **Flyash L.O.I. Reduction**