COMBUSTION OPTIMIZATION OF A 150 MW (NET) 
BOILER UTILIZING AIR AND FUEL FLOW 
MEASUREMENT AND CONTROL

By

Dave Earley
AMC Power

and

J.J. Letcavits
AEP – Pro Serv, Inc.

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ABSTRACT

Coal-fired electric utilities constantly struggle to achieve optimum combustion. While many techniques are currently employed, such as fuel and air control based on O$_2$ and CO measurement of the furnace exit, little has been done with regard to optimizing combustion at each burner. Windbox airflow and pulverized coal flow distribution is known to vary significantly burner to burner. The absence of effective methods to measure coal and air has left the utility industry with no alternative but to accept the resulting performance inadequacies.

In this age of deregulation and concern over utility emissions, the industry continues to search for better methods of fuel and airflow measurement and control. This is especially true with the use of low NO$_x$ burners that require critical airflow and fuel balance for optimum reduction of NO$_x$ while simultaneously minimizing unburned carbon.

In 1999, American Electric Power (AEP) – Pro Serv, Inc. installed a microwave based coal flow measuring device for on line measurement of individual burner fuel flow. This technology utilizes low frequency microwaves to accurately measure relative coal density and true coal velocity in individual coal pipes to determine the mass flow distribution between individual burners. A well-proven technology for measuring combustion airflow had already been in service for measuring and controlling the airflow to each burner. Together, these two measuring systems provide fuel and air massflow inputs to the plant’s DCS system, allowing for combustion optimization and a reduction in NO$_x$ emissions.
INTRODUCTION

In the United States, the Clean Air Act and increasingly competitive markets for electricity are proving to be complimentary drivers of electric utility plant improvements. One factor that contributes to overall boiler efficiency and reduction of power plant emissions is individual burner fuel/air ratios, a factor which has not previously been the focus of plant performance measurement and management. Not only is the fuel/air ratio generally important to optimizing combustion efficiency, it is also critical to the performance of low NOₓ burners and combustion modifications associated with low NOₓ programs (e.g., staged combustion). Poor fuel/air ratio can lead to problems such as slagging, and high unburned carbon in the flyash which adversely impacts ash sales.

 Currently, the method for measuring coal flow into a boiler consists of volumetric or gravimetric coal feeders that measure the bulk coal entering each coal pulverizer. From the pulverizer, the coal is delivered to multiple coal pipes, then via the coal pipes to the individual burners. Balancing of the coal flow distribution between burners has traditionally been attempted through clean or dirty air traversing and the installation of orifice plates. Since it is widely accepted that pipe-to-pipe coal distribution changes with load and time, manual traverses, whose accuracy has been challenged, can not be sufficient for balancing coal pipes to achieve optimum combustion over a range of operating conditions.

Prior to implementing pulverized coal flow measuring equipment, AEP - Philip Sporn Station had installed individual burner airflow measurement (IBAM) equipment supplied by Air Monitor Corporation as part of an AEP designed low NOₓ burner system. This allowed for accurate measurement and control of secondary airflow to the ten burners on this 150 MWN B&W roof-fired boiler (Fig. 1). In 1999, AEP looked to AMC Power to provide pulverized fuel flow measurement to the ten burners using their Pf-FLO™ system. This would allow the plant to match secondary airflow to coal flow at each burner, thus achieving optimum combustion.

This paper focuses on the pulverized coal flow measuring product and the control methodology used to improve boiler performance.
THE OHIO POWER COMPANY
AND
APPALACHIAN ELECTRIC POWER COMPANY
PHILIP SPORN PLANT

Figure 1
Review of Pf-FLO™ Technology

Technology

To obtain the mass flow of coal to a burner, one needs to know both the concentration¹ and the velocity of the pulverized coal in the burner pipe. The Pf-FLO™ system measures both the coal concentration and velocity in each pipe independent of both the measurements performed on the other pipes and the coal feeder information, resulting in velocity outputs for each pipe scaled in units of feet per minute and concentration outputs directly proportional to the coal mass flow in each pipe.

Concentration

The concentration of the pulverized fuel (Pf) is measured using low power low frequency microwaves, with each burner’s pipe acting as its own unique wave guide. Since the coal flow in all pipes comes from a common source, such variables as moisture content, fineness, coal type, etc. are the same for all pipes. Therefore, the only variable pipe per pipe is the dielectric load, i.e. the concentration of the pulverized fuel in the section of pipe being measured. Starting with the known microwave transmission characteristic of each pipe wave guide, the varying dielectric load caused by changing coal concentrations in each pipe produces measurable reductions in signal power and frequency, resulting in quantifiable values that are reported as the absolute coal density in each pipe.

The concentration measurement is performed by paired transmitter and receiver sensors aligned parallel to the longitudinal axis of the pipe, as shown in Figure 2. The polarization of the input microwave signal is axially symmetrical to the centerline of the sensor, producing blind spots at positions 90° to the sensor. The installation of two sensor pairs allows the measurement of the entire pipe cross sectional area as shown in Figure 3.

¹ The term ‘concentration’ is meant as mass concentration or mass density in this report.
Velocity

The velocity of the pulverized coal is measured by a cross correlation method, which is conceptually depicted in Figure 4. Two sensors are mounted at a known distance along a pipe. Stochastic signals created on a pair of upstream/downstream sensors by the charged coal particles are nearly identical, but shifted by the time the pulverized coal takes to travel from one sensor to the other. As the distance between the sensors is fixed, the velocity of the pulverized coal in the pipe can be accurately calculated.

Airflow and Coal Flow Measurement Configuration

The unit consists of ten roof-fired burners receiving fuel from five B&W EL-70 pulverizers. The pulverizers are fed by volumetric table feeders, which provide limited accuracy and repeatability. As such, in addition to not knowing the distribution of fuel between the two pipes of any two mills, there is also an uncertainty of the distribution of total fuel amongst the five pulverizers.
Pf-FLO™ sensors were installed in the vertical pipe runs of all ten coal pipes. Individual burner airflow measurement was accomplished at the plant using AMC Power designed windbox partitions and IBAM technology. *Figure 5* is a drawing of the partitioned windbox with individual burner airflow measurement and control dampers.

**Figure 5**

*Normal Versus Relative Burner Control*

**Boiler Control**

Rather than attempt to control any imbalance in coal flows to the burners, AEP chose to measure and then control the secondary airflow to each burner in a manner that accounted for variations in fuel distribution to each burner. The normal mode of operation assumes equal coal flow to all burner lines for the mills in service via the plant control system, providing equal secondary air (SA) flow to all burners. This is the normal control mode for the boiler and all data in this report that is labelled “normal” refers to data obtained in this mode of operation.

Using the Pf-FLO™ system of burner line coal flow measurement, the relative coal flows between burner lines on individual mills are determined and the SA flow is adjusted accordingly. For example, the “normal” mode of operation assumes the total coal flow to a mill is split 50/50 between the two burner lines and automatically adjusts SA to a 50/50 split. In the relative mode, if the coal flow is 55/45 on a given mill, the SA flow is then corrected to a 55/45 split. It is still assumed that all mills are loaded equally. In this relative mode, the boiler control system is switched over to automatically control in this relative fashion. All data in this report labelled “relative” refers to data collected in this mode of operation.

**Data Analysis**

The testing was completed to review the NOx emissions and distribution of combustion air while operating in the two different modes. Using a portable flue gas analyzer, sampling was completed for NOx, O2 and CO, at eight (8) permanent test probes located within the economizer outlet/air heater gas inlet ductwork.
Test Results, Full Load (163MWG)

Test 1 was in the normal mode, immediately followed by Test 2 in the relative mode. The unit operated at 163 MWG and excess air, based upon the plant’s excess air probes, averaged approximately 15%. Refer to the graphs below for distribution of NO\textsubscript{x}, O\textsubscript{2} and CO. In comparing the graphed data, it is apparent that the O\textsubscript{2} and NO\textsubscript{x} levels were more level in the relative mode than in the normal mode. Further, CO levels were not only more level, but were also reduced. These were the objectives of the test.

\textit{O\textsubscript{2}, NO\textsubscript{x} and CO Tests (1-2)}
The Pf-FLO™ data showed that D mill was more heavily loaded than the other mills with B being the lightest, which agreed with the mill inlet temperatures.

The following is a summary of the burner stoichiometries for Test 1 versus Test 2. As the bar charts indicate, the relative mode leveled out the burner stoichiometries as compared to the normal test. In looking at the bar charts, one can see a similarity in the respective bar chart versus the associated NOx and O2 curves. The higher stoichiometries on the C2 and D2 burners are the likely reason why higher NOx and excess O2 was seen at the south middle region of the boiler. The low stoichiometries seen at C1 and D1 burners are why lower NOx and excess O2 occurred at the north middle area during the normal test.

**Burner Stoichiometries (Normal)**
Relative Versus Absolute Burner Control

Burner Control

For the absolute burner control, in addition to adjusting for the pipe coal variations, the differences in mill loading were also taken into consideration when adjusting burner secondary airflow. For example, in both normal and relative control modes each of the five mills are assumed to provide 20% of the total heat input to the unit when all mills are in service. If the Pf-FLO™ system determines that a mill is supplying 21% of the heat input as compared to the other mills, then the total secondary air for that mill will be increased to 21% of total for the unit. All data generated in this mode of operation is labeled “absolute”.

Data Analysis

For the absolute testing, the mills with the highest and lowest indicated fuel input had their feeder set curves adjusted accordingly in order to achieve greater balance in heat input across the unit. Any further minor variations in mill-to-mill heat input were corrected for in the secondary air supplied to each burner through the absolute mode control set-up.

Test Results, Full Load (160 MWG)

Test 3 was in the relative mode immediately followed by Test 4 in the absolute mode. The unit operated at 160 MWG and excess air, based upon the plant excess air probes, averaged approximately 15%. Refer to the graphs below for distribution of CO, NOx, and O₂.
The Pf-FLO™ data suggested that D mill was more heavily loaded than the other mills with B and C being the lightest, which agreed with the mill inlet temperatures.
The following is a summary of the burner stoichiometries for Test 3 versus Test 4. As you can see, using the Pf-FLO™ data to adjust the heat input of C and D mills, the absolute mode leveled out the burner stoichiometries as compared to the relative test. In looking at the bar graph, one can see a similarity in the respective bar graph versus the associated NOₓ and O₂ curve. In particular, the blue (center) curve shows the high O₂ peak at probe 5 which is in the vicinity of burner C2 for the relative test. The peak disappears after going into the absolute mode.

*Normal Burner Stoichiometries (assumes equal coal flow to each mill and burner line)*

![Sporn Unit 3 - Normal Mode](image)

*Relative Burner Stoichiometries (now taking into consideration the pipe to pipe imbalances)*

![Sporn Unit 3 - Relative Mode](image)
Conclusions

Operation in the relative control mode generally produced a more level profile for $O_2$ and $NO_x$ on the unit, along with decreased CO levels. Operation in the absolute mode produced a further leveling of the $O_2$ and $NO_x$ profiles on the unit and decreased CO levels. As a result of a leveled $O_2$ profile, units may now trim their total $O_2$ level with a greater level of comfort, which will improve the unit heat rate and simultaneously decrease $NO_x$ levels. With a more balanced $NO_x$ profile at the boiler outlet, units will also be in a better position to control reagent injection in an SCR system. That is, in the event SCR is implemented at a given unit, the amount of ammonia and catalyst consumed annually will be reduced as will the ammonia slip.

In conclusion, burner fuel/air combustion management, via individual burner airflow and pulverized fuel flow measurement, is a viable technology capable of providing $NO_x$ reduction, increasing operating efficiency and reducing balance of plant impacts. The pulverized fuel flow measurement also has the potential to be used to adjust feeder curves to provide more balanced fuel input to the unit.

References