Role of Combustion Diagnostics in an Integrated System to Reduce Fly Ash Carbon and Increase Ash Value

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ABSTRACT

Current emission regulations have forced power plant operators to modify combustion and diversify fuel sources, resulting in ash that may contain unacceptable amounts of unburned carbon and/or other undesirable contaminants. Wide swings in ash quality result in less income from ash sales and increased ash disposal costs. The difference between selling and disposing of the ash could be several million dollars per year for a given plant.

Tephra Resources helps plants avoid the cost of ash disposal by considering the entire ash “life cycle”, including fuel selection, preparation, combustion, as well as ash collection, beneficiation, and markets/end uses. Advanced combustion diagnostics and low-cost separation techniques form the cornerstones of our approach. This paper summarizes experience with on-line LOI monitoring and provides case histories. Integration of LOI diagnostics with online burner tuning technologies (such as EPRI’s Flame Dr ™) is a new approach being tested at several plants[1].

ASH IMPACTS ON PLANT OPERATING COSTS

The disposal of fly ash generated from the combustion of coal has become increasingly important, as economic and environmental objectives call for recycling alternatives to traditional landfill options. In inner-city generating stations, landfill cost can become a higher market driver than revenue from ash sales. Fortunately, fly ash is a desirable component in the manufacture of ready mix concrete, as a soil stabilization additive in road construction and as a Flowable Fill component. However, this requires that the fly ash maintain certain properties, which are dictated by the ultimate product application. Often, however, the demands of Low NOx combustion strategies, dictated by ever more stringent EPA regulations, are causing ash as generated to be outside the limits of these properties.

The properties of the fly ash are dependent on many factors, which range from:

- The type of generating unit,
- The type and rank of the coal
- The type of air pollution control equipment.

When the fly ash does not meet the required specification for the product or market intended, it is possible to treat (or beneficiate) it to achieve the desired properties. The beneficiation technology selected must keep in mind the desired application for and properties of the ash as demanded by the local market.

Since the most commercially valuable use of fly ash is in the manufacture of concrete, the final properties of beneficiated ash must be in line with the requirements of the local ready mix concrete manufacturers. Because carbon can cause an increase in the water demand and the required amount of air entraining admixture (AEA) in the concrete manufacturing process, the focus of most fly ash beneficiation methods has been to reduce or eliminate the amount of carbon in the ash so that it can be used in this application.

Ready Mix Concrete consumes in excess of 100 Million tons of Portland cement each year in the United States alone. In fact, consumption in 2004 is expected to report at over 105 Million tons, against a demand significantly larger. This cement shortage has resulted in a general price increase of 6% - 8% in the last year. Since the US imports over 20% of its Portland cement and since the Asian market has recently expanded dramatically, the material generally shipped to the US is under strain to be shipped elsewhere.

The importance of this supply/demand shortfall is that fly ash, with proper quality and availability is positioned to remedy the problem. However, it should be noted that this phrase includes the term availability. A general rule of thumb is that it costs $0.10/Ton Mile to ship cement, or fly ash, by truck in the US. In general, the current market pricing for ash ($18 - $40/Ton), coupled with the cost to pay for beneficiation processing and royalties has limited the available market range to less than 100 miles. Put another way, to be cost effective, beneficiated ash must be consumed within 100 miles of where it is produced.

Landfill cost has three components:

1. Transportation cost
2. Tipping Fee
3. On-Site storage capital charge

Generally speaking older plants inside major city limits have very high tipping fees for ash disposal. However, older plants in rural areas with local pond sites that are at or near capacity can reasonably be charged extremely high internal costs for disposal based on expected costs to replace or upgrade the existing site. The common denominator to both is the age of the generating station.

INCREASING ASH VALUE

Ash markets hate surprises, so the first requirement for an ash product is consistency. Ash needs to be the same, chemically and physically, each and every day. To achieve the desired consistency, plants need to measure and/or control the following:

- Coal ash specifications
- Mill maintenance
- Combustion system performance

All are difficult, but the last can be the most difficult to get your arms around. We think that the key is a **custom-designed integrated system** encompassing not only combustion control but also ash collection, beneficiation, and re-injection options. The topic for discussion today, however, is combustion.

COMBUSTION CHALLENGES

The vast majority of coal-fired boilers in the power industry were built before NO_x emissions were regulated. Over the last two or three decades, emission limits have marched ever downward. Today, virtually no boiler is burning the same fuel with the same burners for which the furnace was sized.

Complete combustion of coal in a utility boiler is, quite simply, a function of three parameters: **oxygen, temperature and time**. If there is sufficient oxygen present to combine with all of the carbon, and if there is sufficient time and temperature for thorough mixing and combustion to occur, then the level of unburned carbon in the ash will be small. Unfortunately, current environmental regulations coupled with older plant physical designs generally lead to a shortage of one or all of these requirements.

Low NO_x Burners/Strategies

The foundation for most low NO_x combustion strategies is the low NO_x burner. This device delays fuel-air mixing, thus assuring that the coal will burn at a lower temperature for a longer period of time. Use of overfire air further shifts the combustion from the burner zone to the upper furnace. In theory there is enough air for complete combustion. In practice there is almost always some unburned carbon penalty. From our perspective, the magnitude of this penalty is not unavoidable and can be controlled with additional tools to help the operator.

Coal Fineness

Low NO_x combustion effectiveness depends on proper coal mill operation. In general, low NO_x burners demand 80% through 200-mesh (and nothing greater than 50-mesh) to meet their design goals. This requirement is generally met at the time of burner commissioning. However, over time and with limited maintenance budgets, coal fineness may become compromised with a resultant increase in unburned carbon levels.

Residence Time

Residence time is constrained by the physical design of the boiler. Burnout stops when the coal particles reach the convective pass. Low NOx combustion methods and varying boiler loads may reduce burnout time by up to 50%! This is especially true given the increased acceptance and installation of over-fire air systems. This residence time shortfall may be partially offset by adjusting mill/burner combinations or OFA damper settings with little effect on NO_x.

COMBUSTION IMPROVEMENT STRATEGIES

For the majority of boilers smaller than 250 MW (i.e., those without SCR for NO_x control), the low-NO_x combustion system is usually pushed to some operating limit and then backed off to allow reliable, efficient power generation. The hierarchy of operating limits varies considerably from boiler to boiler, but all result from flame instability or degradation. Further, the burner or burners that perform the worst reach these limits first.

Increased fly ash carbon is usually the first consequence of pushing the combustion system to lower NO_x. Other problems such as high CO emissions, high steam temperatures, ash deposition in the secondary superheaters, increased opacity, or high tube metal temperatures can also occur. Many plants are forced to operate with higher LOI and lower NO_x while trying to manage other operating risks.

The first step to reduce NO_x, LOI, or both is to identify those poorly performing burners. The following methods have been used to accomplish this task:

1. Measure NO_x and O_2 concentrations in the economizer outlet duct using a multi-point sampling grid[2]. Since flue gas flow is fairly streamlined, concentrations can be related to specific regions of the combustion zone, sometimes to individual burners for 1-wall-fired boilers.
2. Measure fuel flow, primary and secondary airflows, and overfire airflow to individual burners or ports using flow elements.
3. Measure flame quality based on processing flame scanner signals for each burner.

A testing contractor that takes care of maintaining the sampling system, gas analyzers, and data analysis software usually performs Method 1. Computer modeling or parametric testing is used to relate the gas concentrations to burner operation. Plants have found it difficult to operate and maintain their own sampling grid systems.

Method 2 is the most accurate and precise way to monitor air-fuel ratio for each burner or for the first stage of a two-stage combustion system. Several plants have successfully implemented these technologies as reported in the recent MEGA Symposia[3,4]. Some plants cannot afford the expense to install a full array of flow elements and others may not have the skilled personnel available to maintain them.

Method 3 is a lower-cost way to infer air-fuel ratio for individual burners. There are several commercially available systems that involve either replacing the flame scanners or tapping into the signals from existing flame scanners. We prefer Flame Doctor™, a system developed by EPRI and The Babcock & Wilcox Company, because it is sensitive to small changes in flame flicker that can signify large changes in flame quality.

Operation of a generic Low-NO_x burner is illustrated on Figure 1.

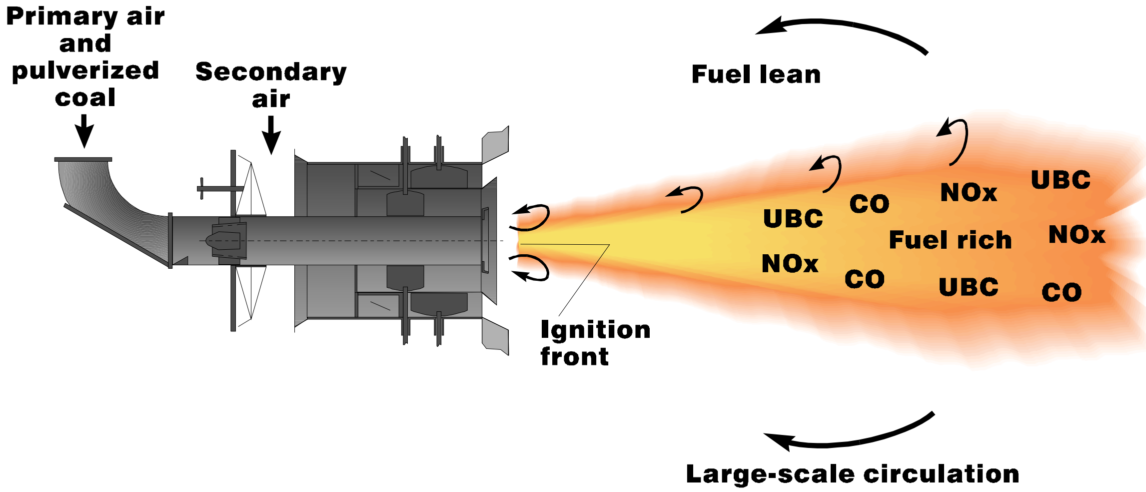

Figure 1. Features of a Low-NO_x Flame

Simplistically stated, the ideal low-NO_x flame has an ignition zone firmly held in the burner throat by recirculation patterns set up by the shape of the coal nozzle and swirl imparted to the inner secondary air. The primary air and coal from the coal nozzle penetrate this recirculation zone, creating a long fuel-rich core where NO_x formed in the ignition zone can be destroyed and other nitrogen compounds released from the fuel are converted to N_2. The rate of mixing along the edges of the flame determines flame length and (along with available oxygen and residence time in the furnace) controls the amount of unburned carbon in the ash.

Small changes in the distribution of coal or air can change the shape, brightness, or flicker characteristics of these flames. These are also changes that affect flame scanner signals. What Flame Doctor does is process the flicker frequency of the scanner signals and then uses chaos theory to create a model of that flame. It then compares the model against known flame characteristics to not only characterize flame instabilities but also to quantify how far along the instability path that a flame may have wandered. This flame model is depicted on Figure 2.

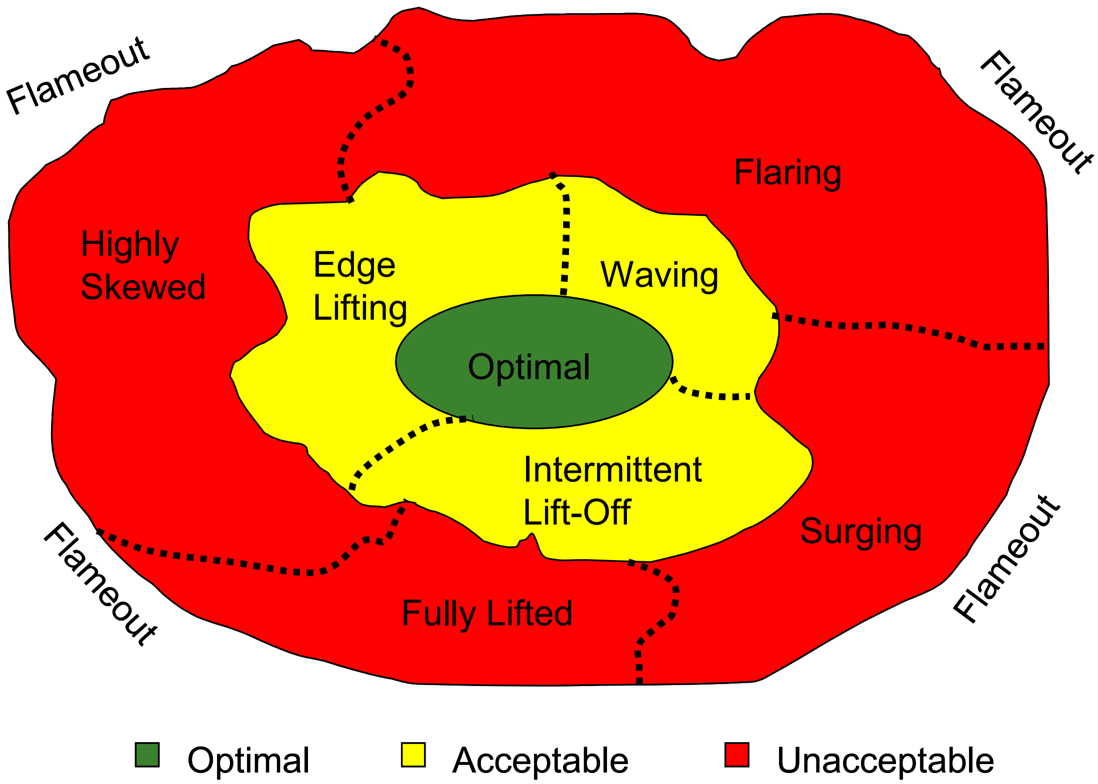

Figure 2. Flame Doctor View of Combustion

Flame Doctor detects proximity to regime boundaries and uses this to grade flames on an absolute scale (0-100**).** It can also provide input on global changes in the flame:

- Size
- Shape
- Position
- Turbulence level

By knowing the distinct "path" the flame is on, engineers can guide the tuning process. The closer to the middle "target" that the flames can stay (and still achieve the desired NO_x emission), the lower the ash LOI is likely to be.

The Flame Doctor system that we are using is portable and travels in a small silver suitcase as shown on Figure 3. Alligator clips provide the connection to the output of the flame scanners prior to any processing by the plant burner management system. Usually this connection can be made at a control panel located in the plant control room or near the burner front.

Figure 3. Portable Flame Doctor

The Flame Doctor is used to find and correct "problem" burners. Once identified, these burners can be tuned using airflow controls or fuel biasing. Since high ash LOI can be caused by just a few badly performing burners, ash quality can usually be improved without increasing NO_x emissions.

COMBUSTION IMPROVEMENT EXAMPLES:

Belews Creek is 1200 MW opposed-fired boiler equipped with 80 low-NO_x burners and 16 Overfire Air (OFA) Ports. Flame Doctor was used here to balance the burners so that the OFA ports could be opened, thus further reducing NO_x emissions upstream of the SCR reactor.

Figure 4 shows the Flame Doctor results for the front-wall burners prior to any tuning. The OFA ports could only be opened part way due to high CO, so the plant was running with one mill out of service to increase burner zone staging and reduce NO_x. After using Flame Doctor to balance the burners, the Unit could open the OFA ports and control NO_x with all burners in service. The Flame Doctor output screen after tuning is shown on Figure 5.

Though these changes do not seem like a lot, the difference in LOI was significant. Figure 6 shows the LOI reduction for these two tests was over 50%!

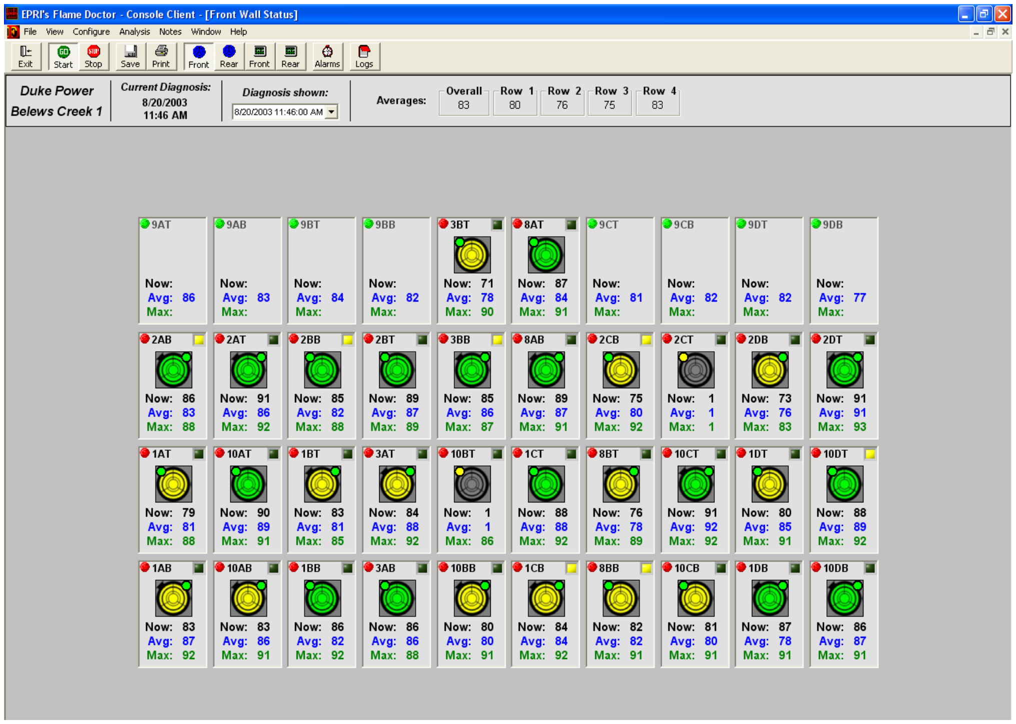

Figure 4. Front Wall Burners Before Tuning

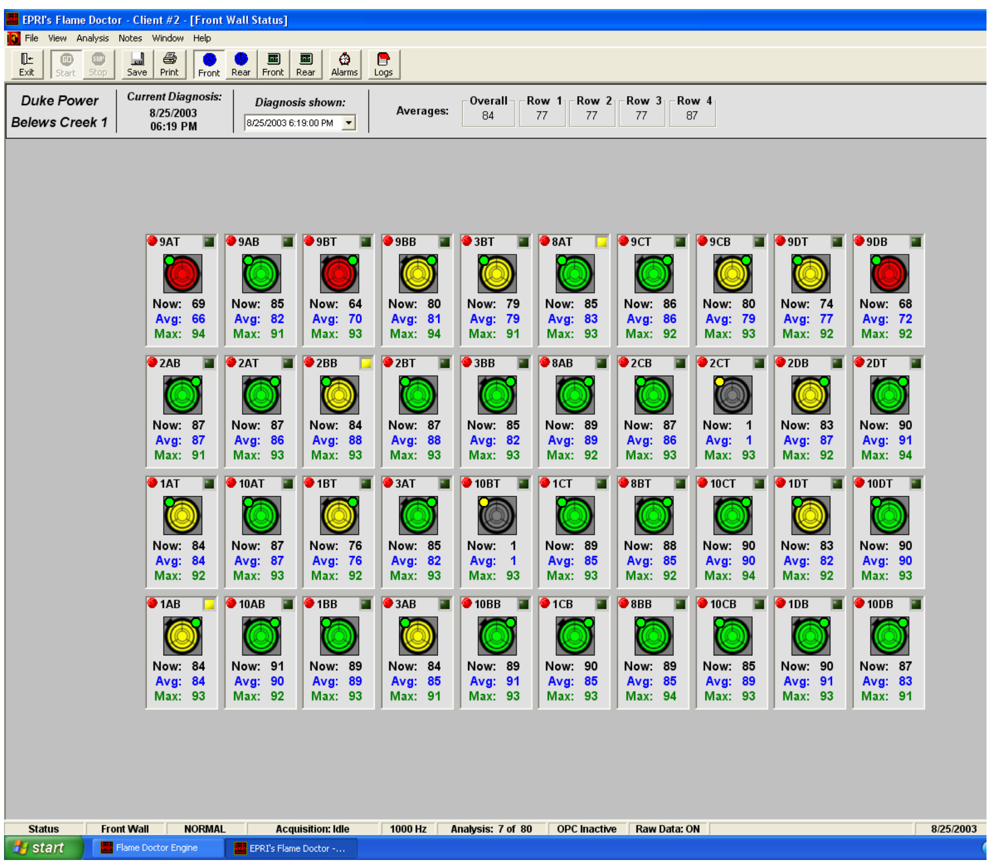

Figure 5. Front Wall Burners After Tuning

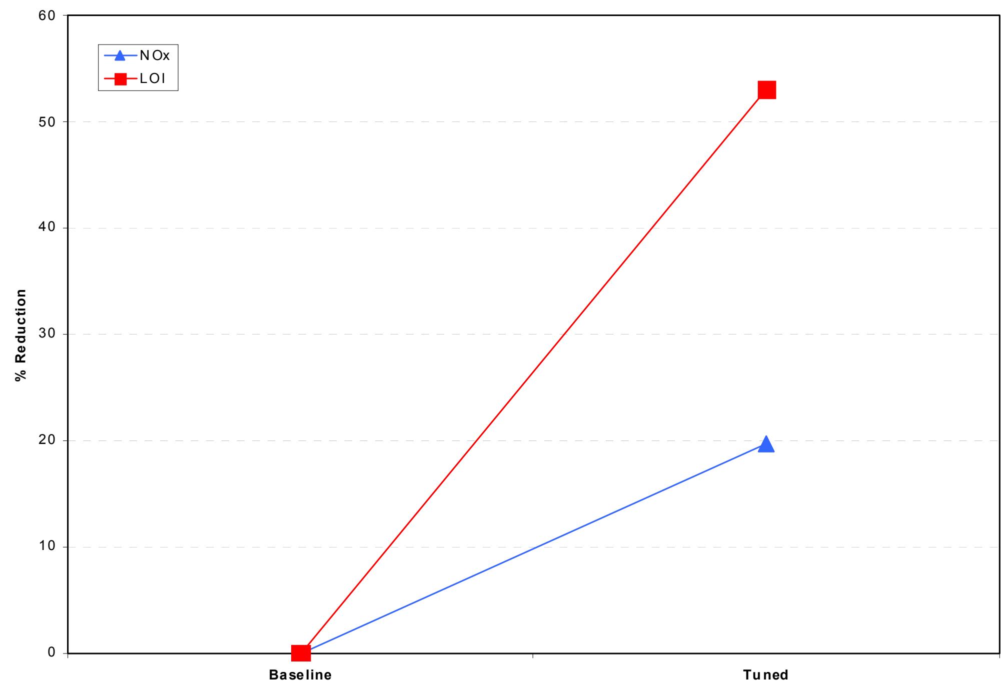

Figure 6. NO_x and LOI Reduction Achieved with Flame Doctor

Tephra is currently using Flame Doctor to lower flyash LOI at two other boilers. Both of these sites are 1-wall fired and both have OFA ports. Both boilers burn similar South American bituminous coals. Additional results may be available in time for presentation at this conference.

CONCLUSIONS

Combustion tuning is the first step toward producing a salable fly ash product. Online analyzers that measure flame quality and ash LOI in real time can provide the feedback necessary to coordinate multiple burners and OFA ports into a smoothly operating combustion system. Without these measurements, operators are flying blind.

Tephra is applying these combustion-tuning tools in conjunction with other technologies designed to improve ash quality. Follow-up strategies could include ash separation based on preferential capture of carbon in certain precipitator hoppers. Inexpensive air classification of ash to separate the lighter carbon from the heavier minerals has also been successful in Europe. Then the carbon-rich stream can be sold, landfilled, or re-injected into the boiler. In the case of re-injection, Tephra is working with partners to develop methods to insure that the unreactive carbon burns completely upon re-injection. We hope to be reporting on the results of these development efforts in subsequent WOCA conferences.

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