Flame Doctor® for Cyclone Boilers – EPRI Beta Demonstration Program Update

Authors:
T.A. Fuller
Babcock & Wilcox
Power Generation Group, Inc.
Barberton, Ohio, U.S.A.

R. Bermke
Alliant Energy
Sheboygan, WI, U.S.A.

J. Barnett
AmerenUE
Sunset Hills, MO, U.S.A.

L. Braun
Associated Electric
Cooperative, Inc.
New Madrid, MO, U.S.A.

J. Stallings
R. Himes
Electric Power Research
Institute
Palo Alto, CA, U.S.A.

Presented to:
Power-Gen International

Date:
December 8 - 10, 2009
Abstract

Cyclone boiler owners continue to drive down NO$_X$ emissions with increasingly sophisticated staging and air distribution schemes. For example, Alliant Energy has employed RMT’s SmartBurn® technology, and AmerenUE has pioneered neural nets to reduce emissions. Under EPRI sponsorship, the team of ORNL and B&W has developed pulverized coal burner diagnostic technology by applying nonlinear signal analysis techniques to flame scanner signals. The technology is known commercially as the Flame Doctor® system. The team has extended the Flame Doctor technology to cyclone boilers to facilitate deeper staging of the cyclones for NO$_X$ reduction. The system is currently undergoing EPRI-sponsored beta demonstration trials at five plants. Preliminary results have shown that the Flame Doctor system can accurately represent the operating condition of the cyclones. Further, the system can identify conditions that may lead to frozen cyclones and provide information to help distribute air more effectively to all cyclones on a boiler. Work is already underway to make the Flame Doctor system part of a closed-loop process for continuous optimization of cyclone operation.

Introduction

Historically, the cyclonic flow in a cyclone furnace has led to very high combustion temperatures, which provided very efficient combustion, but also led to high NO$_X$ emissions. The high NO$_X$ emissions were due to both the nitrogen in the fuel (fuel NO$_X$) and thermal or prompt NO$_X$ from the dissociation of nitrogen in the air and oxidation to NO. EPRI’s Cyclone Interest Group’s response to this problem was to stage the combustion in the cyclone. This was achieved by providing less than the stoichiometric amount of air required to completely burn the coal in the cyclone, and providing the balance of the air required to complete combustion through additional ports in the boiler known as overfire air ports. This had two beneficial impacts on NO$_X$ emissions. First, in the absence of sufficient oxygen, the fuel nitrogen recombined with itself to form molecular nitrogen rather than NO. Second, thermal NO$_X$ formation was also reduced due to the fuel rich environment within the cyclone barrel and lower furnace.

Although NO$_X$ emissions have been reduced considerably with this technique, it has led to some operational problems due to a tighter range of optimum operating conditions. As many cyclone boilers have switched from their typical eastern bituminous design coals to a lower sulfur Powder River Basin or western bituminous coal, lower cyclone barrel temperatures have been encountered due to the higher moisture content associated with these coals. The lower combustion temperatures in the cyclone barrel may cause the temperature of the molten slag to fall below its melting temperature and freeze. If the slag freezes, the burning coal particles exiting the burner will not adhere to the walls of the barrel and will be ejected from the cyclone before combustion can be completed. This leads to high unburned carbon losses from the boiler and lower boiler efficiency. If the slag tap opening is plugged with frozen slag, the cyclone may have to be shut down to remove the slag manually. An additional complicating factor is that the melting temperature of the slag is a strong function of the properties of the coal. Since utility and industrial boiler owners buy coal with a wide range of properties to reduce the operating cost of the boiler, the melting temperature of
the slag can vary considerably day-to-day. Further, other properties of the coal, such as moisture and grind size can negatively impact cyclone operation.

Currently, operators must make visual observations of each cyclone to monitor the condition of slag in the barrel and the quality of combustion. This is a qualitative inspection, and varies from operator to operator. If the operator observes that the slag is beginning to freeze, he (she) may use the lighter, which is typically only used for startup, to increase the temperature in the barrel and melt the slag layer. Since the lighter typically uses a premium fuel such as natural gas or oil, this is an expensive corrective action. Also, by increasing the operating temperature of the barrel, the NO\textsubscript{X} emissions may also increase. Some units are equipped with secondary air dampers that are split into two or three sections. The operator can adjust the position of these dampers to redistribute the secondary air along the length of the barrel, concentrating more air in the vicinity where the slag is freezing, thereby increasing combustion in the area and consequently raising the temperature of the slag. This requires frequent visual inspections on the part of the operator to closely monitor the situation.

Periodically, it is also necessary for the operator to tune the cyclones to optimize the performance or to accommodate a change in the cyclone (e.g., coal properties, hardware changes, refractory replacement, etc.). The procedure for tuning the cyclones to optimize performance is iterative and time consuming. A monitoring technique is required that can assess the quality of combustion in the burner and barrel, and provide guidance to the operator to make adjustments in the air distribution to maintain optimum performance.

Background

Description of Cyclone

A cyclone combustor consists of a burner to perform initial ignition of crushed coal and a barrel to continue the combustion and trap the slag.\textsuperscript{1} Two flame scanners are mounted on the cyclone to monitor combustion for safety. The lighter scanner mounted on or adjacent to the lighter verifies the presence of the oil or gas flame that is used to preheat the cyclone barrel. The main flame scanner is used to verify combustion in the cyclone after the lighter is retracted. As seen in Figure 1, the lines of sight for the two scanners are different. The main flame scanner is primarily monitoring the combustion conditions in the burner and the lighter scanner is monitoring combustion conditions in the barrel.

Performance and operational issues

The air distribution in a cyclone is critical for good performance and problem free operation. Primary air is fed to the burner to ignite the coal. Tertiary air is fed to the burner to cool the burner face and force combustion into the barrel. Secondary air is fed to the barrel to continue burnout of the coal. Many cyclone boilers currently operate the cyclone barrels substoichiometrically to reduce NO\textsubscript{X} emissions. The balance of air required to complete combustion is provided through overfire air ports. The extent of staging is limited by the minimum heat release in the barrel that is required to keep the slag molten and free flowing. Some cyclones are equipped with secondary air dampers that are split to enable the operator to control the air flow distribution front-to-back within the cyclone barrel. This has been shown to be an effective way to inhibit the formation of deposits, or clear an existing deposit.

Secondary air is fed to the barrel to continue burnout of the coal. Many cyclone boilers currently operate the cyclone barrels substoichiometrically to reduce NO\textsubscript{X} emissions. The balance of air required to complete combustion is provided through overfire air ports. The extent of staging is limited by the minimum heat release in the barrel that is required to keep the slag molten and free flowing. Some cyclones are equipped with secondary air dampers that are split to enable the operator to control the air flow distribution front-to-back within the cyclone barrel. This has been shown to be an effective way to inhibit the formation of deposits, or clear an existing deposit.

The primary performance issue in cyclones relates to balancing the air and fuel distribution to individual cyclone barrels, maintaining optimum cyclone barrel flame temperatures and carbon burnout while maintaining free-flowing slag. Low NO\textsubscript{X} emissions are achieved by staging the cyclone combustor primarily by reducing secondary air. While cyclone barrel temperatures initially increase as the cyclone barrel is staged down to stoichiometric air flow rates, further staging starts to reduce the coal combustion and cyclone barrel temperature. Stoichiometries above 0.85, however, will maintain cyclone barrel temperatures of the same order as unstaged combustion conditions at a stoichiometry of 1.15 as the reduced heat release is offset by the reduced mass flow rate of air through the cyclone barrel. The cyclone barrel is more sensitive to changes in the fuel/air distribution, however, with changes resulting in a stoichiometry below 0.85 resulting in a reduction in cyclone barrel temperature below that experienced under unstaged operating conditions. As the cyclone barrel temperature is reduced below an ash specific threshold, its slag becomes more viscous and less sticky. Since the slag layer in the cyclone serves to trap burning coal particles and ash particles, it is essential that the slag is maintained in a free flowing condition. Burning coal particles do not adhere as readily to a viscous or frozen slag layer and are consequently ejected from the barrel into the furnace. The large coal particles that escape the cyclone cannot be burned completely in the furnace. This causes an increase in unburned carbon loss. Further, ash loadings to the back pass and backend equipment will increase. Changes in the air distribution, or drift in coal properties (e.g., moisture, grind size, and heating value) can cause the NO\textsubscript{X} emissions and unburned carbon loss to increase.

Fig. 1 Cyclone combustor.
Some utilities have installed air flow measurement devices in the primary, secondary and tertiary air ducts to provide a continuous measurement of the individual air flows.\textsuperscript{2,3} With this system, operators can maintain a specific air distribution within the cyclone.

Many utilities are switching to a blend of Powder River Basin (PRB) coal and bituminous coal to reduce sulfur emissions. The PRB coal has a lower heating value and less ash than eastern bituminous coals for which many cyclones were initially designed. Since PRB blends tend to burn cooler and have less ash, it is difficult to maintain an adequate slag layer to trap burning coal particles. In addition to changes in the coal blend, other coal properties, such as changes in moisture, ash fusion temperature, and grind size, can significantly change cyclone operation. Frequently, visual inspection provides the only means for the operator to determine changes in the slag properties in the cyclone.

**Flame Doctor system development history**

Under sponsorship of the Electric Power Research Institute (EPRI), Babcock & Wilcox Power Generation Group, Inc. (B&W) and Oak Ridge National Laboratory (ORNL) previously developed a technique to analyze the flame-scanner signal from wall-fired burners, determine the state of the flame, and determine the root cause(s) of non-optimal flame condition (U. S. Patent Nos. 6,775,645 B2 and 6,901,351 B2). This technique was subsequently incorporated into a commercial product known as the Flame Doctor system. The commercial system allows simultaneous, continuous monitoring and evaluation of each burner in a boiler. The information provided by the Flame Doctor system allows operators to adjust the combustion process and achieve improved performance.\textsuperscript{4,5,6}

Recognizing the need for better cyclone monitoring technologies, the EPRI Cyclone Interest Group (CIG) funded a feasibility test to assess the likelihood that the signal-analysis techniques developed for the pulverized coal burner Flame Doctor system would be able to discriminate changes in cyclone operating conditions. B&W and ORNL conducted the feasibility tests over a three day period at AmerenUE’s Sioux Unit 1. The tests consisted of adjusting primary, secondary, and tertiary air flows over a fairly wide range and recording the raw Flame Doctor signal statistics for all 10 cyclones. The B&W and ORNL test team conducted testing at both low load and full load conditions. The test results showed that the Flame Doctor statistics responded well to changes in cyclone operation. The results also showed that the response was repeatable and that there was a difference between the information produced by the main flame scanner and that produced by the lighter scanner.\textsuperscript{7}

Because of the encouraging feasibility test results, the EPRI CIG decided to fund a full-scale Flame Doctor development effort on cyclone-fired units. AmerenUE’s Sioux Unit 1 and Alliant Energy’s Edgewater Units 3 and 4 served as host sites for the development program. The B&W/ORNL team performed two series of baseline tests and one series of demonstration tests at each unit. The baseline test series demonstrated that a representative library of combustion conditions could be generated for both the burner and the barrel of the cyclone. The baseline test results showed that combustion instabilities in the burner could be distinguished from combustion instabilities in the barrel. Specifically, instabilities due to insufficient primary/tertiary air or secondary air (fuel-rich combustion) could be identified. Further, the results showed that upsets in cyclone performance due to operational changes, such as a freezing slag layer or tube leak, could be identified.\textsuperscript{7} Using the baseline results, the team developed a methodology for using Flame Doctor to optimize cyclone performance. This control strategy was demonstrated at both sites.

**Flame Doctor system overview**

The Flame Doctor system consists of high-speed data acquisition hardware and specialized software. The hardware collects and conditions the signals from all flame scanners simultaneously. The flame signals are acquired for a two (2) minute period to ensure reliable, repeatable statistics. The software is based around a typical client/server architecture. The server communicates with the hardware, performs the proprietary calculations and interacts with the local historian. The client presents the results to the user through a graphical user interface (GUI). Flame Doctor’s GUI is shown in Figure 2. The system provides the following information for each cyclone: an overall rating of the burner (also called the burner’s diagnosis number), an overall rating of the barrel (barrel diagnosis number), an alarm indicating low primary/tertiary air flow, an alarm indicating cyclone freezing conditions, and an alarm indicating low secondary air flow and an alarm indicating cyclone freezing conditions.

![Flame Doctor graphical user interface.](image)
EPRI Cyclone beta program

Overview

As a result of the successes achieved in the early feasibility and development programs, the EPRI CIG initiated the Flame Doctor cyclone beta demonstration program. Like most beta programs, the basic goal of the EPRI program is to demonstrate the long-term viability of the Flame Doctor system on cyclones through extended real-world use. More specifically, the goals of the EPRI Flame Doctor cyclone beta demonstration program are to:

- confirm the accuracy of the Flame Doctor system’s cyclone combustion analysis over a wide range of real-world conditions;
- demonstrate sustainable plant performance improvements from using Flame Doctor’s combustion analysis results;
- identify and correct software problems through long-term operation and real-world use; and
- improve the software’s features and user interface through feedback from real users.

To accomplish these goals, each beta demonstration host site is given a permanently installed Flame Doctor system. Plant personnel are trained on the system and its use following installation and initial testing. The plant personnel are then asked to use the system on a routine basis and report on the accuracy and usefulness of the system as well as on any software bugs encountered.

Status and preliminary results

Currently, five (5) units have joined the beta demonstration program. The five units are: AmerenUE Sioux 1, AmerenUE Sioux 2, Alliant Energy Edgewater 4, Associated Electric Cooperative Inc. New Madrid 1 and Dynegy Baldwin 2. A permanent Flame Doctor system has been installed on each unit and initial testing has been performed. Each of the systems has also been connected to either the plant’s historian or DCS so that Flame Doctor results can be viewed on existing control room screens or analyzed with other plant data.

The initial testing has shown good correlation between Flame Doctor’s assessment of a cyclone and the cyclone’s actual condition. A good example of this correlation can be seen in the testing performed at New Madrid 1. During one test, the Flame Doctor team walked down the unit and made notes and videos of each cyclone’s combustion state. The team then compared the visual observations with Flame Doctor’s results and found good correlation. The team decided to initially focus on cyclone AF because it was one of the worst looking cyclones both visually and within Flame Doctor.

The state of cyclone AF at the beginning of testing is shown in Figure 3. Flame Doctor’s rating (diagnosis number) for the burner on cyclone AF had been fluctuating between the high 50s and high 60s and was 68 during this screen capture. Flame Doctor was also showing a low primary air alarm for this cyclone. The inset picture shows that the cyclone was generally a dull orange color with coal visibly coming off of the wear blocks between the 5 and 6 O’clock positions.

The team asked the operator to increase primary air flow to cyclone AF. The operator opened the primary air damper from 62% to 72%. Figure 4 shows the performance of cyclone AF after the unit had time to settle out from the adjustment. The burner now showed a higher diagnosis number and the low primary air alarm had cleared. The freezing alarm was still active because these tests were performed before the freezing algorithm was tuned for New Madrid. Visually, the combustion in cyclone AF was a much brighter yellow-orange and the coal was staying on the wear blocks much longer.

The correlation between Flame Doctor and cyclone condition has been seen at the other test sites too. For instance, during a recent test at Edgewater 4 the Flame Doctor team noted that cyclone 4-3 was getting a diagnosis of 52 and the low secondary air alarm was active. The team inspected the
cyclone and found that it was darker than it had been on previous days. The team raised the stoichiometry set point on cyclone 4-3 from 0.78 to 0.90. This caused the indicated secondary air to increase by roughly 20000 lb/hr (9000 kg/hr). Flame Doctor’s assessment of this cyclone increased to 75 and the low secondary air alarm became inactive. This response is shown in Figure 5. The adjustment to cyclone 4-3 occurred at the right-most vertical line. Note the steady decline in performance prior to the adjustment and that the response of the cyclone is immediate. The team inspected the cyclone after the adjustment and found the cyclone to be brighter in color.

The beta testing has also shown that Flame Doctor can point out relationships between cyclones that the operator may not know about. Figure 6 shows trends of four statistics for cyclone 4 during recent testing at Sioux 1. The four statistics shown are used to determine the diagnosis numbers that are given to the cyclone and should be near the center of the plot for optimum performance. The sudden jump in statistics toward the left side of the lower two plots was caused by the operators suddenly increasing the feeder and secondary air biases on cyclones 1, 3 and 5. The settings on cyclone 4 were not touched but the change to the other three cyclones caused a downward shift in performance on cyclone 4. This was most likely due to the other cyclones stealing secondary air from cyclone 4.

Finally, the beta test results have shown that the overall performance of the unit can be positively impacted by following a methodical tuning strategy guided by Flame Doctor results. This was demonstrated at Sioux 1 during a period when the unit was experiencing combustion issues resulting in high LOI. Flame Doctor’s assessment of the cyclones during that period is shown in Figure 7. Most of the cyclones are showing poor combustion indicating a need for more air. In addition, the “Freezing Probable” alarm which is the red annunciator at the bottom of each cyclone is active for cyclones 1, 2, 4, 6, 9 and 10. Visual observations confirmed that cyclones 2 and 6 were frozen with cyclone 4 and 10 close to being frozen.
Conclusions

The preliminary results from the EPRI beta demonstration program have been very promising. Generally, Flame Doctor has correlated well with observed cyclone performance at all demonstration sites. The system has been successfully used to identify poor performance and improve cyclone combustion through better distribution of the primary, tertiary and secondary airs. Identifying suboptimal cyclones and improving them in a methodical way can lead to measurable improvements in overall unit performance. The Flame Doctor system has also been able to identify cyclones that are in the early stages of freezing so that corrective action can be taken. Extended use of the software as well as feedback from the utility users have led to improvements in the Flame Doctor software.

Future directions

The EPRI beta demonstration program is scheduled to continue into 2010. The next major step in the continuing development and demonstration of the Flame Doctor system is to show how it can be integrated into a closed-loop combustion optimization system. This work is already underway at AmerenUE’s Sioux 1 unit where the Flame Doctor system has been connected to B&W’s FocalPoint™ Advanced Control Platform. The combined system is controlling the secondary air flow to individual cyclones, the air flow to individual overfire air ports, the degree of staging and the O₂ trim. Preliminary results from full closed-loop operation have been very promising.

References


Flame Doctor is a registered trademark of the Electric Power Research Institute.