FOULING MONITOR AND ALARM SOFTWARE – RECENT DEVELOPMENTS

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ABSTRACT

Many utilities have incorporated the increased use of Powder River Basin (PRB) coals as part of their compliance strategies to meet anticipated Oxides of Nitrogen (NO_x) emission regulations. In fact, conversion of a tangentially-fired boiler to 100% PRB coal in combination with the TFS 2000 low-NO_x firing system is an attractive option to avoid the capital cost of an Selective Catalytic Reduction (SCR) system. However, operation under deeply staged combustion conditions with a highly reflective PRB ash can lead to decreased furnace heat absorption and high furnace exit gas temperatures. If boiler operations are not carefully monitored, these firing practices can lead to slagging, fouling episodes, a possible outage, or a decrease in unit availability.

This paper summarizes the development of software to monitor boiler fouling and to provide an advanced warning to the control operators when a fouling episode is imminent. With adequate warning, preemptive action can be taken (e.g., soot blowing, a change in coal blend, etc.) to potentially avoid a costly outage. The software utilizes a unique combination of combustion diagnostic techniques and convective section heat adsorption analyses to identify boiler operating conditions where ash deposition rates may be high and conducive to triggering a fouling episode.

The paper outlines the history of fouling problems and the implementation of the fouling alarm software on several tangentially-fired boilers with relatively narrow reheat tube spacing. Although these Canadian units are not currently operating in a low-NO_x firing mode, the fouling problems and outages that they have experienced with a Western type coal provide valuable insight into how specialized software can minimize fouling outages. Case histories are provided, including a description of the most recent software developments. The latest version allows direct viewing of the boiler control operator's station by plant or corporate supervisors using Internet Explorer 5.x over TransAlta's Local Area Network (LAN).

INTRODUCTION

Increased competition has forced power generating utilities to carefully investigate options for reducing capital expenditures and operating costs while satisfying more stringent environmental regulations. More specifically, conversion to a 100% western low-sulfur PRB coal can significantly reduce NO_x and Sulfur Dioxide (SO_2) emissions and potentially avoid the cost of installing a Selective Catalytic Reduction (SCR) NO_x control system. This is particularly true for smaller, older tangentially-fired units, retrofitted with state-of-the-art low-NO_x firing systems such as the TFS2000. However, even smaller wall-fired units are being converted to high PRB usage and Low-NO_x Burner/OverFire Air (LNB/OFA) control systems at utilities where emissions averaging with large SCR equipped units provides NO_x regulation compliance. Unfortunately, many of these older units, originally designed for eastern bituminous coals, can experience difficulties firing PRB coals under deeply staged low-NO_x firing conditions.

Many PRB coals have a tendency to deposit a highly reflective light colored ash in the furnace that reduces furnace heat absorption and increases the furnace exit gas temperature (FEGT). In addition, deeply staged low-NO_x combustion at high OFA flows can lead to local regions of increased ash deposition in the burner zone. Additional sootblowers and water cannons are often added to improve furnace cleaning; but utilities used to firing eastern coals frequently fall behind in sootblower maintenance and do not carefully monitor furnace exit gas temperatures and operator sootblowing practices. The net result is that furnace ash deposits can build in local fuel-rich regions to the point where ash fusion temperatures are exceeded and the ash becomes "sticky" or semi-molten. This can be aggravated by non-uniform combustion in the burner zone caused by an uneven coal flow distribution to the burners. Under these circumstances, localized delayed combustion may result in burning high in the furnace and into the convective section. Sticky or semi-molten ash can lead to rapidly growing deposits that bridge the entrance to the superheater pendants. A rapid build-up of ash deposits can also occur in the reheat section, particularly on units with narrow reheat tube spacings (i.e., designed for eastern bituminous coals). Although bridging of the superheat entrance is usually quite visible and is often monitored by TV cameras, a rapid build-up and complete pluggage of the reheat section can occur in areas where visibility is poor and/or boiler operators become busy with other duties and, thus, monitor deposits infrequently.

For the reasons outlined above, a cost-effective strategy to achieve NO_x emissions compliance without SCR by low-NO_x firing of PRB coals can backfire, resulting in frequent unit derates and forced outages due to heavy ash deposition and fouling of the convective passes (i.e., superheat, reheat, and primary superheat sections). Many fouling episodes can be avoided by religious sootblower maintenance, optimized sootblowing cycles, frequent monitoring of coal properties, direct measurement of FEGT, maintaining uniform combustion, and frequent boiler inspections. However, the reality is that this ideal world seldom exists at most commercial power plants. Therefore, a need has developed for a fouling episode monitor and alarm system that can alert boiler operators to a potential boiler plugging and prevent a forced outage. Ideally, this monitoring system would not only detect the onset of a fouling episode, but also provide enough advanced warning to alert boiler operators to take evasive action to arrest the fouling and avoid a forced outage.

DEVELOPMENT OF A FOULING EPISODE MONITOR/ALARM (FEMA)®

This paper outlines the history of a fouling problem at TransAlta Utilities and the development of software intended to monitor boiler fouling and provide an advanced warning to the control operators. With adequate warning, preemptive action could be taken (e.g., aggressive sootblowing, a change in combustion conditions, etc.) to potentially avoid a costly forced outage.

TransAlta Utilities awarded a contract to Fossil Energy Research Corp. to develop a Fouling Episode Monitor/Alarm (FEMA)® to minimize the frequency of fouling episodes at Wabamun

Unit 4. More specifically, Wabamun Unit 4 is a 300 MW tangentially-fired unit with a history of fouling problems, primarily because it has a relatively narrow tube spacing in the reheat section. This unit tends to foul when burning a blend involving a high alkaline (but low ash) coal seam. Although the coal is mined at the plant near Edmonton, Alberta, Canada, it has properties similar to western type U.S. coals from the Powder River Basin in Wyoming.

Although the TransAlta Utilities units are not currently operating in a low-NO_x firing mode, the fouling problems and outages they have experienced provide valuable insight into how specialized software could minimize fouling outages on U.S. units firing PRB coals. The development of a custom fouling episode monitor/alarm was justified based on the cost of a typical fouling outage (2.5 days) of roughly $400,000 per event. At the start of the project, Wabamun Unit 4 was averaging two fouling outages per year. Thus, an investment in software to reduce this outage frequency could result in a fairly quick payback.

Project Objective

The primary objective of this project was to prepare a custom software module that would:

- Alert operators to a potential impending fouling episode;
- Identify adverse boiler firing practices that increase the risk of fouling;
- Display graphs of key parameters to aid in fouling event diagnostics;
- Keep a record of alarms for subsequent analysis.

The fouling episode software would initially monitor full-load operating parameters that directly affect the rate of ash deposition. More importantly, it would be *custom calibrated* using unit design and coal-specific test data. The Fouling Episode Monitor/Alarm (FEMA)® should not be confused with commercial soot blowing advisors or boiler performance monitor software. FEMA® utilizes a unique combination of combustion diagnostic techniques and convective section heat absorption analyses to identify boiler operating conditions where ash deposition rates may be high and conducive to triggering a fouling episode. Each FEMA® is custom-configured and tuned for a specific unit based on its unique design, fouling history, and data acquisition system.

Wabamun Unit 4 Fouling History

Wabamun Unit 4 is a 300 MWe tangentially-fired dual-furnace unit supplied by Combustion Engineering (CE) and commissioned in 1967. Unit 4 is equipped with six elevations of burners (48 total) supplied by six CE model RS-823 bowl mills. A hot-side electrostatic precipitator is used for fly ash removal. Design superheat and reheat temperatures are 1005°F and 1006°F, respectively.

Several factors have contributed to the fouling tendency at Wabamun Unit 4 in addition to the coal property factor (high calcium) mentioned previously. They include:

- relatively narrow tube spacing in the reheat section
- occasional maldistributions of fuel and air in the burner zone due to plugged burner pipes
- difficulties maintaining soot blower operation on the back wall
- sodium injection to condition the hot side electrostatic precipitator
- occasional low O_2 operation for opacity reasons.

A detailed analysis of combustion conditions and boiler firing practices just prior to past fouling episodes suggested that a combination of events, rather than just the fuel properties alone, were the primary cause of the fouling episodes. In some respects, each fouling episode appeared to have one (or more) typical "signatures" of related events and parameter excursions. Potentially, they could be monitored with custom PC software to detect an impending fouling episode before it had reached its avalanche-type threshold.

Wabamun Unit 4 Fouling Episode Monitor/Alarm Beta Software

A prototype Fouling Episode Monitor/Alarm (FEMA)® was developed for TransAlta Utilities as custom software designed to operate on a conventional PC using commercial Microsoft applications and a Windows 95 platform. It should be emphasized that the software analyzed the range and relationship of boiler operating parameters that cause high fouling rates, not just the changes in heat absorption. Therefore, FEMA® should not be confused with other boiler performance monitors or soot blowing advisors intended to optimize thermal performance or advise operators when and where to blow soot. The software must be "calibrated" for site-specific design and operating parameter ranges, but this calibration involves much more than simply establishing, at one point in time, the heat absorption under "clean" boiler operating conditions. Parametric testing is recommended, but the initial software calibration was developed using historical fouling episode data from past fouling episodes. Historical data were normalized and rolling averages were applied in selected instances to allow consistent data comparisons on the same basis. Data validation routines were developed to filter out invalid data.

Acceptable ranges and alarm tolerances were established for a total of 20 key operating parameters, available from the plant historian. A logic module was developed to process the various parameter alarms resulting in a "FEMA® Fouling Index" which indicates the relative fouling potential for the current unit operating conditions. A high FEMA® Fouling Index indicates that a fouling event is imminent and the boiler control operator should take immediate action to reduce the potential for fouling. These steps may include:

- aggressive soot blowing
- an increase in excess air (if permitted by NO_x and opacity)
- a rapid load reduction

- a drop in burner tilt position
- removing one or more mills from service.

It should be noted that the FEMA® Fouling Index is computed using an algorithm developed from unit-specific historical fouling data and it bears no relationship to fouling indices that have been developed in the past based on coal properties. The FEMA® Fouling Index is based on boiler operating parameters and calculated values and currently does not contain any coal property data.

Several candidate FEMA® Fouling Index algorithms were back tested using historical fouling data to assess the beta software performance. These simulations provided warnings of potential fouling episodes of from one to three hours before the boiler control operators took evasive action to try to prevent the boiler from plugging up and going "off-line". For example, Figure 1 illustrates the relationship between the normalized reheat heat absorption and a candidate FEMA® Fouling Index algorithm for a March '97 fouling episode. Although the "seeds" of the fouling episode were planted as much as 24 hours before the operators took action at 10:00, a possible pluggage in the west reheat section first appears in the heat absorption data shortly after 04:00 on March 12, 1997, where a divergence in the east and west heat absorption is noted. The FEMA® Fouling Index algorithm, shown by the solid line, begins to increase rapidly after 06:00, and the alarm turns red (FI>0.8) at approximately 07:00, indicating an imminent fouling episode unless action is taken. Although conditions improve somewhat for a short period after 08:15, the FEMA® Fouling Index alarms again at about 09:15. Without the aid of FEMA® at the time, the operators reduced load and took a mill out-of-service at 10:00 in attempt to save the unit. (A FEMA® Fouling Index is not shown past 10:00 because the load decreased rapidly changing the heat absorption.)

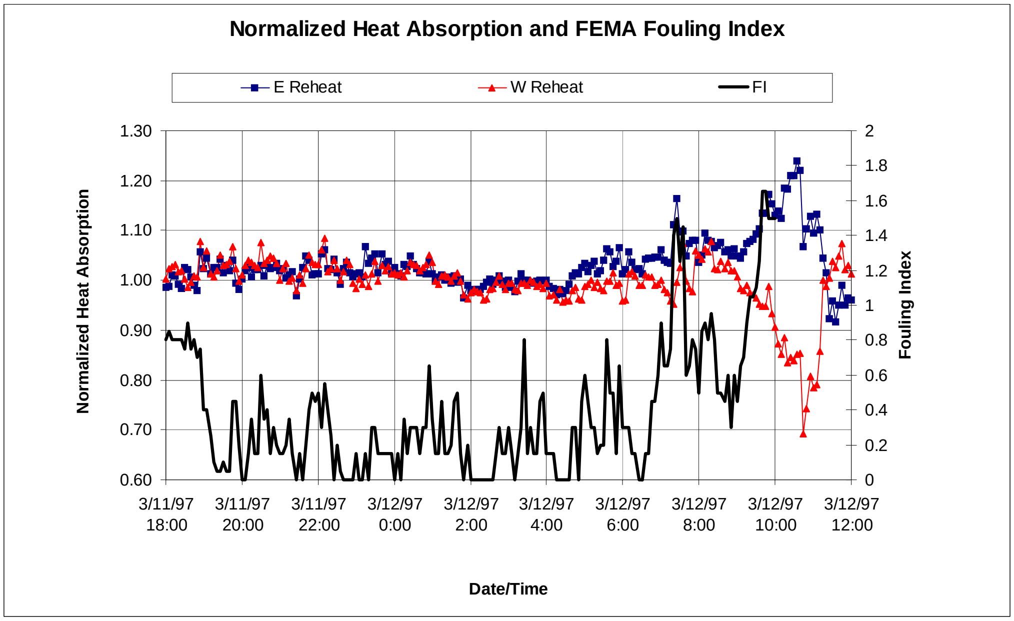

Figure 1. Comparison of the Normalized Reheat Absorption and the FEMA® Fouling Index for the March '97 Fouling Episode

SUNDANCE UNITS 1 & 2 FOULING EPISODE MONITOR/ALARM SOFTWARE

The Fouling Episode Monitor/Alarm (FEMA®) was installed at two other units in the TransAlta system, Sundance Units 1 & 2. Each FEMA® was custom configured for the characteristics of the individual unit. A prototype (alpha) version of the software was tested off-site in a batch data analysis mode. A beta version of the software designed for operation with real-time data was installed in May 1999. It should be noted that the Sundance Units 1 and 2 are considered to be “sister” units to Wabamun 4 in terms of boiler design (narrow reheat tube spacing) and coal use (mine mouth units within sight of the Wabamun station). However, it became apparent during installation testing to calibrate the FEMA® software that the two Sundance units operate differently from each other as well as Wabamun 4 in terms of their heat absorption. Minor differences in the tuning of the combustion controls, plus operator preferences in soot blowing and pulverizer loadings, had a significant affect on the thermal response characteristics of the boiler and the range of “normal operations” between soot blowing. Boiler diagnostic and performance tests, conducted over a range of boiler firing conditions for each of the Sundance units, illustrated the need to conduct unit-specific calibration tests of the FEMA® software.

The FEMA® software installed on Sundance Units 1 and 2 represented a significant upgrade in terms of the calculation methodology for the FEMA® Fouling Index as well as improvements in the user interface. Operating data from an April 1999 fouling episode on Unit 1 were downloaded from the historian to “back test” the calibrated Unit 1 FEMA®. The results of this back testing are shown in Figure 2. The heat absorption data shown in this figure are for the superheat section which provided earlier signs of pluggage than the reheat section. The FEMA® Fouling Index provided an early warning of a potential problem at 16:00 on April 22nd. This warning occurred the day before the fouling finally became so bad that aggressive soot blowing was necessary at 04:00 to keep the unit from plugging and shutting down for a forced outage. The FEMA® Fouling Index peaked at 1.7, but eventually dropped to a very safe level of less than 0.2 about four hours later, confirming that the soot blowing strategy had been successful.

Figures 1 and 2 represent “back testing” of the FEMA® software using historical fouling data as opposed to real-time operation during a fouling event. The software and FEMA® Fouling Index were modified for operator convenience so that a yellow warning now occurred at a FEMA® Fouling Index of 5 and it turned red at 7.5. A serious fouling episode subsequently occurred on the south side of the superheat section of Sundance 1 on October 6, 2000. The FEMA® Fouling Index and the normalized secondary superheat heat absorption are shown in Figure 3 for comparison purposes over the 24-hour period 03:00 on October 6th to 03:00 on October 7th.

The FEMA® Fouling Index issued its first yellow warning at 14:47 and a red alert at 15:37 (50 minutes later). The FEMA® Fouling Index peaked at a value of 10 at 15:52. The FEMA® Fouling Index dropped with aggressive soot blowing, but returned to yellow at 16:42 and subsequently shot up to 10.7 at 18:37, at which time the operators dropped load to 250 MW to clean the boiler. The heat absorption graphs continued to indicate that the south side was not cleaning well and a third red alert was issued at 01:47 on October 7th. We believe the FEMA® Fouling Index warnings and red alerts at three different time periods (including one more than three hours before the operators dropped load to clear the furnace) illustrates the value of the FEMA® software in alerting operators to a fouling event.

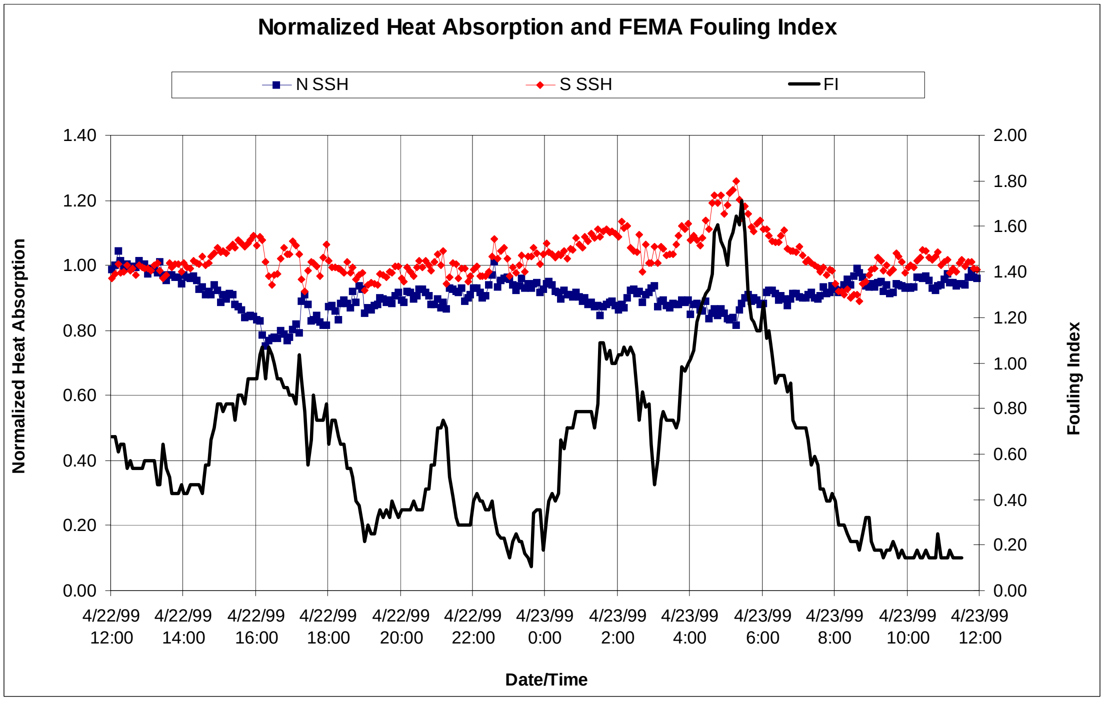

Figure 2. Comparison of Normalized Superheat Heat Absorption and the FEMA® Fouling Index for the April '99 Sundance 1 Fouling Episode

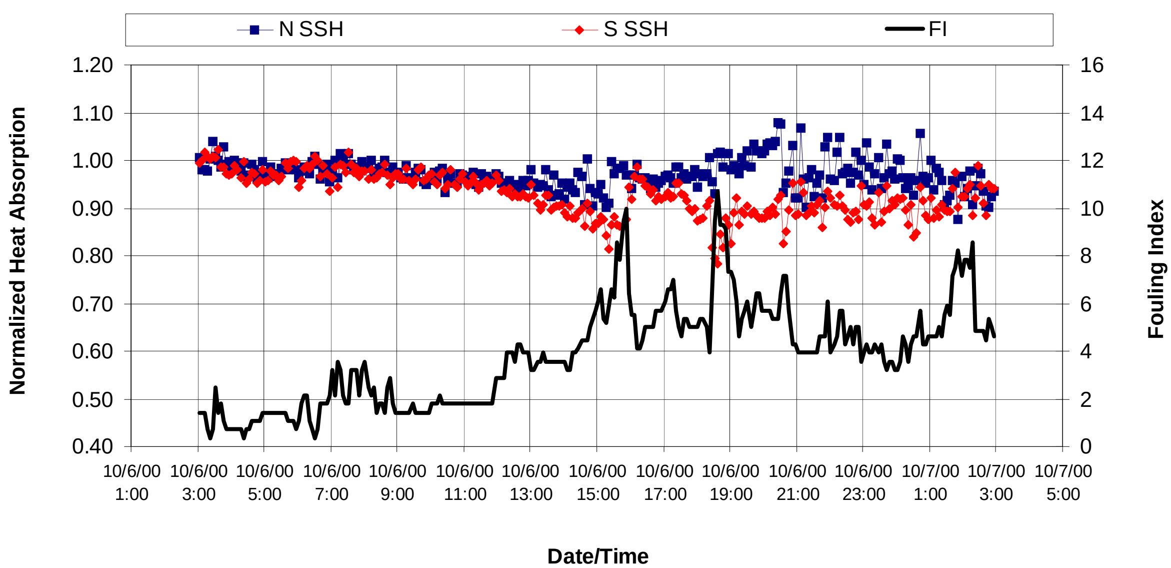

Figure 3. Sundance Unit 1 – FEMA® Fouling Index and Normalized Heat Absorption

A fouling episode also occurred at Sundance 2 during the period November 13-15, 2000, reaching a climax at 04:45 on November 15th. Screen shots of the FEMA® Fouling Index from the FEMA® software are shown in Figures 4 and 5 for the 48-hour period preceding the fouling event.

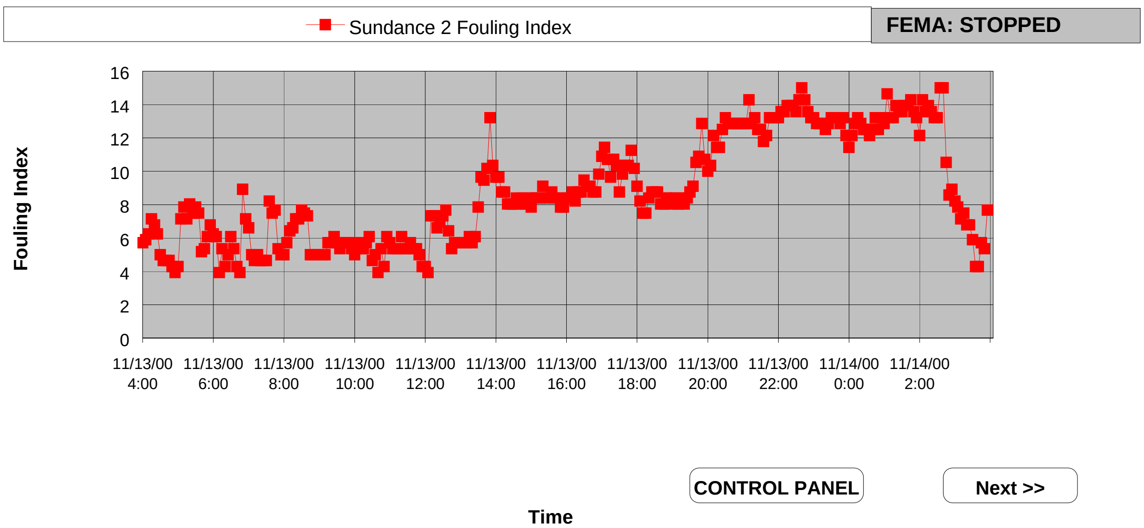

Figure 4. Sundance Unit 2 Fouling Index – November 13th – 14th

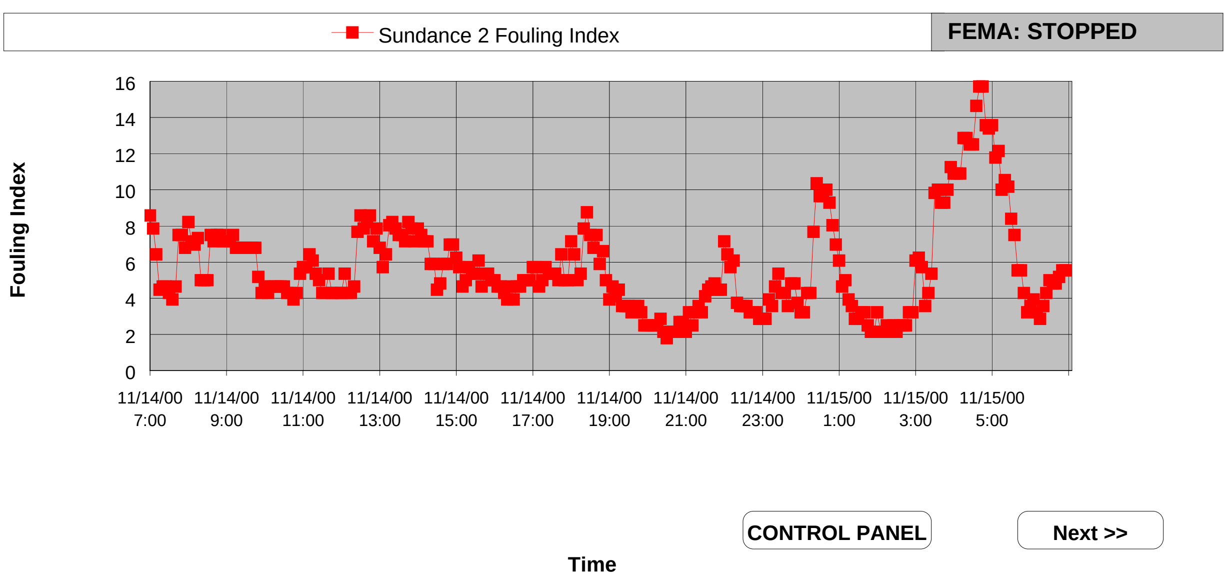

Figure 5. Sundance Unit 2 Fouling Index – 24 Hours Preceding Event

A review of the FEMA® Fouling Index graph for the period starting 48 hours ahead of the fouling event (Figure 4) shows that a series of early warnings was issued between 05:30 and 08:35 on November 13th. A sharp rise in the index to 13.2 at 13:50 indicated the onset of a serious fouling episode. The FEMA® Fouling Index remained in the red for more than 12 hours, until 15:15 on the morning of the 14th, at which time the heat absorption momentarily improved when full load firing was attempted. However, the FEMA® Fouling Index periodically went red at five different times between 07:00 and 19:00 on September 14th (Figure 5), repeatedly warning that the boiler was still fouled. The last "final" episode resulted in an extremely high FEMA® Fouling Index of 15.71 on September 15th, (more than double the red alarm level) before the boiler was finally taken off-line.

The primary point of the preceding discussion is that the FEMA® software does have the ability to respond to fouling events and issue advance warnings to the operator. Unfortunately, the data shown in Figures 3, 4 and 5 were not always available to the boiler control operators due to computer problems and inaccurate input data from the historian.

FEMA® SOFTWARE – RECENT DEVELOPMENTS

The FEMA® software was originally installed on a separate stand alone computer as a Microsoft Excel Visual Basic Application (VBA) running under a Microsoft Windows NT 4.0 operating system. Evaluation of the software, hardware, data exchange, and operator interface identified a number of issues that were addressed in a new version of the software installed at the Sundance station in the Spring of 2001. Some of the lessons learned from the use of the first version of the software were:

- Boiler control operators preferred to have the FEMA® screen displays on the same console as other process control screens, once the software was operating reliably.

- Data retrieval and validation of input data from the historian was unreliable for real-time operation due to continual upgrades and changes in Tag addresses.

- Second generation enhancements to FEMA® approached the limits of the Excel Visual Basic application. (Recoding in Visual Basic with a more robust user interface was implemented.)

- Off-site batch mode analyses of downloaded input data frequently resulted in calculated FEMA® Fouling Index results that differed from the real-time data displayed at the plant.

The latest version of the FEMA® software is now displayed on the same console as other boiler process control software. The input data stream to FEMA® comes directly from the process control computer interface instead of being routed into and out of the plant historian. Plant or corporate supervisors within TransAlta can directly view the same information as displayed on the boiler operator's station by using Internet Explorer 5.x web browser over TransAlta's Local Area Network (LAN) to access FEMA® in the client mode. Input data and calculated results are now archived in a manner that they can be directly downloaded over the LAN and analyzed "off-line" in the batch mode ensuring that detailed data analyses give results consistent with the real-time version. Data validation routines have been enhanced and substitute default parameter values defined to allow FEMA® to continue operating if an input parameter is missing.

CONCLUSIONS

- Fouling episodes leading to a unit derate (or possible forced outage) may become more common as units designed for bituminous coals are converted to 100% PRB coals operating in a deeply staged low-NO_x mode.

- High furnace gas exit temperatures and convective section fouling are often related to poor sootblower maintenance, inadequate or infrequent sootblowing, and non-uniform combustion (often caused by uneven coal flow distribution to the burners).

- The implementation and calibration of the Fouling Episode Monitor/Alarm (FEMA®) software to detect an impending fouling episode could potentially avoid the $400,000 cost of a typical fouling outage at TransAlta Utilities.

- Site-specific boiler design and operating practices, such as relatively narrow reheat tube spacing and occasional low-O_2 operation for opacity reasons, can compound the fouling potential for coals with a fouling tendency.

- A FEMA® Fouling Index Algorithm has been defined that typically provides sufficient advanced warning of a fouling episode to allow boiler control operators to implement preventative measures to clean the boiler and reduce the potential of a forced outage with modified boiler firing practices

- A second generation FEMA® was installed in the Spring of 2001 featuring the following enhancements:

  - Display of an enhanced user interface on the same console as other process control screens instead of on a stand-alone PC.

  - The FEMA® Fouling Index is now calculated using input data obtained directly from the process control computer interface instead of the plant historian.

  - TransAlta supervisors and management can directly access the same information displayed to the operator using a Internet Explorer 5.x browser to access FEMA® over the TransAlta Local Area Network (LAN).

  - Data validation and substitution routines have been improved to allow FEMA® to continue operating reliably when an input parameter is temporarily missing.

- The most recent FEMA® software and FEMA® Fouling Index algorithm shows considerable promise in providing an advance warning of an impending fouling episode.

ACKNOWLEDGEMENTS

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