

ADVANCED CONTROL STRATEGY REDUCES RECOVERY BOILER FOULING WHILE LIQUOR THROUGHPUT IS INCREASED

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ABSTRACT

An advanced process control strategy was implemented on the chemical recovery boiler process at Canadian Forest Products Ltd. Intercontinental Pulp in Prince George, BC. The strategy improved performance of the boiler with increased liquor throughput being obtained coincident with reduced fouling of convection surfaces. In addition, further benefits were realized of increased thermal efficiency and a more stable process operation. Major functionality provided by the control system includes full automatic control greater than 95 percent of the time, liquor firing control by the Consumed Air method, and an enhanced operator interface. The boiler performance is reviewed before and after control strategy implementation. A boiler Fouling Index used by the mill reliably indicates the degree of plugging of convection surfaces. Results show that implementation of advanced control and automatic operation significantly stabilizes recovery furnace operation and reduces the accumulation rate of ash deposits and fouling of the convection surfaces. The time between water washes of the boiler is significantly extended by the system of automatic control.

INTRODUCTION

The Intercontinental (Intercon) Pulp mill recently upgraded the control system for its recovery boiler process by implementing an advanced control strategy. Implementation of the control strategy on the mill's chemical and heat recovery boiler has resulted in meeting the goals of increased run time between water washes while operating at an increased black liquor solids throughput. The liquor solids throughput on the boiler has been increased 8% on an average - from 1460 tonne/d to 1580 tonne/d of dry solids. Ash deposits on boiler convection surfaces had restricted the boiler to a run time of four months between water washes. Recovery boiler operation on advanced control has resulted in stabilizing furnace conditions. The resulting decreased carryover is evidenced by a significant decrease in the rate at which ash builds up on boiler convection surfaces. Operating results show that it is possible to run at least six months without water washing, however, production curtailments and annual scheduled outages have not permitted this potential to be realized. Boiler thermal efficiency has improved through a reduction in the excess air for combustion, with the oxygen in the flue gases reduced from an average of 2.8% to 1.5%.

The control system monitors boiler surface fouling by calculating and recording a Pressure Drop Factor (Fouling Index) that is developed from pressure measurements across each of the convection surface banks of the boiler and the electrostatic precipitator. The factors are calculated using a set of algorithms that compare the measured bank pressure drop and the calculated gas weight to the same parameters with a clean condition for the bank. Over time, it has been demonstrated that these algorithms reliably indicate the degree to which the boiler is plugging.

The Intercon Mill installed the control system to provide a high level of process automation and heat value based liquor firing modulation using the Consumed Air control strategy. The advanced process control strategy provides a stable black liquor burning operation. This makes it possible to optimize operation and to operate the recovery boiler on advanced control about 99 percent of the time that liquor is being burned.

BACKGROUND

Intercontinental Pulp is one of two mills in the Prince George Pulp and Paper Mills Division of Canadian Forest Products Ltd. (Canfor). The mill is located about two miles from downtown Prince George, BC. It is a single line Kraft pulp mill producing principally bleached softwood market pulp.

A project to convert the Babcock & Wilcox recovery boiler to a low odor design was completed in 1993. The conversion combined goals of reducing TRS emissions and a capacity upgrade to accommodate the higher solids flow expected with the mill's addition of oxygen delignification [1]. The recovery boiler black liquor solids firing capacity was upgraded to 1450 tonne/d at 75 percent solids from 1250 tonne/d at 63 percent solids. The new three level air system was further modified after operating tests at high solids with an increase in capacity of the tertiary air fan. The fan rotor was tipped to increase the diameter and the air duct pressure drop was reduced by rebuilding a high pressure air foil measuring element. Liquor firing was optimized by implementing wedge style, splash plate nozzles used successfully in other installations [2]. Ibach reported that TRS levels were achieved that were acceptable to the authorities with an improvement in boiler operation, however, water wash expectations were not met [1]. With high solids firing, there was an increase in mechanical carryover and in the chloride level in the liquor. Both of these adversely affected boiler ash deposits and plugging of convection surfaces gas passages.

The mill also converted the boiler controls to a Distributed Control System (DCS) based system using the Foxboro I/A and Allen-Bradley PLC-5 platforms. This significant improvement provided a modern control platform with excellent capability for the highest level of automatic computer based control. Complete recovery boiler regulatory control was implemented in the DCS, including a liquor control strategy that maintained liquor flow rate at the level selected by the operator in mass or volumetric units. However, air flow and air splits to the primary, secondary and tertiary wind boxes were generally set by the operator at prescribed levels for full load operation. The weakness of this approach was that there was no compensation for the variance in the heating value of the liquor. Further, during periods of production curtailment when the recovery boiler was operating at two-thirds load, the air flow was frequently not reduced below that necessary at full load, nor were the air splits to the three levels adjusted. During these periods, it was observed that the Pressure Drop Factor (PDF) increased more rapidly than at full load. This was considered as an indication that deposits of ash on the heat transfer surfaces were building at a more rapid rate. It was believed that a significant further gain in capacity could be realized, simultaneous with reducing the fouling of surfaces, by stabilizing and controlling the rate of admission of liquor and air into the furnace.

The mill Process Control Department and the control system supplier evaluated the improved boiler performance that would result from upgrading the control strategy to incorporate supervisory control and full automatic control that minimized operator intervention. The goal was to apply the advanced control strategy to achieve improved process stability and result in the desired capacity increase along with increased time between unscheduled outages for water washes, reduced carryover and increased boiler efficiency. It was determined that no mechanical changes were required in the recovery boiler or auxiliaries. The mill and control supplier team implemented an advanced process control strategy in the existing DCS. The system was placed in operation during August 1996.

CONTROL STRATEGY

Process variations cause unstable recovery boiler operation. Unstable process parameters can limit the boiler operator's flexibility for control. When there are fluctuations in process parameters, boiler operators must make accommodations for the worst case. On the other hand, stabilizing furnace operation makes it possible to tightly control process variables and perform nearer to the optimum levels at all times. Incremental performance improvements can be realized by implementing a good process control strategy.

The advanced control strategy for recovery recognizes the paramount importance of stabilizing the rate of heat input to the furnace, and therefore, maintaining a constant heat release from burning black liquor. The goal of the advanced liquor firing strategy is to achieve constant and maximum heat input to the furnace consistent with the mill operation demand. The system accommodates variations in solids concentration and heating value of black liquor as a fuel. This variability has been observed in mill operation where the same steam flow can be achieved with as much as a 15% difference in black liquor flow rate. As steam flow is an indicator of the heat input, the heat value of the black liquor is varying proportionally.

The recovery boiler liquor firing strategy provides stable heat input. A consumed air model combines total air and flue gas oxygen measurements to compute the amount of air used, or consumed, in black liquor combustion. The model compensates for air used by auxiliary fuel and for infiltration air. From the data, the heat input is inferred and used to set liquor flow. Air being consumed is continuously calculated and used to adjust liquor flow to the furnace in order to maintain a heat release that corresponds to the air consumed and excess air. Once heat input stability is achieved, there is a significant reduction in the standard deviation of all process variables.

The control system maintains a constant air flow to the furnace that is a function of boiler load while constantly adjusting liquor flow. The control strategy further provides automatic adjustment of the total air flow and air splits to the primary, secondary, and tertiary levels when the firing rate is changed. As load is reduced, the control set point for oxygen is automatically adjusted upward so that an ideal amount of air is available for combustion at all times. The recovery boiler was equipped with two oxygen meters, one on each side of the economizer outlet. Control is governed by the lowest of these recorded values. Mill rationale for selecting the lowest reading recognizes that a failed analyzer could send the recorded oxygen to the high level of the meter range which would be recognized by the control system as an indication of too much air being used. With the lowest value, there is a reduced probability of having insufficient air for combustion when an oxygen analyzer problem occurs.

Automatic control of the boiler is operator friendly. The "Single knob control" functionality provides operators with a single input interface for changing the recovery boiler load. All other adjustments are automatic based on the load selected. To change load, the operator types an input of the desired new load. With this one input, the computer control system smoothly and precisely ramps liquor flow and air supply to the new load conditions without operator intervention. The throughput change is ramped at a fixed programmed rate determined during start-up. The smooth, ramped load change minimizes drum level, steam header, and furnace pressure upsets. The gradual change further provides furnace stability as load is adjusted to minimize turbulence and carryover that can frequently occur where liquor load is changed and air controls are not.

As load changes, the liquor header pressure may require insertion or removal of guns to maintain proper liquor firing. At a pressure limit, the control system automatically holds the flow rate and provides a message on the operator console to add or remove guns as required. When the change has been made, the control system automatically resumes changing the liquor and air conditions in accordance with the load requested.

The control system has also been implemented with capability to start-up the boiler automatically from a cold condition. After an operator inputs the time desired to be at operating steam pressure, or an intermediate steam pressure, firing natural gas, the system starts the heat-up process by automatically regulating the fuel flow to the start-up burners. As additional burners are required, the operator is prompted to add the additional burners. The start-up rate is automatically constrained to not exceed boiler design limits for drum heat-up rate and clearing the superheater bank tubes of condensate. As described above for changing load, the operator is prompted with messages when gas burners are to be sequentially placed in service.

Overall boiler thermal efficiency is also calculated by the control system. The calculation is done on-line using as a basis the TAPPI Recovery Boiler Performance Calculation procedure [3]. This output is reviewed by Plant Engineering, and has shown little or no deviation.

OPERATING RESULTS

The advanced control system was placed in operation during August 1996 following the annual mill outage. The Pressure Drop Factor algorithms and display were incorporated in the DCS following the 1993 low odor conversion. The equation for PDF is as follows [4]:

$$PDF = \left[\frac{(D - FD)}{(Db - FDb)} \right] * \left[\frac{(Ab + Lb)}{(A + L)} \right]^2$$

Where,

Db	=	Draft pressure on baseline day
D	=	Draft pressure
FDb	=	Furnace draft on baseline day
FD	=	Furnace draft
Ab	=	Total air flow on baseline day (Mass)
A	=	Total air flow (Mass)
Lb	=	Liquor flow on baseline day (Mass)
L	=	Liquor flow (Mass)

The PDF equation accounts for the effects of load change, furnace draft and excess air.

The trend data from the PDF algorithm has proven to be a reliable indication of the degree of fouling of boiler convection surfaces. Figure 1 is a copy of trend plot showing the calculated PDF for five runs; two runs before system start-up and the three runs immediately following. The six trend lines represent the degree of fouling of each of five convection surface banks and the electrostatic precipitator. A factor of 1.0 reflects a "clean" bank, where clean was based on a pressure drop across the bank after a period of operation that had coated the tube surfaces with a layer of ash. The Intercontinental mill collects the baseline numbers using average values during the first week after a water wash. Therefore, the factor can be less than 1.0 immediately following a shutdown when the surfaces have been water washed. The baseline numbers should remain constant unless mechanical changes are made to the surface

The before and after data shows a dramatic difference as a result of stabilizing the furnace. As noted previously, this was achieved with no mechanical changes to the boiler. For Runs 1 and 2, the increased factor for the banks reflects a condition of ash build-up that would have required a forced outage after about four months of operation. With the boiler operating on automatic consumed air control, the potential run time is significantly extended and the boiler can be operated without concern for surface plugging between scheduled outages. The brief shutdown in December 1996 was for Christmas, that in April was for a scheduled production curtailment, followed by the annual mill outage in August 1997. The mill believes that automatic control has increased runability by 20 to 30 percent between water washes, and that a six month run is achievable.

Increased liquor throughput in recovery is a major benefit to the mill. Implementation of the advanced control strategy has made it possible to accomplish the longer operating runs at or above the targeted increased liquor throughput. Table 1 shows the average liquor solids firing rate and steam flow for each of the five runs. The difference between Run 2 and Run 5 of 118 tonne/d of black liquor solids reflects an 8% increase in the average throughput for the runs. As a result of the increased recovery capability, the Intercon Mill has increased its pulp production capability by 26 ad tonne/day of pulp. The mill also obtains an operating cost benefit because less liquor is transferred the 1 kilometer distance to and from their sister mill in Prince George.

Table 1 further shows that the average mole percent chloride in liquor decreased. The potassium concentrations in the liquor are in the range of 4 to 5 mole percent calculated as $K/(Na+K)$. When the mill converted the recovery boiler to low odor operation and high solids firing, a significant increase in chloride level in the liquor was reported [2]. It is possible that some of the subsequent improvement in fouling rate and run time is attributable to the reduced chloride. However, a review of literature on the effect of chloride and potassium on ash fouling shows that the sticky temperature of deposits is above 650°C at either of these low values of chloride [5]. At this relatively high temperature, ash chloride and potassium concentrations are likely to have a minor influence on the fouling of heat transfer surfaces. The cleaner surfaces shown by the PDF for Runs 3 through 5 are believed to be mainly a result of increased upper furnace stability and reduced carryover.

Table 2 tabulates key recovery boiler operating data before and after installation of the advanced control system. The data reflects average values for Runs 2 and 5, respectively. The automatic control system made it possible to reduce the oxygen in flue gas (dry basis measurement) from an average of 2.8% to an average of 1.5%. The standard deviation decrease from 0.45% to 0.11% reflects the significantly improved oxygen control that allows the target setpoint to be lowered. The corresponding excess air reduction from 15% to 7.5% provides additional liquor burning capacity because additional air is available for combustion and the wet flue gas flow is reduced about 5.5%. The oxygen to excess air relationship is derived from a curve found in TAPPI Press publications [6]. With a 5.5% reduction in flue gas weight, the capacity increase of 8% was easily achieved.

Thermal efficiency of the recovery boiler is improved by the decrease in excess air. The increase in efficiency is 0.35% corresponding to about a 1.25 tonne/h increase in high pressure steam flow. In operation of the Intercon mill, this is of little economic value because a surplus of hog fuel is available for the power boiler. In other mills, the increased steam production could reduce the purchase of auxiliary fuel.

OPERATIONS COMMENTS

Canfor operations has viewed the recovery Advanced Control project as an excellent installation. The recovery operators have used the new control functionality fully since it was installed. This would not have been the case if they had felt unsure about its performance. Initial training and coaching was required at time of start-up as there is some complexity to the system. Once operations personnel had seen the strategy work, however, they wanted to know more about it and feel part of it. In addition, the operators have provided good suggestions and input for tuning and tailoring the installation to exact mill needs.

Intercon powerhouse personnel have always known that liquor conditions changed on an ongoing basis, but it has been interesting to see the Advanced Control system raise liquor flow to the boiler during times of low Btu value. These were the times in the past that storage tanks typically filled up. It has been possible to increase overall liquor throughput and on top of this, increase liquor flow during times of poor quality liquor. Boiler startups have also improved with the installation. In the past, operators were busy during these times and would bump up air and liquor to get up to rate. This is now a smooth operation done within tight parameters of air fuel ratio.

CONCLUSION

The implementation of an advanced process control strategy which provided functionality to operate the recovery boiler on automatic control with minimal operator intervention has been very successful. The boiler operates on automatic control 99% of the time when firing black liquor. The average production capacity of the boiler has been increased 8% making possible an increase in mill pulp production of 26 ad tonne/d pulp. At the same time, furnace heat input stability achieved when burning black liquor with consumed air control has significantly decreased the rate of ash fouling of the boiler convection surfaces. Run times have been extended and it is believed that the time between boiler outages for water washing can be extended to 6 months compared to 4 months before the control system upgrade.

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New Control System Eliminates Plugging and Reduces Natural Gas Usage in the #22 Recovery Furnace at Longview Fibre Co.

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ABSTRACT

The #22 recovery furnace at Longview Fibre Co. was upgraded with a new model predictive control (MPC) package called MACS (Multivariable Advanced Control System) from Capstone Technology, Inc. The controller has reduced natural gas use for SO₂ control in this furnace and has helped eliminate plugging in the upper furnace. The controller is described and data is presented to show the benefits of its operation.

INTRODUCTION

Black liquor recovery boilers are the heart and throbbing soul of the Kraft pulping process. Unfortunately, they are also frequently the bottleneck for production. They require careful operation to avoid both plugging in the upper furnace and environmental issues, and can require significant fossil fuel when operating at low black liquor firing rates. Recovery boiler operators learn strategies to partially control these problems over time, but these problems can still be expensive. The #22 recovery furnace at Longview Fibre Company had a history of upper furnace plugging and significant natural gas use at low firing rates to control SO₂ emissions. They decided to try an advanced control system for their recovery furnace to reduce cost and avoid downtime for upper furnace cleaning.

The #22 recovery furnace at Longview Fibre is a 1989 ABB-Combustion Engineering single-drum low-odor unit rated at 3.7 MM lbs of black liquor solids per day. The firebox is 34'11" square and 142'4" tall. It is equipped with three levels of

combustion air with automatic port rodders. It normally uses four black liquor splashplate nozzles.

Operation of the #22 furnace is complicated by an older recovery furnace, #18, and by a power boiler, #20 that are both less reliable than the #22 furnace. When the power boiler is cut back suddenly, a recovery boiler must make up the lost steam to keep the mill in operation. Such a sudden change in either black liquor flow or fossil fuel flow is very disruptive to the main purpose of a recovery furnace, which is moving the right amount of liquor from the black liquor storage tanks to the green liquor storage tanks to support pulp production.

Having two recover boilers of comparable size is not usually a problem, unless the desired production rate is more than one can handle, but much less than two can handle. This means that with one recovery furnace offline the other must be pushed hard, but with both online they are both at very light load. Recovery furnaces generally don't like operating at the extremes. Plugging is a problem at the high end, and char bed control and SO₂ are problems at the low end.

MODEL PREDICTIVE CONTROL OF RECOVERY FURNACES

Capstone Technology, Inc. has very extensive installation list of control systems based on the model predictive control approach, and used this approach with a Consumed-Air strategy for the #22 recovery furnace.

The Consumed-Air strategy for controlling recovery boiler firing has a very long history starting in the 1970s with the work of Bob Chamberlain at McMillan-Bloedel in British Columbia. It has been developed and applied to recovery boilers since then. The basic idea is that instead of setting the flow of black liquor and then adjusting the combustion air to obtain the desired flue gas excess O₂, the combustion air is set and the black liquor is adjusted. This approach simply recognizes that even when the flow rate of black liquor is constant, the rate of input of organic and inorganic cooking chemicals varies with time due to either changes in the liquor composition or changes in the liquor dry solids content from the concentrator.

The advantage of the Consumed-Air strategy is that the response of pumps and of liquids is inherently much faster and easier to control than the response of combustion air and fans. There is also much less mass of black liquor to control than combustion air.

Typically there are about 5 lbs of air per pound of black liquor solids going into the boiler. The combination of faster response and much lower flow rate makes control of the input of black liquor much more responsive than the control of combustion air. The practical application of this is to set a given combustion air flow, and the distribution of air between the air levels, then control the black liquor flow to the furnace to obtain the desired flue gas excess O_2 . The first question from the recovery operator is “I have to control the level in my black liquor and green liquor tanks, how do I set the air flow to do this?” The answer is that the controller actually uses a “target” black liquor firing rate, which is input by the operator. This target is used to calculate the required air flow based on combustion stoichiometry. The easy way of doing this is to obtain the current ratio of air flow-to-liquor flow in order to set the new air flow target when the black liquor firing rate target is changed.

The Controlled-Air strategy identifies which parameter is controlled, the black liquor, but how does the controller handle this with varying liquor quality and varying demand? That is the role of the new software package. Operating conditions for a recovery boiler are changing all the time, even with steady liquor input, due to changes in the char bed shape and size, and changing mill demand for green liquor and steam. The model predictive control strategy uses information about the response of the recovery furnace to changes of each of the inputs to determine the best way of getting from here to there. The idea is simple. While the boiler is running more or less steady, one of the input variables is “bumped” and the boiler response is monitored until the full impact is reached. This gives both the time response and magnitude of the impact of any one variable on furnace output. This response is translated into a model response for the given input by the new controller. An example of the response of excess O_2 to a bump in the black liquor flow is shown in **Figure 1** along with the O_2 model.

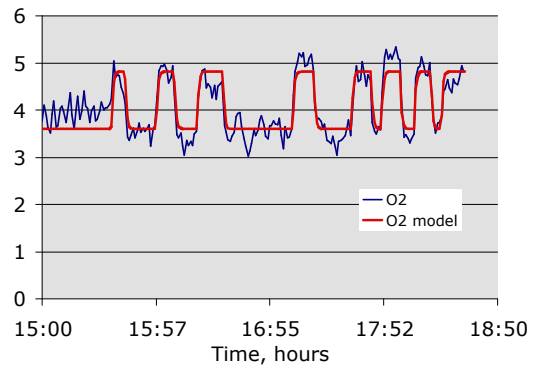


FIGURE 1 – Bump test and O_2 model prediction for O_2 response to BLS flow changes.

Within the controller the model looks like a simple set of time responses as shown schematically in **Figure 2** for excess O_2 response to changes in primary air flow, secondary air flow, tertiary air flow, and black liquor flow.

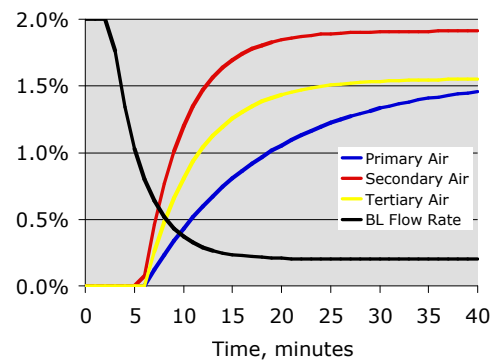


FIGURE 2 –Model response for step changes in air and liquor flow.

The advantage of this approach is that for any given change, the response is reasonably known over time. This information is available for all the input variables, so it is easy to predict what the ultimate result will be for multiple changes to the inputs, even when these changes don’t all occur at the same time. A change in, say, the excess O_2 with a change in secondary air can be predicted even if an earlier change in primary air has not had its full effect yet. This is an extremely powerful approach that can control to desired targets for various output variables, but can also respect constraints on certain variables such as the stack SO_2 limit.

PRACTICAL RESULTS FOR THE LONGVIEW FIBRE #22 RECOVERY FURNACE

Natural gas use in the #22 furnace had been an on-going expense for the mill. Natural gas was very effective at controlling SO₂ emissions from this furnace when it was at light load. Basically anything that increases the temperature in the lower furnace will help control SO₂, including higher black liquor dry solids or improved combustion air system, and of course fossil fuel use. **Figure 3** below shows the natural gas use to control SO₂ before and after the installation of the new control system. The reduction in natural gas use is obvious and is enough to pay for the controller installation in much less than one year.

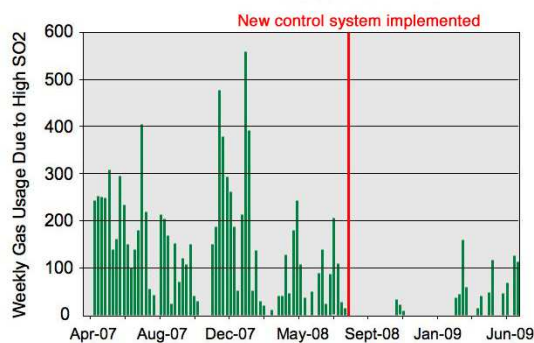


FIGURE 3 – Natural gas use for SO₂ control in the #22 recovery furnace.

Plugging in the upper furnace was also an on-going problem for the #22 furnace requiring either chill-and-blows or water-washes between planned shutdowns. **Figure 4** shows the generating bank draft loss for the period before and after the installation of the new control system. This figure clearly shows the benefit in plugging of the furnace. It also shows a cautionary tale about the necessity for keeping the sootblowers in operation in the critical parts of the upper furnace. On May 7th it was noted that there were a lot of sootblowers out of operation in the generating bank. On Monday the 11th the sootblowers in the generating bank got a lot of mechanical help and were returned to service. The return to normal draft loss immediately after the sootblowers were put back in service is in sharp contrast to the no-way-back look of the previous upper furnace plugging episodes. The cost of avoiding this one plugging episode in May was also enough to pay for the new controller in less than one year.

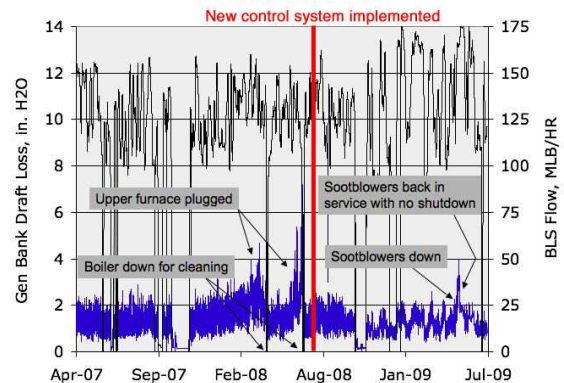


FIGURE 4 – Black liquor firing rate and generating bank draft loss for the #22 furnace.

Note in **Figure 4** that the maximum firing rate after implementation of the new system is higher and that the firing rate goes through periods of both very high and very low firing rates without plugging or high natural gas use.

CONCLUSIONS

A model predictive control software package from Capstone Technology, Inc. was implemented in the #22 recovery furnace at Longview Fibre Co. This control system uses a Controlled-Air strategy and has helped the #22 recovery furnace operate with much lower natural gas use for SO₂ control and avoid plugging in the upper furnace since its installation.