EXTENDING RECOVERY BOILER RUNTIME THROUGH THE TEMPERATION OF STEAM AT THE SOOT BLOWER

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ABSTRACT

Recent advances in soot blower nozzle design have enabled doubling of the jet Peak Impact Pressure (PIP) while maintaining the same blowing pressure in the soot blower. Two main factors that determine the removal of brittle deposits are the PIP of the jet and the strength of the deposit. Due to the flue gas path and geometry of the generating bank it is not unusual to see localized deposit accumulation in this section of the boiler. Left unchecked these deposits sinter to form a strong brittle deposit. During the sintering process these deposits gain strength, and in some instances can even render improved nozzles ineffective.

This happens to be the case reported here, where severe localized plugging was detected 167 days into a run cycle. At this time the addition of full expansion nozzles in the vicinity of the deposit did not reduce the pressure differential in the generating bank. A water wash looked imminent. Specific soot blowers were retrofitted to accept a water spray at the soot blower in order to increase the density of the blowing medium. Following this course of action the boiler was able to run the full cycle without having to be taken off line for a water wash. No adverse effect was seen on the boiler tubes.

Recovery Boilers and Plugging

The black liquor recovery boiler is one of the key steps associated with the kraft pulping process. It is in this furnace that spent cooking chemicals are burnt to recover the inorganic salts while simultaneously generating steam through the combustion of the organic matter in the liquor. This fuel has a very low calorific value when compared to conventional (fossil) fuel. In addition, the black liquor has a very high ash content. The high ash content in this liquor together with its low melting point poses a challenge to the simultaneous process of chemical reduction and heat extraction.

Black liquor is introduced through a spray into the lower part of the furnace with air for combustion. The aim of the spray is to generate droplets small enough to enable complete combustion yet big enough to avoid being carried over to the convection sections of the upper furnace where it deposits on the tubes and leads to plugging. This type of deposit is referred to as a ‘carry over’ type deposit. The mechanism associated with this type of fouling is primarily inertial impaction. These deposits are typically found in the superheater sections and at the entrance to the generating bank. Other sources of carry over particles are those formed during the fragmentation step of the combustion or blown off the char bed. These particles are typically 20µm to 3mm in diameter. They are usually in a molten or semi-molten state which make them very sticky and difficult to remove.

A second type of deposit that forms is due to the condensation of inorganic vapor from the flue gas. These deposits form on the tube surface through a combination of direct condensation and thermophoresis. This type of deposit consists of submicron size particles and is generally quite easy to remove. Since fume is a result of vaporization and condensation, the overall quantity of fume is affected by the bed temperature and is typically found in the upper furnace surfaces and beyond.

The accumulation of fire side deposits on tube surfaces in recovery boilers drastically reduce their heat transfer capabilities resulting in high flue gas temperatures and accelerated plugging of the flue gas passages [Tran, 1992]. These deposits must be removed to maintain the thermal efficiency and uninterrupted operation of the boiler.
During boiler operation, deposits are removed by soot blowers that blast them with high-pressure steam jets [Chappel 1988]. During boiler outages, deposits are washed off with hot water sprayed through the soot blower nozzles [Hayman et. al. 1979]. The unscheduled shutdown of a boiler due to plugging interrupts production and incurs severe financial costs to the mill.

In order to avoid such shutdowns, soot blowers are operated around the clock in order to prevent excessive fouling. The removal of deposits depend to a great extent on the strength of the deposit and the ability of a soot blower to transmit a force in excess of its mechanical or adhesion strength with the tube.

Recent advancements in soot blower nozzle design have enabled a greater amount of the static pressure ahead of the nozzle to be converted to kinetic energy in the jet. This has been accomplished by enabling the gas to fully expand in the nozzle [Jameel et. al., 1994]. This development allows one to operate the nozzle at the same level of dynamic pressure or Peak Impact Pressure (PIP) while saving steam [Jameel et. al., 1995 & Jameel, 1996]. The mechanism for brittle deposit removal indicates that the tensile strength of the material is the main deposit property that is of significance. It has been shown, that in order to remove these deposits [Kaliazine, et. al., 1996]

\[
PIP \geq 2S_t
\]

where \(S_t\) is the tensile strength of the material. Typically in the superheater section of the boiler, the flue gas and deposit temperature is greater than the first melting temperature of ~550°C (1022°F) and generally sticky. A sticky deposit has been defined in the literature as having 15 to 20% liquid phase [Tran, 1997]. At temperatures greater than 800°C (1472°F) the deposit will be completely melted and run off the boiler tube.

In the generating bank where the temperatures are typically in the range of 500-600°C (932-1112°F) most of the deposit is comprised of condensed fume. This deposit can generally be removed without difficulty. However at these elevated temperatures submicron sized fume particles sinter. The sintering process is agglomeration of small particles into a bulk material [Van Vlack, 1980]. It is carried out through a process of diffusion within the solid and is accelerated at elevated temperatures (short of melting). The agglomeration of small deposit particles leads to shrinking of the deposit and an increase in strength. These deposits are typically porous and brittle. Some of the parameters that affect the rate of sintering are the deposit temperature and size. Laboratory results show that for temperatures in the range of 500 to 600°C, such particles (precipitator dust) reach a maximum strength in a matter of an hour [Tran et. al., 1988]. It has been observed that sintering begins at temperatures above 300°C (572°F) [Tran, 1997]. In most cases the generating bank tubes are around 300°C and should normally not pose a problem. However, if the deposits are allowed to accumulate, the deposit furthest from the tube could reach a temperature close to that of the flue gas (>300°C). This will enable the deposit to sinter. During the sintering process a fixed mass of deposit reduces in volume leading to an increase in density. Individual particles fuse together at their boundary to form a porous solid.

The accumulation of deposits on any non-cooled surface, or one that has not been removed by a soot blower eventually reaches the temperature of the flue gas and strengthens through sintering. This deposit provides the platform for further deposit build up and densification. This process eventually leads to localized plugging of the boiler.

**Boiler Design Data**

This paper discusses the case of localized plugging and measures taken to battle this pluggage once it was beyond the ability of conventional soot blowing. Recovery Boiler #2 at the Arauco mill in Chile is a late1980’s design Gotaverken single-drum unit, having a three-stage superheater and two long-flow economizers.
The design parameters for the boiler are as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry solids throughput</td>
<td>2000 t/d (4.4 Mlb/d)</td>
</tr>
<tr>
<td>MCR steaming rate</td>
<td>301 t/d (664 klb/d)</td>
</tr>
<tr>
<td>Steam temperature</td>
<td>455°C (851°F)</td>
</tr>
<tr>
<td>Drum pressure</td>
<td>6970 kPa (1011 psi)</td>
</tr>
<tr>
<td>Lower furnace</td>
<td>5.38 m³ (190 ft³)</td>
</tr>
<tr>
<td>Volumetric heat release</td>
<td>0.177 GJ/h/m³ (4.75 Btu/h/ft³)</td>
</tr>
<tr>
<td>Heat release/projected area</td>
<td>0.444 GJ/h/m² (39 Btu/h/ft²)</td>
</tr>
<tr>
<td>Heat input</td>
<td>954 GJ (0.904 MBtu)</td>
</tr>
</tbody>
</table>

**CASE STUDY**

**History**

The boiler was originally fitted with 60 long retractable soot blowers. In 1996, eight additional soot blowers were added and the MCR rating was raised to 2174 t/d (4.8 Mlb/d). At this time the plugging was primarily at the top of the nose where the flue gas makes a sharp turn in order to enter the generating bank. This has been observed as a classic zone for plugging on most single-drum units.

In 1996 the boiler throughput was around 2334t/d [5.2Mlb/d]. The mill had installed full expansion soot blower nozzles at the entrance to the generating bank in order to keep this area clean. The boiler load was at 107% of MCR. On August 12th, 1996, pluggage was detected in the generating bank. This was identified by the sharp increase in draft loss across this section. Two thermal sheds were made on the 15th and 17th in order to combat this problem. The location of the pluggage was visually confirmed during the chill-and-blow, and full expansion nozzles were installed in the vicinity of the pluggage. By the end of August, 467 days into the cycle (since March 1996) the draft loss indicated that the plugging was becoming severe and that a shut down for a water wash was imminent. This is generally the case for generating bank pluggage and the end is only a few days or at most a week away [Tran, 1997].

By this time the boiler had undergone a total of six thermal shocks. In short, the thermal shedding and the positioning of the nozzles around the pluggage did not address the problem of the pluggage. The deposit had reached a strength that exceeded the deposit removal capabilities of the soot blower jets. This problem of increasing deposit strength has been discussed in the section above. Further, deposit removal by thermal shedding was ineffective in the generating bank. It has been observed that thermal shedding is most effective in the superheater and, when it is performed in the early stages of fouling followed by successive thermal shocks [Tran et. al., 1993].

At this stage, the recommendation was made to the mill to temper the steam in order to increase the density of the blowing medium, which would in turn, increase the PIP of the jet. This was adopted on September 2nd, 1996. As a result of this the draft was restored. The continued use of this soot blowing method allowed the boiler to run uninterrupted until the scheduled outage in April 1997.

**Attemperation Setup**

![Figure 1: Schematic of Steam/Water Supply to Soot Blower](image_url)
The soot blower steam source is 30 bar (435 psig) header. The poppet valves in each case is fully opened and the blowing pressure is 22 bar (319 psig). The conventional nozzles are 22 mm (.875") while the full expansion nozzles are 25 mm (1"). A schematic of the steam supply system is provided below indicating the conditions at boundaries of the PRV, the poppet valve and a control volume for the water injection.

### Table 1: Steam and Water Parameters at the Poppet Valve

<table>
<thead>
<tr>
<th>Location</th>
<th>Pressure (bar(a))</th>
<th>Temp. (°C)</th>
<th>Enthalpy (kJ/kg)</th>
<th>Entropy (kJ/Kg C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>66</td>
<td>380</td>
<td>3112</td>
<td>6.4023</td>
</tr>
<tr>
<td>1</td>
<td>31</td>
<td>350</td>
<td>3112</td>
<td>6.7230</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>20</td>
<td>84</td>
<td>0.2962</td>
</tr>
<tr>
<td>3</td>
<td>23</td>
<td>220</td>
<td>2615</td>
<td>5.9102</td>
</tr>
</tbody>
</table>

\[ m_{\text{water}}/m_{\text{steam}} = 20\% \]

At location 0 upstream of the PRV, the steam is at 65 bar(g) (943 psig) at 380°C (716°F). This is reduced to 30 bar at location 1. Downstream of the poppet valve at location 3, the pressure is 22 bar. For the water injection process the desired outcome was that the steam at location 3 was to be saturated at 22 bar. The water injected at location 2 was at 23 bar (333 psig) and 20°C (68°F). In order to achieve the saturated conditions an energy balance was made for a control volume around the poppet valve. The result of this calculation suggested that the ratio of the weight of water to weight of steam should be 20%.

**Performance Data**

![Figure 2: Daily Average of Boiler Liquor Flow and Steam Production (5/96 to 3/97).](image)

Figure 2 above gives the monthly average for the liquor throughput from May 1996 to March 1997. Until the pluggage in August 1996, the average liquor flow was 2334 tds/day (5.1 Mlbds/day) which is about 7% over design. Following the attemperation the average (5 Mlbds/day) flow was around 2309 tds/day which is about 6% over design.
The ratio of the monthly average for steam production and soot blower steam consumption is given in Figure 3. For this boiler, soot blower steam consumption was about 5% of the total steam production. The soot blowers are operated three at a time and follow a fixed sequence of 30 steps, where the number of blows in the generating bank amounted to about 27% of the total number. The total sequence took 3.5 hours. With steam attemperation, additional blows were made in the critical area. In addition to the blows that were done at the critical location of the pluggage, the entire generating bank was blown with wet steam once every week.

The daily average of soot blower steam consumption for August and September 1996 are shown in Figure 4. The soot blower steam flow for this period shows no increase as the attemperation is done locally at each soot blower. This is downstream of the steam flow meter. Figure 5 also shows the differential pressure $\Delta P$, across the generating bank for the period May 1996 to March 1997. For this cycle the boiler started up from a water wash in April 1996. The division indicated along the horizontal axis is for intervals of 30 days.

In the period around mid-August (~105 day) the differential pressure is seen at its maximum of about 70 mm WC. This together with the readings from the previous days indicated severe plugging in the generating bank.
Two thermal sheds were performed on August 15 and 17. There appears to be a lowering of the differential pressure for only a short period before it returns to the high values. The second peak occurred around the beginning of September. On September 3, local soot blower steam attemperation was initiated. Following this, it is observed that the draft across the generating bank was restored to its pre-August values of about 15 to 20 mm WC. Using the attemperation on a regular basis, the boiler continued to operate at almost the same load for the remainder of the run time, which was until the fall outage in April 1997. Around the beginning of January 1997 the draft loss was once again found to be high. It turned out that the critical soot blowers in the generating bank had faulty poppet valves. Repairs to the valves and temperation of the steam restored the draft loss to acceptable levels. A closer detail of the draft loss values for June 1996 through September 1996 is shown in Figure 6. Also shown is the dry solid loading to the boiler for the same period.

![Figure 6: Generating Bank Draft Loss And Liquor Flow (6/96 To 9/96).](image)

Identified here are three thermal sheds. On Sept 8 the liquor inventory was low. From this plot, it is clearly seen that at the onset of plugging, the draft loss drastically begins to rise in a matter of a couple of weeks. Thermal shedding alone does not help in restoring the draft loss.

**RESULTS**

Figure 7a shows the pluggage prior to tempering the steam. This picture was taken during a chill and blow of the boiler. The pluggage is very localized and has basically closed the gap between the front and back tube bundles. The picture shown in Figure 7b is what was left of the pluggage after blowing with saturated steam. There is a significant removal of the deposit.

![Figure 7: Photograph on the left shows the local pluggage. Photograph on the right shows the same area, after the use of saturated steam in the soot blower.](image)
**Tube Erosion**

The use of saturated steam is something that has been done in the past. In these instances soot-blowing steam was typically taken from the steam drum. A common problem with this system was the erosion of the boiler tubes. Typically, the potential for erosion in a recovery boiler is insignificant in comparison to the coal fired units. This is because black liquor fly ash is not abrasive like the fly ash produced from coal combustion. In this case, fly ash is accelerated in the jet and impacts on the tube surface. For a recovery boiler, the wastage of boiler tubes could generally result by two methods. One is by erosion-corrosion where the soot blower is responsible for removing the oxide layer exposing bare metal to further corrosion [D. Singbeil, 1994]. This has been observed in near-drum corrosion. The second is due to the impaction by water droplets. In this case water droplets travel at high speeds in the jet and impact on the tube surface.

![Figure 8: Schematic of the generating bank showing locations for the soot blowers.](image)

Figure 8 is a schematic of the generating bank with indication for the position of the soot blowers. The pluggage shown in Figure 7a was located between soot blowers 251 and 252 and between 273 and 274. These four soot blowers were identified as the critical units and used soot blowing with saturated steam. A plan view of the boiler bank is shown in Figure 9. The tubes are finned tubes. A detail of a tube location for measuring the tube metal thickness is also shown. The data labeled “front” is for the bank closest to the front wall of the furnace, while the data set labeled “rear” is for the bank adjoining the blind gas pass to the economizer. The data covers the entire first row of tubes at the elevation of the critical blowers. A comparison of the metal thickness at the elevation of the critical blowers 251 & 252 are shown in Figures 10 & 11. This is for data taken in 1992, 1993, and 1997.

![Figure 9: Schematic Illustrating The Plan View Of The Generating Bank.](image)
Figure 10 is for the front bank while Figure 11 is for the rear. These readings are the average reading taken at locations A & B as illustrated in Figure 9. When comparing the data for 1997 with those of 1992 and 1993, the results show no obvious wastage of metal at these locations. The same results were observed for the other soot blower locations. These results have not been reported at this time. The nominal thickness of the tube is 4.5 mm (0.18”). In some instances the data shows increase in thickness. This is physically impossible for this application. Variability can be attributed to precision and accuracy, actual variability of the tube thickness and errors in measurement [Barnes & Sharp, 1995]. Further, the question of visiting the identical location every time, calibration of instruments and different operators can contribute to variations in the data.

IMPLICATIONS

- Unchecked generating bank deposits increase in strength through sintering.
- At the latter stages of plugging the draft loss in the generating bank increases exponentially.
- A threshold is reached in deposit strength when even the full expansion nozzles using superheated steam are ineffective.
- Selective use of saturated steam has provided an effective tool to combat local pluggage and extend boiler runtime.
- The judicious use of saturated steam does not provide as great a threat to metal wear as seen with boilers using this quality of steam all the time.
- As long as there is a deposit on the tube it could shield the tube thereby minimizing the threat of erosion.
- Once the pluggage is cleared there is no need to use tempered steam.
REFERENCES


(TAPPI Engineering Conference, Miami, 1998)