ABSTRACT

An investigation was conducted to determine the cause of the internal corrosion of a number of soot blowers lances installed in two recovery boilers. It was found that the corrosion was the result of flue gases entering the inside of the lance tubes and forming an acidic condensate that in turn rapidly attacked the material. Acidic condensate is formed from the condensation of (acidic) flue gases that contained high concentrations HCl and SO₂. The problem was rectified by making improvements to the low pressure air system that ensures the continuous purging of the soot blower lances to keep the flue gases out. The experience highlights the importance of a properly functioning purge air system for soot blowers.

KEYWORDS

Recovery Boiler, Soot Blower, Lance Tubes, Corrosion, Dew Point, Mill Experience

INTRODUCTION

The accumulation of fireside deposits in a recovery boiler drastically reduces its heat transfer efficiency. This results in high flue gas temperatures which accelerate fouling, leading to the plugging of the downstream passages [1]. In order to maintain uninterrupted operation of the boiler, soot blowers are used to remove deposits and prevent them from excessive buildup. A recovery boiler is typically equipped with over fifty soot blowers in its convective section; these consume 5 to 12% of the total steam produced by the boiler. If soot blowers at critical locations in the boiler are out of service for an extended period of time, massive deposits may build up and lead to an unscheduled shutdown of the boiler.

Most soot blowers used in recovery boilers are of the retracting type, consisting of a beam that supports a traveling carriage for inserting and retracting a lance tube into the boiler. The lance tube is fitted with a pair of nozzles at its end, which are used to produce high speed steam jets to remove the deposits. High pressure steam is delivered to the lance via a steam admission valve known as a poppet valve. A feed tube, attached to the poppet valve, passes through an opening in the traveling carriage and ends inside the lance.

Figure 1 shows a schematic of a typical soot blower hanging off a boiler wall. The blower is at rest with the lance tube retracted from the boiler and the nozzle end sitting in a pipe known as the wall sleeve. One end of the soot blower is attached to boiler steel while the other is attached to the wall sleeve via an intermediary device known as the wall box. This device can be as simple as a steel plate with a hole in the middle to allow for the lance tube to pass through.

In a long, retracting soot blower, the feed tube that delivers steam from the poppet valve to the lance is made of stainless steel (typically SS304). The lance tube is made of a Cr-Mo alloy steel such as T11 that has sufficient strength to support the lance tube at elevated temperatures while it is in the boiler. The nozzle section at the end of the lance is made of stainless steel (typically SS310) since it subjected to the hot flue gas longer than any other component of the soot blower. Over the years, lance tube corrosion was found to occur mostly in the part closest to the boiler. The problem was minimized by adding a section of stainless steel (typically SS304) to move the joint further away from the SS310 lance tip as shown in Figure 2. This is the standard configuration for most soot blowers used in recovery boilers today.
Figure 1. Schematic of a retractable soot blower mounted on a boiler wall

Figure 2. Typical configuration of recovery service lance

Figure 3. Typical soot blower steam and air purge system.
Since corrosion of the internal soot blower components including the lance tubes has been experienced in the past soot blowers have been equipped for some time with what is known as a purge air systems. A typical configuration is shown in Figure 3. Purge air is introduced to each soot blower in the vicinity of the boiler wall from an air header. A portion of the air is sent to the wall box and balance to the lance via the same pipe that carries the steam purge that is used to purge the wall sleeve during the steam cleaning operation of the blower. During that time a check valve at the connection of the air pipe to the steam purge line isolates the low pressure purge air from the high pressure steam. When the soot blower is idle, a spring in the check valve opens the valve allowing the purge air to travel to the poppet valve, through the lance and out of the steam nozzles. Only when air of sufficient pressure and quantity is available at the lance nozzles is the lance and feed tube and the soot blower as a whole are effectively isolated from the aggressive boiler gases.

An orifice is used to control the amount of air going to each the wall box and the poppet valve. Without this, the air would select the path of least resistance, which in this case is the wall box. This leaves little to no air flowing towards the lance. The proper orifice size was determined in tests using air pressures that are typically available in a modern recovery boiler. In most cases the source of air that is the secondary supply to the boiler.

**CORROSION CASE STUDY**

Severe thinning of soot blower lance tubes was recently experienced at a kraft mill in Brazil. A number of lance tubes were reported with high corrosion rates in a short period of time. The mill has three recovery boilers, A, B and C. Boiler A underwent a major retrofit in 2001 which included the installation of 98 new soot blowers to compensate for a substantially increased firing capacity. Boiler B was also upgraded at the same time with an addition of 18 new soot blowers to its 82 existing soot blowers. Boiler C is the newest boiler started up in May 1997. Boilers A and B have burned CNCG since June 2002, while Boiler C has not. Corrosion of lance tubes were found in Boilers A and B around third quarter of 2002. No corrosion has ever been reported in Boiler C.

Figure 4 shows a schematic of the lance tubes for the new soot blowers in Boilers A and B: the lance outside diameter is 102 mm (4”). The lance tip that houses the nozzle is made of a heavy wall 310 SS casting followed by a 660 mm (26”) long 304 SS tube with a nominal wall thickness of 4 mm (0.157”). The rest of the lance tube is made of a high temperature alloy steel of nominal wall thickness 4.8 mm (0.189”). At the weld joint between the 304 SS and the alloy steel the inside of the alloy tube was opened up to match the wall thickness of the 304 SS tube to allow for welding.

![Figure 4. Schematic of lance showing joint design between the heavier alloy wall and lighter wall SS304.](image)

Most of the corrosion was found in the alloy section in the vicinity of this joint which is the closest to the boiler wall of the non stainless portion of the lance. Over a period of 1 year (11/01 to 11/02) many of the lances in RB A showed a reduction in wall thickness of up to 1 to 2mm (0.04” to 0.08”). During this period CNCG combustion was carried out for half of this time (starting 6/02). Over a period of half a year (6/02 to 12/02) similar corrosion was also observed on many lances in RB B where the wall thickness on many lances were reduced to around 2-2.5mm (0.079”-0.098”). CNCG combustion was carried out through out this period.
In some soot blowers, the metal loss of the carbon steel was so severe that holes could be seen from the outside (Figure 5a, arrow). The metal loss was particularly severe near the carbon steel T11 and stainless steel 304 weld where the acidic condensate would first get in contact with carbon steel material resulting in a deep groove in the carbon steel (Figure 5b and Figure 6). Corrosion products and pitting were observed on the interior surface of the lance. In all cases, no significant corrosion was observed on the exterior surface of the lance.

Figure 5a. Section of tube

Figure 5b. Cross section of tube showing ID corrosion.

Figure 6. Section through tube wall at the vicinity of the stainless steel joint.
FIELD INVESTIGATION

BOILER A

Air Supplies

Some time after startup, it was discovered that 88% of the soot blowers in Boiler A did not have the orifice plate at the wall box. It appears that this plate may have been removed from a pipe union at the wall box during the hooking up of the air supply; it is not clear how long the blowers ran without the orifice plates. Without the orifice plates, most of the airflow would be going into the wall box leaving the soot blower lance vulnerable to an intrusion by the boiler gases.

The soot blower purge air system for Boiler A revealed that in spite of a sufficient header pressure of about 3.6 kPa (14”WC) to the soot blowers, there were many blowers that did not have purge air flowing through the lance. When the purge air line was disconnected close to the poppet valve, one could see periodic puffing of boiler gases as it left the valve in a white cloud. This is a clear indication that the furnace pressure was sufficiently above ambient to enable boiler gases to enter the lance and travel all the way back to the poppet valve. When the system was inspected, it was found that there was an accumulation of solid particles (in the form of moist plug) above the check valve, which prevented the air from flowing towards the poppet valve. In some instances there was also a ring of hard scale that had built up in the coupling attached to the check valve that blocked the free flow of air.

With no air flowing to the poppet valve a manometer was attached to the poppet valve of some of the super heater soot blowers. Pressure readings of –25Pa (-0.1” Water Column, WC) to +50Pa (+0.2”WC) were found. Once the valve was cleaned out and or replaced and the air connection restored the air pressure was measured at 3-3.5kPa (12-14”WC), which was more than adequate to ensure a continuous purge of air through the lance tube. In one instance a soot blower without an orifice plate was also found. In both the case of the blocked check valve and the lack of an orifice plate, the nozzle pressure would not be much greater than the ambient atmospheric pressure, making it very easy for boiler gas to travel into the lance via the steam nozzles at the lance tip.

Blocking of the Check Valve

Figure 7 shows a photo of a check valve which was choked off by a foreign matter that had accumulated on top of this valve. The valve is shown here with the coupling attached to the top of the valve. The material had a reddish coloration, and an analysis of this material showed that the material consisted of 95% water-insoluble and 5% water-soluble matter. The water-insoluble was mostly iron oxide, suggesting that it was derived from corrosion products. The water-soluble part had a pH of 7 and contained small amounts of Na₂SO₄ and NaCl. Similar material from another valve was sent for analysis, and results indicated that the material contained mostly Fe (iron) and Si (silicon) in the form of oxides.

Figure 7. Accumulated debris on top of check valve. This results in no air flow to the soot blower.
Further investigation into the origins of this material revealed that the air headers supplying air to the blowers may not have been blown out after fabrication and erection. Furthermore, other construction grinding and cutting may have taken place in the vicinity close to the air intake for the fan that supplied air to the blowers, hence distributing this material through out the air system and into the soot blower. These findings reaffirm the need for extra care during equipment installation, that is, the blowing out of all field fabricated lines prior to hooking up equipment.

BOILER B

Air Supply

The investigation into some of the soot blowers revealed that the air supply to both the wall box and the soot blower was inadequate. One of the super heater blowers that had the air cut off was blocked at the supply hose. The majority of the new blowers had a low point on the air supply hose connecting the air header to the blower. A typical connection is shown in Figure 8a. When the air hose was disconnected at the soot blower, water drained out of the hose, which was looped in such a fashion that it was a potential water trap, preventing the air from reaching the blower. Due to the resulting lack of airflow there was a significant amount of flue gas entering the soot blower. One of the super heater soot blowers that had no purging air supply had a whitish gas leaking from the flexible steam purge hose at the boiler end of the soot blower. Further investigation confirmed it was not steam. This meant that flue gas was making its way into the blower or wall box and eventually into this hose. When the air/steam purge line was disconnected at the poppet valve it was noticed that the inside of the purge pipe had a white coating of condensed fume (Figure 8b). With the poppet valve open to the atmosphere a continuous stream of flue gas would flow out of the valve, especially when a nearby soot blower was in operation. This clearly shows that local positive pressure surges occur in the furnace in spite of the best efforts to maintain an overall balanced or negative draft in the furnace.

There was no evidence of any material plugging the check valves, as was seen in Boiler A, and it also appeared that the orifice plates were in the wall boxes as intended. In this case, instead of a plug of debris choking off the air supply to the lance, the water trap prevented air from reaching the soot blower. This water could have come from (i) water washing with soot blowers and (ii) from the condensed steam in the steam purge line after each soot blower operation. Therefore it is a good practice to avoid setting up any hoses with low points which could be potential water traps. Further it is also good practice to drain all hoses and wall boxes after a water wash.

Figure 8 (a). Air hose hook up resulting in a trap

Figure 8 (b). Boiler gases leaving poppet valve.
Air Flow and Pressure

When a gauge was added to the air hose with no flow to the above mentioned soot blower, it gave a local header pressure reading of 0.8 kPa (3” WC). Since the column of water in the hose was greater than 3” the air was not able to purge the water out of the system. Putting a gauge into the poppet valve showed a furnace pressure of 50 to 100 Pa (0.2 to 0.4” WC). Once the water was drained out of the system, the air pressure at the soot blower was 0.5 kPa (2” WC). The low pressures observed were due to the fact that the source purge air pressure was inadequate. It was determined that the 18 new soot blowers were simply added onto the existing air supply system, hence taxing an already weak air supply.

Based on the results, recommendations were made to the mill to look into raising the source pressure to achieve a pressure of 3 kPa (12” WC). This is sufficient to prevent furnace gas from entering the soot blower lances provided that all components of the purge system work properly.

BOILER C

Air Supply

Since all the soot blowers in this boiler have an air header below them, there is no opportunity for the water to get trapped, and thus block the air supply lines. This boiler has been in operation for some time and has had no problems with corrosion. By disconnecting the air purge line at the poppet valve, a positive airflow to the poppet valve was established. This indicated there were no issues with flow restrictions to the poppet valve as seen on Boilers A and B.

Air Pressure

With no airflow to the soot blower, the header pressure at a typical superheater soot blower measures around 3.7 kPa (15” WC). With air flowing to the soot blower, the air pressure is about 3.0 kPa (12” WC). This represents a desired operational condition for a soot blower seal air system.

CORROSION CHEMISTRY

Corrosion occurred in an area near the weld between the carbon steel lance and the SS304 lance extension. Since the stainless steel is more “noble” than the carbon steel, galvanic corrosion is possible. In order for galvanic corrosion to take place there must also be an electrolyte in contact with these metals at their welded junction. This could come from the condensation of materials from flue gas that entered the lance, or from the condensation of steam remaining after a soot blowing cycle. Since all of the ingredients for galvanic corrosion to take place were present, it is most likely that galvanic corrosion took place while the soot blower was idle between blowing cycles. This type of corrosion would be located only in the vicinity of the weld area; however, since there was a loss of metal, pitting and corrosion products away from the weld, galvanic action was not the only mechanism for the observed corrosion pattern.

Both the flue gas and metal temperatures in a recovery boiler are generally high enough that dew point corrosion does not play a major role in the convection pass of the boiler. In the case of the soot blower lance, it sits outside the boiler, and is only periodically is inserted into the hot flue gas stream. During this time steam fills the lance and is ejected out of the nozzles, at which time no boiler gases can enter the lance tube. During the idle periods the lance tube reaches the ambient temperature of the boiler house: on a hot day the temperature in a upper parts of a boiler house reach 50-60C (120-140F).

Since it has been shown that fume, which contains sodium sulfate (Na₂SO₄), and both sulfur oxides and water vapor can be blown from the furnace into the soot blower lance tube, it is possible that acidic sodium sulfate salts may be formed as a result. Sodium bisulfate (NaHSO₄) is one such acidic sulfate: it would become molten as the lance temperature increases as it is pushed into the furnace. Molten sodium bisulfate is an aggressive corrosive liquid which attacks both carbon steel and stainless steel alloys [2].

Acidic dew point corrosion occurs when flue gases drop below about 150C (300F): the exact temperature is a function of the concentration of sulfur oxides and moisture content of the flue gas. Sulfur trioxide (SO₃), which is highly hydroscopic, turns into sulfuric acid in the presence of water; therefore, if substantial amounts of SO₂ enters the lance with the flue gas, it can react with water from two possible sources: i) the condensing of moisture from the hot flue gases, and ii) condensate generated from the residual soot blowing steam in the lance. Since the soot blowers are slightly tipped toward the boiler, this condensate would accumulate in the vicinity of the tip of the lance.
Another acid that could be present is hydrochloric acid, with a dew point of about 54°C (130°F). Laboratory analysis of the corrosion products found in the failed sample did not show any Cl peaks, suggesting that HCl did not play any role in the corrosion process in this particular instance. This leaves sulfuric acid as the most likely candidate for the dew point corrosion which occurred in the lance. Typically, this would not be a problem if there was a sufficient quantity of carbonate in the ash (fume) deposited in the soot blower lance to neutralize the acid. With low lower furnace temperatures, the SO₂ concentration, and hence the SO₃ concentration, in the upper furnace is higher than when the furnace temperature is high. In addition, the combustion of CNCG adds to the sulfur load in the upper furnace. In the absence of a properly functioning lance purge, these gases could enter the cold lance resulting in acidic dew point corrosion of the carbon steel.

Comparison of Boiler Chemistry

Table 1 compares the electrostatic precipitator (ESP) ash, and flue gas chemistry for all three boilers. It should be noted that all three boilers are supplied with liquor from the same source, and fired at about 73 to 78% dry solids.

It is evident that Boilers A and B would be the boilers that would more likely experience soot blower lance tube corrosion due to higher concentrations of SO₂ in the flue gas, and the lower carbonate content in the ESP dust. Boiler C has not only had a properly functioning air purge system from the time of startup, but also has flue gas and ash chemistries that are not conducive to lance tube corrosion. This explains why to date the soot blower lances in this boiler have shown no signs of corrosion.

<table>
<thead>
<tr>
<th>Boiler</th>
<th>Firing Load, TSS</th>
<th>Precipitator Ash</th>
<th>Stack Gases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO₂, wt%</td>
<td>Cl, wt%</td>
<td>K, wt%</td>
</tr>
<tr>
<td>A</td>
<td>3.44</td>
<td>&lt;0.6</td>
<td>5-6</td>
</tr>
<tr>
<td>B</td>
<td>3.44</td>
<td>&lt;0.6</td>
<td>5-6</td>
</tr>
<tr>
<td>C</td>
<td>2.90</td>
<td>10 - 20</td>
<td>5-6</td>
</tr>
</tbody>
</table>

In order to further quantify the aggressive nature of the flue gas in Boilers A and B compared to that in Boiler C, the purge air was disconnected to selected soot blowers in the superheater region of each boiler to allow boiler flue gas to enter the lance. A plastic tube was attached at one end to the side plug in the poppet valve, while the other end of the tube was immersed in test tube with distilled water (Figure 9).

![Figure 9. Schematic of flue gas sampling system through the soot blower.](image-url)
Positive pressure surges in the furnace forces the flue gas to enter the soot blower lance via the steam nozzles. The resulting over pressure in the lance forces the gas in the lance to bubble through the water in the beaker. Any sodium salts and acids in the air would dissolve in the water. This would represent a typical case where an idle lance with some condensed moisture is suddenly exposed to boiler gases. The water samples that were gathered from each boiler were analyzed together with some of the original distilled water. The results are shown in Table 2.

<table>
<thead>
<tr>
<th>Sample</th>
<th>pH</th>
<th>Cl, ppm</th>
<th>SO₄, ppm</th>
<th>Na, ppm</th>
<th>K, ppm</th>
<th>Fe, ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distilled water</td>
<td>6.9</td>
<td>0.3</td>
<td>0</td>
<td>0.1</td>
<td>0.2</td>
<td>0</td>
</tr>
<tr>
<td>Boiler A</td>
<td>4.9</td>
<td>1.7</td>
<td>7.1</td>
<td>4.6</td>
<td>0.7</td>
<td>0.02</td>
</tr>
<tr>
<td>Boiler B</td>
<td>3.2</td>
<td>17.7</td>
<td>172</td>
<td>42.0</td>
<td>9.1</td>
<td>0.02</td>
</tr>
<tr>
<td>Boiler C</td>
<td>6.8</td>
<td>0.3</td>
<td>0</td>
<td>0.1</td>
<td>0.1</td>
<td>0</td>
</tr>
</tbody>
</table>

The results clearly show that the distilled water turned into an acidic solution when it was exposed to the flue gases from Boilers A and B. This is consistent with the chemistry of the flue gas and ash of these boilers.

**WALL SLEEVE ARRANGEMENT**

In contrast to Boiler A, which has 98 new soot blowers, Boiler B had only 18 new soot blowers. The 82 old soot blowers have been in operation for different lengths of time at the end of 2002. The lance tubes of these older soot blowers were made from a tube with a nominal OD of 88.9mm (3.5”) and a wall thickness of 5.6mm (0.220”). Consequently, the joint between the lance and the nozzle extension was not accompanied by any change in wall thickness. Wall thickness measurements taken from some of these older soot blowers indicated no significant metal loss over the same period of time. This poses a question as to why these old soot blower lances do not show the same levels of corrosion as the new soot blower lances when used in the same boiler over the same period of time. Further investigation showed that the position of the tip of the nozzles for these old soot blowers was not the same as for the new ones.

![Figure 10. Schematic of wall box and lance position for Boilers A & B.](image)

Figure 10 is a schematic representation of the wall sleeve cross section showing the lance, the wall box and a section of the water wall tube. It shows that the new soot blowers (left) had the lance tips parked at the center line of the water wall tube while the older soot blowers (right) had the lance tips retracted into the wall sleeve. The arrows with the broken line, represents flue gases that could easily enter the lance sleeve during positive surges in the furnace. With little to no purge air through the lance, such as occurred in Boiler A, and with the lance tip parked at the widest point in the sleeve, makes the lance more vulnerable to an intrusion of flue gases. In instances where the orifice was missing in the wall box, the majority of the air would flow into the wall box and into the sleeve, as shown by the solid line arrows. However, the nozzles were not in close proximity to the air exiting the wall box, making the air flow less effective in protecting the lance tip. This
difference in the lance tip position in relation to the boiler wall for this sleeve arrangement seems to be the most probable reason why there was no indication of corrosion in the old soot blower lances.

Typical wall sleeves are made from a single piece of pipe of uniform diameter. The internal diameter of the sleeve is selected to be just large enough to provide free passage of the lance: a schematic of this is shown in Figure 11. Comparing the two sleeve arrangements (Figures 10 and 11) it appears that it would be more difficult for boiler gases to enter this sleeve than the one with the variable cross section. It is therefore conceivable that seal air to the wall box could play a greater role in sealing off the nozzle openings at the lance tip. Experience suggests, that independent of sleeve design it would also be advisable to try to park all lance tips as far away from the boiler wall as is possible. When it comes to a wall sleeve with the variable cross section, it will be more important to ensure that the flow of purging air to the lance is maintained while the lance tip is pulled back.

![Figure 11. Typical soot blower lance and wall sleeve arrangement.](image)

**REMEDIAL ACTIONS**

A comprehensive survey of the lance wall thickness of the carbon steel section was made for all 98 soot blowers in Boiler A and for the 18 new soot lower in Boiler B. Four readings were made 90 degrees apart at both the weld location for the alloy steel SS304, as well as at a distance of 305 mm (1’) from this weld. At the weld joint the measurements were taken on the side of the alloy steel. Based on these readings, all lances with a wall thickness reading (at the weld) less than or equal to 3 mm (0.118”) had the nozzles (lance ends) replaced. This amounted to 33% of the lances for Boiler A, and 50% of the lances for Boiler B. 11% of the lances in RB A and 4% of the lances in RB B had wall thickness readings less than 2.5mm. The average wall thickness at the 12” mark was no less than 4 mm, indicating that the corrosion primarily occurred close to the weld.

The replacement nozzles had the SS304 extensions made with the same wall thickness as the alloy tube. This ensured that there was maximum allowance for corrosion. Since it was determined that no major corrosion occurred at a distance of 305 mm (12”) from the carbon steel/stainless steel weld, the replacement nozzles had the stainless section extended beyond this point to provide added protection for the welded joint.

In order to minimize the risk of flue gas intrusion into the lance via the steam nozzles, the lances were shortened by 76 mm (3”). This brings the lance tip further into the sleeve and away from the wide sleeve opening at the boiler wall. The added benefit from this change is that more of the wall box seal air would now be available to provide a secondary role in blocking the nozzles openings from any boiler flue gases.
The check valves were all inspected and non functioning valves were restored to working order, and wall boxes were checked to make sure that an orifice was present. It was recommended that the pressure of the seal air to boiler B be increased, and that the air hoses in Boiler B be rerouted to ensure that no water traps were present.

SUMMARY

The infiltration of flue gases into the lance tube of soot blowers has the potential to cause corrosion of soot blower lance tubes. The corrosion is primarily due to the presence of acidic solutions that accumulate in the forward sections of the lance. The acidic condensate is formed by flue gases contain high concentrations of \( \text{SO}_2 \), together with fume that has low carbonate content.

It is important to both provide and maintain a properly functioning air purge system for the lance tubes. Air must be blown to idle soot blower at all times, and the pressure and flow of purging air to the individual blower should be sufficient enough to overcome the local surges in flue gas pressure. In order to ensure the continuous flow of air it is necessary to make sure that all air lines are blown free of debris prior to being hooked up to equipment. Hoses and piping must be routed to avoid any trapping of water. All check valves must be kept in working order, and orifice plates must be present. A minimum air pressure and flow to individual soot blowers for typical recovery boilers is 2.5 kPa (10″WC) and 45Nm\(^3\)/h (27 SCFM) respectively. For design purposes, pressures and flows that are higher than these should be chosen. It is also recommended to check the proper purge air supply to all individual soot blowers in a system not only at start-up but also at regular intervals to ensure its adequacy.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Marcos Arcuri of Clyde Bergemann do Brasil for all his work during the field investigation, as well as the acquiring of lance wall thickness data. The valuable input from Mr. Paul Praszkier of Kvaerner Pulping is also acknowledged.

REFERENCES
