# MILL TRIAL ON NEW SOOTBLOWER DESIGN AND STRATEGY TO COMBAT PLUGGING IN A RECOVERY BOILER

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## ABSTRACT

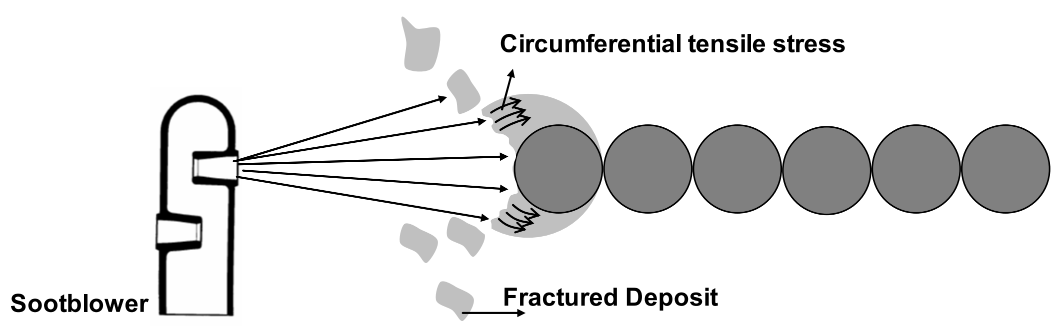
Massive deposit build-up in recovery boilers will not only reduce the heat transfer efficiency, but may also lead to costly unscheduled shutdowns due to the plugging of the flue gas passages. Deposits accumulated on the leading edge of tube banks have been identified as the main root cause of boiler plugging, especially in the superheater section of a recovery boiler. These are also one of the most difficult deposits to remove with conventional sootblowers. This paper discusses a new sootblower that is designed to increase the effectiveness of deposit removal on the leading edge of boiler banks and the preliminary results of the mill trial conducted in a recovery boiler located in the south east USA. While conventional sootblowers rely only on the brittle break-up mechanism to remove the leading-edge-deposits, the new sootblower design leverages both brittle break-up and debonding mechanisms to effectively remove these deposits.

## INTRODUCTION

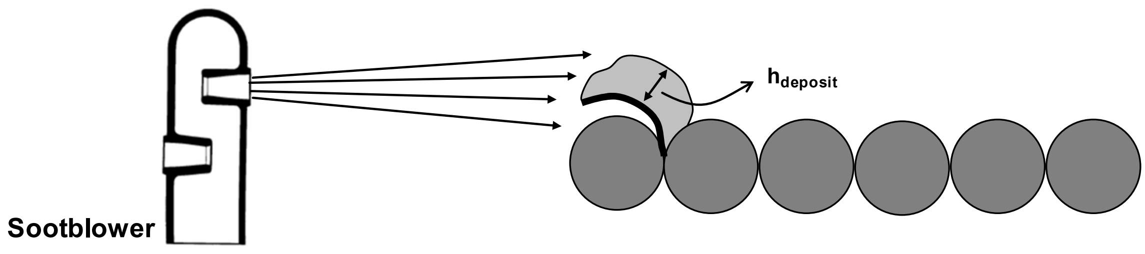
The accumulation of fireside deposits on recovery boiler heat transfer surfaces not only creates an insulating barrier that reduces the boiler thermal efficiency, but can also lead to costly unscheduled shutdown due to the plugging of the gas passes. Control of the deposit accumulation is attained by sootblowers, which periodically blast deposit off the tube surfaces with high pressure superheated steam.

Brittle break-up and debonding are the two most important deposit removal mechanisms by sootblower jets. Brittle break-up occurs when the stress exerted by the sootblower jet on the deposit ($S_{Jet}$) is powerful enough to fracture the deposit and/or to enlarge the existing cracks around the jet/deposit impact point. The deposit is detached from the boiler tube when the propagation of the crack reaches the deposit/boiler tube interface and the crack is enlarged by the act of circumferential tensile stress and the shear stress developed by the sootblower jet as illustrated in Figure 1 a. This mechanism can only take place if $S_{Jet}$ exceeds the deposit tensile strength ($S_{tensile}$).

Debonding is a deposit removal mechanism that relies on weak deposit adhesion strength ($S_{adhesion}$) at the interface between the deposit and the tube surface (Figure 1 b). To remove a deposit with debonding, the $S_{Jet}$ has to be greater than the $S_{adhesion}$. A deposit with high $S_{tensile}$ can be pushed away from the tube, even with a relatively weak sootblower jet force, providing that the jet can overcome the $S_{adhesion}$.




a) Brittle Break-up




b) Debonding

**Figure 1.** *Brittle break-up and Debonding deposit removal mechanism*

The brittle break-up deposit removal criteria for thin layer of deposit strongly attached to a boiler tube is

$$P_{Jet} > \frac{1-\nu}{1-2\nu} S_{tensile} \quad (1)$$

While, for thick layer of deposit, the deposit removal criteria is as follows

$$P_{Jet} > \frac{2}{1-2\nu} S_{temsile} \quad (2)$$

Detailed derivation of these equations can be seen in reference [1].

$P_{Jet}$ = Sootblower jet stagnation pressure at the jet/deposit impact point
$\nu$ = Deposit Poisson's ratio
$S_{tensile}$ = Deposit tensile strength

The jet power required to break a brittle deposit increases with deposit thickness. In other words, it is more difficult to remove thick deposits with brittle break-up mechanism than that of thin deposits. For a typical deposit Poisson's ratio of $\nu$ = 0.2, the removal criteria for thin layer, equation (1), becomes $P > 1.33\ S_t$ and the removal criteria for thick layer, equation (2), reduces to $P > 3.33\ S_t$. The jet power required to remove thick deposit with $\nu$ = 0.2 is two and a half times higher than that of thin deposit. In addition, for thick deposits, the tensile stress created by the sootblower jet drops quickly from the point away from the jet/deposit impact point. In this case, the crack created by the jet may not be able to penetrate deep into deposit/boiler tube interface. Hence, only a small portion of deposit is removed by the sootblower jet as illustrated in Figure 2.

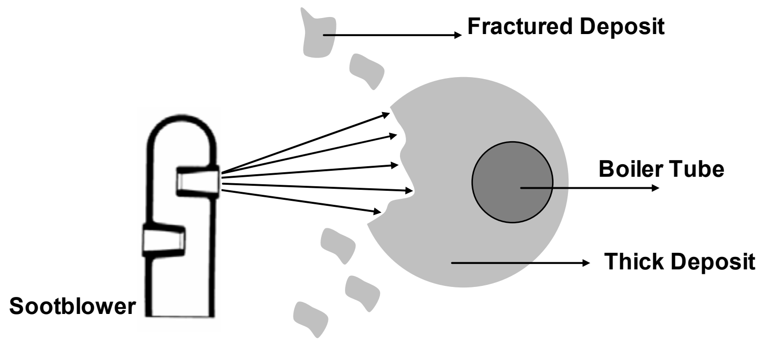


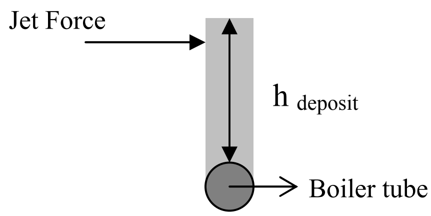

**Figure 2.** *Small portion of thick deposit removed by brittle break-up mechanism*

Unlike brittle break-up, it is easier to remove thick than thin deposits by debonding. Analysis of stresses at the interface between the deposit and tube shows that removal criteria for debonding may be presented as follows [2]:

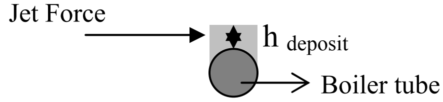
$$P_{Jet} > \Psi S_{adhesion} \frac{D_{tube}}{h_{deposit}} \qquad (3)$$

$P_{Jet}$ = Sootblower jet stagnation pressure at the jet/deposit impact point
$\Psi$ = A coefficient which depends on deposit shape and interface area
$\Psi \approx 1$ for deposit that covers half of the tube circumference
$S_{adhesion}$ = Deposit adhesion strength
$D_{tube}$ = Tube diameter
$h_{deposit}$ = Deposit thickness as shown in Figure 1b

As seen in equation (3), $h_{deposit}$ is located in the denominator of the equation. Hence, the thicker the deposit, the easier it is removed by debonding. This principle can also be understood by evaluating the torque exerted by the jet on thick and thin deposits as seen in Figure 3. Note that the torque experienced by the deposit is proportional to the magnitude of the jet force times the moment arm of the force.




(a) Thick deposit is easier to debond due to higher torque and larger moment arm of the force




(b) Thin deposit is more difficult to debond due to lower torque and smaller moment arm of the force

**Figure 3.** *Torque exerted by the jet on thick and thin deposits*

Brittle break-up mechanism is more effective in removing thin and small deposits, while debonding is more effective in removing thick and large deposits.

## PLUGGING ON THE LEADING EDGE OF A TUBE BANK

Plugging in the convection section of a recovery boiler generally starts from the deposit accumulation in the entrance of a tube bank. These deposits are responsible for the plugging of a recover boiler, especially in the superheater section [3]. Figure 4 illustrates the process of carryover deposition on the leading edge of superheater tubes, which leads to the plugging of the flue gas passage.

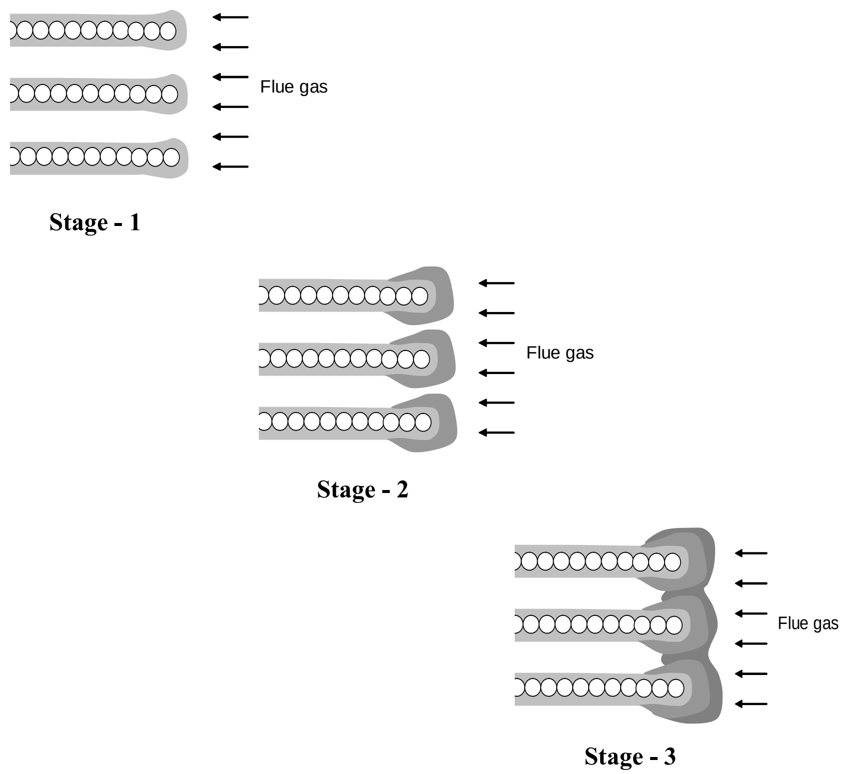



**Figure 4.** *Plugging process in a recovery boiler superheater platen*

Conventional sootblowers generally consist of two 180$^o$ opposing nozzles as shown in Figure 5. Because of this nozzle arrangement, conventional sootblowers can only attempt to remove the leading-edge-deposits with the brittle break-up mechanism. The jets, which exert force parallel to the gas flow and perpendicular to the deposits, hit the deposits and push it against the tubes (Figure 6). Hence, there is no significant toque produced by the jets to promote debonding removal mechanism.

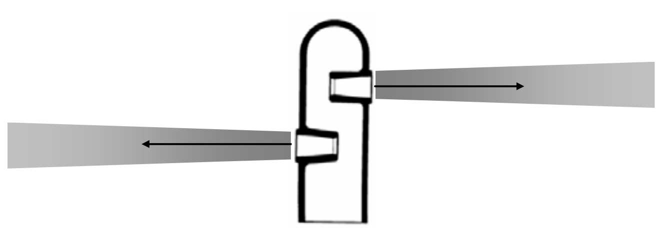


**Figure 5.** *Conventional sootblower with two 180$^o$ opposing nozzles*

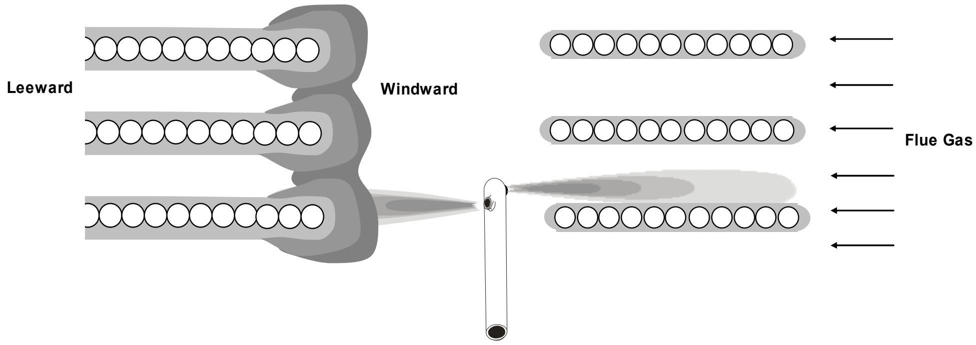



**Figure 6.** *Conventional sootblower attempts to remove leading-edge-deposits*

Since the deposits accumulated on the leading edge of a tube bank are generally fast-growing and thick, the brittle break-up mechanism is ineffective in removing the deposits. This was confirmed by many boiler inspections carried out using a high temperature infrared camera [4].

In regions where the deposit temperature is above 350 $^{o}$C (662 $^{o}$F), the deposit adhesion strength ($S_{adhesion}$) is generally significantly smaller than the deposit tensile strength ($S_{tensile}$) [2]. This suggests that it would be easier to remove deposits in the superheater or hot-side of the generating bank with debonding than that of brittle break up.

Some sootblowers, mainly for coal fired boiler applications, are designed with a lead-lag nozzle to promote the debonding removal mechanism (Figure 7).

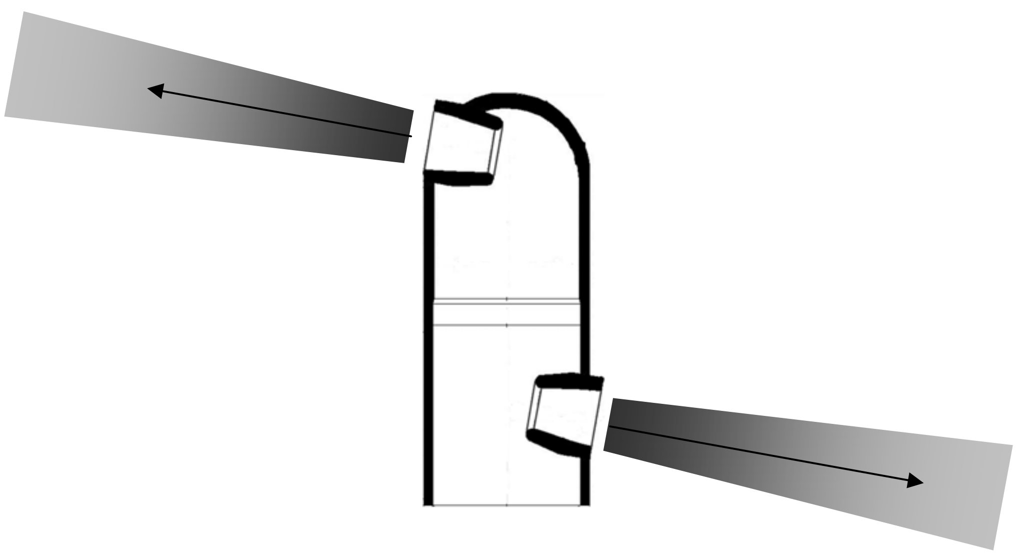


**Figure 7.** *A lead-lag nozzle*

Although the lead lag nozzle arrangement may be effective in removing deposits that are accumulating on the leading edge of the tube, it is not effective in removing thin deposits and may fail to penetrate deep down into the tube bank passage. This is especially true for recovery boilers which have tight side spacing (typically 10 inch as seen in Figure 8). In this case, the deposit located deep inside the tube bank may accumulate and plug the banks.

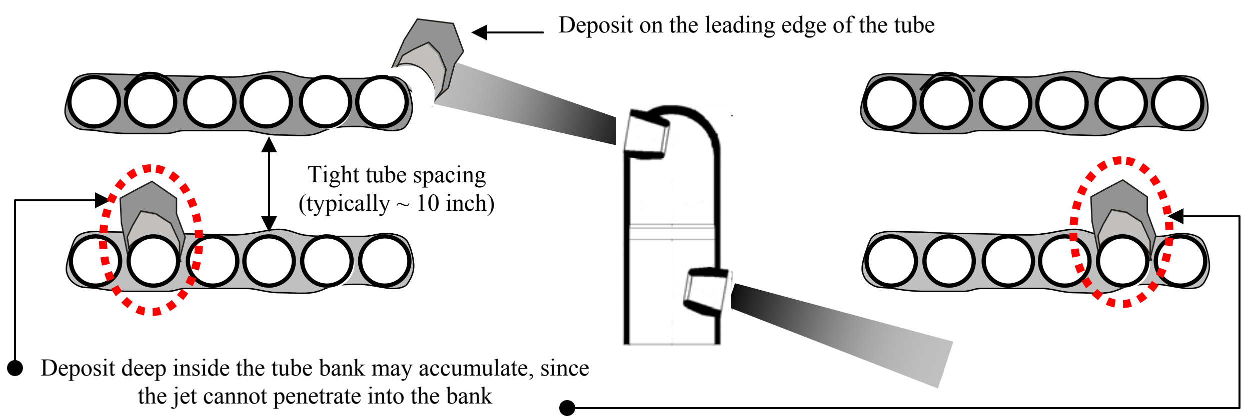



**Figure 8.** *Deposit removal scenario by a lead- lag nozzle*

The focus of the new sootblower design discussed in this paper is directed to not only equip the sootblower to remove deposits with brittle break-up but also to remove them with debonding.

## THE NEW SOOTBLOWER NOZZLE ARRANGEMENTS

The sootblower jet angle of attack ($\alpha$) dictates whether a deposit is more likely to be removed by brittle break-up or debonding. Zero angle of attack is a condition where a sootblower jet is positioned normal to the boiler tube and is pushing the deposit against a stationary object, such as a boiler tube (Figure 9). In this case, the jet produces zero torque and brittle break-up is the only way the deposit can be removed from the tube.

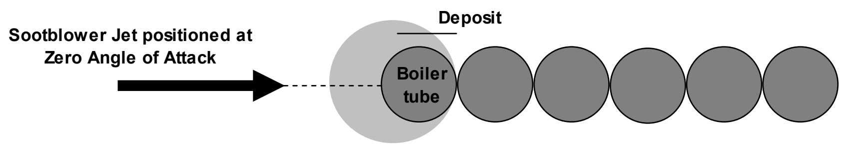



**Figure 9.** *Zero angle of attack*

For debonding to occur, the jet angle of attack has to be greater than zero. This is due to the fact that debonding requires the sootblower jet to produce sufficient torque to debond the deposit. Torque exerted on deposit can only be generated with an angle of attack greater than zero (Figure 10).

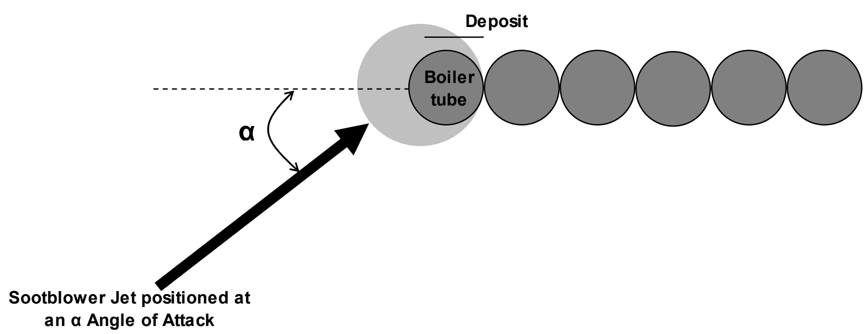



**Figure 10.** *Sootblower jet positioned at an α angle of attack*

The new sootblower is designed with one nozzle positioned in an angle while the other is positioned straight facing the tube bank passage. Figure 11 illustrates the new sootblower nozzle configuration with one nozzle positioned in an angle and the other one positioned straight facing the tube bank passages.

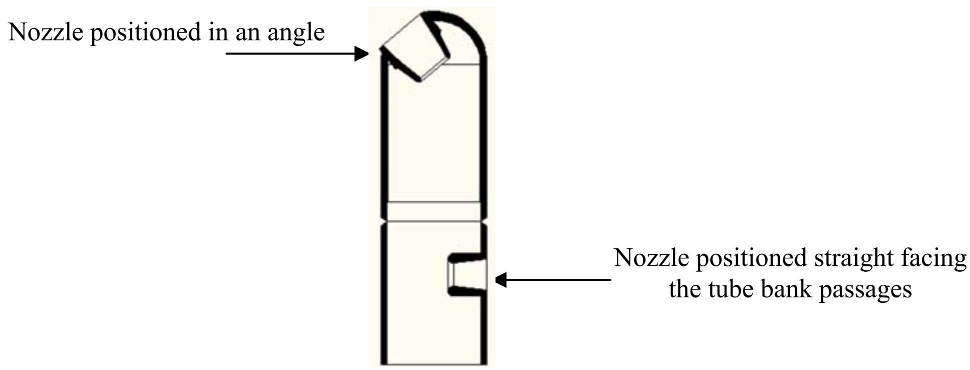



**Figure 11**. *New sootblower nozzle configuration [Patent Pending]*

The main role of the angled nozzle is to deal with the deposit accumulation on the leading edge of the tubes and promote the debonding removal mechanism. On the other hand, the straight nozzle's role is to deal with deposits that are more efficient to be removed with brittle break-up mechanism, such as those that are small in size, and to generate a jet that can penetrate deep into the tube bank and control the deposit accumulation inside the banks. Figure 12 illustrates this idea.

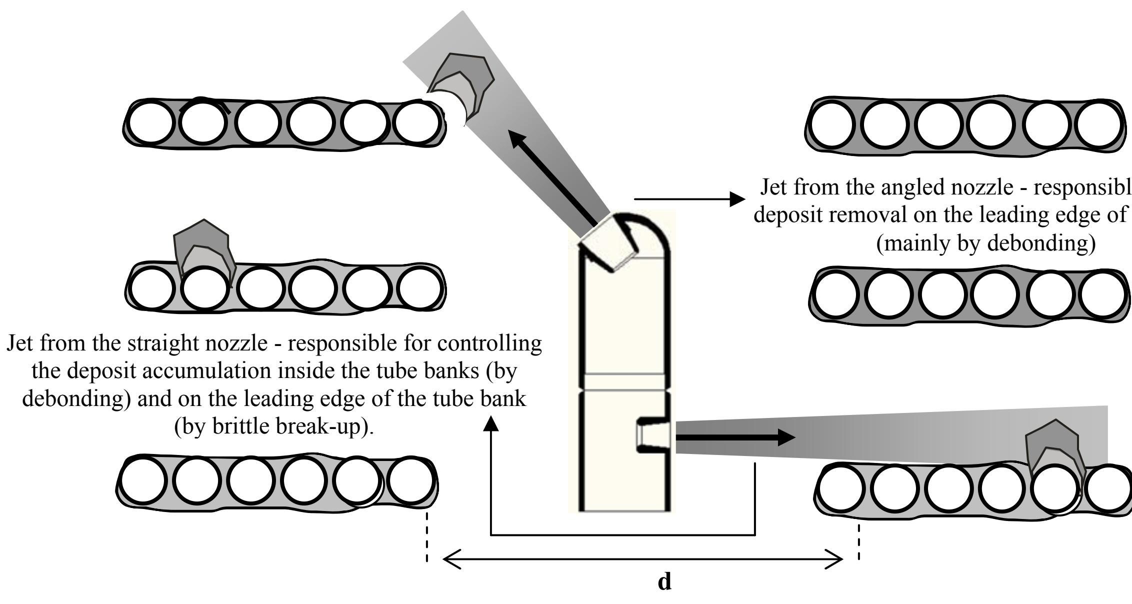



**Figure 12.** *Deposit removal by the new sootblower nozzle configuration*

Since the two nozzles have different angle of attacks, the resultant forces have to be balanced to prevent lance imbalance. Lance imbalance occurs when the magnitude of $F_{1x}$ is not the same as that of $F_{2x}$ as shown in Figure 13. This imbalance, especially in the long retractable sootblower, may cause the lance tube to move erratically, hit and damage the boiler tubes. In order to balance the jet force, the angled nozzle has to be designed with a larger nozzle throat diameter than its straight nozzle counterpart or by manipulating the shape factor (β) to equalize $F_{1x}$ and $F_{2x}$ (Equation 4).

$$F_{1x} = F_1 \cos \delta = \beta F_{2x} \qquad (4)$$

Where β is a shape factor which depends on the nozzle configuration, such as the distance between the two nozzles, lance diameter, nozzle size, etc. β approaches one as the lance diameter increases. The nozzle angle (δ) should be designed to create maximum debonding effects on the leading edge deposits. The smaller the distance between the upstream and downstream tube banks (d as shown in Figure 12) and the thicker the deposit buildup on the leading edge of the bank, the greater the δ is required to provide significant debonding effects.

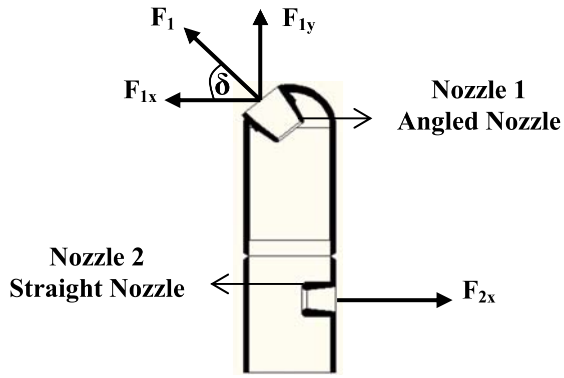



**Figure 13.** *Jet force distribution of the new sootblower nozzle*

## PRELIMINARY RESULT OF THE MILL TRIAL

The mill trial was performed on a B&W recovery boiler unit designed to burn 3.8 million lb/day (1721 ton/day) of black liquor dry solids (BLDS) and to produce 567,700 lb/hr (253,367 kg/hr) steam at 900 $^{o}$F (482 $^{o}$C) and 1525 psig (105 bars). Figure 14 shows the side elevation of the recovery boiler and the four sootblower locations (SB#1, #13, #15, #25) where the conventional nozzles were replaced with the new sootblower nozzles. The performance of these four new nozzles in cleaning the right side of the secondary superheater section was evaluated against the performance of their conventional nozzle counterparts in cleaning the opposite side (i.e., the left side of the secondary superheater section).

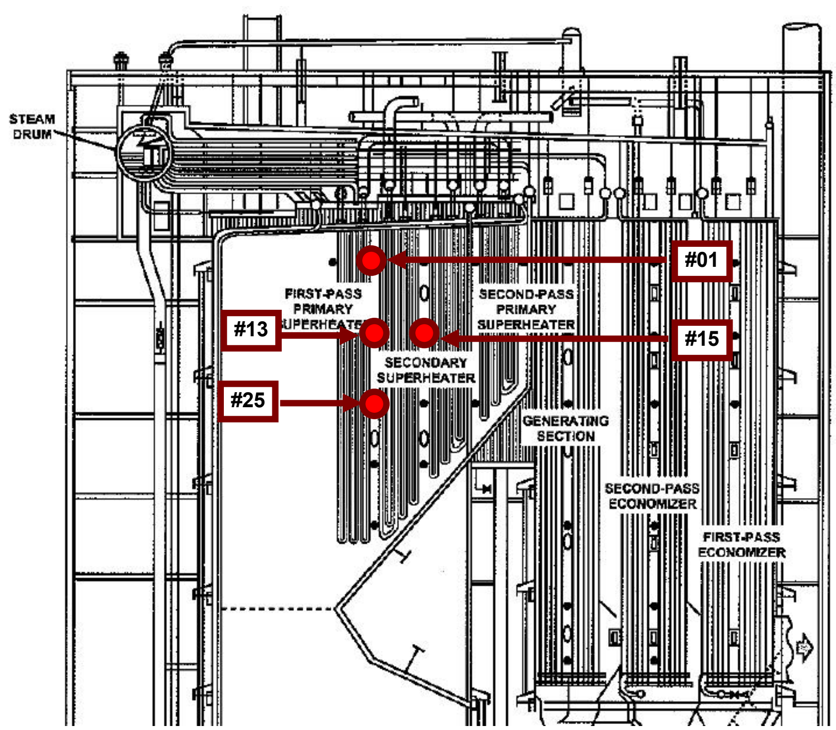



**Figure 14.** *Location of the new sootblower design*

The cleaning efficiency of the new nozzle design during the trial was determined using a fouling index. If this index trended up with time, it indicates that the right side of the secondary superheater section is dirtier than the left side of the secondary superheater sections and vice versa.

As seen in Figure 15, before the installation of the new nozzle design (Period before December 17th, 2010), the difference in the fouling index between the right and the left sides of the superheater consistently trended up with time, indicating that the right side of the secondary superheater fouled at a faster rate than the left side. After the installation of the new nozzles (Period after December 17th, 2009), the trend reversed, suggesting that that the new nozzle design has higher deposit removal efficiency than that of the conventional nozzles.

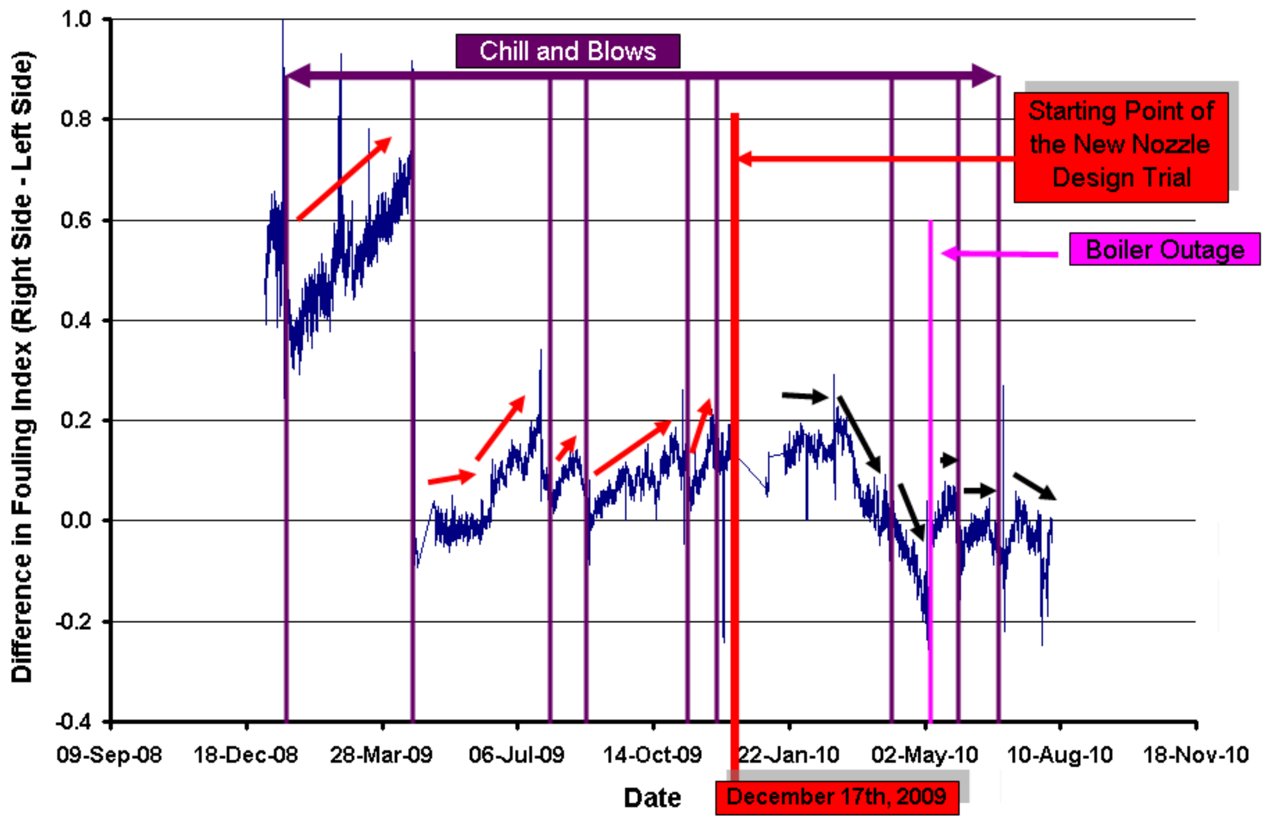



**Figure 15.** *Difference in Fouling Index (Right Side minus Left Side of the Secondary Superheater)*

## SUMMARY

Plugging in recovery boilers, especially in the superheater section, starts with the deposit accumulation on the leading edge of the tube banks. In the hot side of recovery boiler convection sections, where the deposit temperature is generally above 350 °C (662 °F), the deposit adhesion strength ($S_{adhesion}$) is significantly smaller than the deposit tensile strength ($S_{tensile}$) [2]. This suggests that it would be easier to remove deposits in the superheater or hot-side of the generating bank with debonding than that of brittle break up. Unfortunately, conventional sootblowers, which exert force parallel to the gas flow and perpendicular to the deposits, hit the deposits and push it against the tubes. Hence, there is no significant toque produced by the jets to promote debonding removal mechanism. With this cleaning strategy, conventional sootblowers can only attempt to remove the leading-edge-deposits with the brittle break-up mechanism.

A new sootblower design has been developed and its performance is currently being evaluated in a south east US pulp mill. The new sootblower is designed with one nozzle positioned in an angle while the other is positioned straight facing the tube bank passage. The main role of the angled nozzle is to deal with the deposit accumulation on the leading edge of the tubes and promote the debonding removal mechanism. The straight nozzle, on the other hand, is to deal with deposits that are more efficient to be removed with brittle break-up mechanism, such as those that are small in size, and to generate a jet that can penetrate deep into the tube bank and control the deposit accumulation inside the banks. Since the two nozzles have different angle of attacks, the resultant forces have to be balanced to prevent lance imbalance In order to balance the jet force, the angled nozzle has to be designed with a larger nozzle throat diameter than its straight nozzle counterpart or by manipulating the shape factor (β) to equalize $F_{1x}$ and $F_{2x}$.

Preliminary results of the mill trial suggest that the new sootblower removes deposits more effectively than that of conventional sootblowers.

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