INTRODUCTION

In 1998, the U.S. pulp and paper industry consumed 4,319 PJ of energy, accounting for about 23% of the total U.S. manufacturing sector energy use [1]. Since then energy prices have risen markedly as illustrated in Figure 1, which shows the average monthly price of natural gas at the Henry hub. In May 1998 the average price of natural gas was 2.3 [US $/GJ], whereas the price in March 2006 was 6.6 [US $/GJ] an increase of more than 280%. The general trend points to a continued increase in prices. With energy costs accounting for up to 25% of total manufacturing costs there has been an increased urgency to control and reduce these costs.

Sootblowers, used on both recovery and power boilers to control fireside deposit buildup, play an important role in influencing pulp mill energy costs. The sootblowers have to effectively clean the heat transfer surfaces allowing for high boiler efficiencies and maximum steaming rates. If the sootblower effectiveness drops, the use of supplemental fuel increases, to compensate for the gradual decrease in the boiler steaming rate. Conversely, maintaining sootblower effectiveness
While consuming a large amount of steam will also result in increased energy costs. This makes it important to optimize the operation of the sootblowers.

There have been numerous efforts to optimize sootblowing, both from a hardware and control standpoint. This is highlighted by the improvements to the sootblower nozzle efficiency in progressing from the low profile full extension nozzle [2] in the early 1990’s through to the Gemini® nozzle [3] in 2001. These efforts were complemented by progressive control strategies such as One Way® cleaning [4] and the variable flow system [5]. All these efforts, however, focused on optimizing the use of traditional “high” pressure steam. The ability to utilize a lower pressure steam source for sootblowing would increase the availability of high pressure steam for power generation. The additional power provides a significant opportunity for mills to lower their operating costs.

This paper presents enhancements made to sootblowing systems that allow use of lower steam supply pressures. Pressure losses in a traditional sootblowing system are examined and constraints to these systems are identified. Improvements made to various components and the associated performance are also presented and discussed.

DEFINITIONS AND TERMINOLOGY

Peak Impact Pressure (PIP): is a measure of the sootblower cleaning force, and is simply defined as the peak stagnation pressure for the nozzle jet measured by a pitot tube downstream from the nozzle exit. To allow for easy comparison, all nozzle performance curves show PIP measurements made 762 mm (30 inches) from the nozzle exit.

Poppet Valve Pressure: is the desired blowing or head pressure measured at the poppet valve. This pressure is used to regulate the sootblower cleaning force. The poppet valve pressure is an operational variable.

Nozzle Pressure: is the pressure measured at the inlet to the sootblower nozzle and is lower than the poppet valve pressure due to the pressure drop across the lance and feed tubes. The nozzle pressure is a design variable.

Figure 2 – Illustration of Definitions and Terminology
TRADITIONAL SOOTBLOWING SYSTEM

When retrofitting a traditional system to use a lower pressure steam source, a typical question posed is “With the existing sootblower systems, what currently prevents the use of a lower pressure steam source?” To address this and to determine minimum supply pressure required in traditional sootblowing systems, consider the case where a sootblower with the specifications listed in Figure 3, is used to provide a cleaning force \((P_1)\) of 271 kPa (80 in. Hg). To deliver this level of cleaning the poppet pressure \((P_2)\) would have to be set at 2,137 kPa (310 psig). Depending on the supply piping design, the pressure drop in the piping can be as low as 345 kPa (50 psig) or as high as 689 kPa (100 psig). This means that, for this case, the minimum sootblowing source required in a traditional system is between 2,482 kPa (360 psig) and 2,827 kPa (410 psig).

![Figure 3 – Traditional Sootblowing System](image)

ENGINEERING A SYSTEM TO USE A LOWER PRESSURE STEAM SOURCE

When engineering such systems the first step is to identify an available lower pressure steam source. Pulp and paper mill production units require process steam delivered at various pressures, and most mills have a header in the 1,034 kPa (150 psig) to 1,138 kPa (165 psig) range. For illustrative purposes the 1,138 kPa (165 psig) header will serve as the desired source for this paper. Comparing this header pressure to the minimum pressure source required with a traditional system derived above, it is evident that for this case pressure savings of 1,344 kPa (195 psig) to 1,689 kPa (245 psig) are needed.

Having identified the steam source and the pressure savings needed, the required boiler cleaning needs have to be assessed and cleaning system deficiencies identified. Traditional systems are frequently operated where the sootblowers do not provide the required cleaning force, resulting in frequent water-washes and or forced boiler outages. Failure to determine the optimal cleaning
needs will result in a system designed to provide lower cleaning forces which will lead to operating inefficiencies.

Finally the entire sootblowing system has to be analyzed to identify choke points or areas with high pressure losses. Engineering changes are made to eliminate each of these choke points until the system pressure losses are such that the new lower pressure source can provide the required cleaning.

The following sections will examine each of the engineering studies that have to be completed; recovery boiler cleaning evaluation and a cleaning media supply piping analysis. In addition the redesign of the sootblower components needed in the system will be discussed.

**RECOVERY BOILER CLEANING EVALUATION**

The primary goal of the evaluation is to determine the optimal poppet pressure setting and operating frequency for each sootblower. This is accomplished by reviewing current operating trends, mapping out in-situ deposition patterns and deposit characteristics. In addition cleaning deficiencies, and in some cases areas of over-cleaning are identified and corrected.

Two imaging tools are used during these assessments; a line of sight camera and a remote inspection camera, **Figure 4**. The line of sight camera is used to look down the sootblower cavity and provides insight on leading edge deposits, and carryover levels in the upper furnace. When used at the bullnose elevation or in the lower furnace, it can help assess liquor firing and air system setup to assist in addressing carryover concerns. This camera, however, cannot look down the flue gas lanes between the boiler tubes. To accomplish this, the camera has to be equipped with a ninety degree lens and be able to extend into the furnace, allowing viewing down each lane. The remote inspection camera, which extends to about 6 m (20 ft) in length, fills this need. In addition to the two imaging tools, an array of diagnostic equipment is also used as needed. Gas temperatures are measured with an optical pyrometer, GasTemp-RB®, fume levels are determined using a fume sensor and a carryover monitor is used to analyze long term carryover levels.

![Remote Inspection Camera](image1) ![Line-of-Sight Camera](image2)

*Figure 4 – Recovery Boiler Evaluation Cameras*

Completion of the cleaning evaluation provides corrective actions that should be undertaken to optimize the operation of the boiler cleaning equipment and that will yield the highest payback following the implementation of the lower pressure sootblowing system. The evaluation also
provides one of the design points for the new sootblowing system the PIP required for optimal cleaning.

**POPPET VALVE DESIGN**

The poppet valve is mechanically operated and controls steam flow to the sootblower. Figure 5, illustrates a cut-away view of a traditional poppet valve in the rest position, and will be used to describe the valve operation. The floating disc (D) is pressed against the valve seat (C) resulting in a self-pressurized disc, which stops steam flowing into the blower. When the sootblower cycle begins, the arm (A) is actuated, which pushes down on the valve stem (B) which moves the floating disc (D) down. Steam flows in the valve (E), through the gap created between the valve seat (C) and the floating disc (D) and out of the poppet valve (F) to the sootblower.

It is readily apparent that due to the restrictions in the valve, there are substantial pressure losses encountered. In designing a new valve for this application, three major design constraints had to be met:

- The primary design criteria, was to significantly reduce the pressure drop across the poppet valve.
- Since an existing installation was being retrofitted, the new valve has to mate to the existing sootblower and steam supply line. This minimizes piping modifications and significantly reduces capital costs.
- The valve has to match the reliability of the existing valve.

The pressure drop across a poppet valve is calculated using Bernoulli’s equation, which combined with the design criteria, indicates that the loss factor, $K$, has to be reduced in order to reduce the pressure drop across the valve. Geometrically a ninety degree elbow would represent the lowest losses that can be attained. The inclusion of a valve seat to properly seal the valve when the sootblower is in the parked position contributes to preventing the loss factor from equaling that of a ninety degree elbow. The new low loss valve, Figure 6, is a drop in replacement for a traditional poppet valve and utilizes the same linkage style to actuate the valve. When the valve is open, the internal geometry provides the cleaning media with a smoother transition into the valve similar to the flow in an elbow. The elimination of the flow restrictions and tortuous path followed by the cleaning media in the traditional poppet valve yields the low pressure drop. Figure 7 illustrates the loss factors for the new low loss poppet valve as compared to other common piping fixtures.

$$\Delta P = K \rho \frac{V^2}{2 g}$$

Where:
- $\Delta P$ is the total change in pressure between (E) and (F) points,
- $K$ is a system constant corresponding to the system loss factor
- $\rho$ is the density of the cleaning fluid
- $g$ is a constant corresponding to the acceleration of gravity,
- $c$ is a height change of the cleaning fluid as it flows between (E) and (F) points, and
- $V$ is the velocity of the cleaning fluid.
NOZZLE DESIGN

The nozzle performance for two traditional nozzles is illustrated in Figure 8, which shows the cleaning force as measured by the PIP plotted against the poppet valve pressure. This curve is specific to the sootblower parameters depicted in Figure 3. Continuing with the example cited, if a cleaning force of 80 in Hg (Point A) is required, with the existing MPCS nozzle, the poppet valve pressure would have to be set at 2,137 kPa (310 psig) (Point B). If the most advanced traditional Diamond Power® nozzle currently commercially available was used to provide the same level of cleaning, the new poppet pressure would be 1,620 kPa (235 psig) (point C).

While there is a significant reduction, 24%, in the poppet pressure, it is readily apparent that traditional nozzles cannot deliver the required cleaning force at significantly lower pressures. Traditional nozzles have been optimized for higher pressures and there has not been the need for lower pressures until now.
By taking advantage of advanced computer modeling techniques the new low pressure nozzle has been designed to minimize flow losses both in the nozzle body and downstream of the exit. Extensive full scale laboratory testing and field trials have confirmed that the new low pressure nozzle design can produce effective boiler cleaning while utilizing significantly lower steam pressures than was previously possible. This is illustrated by continuing with the example cited, if the low loss Gemini® nozzles are used to deliver a cleaning force of 271 kPa (80 in. Hg), the new poppet valve pressure would be 1,254 kPa (182 psig) point (D) in Figure 8. This represents a 41% reduction in system pressure losses.

![Figure 8 – Performance Nozzle Curves](image)

**CLEANING MEDIA PIPING ANALYSIS**

In conjunction with the new sootblower components presented, all aspects of the sootblower cleaning media supply system have to be evaluated to determine pinch points that could restrict flow to the sootblowers. Traditional sootblowing systems utilize high pressure steam, typically obtained from a header at pressures between 4,137 kPa (600 psig) to 10,342 kPa (1,500 psig). When this pressure is compared to the minimum pressure required, it indicates that there is an “excess” pressure between 1,655 kPa (240 psig) to 7,515 kPa (1,090 psig). This differential typically absorbs or hides any additional pressure losses due to the addition of instrumentation, valves, and process inefficiencies all of which can be compounded by improper sizing.

A proprietary code is used to model sootblower supply systems that enable the study of changes to system parameters. To illustrate the piping engineering study, the system illustrated in Figure 9 will be analyzed. This application utilizes steam as the cleaning media, which is fed from a common 10,342 kPa (1,500 psig) mill header. There is a long pipe run to the boiler house after...
which the main sootblowing supply splits into two branch lines that feed sootblowers mounted on each side of the boiler. On each side of the boiler the branch lines spit into two additional vertical lines, one feeding sootblowers in the superheater and generating bank and the other sootblowers in the economizer.

Figure 9 – Schematic of Piping System Modeled

A portion of the piping model is shown in Figure 10, where all the piping description and pressure losses are represented by the symbol P, and all other components such as bends, elbows, valves, instrumentation are represented by the symbol J. The system has a flow transmitter, J46, on each vertical line, and local sootblower isolation valves, J24.

The model is validated by simulating the existing system for different conditions and the results are compared to the corresponding operating data. Once the model is validated, the model is used to determine pressure losses in the system, and to examine the benefits associated with changing various components. In this analysis the flow transmitter was observed to have a large pressure drop across it, which was due to an improperly sized orifice plate. The analysis also identified the local sootblower isolation valve, which was properly sized, but due to the design used had a significant pressure drop across it. Replacing both the orifice plate and the isolation valve yielded pressure savings of 49%.

While there are numerous other changes that can be made to reduce the pressure losses, the associated economics negates them. The intent here was to demonstrate that, frequently, there are some relatively easy changes that can allow for significant pressure savings. To realize these savings an engineering study of the existing supply system has to be undertaken.
ADDITIONAL SYSTEM COMPONENT

There may be a few cases where either economics prevents the implementation of all the changes required or there simply are not sufficient opportunities to yield the needed pressure savings. These situations necessitate the use of a thermocompressor. A thermocompressor, Figure 11, is a device that boosts the pressure of the cleaning media from a low pressure source to an intermediate pressure using a higher pressure source. The cleaning media from the high pressure source is used as a motive fluid and the low pressure stream as a suction fluid. The high velocity motive fluid entrains the suction fluid entering at the suction inlet, forcing both into the mixing chamber where the two fluids are combined. The mixed fluids are then recompressed to an intermediate pressure through the diffuser, which functions as a nozzle in reverse, reconverting the kinetic energy of the high pressure fluid to static energy to boost the pressure of the suction fluid.

For this application, the high pressure source would be the existing supply, the low pressure source would be the desired lower pressure source and the discharge pressure would be the pressure required to meet the cleaning needs.
SYSTEM BENEFITS

There are three major benefits that can justify retrofitting an existing system to use a lower pressure steam source:

1. For applications using steam for the cleaning media, the saved high pressure steam is diverted to a turbine to generate additional electrical power. This is only feasible if there is additional turbine capacity available or the existing turbine is being replaced with a larger unit.

2. For applications using steam for the cleaning media, the decreased demand for the high pressure steam allows an improvement to the boiler fuel mixture. The use of the more expensive fuels is minimized in favor of cheaper fuels.

3. Implementation of this system reduces capital costs associated with upgrading the cleaning media supply equipment.

CASE STUDY

A study was undertaken at a mill in the United States where the system was tested and the system’s reliability and benefits were demonstrated. The results of this test will be presented in a technical paper to be presented at the 2006 TAPPI Engineering Conference.

REFERENCES


