Control System Improves Reliability and Safety of Recovery Boilers

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ABSTRACT

Pulp and paper mill recovery boiler owners and operators strive to maximize recovery boiler safety, reliability and availability. Improved control of boiler water chemistry and the ability to reliably detect boiler leaks both serve those goals. This paper discusses a monitoring and control system used in pulp and paper mills to provide both precise boiler chemistry control and mass balance-based recovery boiler leak indication. The system is described and field results are presented.

Good control of boiler water chemistry is necessary to avoid boiler corrosion and deposition, either of which can lead to tube leaks or failures. Maintaining boiler chemistry within congruent pH/phosphate guidelines avoids the corrosive conditions that exist when operating outside the guidelines. Improved response to input variability reduces out of control incidents caused by system upsets.

Early detection of leaks is a primary objective of recovery boiler operators because of the potentially serious consequences of a water leak into the furnace. A leak detection system has been developed to provide early detection of leaks while avoiding alarms from signal noise and process variability. This is accomplished through proprietary statistical modelling and by employing fuzzy logic and software that learns and adjusts to each unique boiler. The system uses both chemical and/or water mass balances around the waterside of the boiler to provide early detection and an indication of whether the leak may be in a critical area. The ability of the controller to detect leaks, in addition to providing precise control, further improves the reliability and safety of recovery operations.

INTRODUCTION

The Solenis OnGuard™ i controller is the centerpiece of a monitoring and control system used for both boiler water congruent phosphate control and mass balance-based leak indication. Field experience is presented that demonstrates improvements in chemistry control in pulp and paper mill boilers when using this system for boiler pH phosphate control (BPPC). Recovery boiler leak indication using the Leak Alert software for mass balance-based leak indication is then presented with configuration details and field experience.

Figure 1 shows the necessary instrumentation for BPPC, water mass balance (WMB) leak indication, and chemical mass balance (CMB) leak indication. The BPPC software and the leak indication software reside in the controller. A typical installation includes both BPPC and leak indication, although either could be implemented without the other. The leak indication software includes WMB and CMB, both of which typically are employed, although either could be implemented without the other.
BOILER PH/PHOSPHATE CONTROL

In all cases where the makeup water is demineralized or evaporated and the operating pressure is 600 psig (4.4 MPa) or greater, the internal boiler water chemistry should follow either congruent phosphate, coordinated phosphate or all-volatile treatment [1]. The most common treatment regimen for recovery boilers is congruent phosphate control, with the objective of avoiding corrosive attack from either free caustic or acid phosphate in the boiler water.

The importance of avoiding corrosive conditions and the requirements for recovery boiler programs operating under congruent phosphate control are documented in the literature [2,3,4]. Achieving congruent control requires operating the boiler chemistry within a specified range of sodium-to-phosphate ratios [5,6], presented in Figure 2 as a graph of pH versus phosphate for various pressures. Operating above the range can result in caustic corrosion and operating below the range can cause acid phosphate corrosion.

Controlling boiler chemistry within the congruent phosphate chemistry control boxes shown in Figure 2 is commonly referred to as operating in the box. The measurement of the success of the control is referred to as time in the box (TIB) [7] and usually is expressed as a percentage.

Figure 1. Instrumentation for a typical recovery boiler installation with BPPC and leak indication.

**Figure 2.** Congruent control ranges (boxes) designated by operating pressure. The vector diagram indicates the movement of the operating point resulting from changes in chemical addition and blowdown.
Minimizing the risk of either caustic corrosion or acid phosphate corrosion is a key objective of boiler operators, and this is best accomplished by maintaining control in the designated box. Corrosive attack can occur during excursions when operating outside the box. Although each excursion may be minor, the corrosive result is cumulative and can be serious.

Boiler operators may maximize TIB by adjusting the feed of various phosphate species (tri-, di- and mono-sodium phosphates), adding caustic or adjusting blow down as shown in the vector graph in the lower right corner of Figure 2 [8]. This paper presents examples of the improvements achieved over time as the control capability and resulting TIB performance improved.

**Control Method Evolution**

The control methods available to improve boiler chemistry control, and especially BPPC control, have evolved from traditional manual control to new technologies using fuzzy logic and knowledge-based control.

**Manual boiler pH/phosphate control strategy:**

1. Obtain boiler water sample.
2. Conduct lab analyses for pH and phosphate.
3. Plot on X/Y axis (see Figure 3).
4. Compare new result to the desired pH and phosphate reading, being mindful of the sodium-to-phosphate ratio required to stay congruent.
5. Consider current load trends, boiler feedwater quality, boiler cycles, and so forth, and decide whether to increase or decrease phosphate products or to adjust blowdown.

This control process can be a manual operation using operators and wet (bench) testing, a blend of manual and on-line instruments or can be totally automated. Figure 3 depicts TIB performance for a manually adjusted chemical control process in a recovery boiler.

![Figure 3. Graph of pH and phosphate values representing the sodium-to-phosphate ratio box in a mill using manual control.](image)

Some mills using manual chemical control achieve a high percentage of TIB control but there usually is significant scatter to the data and there is significant time between tests where the system is vulnerable to upsets from feedwater contamination. The main sources of feedwater contamination in paper mills are demineralizer upsets and liquor intrusion into condensate. Manual control often results in a significant time lag between the contamination event and the response, potentially exposing the boiler to an out of control condition.

The objectives for recovery operation are maximum reliability and economy, and these are best achieved with optimum process control. Optimum control can only be accomplished by using modern control techniques. The recovery boiler is a critical element of the mill and boiler chemistry should be optimally controlled, as is any other important mill process.
On-line instrumentation and simple automation can improve total TIB performance and provide leak indication. A unique controller was designed to improve upon manual and traditional automation systems by using fuzzy logic and knowledge-based control. The controller learns how the boiler system will respond to change and reacts quickly and accurately without the associated over/under-feeds in chemistry that can lead to incongruent results, phosphate hideout and caustic attack on boiler tubes.

The controller performs the same functions as manual control; however, monitoring and automation significantly improve performance. Where on-line monitoring is not available, manually entering data into the controller is an option. Based upon pH, phosphate and multiple other process inputs, the controller simultaneously feeds the required blend of phosphates to achieve congruent control.

Instead of using a true sodium value for control, pH is used. The sodium content in the water never matches the phosphate that provides the actual boiler water pH because of the mixture of cation and anion impurities present in high purity water. Bench testing for sodium is very difficult. On-line sodium analyzers are more expensive and less reliable than pH meters and pH has proven to be an acceptable surrogate.

Operating Experience with Improved Controller

Field experience with the controller has proven the concept by providing improved control. Improved control results in lower risk of corrosion and improved boiler reliability. Added benefits include immediate response to feedwater contamination, load swings and other process upsets.

Case history 1: improved control and reduced costs in a previously automated boiler system. A 60 bar (600 psi) recovery boiler equipped with a first-generation controller averaged 75% to 98% TIB with considerable variation in results. The control system was replaced with a new controller, and over the next year TIB improved to consistently greater than 90% with greatly reduced variation. Using the new controller with system optimization, this mill now routinely achieves 98% TIB for multiple boilers. Another benefit of improved control was demonstrated by an 18% reduction in chemical cost compared to the previous controller. The new controller successfully avoids over-feed and under-feed of product, which reduces cost by being in statistical control as opposed to merely operating within control limits.

Figure 4 shows the mill operating data before and after the new controller was installed.
Figure 4. Mill data showing improved TIB control and 18% reduction in chemical usage with new chemical control system.

Case history 2: improved control in recovery boiler restart. An idled pulp mill restarted with a reconfigured steam system where the 103 bar (1500 psi) recovery boiler would be the primary steam producer and would take most of the load swings. The mill required a chemical control system that would improve control while using some manual operator testing data versus completely automated on-line instrumentation. The previous control system had performed well by company standards (see Figure 5) with TIB greater than 90%. Prior to the mill re-start, a new controller replaced the legacy system. Figure 6 shows the improvement in control that resulted. Even with increased variation in steam production, the chemical control was significantly better than before.

Figure 5. Previous control system achieved better than 90% TIB control but with significant variability.
Figure 6. New controller achieved improved TIB control and reduced variability.

Case history 3: improved recovery boiler control during sodium spikes. A Northwestern pulp mill with a 58 bar (850 psi) recovery boiler commonly experienced high sodium spikes in the boiler feedwater. The sodium excursions were due to contamination from the evaporator condensate, which was intermittent and unpredictable. The resulting boiler chemistry control was often less than 80% TIB (see Figure 7), which increased the potential for boiler corrosion. An immediate remedy for preventing the sodium spikes was not available; therefore, an improved controller was installed. Figure 8 shows the improved control with the same feedwater quality.

Figure 7. Unacceptable control with previous control system.
Case history 4: control maintained during feedwater contamination event. A boiler feedwater contamination event resulted in a decrease in boiler water pH. This was detected by the controller, which began feeding more of the high Na:PO₄ product and less of the low Na:PO₄ blend. This stopped the pH depression in the boiler and increased the pH level to maintain the boiler within congruent control. The pH variation between the lowest and highest value was approximately 0.24 pH units, indicating the sensitivity of the controller while not over-shooting during the correction. This allowed continued operation without interrupting production.

Figure 9 shows the response of the controller to the low pH event. The boiler chemistry was maintained in congruent control and boiler operation was not interrupted.
Case history 5: value of improved control. The improvement in control achieved in a mill can be demonstrated with statistical analysis. Figure 10 illustrates the distribution of data in a boiler prior to installing the new controller. This mill achieved an average of 98% TIB control, but the variation of Na:PO₄ is significant.

Figure 10. Prior data distribution of the Na:PO₄ ratio around the mean for one month.

As shown in Figure 11, after the new controller was installed, typical monthly data scatter was reduced. This reduction in variation provides a cushion or zone of safety around the control point, which allows the controller to respond to variations while still maintaining the system within control limits. Maintaining tight control of the Na:PO₄ ratio is achieved by the controller’s fuzzy logic and its ability to respond to external variations.

Figure 11. Data distribution for one month after installation of new controller.

Although the TIB increased only from 96 to 97% by converting to the new controller, a major improvement in process control occurred because the process was centered [9]. Consequently, the variability was reduced by 64%, as measured by standard deviation.

Boiler Congruent Control Summary

The new controller can improve TIB for boiler pH/phosphate control under a variety of conditions. These include base-loaded, steady-state boilers and highly variable swing boilers. The response to feedwater contamination is
rapid and effective control is often maintained under upset conditions. The data necessary for control can come from operator-generated manual data input, on-line instrumentation or a combination of both. Boilers with well-managed manual control showed statistically significant improvement after implementing the new controller.

**BOILER LEAK DETECTION**

The value of early leak detection in recovery boilers has been well-established [10]. The use of waterside mass balance information is one of several means used to determine the presence of boiler leaks. Other methods include acoustic and operator observations. Each method has limitations; thus, multiple methods for detecting leaks can be employed [11] and may improve detection, provide redundancy or confirmation, and potentially help avoid boiler damage or unnecessary emergency shutdown procedures (ESP). The new controller provides the ability to monitor WMB and CMB and to provide information on the existence and location of a leak. The ability of the controller to detect leaks, in addition to providing precise control, further improves the reliability and safety of recovery boiler operations.

**Mass Balances for Boiler Leak Indication**

Waterside mass balances employing various levels of sophistication are used for leak indication on recovery boilers. In some cases, operators may notice a decline in boiler chemical residuals during routine manual testing or the separation of feedwater and steam flows on boiler trend charts as indications of possible leaks. In other cases, fully automated systems with continuous monitoring and statistical methods are used to provide information on possible leaks.

With any leak indication system, the goal is to detect small leaks accurately and quickly. The background variability that exists with boiler mass balances creates challenges with achieving that goal [12]. Additionally, since mass balance calculations will indicate other water losses besides furnace leaks (such as an open drain line), additional means of assessment, operator observations, and the use of checklists should be incorporated into a mill response when mass imbalances are indicated.

Automated mass balance indicators, especially when refined to optimize performance, can provide early indication of furnace leaks and other process issues such as flowmeter problems, open drain lines and chemical feed line leaks. Using both WMB and CMB information can provide a level of leak indication redundancy and may provide some indication of leak location [12] as shown in Table I. The WMB indicator increases in response to leaks included in the WMB calculation and includes any type of water leak from the economizer, boiler or superheater. The CMB indicator increases in response to cycled boiler water leaks or leaks in the chemical feed line.

**Table I. Leak location information derived from WMB and CMB indicators.**

<table>
<thead>
<tr>
<th>Water Mass Balance Leak Indication</th>
<th>Chemical Mass Balance Leak Indication</th>
<th>Potential Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Indication</td>
<td>No Indication</td>
<td>No water or chemical loss.</td>
</tr>
<tr>
<td>Indication</td>
<td>Indication</td>
<td>Water loss in cycled part of boiler.</td>
</tr>
<tr>
<td>No Indication</td>
<td>Indication</td>
<td>Water loss in cycled part of boiler (but not large enough to be seen by water mass balance). Chemical loss such as a chemical feed line leak downstream of chemical feed measurement.</td>
</tr>
<tr>
<td>Indication</td>
<td>No Indication</td>
<td>Water loss in economizer or superheater. Water loss in cycled part of boiler (but not large enough to be seen by chemical mass balance.</td>
</tr>
</tbody>
</table>

In some situations, leak location information may allow a mill to avoid an ESP. For example, some economizer leaks do not require an ESP [12]. Economizer leaks represent a large percentage of the leaks that occur in recovery boilers. Although mass balance information may not be definitive on leak location, early indications may provide direction for investigation and confirmation by other means.
Mass Balance Leak Indicator

Proprietary leak indication software incorporates both WMB and CMB methods. It uses a statistical approach for evaluating mass balance information to provide imbalance indications to operations personnel. Data filters improve the sensitivity and speed of detection and reduce the false alarm rate. For example, averaging techniques help to reduce random noise and proprietary data filters help to minimize the impact of noise and to optimize the tradeoff between early detection and sensitivity [13].

The elimination of all mass balance variability is not practical, especially if non-furnace leak water or chemical losses are considered to be part of that variability. This leak indication software uses a unique statistical approach that acknowledges the presence of mass balance variability and uses historical data as a reference data set to serve as a basis for distinguishing between typical and unusually large mass imbalances. This reference data set is updated continually to include the most recent data, which provides a self-calibration mechanism that allows for some level of hands-off operation. However, further optimization of performance can be achieved with routine historical data review of the mass balance variability profiles. The leak indication charts allow the user to understand how historical variability affects the sensitivity and the alarms. Alarm zones can be expanded or contracted easily to address any obvious changes in these system variability profiles.

**Hardware for water mass balance.** Hardware requirements for WMB calculations are relatively simple. Flow signals for water and steam into and out of the boiler must be available (see Figure 12). In most cases, additional flow signals, such as attemperation water flow or sootblower steam flow, may be needed if they are required to close the WMB around the boiler.

![Figure 12. Hardware requirements for WMB leak indication.](image)

**Hardware for chemical mass balance.** The hardware required for CMB calculations is more complex, however it is essentially the same hardware required for the BPPC configuration (see Figure 13).
The flows of chemicals into and out of the boiler must be monitored. The quantity of chemical fed into the boiler is determined by measuring the flow of chemical into the boiler along with the as-supplied concentration of the measured species (in this case, phosphate). Options for chemical flow measurement include flowmeters, automated drawdown chambers and flow-measuring dosing pumps. The quantity of chemical leaving the boiler is determined by measuring boiler blowdown flow rate and the chemical concentration using a continuous analyzer. Steam chemical concentration, and hence chemical flow, can be assumed to be zero provided that a non-volatile chemical, such as phosphate, is used. The hardware configuration in Figure 13 shows two separate chemicals being fed. This depicts the typical recovery boiler application on a congruent phosphate program with automated control discussed in this paper. A boiler application that uses a single chemical can also be used to perform leak indication.

Software. The use of software to process data maximizes the potential for mass balance data to provide useful information.

A detailed discussion of statistical methods and other elements of the software are beyond the scope of this paper; however, the following elements are included in the software:

- A data processing approach that optimizes the speed of detection and the sensitivity level; excludes invalid data; and avoids the effects of systematic errors such as mis-scaling, boiler liquid mass uncertainty, and the lack of time synchronization.
- A proprietary statistical approach to processing the data that maximizes the potential for hands-off operation; although the system is also designed to allow for knowledge-based and goal-based adjustments to the statistical limits.
- A provision for estimating detectible leak size.
- A simple user interface/alarm signal display (see Figure 14).
The software condenses the WMB and CMB evaluations to separate indexes for each mass balance indication. The software is designed to provide a self-calibration mechanism that allows for some level of hands-off operation by using a rolling window of historical data. However, further optimization of performance can be achieved with routine review of this historical data. Additional charts are available that allow the user to understand how historical variability affects the sensitivity and the alarms. Alarm zones can be easily expanded or contracted to address any obvious changes in these system variability profiles.

The mass balance evaluations employed by this system use the signals from the hardware elements shown in Figures 12 and 13.

The basis for the WMB evaluation is

\[ WMB = \frac{(\text{actual flow in} - \text{expected flow in}) \times 100}{\text{expected flow in}} \]

where \( \text{actual flow in} \) is provided by the boiler feedwater flow signal and \( \text{expected flow in} \) is provided by a sum of the flows leaving the boiler, which is typically steam and blowdown.

The basis for the CMB evaluation is

\[ CMB = \frac{\text{expected phosphate} - \text{actual phosphate}}{\text{expected phosphate}} \times 100 \]

where \( \text{actual phosphate} \) is the concentration provided by a continuous phosphate analyzer and \( \text{expected phosphate} \) is the expected boiler chemical phosphate concentration derived from the blowdown flow rate, the chemical feed rates, the concentration of the phosphate in the chemical product(s) fed and the boiler water mass.

**Boiler Mass Balance System Boundaries**

The primary goal for a recovery boiler user of leak indication software is the early detection of leaks in a boiler. The simple system diagrams in Figures 15 and 16 illustrate the typical boiler system boundaries associated with the instrumentation used to calculate mass balances. These boundaries can illustrate the other types of losses that may register as a leak to a mass balance leak indicator. For example, an open drain line that is located within the boundaries depicted would create an imbalance in WMB and CMB calculations. This underscores the need for checklists and other tools when using mass balances as part of a leak detection program. A mill can also benefit from early indications of process issues such as open drain valves, chemical feed system leaks and pump failures.

![Figure 15. Boiler system WMB and boundary depiction.](image-url)
Figure 16. Boiler system CMB and boundary depiction.

Leak Indication Field Experience

In field installations, the monitoring and control system incorporating the leak indication software has responded to furnace leaks, other water and chemical losses and process changes such as flowmeter recalibration. Table II shows specific events that have occurred in field installations.
Table II. Field incidents from mills using leak indication software.

<table>
<thead>
<tr>
<th>Alarm Indication</th>
<th>Incident Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMB index alarm/WMB index increase</td>
<td>See Case History One - Recovery Boiler Tube Leak</td>
</tr>
<tr>
<td>WMB index alarm</td>
<td>Occurred during a known steam-venting incident. Alarm cleared after venting stopped. Incident provided confirmation of leak indicator response to a water (steam) loss.</td>
</tr>
<tr>
<td>CMB index alarm/WMB index increase</td>
<td>Open valve discovered on manual mud drum blowdown line in separate incidents. Incidents provided confirmation of leak indicator response, possible causes for mass imbalances, and the need for investigation.</td>
</tr>
<tr>
<td>WMB index alarm</td>
<td>Occurred when relief valve on economizer failed. Incident provided confirmation of leak indicator response to water loss.</td>
</tr>
<tr>
<td>CMB index alarms</td>
<td>Leaks in chemical systems found on two separate occasions. Incidents provided confirmation of leak indicator response, possible causes for mass imbalances, and the need for investigation.</td>
</tr>
<tr>
<td>CMB index alarm followed by WMB index alarm</td>
<td>Recovery Boiler Tube Leaks</td>
</tr>
<tr>
<td>WMB index alarm; no evidence of phosphate change</td>
<td>Superheater leak had been discovered via other means. System had been recently installed and was not connected to DCS. WMB index responded as expected; no effect on CMB index is expected for a superheater leak. Incident provided confirmation of leak indicator response.</td>
</tr>
<tr>
<td>Ongoing offset in CMB observed since start-up of installation. <em>WMB index not calculated at this site.</em></td>
<td>Leaking manual blowdown valve (from floor tube header) discovered. The observed offset had prompted the investigation. (Note: Generally, consistent offsets are not expected to have negative impact on indicator performance/sensitivity).</td>
</tr>
<tr>
<td>CMB index alarm reported to control room; <em>WMB index not calculated at this site.</em></td>
<td>Control room reported intermittent blowdowns were conducted (for level control issues). Confirms system response to unmeasured boiler water losses.</td>
</tr>
<tr>
<td>Persistent CMB index alarm after startup after mill outage; <em>WMB index not calculated at this site.</em></td>
<td>Investigated. Leaking/open valves on intermittent blowdown valves discovered.</td>
</tr>
<tr>
<td>Step change in WMB index signal observed.</td>
<td>Investigated. Calibrations on flowmeters reported to have been performed during recent short boiler outage.</td>
</tr>
<tr>
<td>No WMB index alarm/No CMB index alarm</td>
<td>Economizer leak found - water in ash hoppers was the indication. Sensitivity on WMB was low due to a flowmeter problem; Follow-up: empirical correction employed to system yielding 5-fold sensitivity improvement. No CMB index alarm is expected on an economizer leak.</td>
</tr>
<tr>
<td>CMB index alarm/WMB index alarm</td>
<td>Boiler silica excursion led to operators conducting manual blowdowns. Incident provided confirmation of leak indicator response to an unmeasured water loss.</td>
</tr>
</tbody>
</table>

**Case history 1: recovery boiler tube leak.** A mill in the Southeastern United States had an installation of the monitoring and control system including BPPC and leak indication. Following startup from a boiler outage, the system showed an unusually high WMB indication. Although the mass balance indexes were not initially at an alarm level, the chemical feed systems were checked, drain lines and manual blowdown lines were checked and walkdowns of the system were conducted. No further indications were found. The system was shut down for a short outage and then was brought back on-line.

After the re-start, both the WMB and CMB indexes were high, indicating the possibility of a leak, and a short time later the CMB alarmed. During a boiler walkdown, an operator detected a leak in a screen tube and an ESP was initiated.
Figure 17 shows the mass balance leak indication information. The WMB index and CMB index are shown and are expressed as a percent ranging from 0 to 100, with 50% as the alarm point. Both the higher than normal WMB index and the CMB alarm indicated the possibility of a leak. Neither index suggested that the leak grew during that time. Both indexes dropped to zero during times when the boiler was brought offline for short periods. The mill used the leak index as an effective indicator of something unusual. Further investigation revealed the leak and mill operators responded accordingly.

![Figure 17. WMB index and CMB index data for mill incident.](image)

Case history 2: loss of chemical feed and improperly seated drain valve detected. The leak detection system has the added advantage of alerting to undetected chemical loss and improperly seated drain valves. The system detected such events in multiple instances at several mills.

After startup from a mill outage, the leak indication system showed an unusually high CMB alarm, indicating an unexplained loss of boiler chemical occurred. The WMB index remained at the normal low level. This indicated that a leak occurred in a chemical pump or feed line (see Table 1). The boiler was walked down and no leak was found. Further investigation showed that damage during the outage had caused an undetected leak in the chemical feed line, which was repaired.

Another mill often has problems with a leaking emergency drain valve, and as expected, the leak indication system WMB and CMB indexes reliably indicate whether the valve is seated or whether they have to manually seat the valve.

Another mill was having an unusual control response to chemical addition changes and it was thought that the boiler was experiencing phosphate hideout. The WMB index remained at a constant low level, while the CMB index began to climb. This indicated a leak in the chemical addition system because the WMB indicated no water was lost
from the boiler. An investigation of the chemical feed lines found a leak in a stainless line that had been abraded by contact with the concrete floor. This leak was repaired and the boiler chemistry control returned to normal.

**Case history 3: recovery boiler tube leak.** A CMB index alarm on a recovery boiler prompted repeated, rigorous system walkdowns to find the cause of the alarm and the suspected leak. The CMB alarm and lower-than-expected boiler phosphate level persisted, prompting an adjustment to the chemical feed rate to increase the phosphate residual in the boiler and to maintain the target value.

During one of the walkdowns, an operator discovered a manual blowdown valve that was not fully closed and thus leaking. The valve was closed; however, that did not address the chemistry effects observed and the persistent alarm. No evidence of a furnace leak was found that could explain the persistent alarm signal. The WMB index also began to increase.

Eventually, an abrupt, large leak apparently occurred. Operators observed effects such as a wide separation of feedwater and steam and a rapid drop in the drum level. The WMB and CMB were both alarming.

An ESP was initiated. The leak indication data from the incident are shown in Figure 18. The WMB index and CMB index are shown and are expressed as a percent ranging from 0 to 100, with 50% as the alarm point.

![Figure 18. Leak indication system data for mill incident.](image)

Upon inspection, three leaks were discovered. It appeared that a very small roof tube leak had sprayed onto the wall tubes causing the larger leaks.

The experience validated the mass balance responses and its use as a tool for early leak detection and as part of an overall leak indication response plan. Unfortunately, no other indications were found during the apparent duration of the smaller leak and, therefore, it was not until the larger leak occurred that an ESP was initiated.

**CONCLUSION**

The capabilities of the new controller have eliminated many of the drawbacks associated with other systems. The saw-tooth chemistry results from the on-off feed of either low pH or high pH products has been replaced with improved control by using continuously modulated feed of both products at varying proportions. The problems of over and under shooting the phosphate and pH set point targets were corrected by using proprietary fuzzy logic that adapts to recovery boiler system lag times and performance characteristics. The controller is capable of managing
four separate systems simultaneously, can control up to 19 chemical feed pumps and will integrate with most mill distributed control systems.

Early detection of recovery boiler leaks continues to be an important objective for recovery operations personnel because of the serious consequences of a water leak into the recovery boiler furnace. Leak indication software has been developed that uses WMB and CMB around the waterside of the boiler. A combination of data filtering and software design along with personnel knowledge and input can maximize the effectiveness of using waterside balances as a tool for early detection of leaks and system upset conditions. The combination of precise, responsive control and leak indication provide improved reliability and safety for recovery boilers.

REFERENCES
Control System improves Reliability and Safety of Recovery boilers

Marshall Lewis
Outline

• Recovery Boiler Water Treatment
• Congruent Chemistry
• Chemistry Control Advancements
• Value of Improved Control
• Mass Balances For Leak Indication
• Experience from Leak Indication Installations
Recovery Boiler Trends

• Higher pressures
  ▪ Require higher quality feedwater

• Improved feedwater quality
  ▪ Demineralizers
  ▪ Original installation of RO
  ▪ Conversion of softeners to RO

• Demand for improved control

• Asset protection is paramount to mill operations
• Unique recovery boiler leak risks
Boiler Chemistry

• ASME, industry best practices indicate congruent chemistry for higher purity feedwater.
  
  Boilers 600 psi and greater

• Treatment emphasis moves from scale control to corrosion prevention
  
  Acid phosphate corrosion
  
  Caustic corrosion
Congruent phosphate chemistry

Potential for caustic attack

Potential for acid attack

Na:PO4 = 2.7
Na:PO4 = 2.2
Congruent Phosphate Chemistry

- Best Practice for boilers with high purity feedwater

- Control can be challenging with variable quality feed water

- “Time in the Box” (% TIB) is a metric adopted by many mills/corporations

- The need for improved chemistry control was evident
  - What is considered industry best practice?
Evolution of control programs

Phosphate - PPM

Manual
Automation c 2000
Automation c 2019
Automated monitoring and control system
Features leading to better control

Proprietary BPPC Software

- Fuzzy logic
- System learning to improve control
- Integrated pump control and feed verification
- Feedback on pH and phosphate

2 - chemical approach

- 1 high pH
- 1 low pH

\{ Usually with same level of phosphate and dispersant \}
In the BOX...
In the box vs IN control
In the box vs In control

By tightening control...

✓ Investment protection is improved
✓ Upset events are fewer and less severe
✓ Costs are improved
Case history 1

Manual

Automated

Past

Current
Case history 2

First Generation Automation

Current Control Capability
Case history 3 - previous manual control

- Free Caustic Region
- Captive Alkalinity Region

Chart showing pH vs. ppm Phosphate as PO4 with data points indicating the free caustic and captive alkalinity regions.
Case history 3 - current automated control

- Free Caustic Region
- Captive Alkalinity Region

Graph showing pH and ppm Phosphate as PO₄ relationship.
Swing power boiler control improved

- Before Automation: 74%
- After Automation: 97%
Provides Immediate response to upsets
What is the value of good control?

• Protect Investment
  ✓ Minimize corrosion threat
  ✓ Greater margin of protection with centered control
  ✓ Optimize boiler deposit control
  ✓ Instant response to upsets

• Reduce costs
  ✓ Reduce overfeed; potentially lower set point

• Prevent Upsets from variable chemical delivery
  ✓ Continuous chemical feed verification

• What are the costs of poor control?
Leak indication capability

• Excellent boiler chemistry control minimizes risk, lowers costs
• Additional capability for early leak indication

• Challenges for Leak Detection
  ▪ Sensitivity
  ▪ Speed of detection
  ▪ Low false alarm rate
  ▪ Location of leak

• Employed as a tool to be used with other mill procedures for responding to suspected leaks.
Challenges met with unique software

• **Sensitivity**
  - Adjustable for each system needs
  - Excellent data on chemical delivery

• **Speed of Detection**
  - Multiple statistical measures improve response
  - Rapidly detects process change

• **Low False Alarm Rate**
  - Software differentiates between noise and process change

• **Location of Leak**
  - Dual mass balances provide indication of source
Leak Alert Leak indication system
Same hardware as control system described.

Water Mass Balance

Chemical Mass Balance
Water Mass Balance

- Reliefs
- Vents
- Superheated Steam
- Attemperation Water
- Superheaters
- Sootblower Steam
- Boiler Feedwater
- Economizer
- Sweetwater condenser
- Blowdown
- Drains
- Manual Blowdown
Water Mass Balance

- Detects leak from any part of the boiler system
  - Cycled boiler water
  - Steam
  - Superheater
  - Economizer
  - Boiler drains
Chemical Mass Balance
Chemical mass balance

- Detects leaks from cycled boiler water only
  - Leaking drain valves
  - Boiler tube leak
  - Loss of chemical feed or chemical leak
Aids in locating source of leak

<table>
<thead>
<tr>
<th>WMB Indication</th>
<th>CMB Indication</th>
<th>Potential Conclusion*</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Leak</td>
<td>No Leak</td>
<td>No Leak</td>
</tr>
<tr>
<td>Leak</td>
<td>Leak</td>
<td>Leak in cycled part of boiler</td>
</tr>
<tr>
<td>Leak</td>
<td>No Leak</td>
<td>Leak in economizer or superheater</td>
</tr>
</tbody>
</table>
| No Leak        | Leak           | Chemical leak  
Leak in cycled part of boiler |
Recovery Boiler leak incident

- CMB Index increase
- WMB index alarming/fluctuating
- Variation - may not be related to leaks
- ESP
System gave early warning of leak

- Chemical index increased
- Mill walked down boiler – no leak observed
- Water index increased
- Chemical index alarmed, water balance alarmed
- Mill detected leak, ESP boiler

- Small leak subsequently cut two other tubes, increasing leak size
Examples of System Response

<table>
<thead>
<tr>
<th>Mill</th>
<th>Incident</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>WMB index alarm</td>
<td>Steam-venting incident.</td>
</tr>
<tr>
<td></td>
<td>CMB index alarm / WMB index increase</td>
<td>Open valve on manual blowdown line</td>
</tr>
<tr>
<td></td>
<td>CMB index alarm / WMB index increase</td>
<td>Screen tube leak. Leak confirmed by operator prior to ESP.</td>
</tr>
<tr>
<td></td>
<td>CMB index alarms</td>
<td>Leaks in chemical system <em>(found on two separate occasions.)</em></td>
</tr>
<tr>
<td>2</td>
<td>WMB index alarm; no evidence of phosphate change</td>
<td>Superheater leak</td>
</tr>
<tr>
<td>3</td>
<td>Step change in WMB index observed.</td>
<td>Calibrations done on flowmeters.</td>
</tr>
<tr>
<td>4</td>
<td>CMB index alarm / WMB index alarm</td>
<td>Leaking drain valve after outage</td>
</tr>
</tbody>
</table>
New Monitoring and control system

• Excellent boiler chemistry control minimizes risk
• Provides process centered control
• Mass balances for leak indication
  ✓ Overcoming noise is the key
  ✓ Enhanced sensitivity through
    • Excellent chemistry control
    • Software design
  ✓ Low false alarm rate
  ✓ Adjustable sensitivity
  ✓ Water losses and other process changes can be detected.
Boiler chemistry control and leak indication

Questions?