PEER REVIEWED

Effect of char bed temperature and temperature distribution on fume generation in a kraft recovery boiler

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ABSTRACT

A systematic study on a commercial recovery boiler showed that the amount of internal dust recycle that consisted mostly of fume increased with an increase in bed temperature. At the same average bed temperature, the amount of internal dust recycle was twice as much when bed temperatures had poor distribution as the amount when the bed had a uniform temperature distribution. A significant increase in boiler throughput results by minimizing the char bed temperature distribution range to reduce the internal recycle.

Application:

A system to determine char bed temperatures and temperature distribution with on-line measurement of internal dust recycle can aid in recovery boiler control.

CALCULATIONS USING VARIOUS thermodynamic and kinetic models have shown that char bed temperature is the main parameter influencing the quantity and composition of fume in kraft recovery boilers *(1–4)*. Due to the difficulty in measuring char bed temperatures and large temperature fluctuations in the lower furnace, the effect of char bed temperature on fume quantity is not clear for an operating recovery boiler. Because of the dynamic nature of the bed that results from uneven spray of black liquor and the turbulence of combustion air, the size and shape of the bed constantly changes.The distribution of the char bed is never uniform. Bed imaging cameras installed in boilers often show a large contrast in the color of bed pictures. Bright colors indicate high temperatures or hot spots, and dark colors indicate low temperatures or cold spots in the bed.

A nonuniform bed temperature distribution should have a great impact on fume generation and fume chemistry. Hot spots occur where oxygen effectively transfers to the bed surface to provide intense combustion. These locations are where fume generates in a large quantity and where fume has a high carbonate content because of high temperatures and oxidative fuming reactions. The marked increase in fume quantity and carbonate content with temperature means that a uniformly distributed temperature bed would produce less fume. Profile I of **Fig. 1** shows this conceptually. Profile II in the figure shows a lower carbonate content than a poorly distributed temperature bed that has the same average bed temperature.

This work was part of the Control of Recovery Boiler Fireside Deposits and Corrosion Research Program at the University of Toronto aimed at developing a fume chemistry model to predict the composition of fume at various locations in a boiler as a function of black liquor chemistry and boiler operating conditions.The work involved laboratory and field studies to investigate the effect of char bed temperature and temperature distribution on fume generation in recovery boilers. The paper discusses the results of the field study conducted at a commercial recovery boiler.

The recovery boiler is a 1982 low odor boiler designed to burn 1,700 tons/day (3.7 million lb/day) of black liquor dry solids and produce 270 tons/h (600 Klb/h) steam rated at 64 bars (900 psig) and 420°C (790°F).

TEST PROCEDURE

Bed temperature monitoring used a commercially available system having two infrared bed imaging cameras. **Figure 2** shows a schematic of the camea postion. Each camera had a wide-angle lens, a through-the-lens pyrometer (TLP), an input/output interface module, and a computer processor. The monitor shows five temperature measurement regions. Four of these cover a fixed area.The fifth region is movable and can zoom in and out of various areas of the bed. During this study, we moved one fixed area box to cover the same part of the bed as the TLP.The other three had uniform spacing over the remainder of the bed.

Camera locations were at opposite corners of the boiler—one at the front-right wall corner and the other at the rear-left wall corner.The cameras tilted down at a 5° angle. For each camera, approximately two-thirds of the image covered the char bed, and one-third covered the furnace wall.

Calibration of the monitor

Before the study, the temperature recorded by the monitor was calibrated against the temperature measured with a temperature probe.The probe was a thermocouple embedded in a 3.7 m long, closed-end stainless steel tube. A “detection” bar welded at the tip of the stainless steel tube made determination whether the tip touched the bed surface easy as **Fig. 3** shows.The probe was inserted slowly into the boiler through an inspection door. The detection bar was partially immersed in the char bed and held there until the recorded temperature stabilized. The monitor gave a simultaneous reading by moving the movable box on the monitor to cover the tip of the probe.

Figure 4 compares the temperature measurements by the probe with the values provided by the monitor for one camera. The monitor temperature readings compared favorably with the thermocouple readings at low temperatures. Above 1075°C, the deviation of readings between the temperature probe and the monitor increased. This was probably due to the camera "seeing" only the haze and flame in front of the char surface at high temperatures. The monitor therefore recorded a gas temperature rather than a bed temperature.

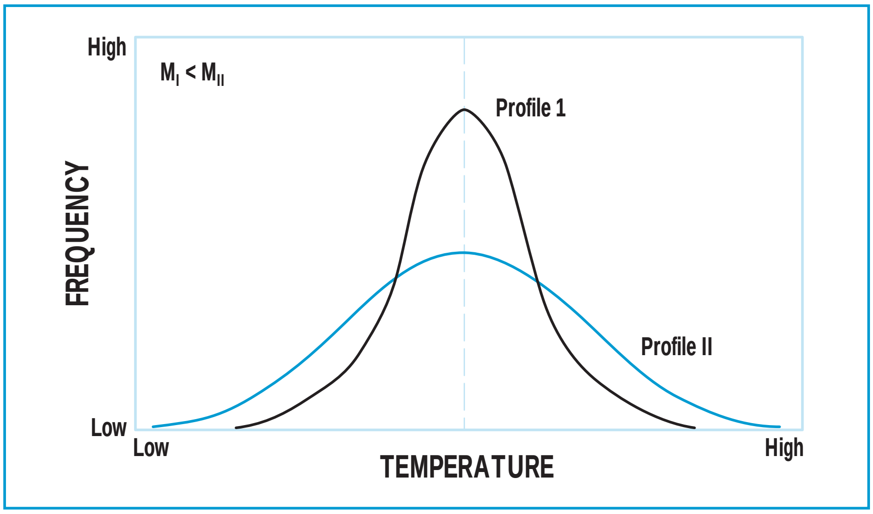
Char bed temperatures

Significant confusion has existed regarding what temperature to use as a char bed temperature. Should it be the temperature of the bed surface, the molten smelt pool temperature, or the temperature of the combustion gas immediately above the bed surface? To examine the typical temperature variation through the char bed in this study, we determined temperatures at different char bed depths using a long temperature probe. The probe was inserted into the boiler until it hit the frozen smelt layer and then slowly withdrawn from the frozen surface in 5-cm increments. At each increment, temperatures were measured after allowing time for stabilization.

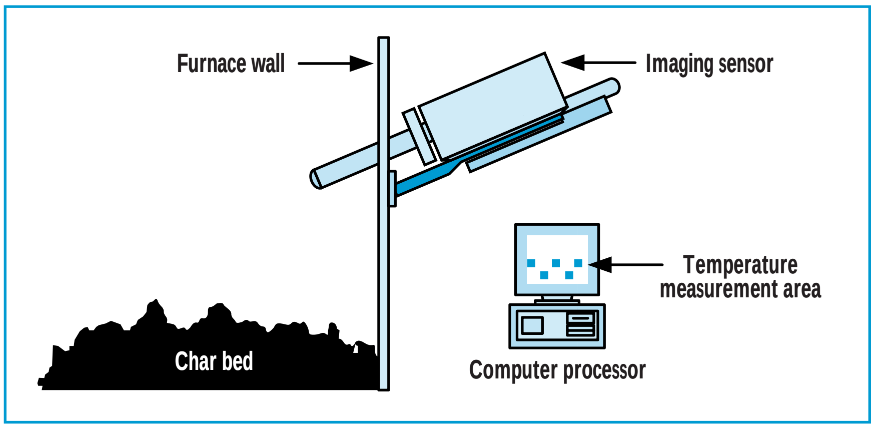
Figure 5 shows a typical temperature profile through the char bed. At point B—the deepest point in the bed at the surface of the frozen smelt layer, the temperature was about 750°C. It remained constant until the tip of the probe was about 15 cm from the surface of the frozen smelt layer at point C. From this point, the temperature increased from 750°C to about 1080°C at point D as the probe moved away from the furnace floor. Temperature remained constant thereafter. Similar temperature profiles also resulted at different times during the study as **Fig. 6** shows. In all the profiles, the temperature from points B to C was almost constant, increased from points C to D, and remained almost constant thereafter.

The temperature profile through a bed can be interpreted by reference to **Fig. 7**. Point A represents the crown of a floor tube, point B represents the top of the frozen smelt layer, point C is the top of the molten smelt layer, and point D is the surface of the char bed. The marked increase in temperature between points A and B is due to the low thermal conductivity of the frozen smelt. The constant temperature in the region between points B and C reflects the high effective thermal conductivity of the molten and flowing smelt. The increase in temperature in the region between points C and D is due to the combustion of the char bed. The constant temperature from point D onward is because the thermocouple is in the turbulent gas phase regime.

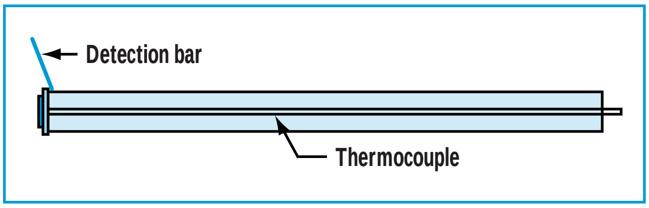
These results suggest that the temperature at point D should be the char bed temperature. Since no significant difference in temperature between point D and the gas phase directly above the bed exists, the temperature recorded by the monitor may reasonably represent the temperature of the char bed.



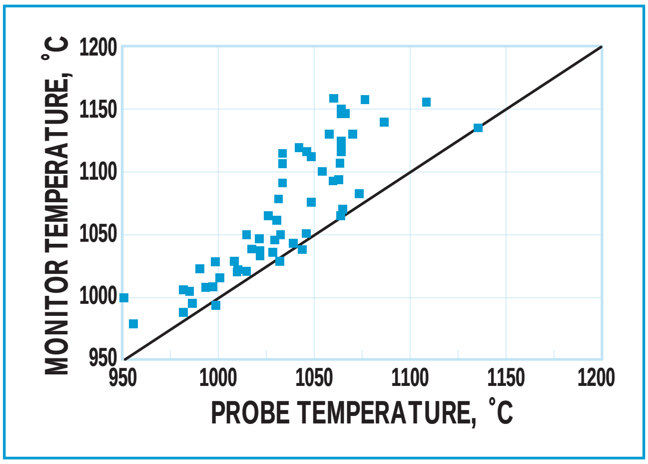
1. Char bed temperature profiles vs. fume generation where M_I is the mass of fume generated from profile I and M_{II} is the mass of fume generated from profile II



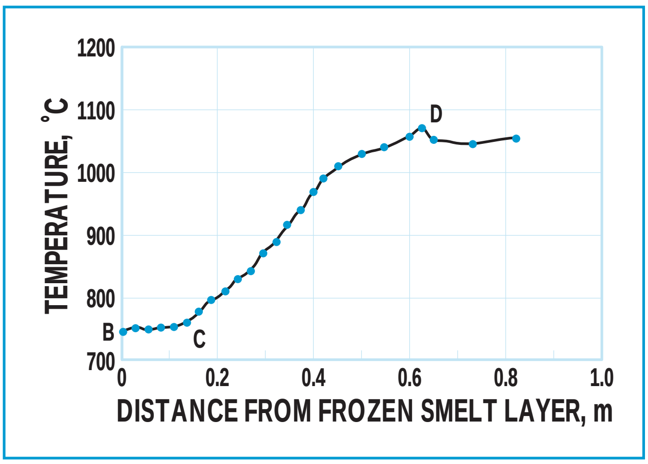
2. Schematic of the monitor used in this study



3. Schematic of the thermal probe



4. Temperature calibration results for one camera



5. Typical temperature profile through the char bed

BED TEMPERATURES VS. INTERNAL RECYCLE

Effect of bed temperature

Since fume is most of the internal dust recycle, we used the amount of internal recycle as a measure of the actual amount of fume generated. Performing a mass balance calculation around the electrostatic precipitator mix tank gave the internal recycle of **Fig. 8**. An on-line flow meter placed before the sluiced liquor line going to the precipitator measures the flow rate of the liquor going to the electrostatic precipitator mixing tank. A manual solids test twice every hour gave the solids content of the liquor. On-line meters provided the as-fired liquor flow and solids content. The solids content of the as-fired liquor was cross-checked with manual measurements at two hour intervals.

While the monitor provides a reasonable estimate of the bed temperature distribution, the system as provided could give the necessary temperature data. Examining an image from each camera at 30-min intervals provided the detailed bed temperature and temperature distribution data. The image was divided into 76,800 cells (a 240 x 320 grid). Each cell represents a spot in the boiler. Approximately 50,000 cells r-mained after removing the portions of the image that showed the boiler wall. The temperature of each cell was calculated using an algorithm. Averaging the temperature of all the cells provide the "average bed temperature."

Figure 9 shows the internal recycle plotted against the average bed temperature for one camera from May to August 1996. No apparent trend between the amount of the internal recycle or fume and the average bed temperature existed. This is not surprising, since the data shows the effect of the char bed temperature and temperature distribution. The second camera gave similar results.

To negate the variation in the temperature distribution profiles at any average temperature, **Fig. 10** shows a plot of the internal recycle against the "theoretical" amount of fume generated. The following procedure gave the "theoretical" amount of fume. The amount of fume generated in each of the approximately 50,000 cells was calculated using the chemical equilibrium correlation of **Fig. 11** established previously for this boiler *(4)*. The total "theoretical" amount of fume generated is then the sum of fume generated from all cells at a particular time.

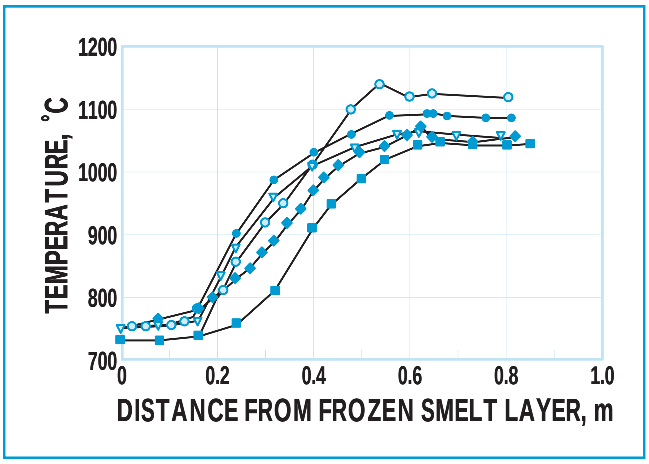
The results in Fig. 10 confirm that temperature is an important parameter influencing the fume quantity. This relationship is only valid if the correlation shown in Fig. 11 is correct.

Effect of temperature distribution

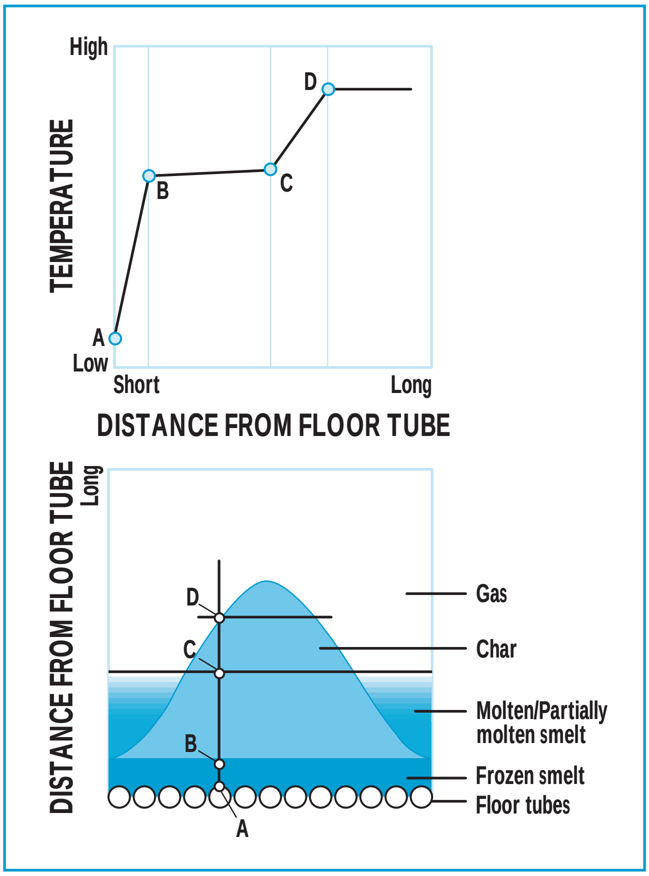
Figure 12 shows the temperature distribution profiles of the char bed at two different times on the same day with the boiler operating at the normal firing load. While the profiles were different—profile A has a good distribution, and profile B is a poor distribution, the average temperatures were the same at 1105°C.

Figure 13 shows the amounts of internal recycle during these times plotted against the average bed temperature with those at different average bed temperatures. This clearly suggests that the amount of internal recycle or fume generated is a strong function of the char bed temperature. At the same average bed temperature, the difference in temperature distribution profile has a strong effect on the amount of internal dust recycle.

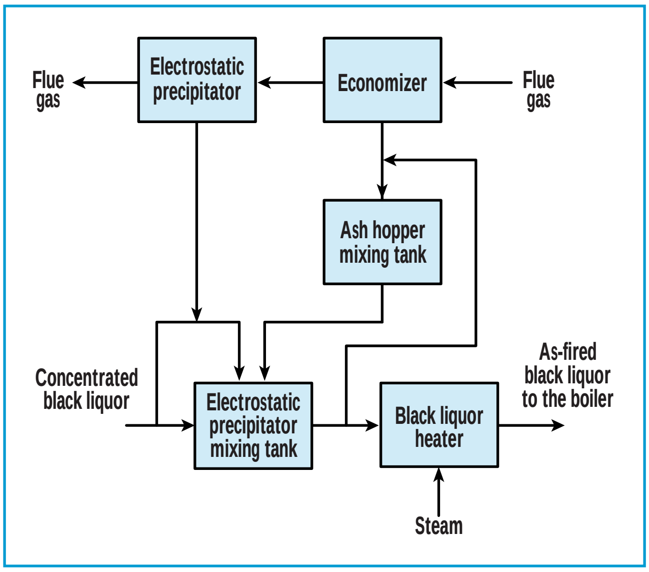
Both profiles also illustrate the effect of char bed temperature where the internal recycle increases with bed temperature for a given distribution. This reiterates the conclusion drawn earlier that temperature is an important parameter influencing fume quantity. Note that the



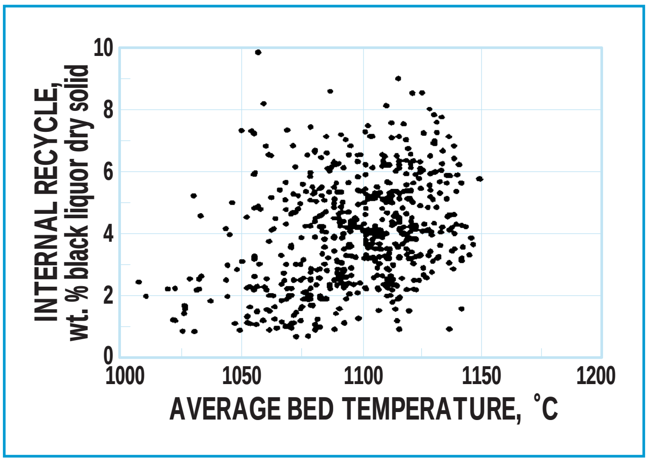
6. Temperature profiles through the char bed at different times



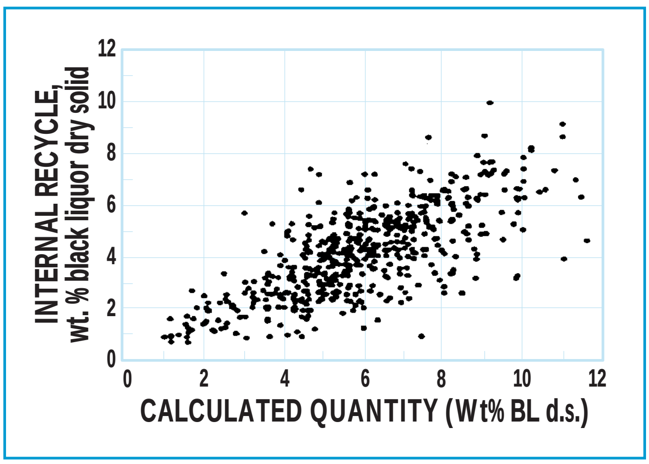
7. Schematic temperature profile in the lower furnace



8. Schematic of the boiler dust handling system



9. Average bed temperature vs. internal recycle

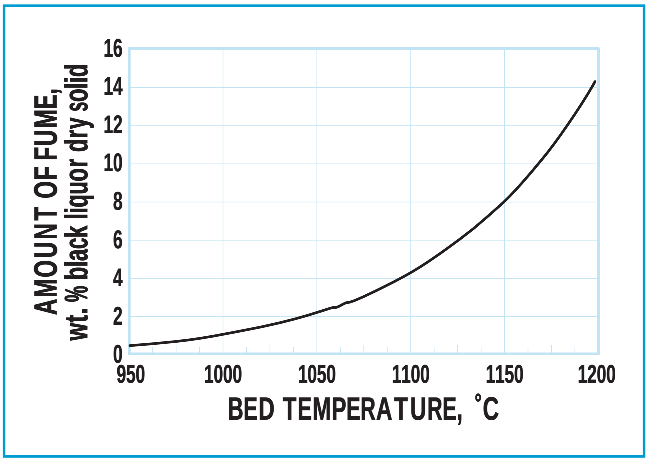


10. Correlation between actual and predicted quantity of fume generated

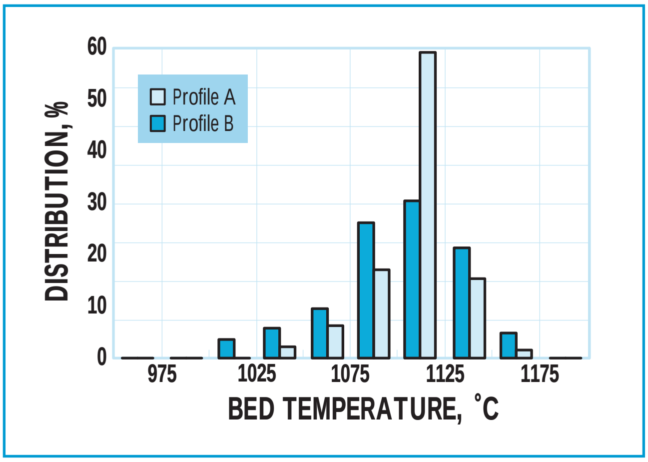
conclusions drawn from Fig. 13 only used the raw data and are independent of the assumption that the relationship shown in Fig. 11 is valid.

IMPLICATIONS

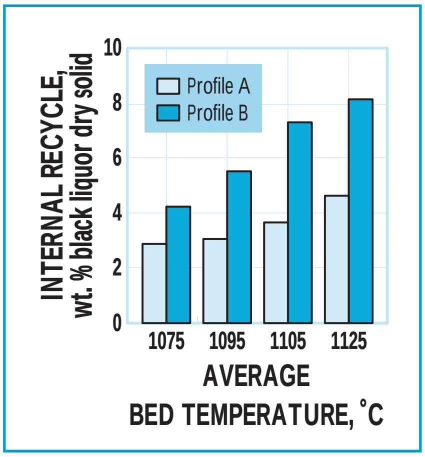
This study clearly shows that the amount of the internal recycle that consists mostly of fume increases with an increase in bed temperature. Even at the same average bed temperature, the amount of internal dust recycle generated from a char bed with a poor distribution is



11. Predicted amount of fume as a function of bed temperature (4)



12. Two distribution profiles with the same average bed temperature



13. Internal recycle as a function of average bed temperature

twice as much as the amount of internal dust recycle as for char beds with a good or uniform temperature distribution.

The internal recycle is essentially a "dead load" circulating within the boiler. Reducing it by 3%–4% by weight of the total as-fired black liquor dry solids through improvement in bed stability and careful air flow control to ensure uniform temperature distribution can have significant effects on boiler operation.

SUMMARY

A systematic study examined the effect of the char bed temperature and temperature distribution on fume generation in a commercial recovery boiler. The results showed the following:

- The amount of the internal dust recycle that consists mostly of fume increases with an increase in bed temperature. At the same average bed temperature, a char bed with a poor temperature distribution generates twice as much internal dust recycle as a char bed with a good temperature distribution.
- An increase in boiler throughput may result from minimizing variations in the char bed temperature.
- A bed temperature measurement system such as the monitor described equipped with bed imaging cameras with temperature sensors can be modified for use in determining char bed temperatures and temperature distribution. Such a modified system with an on-line measurement of the amount of internal dust recycle can be a useful tool to aid in recovery boiler control. TJ

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Received for review June15, 1997.
Accepted Jan. 21, 1998.

Presented at the TAPPI 1997 Engineering Papermakers Conference.

Acknowledgments: This work is part of a research program on Control of Recovery Boiler Fireside Deposits and Corrosion jointly supported by ABB Power Generation Segment, Ahlstrom Corporation, Aracruz Celulose S.A., Babcock & Wilcox Company, Clyde-Bergemann USA, Boise Cascade Corporation, Champion International Corporation, Diamond Power Speciality Company, E.B. Eddy Forest Products Ltd., Georgia Pacific Corporation, International Paper Company, Irving Pulp & Paper Limited, James River Corporation, Kvaerner Pulping Technologies, Potlach Corporation, Union Camp Corporation, Westvaco Corporation, Weyerhaeuser Company, Willamette Industries Inc., and the Natural Sciences and Engineering Research Council of Canada through its CRD program.

The authors also acknowledge the technical support provided by Dr. Tom Moskal and Mr. John Comer of Diamond Power Speciality Company.

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