In the recovery boiler, the inorganic elements in the incoming black liquor are converted to a mixture of molten salts (primarily sodium carbonate and sulfide). This molten salt mixture, called smelt, accumulates on the hearth, along with a char bed, and drains from the recovery boiler into a tank, where it is dissolved in water to form green liquor for subsequent processing. The smelt flows out from the furnace through water-cooled spouts, as schematically shown in Fig. 1. Steam shatter jets are used to break up the smelt stream to provide for safe, effective dissolution. Agitators are used within the tank to facilitate dissolution. The tank is provided with a vent system to help remove the steam and other gases released during dissolution.

Smelt dissolution is a potentially violent process. The large difference in temperature between the smelt and green liquor can lead to explosively rapid steam generation. Severe cases of violent smelt dissolution can result in so-called dissolving tank explosions, which are a risk to personnel and can damage the equipment. Excessive smelt flow, often called heavy runoff, can overwhelm the capability of the shatter jets and tank to provide safe dissolution. Variability in the rate of smelt flow into the dissolving tank is inherent in the process since there is no direct control of the smelt flow rate out.
of the recovery boiler. This not only has safety implications, but also can have a significant influence on green liquor process control and causticizing operations.

Violent smelt dissolution is a danger to personnel and may also damage equipment. The dissolving tank area is noisy and many operators are not comfortable working around the spouts. There is a danger of burns from smelt spatter or green liquor ejection. During periods of heavy runoff, the tank venting system can be overwhelmed, resulting in fume, mist, and total reduced sulfur (TRS) in the area around the tank. Loud bangs may be heard and the building may tremble. In the extreme, there may be damage to the tank or surroundings and the incident is classified as a dissolving tank explosion.

An analysis of 27 dissolving tank explosions reported to the Black Liquor Recovery Boiler Advisory Committee (BLRBAC) between 1973 and 2005 was carried out by Lien and DeMartini [1] and reported to the American Forest Products & Paper Association (AF&PA) Recovery Boiler Committee in 2008. They found that 24 of the 27 incidents were related to heavy smelt runoff, with 19 of the 24 occurring on recovery from a boiler trip or chill-and-blow. Five dissolving tank explosions have been added to the BLRBAC list since their analysis was done, and all five involve heavy smelt runoff [2,3].

Figure 2 summarizes the relevant geometry for the 29 dissolving tank explosions caused by heavy runoff on the BLRBAC list. Clearly, the sloped floor units are more vulnerable to dissolving tank explosions. A paper by MacCallum presented at BLRBAC [4] also identified this vulnerability.

While heavy runoff is an important factor in dissolving tank violence, it is not the only one. Other factors such as smelt properties (as reflected in viscosity and freezing temperature), degree of shattering of the smelt stream, and conditions in the dissolving tank also play a role [5,6].

This paper deals only with the issues directly connected to excessive smelt flow rates (heavy runoff) and not dissolving tank violence. Specific items that will be covered include: 1) the general mill experience with heavy runoff, 2) the governing physics of smelt flow to the spout opening and down the spout trough, 3) application of these principles to understanding the role of furnace bottom geometry in runoff events, and 4) the effects of smelt properties on smelt flow and drainage problems.

**MILL EXPERIENCE WITH HEAVY SMELT RUNOFF**

**AF&PA survey**

In a recent survey conducted by AF&PA [2,3], 80% of the respondents indicated having experienced heavy runoff. Opening plugged smelt spouts after a chill-and-blow or furnace trip was the predominant cause of the heavy smelt runoff events that led to reported dissolving tank explosions. There are also other causes for heavy smelt runoff, especially for those cases leading to lesser violence. These include not only opening plugged spouts, but also burning down a large bed, liquor chemistry issues (especially sulfidity), startup with a bed or smelt in the unit, improper firing practices, misuse of auxiliary fuel, and bed collapse. It is evident that fuel and air changes are implicated in many heavy runoff situations. The resultant changes in heat input can increase local smelt production and lead to smelt flow surges.

There are many steps mills can take to reduce the likelihood of heavy runoff. The biggest item is managing and controlling the combustion process, i.e., following correct firing procedures with respect to liquor and lower furnace air. Controlling the size and stability of the char bed is considered an important factor. Keeping spouts open to avoid a smelt pool buildup is obviously important. A number of mills mentioned controlling liquor chemistry (sulfidity) as a factor in reducing the extent of heavy runoff.

The most common response to a heavy runoff event is to reduce firing rates, especially black liquor, since burning black liquor produces more smelt. Auxiliary fuel use is often continued and may be added near spouts to help keep them open. Air flow in the lower furnace is commonly adjusted to control the rate of bed burn down. Another common response to heavy runoff is to activate backup shattering capability or increase shatter jet pressure. Some mills use spout plugs or flow restrictors inserted into the opening to try to reduce the smelt flow rate. This has had mixed success at best. Extra attention is also given to dissolving tank density and level control.

Several field studies were also conducted at the University of Toronto over the past few years. These mainly involved analysis and interpretation of recovery boiler and dissolving tank operating data collected from several kraft mills.

**Experience at mill A**

Mill A had a decanting bottom boiler that experienced severe smelt runoff problems during the third week of August 2011. The boiler had four smelt spouts. The runoff problems were clearly indicated by the abrupt change in exit temperature of the spout cooling water. Since all four spouts responded si-
multaneously to each runoff event in a similar manner, for clarity purposes only the data for spout 3 are shown here.

As shown in Fig. 3, before August 17, the smelt flow condition was relatively calm, and the cooling water exit temperature was around 176°F (80°C) with no temperature surges. Between August 17 and 22, numerous instances of heavy runoff occurred, causing the cooling water exit temperature to exceed 190°F (88°C) at times. Since black liquor flow was essentially constant during most of this period, changes in black liquor firing rate were not the cause of the surges, although a reduction in firing rate at the end of the period may have helped overcome the problem.

In order to determine the possible cause(s) of smelt runoff and the effect of runoff on recovery boiler and dissolving tank operations, the period between the dotted lines in Fig. 3 is examined in greater detail. During this 28 hour period, no runoff was registered in the first 13 hours, six heavy runoffs consecutively occurred within the next 10 h, and none occurred in the last 5 h. A total of 55 operating variables were investigated, including black liquor flow rate, solids, temperature, pressure, air flow rates, distributions, temperature and pressure, flue gas temperatures, TRS emissions, dissolving tank liquor level, density, temperature, etc. Results for key variables are shown in Fig. 4.

The smelt flow surges triggered excursions in the dissolving tank level, which could persist for some time after the surge ended (Fig. 4a). This behavior is presumably influenced by the liquor level and density control systems. Heavy runoff also had a clear effect on dissolving tank liquor temperature, as shown in Fig. 4b. The liquor temperature decreased prior to a smelt flow surge and increased after the surge. This consistent liquor temperature swing indirectly indicates that smelt first accumulates inside the boiler and then releases, causing a runoff event.

Smelt flow surges also always triggered an immediate rise in green liquor density (Fig. 4c). The density control system then responded to bring the density back down. As a result, the density rise at the surge is always more rapid than the decline after the surge. The excess O₂ in the flue gas always decreased during smelt flow surges, as seen in Fig. 4d. A possible explanation for this is that the runoff might have been caused by a sudden collapse of the char bed, exposing more char surface to the combustion air. As a result, more air is consumed, resulting in low excess O₂. Figure 4e shows the correlation between smelt flow surges and TRS. In this case, while the correlation between smelt flow surges and TRS was not as clear as the correlation between smelt flow surges and excess O₂, it appears that there is an increase in TRS emissions during the smelt runoff. It is likely that the TRS spikes are caused by incomplete combustion (low excess O₂) and perhaps dissolving tank vent gases; however, without more information on the system at mill A, this is uncertain. Figure 4f shows a consistent drop in floor temperatures at the time surges occur, suggesting a corresponding surge in colder feedwater into the floor tubes. The reasons for this are not clear. Floor temperature measurements normally reflect the saturation temperature corresponding to the boiler pressure.

**Experience at mill B**

Mill B had a sloped floor recovery boiler that occasionally had heavy smelt runoff problems, even at a constant black liquor flow rate (Fig. 5a). In this case, an abrupt increase in dissolving tank liquor level (e.g., the peak at around 900 min mark) was used as an indicator of a smelt flow surge. The weak wash flow rate (Fig. 5b), the green liquor total titratable alkali (TTA) (Fig. 5c), and green liquor temperature (Fig. 5d) were all found to increase almost simultaneously with one another during the smelt flow surge. While variable smelt flow is almost certainly the driver, the data are hard to interpret since it is difficult to remove the effects of the dissolving tank control system response from other effects.
Smelt flow rates

The average smelt flow rate from the recovery boiler can be estimated at about 45% of the virgin black liquor solids firing rate. The average flow per spout depends on the number of spouts in use, and is typically on the order of one liter per second (1 L/s). This is a useful benchmark when looking at the extent of heavy runoff.

An estimate of typical smelt flow rates for 63 different boilers was made using the boiler solids rating from the BLRBAC Recovery Boilers in Service List and data on the number of spouts from a recent AF&PA dissolving tank survey. Smelt flow rates ranged from 0.44 to 1.0 L/sec with an average of 0.96 L/sec and a median of 0.95 L/sec. In general the lowest smelt flow rates were on small recovery units, and apparently reflected a desire to have a minimum of two spouts on the unit. The other units with relatively low smelt flow rates had two dissolving tanks and smelt drainage from two sides. It is possible that some of these units operated with some spouts...
deliberately plugged in order to increase the smelt flow out of the operating spouts. Recovery boilers with more spouts are more tolerant of individual spout plugging and can continue to operate at higher black liquor firing rates than those with fewer spouts. Operating practices when spouts plug reflect this tendency.

**Measurement of smelt flow rates**

While considerable anecdotal information on heavy smelt runoff is available, it is more difficult to find quantitative data. Estimates of smelt flow rates through individual spouts can be made by comparing the spout cooling water temperature rise with that which occurs during normal, steady operation. The principle is illustrated in Fig. 6 using the operating data from mill A. As the smelt flow increases, the smelt level on the trough rises, increasing the smelt-trough contact surface area. This, in turn, causes the cooling water discharge temperature to rise. If the water flow rate inside the trough remains constant, the relative temperature rise can be taken as a measure of smelt flow out the spout. As shown in the figure, under normal operation, the cooling water temperature increased from 76°C at the spout inlet to 80°C at the spout exit, a 4°C
increase. However, under heavy runoff conditions, the increase was 12°C (from 76°C to 88°C), triple that under normal operation. This implies that under heavy runoff conditions, the running smelt would cover at least 3 times more surface area on the trough than normal. From the trough geometry, this increase in smelt-trough contact surface area can be translated into a smelt flow rate at least 5 times higher than average.

Another method of estimating smelt flow rates is with a dissolving tank mass balance, based on green liquor flow rate and TTA. The method, however, will determine the total smelt flow into the tank through all of the spouts, not the smelt flow through individual spouts. It will also be somewhat time-averaged because of the residence time of green liquor in the dissolving tank. Nevertheless, it can provide valuable information on the variations in smelt flow. An example of such data is given in Fig. 7 for a small recovery boiler during normal operation [7]. The smelt flow rate averaged 22 tons/h over a 3.5 h period, but varied widely from 8 tons/h (less than half) to 48 tons/h (more than double the average flow rate).

Experience at a mill where a smelt pump was used to remove smelt from below the spout opening in a decanting bottom unit during a normal maintenance outage showed it is possible to operate at high smelt flow rates without problems with smelt dissolution. It was estimated that the smelt flow through the single spout being used was about 5 times the normal smelt flow out this spout (Fig. 8). The smelt was highly fluid, with low viscosity, and the shatter jets were properly adjusted and operating. The smelt being pumped out was easily handled in the dissolving tank, without violence, and the dissolution operation proceeded with very little noise. This example clearly showed that high smelt flow rates, by themselves, are not the primary cause of dissolving tank violence.

**SMELT FLOW CONSIDERATIONS**

There are two basic requirements for heavy smelt runoff to occur. The first is the accumulation of molten smelt in the unit at a level above the bottom of the spout trough. The accumulation may be brought about by plugged spouts, dams near the spout openings, or in craters in the char bed. Viscous jelly-roll smelt may also lead to molten smelt accumulation by slowing down the rate of smelt discharge. The second requirement is the sudden release of the accumulated molten smelt by reestablishment of a flow path to and out of the spouts. This could be triggered by cleaning a plugged spout, bed collapse, bed burn down, falling deposits, etc.

The duration of a heavy runoff event depends on the amount of molten smelt accumulation and the rate of smelt flow out the spout(s). As shown in Figs. 4 and 5, each smelt runoff event lasts 30 min or less, but its effects may last for more than 1 h (considerably more if the tank or associated equipment is damaged). Limited data on the duration of the heavy runoff in the dissolving tank explosion incidents indicated the heavy runoff lasted between 5 min and 20 min. Heavy runoff is self-limiting, because the heavy runoff reduces the amount of smelt available to run out (of the spout) and lowers the hydrostatic head driving the flow.

The smelt flow rate at the peak of a runoff is typically 3 to 5 times the normal flow rate and is much higher than that in severe runoff. There were incidents reported where the heavy smelt runoff filled and overflowed the sides of the spouts and at least one where the smelt shot out the spout opening near-horizontally above the trough.

The relationship between smelt volume flow, $V$, average velocity, $U$, and spout cross-sectional area occupied by smelt, $A$, is $V = U \times A$. The smelt velocity and cross-sectional area adjust themselves to match the volume flow entering the spout [5]. The steeper the spout angle, the higher the smelt velocity and so the smaller the cross-section of the spout occupied by smelt. Similarly, the more viscous the smelt, the slower the smelt velocity and the higher the cross-section of the spout occupied by smelt. The net result is that conditions in the spout trough do not control the rate at which smelt leaves the unit. Rather, the smelt flow rate out of any given spout is controlled by conditions on the furnace side of the spout opening.

Smelt flow is gravity driven. However, the conditions on the furnace side of the spout opening are too complicated to develop any direct, quantitative relation between the hydro-
static head of the molten smelt pool in the furnace and the smelt flow rate. With a low viscosity smelt, the viscous resistance is relatively low, and thus the smelt velocity will be more closely determined by the conversion of potential energy (from the hydrostatic head) into kinetic energy. In this case, the smelt velocity out the spout opening will tend to vary as the square root of the head. With a more viscous smelt, the relation will be closer to linear. For jelly-roll smelt, which is viscoelastic, the relationship is even more complex. In general, however, the higher the height of the smelt pool in the furnace, the greater smelt flow rate will be.

Heavy smelt runs typically develop rapidly when they occur and then taper off more slowly. Hot flowing smelt can melt frozen smelt or deposits that are restricting flow paths and rapidly widen the path to the spouts, bringing more accumulated molten smelt into play. In severe cases involving plugged spouts, operators often have to leave the area around the spouts as soon as they are opened. An illustrative diagram of a smelt runoff event is shown in Fig. 9. The actual smelt flow peak at point P may be broader than that shown in the illustration and the flow decay may be more exponentially shaped as opposed to linear, but the general behavior is represented reasonably well. The area under the curve represents the total smelt mass, $M$, flowing out the boiler during the runoff. $M$ is essentially the sum of $M_1$ (additional smelt mass accumulated before the runoff) and $M_0$ (smelt mass during normal operation). Based on this basic trigonometry, the peak relative smelt flow rate, $F_p/F_0$, is given as:

$$\frac{F_p}{F_0} = \frac{2M}{M_0} + 1$$

where $F_p$ and $F_0$ are respectively the peak smelt mass flow rate during runoff and the smelt mass flow rate during normal operation. In the case described previously at mill A, the peak relative smelt flow rate during runoff was 5 times higher than that during normal operation. This means that $M/M_0 = (5 - 1)/2 = 2$, indicating that the total amount of smelt accumulated in the boiler before the runoff was twice as much as during normal operation.

**EFFECT OF LOWER FURNACE GEOMETRY**

Two of the important factors in the occurrence of heavy smelt runoff are the shape of the furnace bottom (hearth) and the location and number of the smelt spouts relative to the bottom and the nose arch. This affects the likelihood of spouts plugging when material sheds from the upper furnace and the volume and hydrostatic head of smelt pools that form behind plugged spouts. There are three basic cases:

1. Sloped floor units with spouts flush with the floor: spouts on front wall (older units) or spouts on rear wall under arch (newer units).
2. Decanting bottom (flat floor) with elevated spouts: spouts on one or more walls.
3. Partial decanting units: V-shaped floor with spouts under the arch or sloped floor with spouts elevated on spout wall.

The key issue in bottom shape is the effect it has on the height of the smelt pool for a given volume of molten smelt. The volume of the smelt pool in the furnace depends on three main factors: the length of time operating with impaired smelt drainage, the frozen and molten smelt inventory on the hearth, and the heat input. Since smelt flow is by gravity, the driving force for smelt flow is the height of the pool (the hydrostatic head) above the bottom of the spout trough. The higher the pool height, the heavier the potential runoff is when a flow path opens up.

**Figure 10** shows the smelt pool configuration in a sloped floor unit and a decanting bottom unit along with the critical geometry values. The volume of the smelt pool that is capable of flowing out the spouts in a decanting bottom unit is $V = h_d L W$, where $h$ is pool height, $L$ is length from front to back, and $W$ is boiler width. On the other hand, the volume
of the smelt pool in a sloped floor unit is \( V = \frac{h_s^2 W}{2 \tan \Theta} \), where \( \Theta \) is the slope angle.

For the same smelt pool volume in the two types of units, the relation between pool heights is:

\[
h_s = \sqrt{2 h_d L \tan \Theta}
\]

While not immediately obvious from this equation, for a given pool volume, the pool height is always greater in a sloped floor unit. For recovery boilers with the distance between front wall and rear wall of 10 meters (i.e., \( L = 10 \) m), the relationship between smelt pool height in sloped floor unit and that in decanting bottom unit as a function of \( \Theta \) is shown in Fig. 11.

The relative smelt pool height in sloped floor units compared to decanting bottoms is greatest for small pool volumes and diminishes as the pool grows in size and spreads to occupy a greater portion of the floor. A consequence of this is that sloped floor units are more vulnerable to heavy smelt runoff, not only because the spouts may plug more easily, but because they rapidly develop hydrostatic head, which is the driving force for smelt flow. It is therefore more important to open plugged spouts quickly in sloped floor units, to go off liquor quickly when spouts plug to avoid forming more molten smelt, and to control auxiliary fuel firing to minimize pool buildup while trying to open spouts.

Decanting bottom units are inherently more tolerant of smelt pool buildup. They also have the advantage that smelt drainage can be set up to take place from more than one wall. Experience shows they can be operated on black liquor for considerable time while trying to open spouts without a major risk of heavy runoff.

Partial decanting units are intermediate to these extremes. The geometry of the smelt pool in a sloped floor unit with elevated spouts is basically the same as the pool in a V-shaped partial decanting unit. This suggests elevating spouts in sloped floor units could help improve smelt drainage.

**SMELT PROPERTIES**

The viscosity of the molten smelt can play a significant role in heavy runoff and dissolving tank violence. Low-viscosity, fluid smelt flows smoothly and is easy to shatter. Viscous smelt (often called jelly-roll smelt, a shear-thinning viscoelastic condition) does not flow well and cannot be shattered readily. The sluggish smelt can form temporary dams near spout openings and frequent spout blockage and lead to molten smelt accumulation.

Smelt fluidity is dictated by its melting/freezing behavior [8]. Smelt, which is mainly \( \text{Na}_2\text{S} \) and \( \text{Na}_2\text{CO}_3 \), melts over a range of temperatures, depending on composition (sulfidity). The system \( \text{Na}_2\text{S} - \text{Na}_2\text{CO}_3 \) has a minimum freezing around 40% sulfidity [9,10]. Most kraft mills operate with sulfidities lower than 40%, so the freezing temperature rises as the sulfidity decreases. This means that the likelihood of operating below the temperature at which the molten smelt begins to freeze is greater at lower sulfidity. The importance of temperature on smelt viscosity is summarized below:

- **When** \( T > T_{\text{freezing}} \): low viscosity, fluid, free-flowing smelt
- **When** \( T < T_{\text{freezing}} \): highly viscous, sluggish, jelly-roll smelt

Since the smelt freezing temperature is a function of sulfidity, it is not surprising that sulfidity has a large effect of smelt runoff problems. Mill experience bears this out. In the recent survey, 65% of the respondents indicated sulfidity was the most important liquor property to be tracked. The three main causes given for why jelly-roll smelt occurred were sulfidity (66%), combustion problems (18%), and a cold bed (15%). Sulfidity control is the most important means of preventing jelly-roll smelt. If the sulfidity is in the wrong range, other means of dealing with jelly-roll smelt will not be as effective. Some mills add NaSH or elemental sulfur to black liquor to raise sulfidity when smelt drainage is impaired and smelt dissolution is violent.

The smelt on the hearth after a fall of sulfate-rich ash from the upper furnace will consist of three major components: \( \text{Na}_2\text{S}, \text{Na}_2\text{CO}_3, \) and \( \text{Na}_2\text{SO}_4 \). The phase behavior for this three component system has not yet been defined, but it is likely that it will act as if the smelt has lower sulfidity and thus be more likely to have a higher freezing temperature.

It is unclear to what extent entrained char plays a role in jelly-roll smelt. Char is highly porous and conceivably could act as a sponge absorbing smelt and hindering smelt flow. However, a number of laboratory studies have shown that smelt does not wet char particles and smelt and char remain apart. Char is light and can float on smelt. It could be carried to spout openings and possibly block them, if there is a large amount of char present [8].

**INFLUENCE OF SLAG FALLING FROM UPPER FURNACE**

Large amounts of deposits can accumulate on heat transfer tube surfaces in the upper furnace and fall to the hearth dur-
ing normal operation or during upsets such as boiler trips. They may also be dropped on the bed deliberately during chill-and-blows. Lien and DeMartini noted that 80% of the dissolving tank explosions resulting from heavy smelt runoff occurred while recovering from a furnace trip or chill-and-blow.

It is not surprising that the introduction of a large amount of slag onto the hearth can affect smelt drainage and ultimately lead to runoff problems. The initial effect will be to block smelt flow paths and possibly plug spouts. Plugging of spouts by falling slag is heavily influenced by the spout location relative to the nose arch, with sloped floor units with front wall spouts being most vulnerable. However, large masses of slag falling on one part of the bed could push other bed material against the spout wall(s) and also cause plugged spouts. But spout plugging or dam formation is only one of the effects of slag falling from the upper furnace. The volume of slag landing on the hearth can displace molten smelt already pooled on the hearth, leading to elevated pool levels and higher smelt flows. It increases the inorganic inventory on the hearth, which when melted, adds to the smelt flow. The addition of large amounts of ash to the bed can distort combustion patterns and lead to firing changes that produce heavy runoff. The falling ash also can affect smelt properties through reduced sulfidity and lead to sluggish or jelly-roll smelt.

The slag that falls on the hearth from the upper furnace contains minimal amounts of sulfide and carbon and so has negligible fuel content. It will not burn when brought into contact with air and must be melted out by heat supplied by combustion of other fuels in the lower furnace. This is in direct contrast with normal smelt, which contains large amounts of sulfide and which can heat up considerably when brought into contact with air.

The slag on the hearth is an extra inorganic load that, when melted, adds to the total smelt flow rate unless the black liquor firing rate is correspondingly reduced. On the other hand, extra heat is needed to melt the relatively cold, frozen slag that lands on the hearth. Thus, large slag falls can result in a shift in the fuel mix, with a reduction in black liquor firing and an increase in auxiliary fuel. This is especially likely if spouts plug. The extent of fuel shifting depends somewhat on the furnace bottom geometry.

The melted slag will mix with the normal smelt in the unit as it flows to the spouts or contributes to a smelt pool. Depending on the proportions of melted slag and normal smelt, the sulfidity of the combined smelt will be lowered, potentially by a significant amount. This could have an effect on smelt viscosity and flow characteristics, and could lead to jelly-roll smelt.

One of the least recognized consequences of high-sulfate melted slag on the hearth is the response to primary air. With normal smelt, an increase in primary air above the spouts will tend to increase the local temperature and make the smelt flow more easily. Just the opposite effect occurs with melted slag. Instead of getting hotter and flowing more easily, the air blowing on the molten slag will cool it, increasing the likelihood of flow problems. This difference in behavior can lead to considerable confusion in how best to respond to sluggish smelt flow when it occurs.

**SUMMARY**

Most mills have experienced heavy runoff problems. Causes include opening plugged spouts, burning down a large bed, low sulfidity liquor, startup with a bed or smelt in the unit, improper firing practices, misuse of auxiliary fuel, and bed collapse. Steps mills take to reduce the likelihood of heavy runoff include managing and controlling the combustion process, controlling the size and stability of the char bed, keeping spouts open to avoid a smelt pool build up, and controlling liquor chemistry (sulfidity).

The most common response to a heavy runoff event is to reduce firing rates, especially black liquor, since black liquor burning produces more smelt. Auxiliary fuel is less likely to be reduced and may be added near spouts to help keep them open. Air adjustments in the lower furnace are commonly made to control the rate of bed burn down. Another common response to heavy runoff is to activate backup shattering capability or increase shatter jet pressure. A few mills use spout plugs or flow restrictors with mixed success.

A smelt flow rate of 1 L/sec is a useful benchmark for a typical smelt flow rate per spout. The duration of a heavy runoff event depends on the amount of molten smelt accumulation and the rate of smelt flow out the spout(s). A typical smelt runoff event lasts from 5 min to 30 min. Heavy runoff is self-limiting because the heavy runoff reduces the amount of smelt available to run out and lowers the hydrostatic head driving the flow. The smelt flow rate at the peak of a runoff is typically 3 to 5 times the normal flow rate and in severe runoff much higher than that.

The shape of the furnace bottom (hearth) and the location and number of the smelt spouts relative to the bottom and the nose arch are important factors in the occurrence of heavy smelt runoff. These factors affect the likelihood of spout plugging caused by falling deposits from the upper furnace and the hydrostatic head of smelt pools that form behind plugged spouts. Sloped floor units are most vulnerable to smelt pool buildup and heavy runoff when released. Decanting bottom units are inherently more tolerant of smelt pool buildup.

Low-viscosity, fluid smelt flows smoothly and is easy to shatter. Viscous smelt (often called jelly-roll smelt, a shearthinning viscoelastic condition) does not flow well and cannot be shattered readily. The viscosity of molten smelt is strongly dependent on sulfidity. Mills have found that there is a critical range of sulfidity where smelt drains well and runs out steadily. Some mills add sulfur compounds to black liquor or cut back on NaOH to evaporators to get out of drainage difficulties.

Material falling on the hearth from the upper furnace can be involved in runoff events. Slag falls can result in spout plugging and dam formation. There can be a considerable mass of inorganic material that has to be melted out. It can lead to a...
lowering of smelt sulfidity, which could affect viscosity and melting temperatures. Slag changes the response to lower furnace air, cooling rather than heating up when contacted by primary air. The potential consequences are an increased likelihood of smelt pooling and heavy runoff, and smelt that may be harder to shatter. TJ

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LITERATURE CITED

ABOUT THE AUTHORS
We chose this topic to research because smelt runoffs have been a persistent problem in many mills and yet their root causes are not well understood. There is currently no sensor that can alert boiler operators when a smelt runoff is about to occur, and how severe it is. We addressed the problem by systematically examining all relevant boiler operating variables and determining if they have deviated from their normal values during a runoff event. We then used the magnitude of the deviation to indicate the severity of the problem.

We discovered that the durations of all runoff events examined were almost the same, about 30 min, and that in severe cases, the smelt flow rate at the peak of each runoff was about 5 times greater than the normal smelt flow rate.

Mills may use the information presented here to minimize smelt runoffs and to ensure the safety of their boiler operators.

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