

Passive Acoustic Monitoring of Recovery Boiler Dissolving Tank Operation

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Abstract

The normal operation of a dissolving tank within the kraft chemical recovery process is loud and violent, as hot molten smelt pours continuously from the recovery boiler into the relatively cool water in the tank. Yet boiler operators can tell when a tank is experiencing problems, because the tank becomes even louder. This allows them to take preventative measures to avert a potentially catastrophic dissolving tank explosion that can lead to equipment damage, an unscheduled shutdown, and personnel injury. Such explosions are thankfully rare, but remain a concern of mill operators. Here we report preliminary findings of a study to characterize the operating conditions of a recovery boiler dissolving tank using acoustic analysis. The sounds and vibrations of a dissolving tank were measured at an operating pulp mill at various locations and at different conditions. The signals were analyzed and the soundscape of smelt-water interaction in the tank characterized.

Keywords: *acoustics; monitoring; safety; control system; dissolving tank; recovery boiler*

I. INTRODUCTION

The kraft pulping process involves the use of so-called “white liquor”, a solution of sodium hydroxide and sodium sulfide, to dissolve wood chips into the cellulose fiber that is used to make paper [1]. The spent, or “black liquor” then enters a chemical recovery cycle that includes combustion in a recovery boiler, that burns waste organic matter to produce steam and power, and converts the spent chemicals into a molten salt mixture of sodium carbonate and sodium sulphide, referred to as “smelt” [2]. As illustrated in Fig. 1, the smelt forms on the char bed at the bottom of the boiler, continuously flows out of the boiler down multiple spouts, and falls into a dissolving tank where the smelt mixes with an aqueous solution to form “green liquor”, which will eventually be converted back to white. Fig. 2 illustrates molten smelt flowing down a spout.

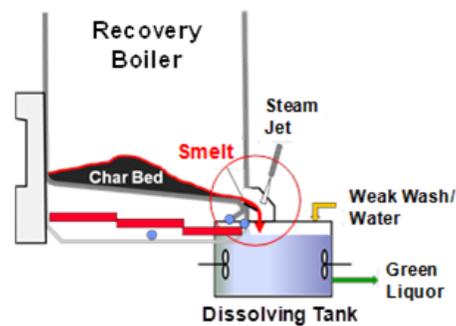


Figure 1. A smelt stream from the bottom of the recovery boiler is shattered by a steam jet before falling into the dissolving tank.

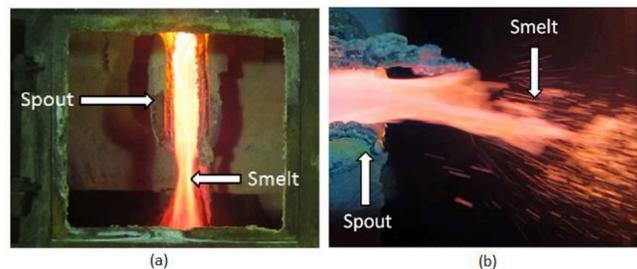


Figure 2. A smelt spout viewed (a) from the front, (b) from above. Note that these pictures do not illustrate shattering, as the shatter jets are located somewhat below the spout lip.

The interaction of the extremely hot smelt, at about 800° C, and relatively cold water causes the rapid vaporization of water within the tank. To control this violent smelt-water interaction, the molten smelt stream is atomized into a spray of droplets before it reaches the tank, by the use of so-called steam “shatter jets”. As shown in [3], even single smelt droplets exhibit vapour explosion behaviour when they fall into water: depending on the smelt and water temperatures, they may explode on contact with the water surface, explode beneath the water surface, or not explode at all and eventually freeze into solid smelt. In a situation where thousands of droplets of smelt are sprayed into the dissolving tank every second, chain reaction explosions likely occur as exploding

droplets trigger the explosions of unexploded droplets. Nevertheless, when smelt is well shattered, the smelt-water mixing within the dissolving tank is well controlled.

However, situations do arise when tank operation becomes dangerous and unpredictable, and in rare cases leads to catastrophic “dissolving tank explosions” involving equipment damage, an unscheduled shutdown, and even personnel injury [4,5]. Although the conditions behind such events are still being studied, accepted reasons include malfunctioning shatter jets, smelt flow surges that may occur during boiler upset events, and changes in smelt temperature and composition that increase the viscosity of the smelt and make it harder to shatter. Within the pulp and paper industry in North America over the past 30 years, approximately one dissolving tank explosion incident has been reported every year, and other less catastrophic incidents likely go unreported.

Experienced recovery boiler operators claim that irregular dissolving tank behaviour can be detected simply by listening to the tank, and that based on what they hear, they will direct personnel to clear plugged spouts and fix shatter jets. However, such operator experience suggests that a monitoring system that does not require the presence of an experienced operator would also be useful, to ensure the safe and normal operation of the dissolving tank. Unfortunately, the environment in and above the dissolving tank is extremely hot and dangerous and the installation of surveillance cameras, for example, is likely infeasible. However, a sound-based monitoring system positioned outside of the dissolving tank might be useful. An automatic acoustic detection system that could warn when a dissolving tank begins to get louder could be an important part of a plant safety system. To design such a system, the sounds heard by the operators must be identified and characterized.

II. METHODOLOGY

Acoustic measurements of an operating dissolving tank were taken at the Domtar Paper Mill at Espanola, Ontario in December 2013. This particular mill is equipped with two dissolving tanks, each fed by 4 spouts pouring smelt at a rate of approximately 1L/s each. The sounds and vibrations of the mill environment around one of the dissolving tanks were recorded with a microphone placed 2 m from the dissolving tank, 1 m off the ground, and an accelerometer attached to the outside of the tank. To simulate malfunctioning shatter jets, a mill operator turned off all four of the shatter jets for short periods of time. Standing next to the dissolving tank, the change in sound intensity from the tank when the shatter jets were turned off was very clearly perceived by the human ear.

Only the microphone data is presented in this paper as it captured a more complete soundscape of the environment. The accelerometer data was used to verify results obtained from the microphone.

III. RESULTS

Dissolving tank noise was recorded with the shatter jets on, and with all four of the shatter jets turned off, to simulate malfunctioning jets. Fig. 3 shows a comparison of the raw sound output from those two conditions. Note that these are two distinct measurements that have been concatenated at the 45 s mark. A transition between the on and off jets can be seen in Fig. 2. While the shatter jets are on and fully functional, the average sound level is at 85dB. When the four jets are off, the average sound level climbs to 88dB. A difference of +3dB indicates a doubling of the acoustic energy. This rise can be seen in Fig. 4. The jets were turned off at approximately 40 s. From Fig. 4, it is easy to see the 3dB increase in sound energy, that boiler operators can also hear when shatter jets are not functioning properly.

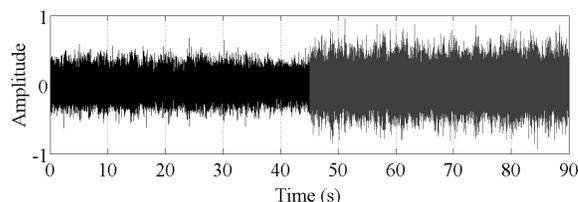


Figure 3. Comparison of dissolving tank noise with and without smelt shattering.

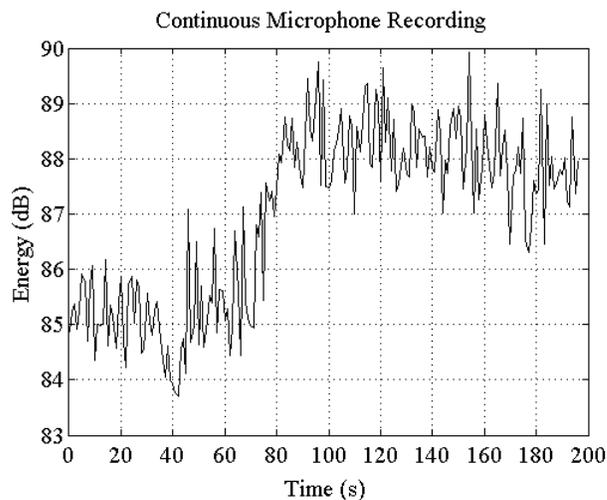


Figure 4. Sound level transition from shattering to no shattering.

Next, we investigated if there was anything else that had changed in the sound signal. A spectral analysis was performed on both (on/off) sound signals to determine the frequency bands in which the sound energy had increased (or decreased). Fig. 5 shows the result of a Welch periodogram using a 100 ms Hamming window.

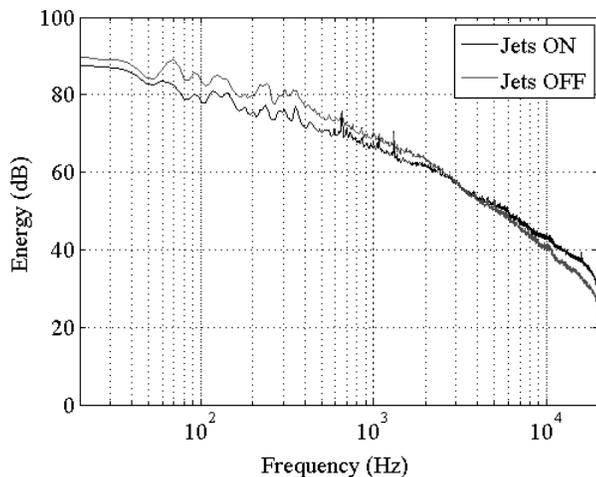


Figure 5. Frequency spectrum of tank operation.

Notice that the acoustic energy only increased at low frequencies. Conversely, for frequencies above 3000Hz, the energy decreased. This is likely due to the absence of the shatter jet noise, which likely lies in the high frequency range. This hypothesis was later tested in a separate experiment in a controlled university laboratory environment where shatter jet nozzles were recorded while blowing air. The results of this experiment as well as a recording of the baseline lab noise can be seen in Fig. 6.

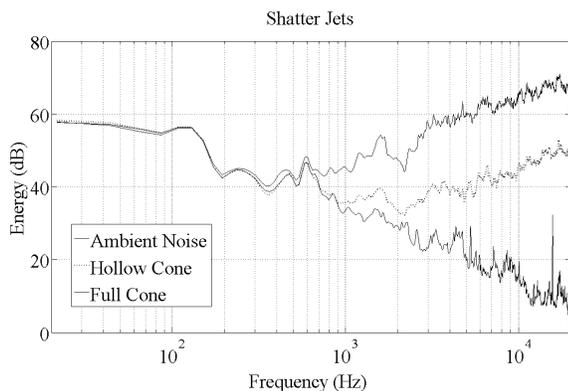


Figure 6. Frequency spectrum of different shatter jet nozzles blowing air.

Shown in this figure are the results obtained from two nozzle jets: a full cone and a hollow cone. Both of these designs are commonly used in recovery boilers. These nozzles were tested using the same airflow of 10 standard cubic feet per minute (scfm). In the low frequency range, the shatter jet noise closely follows the ambient noise in the lab. At higher frequencies, the air jets dominate other sounds produced in this environment. From this we concluded that the drop in acoustic energy in the higher frequency range (3000Hz+) in Figure 5 is likely due to the shutting off of the shatter jets, while the increase in low frequency energy is due to the increased intensity of vapour explosion events from the unshattered smelt interacting with water.

IV. FUTURE WORK

Future work will include a more theoretical study of the physical and chemical properties of molten smelt-water interaction. An analysis of the energy exchange may offer further insight into how the sound associated with vapour explosion events is generated.

As well, we plan to develop a stochastic model of smelt droplet interaction with water in terms of branch processes, that will allow for a more intimate understanding of the processes that take place in a dissolving tank. This model will allow us to better associate the sound and vibration measurements obtained externally to the actual events taking place inside the dissolving tank.

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