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Recent Process Improvements to Increase High Level Waste Throughput at the Defense Waste Processing Facility (DWPF)

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Abstract

The Savannah River Site's (SRS) Defense Waste Processing Facility (DWPF), the world's largest operating high level waste (HLW) vitrification plant, began stabilizing about 35 million gallons of SRS liquid radioactive waste by-product in 1996. The DWPF has since filled over 2000 canisters with about 4000 pounds of radioactive glass in each canister. In the past few years there have been several process and equipment improvements at the DWPF to increase the rate at which the waste can be stabilized. These improvements have either directly increased waste processing rates or have desensitized the process and therefore minimized process upsets and thus downtime. These improvements, which include glass former optimization, increased waste loading of the glass, the melter heated bellows liner, and glass surge protection software, will be discussed in this paper.

Introduction

The Savannah River Site's (SRS) Defense Waste Processing Facility (DWPF), the world's largest operating high level waste (HLW) vitrification plant, began stabilizing about 35 million gallons of SRS liquid radioactive waste by-product in 1996. As of April 2006, over two million gallons of radioactive waste with about ten million curies of activity have been vitrified into about eight million pounds of radioactive glass and poured into over 2000 canisters.

During the initial DWPF operation, the nominal targeted waste loading for the glass was about 28%. Several process improvements were made, including the use of an insert in the melter pour spout that doubled canister production rates by lowering down time due to plugging of the pour spout by an erratic glass pour stream. See Figure 1 for a cross-section view of the DWPF Melter. Recently incentives have been given by the Department of Energy (DOE) that pay the operating contractor (now Washington Group International or WGI) for the amounts of waste processed per contractual period. These incentives were positive in that they rewarded the contractor to process the waste faster (thereby decreasing the overall costs of treating the waste by shortening the processing years). Before and after these contractual changes, several improvements at DWPF have been made in the last few years that have either directly increased waste processing rates or have desensitized the process and therefore minimized process upsets and thus downtime. These improvements include glass former optimization, glass waste loading increases, melter heated bellows liner, and glass surge protection software implementation. The rest of this paper discusses these improvements and their impact on increasing waste throughput. Sludge preparation changes have also occurred but are not part of this discussion.

However, a brief description of the DWPF Melter is needed before a discussion of the improvements is given. The glass in the melter is joule heated by passing current through the glass via a set of diametrically opposed upper and lower electrodes. The vapor space is heated via lid heaters which aid in the melting of the slurry feed (about 50 weight percent solids) that is delivered onto the top of the melt pool via one or two feed tubes. The feed is a mix of radioactive sludge and a glass former frit that is added to the sludge to achieve an acceptable glass composition for processing and glass quality properties. Glass is poured out of the melter via a teapot configuration that has a riser (where glass flows up out of the bottom of the main melter chamber) and a pour spout (where the glass flows downward into a 10 foot tall, 2 foot diameter stainless steel canister). The pour spout is connected to the canister by a bellows, which can be contracted to allow removal of the canister after it is filled with about 4000 pounds of radioactive glass. The normal glass level is maintained about 2 inches below overflow. Glass pouring is initiated by pulling a vacuum on the bellows relative to the vacuum in the melter vapor space above the glass pool. To stop glass pouring, the bellows is pressurized relative to the melter vapor space.

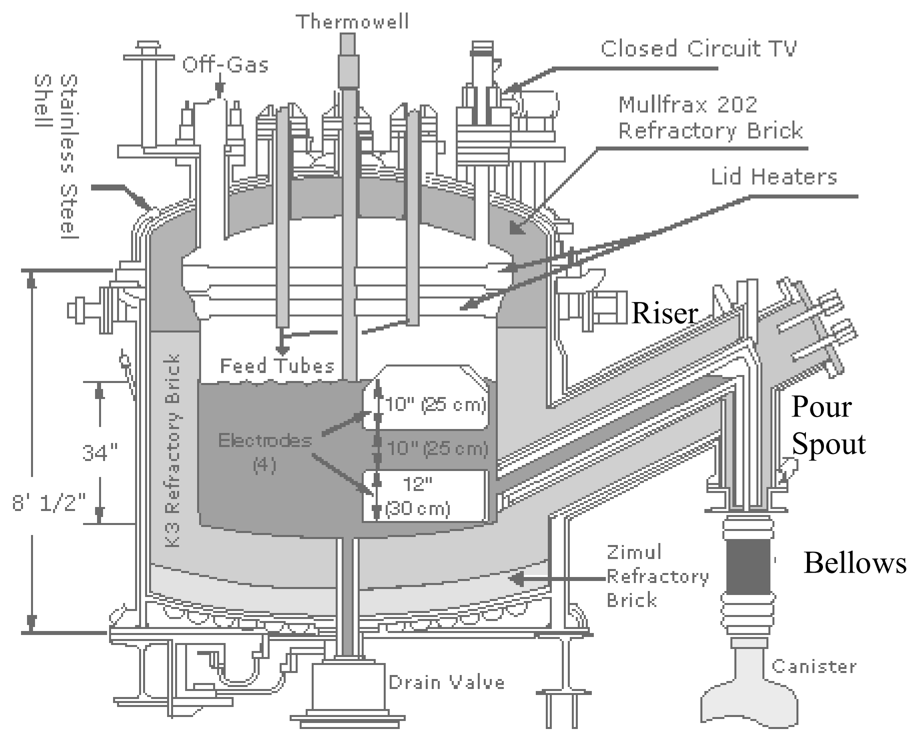

Figure 1: Cross-sectional view of the DWPF Melter.

Glass Former Optimization and Increased Waste Loading

During the initial processing of radioactive feed in DWPF [1], optimization efforts were a lower priority as dealing with various processing and equipment issues that are typical in a new plant. As discussed in the Introduction section, incentives were then given by DOE to the contractor to process the waste faster at DWPF. The Savannah River National Laboratory (SRNL) began an effort in which the glass composition for each sludge batch (processing time at DWPF about two years) was optimized for melt rate. In other words, the strategy shifted from a "global" sludge batch approach to a "tailored" glass composition for each sludge batch. The primary focus in this effort was to a frit (glass former) development strategy that would accomplish the following.

- Provide relatively large projected operating windows.
- Provide robustness to compositional variation in the sludge.
- Provide a glass system that meets processing expectations.

A major part of this strategy was to develop or modify process control models to reduce the uncertainties associated with the models and/or revisit process control constraints that limited changes that could be made to the glass composition to increase melt rate/waste throughput. Figure 2 shows how various control limits can be widened to increase the acceptable operating window. These process control models are used by DWPF to ensure that the final glass product is acceptable. Due to the large scope of this effort, only a high level discussion of this work can be given.

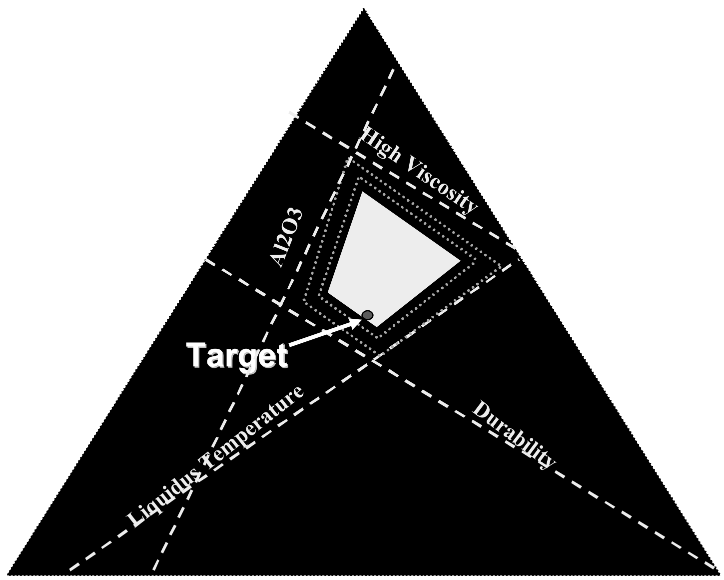

Figure 2: Schematic of how operating windows of DWPF glass composition can be increased.

After much experimental work and statistical analysis, the uncertainties of the models used to predict liquidus and durability were lowered. In addition, testing was performed that increased the sulfate solubility limit for Sludge Batch 3. With the operating windows opened, frits which could result in higher melt rates (via higher alkali glass compositions from higher alkali frits and less sludge washing that results in higher alkali sludges) were deemed acceptable for various DWPF sludge batches. Some of these frits were then tested with non-radioactive Sludge Batch 2 and then Sludge Batch 3 simulants in the dry-fed Melt Rate Furnace (MRF). The MRF is used as low cost scoping melt rate tool. Frits which resulted in higher melt rates were further tested in the Slurry-Fed Melt Rate Furnace with Sludge Batch 2 and 3 simulants. Based on the results of this melt rate/waste throughput program, higher melt rates have been achieved in Sludge Batches 2 and 3 than would have been reached without this program.
A final part of this program was an investigation into the impact of waste loading on melt rate and waste throughput. This was allowed in part by increasing the operating window of the DWPF glass composition as discussed above. Melt rate testing at SRNL with Sludge Batch 2 revealed that melt rate decreased with increased waste loading.

However, higher waste loadings resulted in higher waste throughput until a peak was reached and then waste loading then began to drop if waste loading was further increased (see Figure 3). In other words, there is a waste loading "sweet spot" for maximum waste throughput for each sludge batch. This is because even though the melt rate goes down with waste loading, the amount of waste per pound of glass melted is higher as waste loading increases. However, as waste loading is further increased, the melt rate decreases too fast relative to the higher amount of waste in the glass. At this point, waste throughput then begins to decrease below that of the "sweet spot".

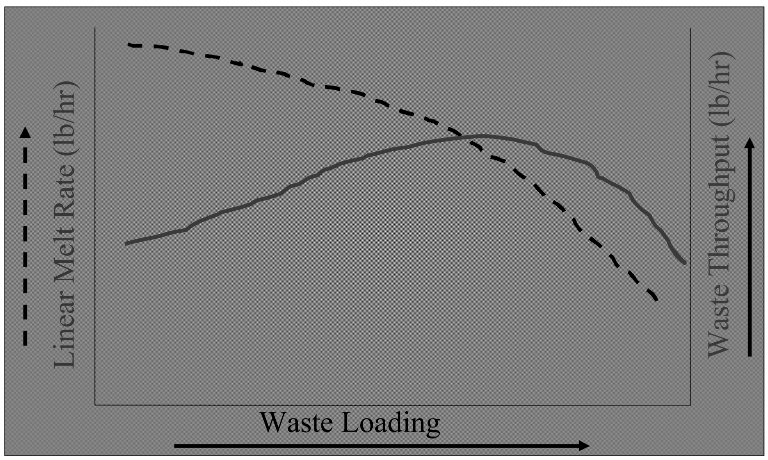

Figure 3: Impact of waste loading on melt rate and waste throughput.

This was proven during DWPF processing of Sludge Batch 2 when a higher alkali frit (Frit 320) began to be used at a waste loading of 30%. After a period of time, the waste loading was increased to 37%. This higher waste loading resulted in processing problems and consequently the feed rate had to be lowered. The maximum melt rate was about 131 pounds per hour at 37% waste loading (waste throughput of about 48 pounds per hour), while the maximum melt rate at 30% waste loading had been about 160 pounds per hour (waste throughput about 48 pounds per hour as well). When the targeted waste throughput was lowered to about 35%, the waste throughput increased. Based on this finding, waste loading was ultimately adjusted with Sludge Batch 3 to maximize its waste throughput as well. Direct comparisons of melt rate/waste throughput of various sludge batches are difficult due to various processing and equipment changes/improvements over time.

Heated Bellows Liner

During glass pouring, the glass stream may become unstable and waver to the side. Intermittent slugs of glass may occur as well. The unstable glass stream may contact the inside of the bellows and begin to buildup. Eventually the glass may begin to plug the bellows and also the pour spout that is located just above the bellows. These glass stream instabilities are usually caused by melter vapor pressure spikes. These are caused when the melter is overfed and the unmolten cold cap becomes too thick and traps gasses that are generated during the melting of the cold cap. These trapped gasses will then periodically release into the melter vapor space, causing melter vapor space spikes which then causes pour stream instability.

In an effort to desensitize the process, a heated bellows liner was designed and installed in the DWPF bellows. Figure 7 is a sketch of the bellows without and with the Inconel 690 heated liner. Figure 8 is a picture of the heater and the weldment that holds the heater (liner not shown). The funnel shown in the before the heated bellows liner is a liner that protects the rest of the bellows. This is where glass normally built up in the bellows. The heated bellows liner is shown above this liner. The liner has two heater zones with a targeted temperature of 1050 ºC. When glass contacts this heated bellows liner, it is hot enough so that the glass does not normally buildup. In addition, the heated bellows liner directs any glass that contacts it more to the center of the unheated liner below, thereby decreasing the chances that an unstable glass stream will contact the lower unheated liner.

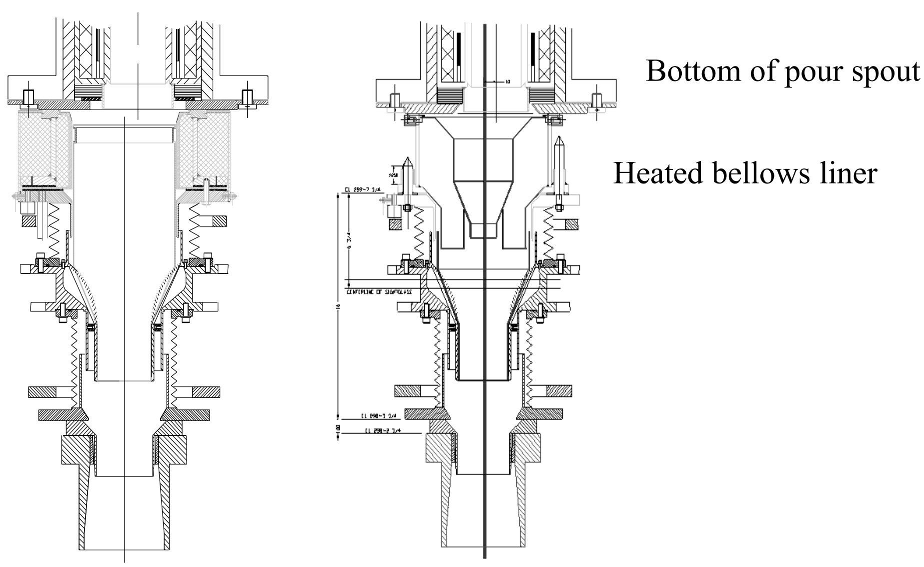

Figure 7: DWPF Melter bellows without (left) and with (right) heated bellows liner.

The first heated bellows liner was installed on June 3, 2004. Several design iterations were required to improve the reliability of the liner and to ensure adequate heater temperatures were achieved. As of April 2006, nine heated bellows liners had been used. The normal life span of the liner has been about 60-90 days.

Figure 8: Heater (upper and lower combined) and weldment (located on right).

The liner has improved melt rate and waste throughput via several factors. First, melter utilization has increased as the number of down times for bellows and pour spout cleanouts has decreased. Secondly, melt rate/waste throughput has been increased as the heated bellows liner has allowed processing of the feed at higher rates by desensitizing the process to glass stream instabilities (due to overfeeding of the melter). Another smaller positive melt rate impact is that with less Melter Feed Tank (MFT) feed pump stoppages for bellows cleanouts, the number of MFT feed pump primings (which are required each time the feed pump is restarted) has been reduced, thereby minimizing the dilution of the feed with water which lowers melt rate.

Glass Siphon Protection Software

As previously discussed, glass is poured via a pressure differential between the melter vapor space and the bellows. All melter siphons or glass "slugging" observed to date have been preceded by a spike in melter vapor space pressure. Some melter pressure spikes push a 'slug' of glass (between 50 -150 pounds) into the canister and then the glass transfer stops on its own in less than 1 minute. Other spikes push over a slug of glass that starts a self perpetuating siphon that can continue for several minutes and transfer up to 1500 pounds of glass into the canister. While the 100 pounds slugs of glass are a concern, it is doubtful the DWPF melter off-gas pressure control system could act to reduce the magnitude of the glass slug leaving the melter. However, it is possible for the control system to detect glass siphons and to take actions to stop them.

Several melter glass siphons have been experienced while processing Sludge Batches 2 & 3. These uncontrolled transfers of glass from the melter to the canister have resulted in hundreds of pounds of glass transferred to the canister in just a few minutes. Should this happen near the top of a can, the potential exists to overfill a canister. In addition, uncontrolled slugs of glass can plug the bellows which is the union between the melter pour spout and the canister. These plugs require long down times to remove the glass from the bellows and/or canister. Thus, a means of identifying siphons and taking timely corrective actions was necessary to minimize the chance of overfilling canisters.

Before going further, some discussion of a glass siphon is needed. A siphon is defined as an uncontrolled transfer of glass from the melter to the canister which is caused by molten glass completely filling the riser and down spout such that the excess weight of glass in the down spout applies sufficient force to carry additional glass over the apex of the riser and sustain a continuous flow. When the down spout is filled, the falling glass can pull more glass out of the melter and continue the chain reaction. Unchecked, this chain reaction will continue until the melter level falls so much that the suction generated by the falling glass can no longer pull glass up the riser.

This continuous flow could be detected easily if a 'glass flow meter' was available. However, in lieu of that instrument, the flow is inferred by computing the change in melter level per unit time and the change in canister weight per unit time. The greater the glass flow, the greater the change in canister weight and the greater the loss in melter level. Unfortunately, due to the high noise on the weight and level signals, computing the flow rate requires large signal filters that delay the computation.

It is obviously critical to detect the siphon event in a timely manner. With sustained flow rates exceeding 250 pounds/minute, it is clear that a siphon must be stopped rapidly, particularly if the canister is almost full. During the data analysis, it was noted that every siphon event was preceded by a melter pressure spike. While not all pressure spikes caused siphons, the higher the spike, the more likely to cause a siphon. By using the time at which the initiating melter pressure spike first rises past 0 inches of water column (inwc) as the point at which to start the clock, one can fairly compare the response time of any of the three combination of events listed below which can cause a melter siphon and in turn cause a melter siphon alarm. Once the alarm is triggered, the control system immediately increases the setpoint of the pour spout pressure controller, PDIC3526, from its normal value of about -4 inwc to +4 inwc. This rapid increase in bellows pressure stops the pour. In addition, melter feeding is not automatically stopped. This prevents process down time. This is important as well for melt rate, as each restart of the melter feed pump requires a large amount of water to prime the pump dilutes the contents of the Melter Feed Tank. Feeds watered down to a lower weight percent solids result in lower melt rates.

Listed below are the three sets of conditions that trigger the glass siphon interlock. Only one of these three sets of conditions is required for the interlock to occur.

- Melter pressure > 9 inwc. This first "OR" will detect all siphons in less than 10 seconds which is simply the time for the pressure to rise from 0 to 9 inwc. Almost all spikes of this magnitude cause a siphon therefore, it is prudent to act as quickly as possible to stop the pour and limit the uncontrolled glass flow.

- Melter pressure > 4 inwc and canister weight change > 120 pounds/minute. This second "OR" will detect all siphons in about 20 seconds. Since only a portion of pressure spikes > 4 inwc cause a siphon, the further discriminator of increasing canister weight is used to reduce false detections. Likewise, there are a number of normal plant evolutions not indicative of a siphon event that can cause a weight change > 120 pounds/minute such as, loading a canister, lowering the bellows, and the initial canister heat up at break-over. Thus, by requiring a melter spike within the preceding minute in combination with the rapid canister weight change, false detections are nearly eliminated while catching all true siphons and preserving a rapid detection time.

- Canister weight change > 120 pounds/minute and melter level falling > 0.4 inches/minute. This third "OR" can take about 45 seconds to detect a siphon. Since it is possible to have a siphon without an initiating pressure spike, this set of conditions does not require the pressure spike discriminator. If there is a simultaneous rapid increase in canister weight and rapid decrease in melter level, a siphon is declared. As mentioned earlier, excessive noise on the weight and particularly the level signal requires time averaging of the signals to reduce the noise. This filtering delays the declaration of a siphon event. The lowest pressure spike to date that caused a siphon was 2.1 inwc. This is well below the 4 inwc threshold used in the second "OR".

The siphon detector logic is based on analysis of 1677 spikes during the period spanning 5/1/03 and 6/1/04 which had peak amplitudes greater than -2 inwc. It also considered all the data between 4/1/04 and 5/31/04 in order to quantify the number of false positives during normal operating conditions.

Based on the historical data listed above, the detector will catch every true siphon that has occurred. It will also catch many of the glass slugs, particularly for spikes > 4 inwc. If one considers a slug as a false detection, than there were 13 false detections over the evaluation period. However, detection of a slug should not be considered a false positive since, in real time, one could not determine if the initiating pressure spike would cause a true siphon or a slug unless the event was allowed to proceed unimpeded for several minutes, at which time it is too late.

There were no other false positives during the evaluation period. These false positives would have most likely come from the weight change resulting from lowering the bellows, canister expansion at the beginning of pour, melter level blow-down, etc. While it is likely that at some point some convolution of these random events will result in a false positive, it was not observed in the data set.

It is difficult to determine the exact impact of the glass siphon protection software. As discussed, the software minimizes downtime and prevents the melter feed from being diluted. Since the software desensitizes the process, the melter feed rate can also run at higher rates (and therefore resultant higher melt rate) before conditions occur that cause glass siphoning.

Conclusions

Several improvements at DWPF have been made in the last few years that have either directly increased waste processing rates or have desensitized the process and therefore minimized process upsets and thus downtime. These improvements include the following.

- Glass former optimization - The optimization included increasing the acceptable range of the glass composition, thereby allowing higher alkali glasses which have resulted in faster melt rates and therefore higher waste throughputs.
- Increased waste loading - Due to increases in the glass composition ranges, higher waste loading glasses can now be processed in DWPF. Even though melt rate decreases with higher waste loading, it was determined experimentally with simulant waste feeds and then verified at the DWPF with Sludge Batches 2 and 3 that there is a waste loading “sweet spot” that maximizes waste throughput. This “sweet spot” is also a function of the feed rheology, which has also greatly improved for Sludge Batch 3.
- Heated bellows liner - The heated bellows liner has minimized glass buildup in the bellows, thereby decreasing the number of downtimes for cleanouts of the bellows. Secondly, melt rate/waste throughput has been increased as the heated bellows liner has allowed processing of the feed at higher rates by desensitizing the process to glass stream instabilities (due to overfeeding of the melter).
- Glass surge protection software – This software has minimized the downtime for cleanouts of the bellows. As with the heated bellows liner, the software has desensitized the process, therefore allowing higher melter feed rates (and therefore resultant higher melt rate) before conditions occur that cause glass siphoning.

References

1. S. L. Marra, J. T. Gee, and J. F. Sproull, “The Defense Waste Processing Facility: Two Years of Radioactive Operation,” *Environmental and Waste Management Issues in the Ceramic and Nuclear Industries IV, Ceramic Transactions Volume 93* (1999).