This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U. S. Department of Energy.

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DWPF MELTER GLASS PUMP IMPLEMENTATION AND DESIGN IMPROVEMENT

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ABSTRACT

In order to improve the melt rate of high level waste slurry feed being vitrified in the Savannah River Site's (SRS) Defense Waste Processing Facility (DWPF) Melter, a melter glass pump (pump 1) was installed in the DWPF Melter on February 10, 2004. The glass pump increased melt rate by generating a forced convection within the molten glass pool, thereby increasing the heat transfer from the molten glass to the unmolten feed cold cap that is on top of the glass pool. After operating for over four months, the pump was removed on June 22, 2004 due to indications that it had failed. The removed pump exhibited obvious signs of corrosion, had collapsed inward at the glass exit slots at the melt line, and was "dog-legged" in the same area. This lead to the pump being redesigned to improve its mechanical integrity (increased wall thickness and strength) while maintaining its hydraulic diameter as large as possible. The improved DWPF glass pump (pump 2) was installed on September 15, 2004. The impact of the new design on pump life, along with analysis of the glass pump's impact on melt rate in the DWPF Melter is discussed in this paper.

INTRODUCTION

A DOE Tank Focus Area program to assess possible means of increasing the Defense Waste Processing Facility (DWPF) Melter melt rate was initiated in 2001. A lumped parameter comparison of DWPF data with earlier pilot plant scale data indicated that melt capacity for a given feed was limited by overheating of the glass immediately under the reacting feed (cold cap). Pumps were considered as a means of increasing glass circulation and opening a vent hole in the cold cap to allow increased electrode power, and thus increased melter total power. Limited locations for a pump in the DWPF melter top head, and glass pumping limitations of traditional bubblers lead to the development of a system utilizing air-lift pumping.

A paper proposed for a presentation and publication in the conference transactions of the 107th Annual American Ceramic Society Convention, Baltimore, Maryland, April 10-13, 2005.

In Figure 1, the glass pump concept is shown beside the standard bubbler concept. In a bubbler, gas is injected into the bottom of the melt pool and disperses upward. In the glass pump, the gas is injected into the bottom of an open pipe. Hot glass from the bottom of the melter is "pumped" directly to the top of the melt pool via slots in the pump located near the glass pool surface.

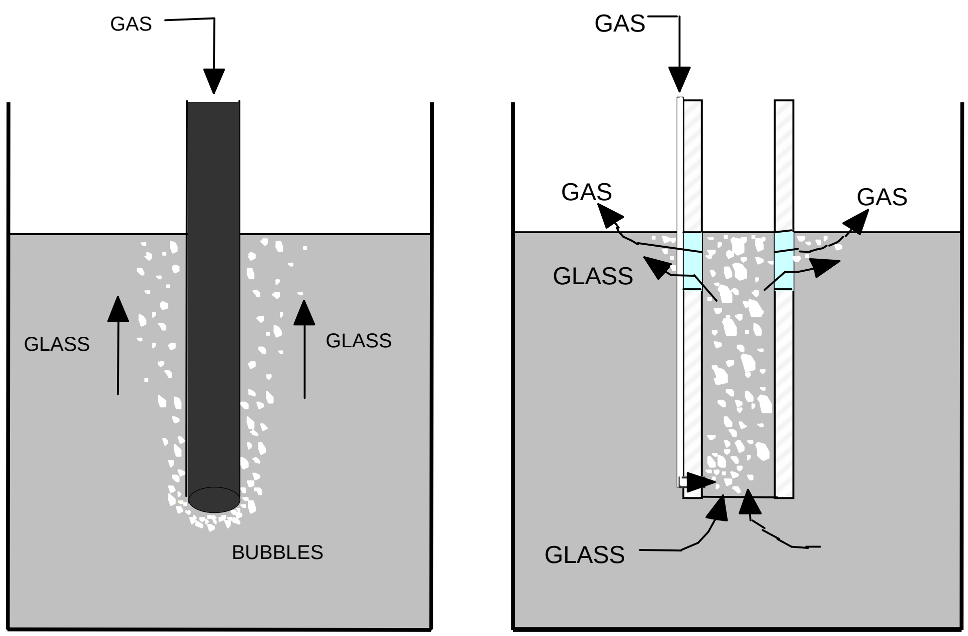

Figure 1. Schematic of Standard Bubbler (Left) and Glass Pump (Right)

The air-lift concept was tested with glycerin and an Inconel 690 proof-of-principle air- lift was tested in molten glass and found to be an effective pump. In addition, small scale air-lift pumps were tested in the Slurry Fed Melt Rate Furnace (SMRF) to evaluate the overall behavior of the cold cap with an air-lift pump. Details of these tests and others are given elsewhere[1,2]. Finally, a full-scale Inconel 690 unit was fabricated and installed in a glass hold tank at the Clemson Environmental Technologies Laboratory (CETL) facility in 2002. The main purpose of this test was to evaluate the expected unit life. In addition, it was used to provide initial indication of the interactions with the cold cap during a one day slurry feeding test[2]. The life cycle testing lasted for 72 days and the subsequent inspection of the pump showed no major problems.[3]

Anticipated benefits to DWPF of the air-lift pump were:

- Enhanced melt rate from direct action of increased overall glass circulation rates improving transfer of electrode power to the bottom of the cold cap. This may be the result of increased overall glass velocity or improved venting of cold cap gases trapped under the cold cap. This is the mode of melt rate improvement of traditional pumps operated with modest gas flow rates. However in the present case, the efficiency of the pumping action is improved, so that lower gas flows are required, and the gas is not forced to accumulate under the cold cap.

- Additional increases to melt rates from enhanced power available to the cold cap and slurry indirectly by heat transfer from the pumped glass to the melter plenum. It increases total power available to the melter by allowing additional electrode power to be applied without overheating of the glass under the cold cap.
- More uniform glass pool temperatures, making it easier to stay within temperature operating limits at the top and bottom of the glass pool.

IMPLEMENTATION OF AIR-LIFT PUMP 1 IN DWPF

With the findings of the life cycle tests, an air-lift pump was designed and fabricated for use in the DWPF Melter. The center melt pool thermowell nozzle located in the middle of the top of the melter was chosen as the nozzle in which the pump was to be installed. The melt pool thermowell was removed and the new pump was put in place on February 10, 2004. An argon gas flow of 566 standard liters/hour was evaluated to be sufficient for pump operation. This was the same flow rate used in the previously mentioned life cycle test.[3]

At this time DWPF was processing a mixture of radioactive sludge named Sludge Batch 2 (SB2) and a fritted glass called Frit 320. The feed was designated SB2/Frit 320. The weight percent of the waste in the final glass product (waste loading) was being targeted at 35% in an attempt to achieve the highest waste processing rate possible with this sludge/frit combination.

The use of glass pump 1 with SB2/Frit 320 feed (at 35% waste loading) resulted in the following conclusions:

- The glass pump is effective in decreasing the temperature gradient in the melt pool.
- The glass pump is effective in increasing the overall melt pool temperature by 15°C based on temperature indications from the outer thermowell.
- The more uniform melt pool temperature and increased average melt pool temperature increases the ability to maintain the melt pool within its maximum and minimum temperature limits (this is especially important to prevent high upper glass temperatures which result in the automatic shutoff of the upper electrodes).
- With the same feed rate (1.76 l/min) as before the pump was installed, the total electrode power (upper and lower electrodes) increased by 7 kW (5%), the upper electrode power increased by 5 kW (13%), the total vapor space heater power decreased by 3 kW (1%), and the vapor space temperature increased by an average of 17°C.
- The above changes and power and temperature indicate that the pump is effective in increasing heat transfer to the cold cap, providing the ability to increase the melt rate of the DWPF Melter.

- Due to other process variables that changed throughout this time frame (lower feed waste loading and weight percent solids, as well as melter attainment), it was not possible to determine an exact increase in production rate that could be attributed to the use of the glass pump with SB2/Frit 320 feed (best estimates ranged from 6 to 10%).

In mid-April of 2004 DWPF began processing sludge batch 3 (SB3) with Frit 418. Not enough operational time was achieved to determine highest achievable melt rate/waste throughput with the new feed (SB3/Frit 418), but initial findings indicated that the glass pump was working quite well with this new feed.

INSPECTION OF GLASS PUMP 1

After approximately 4 months of service, the backpressure on the argon supply to pump 1 decreased, indicating that the wall between the argon supply line and the inside diameter of the pump had been breached. Upon removal of pump 1 from the melter on June 22, 2004, it was inspected with closed circuit television. It showed obvious signs of corrosion, had collapsed near the melt line where glass exits the pump, and was "dog-legged" in that same area (see Figure 2).

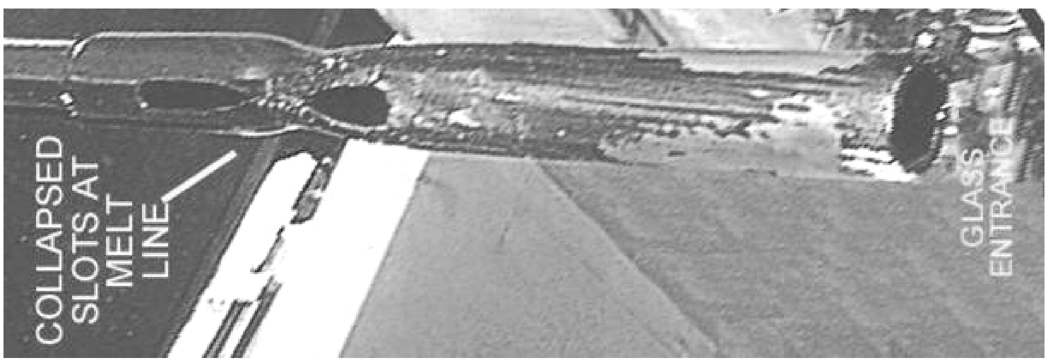

Figure 2. Air-Lift Pump 1 after Removal with Over 4 Months of Operation

No destructive analyses were performed, but the visual inspection was used to determine an approximate corrosion rate at the bottom of the slots of about 2.4 mils per day. This is the same order of magnitude determined for worst case conditions per previous Inconel 690 corrosion tests performed by SRNL in 1984.[4]

AIR-LIFT PUMP DESIGN CHANGES

Based upon the observed failure mode, the pump was redesigned (designated glass pump 2) to improve its mechanical integrity (increase wall thickness and strength) while maintaining its hydraulic diameter as large as possible. The hydraulic diameter is a measure of the effective flow path of an irregular (non-cylindrical) channel. The bore was decreased in size, resulting in a hydraulic diameter of 5.98 cm for glass pump 2 (versus 6.38 cm for glass pump 1). This allowed for a significant increase in the wall thickness (from 0.71 cm to 1.12 cm) between the pump inside diameter and the argon supply channel. Also, the wall thickness at the elevation of the glass exit slots was increased (from 1.85 cm to 3.00 cm) by specifying a milled 3.18 cm wide slot through that section rather than continuing the lower bore to above the melt line. This greatly increases the resistance to bending of collapse while in service. Representative cross-sections of glass pump 1, glass pump 2, and the life cycle test pump at the slot heights are shown in Figure 3 for comparison. Figure 4 gives a schematic of the two pumps that shows the difference in the pump walls in the slotted section of the pumps.

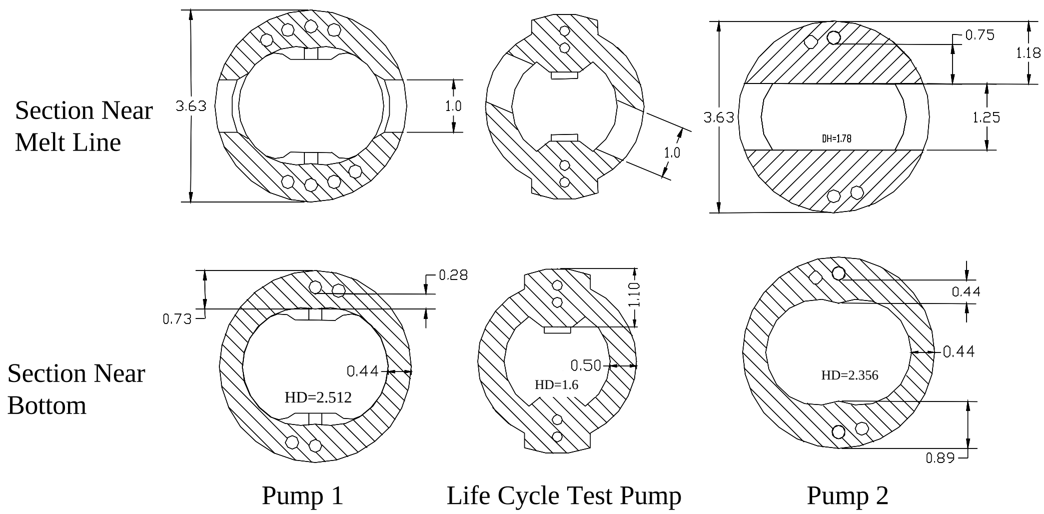

Figure 3. Cross-Sections of Glass Pumps 1 and 2, and the Life Cycle Test Pump

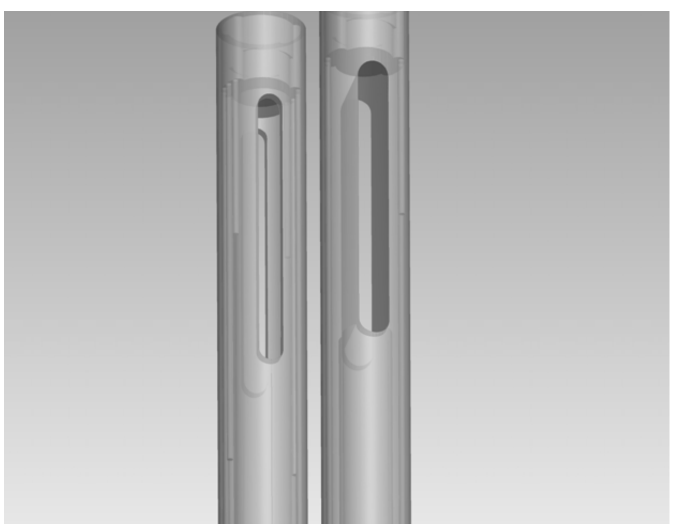

Figure 4. Schematic of Slotted Sections of Pump 1 (on Left) and Pump 2

INSTALLATION AND OPERATION OF PUMP 2 IN DWPF

While pump 2 was being fabricated, a decision was made at SRS to use Frit 202 with SB3 near the end of SRS fiscal year 2004. Frit 202 had been used with a previous sludge batch and several months supply of Frit 202 was available. SRS realized that Frit 202 would result in lower melt rates, but it was believed that DWPF could still meet the 2004 production objectives with Frit 202. Therefore DWPF processing of SB3 with Frit 202 began in July 2004. Processing of SB3/Frit 202 continued in the DWPF Melter without the glass pump until the pump 2 fabrication was completed and the pump installed in the DWPF Melter on September 15, 2004. A review of the operational data before and after pump 2 was installed while processing SB3/Frit 202 feed resulted in the following conclusions about the impact of the pump:

- The upper/lower electrode power was not impacted but vapor space heater power increased by about 7 kW.
- Lower glass pool temperature increased from 1085°C to 1104°C.
- Upper glass pool temperature shutoff interlocks were eliminated.
- The maximum feed rate was increased from 1.51 liter/minute to 1.59 liter/minute (5% gain), the resultant melt rate was increased from 54.2 kg/hour to 56.7 kg/hour (5% gain), and the waste throughput was increased from 18.3 kg/hr to 20.2 kg/hr (10% gain due to higher average waste loading of feed when pump was being used).

This 5% increase in melt rate/canister production rate was better quantified that the gains realized with pump 1 as the DPWF process was more stable during the time of the SB3/Frit 202 processing. After fiscal year 2005 began in October 2004, DWPF transitioned back to vitrifying SB3 with Frit 418. Due to process variability, the highest achievable melt rate for SB3/Frit 418 feed could not be determined before glass pump 2 was removed for a scheduled three month operation time inspection in early December, 2004. Findings of the inspection are discussed in the next section.

INSPECTION OF PUMP 2

Glass pump 2 was removed about a week (December 7, 2004) earlier than the planned inspection date of December 15 due to other DWPF schedule considerations. Figure 5 is a picture of pump 2 after its removal. Unlike pump 1, the backpressure for the argon had not gone down before the inspection.

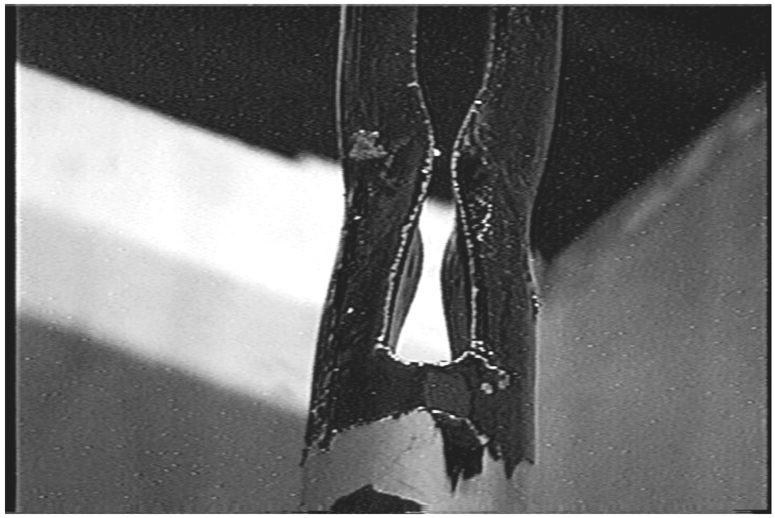

Figure 5. Air-Lift Pump 2 after Removal with About 3 Months of Operation

Although the slotted pump 2 section had not collapsed as much as pump 1 (probably due to having a thicker wall at the slot area), the appearance of pump 2 was not deemed acceptable for use longer than three months. In addition to the observed slot collapse, the apparent tears at the bottom of the slotted section on both pumps 1 and 2 raised concerns as well. Due to various constraints, the pump could not be sectioned and removed from the DWPF Melt Cell for a more detailed analysis of the pump. Before continuing with any further design improvements, a review of the conditions at the slot section and a determination of the cause of the collapses were performed.

One key observation was the thermal cycling of the glass pump in the slot area. The measured temperature cycled from 1000°C to 400°C while the upper glass pool temperature remained above 1000°C. It was postulated that the inside of the pump was remaining at 1000°C while the outside of the pump was being cooled down due to the intermittent contact of the pump by the cooler unmolten feed (cold cap). This thermal cycling (about 8 times per day) was simulated on the pump 2 design using a finite element 3-D model. The model showed that this thermal cycling would result in the collapse of the slotted area as experienced by both glass pumps 1 and 2. The tears could be caused by the thermal cycling as well as during the heatup portion of the cycle tensile stresses would be exerted on the lower portion of the slots.

Therefore several options were considered for the third pump design. The design chosen makes the slot much shorter in length and lowers the slot several inches below the melt line. The shorter slot increases the structural integrity of the pump in that area and the lowering of the slot minimizes the thermal gradient at the slots. Moving the slots above the melt line was also considered, but this would have then required a large effort to ensure that the melter off-gas safety window was not exceeded.

Mockup of the design using molasses to simulate molten glass was performed to ensure that the pumping capabilities of the new design were still sufficient. A finite model analysis was performed on the new design. It showed that the new design would not experience the problematic thermal cycles at the slot region of the pump. Current plans are to fabricate pump 3 with this new slot design and then install it in the DWPF Melter in the spring of 2005.

CONCLUSIONS

Based on the current operating experience with glass pumps in the DWPF Melter, the following conclusions can be made:

- The pump is effective in increasing heat transfer to the cold cap, thereby increasing melt rate by at least 5 -10%.
- The pump is effective in stabilizing melter operation by minimizing high upper glass temperature interlocks and increasing the lower glass pool temperature.
- Thermal cycling in the slotted portion of glass pumps 1 and 2 resulted in collapse on the pump in this area.
- Based on this thermal cycling problem at the melt line, a new glass pump design is being pursued that has shorter slots which are located several inches below the melt line.

REFERENCES

1. H. N. Guerrero and D. F. Bickford, “DWPF Melter Air-Lift Bubbler: Development and Testing for Increasing Glass Melt Rates and Waste Dissolution (U)”, USDOE Report WSRC-TR-2002-00196, WSRC.
2. D. C. Witt, T. M. Jones, D. F. Bickford, “Airlift Mini-Bubbler Testing in the Slurry Fed Melt Rate Furnace (U)”, USDOE Report WSRC-TR-2002-00494, WSRC.
3. M. E. Smith, A. B. Barnes, D. F. Bickford, K. J. Imrich, D. C. Iverson, and H. N. Guerrero, “DWPF Glass Air-Lift Pump Life Cycle Testing and Plant Implementation” , Environmental Issues and Waste Management in the Ceramic and Nuclear Industries X, Ceramic Transactions, Vol. 23, ed C. C. Herman (2004).
4. D. C. Iverson and D. F. Bickford, “Evaluation of Materials Performance in a Large-Scale Glass Melter after Two Years of Vitrifying Simulated SRP Defense Glass”, Sci. Basis for Nucl. Waste Mgt., VIII, Material Research Society, Pittsburg, PA, 839-845 (1985).