Improvements in Design and Operation of Bubblers in the Savannah River Site Defense Waste Processing Facility Melter - 15163

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ABSTRACT

In order to accelerate the closing of High Level Waste (HLW) tanks at the Savannah River Site (SRS), it was necessary to process more waste throughout the SRS liquid waste facilities. Therefore the Defense Waste Processing Facility (DWPF) needed to increase its production rate of radioactive waste glass filled canisters. To attain the increased production rate, four bubblers were installed in the DWPF Melter in September 2010 to agitate the DWPF Melter glass pool. The four bubblers were designed to be installed in existing nozzles on the top-head of the DWPF Melter. After a few years of successful operation with the original design, several changes have been made to the bubblers. The main change allows for the lower end (inside melter) of the bubbler to be replaced while the top end (outside melter) of the bubbler can be reused. This minimizes cost and waste at the DWPF. Material testing of the Inconel 690 bubbler pipes of used lower bubblers has been performed. Based on the material testing and issue with the integrity of some lower bubbler pipes used in the melter, a protective sleeve at the melt line was also added. Other changes for operational improvement or cost savings have also been made. Overall, performance of the bubblers continues to be excellent as canister production records have been achieved at the DWPF due in large part to the use of bubblers.

INTRODUCTION

The DWPF has been in radioactive operations since 1996. As of September 30, 2015, approximately 3900 radioactive glass filled canisters have been processed through the facility. Waste glass production has been accomplished using two separate Joule heated melters. Melter 1 was in service from 1996 to October 2002, while Melter 2 is currently in service after beginning operation in March 2003. The waste glass is vacuum poured from the melter into stainless steel canisters which hold approximately 1815 kg (4000 lb) of the glass. Fiscal Year canister production had averaged 215 canisters. It was necessary to increase this production rate by increasing the melt rate of the DWPF Melter as it had been the "bottleneck" of the DWPF process.

The DWPF Melter bubblers design called for four bubblers to replace already existing components (glass level probe, feed tubes, thermowell) installed in the melter top-head. This required that two of the bubblers (in melter nozzles C2 and C4) have functions (plenum pressure and glass level for C2, and glass pool temperature measurement for C4) in addition to the agitation function. The remaining two bubblers (in nozzles B1 and B2) initially provided the agitation function only. Figure 1 shows the orientation of the relocated/redesigned center feed tube (in nozzle E) and the B1and B2 bubblers. [1] Before bubblers there were two feed tubes

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located in the B1 and B2 nozzles, but it was determined that one feed tube was sufficient to reach targeted production goals. This allowed for the best possible symmetric location of the bubblers.

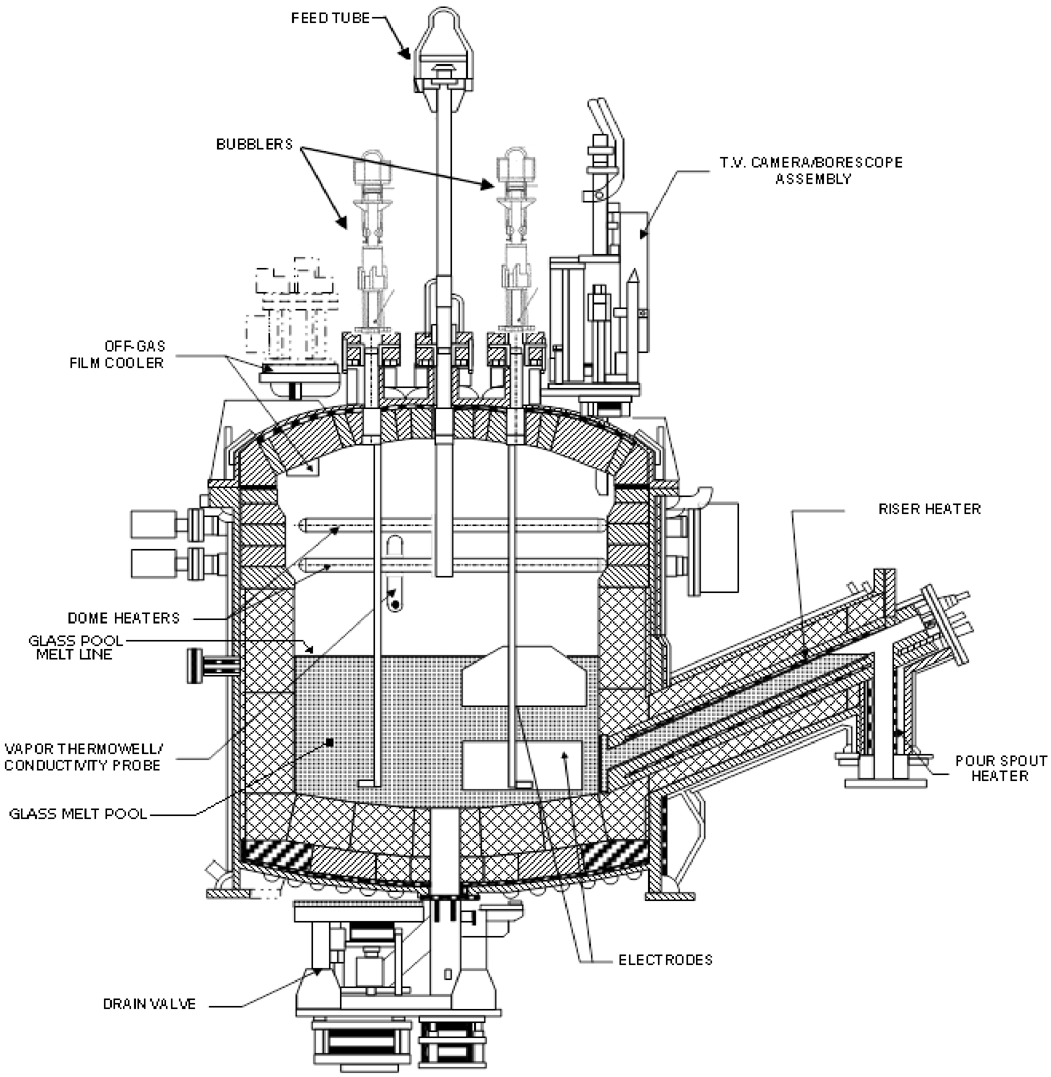

Figure 1. Cross-section of melter showing center feed tube as well as the B1 and B2 Bubblers.

BUBBLER OPERATION

The DWPF began processing with the bubblers installed at the end of September 2010 and they continue to be used up to the present. A change in glass pool dynamics was observed, as expected, when bubbler operation began. The most notable observation was the convergence of the upper and lower glass melt pool temperatures. This was definitive evidence of the increased glass circulation within the melt pool. In addition, there was a decrease in the power needed to maintain the melter dome heaters temperature setpoint. This provided evidence of the bubblers helping to turn over the cold cap and increasing the heat transfer from glass pool to cold cap. This heat transfer increase was vital to increasing the melt rate and subsequently the glass production rate. The nominal glass melt pool temperatures have also risen. Both upper and lower glass temperatures are in the 1130 to 1140°C range, thus making the increased heat transfer more effective in increasing melt rate.

The bubbler flow rate is normally set in the 28.3 to 39.6 L/min (1.0 to 1.40 ft^3/min) range while the slurry feed rate is in the 4.16 to 4.54 L/min (1.0 to 1.4 gal/min) range. The slurry feed rate prior to operating the melter with bubblers was in the range of 2.65 to 3.03 L/min (0.70 to 0.80 gal/min). DWPF canister production records continue to be achieved with the bubblers. These include highest monthly (40 canisters), fiscal year (277 canisters), and rolling 12 month period (337 canisters).

During the use of bubblers in the DWPF Melter several other bubbler benefits were discovered when melter related equipment failed. The first event was in December 2012 when the transformer for the Melter 2 lower electrodes failed. Therefore only the upper electrodes were available to keep the glass pool above the minimum temperature to prevent the formation of crystals in the melt pool. When this occurred the melter was not being fed and the bubbler flows were all set at the low idle rate of 1.42 L/min (0.05 ft^3/min). Initially the glass pool temperature began to drop. The upper electrode power was turned up to the maximum 90% output and the bubbler rates were increased to above 28.3 L/min (1.0 ft^3/min). These actions resulted in a more isothermal melt pool temperature of about 1000°C (which was above the calculated liquidus of the melt pool). If the bubblers had not been installed, it could have resulted in either a shutdown of the melter followed by an untried melter startup from a solid glass pool or the replacement of the melter. Instead the transformer was replaced about a day later and the melter continued to be used at DWPF. This prevented extensive downtime and kept the facility from using the one spare DWPF Melter that was available at that time.

In February 2013, one of four dome heater sets (dome heater D) in DWPF Melter 2 failed and therefore 25% of the dome heaters capacity was lost. The dome heaters are used in part to supply energy to help melt the feed. However, no noticeable drop in melt rate/glass production was observed in Melter 2. In fact, the record monthly DWPF canister production record of 40 canisters was reached after this dome heater failure (July 2013). When previously DWPF Melter 1 (non-bubbled) had lost one dome heater set, the melt rate/glass production rate decreased appreciably.

REUSABLE TOP COMPONENT BUBBLERS

The design life of the DWPF Melter bubblers is six months. This design life is based on bubbler corrosion testing in Hanford WTP pilot melters using Hanford non-radioactive surrogate WTP high level waste glass. [2] Based on this testing, it was determined that the bubblers were adequate to achieve the six month design life. [3] The limited design life is due to the life of the ¾” schedule 160 Inconel 690 bubbler pipes in the corrosive, high temperature melt pool. The attack on the pipes is normally greatest in the melt pool/cold cap area. The cold cap is unmolten feed which is on top of the melt pool where multiple chemical reactions occur to turn the cold cap into glass. A metallurgical examination of one of the bubblers from the first set removed from the DWPF after 6.75 months indicated little material loss on the outer diameter (OD). However, intergranular attack and internal void formation were noted near the OD surface. Total depth of attack near the glass melt line ranged from 1 to 2 mm (0.04 to 0.08 in). This degree of attack did not imply that the bubblers are in jeopardy at six months exposure. [3] However, the information gathered also did not allow for increasing the bubbler design life beyond six months.

Based on the six month life of the bubblers, new reusable top component bubblers were designed. Figure 2 shows one of the original bubblers (on the right) used for the first two years of bubbler operation and the new reusable top component conceptual design. The new reusable top component design allows for removal/replacement of the lower bubbler component which has the bubbler pipes while being able to reuse the more costly (about 3 times more than lower components) upper components. In addition, the new design results in a lower number of the bulky and difficult to cut up used top sections (weigh about 3 times more than lower components). The lower components can be easily size reduced by cutting the bubbler pipes. This is especially important as available storage space on the various DWPF cell covers for used contaminated equipment is becoming less and less the longer that DWPF is operated.

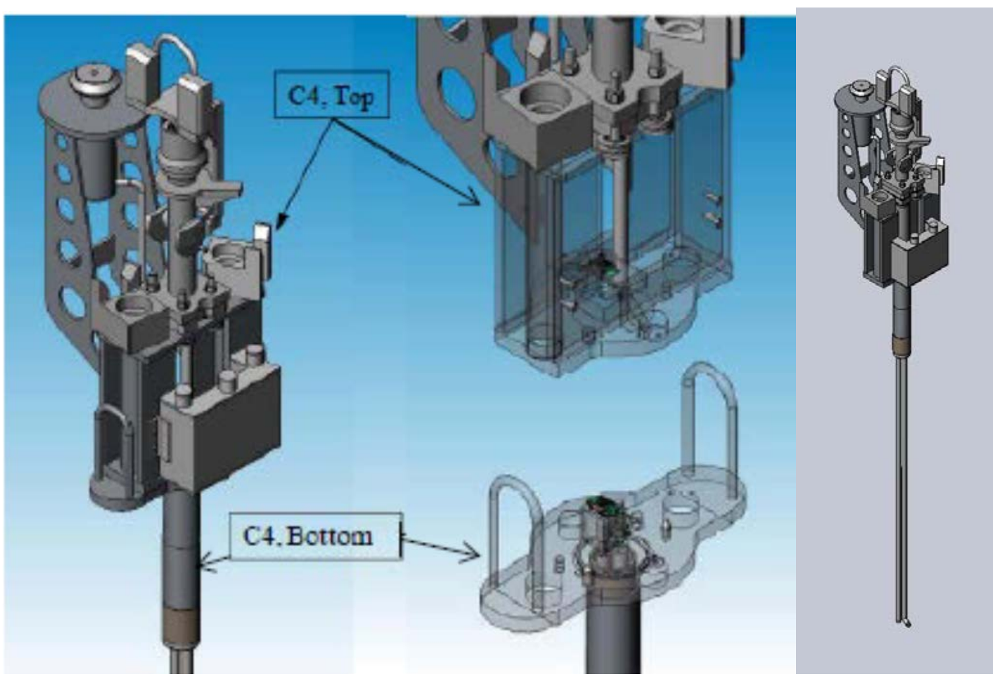

Figure 2. Initial dual purpose C4 Bubbler/Thermowell (right) and conceptual design for Reusable Top Component C4 Bubbler (left)

The two key design issues were 1) the remote connection of the thermocouple wires from the bubblers with the melt pool thermocouples (B2 was redesigned to be a dual purpose bubbler/thermowell like C4) between the top and lower components and 2) the seal between the top and lower components for the argon bubbler gas. The thermocouple connections were accomplished with the use of Hypertronics connectors installed on both the lower (male connector) and upper (female connector) for the dual purpose B2 and C4 bubbler/thermowells. These types of connectors had been previously used for other remote applications at SRS. For the argon seals, heat resistant silicon rubber seals were installed on the top of the lower component plate. Therefore the seals only needed to last six months. The seals and Hypertronics connectors were evaluated for the worst case temperature (120°C) and radiation dose (2 x 10^7 rads) scenarios expected at their locations. The projected minimum design life for the upper components was three years but could be longer.

The reusable top component bubblers were first installed in the DWPF in November, 2012 (see Figure 3 for DWPF Melter top view with new B2 bubbler/thermowell). This was the fifth overall set of bubblers to be used in the DWPF Melter. Installation of the bubblers was first proven by placing them in spare DWPF Melter 3 using a DWPF Y24 yoke to install and remove the lower components. The normal crane hook used for the installation of previous melter bubblers and other top head components was utilized with the Y24 yoke. The lower components are still being replaced every 6 months but all of the original upper components are still being used.

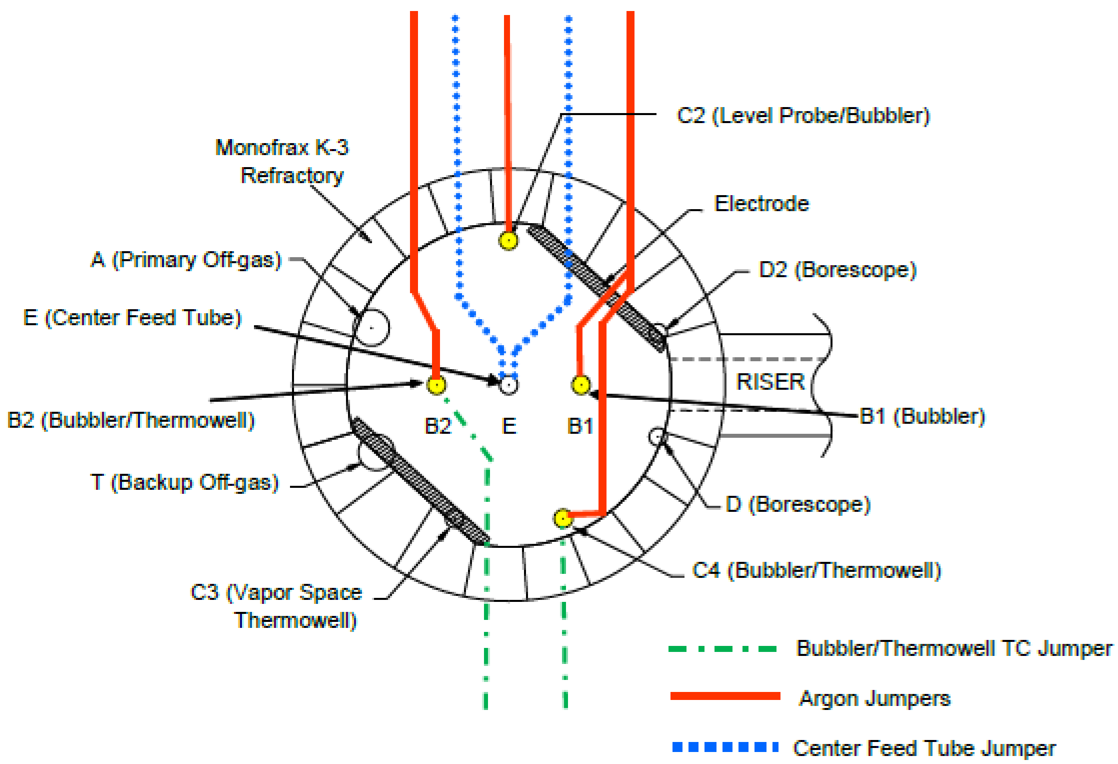

Figure 3. DWPF Melter top head with new B2 Bubbler/Thermowell and B2 Thermocouple Jumper

A spare set of upper components was fabricated when the first set (top and lower) of reusable top component bubblers was fabricated. Test jigs were fabricated which simulate the fit up of the four melter nozzles where the bubblers are installed. Additional test jigs were made to simulate the four upper component lower plates. These test jigs can be used to test the fit up of fabricated bubbler lower components with their respective upper components. This includes argon seals and thermocouple wire connections via the Hypertronics connectors located on the upper and lower components. This allows for pressure decay and flow tests for the argon as well as continuity testing for the thermocouple wires.

THERMOCOUPLE THERMOWELL ASSEMBLY DESIGN AND USE

During the first two years of bubbler usage the only melt pool thermowell was the dual function C4 bubbler. Type B Pt/Rh sheathed thermocouples which were used in previous DWPF melt pool thermowells were installed in the C4 thermowell pipe. Due to the small inner diameter of the bubbler pipe (1.56 cm or 0.614 inch), only five thermocouples could be inserted instead of six (three upper melt pool and three lower melt pool) as was done prior to bubblers. These thermocouples were designed for long term use (two or more years). With the change of the B2 bubbler to a dual purpose bubbler/thermowell bubbler for the reusable top component bubblers, the need to find a less costly thermocouple design became preferable.

The first design (see Figure 4) used incorporated a 1.27 cm (0.5 inch) outer diameter/ 0.95 cm (0.375 inch) inner diameter alumina protection tube with six type B thermocouples (0.762mm diameter wires). The thermocouple wires were insulated from each other by 2 hole or 4 hole alumina isolator tubes that were stacked on top of each other. The void space inside of the protection tube was filled with alumina powder. The powder was filled to the bottom of the tube to support the thermocouple junctions. The thermocouple wires extended above the top of the protective sleeve and were held in place by epoxy.

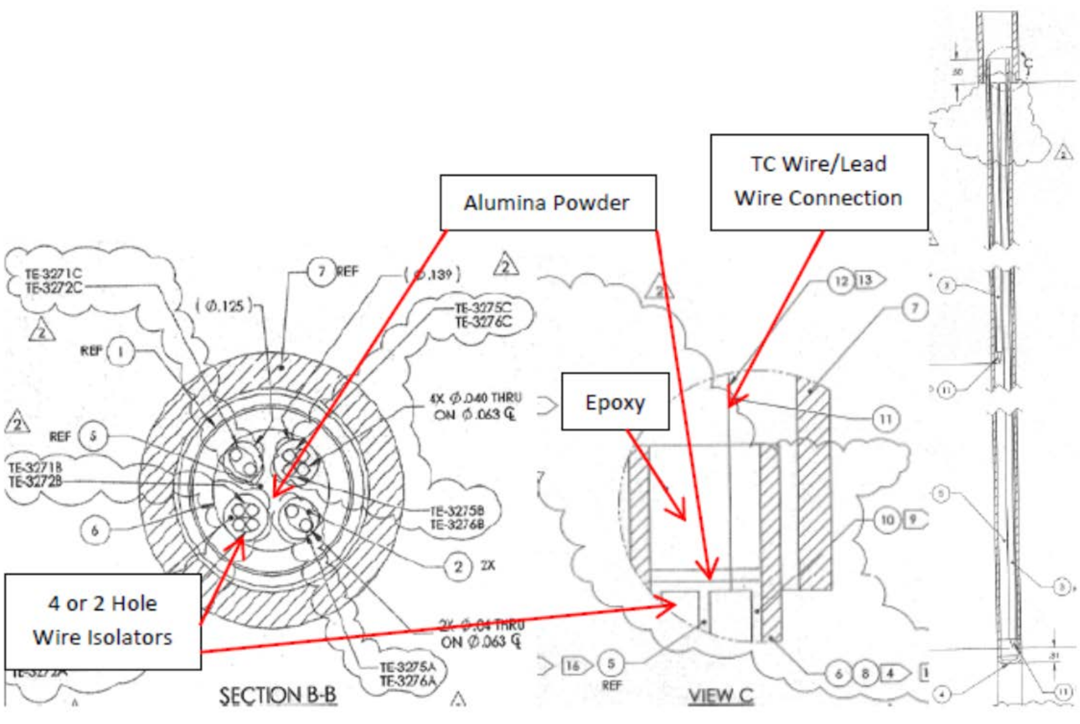

Figure 4. Details of the original thermowell assembly

These assemblies were used for the first time in bubbler set 5 (first set of reusable top head components) in both the B2 and C4 bubbler/thermowells. Over time multiple thermocouple failures occurred but enough thermocouples worked to allow melter operation to continue without changing out these two bubblers. Therefore the assemblies were redesigned when it became apparent that the original design had the following issues:

- The epoxy at the top of the assemblies locked in the thermocouples wires so that they were not free floating and therefore susceptible to breaking due to thermal expansion
- The wire isolators which held the thermocouple wires were not adequately supported at the bottom, especially the upper isolators/thermocouple wires which were only supported by 51 cm of alumina powder
- The thermocouple wires were brazed to lead wires above the top of the alumina protection tube and therefore could fail under stress

The key modifications to the design (see Figure 5) were as follows:

- The two and four hole alumina wire isolators were replaced with twelve hole magnesium oxide isolators that go down to the very bottom of the protective tube for both the upper and lower melt pool thermocouples
- The epoxy at the top of the assemblies was eliminated to allow the thermocouple wires to be free floating
- The thermocouple wire/lead wire connection was eliminated and the thermocouple wire was directly connected to the lower unit male hypertronics connector

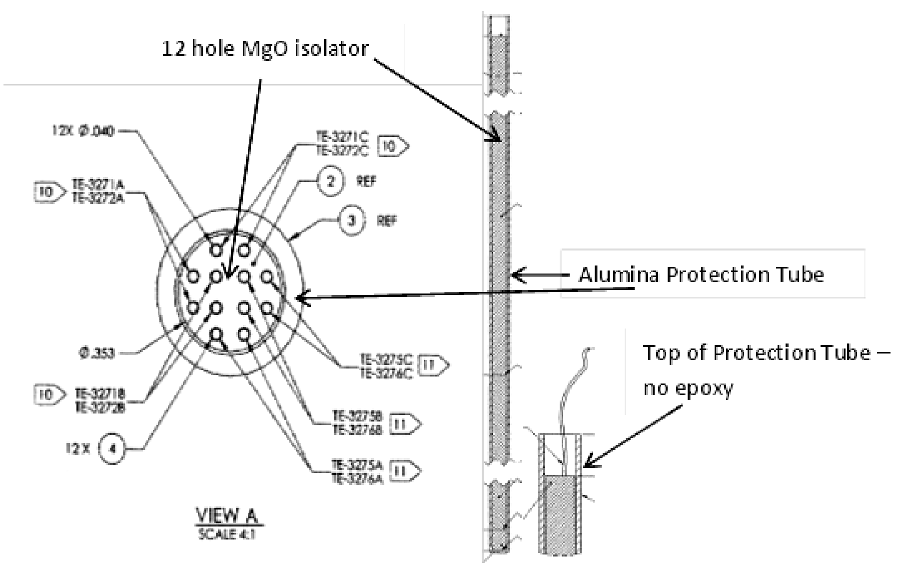

Figure 5. Details of the new thermowell assembly

For the Set 6 B2 lower bubbler/thermowell component, the old style thermowell assembly was installed while the C4 lower bubbler/thermowell component had 5 old style Type B Pt/Rh sheathed thermocouples installed. Several of the B2 thermocouples began to give erratic readings after about 4 months of use in the melter. The new thermowell assemblies were fabricated for the Set 7 installation in the DWPF Melter in September 2013. The B2 lower component had the new thermowell assembly. Due to the unproven design, 5 old style Type B Pt/Rh sheathed thermocouples were used in the C4 bubbler to try to ensure there would be enough working thermocouples during the 6 months the bubblers were used in the melter.

After six months of operation, all six thermocouples in the B2 thermowell assembly were still working. When the Set 8 lower components were installed in March of 2014, the new design thermowell assemblies were placed in both the B2 and C4 bubbler/thermowell lower components. No thermocouple failures occurred with the Set 8 B2 and C4 thermowell assemblies.

LOWER BUBBLER PROTECTIVE SLEEVES

As previously discussed, the first set of reusable top component bubblers were installed in November 2012 (Set 5). All six B2 melt pool thermocouples stopped giving a temperature indication (failed open) over a period of a few days starting on April 5, 2013. This indicated a catastrophic failure of the thermocouples, the Hypertronics thermocouple wire connectors, or the Inconel 690 thermowell pipe. The lower component B2 and C4 thermowells were replaced soon afterwards and a visual inspection of the removed B2 lower component showed a complete failure of the thermowell pipe at the glass pool melt line. Figure 6 shows a view of the B2 lower component thermowell pipe after removal where it failed at the melt line. A review of multiple melter parameters indicated that the main issue was the overall increase in the level of sulfate in the melter feed. At the time of the B2 failure, the sulfate level had progressively increased by about 50% with new sludge batches processed at DWPF since when the bubblers were first installed in September 2010. Although the amount was still below the DWPF glass limit (based on glass solubility), it was approaching levels that raised some concerns about whether or not the 6 month usage of the bubblers could still be achieved.

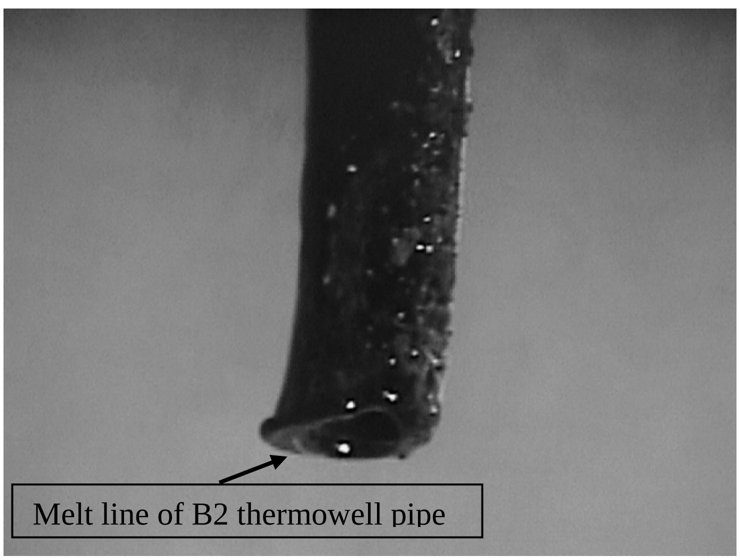

Figure 6. B2 Lower Bubbler/Thermowell Component pipe after removal in April 2013

Therefore a design change was made to add 2.54 cm (1 inch) schedule 10 pipes called protective sleeves over all bubbler pipes in the area of the melt line. The sleeves were welded at the top to the bubbler pipes. Originally they were to be 45.7 cm long (22.85 cm above melt line and 22.85 cm below melt line), but concerns were raised that this could cause interference issues for installation and removal of the lower components. Therefore the portion of the sleeves below the melt line was reduced by 5.1 cm (2 inches). The first set (7) to have the protective sleeves was installed in September 2013 after having remotability tests performed on all four lower components by using spare DWPF Melter 3. Figure 7 shows the protective sleeves.

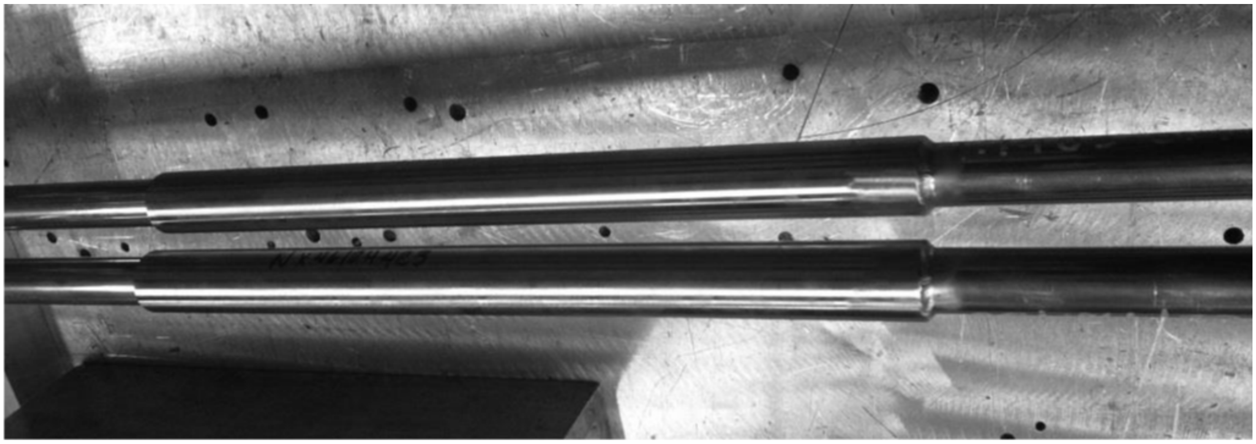

Figure 7. Protective sleeves on bubbler pipes

During the installation of the B1 lower component into the DWPF Melter, the bottom of the protective sleeve got caught on the B1 melter nozzle and the component fell off of the Y24 lifting yoke. Although the alumina isolator sleeves were damaged and subsequently removed (see Figure 8), the B1 lower component was installed without the alumina isolators and used in the melter without any issues.

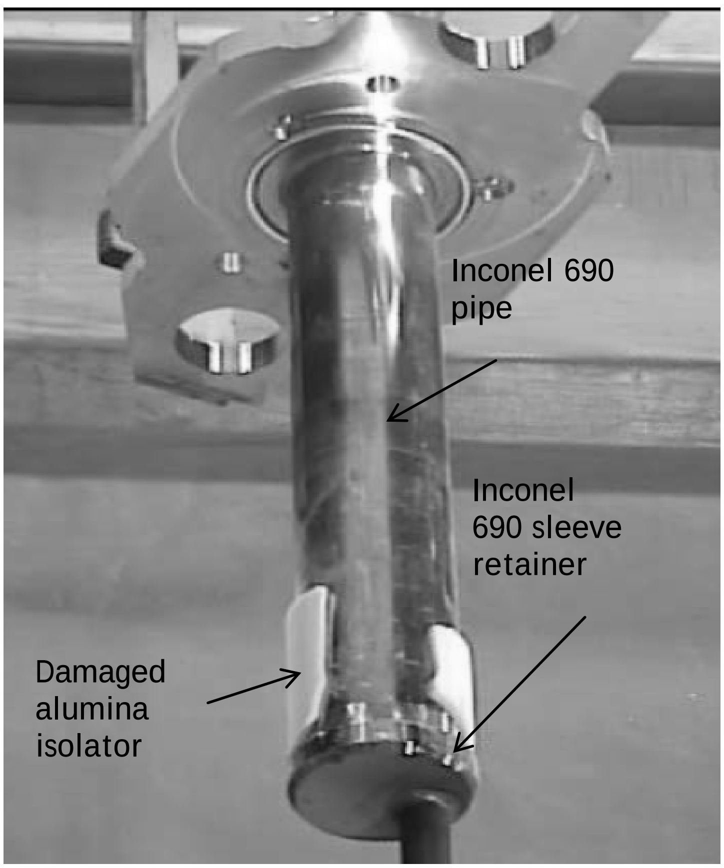

Figure 8. Set 7 B1 Lower Bubbler Component after being dropped during installation

A design change was made to put a 45 degree chamfer on the bottom of all subsequent bubbler protective sleeves. The next set installed (Set 8) had these chamfers and there were no installation problems. The Set 7 lower components were remotely inspected after being removed and all the bubbler pipes were intact. The protective sleeves were still there, although some of the lower portions of the sleeves were missing (see Figure 8). Finally, the bubbler pipes for the Set 7 bubblers were generally straighter than previous lower bubblers removed without the protective sleeves. The protective sleeves had apparently added some rigidity to the pipes at the melt line. There are plans to take samples of the sleeves and bubbler pipe for additional metallurgical evaluation and determination of the extent, if any, of the loss of the bottom of protective sleeves as indicated in Figure 9.

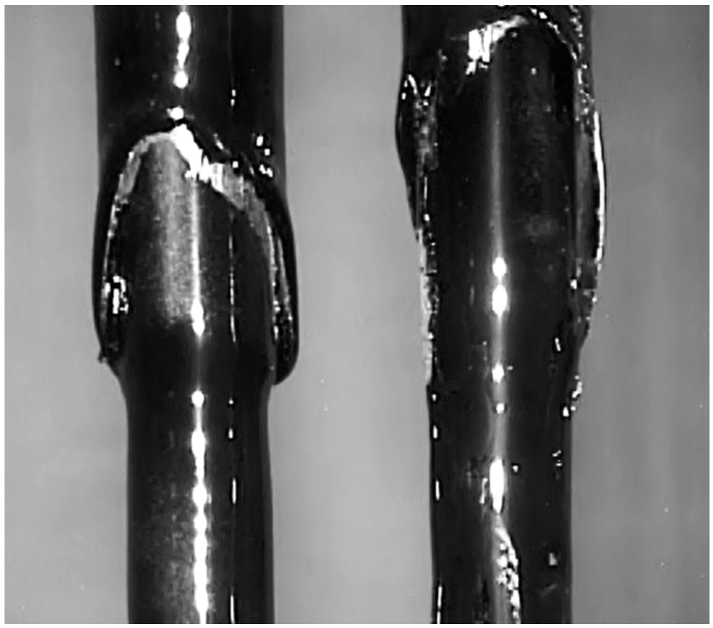

Figure 9. B2 Lower Component protective sleeves after removal from DWPF Melter

CONCLUSIONS / PATH FORWARD

The installation of the bubblers accomplished the goal of increasing the glass production capability of the DWPF Melter and bubblers continue to be used since initially being installed in September 2010. As a result of the higher glass production rates with bubblers, the DWPF has set radioactive operations monthly, fiscal year, and 12 month rolling canister production records. These accomplishments can be directly attributed to the bubblers ability to increase mixing/convection within the glass melt pool, thereby improving the heat transfer from melt pool to the cold cap. Furthermore, this has helped SRR take a significant step forward toward closing the HLW tanks at the aggressive pace set forth in the liquid waste contract at the SRS.

The bubblers have to be removed after six months of melter operations due to the wear experienced by the bubblers pipes in the melt pool. A new reusable top component design was employed to allow for removal/replacement of the lower bubbler component which has the bubbler pipes while being able to reuse the more costly (about 3 times more than the lower components) upper components. A new less expensive thermocouple design has also been successfully implemented.

With the increase in the sulfate levels in the glass in the last few sludge batches processed at DWPF, there were some concerns as to whether or not the bubblers could still last in the melter for the cited 6 months. After failure of one bubbler pipe at the melt line, protective sleeves were added to the bubbler pipes at the melt line. Initial data indicated that this has helped to ensure at least a 6 month usage life in the DWPF Melter.

As a path forward, the DWPF is continuing work to complete the final metallurgical examination of bubbler samples with protective sleeves to determine if the design life of the bubblers can be go beyond the current 6-month restriction.

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