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Installation of Bubblers in the Savannah River Site Defense Waste Processing Facility Melter

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ABSTRACT

Savannah River Remediation (SRR) LLC assumed the liquid waste contract at the Savannah River Site (SRS) in the summer of 2009. The main contractual agreement was to close 22 High Level Waste (HLW) tanks in eight years. To achieve this aggressive commitment, faster waste processing throughout the SRS liquid waste facilities will be required. Part of the approach to achieve faster waste processing is to increase the canister production rate of the Defense Waste Processing Facility (DWPF) from approximately 200 canisters filled with radioactive waste glass per year to 400 canisters per year. To reach this rate for melter throughput, four bubblers were installed in the DWPF Melter in the late summer of 2010. This effort required collaboration between SRR, SRR critical subcontractor EnergySolutions, and Savannah River Nuclear Solutions, including the Savannah River National Laboratory (SRNL). The tasks included design and fabrication of the bubblers and related equipment, testing of the bubblers for various technical issues, the actual installation of the bubblers and related equipment, and the initial successful operation of the bubblers in the DWPF Melter.

INTRODUCTION

The DWPF has been vitrifying SRS HLW from waste tanks since 1996 via the DWPF Melter (see Figure 1). The glass pool is heated via independently controlled upper and lower electrodes that pass current through the glass pool (Joule heating). The vapor space is heated by dome heaters which provide additional heat to the cold cap as well. The durable waste glass is vacuum poured from the melter into stainless steel canisters which hold about 1815 kg (4000 lb) of the glass. Since start of radioactive operations, multiple process improvements to the DWPF Melter have been made to increase utilization and melt rate. [1]

Even with these changes, yearly DWPF canister production has not exceeded 250, and most years has averaged 215 canisters. To allow for closure of 22 waste tanks in 8 years per the new SRR contract with DOE, this production rate needs to be increased to 400 canisters per year. The current melter configuration could not achieve the required higher melt rate. One method to increase the melt rate is to increase convection/mixing of the glass in the melter. An efficient way to increase this convection is to agitate the melt pool with bubblers.

In this method rising bubbles agitate the pool and increase the heat transfer to the cold cap. The cold cap is a layer of unmolten feed that is on top of the melt pool after being slurry fed into the melter as a mixture of waste, glass frit, and water. SRR critical subcontractor EnergySolutions worked with SRR to propose the installation of bubblers in the existing DWPF Melter via melter top head nozzles in which various top head components were previously inserted (thermowells, level probe, feed tubes, etc.).

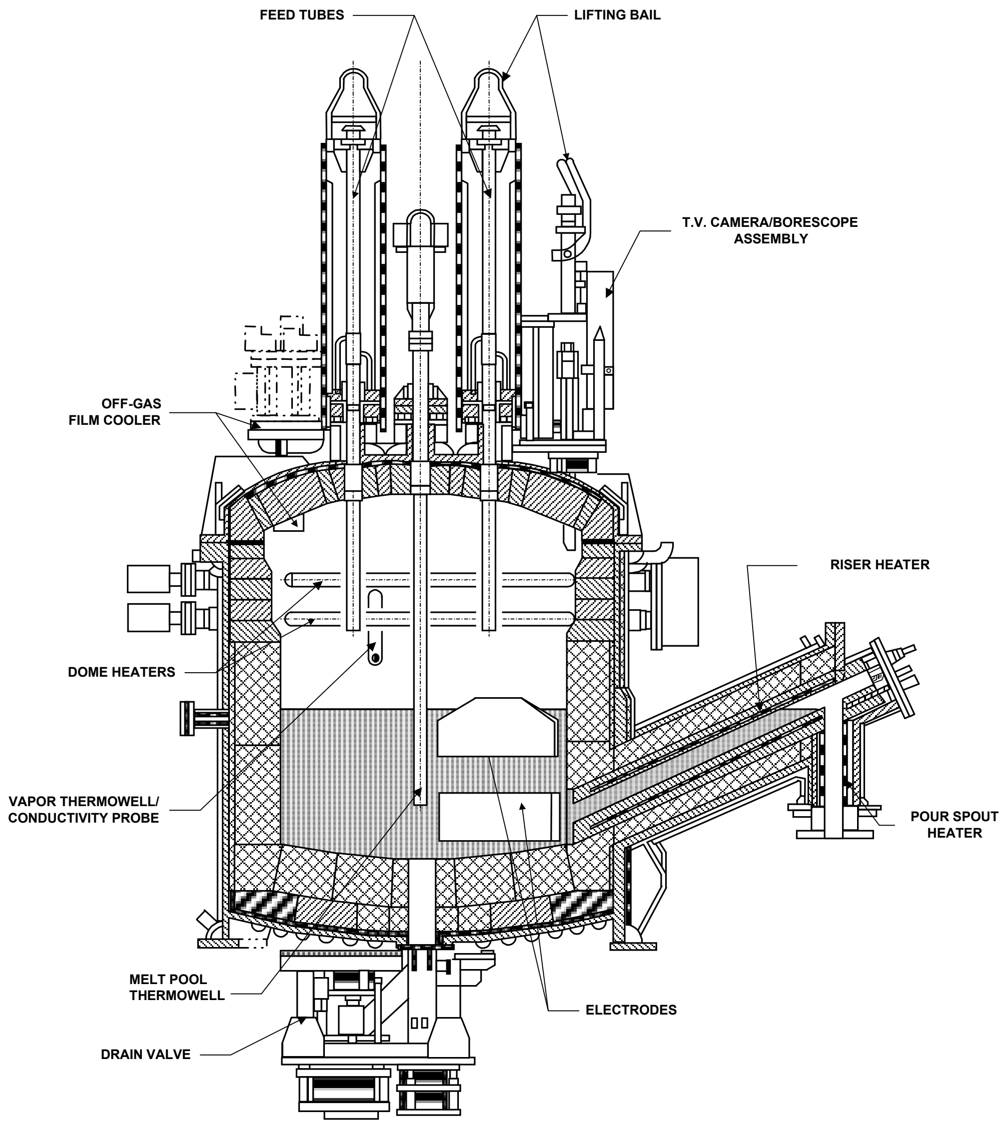

Fig. 1. Cross-Sectional View of the DWPF Melter prior to Installation of Bubblers

To achieve the installation of the bubblers in the DWPF Melter, multiple fast track tasks were required. The first was the development of a pre-conceptual design which maximized the number of bubblers in the melter. This pre-conceptual design defined the locations for four bubblers, eliminated one of two existing feed tubes, relocated the other feed tube to the melter center nozzle, and defined a basic jumper layout. Due to the limited availability of melter top head nozzles, two of the bubblers had to be dual function (bubbler/melt pool thermowell and bubbler/glass level probe).

EnergySolutions then designed the four bubblers with input from SRR. As noted above, one key task was the first time design of multiple function bubblers to allow glass level detection and measurement of glass temperature. Testing was performed by EnergySolutions to determine the impact of bubbling on glass level measurement as well as the impact of using argon versus air for the bubbler gas. Fabrication of the bubblers was performed for EnergySolutions by a subcontractor.

An existing spare DWPF feed tube was modified by SRS personnel per a design from SRNL to allow installation into the center nozzle of the DWPF Melter top head. All jumpers were fabricated by SRS personnel. After fabrication of the bubblers, feed tube, and jumpers, they were installed in a non-radioactive DWPF Melt Cell mockup to verify that all components could be remotely installed.

In addition to these tasks, SRNL performed tests on a pilot scale melter to determine the impact of bubbling on the current safety limits for off-gas flammability for the DWPF Melter. The tests determined the impact of bubbling on the surges of non-condensable (flammable) gasses while feeding a surrogate of the high level waste feed to be the first processed when the bubblers were installed and initially run in the melter. Calculations based on data gathered during this test determined that no changes to the DWPF Technical Safety Requirements were needed for bubbled operation.

This paper summarizes these various tasks as well as the initial operation of the DWPF Melter with bubblers.

PRE-CONCEPTUAL DESIGN

A number of assumptions and constraints were made for the pre-conceptual design, and some impacted the decision of which melter top head nozzles could be used and how many bubblers could be inserted. These assumptions are listed below:

- Certain existing functionality must be retained with the bubbler retrofit. This includes vapor space and glass pool temperature measurement, plenum pressure measurement, melt pool level indication, and slurry feeding capability. In order to retain these functions, some of the bubblers must perform multiple functions.
- Structural integrity/robustness of existing components (thermowell, feed tube, level dip tube) must not be negatively impacted by incorporation of bubblers.
- Bubblers cannot require compound crane movement for installation or removal. The bubblers should be installed by simply lowering them into the nozzles as is currently the practice for other components.
- Bubbler arrangement must be fairly uniform so that the bubbling pattern generated maximizes mixing and does not cause a cold cap accumulation in a non-bubbled region of the melter.
- Bubblers cannot be located any closer than 10 cm (4 inches) from the refractory wall or floor.

- If possible, use just one feed tube to maximize the number of bubblers that can be installed.
- If possible, use a feed tube design that does not require a parking position for the feed tube outside of the melter. If not, use the same basic feed tube design to allow the parking of the feed tube and insertion of feed tube into the melter.
- The bubbler retrofit design must consider ease of removal/installation of top head components and associated jumpers.
- The bubbler gas will be argon to address concerns of impacting the oxidation state of the glass as well as Inconel 690 oxidation.
- The design of the "wetted end" of the bubblers will be provided by EnergySolutions. The scope of the pre-conceptual design does not include that aspect.
- Bubbler life in the melter is assumed to be 6 months for the pre-conceptual design. Bubblers will be replaced on a 6 month frequency.

An initial review of the DWPF melter design indicated that the melter top head had five nozzles that would allow top head components to be inserted into the melt pool (nozzles B1, B2, C2, C3, and C4). However, one of these nozzles (C3) was ruled out as there was an interference issue with the melter electrodes. Since certain melter parameters must be measured, two of the units had to retain their existing functions as well as serve as bubblers. These two were C2 (glass level probe and vapor space pressure indication) and C4 (melt pool thermowell).

To allow the use of nozzles B1 and B2 (previously used for two feed tubes), it was proposed to insert one feed tube in center nozzle E (previously used for glass pump to increase melt pool circulation). Figure 2 shows the nozzle locations for the new bubbler top head components on the DWPF Melter as well as their associated jumpers.

A pre-conceptual design was performed by SRR which documented these decisions as well as proposed locations of jumpers to supply the bubbler gas (argon) to the various bubblers. In the DWPF the jumpers are connected to various nozzles in the Melt Cell wall to supply power or gases to melter related components. In addition, some jumpers are used as electrical connections for temperature indications or other control signals.

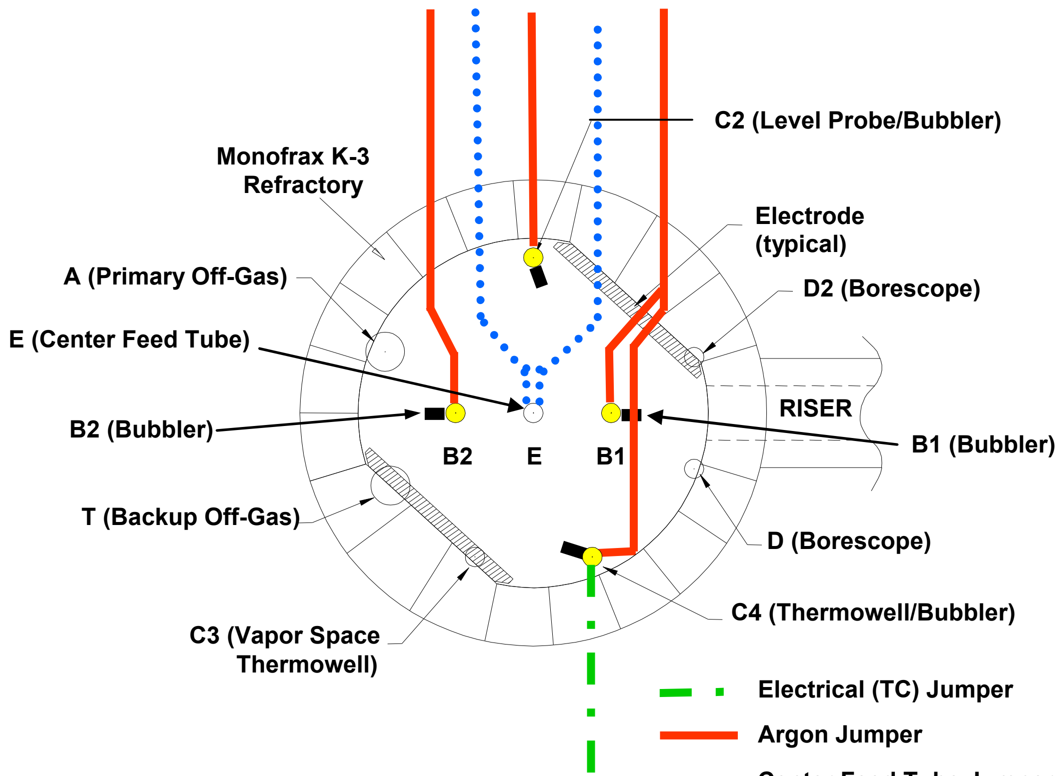

Fig. 2 – Nozzle Locations of DWPF Melter Bubblers, New Center Feed Tube, and Associated Jumpers

DESIGN

With the pre-conceptual design completed, several design tasks were required before fabricating the various bubblers, feed tube, jumpers, as well as other modifications to DWPF. SRR reviewed and approved all designed components and modifications. This effort required collaboration between SRR, SRR critical subcontractor EnergySolutions, and Savannah River Nuclear Solutions, including the Savannah River National Laboratory (SRNL). These design tasks were as follows:

- Design B1 and B2 bubblers, as well as dual purpose C2 level probe/bubbler and C4 glass thermowell/bubbler (EnergySolutions)
- Design new center feed tube by modifying existing feed tube design (SRNL)
- Design jumpers for bubblers and feed tube (SRR)
- Design modifications for additional argon supply piping for bubblers (SRR)

For the design of the four bubblers, the designs of the non-wetted upper ends (sections out of melt pool) were kept the same as existing top head component designs where possible. The existing top head components that were in the glass pool were made of Inconel 690 for the lower glass contact portion and 304L stainless steel for the upper end portions. These same materials of construction were used in the same locations for the bubblers. The existing top head components had 7.6 cm (3 inch) outer diameter pipes in the glass contact parts. However, since the DWPF top head nozzles used were only about 10 cm (3.9 inch) in diameter, this limited the length that the exit port for the bubblers could be from the horizontal bubbler pipes. Therefore the bubblers had 1.91 cm (0.75 inch) diameter pipes to allow the gas point injection ports to be as far away as possible from the vertical section of the bubbler pipe. This minimized the chance that bubblers would attach to the vertical bubbler pipe as they rose, thereby negatively impacting the effectiveness of the bubbling.

The B1 and B2 bubblers designs were basically the same except the bubbler exit ports face in opposite directions. Each of the bubblers had an accumulator tank in the argon supply to help stabilize argon supply pressure and flow. The targeted argon flow for all of the bubblers was 0-57 L/min (0-2 ft^3/min). New jumpers were designed to supply argon to these two jumpers. Figure 3 shows the C2 level probe/bubbler and C4 glass thermowell/bubbler. The B1 and B2 bubblers are very similar to the C2 level probe/bubbler but only have the one bubbler pipe.

The C2 level probe/bubbler (see Figure 3) had to have the existing functions of plenum pressure measurement and melt pool level indication as well as the new function of bubbling. The non-glass contact upper section remained essentially the same. Below the alumina isolator sleeves are three pipes. One short pipe is used to measure vapor space pressure and ends at the height that the existing level probe vapor space pressure port. The second pipe measures glass level and is at the same height as the port that measures glass level on the existing level probe. The third pipe (bubbler) is the same design as the B1 and B2 bubbler pipes but is slightly shorter as the outer part of the melter floor is higher than the center of the melter where the B1 and B2 bubblers are located. The existing level probe argon jumper was used as it had a spare port to allow an additional argon source for bubbling. As discussed previously, some modifications to the existing DWPF argon supply were designed by SRR.

As with the C2 level probe/bubbler, the C4 thermowell/bubbler design used a similar design to the existing thermowell for the non-glass contact upper end with the exception of an argon nozzle. This nozzle was placed in a position such that one argon jumper could supply argon to both the C4 thermowell/bubbler (see Figure 3) and the B1 bubbler. This design allowed the use of the existing C4 electrical jumper for the thermocouples in the thermowell which measure upper and lower glass pool temperatures.

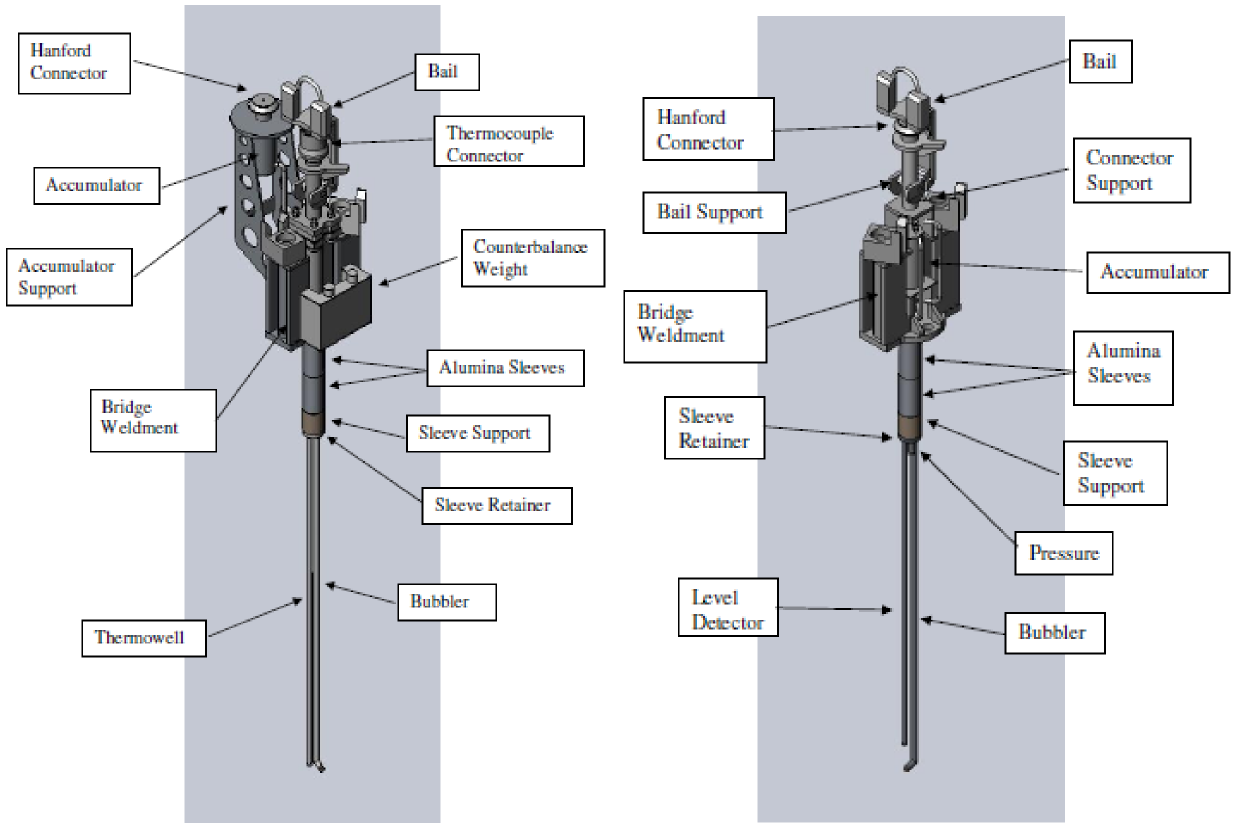

Fig. 3. Dual Function C4 Thermowell/Bubbler (Left) and C2 Level Probe/Bubbler (Right)

The final top head component that required redesign was the feed tube. Prior to the installation of the bubblers, there were two feed tubes that were located in nozzles B1 and B2. To maximize the number of bubblers, these two nozzles were used as locations for the B1 and B2 bubblers and a single feed tube was designed to be placed in the center nozzle E. This nozzle had previously contained a glass pump that had been used to increase melt rate. Due to differences between nozzles B1 and B2 versus E, changes were required for the feed tube. The existing feed tube design was used as a starting point, but the decision to not require a parking position for the feed tube outside of the melter allowed for a much simpler design. The new center feed tube design eliminated the support frame assembly required for the parking position. The water cooled feed tube that delivers the feed into the melter remained the same. This design allowed the use of an existing spare feed tube that had not been used with radioactive feed. The support frame assembly was removed and modifications which included new cooling inlet and outlet piping were made to this feed tube.

By only installing one feed tube in the melter for bubbler operation, the requirement for feed tube jumpers for both melter feed loops 1 and 2 was no longer needed. Therefore a jumper which delivered feed from only feed loop 2 was designed and fabricated for the initial bubbler installation. A second feed jumper is being designed/fabricated a dual feed loop jumper to connect either feed loop to the feed tube. In this new design, still only one feed loop would actually be used at any time for feeding the melter. A new design electrical jumper for the motorized electrical valve (MOV), as well as new design flush water and flexible cooling water jumpers were fabricated as well. Figure 4 is a drawing of DWPF Melter 2 with the bubblers, feed tube, and jumpers installed.

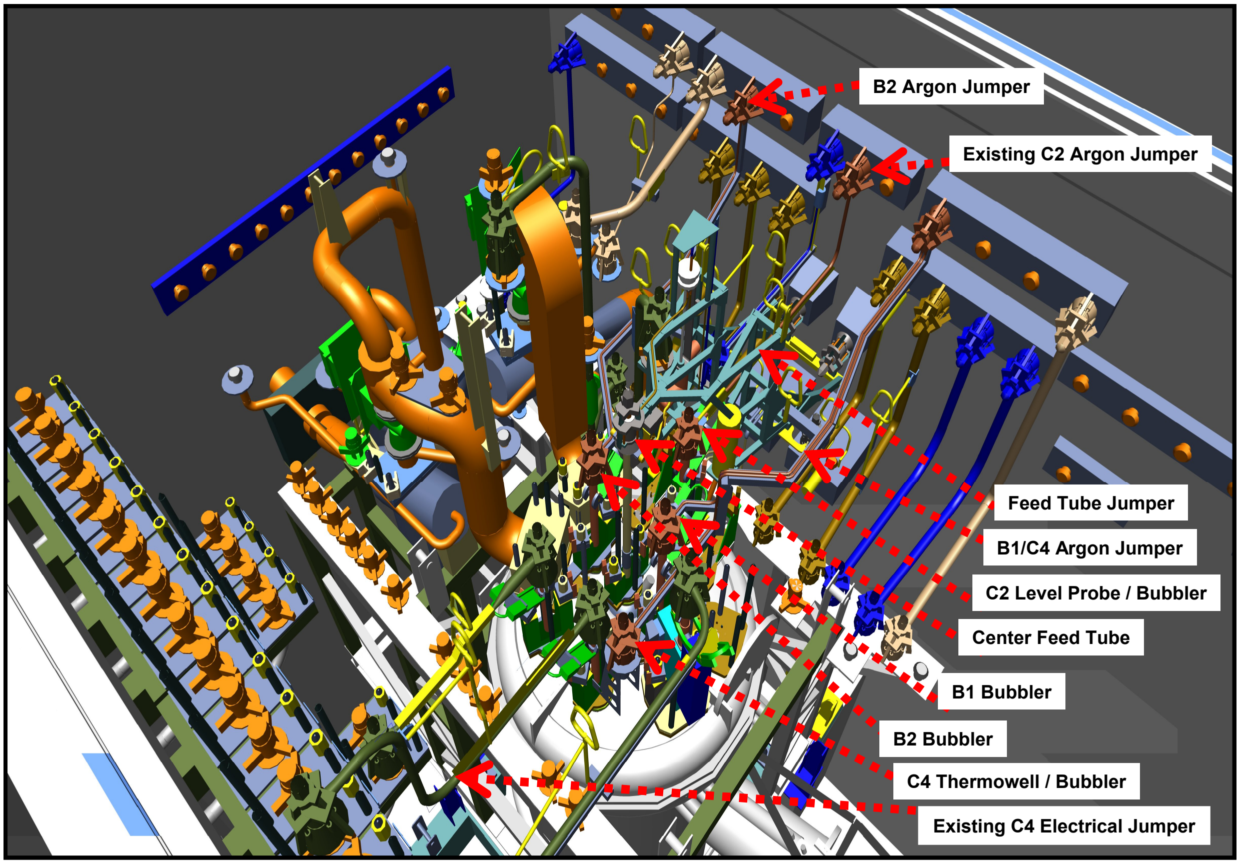

Fig. 4. Perspective View of DWPF Melter with Installed Bubblers, Feed Tube and Jumpers

BUBBLER RELATED TESTING

Concurrent with the design of the bubblers and related equipment, several tests were performed in support of the bubbler project as listed below.

- Level probe/bubbler operation
- Impact of use of argon as bubbler gas on glass oxidation state
- Assessment of impact of potential for melter off-gas flammability with use of bubblers

Level Probe/Bubbler Operation

The C2 level probe/ bubbler has both a bubbler leg and a glass level leg. There were concerns that due to the close proximity of the two legs (see Figure 2) that bubbler operation would impact the reliability and accuracy of the level measurement. In addition, various bubbler operating characteristics such as back pressure versus bubbler rate needed to be investigated, as well as the determination of effectiveness of mixing and operation with various bubbler orifice sizes. Therefore a series of tests were performed by EnergySolutions in the Vitreous State Laboratory

(VSL) at Catholic University. The DM1200 melter unit was selected for testing since it provides both sufficient melt surface area (50%) and glass pool depth (85%) of the DWPF Melter.

A level probe/bubbler was fabricated which had prototypic bubbler and level probe legs of the DWPF bubbler/level probe. Two different bubbler orifice size diameters of 0.64 cm (0.25 inches) and 0.32 cm (0.125 inches) were tested. The level probe gas flow rate was set the same as that currently used by the DWPF level probe (14.2 L/hr or 0.5 ft^3/hr), and the bubbler gas flow rate was tested over a range of 17.0 to 56.6 L/min (0.6 to 2 ft^3/min). The glass pool was controlled at about 1150ºC. The estimated glass viscosity at this temperature was about 6 Pa·s (60 poise).

The main conclusions of the test are as follows:

- The bubbler agitation affected the indicated glass level by less than 0.25 cm (0.1 inches) and therefore had no discernible affect on the bubbler's ability to accurately indicate glass level.
- Both bubbler orifice sizes resulted in acceptable mixing and operation, although the larger 0.64 cm (0.25 inches) orifice may have been slightly more effective for mixing. The 0.64 cm orifice was deemed to be better as it is adequate for the full range of anticipated bubbler rates.

Impact of Use of Argon as Bubbler Gas on Glass Oxidation State

One of the important glass properties controlled at DWPF is the oxidation state of the glass as indicated by REDOX (REDuction/OXidation or $Fe^{2+}/\Sigma Fe$). A glass REDOX of zero indicates that the glass is fully oxidized. DWPF normally targets a REDOX of 0.2, while the range is kept between 0.33 and 0.1. If the glass in the melter is too reduced (REDOX above 0.33), then the noble metals present in the waste may be reduced to their metallic form and settle to the bottom of the DWPF Melter. Over time this could result in a conductive layer in the bottom of the melter and negatively impact the ability of the melter to keep the lower melt pool hot enough for vitrification of the waste. If the glass is too oxidized (REDOX below 0.1), foaming in the melter could lower the melt rate. [2]

Argon was chosen as the bubbler gas since it is inert and has been used in the DWPF Melter with the glass level probe and the glass pump without any negative consequences. A concern was later brought up that argon could act to reduce the glass in the melter. At that time there was a set of tests planned to be performed by VSL on a projected future SRR sludge batch (high alumina SB19) with and without air bubbling. Therefore testing with argon bubbling was added to the test scope so that impacts of argon bubbling on REDOX (versus no bubbling and bubbling with air) could be better determined. Each test (Test 1- air bubbling, Test 2 - no bubbling, and Test 3 - argon bubbling) lasted 50 hours and was performed in the order Test 1, Test 2, and finally Test 3. The tests were performed with the DM100 ($1/20^{th}$ melt surface of DWPF Melter). Glass pour samples were taken throughout the tests. All glass samples from Tests 1 and 2 contained no measurable divalent iron (REDOX of 0) while the Test 3 glass samples with argon bubbling showed a gradual rise in REDOX up to about 0.15 (15% divalent iron). This initially suggested that argon may have reduced the melt pool.

After the VSL tests, SRNL performed testing in the Cold-Cap Evaluation Furnace (CEF) with simulated SRR Sludge Batch 6 (SB6) feed with and without argon bubbling to assess the impact of bubblers on melter off-gas flammability. SB6 is the sludge batch to be processed when the bubblers were to be installed. The feed was made fully oxidized, and glass pour samples were taken throughout the test. All glass pour samples taken had less than 0.01 percent (detection limit) divalent iron. In other words, the glass was fully oxidized. This test indicated that bubbling with argon did not reduce the glass pool, therefore contradicting the VSL test results.

With these mixed results, SRR did not change the decision to use argon as the bubbler gas. A DWPF Engineering Position paper was written documenting the decision to target a feed REDOX of 0.1 (versus normal target of 0.2) during the initial operation of the bubblers in the DWPF Melter. This would allow some REDOX "buffer" if indeed bubbling with argon reduced the glass.

Assessment of Impact of Potential for Melter Off-Gas Flammability with Use of Bubblers

Whenever an equipment or process change is made at an SRR facility, an evaluation must be made to determine if the change will impact the documented safety analysis (DSA) for the facility. One of the accident scenarios evaluated for DWPF involves flammability of the melter off-gas and resultant explosion in the off-gas system. The review process indicated that an assessment of the potential for impacting DWPF Melter off-gas flammability was required before the bubblers could be installed (a similar flammability assessment is also required for each new sludge batch before it is processed in the DWPF Melter).

An existing SRNL melter and off-gas system were modified and two melter bubblers installed to perform tests with simulant SB6 feed. SB6 is the sludge batch to be in process when the bubblers were to be installed. Both bubbled and non-bubbled conditions were run to determine the impact of bubbling on off-gas flammability. The main findings were as follows:

- The existing correlation between the measured and actual melter vapor space gas temperatures is valid for both bubbled and non-bubbled conditions (vapor space temperature is a key parameter that is monitored to prevent a flammable condition in the off-gas system).
- The existing defined approved region of DWPF operation during both normal and seismic operation is still sufficient to ensure the safety of the offsite public and the onsite worker.

FABRICATION AND INSTALLATION OF BUBBLERS AND RELATED EQUIPMENT

EnergySolutions, via a contract with SRR, arranged the fabrication of two sets of bubblers. The two bubbler sets were fabricated in the summer of 2010 and shipped to SRR in late August, 2010 after being inspected at the fabricator's site by SRR personnel. In addition to the bubblers, several jumpers had to be fabricated by SRS Construction personnel.

When the bubblers were received at SRS, SRS construction personnel installed thermocouples into the two C4 thermowell/bubblers. Both sets of bubblers and associated jumpers were remotely installed in the DWPF Melter 3 which is currently in the 717-F mockup facility. This activity helped to ensure that the bubblers and jumpers could be installed in Melter 2 which is currently operating at the DWPF.

After the mockup activities were completed for the first set of bubblers, the bubblers and associated jumpers were transported to DWPF and installed during a scheduled outage in September 2010. In addition, a borescope was installed so that a view of the cold cap during bubbler operation could be obtained.

INITIAL BUBBLER OPERATION

The four bubblers were started with a flow rate of 14.2 L/min (0.5 ft^3/min) on September 28, 2010 and then processing of SB6 feed in the melter began at 3.1 L/min (0.8 gal/min). This was the SB6 feed rate previous to bubbler installation. The bubbler flow rates were gradually increased over several days to about 34.0 L/min (1.2 ft^3/min) while the feed rate was incrementally increased to about 4.7 L/min (1.2 gal/min). Several overall observations were made during the initial bubbler operation.

- Use of the bubblers has changed the melter glass pool dynamics. For example, initial argon flows of 14.2 L/min (0.5 ft^3/min) per bubbler caused the lower indicated melt pool temperatures to drop about 140ºC in less than one hour with the upper and lower electrodes in manual control at fixed outputs. When argon was shut off later, the lower pool increased by 90ºC in 9 minutes. Adjustments to electrode power outputs are now made when bubbler flows are changed to prevent these rapid melt pool temperature changes.
- The bubblers increased melt pool circulation. This is indicated by the convergence of the upper and lower glass temperatures when the bubblers were used.
- The approximate increase in instantaneous glass production rate with the use of bubblers was from about 59 kg/hr (130 lb/hr) without bubblers to about 91 kg/hr (200 lb/hr) with the bubblers. A greater increase may be possible as the operation of the bubblers in the melter has not yet been optimized and the slurry feed being vitrified during initial bubbler operation was lower in weight percent solids (less than 40%) than the desired 45%. If the slurry feed weight percent solids is kept above at of above 45%, then a yearly canister production rate of 400 canisters per is achievable. However, this production rate cannot be reached until several DWPF feed preparation enhancements are made to allow a higher feed preparation rate. These are needed as currently the melter can vitrify the feed faster than it can be made. These enhancement projects (including new feed preparation flowsheet and dry frit addition) are currently being worked on and will be implemented in the DWPF in the next few years.

CONCLUSIONS/ PATHFORWARD

The following conclusions can be drawn from the installation and initial operation of bubblers in the DWPF Melter. In addition, several pathforward items are planned as well.

Conclusions

- Instantaneous melt rate was increased with the operation of the bubblers from about 59 to 91 kg/hr (130 to 200 lb/hr). Greater gains may be possible as the operation has not been optimized and the feed initially processed had a lower than desired weight percent solids.
- This initial melt rate increase to 91 kg/hr should result in a canister production rate of about 400 per year when enhancements are completed on the DWPF feed preparation system to increase the rate that the feed can be prepared. Currently the melter can vitrify the feed faster than it can be made.
- The melter glass pool dynamics were different with bubblers. Indicated glass pool temperatures changed quickly when bubbler rates are either reduced or increased.

Pathforward Items

- The first set of bubblers will be inspected after about 3 months of service to verify that there is not unexpected bubbler erosion/corrosion (expected life in melter is 6 months).
- Improvements to the bubbler designs will be pursued with regards to ease of fabrication and possible reuse of the non-glass contact components of the bubblers. Reuse of the non-glass contact bubbler components will decrease fabrication time and costs as well as reduce the number of contaminated top head components that must be disposed.
- Implementation of several DWPF feed preparation improvements to increase feed preparation rate will be performed in the next few years to allow achievement of the 400 canisters per year production goal.

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