Advanced Joule Heated Melter Design to Reduce Hanford Waste Treatment Plant Operating Costs - 11131

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ABSTRACT

The operating costs for vitrifying radioactive waste is a major contributor to the overall project cost and increasing the melter production rate can significantly reduce costs. Increasing the rate at which the Waste Treatment Plant (WTP) can convert Low Activity Waste (LAW) and High Level Waste (HLW) into glass will reduce the total waste processing time and will thus lower the operating costs for that project. Each year of operation costs approximately $500 million so that increasing the melter throughput by a factor of 2 could potentially save several billion dollars. This paper describes the next generation melter design activities underway to develop the Advanced Joule Heated melter technology for implementation at the WTP for the purpose of increasing the waste processing rate and glass waste loading.

Energy*Solutions* (ES) and the Vitreous State Laboratory (VSL) at the Catholic University of America, the original designers of the WTP vitrification melters, have been contracted to develop their Advanced Joule Heated Melter Technology for potential use as Next Generation Melters (NGM) at the WTP. The WTP is currently designed to produce waste glass at rates of 30 metric tons per day (MT/d) and 6 MT/d, for the LAW and HLW plants, respectively. The goal for the NGM project is to achieve glass production rates of at least 42 MT/d and 8 MT/d, for LAW and HLW, respectively. ES, in collaboration with their exclusive teaming partner the VSL, are designing LAW and HLW NGMs per a program that maximizes the performance of the melters at a minimum risk. The first stage of the design, referred to as the basic NGM, will utilize three technologies that have previously demonstrated during large scale melter testing to raise process rates. These combined technologies are predicted to increase the processing rates to 90 MT/d and 18 MT/d, for LAW and HLW facilities, respectively. The second phase of the NGM design is producing enhancements to the basic NGM design that can be added to further increase the processing rate. These enhancements are designed as “add-ons” because while they are promising new technologies they have not been demonstrated at the same scale as the basic technologies.

INTRODUCTION

Background

The WTP baseline LAW and HLW melters were designed by ES with work completing in 2003. The melters were designed to be an integral part of the WTP facility with their size, weight, and capacity matched to the project requirements. The baseline melters are electrically heated, ceramic-lined glass furnaces. They contain a pool of molten glass that is maintained at a nominal temperature of 1150ºC by passing electrical current from submerged metallic electrodes through the glass. The waste feed slurry, which is a mixture of waste and glass forming chemicals, is dropped onto the surface of the molten glass where heat from the melt pool evaporates water from the feed, decomposes feed chemicals, and eventually melts the remaining feed material into the glass pool. The material on top of the glass pool in the process of melting into the pool is referred to as the cold cap. Molten glass is periodically discharged from the melter into stainless steel canisters to maintain a relatively constant melter glass pool level.

The glass pool is lined with highly corrosion resistant refractory blocks. The refractory is installed in layers with its outermost surface being water cooled. The gas space above the glass pool is also lined with refractory to produce a plenum where entrained feed materials separate from steam and gases exiting the melter. The melter is capped with a lid, which is lined on its bottom surface with corrosion-resistant refractory. The entire melter refractory package is encased by a metallic shell referred to as the gas barrier that allows the melter to be maintained under vacuum and prevents the escape of melter exhaust gases.

The melter glass pool is actively mixed by a patented/proprietary glass pool mixing system. This system injects gas into the glass pool (i.e., sparging) to force convection within the molten glass thus increasing the waste-processing rate. The gas is injected through replaceable assemblies referred to as bubblers.

Purpose

It has been determined that increasing the waste processing rate of the melters could significantly shorten the length of time required to complete the processing of Hanford tank waste [1]. The Next Generation Melter program has been established to develop technologies that can accelerate the WTP processing rate. A portion of that program is focused on development of the Advanced Joule Heated Melter (AJHM) technology to meet this need. Energy*Solutions* has been engaged in developing a conceptual design for implementing the AJHM for the WTP. The goal of the AJHM design work is to develop the technology to increase WTP throughput without imposing an undue burden on the associated physical plant, connecting equipment or services. The NGM would replace the baseline WTP during the first melter replacement. This paper discusses the results of the AJHM design work completed to date.

CONCEPTUAL DESIGN

The conceptual design approach being taken for the implementation of the AJHM technology for the WTP, which will greatly increase the waste throughput, is to minimize the potential impact on the facility structure, services, operations, and safety basis. This will be achieved by maintaining the existing interfaces and foot-print of the baseline LAW and HLW melters in the design of the AHJM. Accordingly, this paper will describe the AJHM technology in terms of the changes to be made to the baseline melter design.

The design work has been broken into two areas: Basic AJHM, and Enhanced AJHM. The purpose of dividing the work is to allow the design to progress to include those changes and technologies that have been demonstrated at scale and therefore have a high probability of success while posing low risks (Basic AJHM). By itself, the basic AJHM possesses the potential to greatly increase the melter throughput thus lowering WTP costs. In addition to the basis AJHM, other technologies and changes, which do not have the same level of supporting data and thus pose a higher level of risk, are being developed as enhancements to the basic AJHM to allow them to be added in a modular fashion once they have been demonstrated at scale (Enhanced AJHM). The enhanced AJHM will provide the capability to maximize the melter throughput.

Basic AJHM Design

The changes to the baseline design that form the Basic AJHM fall into three main areas: increasing glass pool temperature, increasing glass pool surface area, and optimizing the glass pool bubbling.

ES and the VSL have, and continue to operate test vitrification systems with the data gathered from them used to support the design of the AJHM. Three of these systems are the DM100, DM1200, and DM3300. Each of these system is centered about a joule heated, ceramic lined melter, which are essentially smaller versions of the WTP melters. The rated throughput of these systems is based on the glass pool surface area. The surface area of these test system is $0.11m^2$, $1.2m^2$, and $3.3m^2$ for the DM100, DM1200, and DM3300, respectively.

Increased Glass Pool Temperature

Increasing the operating temperature of the melter glass pool has been shown to raise the waste processing rate through extensive testing [2, 3, 4]. The testing results show that the production rate can be expected to increase by approximately 1% for each 1^oC increase in temperature [5, 6, 7, 8]. Testing performed at large scale generally supports this with an increase in production rate of approximately 60% for a 75°C temperature increase (refer to Figure 1). The AJHM will operate at temperatures of up to 1250°C compared to the baseline operating temperature of 1150°C. This change is predicted to increase the melter waste processing rate by 100% for both the LAW and HLW melters.

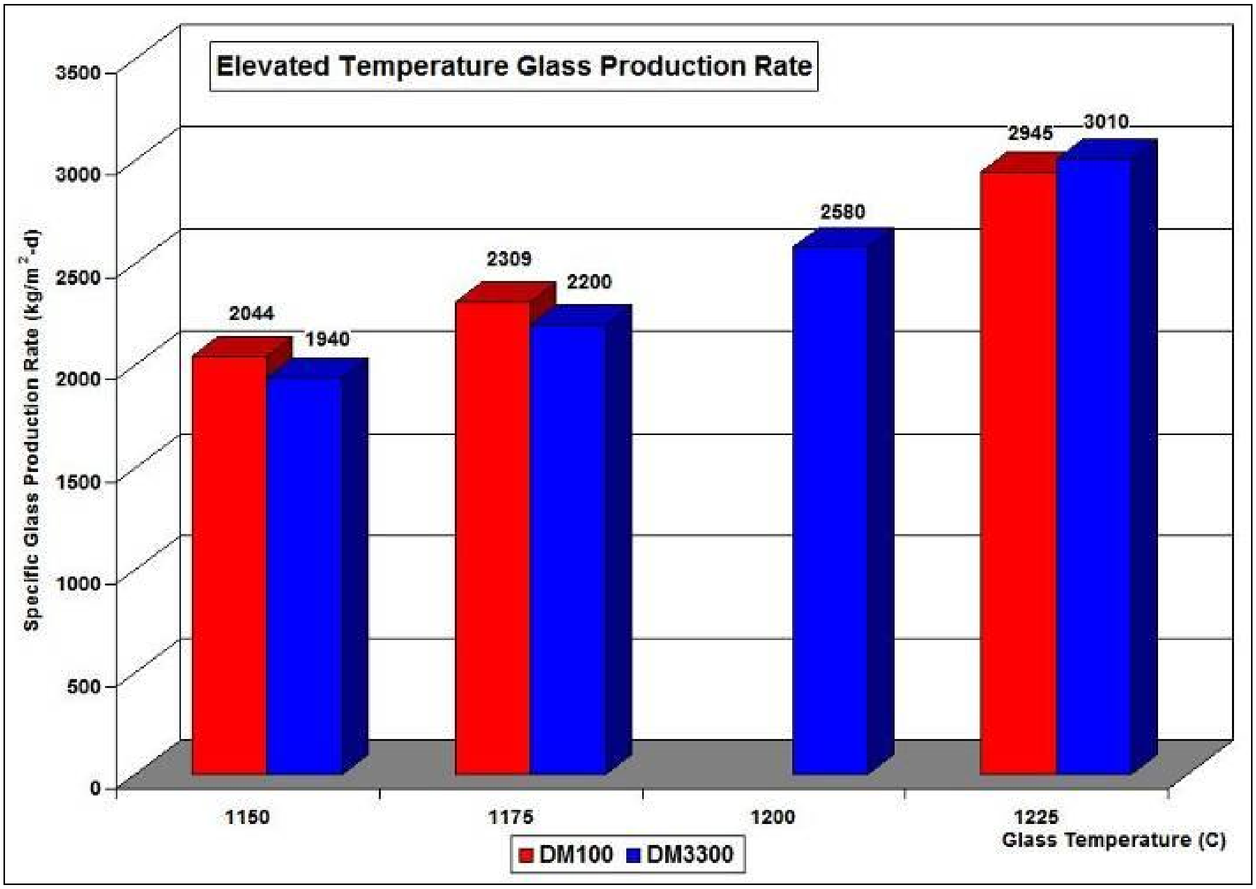

Figure 1: Test Data for Increased Melter Throughput with Increased Glass Pool Temperature

Increasing the temperature will have an impact on the melter components that will be exposed to this elevated temperature. The glass contact refractory is fabricated from Monofrax K-3 and Monofrax E. These materials are capable of operating at temperature in excess of 1250°C. At the elevated temperatures, it is anticipated that the rate of corrosion will increase. However, corrosion rate measurements of these materials are routinely made at 1208°C, which may partially explain why corrosion rates measured in operating melters, which operate at 1150°C, are much lower than that measured in laboratory tests. The melter refractory design corrosion rate is up to 1 inch per year. Measurements of refractory corrosion at 1250°C indicate that the anticipated rate of corrosion is less than this design value [12]. Therefore, there will be little impact on the melter refractory life from operation at these elevated temperatures.

Increasing the glass pool temperature will also pose a challenge to the metal components within the glass pool. Specifically, the electrodes are non-replaceable metallic component that must withstand the effect of the hotter glass for the design life of the melter. Previous testing performed by the VSL determined the corrosion rates of a selection of alloys at elevated temperature [14, 13]. These tests indicate that the electrode material should be changed from Inconel 690 (UNS N06690) to Inconel Type MA 758 to better accommodate operation at elevated temperatures. Additional testing of alloys using the most recent glass compositions is on-going to verify these results.

Increased Glass Pool Surface Area

The amount of feed material undergoing transformation into glass within the melter cold cap is directly proportional the melter throughput. Increasing the glass pool surface area will raise the amount of feed material within the melter being converted and will thus raise the production rate. It has been shown through the correlation of existing test data from previous HLW and LAW melter testing, including the LAW DM3300 pilot melter (3.3 m^2 glass surface area) operated at ES facility from 1998- 2003, the DM1200 at the VSL (1.2 m^2), and the DM100 at the VSL (0.11 m^2), that for a given level of glass pool bubbling, the specific glass production rate is approximately constant, independent of the overall size of the glass pool (refer to Figure 2). These data show that the waste processing rate is directly related to the size of the melter glass pool and the resulting production rate for this scale up can be reliably predicted.

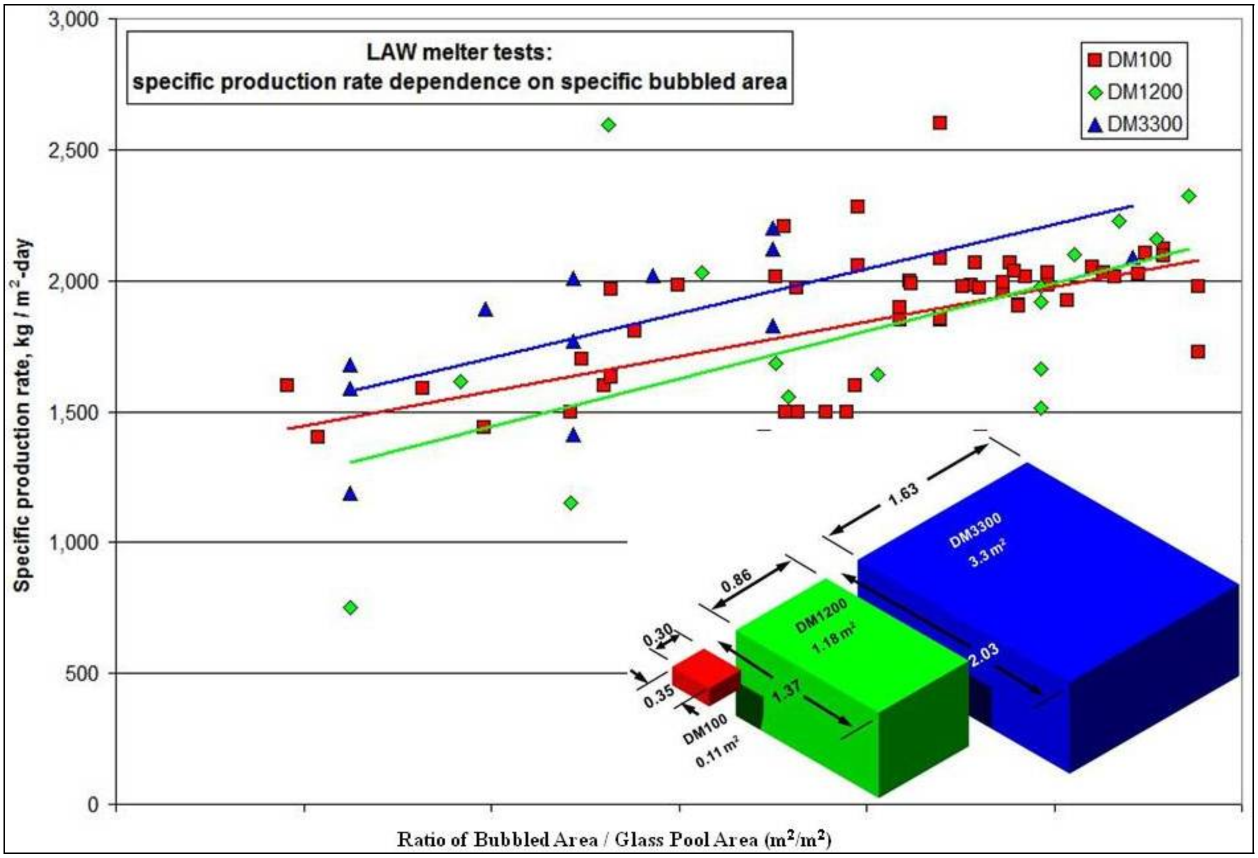

Figure 2: Melter Glass Pool Scaling Data

Increasing the melter glass pool surface area without changing the melter external dimensions has been one of the major focuses of the AJHM design work. While the specific features of the LAW and HLW melters are very different, a common approach was used to maximize the glass pool surface area within the available external envelope. The melter structural modules (walls, shielding, etc.) were evaluated and excess space re-dedicated to expanding the glass pool. The glass pool refractory was evaluated to take advantage of the most recent data from the operating HLW pilot melter (DM1200), which allowed further expansion of the glass pool. The combination of these changes has allowed the LAW melter glass pool surface area to be increased by 50% and the HLW melter glass pool surface area to be increased by 27%. This will lead to a 50% and 27% increase in the LAW and HLW melter production rate for LAW and HLW, respectively.

Optimized Glass Pool Bubbling

Energy*Solutions* and the Vitreous State Laboratory have developed a proprietary glass pool bubbling technology that has been demonstrated to greatly enhance the waste processing rate of the melters [15]. The baseline WTP melters incorporate this technology. However, the installation of bubbling in the HLW is not optimal due to space constraints when they were added late in the original design process. Optimizing the bubbler installation can increase the waste processing rate without the potential negative side effects associated with high rates of bubbling gas injection (refer to Figure 3). The installation of bubblers for the HLW melter will be optimized in the AJHM.

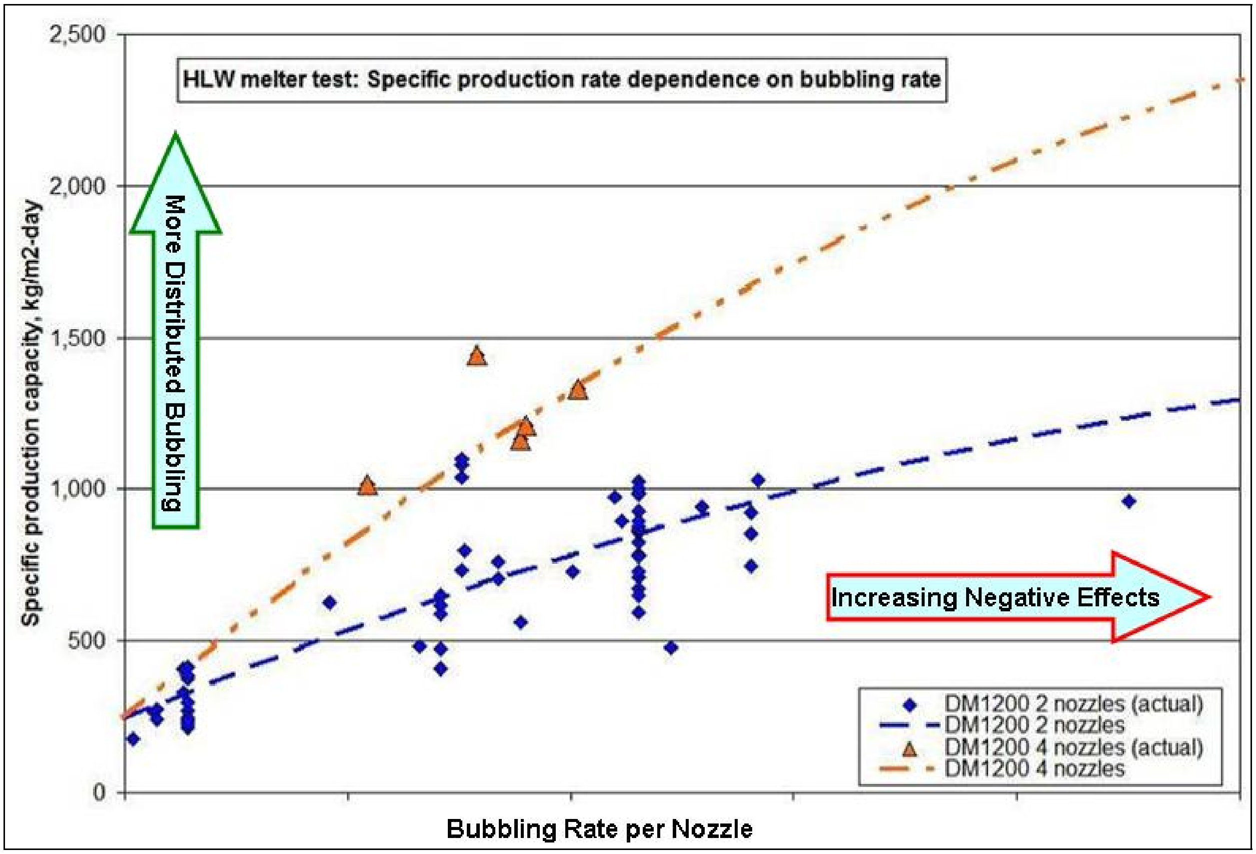

Figure 3: Bubbler Optimization Data

In order to produce the greatest increase in glass production rate, the location of the bubbler gas injection points must be positioned in the optimal pattern. This is a different approach than is usually followed for remote equipment design where the requirements of the maintenance systems usually dictate the size and location of components. Conversely, the baseline LAW melter was designed to place the glass pool bubbler assemblies in the optimal locations and then the melter services and maintenance features were selected to support that design. That design philosophy has been followed for the AJHMs.

The LAW AJHM will contain 23 bubbler assemblies to achieve the optimal configuration for the enlarged glass pool compared to the 18 utilized in the baseline design. The HLW AJHM will contain 8 bubbler assemblies versus the baseline of 5. Because the bubbler design was already optimal for the LAW melter, no increase in production rate is anticipated beyond that related to the larger melter area. The HLW melter production rate is predicted to increase by approximately 50% because of the bubbler optimization.

Enhanced AJHM Design

The enhanced AJHM design evaluated numerous technologies and design changes with the goal of identifying approaches that could provide large increases in the melter processing rate with minimal impacts on the WTP. Many of the technologies evaluated, while potentially providing large improvements were determined to require changes that were too extensive and were dropped from further consideration. The technologies that were determined to be promising were advanced into the AJHM conceptual design.

The technologies selected for the Enhanced AJHM are: microwave heating through the plenum, heating of the cold cap using a plasma torch, heating of the cold cap using heat pipes, pre-heating the melter feed prior to the melter, and ruggedizing the off gas film cooler. All except the feed pre-heater and off gas will increase the rate of heat transfer to the cold cap by heating it from the top so that feed may be fed at a higher rate, thus increasing capacity. The feed pre-heater will heat the feed to boiling so that this heat will not be required to be drawn from the cold cap. This will reduce the amount of energy that must be drawn from the glass pool for a given amount of feed and will result in the feed converting to glass at a faster rate. The off gas enhancements are design changes to the film cooler to minimize plugging as prior experience [9, 10, 11] in melter operations has indicated that a large fraction of lost processing time can be associated with the collection of entrained feed solids in the off-gas duct work.

Each of the Enhancements has been planned for testing on the AJHM pilot facility to demonstrate their capabilities and to develop the technology for implementation on the AJHM. This testing is necessary to underpin the design of these components.

CONCLUSIONS AND FUTURE WORK

An investigation into basic design improvements for the HLW and LAW melters has been performed. This investigation has evaluated three areas: increasing the glass pool surface area, increasing the glass pool temperature, and optimization of bubbler placement.

For the HLW and LAW melters, the glass pool surface area increase is 27% and 54%, respectively. This translates to an equivalent increase in production rate for each melter. Raising the glass pool temperature from 1150°C to 1250°C will increase the throughput by approximately 100%. Optimizing the glass pool bubblers will provide a production rate increase of 25%. Taken together, the production rate improvements are anticipated to be approximately 300%. This raises the production rate from 3.75 MT/d of glass production per melter to 11.3 MT/d of glass production per melter for the HLW and from 15 MT/day of glass production per melter to 45 MT/day of glass production per melter for the LAW. These changes will allow the accelerated processing of Hanford tank waste through the WTP reducing the project operating period and thus could provide substantial cost savings for the government. Additional cost savings would also be realized by the ability to reduce the duration that the tank farm would be maintained in an operating condition. The accelerated processing rate would more quickly remove the environmental risk that the waste poses to the Columbia River.

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