

Small Scale Mixing Demonstration Batch Transfer and Sampling Performance of Simulated HLW - 12307

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ABSTRACT

The ability to effectively mix, sample, certify, and deliver consistent batches of High Level Waste (HLW) feed from the Hanford Double Shell Tanks (DST) to the Waste treatment Plant (WTP) has been recognized as a significant mission risk with potential to impact mission length and the quantity of HLW glass produced. At the end of 2009 DOE's Tank Operations Contractor, Washington River Protection Solutions (WRPS), awarded a contract to EnergySolutions to design, fabricate and operate a demonstration platform called the Small Scale Mixing Demonstration (SSMD) to establish pre-transfer sampling capacity, and batch transfer performance data at two different scales. This data will be used to examine the baseline capacity for a tank mixed via rotational jet mixers to transfer consistent or bounding batches, and provide scale up information to predict full scale operational performance. This information will then in turn be used to define the baseline capacity of such a system to transfer and sample batches sent to WTP.

The Small Scale Mixing Demonstration (SSMD) platform consists of 43" and 120" diameter clear acrylic test vessels, each equipped with two scaled jet mixer pump assemblies, and all supporting vessels, controls, services, and simulant make up facilities. All tank internals have been modeled including the air lift circulators (ALCs), the steam heating coil, and the radius between the wall and floor. The test vessels are set up to simulate the transfer of HLW out of a mixed tank, and collect a pre-transfer sample in a manner similar to the proposed baseline configuration. The collected material is submitted to an NQA-1 laboratory for chemical analysis.

Previous work has been done to assess tank mixing performance at both scales. This work involved a combination of unique instruments to understand the three dimensional distribution of solids using a combination of Coriolis meter measurements, in situ chord length distribution measurements, and electro-resistive tomography. This current work utilized the same instruments to monitor simulated waste transfers.

This paper will discuss some of the scaling compromises when it came to the scaled sampling system design, handling of large quantities of material for sampling, and present data for the discuss of likely behavior of the full scale DST based on scaling correlations using a scale ratio exponent (SRE) from 0.25 to 0.45 and the behavior observed in the SSMD platform. This does not establish a scaling factor for DST mixing using paired jet mixers but is an attempt to envelope the likely performance ranges in terms of certification sampling bias, certification sample root-mean-square-deviation, and bath to batch relative standard deviation.

INTRODUCTION

The SSMD program is focused on the portion of the River Protection Project (RPP) mission where the HLW waste is delivered from the tank farms DSTs to the WTP. The HLW feed will be staged in DSTs that contain up to 178 cm (70") (~720,000 liters) of settled solids on the bottom of the tank with the remaining tank volume (up to 3,407,000 liters) filled with liquid

supernate. Prior to feed delivery the solids will be mixed with the supernate to create an HLW feed slurry. There is some uncertainty surrounding the ability of the baseline DST mixer pump system to adequately suspend and homogeneously distribute the HLW solid particles within a million gallon tank. Homogenous, as used here, should be interpreted as the same concentration and makeup of solid particles occur at any point and time within the volume of the mixed tank such that a sample taken from one location would be representative of the entire tank contents. The WTP design basis assumes each staged HLW feed tank is homogeneously mixed and delivered in consistent feed delivery batches of 570,000 liters (150,000 gallons). Consistent, as used here, is intended to mean that the first 570,000 liter batch has the same solids composition as the last 570,000 liter batch.

There is also a sampling risk in meeting the requirement that each DST be sampled and characterized to a high degree of confidence prior to delivery to the WTP as certified feed. The number and location of sample collection events required for feed certification increases as tank heterogeneity and required confidence levels increase. The sample must be representative of each batch, which becomes problematic if there is variability between batches. It is known that the present baseline DST mixing systems will not homogeneously distribute sludges in a typical HLW feed DST, which will complicate the ability to collect samples that meet feed certification confidence requirements. Additionally, some of the WTP feed acceptance requirements are based on physical and transport properties (e.g. particle hardness, densities and critical velocity) that are not easily measured in an analytical laboratory.

This paper reviews the key parameters in the platform design which had to be prototypically scaled, and discusses the approaches used when this was not possible. Scaling up complex particulate behavior in large tanks mixed by rotating centrifugal jet pumps includes multiple parameters, many of which scale up differently. For example, it was not possible to build prototypic jet mixers similar to those proposed for the DSTs and this paper will discuss the solution and associated compromises (due to system hydraulics) in detail. This modeling problem is significantly different to conventional stirred tanks, in that mixing is achieved by fluid jets rotating through the liquid, and the jet velocity and angular rotation rate are interdependent and differ in how they scale as vessel size increases. Since one of the objectives of this platform was to define the (unknown) scaling correlations, the platform was designed to cover the full range of flows and rotational rates possible.

OBJECTIVES

The primary objectives of this phase of demonstrations were to:

- Quantify the representativeness of the proposed DST sampling method
- Quantify the variability of batch variation
- Identify operational parameters affecting batch transfer and sampling performance

METHOD

The scaled test platforms include a 43.2” diameter vessel (1/21 scale) of 111 gallon capacity, and a 120” diameter vessel (1/7.5 scale) of 2379 gallons capacity. All tank internals, pumps and associated systems are scaled prototypically where possible. Where it is not possible to do this, due to, for example, dimensions being too small, the final scaled dimensions will be as close to prototypic as possible.

The batch transfer volume for AY-102 is 150,000 gallons, and this scales to 16.6 gallons for the 43.2" tank, and 355 gallons for the 120" tank respectively. Transfer of each 150,000 gal batch of waste out of AY-102 will occur at a flow rate of 90 – 140 gpm. The actual transfer pump system is still under design, but based on previous transfer pumps, the suction inlet is 2.25" diameter [Ref. 1] and the transfer line is 3.068" [Ref 2, Table 2]. This equates to a linear velocity of 7.26 – 11.3 ft/s at the suction inlet, a linear velocity of 3.9 – 6.1 ft/s in the transfer line, and a transfer time of 1071 – 1667 minutes (18 – 28 hours) per batch.

Extensive discussion occurred with mixing experts as to what are the important parameters for scaling the batch transfer system. One key parameter that cannot be scaled is the transfer velocity, since the particle size and density in the test simulants are not scaled. Scaling on flow will give too low a linear velocity resulting in settling and line plugging. If the line diameter is scaled (for the 43.2" inch tank), the diameter becomes too small to be operable in consideration of line plugging. A further problem is caused by the fact that the scaled transfer pumps are not submersed in the tanks, but sitting above the tanks and pulling liquid up a significant vertical leg on the suction side of the pump. This creates problems with net positive suction head (available) (NPSHa) at the small line sizes being used. Transfer velocities in the range 6 – 11.3 ft/s were selected for this study in order to widen the band and increase the magnitude of any effect observed.

The approach adopted for the transfer line out of the 43.2" vessel is to use a 0.28" suction inlet and match the range of linear velocities at the suction inlet to ensure similar particle entrainment to the full scale system. This equates to a flow rate of 1.15 gpm at 6 ft/s, to 2.17 gpm at 11.3 ft/s. The corresponding batch transfer times are approximately 8 mins to 14 mins. It should be noted that immediately after the suction inlet, the line internal diameter increases to 0.31" to minimize frictional losses and provide a workable NPSHa for the system. This was chosen as the geometrically scaled line inlet would be 0.01" in diameter which would have presented an unworkable NPSHa and problems with line plugging.

For the 120" vessel, a 0.32" suction inlet is used. This yields a flow rate of 1.5 gpm at 6 ft/s, to 2.8 gpm at 11.3 ft/s. The corresponding batch transfer times are approximately 127 mins to 237 mins. It should be noted that, as with the 43.2" tank, immediately after the suction inlet, the line internal diameter increases to 0.375" to minimize frictional losses and provide a workable NPSHa for the system. The 0.32" inlet diameter is the correct geometrically scaled size.

Prior to commencement of, and during the course of, the batch transfers, several samples are required to be taken from the test tanks. The purpose of these samples is to certify the feed as acceptable for feeding forward to the WTP. The first "certification" sample is taken prior to any batch transfers and is taken while the slurry is recirculating through the transfer pump and back into the tank again. The Coriolis® meter, along with visual observation was used to define when steady state has been achieved after start up of the mixers (at start up from quiescent conditions, the density will change as the tank contents suspend until they reach equilibrium). This initial sample simulates the certification sample taken from a full DST that is used to certify all the WTP waste acceptance criteria (WAC) have been met prior to transfer.

For all sampling operations there is the added complication that the tanks are at a dynamic steady state condition, and mixing is non-homogeneous. Thus a sample cannot be taken out of the tanks or recirculation/batch transfer line at a single point in time. As the mixer jet pumps (MJPs)

rotate, the solids concentration, and possibly, composition, in the sample line will fluctuate. Thus samples were taken over a time period of at least one MJP rotation.

Sampling of the batch transfers for the SSMD project were accomplished by collecting either the entire batch for the 43.2” vessel or by diverting a portion of the batch for the 120” vessel. The volume that was collected for each tank scale was designed to be the same. This was accomplished by diverting batch transfer flow in its entirety based on the number of MJP rotations taken place such that approximately seventeen gallons is collected. Seventeen gallons is the approximate batch size of one small vessel batch transfer. The large vessel has the flow diverted by an automatically actuated valve controlled by the programmable logic controller, and based on the MJP encoder position, such that consistent operation is achieved and delivered in the same seventeen gallon quantity that is used in the 43.2” testing. The reason for this sub-batch is that a full batch in the large vessel is approximately 355 gals, and this would have to be sub-sampled before sending to the labs for analysis. Homogeneously mixing a batch will be problematic, so extracting a sub-batch similar in volume to the batch size from the small vessel, and then using the same decant and sampling procedure (described below) was used to make process easier and more repeatable.

The batches are collected directly in a floor standing cement mixer. The solids are allowed to settle (at a minimum of 24 hours) and then supernate is decanted off using a small pump and, if necessary, a large pipette. The resulting wet, but dewatered, solids slurry is then mixed to homogenize. Once the sample is homogenized it is sub-sampled by hand and sent to an offsite lab for chemical analysis and particle size distribution. This method was qualified using known input concentrations and taking multiple sub samples before being implemented in actual test work.

The simulant mixture was a solids weight percent of 19% in water, with 10% being contributed by Zirconium Oxide (d50 12 micron), 6% Gibbsite (d50 10 micron), and three spike particles at a concentration of 1% each of Bismuth Oxide (d50 38 micron), Silicon Carbide (d50 150 micron), and Stainless Steel (d50 128 micron).

Testing at SRNL indicated that the dominant parameter that affects mixing performance is the MJP jet velocity (Ref 3, 4, and 5). It is expected that the MJP will similarly be the dominant factor affecting pre-transfer sampling and batch transfer consistency.

Using the following correlation for scaling, the range of SREs tested in the two test vessels is illustrated in calculated.

$$\frac{Vel_1}{Vel_2} = \left(\frac{Dia_1}{Dia_2} \right)^n \quad (\text{Eq. 1})$$

Where *Vel* is the nozzle velocity, *Dia* is the tank diameter, *n* is the SRE. Testing in the 43.2” tank took place at SREs of 0.41 (16.9 ft/s), 0.32 (22.1 ft/s), 0.29 (24.8 ft/s), and 0.25 (27.6 ft/s). Testing in the 120” tank took place at SREs of 0.48 (22.3 ft/s), 0.35 (28.7 ft/s), 0.30 (31.9 ft/s), and 0.25 (35.4 ft/s).

The sample to batch representativeness was assessed through calculated measures of the Average Bias (AB), Root Mean Square Deviation (RMSD), and Relative Standard Deviation (RSD).

These were chosen for their simplicity in reducing complex data sets to simple number representation of sampling and transfer performance.

$$\text{Average Bias} = \frac{\sum_i^n \frac{\text{Sample Mass}_i - \text{Batch Mass}_i}{\text{Sample Mass}_i}}{n} \quad (\text{Eq. 2})$$

$$\text{RMSD} = \sqrt{\frac{\sum_i^n \left[\left(\frac{\text{sample} - \text{batch}_i}{\text{sample}} \right)^2 \right]}{n}} \quad (\text{Eq. 3})$$

RESULTS

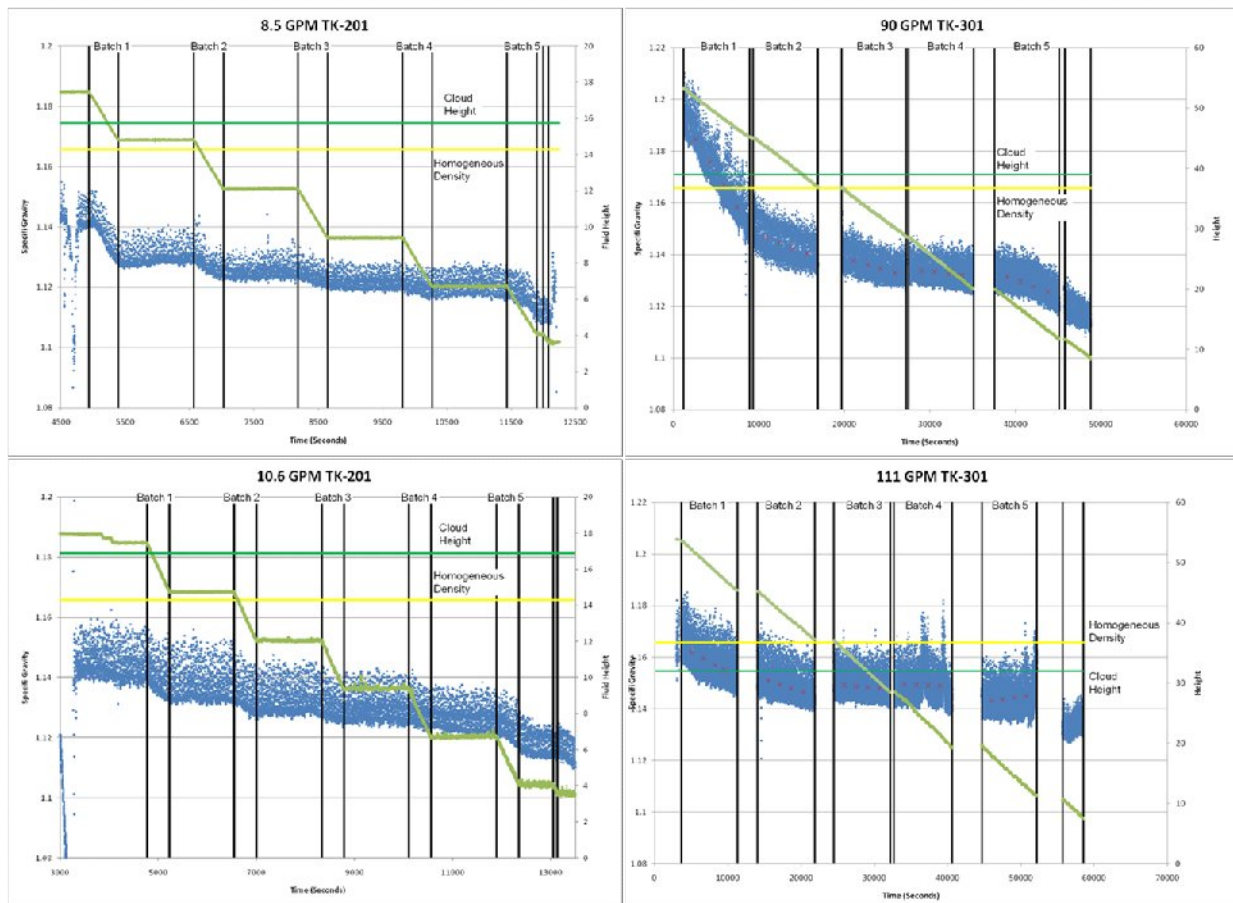


Figure 1 Example Coriolis Data

Figure Shows four example density traces generated during testing operations. Of particular note is the consistent decrease in density as the pump down continues across the five batches.

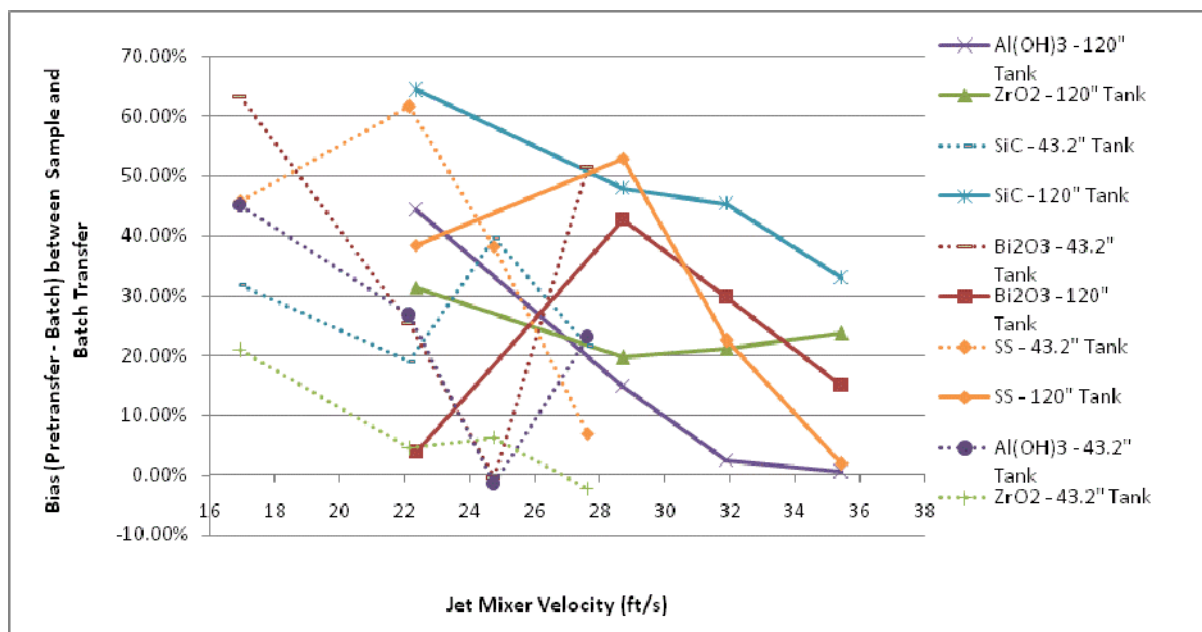


Figure 2 Average Bias

In Figure solids lines are representative of the 120" tank, and dashed lines are representative of the 43.2" tank.

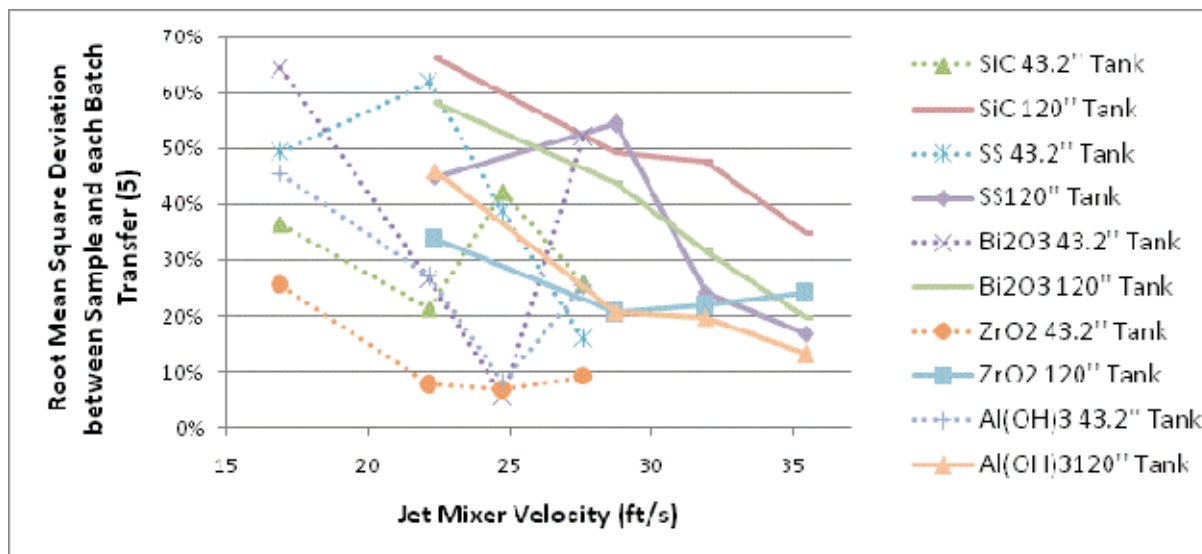


Figure 3 Root Mean Square Deviation

In Figure solids lines are representative of the 120" tank, and dashed lines are representative of the 43.2" tank.

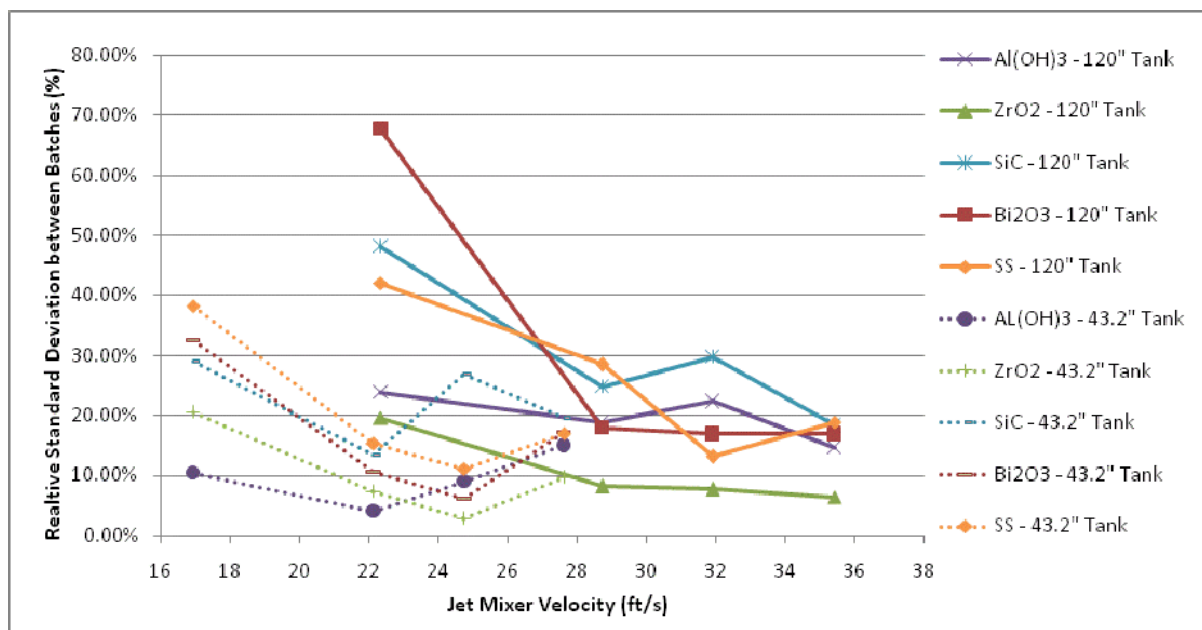


Figure 4 Relative Standard Deviation

In **Figure** solids lines are representative of the 120” tank, and dashed lines are representative of the 43.2” tank.

DISCUSSION

Figure shows the density as a function of batch pump outs. Because the density is highest at the point in time where the pre-transfer sample is taken this leads to a trend in which the solids are over represented in the pre-transfer sample. This shows up in Figure 2 as a positive bias. All species were over- represented in the pre-transfer sample, with only ZrO₂, Gibbsite, and Bi₂O₃ having an average that was negative in the 43.2-in tank. In the 120-in tank, at all MJP velocities, the average bias was never less than 0%. This leads indicates that the full scale DST should have a similar high sampling bias for the pre-transfer certification samples.

Variability of the sample to the batch is represented in the RMSD values displayed in Figure 3. Both the 43.2’ tank and the 120” had similar levels of variability and indicate that the full scale DST would experience similar behavior.

Batch to batch variability is measured is by the RSD and is illustrated in Figure . The 43.2” tank showed lower RSD values than the 120” tank at comparable velocities, this would indicate that a full scale DST would experience an increase over what was measured in the 120” tank.

In the case of the AB and the RSD the values tend to decrease with an increase in MJP velocity. The RMSD has a similar behavior as the AB and RSSD but does not show up as strongly. In terms of scaled performance to a full scale DST, if the actual SRE is >0.4 the samples would have a higher AB and an increase in RSD, if the actual SRE is closer to 0.33 then the AB and the RSD would decrease.

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