Estimating High Level Waste Mixing Performance in Hanford Double Shell Tanks - 11193

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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 (DSTs) to the Waste Treatment and Immobilization Plant (WTP) presents a significant mission risk with potential to impact mission length and the quantity of HLW glass produced. The Department of Energy's (DOE's) Tank Operations Contractor (TOC), Washington River Protection Solutions (WRPS) is currently demonstrating mixing, sampling, and batch transfer performance in two different sizes of small-scale DSTs. The results of these demonstrations will be used to estimate full-scale DST mixing performance and provide the key input to a programmatic decision on the need to build a dedicated feed certification facility. This paper discusses the results from initial mixing demonstration activities and presents data evaluation techniques that allow insight into the performance relationships of the two small tanks. The next steps, sampling and batch transfers, of the small scale demonstration activities are introduced. A discussion of the integration of results from the mixing, sampling, and batch transfer tests to allow estimating full-scale DST performance is presented.

INTRODUCTION

Hanford HLW will be staged in 3785-cubic meter (1-million gallon), underground DSTs prior to delivery to the WTP for treatment. HLW is a combination of liquid and undissolved solids that settle and form sludge in the bottom of the DSTs. The DSTs are approximately 23 meters (75 feet) in diameter and 12 meters (40 feet) high, with equipment access provided through risers located in the dome of the tank. The baseline design for transferring the HLW to the WTP for treatment includes using two 760,000 BTU/hr (300-horsepower) centrifugal mixer pumps with two opposed nozzles each to mobilize the sludge particles, and one submerged centrifugal transfer pump to deliver the HLW slurry through pipelines to the WTP. The HLW feed certification and delivery strategy includes mixing and sampling the waste in a 3785-cubic meter (1-million gallon) staged DST, certifying it as compliant with WTP requirements, and then transferring multiple 600-cubic meter (160,000-gallon) batches to the WTP [1]. The level of accuracy for certifying waste feed is still being developed, but the feed must be shown to meet the regulatory, safety basis, and operational requirements within the yet-to-be-defined tolerance band. Traditional methods used in Hanford's tank farms to sample DSTs consist of individual grab sample (liquids) or core sample (settled solids) events while the tanks are quiescent (that is, not being mixed). However, these methods cannot provide a representative slurry sample of the waste that would be transferred to the WTP. Hanford's Waste Feed Delivery Mixing and Sampling Demonstration program is focused on identifying representative sampling techniques and demonstrating that consistent 600-cubic meter (160,000-gallon) transfers can be made from existing DSTs.

DEMONSTRATION PROGRAM

The Mixing and Sampling Demonstration Program is structured to define appropriate DST sampling techniques that result in representative samples, and to define batch transfer techniques that will deliver consistent batches of HLW to the WTP. The program builds on information gained from progressively larger and more complex small-scale mixing platforms that are scaled to match the full-size DST configuration. The mixing demonstration strategy is built around the following progressive concepts:

- Demonstrate DST mixing and batch transfer phenomena with small-scale ‘scouting studies’
- Develop small-scale mixing and batch transfer performance data using two different small-scale mixing platforms
- Demonstrate representative sampling capability on two different small-scale mixing platforms
- Develop computer modeling capability that is calibrated to small-scale mixing results and can be used to estimate full-scale performance sensitivities

The information gained from the small-scale demonstrations will be compared against emerging WTP data tolerance requirements. Once a functional sampling and batch transfer system is defined, full-scale performance will be confirmed with a full-scale demonstration of system capabilities in the DST designated for WTP commissioning. This document focuses on the evaluation of data collected from the small-scale mixing demonstrations performed in July and August, 2010.

SMALL SCALE DEMONSTRATIONS

Mixing Platform

The mixing and sampling demonstration program initially focuses on the first HLW planned for transfer to WTP, (from tank AY-102). Consequently, small-scale demonstration tanks were geometrically scaled by linear dimensions to match AY-102. AY-102, is approximately 23 meters (75 feet) in diameter, with an operating liquid height of 9.2 meters (364 inches) and a sludge (settled solids) height of 1.4 meters (55 inches). The particle size of the solids in AY-102 ranges from 2.5 to 16.8 (99th percentile) microns, and density varies from 2.4 to 11.4 g/cm3 [2]. The baseline tank configuration will include two mixer pumps, with opposing 15 centimeter (6 inch) diameter nozzles that will circulate tank waste at approximately 315 liters per second (5000 gallons per minute) per nozzle. The mixer pumps can be rotated such that the nozzles cover a full 360° of rotation. AY-102 also contains 22 air lift circulators (ALCs) that are currently not functional. The ALCs are effectively cylindrical obstructions in the tank, each 0.8 meters (30 inches) in diameter extending down to within 0.8 meters (30 inches) of the tank floor.

The Small Scale Mixing Demonstration (SSMD) platform contains two functionally equivalent tanks of approximately 1/20th and 1/8th scales. The smaller tank size of 1.1 meters (43 inches) diameter was selected to match the size of the scouting study tank at Savannah River National Laboratory (SRNL) that has been operating since March 2009 [3]. This size allows direct comparison of performance data between the two tanks. The larger tank size of 3.0 meters (120 inches) was selected to provide a noticeable scale difference (nearly three times) from the small tank while still remaining small enough to allow clear visual observation of mixing performance. The two scaled tanks and associated operating equipment are shown in Figure 1. The small scale of the demonstration tanks made it impractical to mechanically duplicate the rotating, centrifugal mixer pumps found in the full-scale DSTs. The scaled flow characteristics of the mixer pumps were duplicated in a similar manner to those used in the SRNL tank. A pump external to the tank provides the suction through a central column and mixer flow through annulus fed jet nozzles that were scaled appropriately to match the full-scale mixer pump configuration. Figure 2 shows the scaled mixer pump configuration.

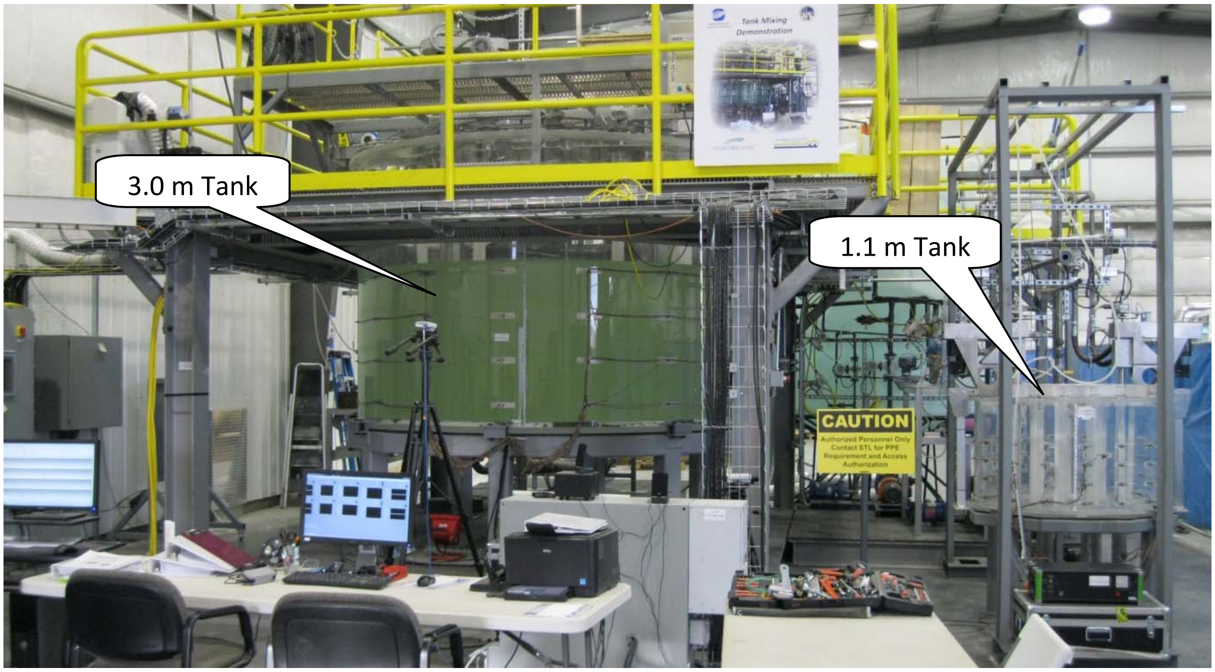

Figure 1. Small Scale Mixing Demonstration (SSMD) Platform

A range of simple to complex particulate simulants was selected to represent a broad spectrum of potential mixing conditions and build correlations with the data collected at SRNL and the expected waste conditions in AY-102. The simulant used was a combination of Gibbsite, zirconium oxide, silicon carbide, and bismuth oxide with particle size distributions specifically selected to match potential tank waste characteristics [4]. The first phase of demonstrations was focused on mixing performance in the two tanks under varying conditions. The objective of the mixing phase was to understand mixing performance in the two scales to the extent necessary to provide confidence that both tanks can be operated under similar conditions. Once equivalent operating envelopes were defined for each tank, the second phase of demonstrations began. The second phase is focused on representative sample collection and consistent batch transfer demonstration.

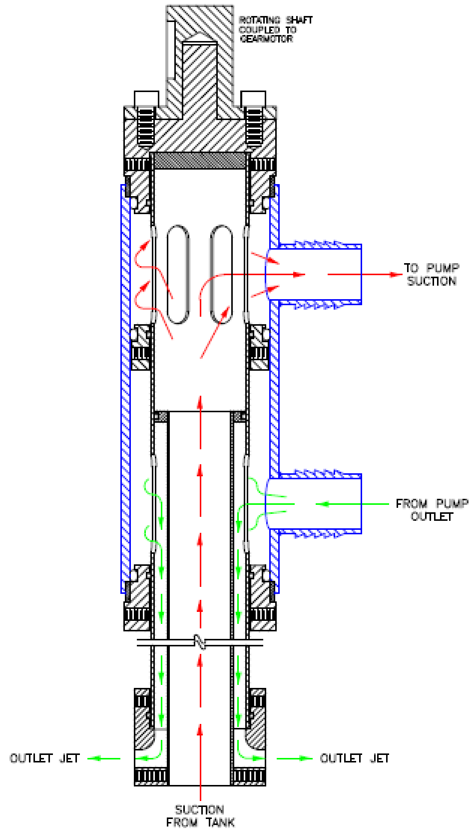

Figure 2. Scaled Mixer Pump Configuration

Data Collection

Both tanks were equipped with specialized instruments designed to collect specific solids information to evaluate tank mixing behavior. The instruments described below collected solids data from various tank locations representing multiple points in time.

A coriolis meter was used during testing to determine the density at a specific location in the testing tank. A recirculation loop allowed the mixed slurry present to be sampled at any location within the tank. The recirculation allowed continuous monitoring of selected locations so the dynamic nature of the mixing behavior could be measured and quantified. The coriolis measurements were a primary source mixing behavior data.

A Focused Beam Reflectance Measurement (FBRM®) instrument allowed measurement of the chord length distribution (CLD) of particles in the test tanks in real time without sampling or extracting the simulant. The CLD measurement is a function of particle size, particle shape, and particle population. While this measurement does not provide an exact particle size distribution, it provides a correlation to particle sizes present. This instrument is particularly useful in identifying trends or changes that may occur over time.

Visual observation and video recording of mixing demonstrations provided useful documentation of overall tank performance and allowed data measurements to be correlated with observed visual phenomena. The most valuable insight gained from the visual observations is an appreciation for the complex, dynamic, and chaotic nature of the mixing phenomena.

Data was generally collected at nine vertical elevations and three distinct radial positions over a series of 33 different operating conditions for both tanks. This strategy resulted in an overwhelming amount of data and created a significant challenge to focus on the objectives and not get caught up in “interesting data discussions” that were not relevant to the end objective. The primary objective of this mixing phase of the demonstration was to determine if similar tank mixing phenomena could be observed in both tanks. Confidence that data is being collected when the scaled tanks are operating under similar conditions is imperative when taking the next step of estimating performance in a full-scale tank. Early in the mixing program development, it was decided that defining a range of similar operating conditions was much preferred over attempting to define one precise point where both tanks were behaving similarly. If an operating plateau of consistent mixing could be defined for both tanks, then translating that plateau to the full-scale tank would provide a measure of how close full-scale operating conditions are to the edges of the acceptable operating plateau.

DATA EVALUATION

It was found that the density data collected by the coriolis meter was the most useful in evaluating and comparing overall mixing performance. The FBRM and visual data allowed more specific aspects of the general performance to be probed. This paper limits the discussion to the density data and is therefore focused on a discussion of the general mixing characteristics.

The SSMD Initial Results Report [5] evaluated the data as a collection of data points associated with each individual test conditions. These data were then plotted in two different ways to identify noticeable characteristics observed in both tanks. In the first plot (Figure 3) the density for each elevation is plotted on lines of constant mixer pump flow rates. In the second plot (Figure 4) density versus flow rate is plotted on lines of constant elevation.

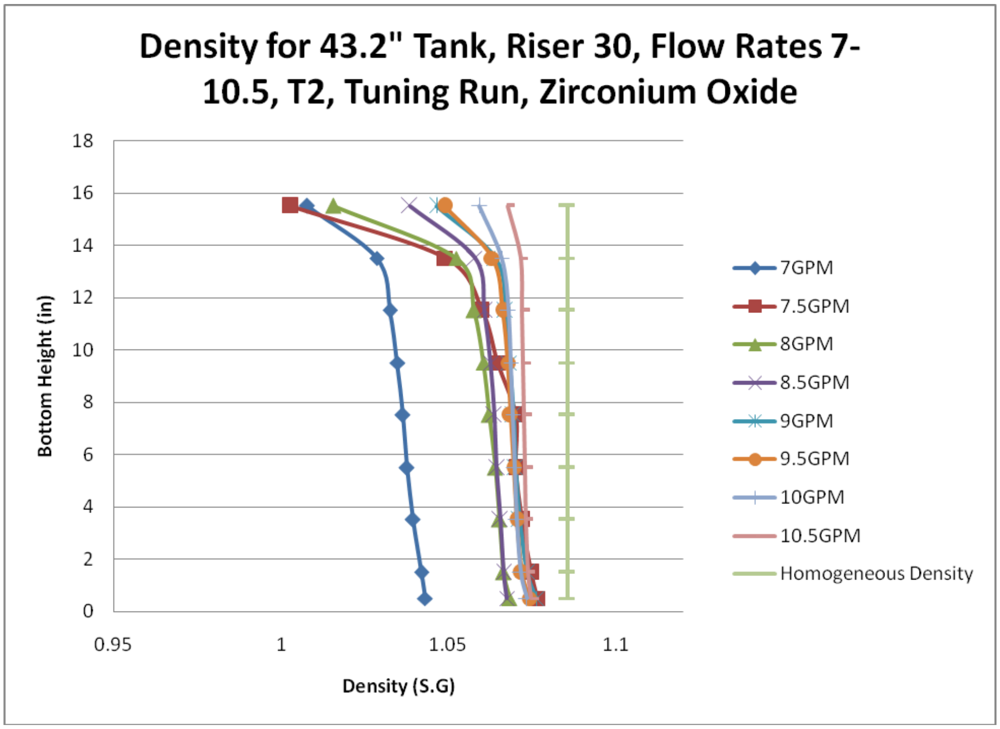

Figure 3. Example Density at Elevation Plot

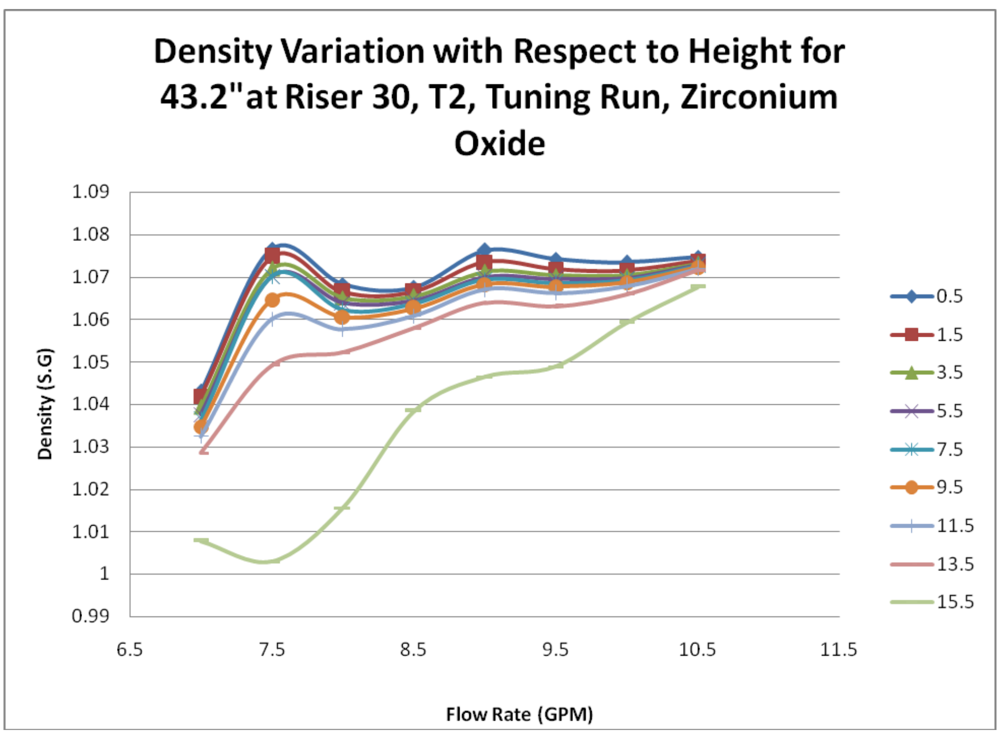

Figure 4. Example Density verses Flow Rate Plot

This data presentation and evaluation allowed selection of mixer pump flow rates that are indicative of noticeable degradation in mixing performance. For example, inspection of Figures 3 and 4 indicates a noticeable change in mixing performance when the flow rate drops below 0.47 liters per second (7.5 gallons per minute). Mixing performance above this point shows some variations but was generally similar and consistent as flow rates were increased. These data allowed identifying flow rates representing “the edge of performance” for both scaled tanks.

SCALE COMPARISON

While the look at independent data points described above is useful in understanding individual tank behavior, correlating the behavior between scales requires a more comprehensive look at all the data from both tanks as one complete data set. Evaluating the complete set of density data identifies the operating conditions in which both scaled tanks are behaving most similarly. The statistical basis and methodology for the data evaluation discussed below is described in more detail in Reference 6.

Mixing Comparison

For the purposes here, similar mixing behavior is defined as occurring at the corresponding tank flow rates where the difference between the density measurements at corresponding (scaled) vertical locations, taken across all vertical locations, is smallest. This is the objective function that is referred to in the following discussion. Mathematically, this result will be calculated as the sum, taken over the (scaled) vertical locations, of the squared difference between the predicted density for the large tank and the small tank for a given (scaled) vertical location. The squared difference is used for two reasons. First, it removes any directional effect, i.e., it ignores which tank has the higher density. Second, it increases the impact of larger differences. This process will tend to favor the situation where the differences are more consistent. Intuitively, this definition identifies the corresponding flow rates where the plots of density against location for each tank are “closest together” over the range of locations.

Given this definition, and the model obtained from the regression analysis, it is possible to perform a numerical optimization over the flow rates for the two tanks, to determine the corresponding flow rates that produce the minimum value of the objective function defined above. Microsoft Excel, for example, provides this capability through the Solver add-in. However, due to the complexity of the regression model, and the correspondingly high probability of error in manually transferring the model equation into Excel, a less rigorous, graphical approach was selected. Figure 5 shows the result of this optimization. Note that, by using a regression model, a much finer grid of flow rates than actually measured in the demonstrations can be shown on the graphical optimization.

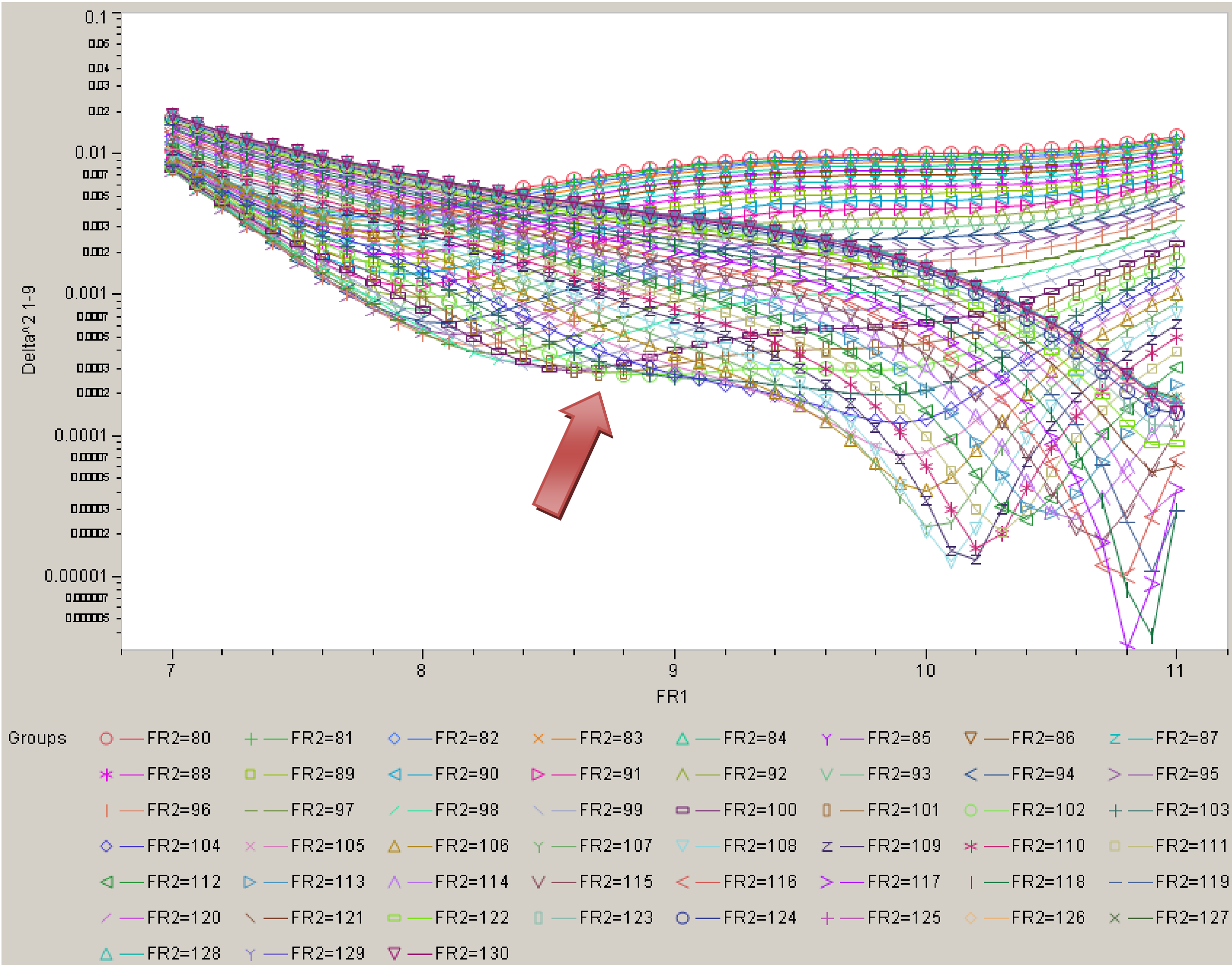

Figure 5. Density Variance Optimization Plot

The horizontal scale represents the small tank flow rate. Each curve drawn on the chart corresponds to a large tank flow rate. The specific value plotted is the sum, over the nine corresponding (scaled) locations in each tank, of the squared difference between the predicted densities in the small tank and the large tank at the corresponding (scaled) location. The general intent of the optimization is to find the corresponding flow rates that produce the minimum curve on the graph. At first glance, this rate is rather obviously near a small tank flow rate of 0.69 liters per second (11 gallons per minute) with a large tank flow rate of 7.38 liters per second (117 gallons per minute). However, this interpretation turns out to be the "non-interesting" solution. Generally speaking, as the flow rates approached their maximum levels in each tank, the tanks were fairly consistently mixed. Therefore, it is not surprising that they appear to be similar at these higher settings. This finding is not interesting because the objective is to find flow rate settings where the mixing behavior is similar when the tanks are not necessarily well mixed. To find these settings, one must look for the lowest flow rate on the small tank where the objective function is small. Using this objective, a more reasonable set of flow rates is indicated by the red arrow. This line identifies the small tank flow rate as 0.55 liters per second (8.7 gallons per minute) and the large tank flow rate as 6.37 liters per second (101 gallons per minute). The graph also indicates that this area is somewhat flat with respect to the objective function. If the small tank flow rate is reduced to 0.54 liters per second (8.6 gallons per minute), then the corresponding large tank flow rate is 6.31 liters per second (100 gallons per minute), with the objective function increasing by approximately 7%.

Plateau Comparison

To gain insight into the scaled performance differences, it is useful to understand where this point of "most equivalent mixing" lies on the plateau of acceptable mixing performance. The Data Evaluation section described, a method to define a flow rate where noticeable degradation of mixing performance was observed. While the methodology described proved useful for defining operating parameters to collect data, it is not statistically rigorous enough to define a point at both scales where mixing performance is noticeably and equivalently degraded.

First it is necessary to explicitly define how the "degraded" mixing will be identified. For the purposes here, degraded mixing will be identified as the flow rate when the standard deviation, calculated from the predicted density across the vertical locations for specified tank and riser values, increases. As discussed with the mixing comparison, this rate can result in a non-interesting point of degradation as the tank will become less homogeneously mixed with any reduction in mixer pump flow. The more interesting point to identify is that where a significantly changed mixing condition is identified, rather than simply a gradual reduction in particle mobility. This can be accomplished by looking at the density data from a different perspective.

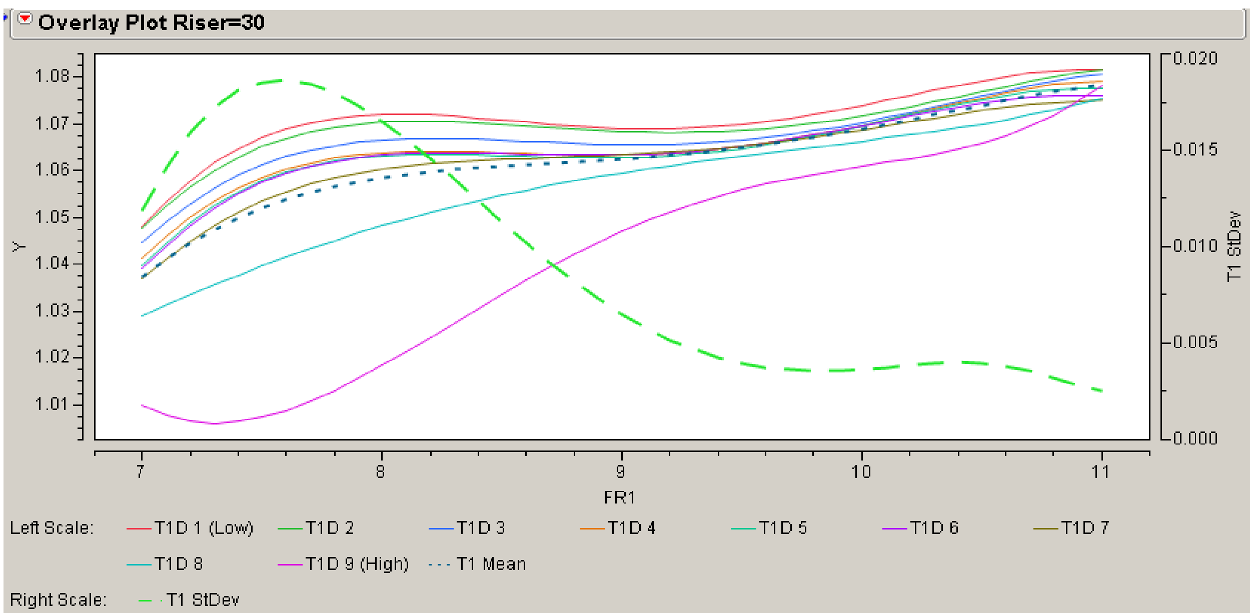

Figure 6. Small Tank Density and Standard Deviation Plot

The green dashed curve in Figure 6, referenced to the right vertical axis, shows the density standard deviation calculated across the nine vertical locations, for the small tank, at the flow rate indicated on the horizontal axis. To provide additional illustration of the actual mixing behavior, the solid curves, referenced to the left vertical axis, represent the predicted density for each of the nine vertical locations (T1D1 is the lowest measurement point and T1D9 is the highest). The dotted curve, also referenced to the left vertical axis, represents the average of the nine vertical locations.

Looking at the standard deviation curve, it is clear that the maximum value occurs at a flow rate of approximately 0.47 liters per second (7.5 gallons per minute). Further inspection of the additional vertical location curves provides more insight into this value. At the higher flow rates, all vertical locations are relatively similar, resulting in a small standard deviation. As the flow rate is reduced, the higher vertical locations begin to “peel off” from the remaining lower vertical locations, suggesting that a progressively lower height in the tank is being consistently mixed. As the flow rate continues to be reduced, it reaches a point where all vertical locations begin to drop, indicating that the mixing is no longer the same. As the densities all drop off, the densities become more consistent at lower values, resulting in a smaller standard deviation. At the flow rate of 0.47 liters per second (7.5 gallons per minute), the standard deviation is largest, and then begins to drop with lower flow rates. This finding suggests that 0.47 liters per second (7.5 gallons per minute) is the lower flow rate where mixing noticeably degrades for the small tank.

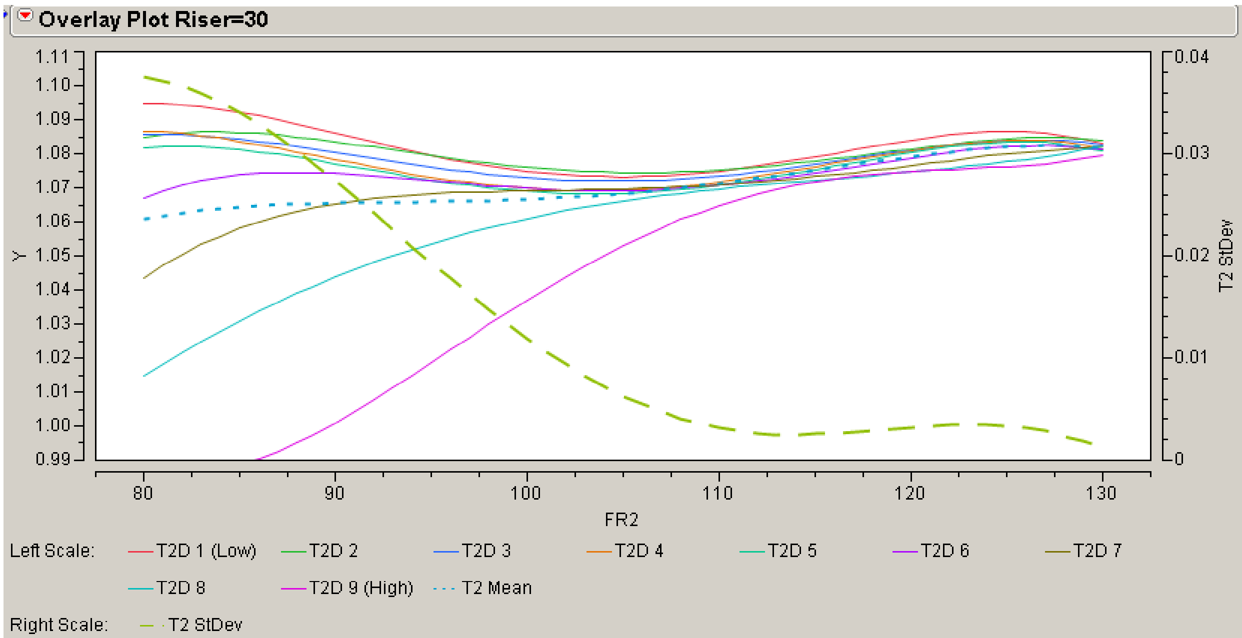

Figure 7. Large Tank Density and Standard Deviation Plot

Figure 7 presents the same data for the large tank. The first item to note is that the standard deviation appears to reach its maximum at the lower boundary of flow rate. Inspection of the individual vertical location curves indicates that, as the flow rate is reduced, the higher locations “peel off” in similar fashion to those in the small tank. As more vertical locations drop, the standard deviation increases. However, in the small tank, after the top two vertical locations dropped individually, the remaining seven dropped as a group as flow rate was reduced. In the large tank, the top four vertical locations dropped individually, while the remaining five still appear to have remained as a group at the lowest flow rate. This observation suggests that the range of flow rate testing for the large tank did not extend low enough to see the degradation in mixing that was identified in the small tank.

In both tanks it appears that, as the flow rate is reduced, a smaller volume of the tank remains relatively consistently mixed, as indicated by the densities at the specific vertical locations. For the small tank, a flow rate was identified where this relatively consistent mixing no longer occurs. This rate also corresponds to a vertical height (vertical location seven), below which relatively consistent mixing no longer occurs. Unfortunately, this “break-point” was not identified in the large tank, most likely because low enough flow rates were not explored. The current analysis suggests that this “break point” would occur at a flow rate below 0.50 liters per second (80 gallons per minute), and a corresponding vertical location below five.

A mixing plateau can be defined as the distance between the flow rate where noticeable degradation occurs and the flow rate where the two scales are most equivalent. Since it is likely that the point of noticeable degradation for the large tank is below the lowest flow rate tested, the lowest value of 0.5 liters per second (80 gallons per minute) will be used for purposes of illustration. The mixing plateaus for the two tanks are identified in Table 1.

	Equivalent Flow Rate (L/s)/(gpm)	Degradation Flow Rate (L/s)/(gpm)	Mixing Plateau Range (L/s)/(gpm)	Percent of Equivalent Flow Range (%)
Small Tank	0.55 / 8.7	0.47 / 7.5	0.08 / 1.2	14
Large Tank	6.37 / 101	0.50 / 80	5.87 / 21	21

Table 1. Tank Mixing Plateau Estimate

The information presented in Table 1 is the first set of data needed to build an understanding of acceptable operating plateaus. This information will be integrated with results from the sampling and batch transfer testing, scheduled to be completed in May 2011, and should provide insight into the relationship between the performance plateaus of the two tanks.

BATCH TRANSFER PERFORMANCE

Batch-to-batch consistency between the multiple batches transferred to the WTP from each DST is a primary performance requirement. Initial scouting demonstrations performed at SRNL for a wide variety of tank mixing and transfer conditions have shown that batch-to-batch consistency is good and is relatively insensitive to changes in operating parameters. [7]

Preliminary density data was collected during pump-down of both scaled tanks upon completion of the mixing phase tests in August 2010. This data suggests there is reasonable consistency as the tank is emptied with a slight decrease in density observed over time. Figure 8 provides an example of this behavior for the small tank. While this data is not precise enough to indicate how each species of simulant is behaving, it is encouraging to see similar results between both tanks.

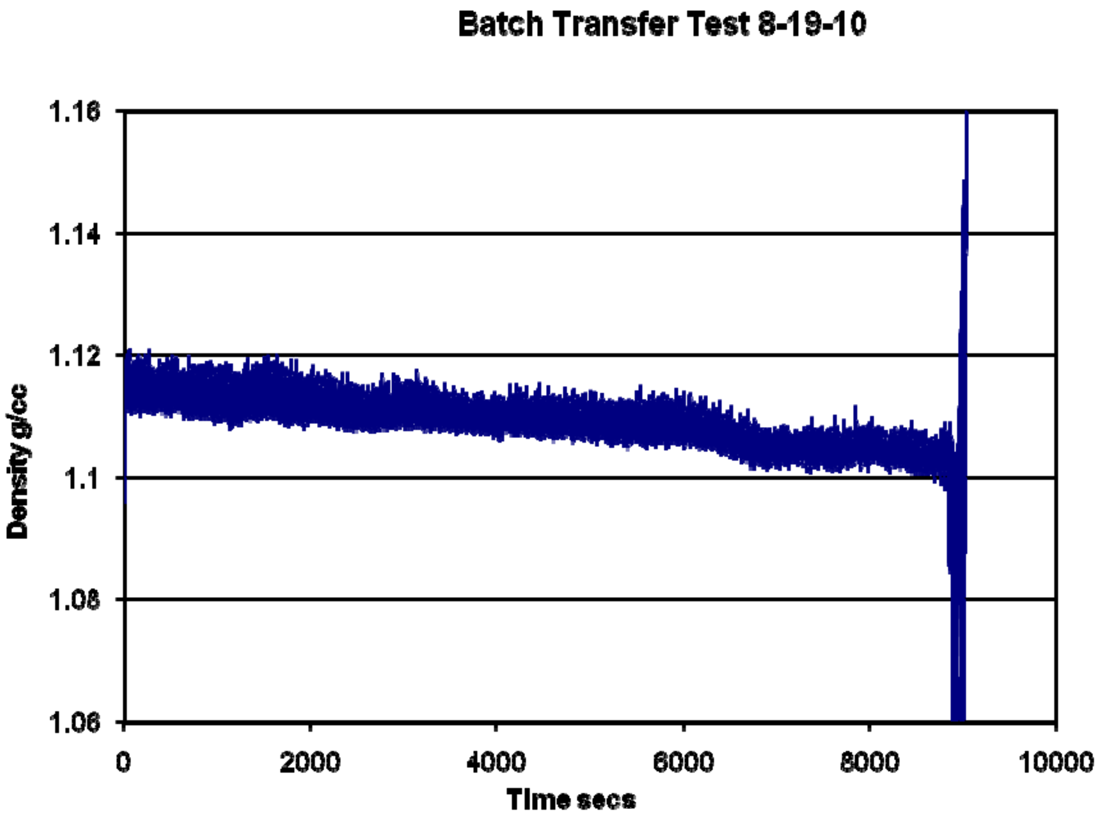

Figure 8. Example of Density Change During Tank Pump-Out

Preliminary data collected from initial batch transfer performance demonstrations in December 2010 supports the concept of defining acceptable performance plateaus. Preliminary transfer density data collected at different mixer pump flow rates suggests an operating region exists where similar transfer performance is observed and an operating edge of performance can be observed where transfer characteristics are noticeably changed. It is anticipated that data collected during the batch transfer phase will support a similar statistical analysis, described previously for the mixing phase, which can define operating plateaus of acceptable batch transfer characteristics for both scaled tanks. The relative size of these operating plateaus will provide insight into full-scale performance implications.

SAMPLING PERFORMANCE

The most challenging feed certification requirement is the ability to collect a sample of the full DST that is representative of the entire tank contents. While quantitative sampling data has not yet been collected, the mixing performance data and the preliminary batch transfer density data suggest that a sample taken near the center and bottom of a mixed tank is a reasonable place to begin. Assuming the characteristics demonstrated in Figure 8 are maintained, a sample collected from the transfer line prior to tank pump should bound the average particulate content of the slurry. The uncertainty that remains to be defined is whether the average content of the slurry is representative of the individual particulate species. The sampling and batch transfer phase of the SSMD program is designed to gather this information.

FULL SCALE IMPLICATION

Scaling up performance data from the small-scale demonstration tanks to the full-scale DST is a complex and uncertain process. Multiple factors are involved, many of which scale differently and some of which are not scaled at all (e.g. particle size and gravity). While the performance metrics of most interest are the ability to representatively sample the DSTs and consistently transfer small batches out of the DSTs, clearly the mixing performance plays a role in these two metrics.

The program focus is to build sufficient data on the mixing, sampling, and batch transfer performance at both small scales such that performance plateaus can be defined for all three characteristics. Integrating these results with CFD modeling estimates of mixing performance plateaus at both small scales and at full scale should allow preliminary estimates of full-scale DST performance. The goal is to define a full-scale performance plateau that describes an operating range where acceptable performance can be expected.

CONCLUSION

Mixing HLW slurry in Hanford DSTs is a complex, dynamic, and chaotic process that is not well understood at full scale. Estimating full-scale sampling and batch transfer performance using data from multiple small-scale tanks adds additional complexity and uncertainty. This uncertainty can be addressed by attempting to scale up acceptable performance ranges from small scale to large scale rather than trying to scale down full-scale operating conditions to specific points on the small-scale demonstrations. A statistical evaluation of the voluminous data collected during the mixing phase of the SSMD testing has created the ability to define equivalent mixing plateaus for both small-scale tanks.

Applying similar analysis techniques to the results of the sampling and batch transfer demonstrations is expected to define batch transfer and sampling performance plateaus. Integrating these performance plateaus with CFD modeling estimates and the limited full-scale DST performance data should provide estimates of full-scale DST performance. These estimates and the associated uncertainties will be key inputs to the Hanford programmatic decision on the need to build a separate and dedicated WTP feed certification facility.

If small scale sampling and batch transfer demonstration results show that acceptable sampling accuracy and batch transfer consistency can be achieved then the tank farms baseline configuration of feed certification in DSTs is supported and full-scale testing to confirm small-scale results will be pursued. If the demonstration results show acceptable accuracy cannot be achieved or that performance scale up estimates result in smaller or unacceptable operating plateaus then an alternate certification strategy must be developed. One alternate feed certification strategy includes a new tank farms facility that would be specifically designed to mix and sample HLW slurry to meet the WTP feed certification sampling requirements. A separate feed certification facility represents hundreds of millions of additional dollars to the Hanford budget. The cost of new facilities highlights the importance of not only collecting quality data from the SSMD work but also accurately translating small-scale results to estimated full-scale performance. The development of acceptable performance plateaus at multiple scales is a promising concept that will reduce the risk associated with estimating full-scale performance.

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