

## **Evaluating Feed Delivery in Scaled Double-Shell Tanks – 14070**

Kearn Lee\* and Mike Thien \*\*

\*AREVA Federal Services, LLC, Richland, Washington, 99354

\*\*Washington River Protection Solutions, Richland, Washington, 99352

### **ABSTRACT**

The Hanford Tank Operations Contractor and the Hanford Waste Treatment and Immobilization Plant contractor are both engaged in demonstrating mixing, sampling, and transfer system capability using simulated Hanford HLW formulations. This work represents one of the remaining technical issues with the high-level waste treatment mission at Hanford. The ability to adequately mix and sample high-level waste feed to meet the WTP WAC Data Quality Objectives must be demonstrated. The tank mixing and feed delivery must support both tank farm and WTP operations. The tank mixing method must be able to remove settled solids from the tank and provide consistent feed to the WTP to facilitate waste treatment operations. Two geometrically scaled tanks were used with a broad spectrum of tank waste simulants to demonstrate that mixing using two rotating mixer jet pumps yields consistent slurry compositions as the tank is emptied in a series of sequential batch transfers. Testing showed that the concentration of slow settling solids in each transfer batch was consistent over a wide range of tank operating conditions. Although testing demonstrated that the concentration of fast settling solids decreased by up to 25% as the tank was emptied, batch-to-batch consistency improved as mixer jet nozzle velocity in the scaled tanks increased.

### **INTRODUCTION**

The Hanford Waste Treatment and Immobilization Plant (WTP) is being constructed to vitrify HLW from underground storage tanks at the Hanford Site. Hanford HLW will be staged in 3,785-cubic meter (1-million gallon), underground double-shell tanks (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. Undissolved particulates in the HLW feed staging tanks will be mixed in place using two submersible rotating mixer jet pumps with two opposed nozzles each to mobilize the sludge particles, and one submersible slurry 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 3,785- cubic meter (1- million gallon) staged DST and certifying it as compliant with WTP requirements. Sample analysis will be a lengthy process that involves many analyses of mixed (chemically hazardous and radioactive) tank waste. Once certified, the actively mixed slurry will be transferred to the WTP using sequential transfer batches, each representing approximately 13% of the maximum operating volume of the feed staging tank. After the feed staging tank is emptied to its operating limit, the feed staging tanks will be replenished with tank waste from other storage tanks and the mixing, sampling, and delivery process will be repeated.

The tank mixing and feed delivery must support both tank farm and WTP operations. The tank mixing method must be able to remove settled solids from the tank and provide consistent feed to the WTP to facilitate waste treatment operations. Delivering consistent feed batches to the WTP represents one of the largest uncertainties in the high-level waste treatment mission at Hanford. The feed delivery sampling plan assumes that the tanks are mixed adequately enough so that the pre-transfer samples are representative of the contents of each subsequent transfer batch until the feed staging tank contents are replenished. In order to build confidence in this assumption, small-scale testing was conducted to evaluate batch transfer consistency in tanks mixed with rotating mixer jet pumps. Testing in two

geometrically scaled tanks was performed with tank waste simulants covering a broad spectrum of physical attributes. Testing was performed to evaluate this assumption and provide confidence that each subsequent transfer from a feed staging tank is consistent with the pre-transfer samples.

Previous scaled testing with tank waste simulants in water [1, 2] demonstrated that fast-settling solids were not homogeneously distributed throughout a tank. However, sequential transfers from the tank were generally consistent with the pre-transfer sample collected prior to the start of the transfers. Using simulants covering a broader spectrum of Hanford tank waste, additional testing was performed to demonstrate that a pre-transfer sample taken from the slurry transfer line will be representative of subsequent batches until the tank is replenished.

## DESCRIPTION

Testing in two geometrically scaled tanks was performed with tank waste simulants to evaluate compositional consistency between pre-transfer samples and batch transfer samples. For each tank scale, compositional consistency was evaluated for different simulant compositions (undissolved solids and fluid rheology) and different tank mixing and transfer operating conditions (mixer jet nozzle velocity and transfer pump suction velocity). Slurry samples were collected when the tank was full (the pre-transfer sample) and during each subsequent transfer batch from the tank. Tank waste replenishment was not simulated. Laboratory analyses determined the composition of the collected samples and the slurry composition for the pre-transfer sample and subsequent batch transfer samples were compared.

## Equipment Configuration

Two geometrically scaled tanks (Figure 1) were outfitted with dual rotating mixer jet pumps and a transfer pump that simulated the full-scale process in a feed staging tank. The properties of the scaled test equipment are provided in Table I. Relative to a Hanford double-shell tank, the tank scales were 1:7.5 and 1:20.8. For simplicity, these are referred to as the 1:8-scale and 1:21-scale tanks, respectively. The cylindrically-shaped, acrylic test tanks had flat bottoms. The suction for mixer jet pump was at the bottom of the mixer jet pump near the tank bottom. Each mixer jet pump had two opposing discharge nozzles. The mixer jet pumps rotated continuously in the clockwise direction and the discharge jets were synchronized to meet in the center of the tank. Slurry was transferred from the mixing tanks using progressive cavity pumps that were located external to each mixing tank. The suction of the transfer pump was placed off-center of the tank but was equidistant from each mixer jet pump.

TABLE I. Properties of the geometrically scaled test tanks and test equipment

Property	Full-Scale	1:8-Scale	1:21-Scale
Tank Diameter	22.9 m (75 ft)	3.05 m (10 ft)	1.10 m (3.6 ft)
Mixer Jet Pump Nozzle Diameter	0.152 m (6-in)	0.0203 m (0.8 in)	0.00711 m (0.28 in)
Mixer Jet Pump Nozzle Elevation	0.457 m (18 in)	0.0610 m (2.4 in)	0.0218 m (0.86 in)
Mixer Jet Pump Suction Diameter	0.279 m (11 in)	0.0373 m (1.47 in)	0.0135 m (0.53 in)
Mixer Jet Pump Suction Elevation	0.127 m (5 in)	0.0170 m (0.67 in)	0.00610 m (0.24 in)
Mixer Jet Pump Distances (0° & 180° Orientations from Tank Center)	6.71 m (22 ft)	0.884 m (2.9 ft)	0.323 m (1.06 ft)
Transfer Pump Suction Velocity	1.16 - 3.44 m/s (3.8 – 11.3 ft/s)		
Transfer Pump Suction Elevation	0.152 m (6 in)	0.0203 m (0.8 in)	0.00711 m (0.28 in)
Transfer Pump Distance (90° Orientation from Tank Center)	1.83 m (6 ft)	0.244 m (0.8-ft)	0.0884 m (0.29 ft)



Figure 1. Small-scale mixing demonstration test platform

### Simulants

Tank waste simulants included undissolved particulates in a suspending fluid. Multi-component simulants consisting of up to a four component mixture of undissolved particulates were used during testing. Two solids compositions were tested, TYPICAL and HIGH [3]. The naming convention for the two solids compositions was based upon the relative difficulty to mix and transfer the solids compared to characterized tank waste from Hanford single-shell tanks. The solids particulates were a mixture of gibbsite, sand, stainless steel, and zirconium oxide. Stainless steel and larger sand particles were selected to represent fast settling solids in the tank waste. The mass of solids added to the specified test volume was 13 weight percent of the slurry. The particle size and percentages of the different components used in testing are presented in Table II.

The simulant components were selected to be representative of the particle sizes and densities observed in the characterized tank waste. Simulant selection also considered materials that were non-hazardous, available, reasonable with respect to cost, amenable for simulant preparation and handling, relatively non-eroding of test system components, and acceptable for commonly applied analysis techniques [4]. The mixing, sampling, and transfer performance of the particulates is a strong function of the particles size and density distribution; however, this function is not necessarily dominated by any one physical attribute (e.g., particle size or particle density) or one physical phenomenon (e.g., particle suspension or particle settling). In order to select appropriate simulants, the developed simulants were compared to a number of performance metrics related to mixing and transfer phenomena [3, 4]. Figure 2 demonstrates the performance of the selected blend using a distribution of Archimedes Numbers. Note that the LOW (light blue open squares) and HIGH (red open squares) simulants border the left and right edges of waste distributions and that the TYPICAL (green open squares) is closely aligned with the volume weighted combination of the combined Hanford sludge (black squares).

TABLE II. Properties and composition of undissolved particulates

Undissolved Particulate	Particle Density (g/cm <sup>3</sup> )	Particle Size Distribution <sup>a</sup> (micron size by volume percentile)				Solids Mass Fraction	
		5th	50th	95th	99 <sup>th</sup>	TYPICAL	HIGH
Small Gibbsite	2.42	0.40	1.8	5.1	7.5	0.27	0
Large Gibbsite	2.42	0.71	8.7	26	37	0.44	0.03
Small Sand	2.65	1.5	37	150	220	0	0.35
Medium Sand	2.65	116	230	530	770	0.13	0
Large Sand	2.65	200	430	670	750	0	0.21
Zirconium Oxide	5.7	0.75	14	36	49	0.10	0.08
Stainless Steel	7.9	25	96	230	340	0.06	0.33

<sup>a</sup> Particle size distributions were measured on component samples using a Horiba LA-910 particle size analyzer.

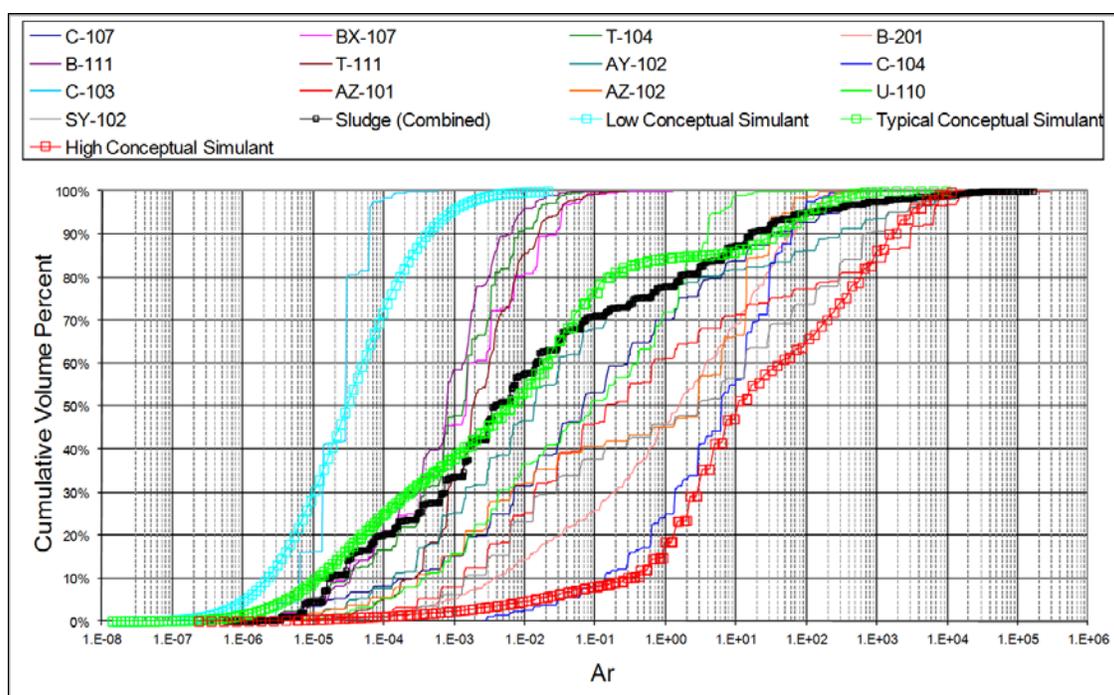


Figure 2: Comparison of selected simulants and characterized tank waste

Testing included 26 tests with three different Newtonian suspending fluids, TYPICAL, MODIFIED HIGH, and HIGH. The compositions of the suspending fluids are presented in Table III. The fluids were solutions of sodium thiosulfate in water or sodium thiosulfate, glycerin, and water. Additional test results using non-Newtonian suspending fluids are described in [5].

TABLE III. Target properties and composition of the suspending fluids

Suspending Fluid	Target Properties <sup>a</sup>			Weight Fraction (@ 20°C)		
				Water	Sodium Thiosulfate	Glycerin
TYPICAL	Density	1.29±5%	g/mL	0.68	0.32	0
	Viscosity	3.6±1	g/m·s (cP)			
MODIFIED HIGH	Density	1.32±5%	g/mL	0.58	0.38	0.04
	Viscosity	8.0±20%	g/m·s (cP)			
HIGH	Density	1.37±5%	g/mL	0.47	0.33	0.20
	Viscosity	15±20%	g/m·s (cP)			

<sup>a</sup> Actual values for each test volume were measured and compared to acceptable tolerances.

### Tank Mixing and Operating Conditions

In addition to varying the simulants used in the 26 tests performed at each tank scale, the mixer jet nozzle velocity and transfer pump suction velocity were operational parameters that were modified. For testing, mixer jet pump operations were assumed to follow the scaling relationships in Equations 1 and 2. Equation 2 equates the number of tank turnovers processed through the mixer jet pumps during one revolution.

$$\frac{U_1}{U_2} = \left(\frac{T_1}{T_2}\right)^a \quad \text{Equation 1}$$

$$\frac{\omega_1}{\omega_2} = \left(\frac{T_2}{T_1}\right) \left(\frac{U_1}{U_2}\right) \quad \text{Equation 2}$$

Where,  $U_i$  is the mixer jet nozzle velocity in the two scaled tanks (each denoted by a separate subscript,  $i = 1, 2$ ),  $T_i$  is the diameter of the two scaled tanks,  $\omega_i$  is the mixer jet pump rotation rate in the two scaled tanks, and  $a$  is the scale factor exponent that equates performance between two scaled systems. To illustrate the scaling relationship described in Equation 1, if a 3.05 meter diameter tank with a mixer jet nozzle velocity of 11.7 m/s results in a transferrable slurry concentration equal to 1 g/L and testing with the same simulant in a 1.10 meter diameter tank identifies that a mixer jet nozzle velocity equal to 10.3 m/s attains the same transferrable slurry concentration, then the scale factor exponent,  $a$ , for equivalent mixing and transfer performance is 0.12. Applying the same scaling relationship and scale factor exponent, a tank with a 22.9 meter diameter would yield the same transferrable slurry concentration at a mixer jet nozzle velocity equal to 14.9 m/s.

Whereas, the simulant properties were matched for paired tests (i.e., similar test conditions performed at each scale), operating parameters for the test pairs were not matched to yield equivalent batch transfer consistency performance between scales. Preliminary testing was used to establish the mixer jet nozzle velocity range for each tank scale based on equivalent bottom clearing performance using similar simulant conditions. Transfer pump suction velocities were equated between scales, adjusting the size of the suction opening and transfer rate to yield equivalent values while still maintaining a flow velocity above the critical velocity in the transfer line. The highly fractionated test matrix included five nozzle velocities and three suction velocities, which are presented in Tables IV and V, respectively. Comparisons between test conditions and the anticipated full-scale operating condition, a mixer jet nozzle velocity of 18.0 m/s (59 ft/s), are shown in Figure 3.

TABLE IV. Operational parameters for the mixer jet pumps

Velocity ID	1:21-Scale Target Velocity		Rotation Rate	1:8-Scale Target Velocity		Rotation Rate
	m/s	ft/s	rpm	m/s	ft/s	rpm
V1	5.55	18.2	1.29	8.75	28.7	0.73
V2	6.74	22.1	1.56	9.48	31.1	0.79
V3	7.96	26.1	1.84	10.2	33.5	0.85
V4	9.14	30.0	2.12	10.9	35.9	0.91
V5	10.3	33.9	2.39	11.7	38.3	0.97

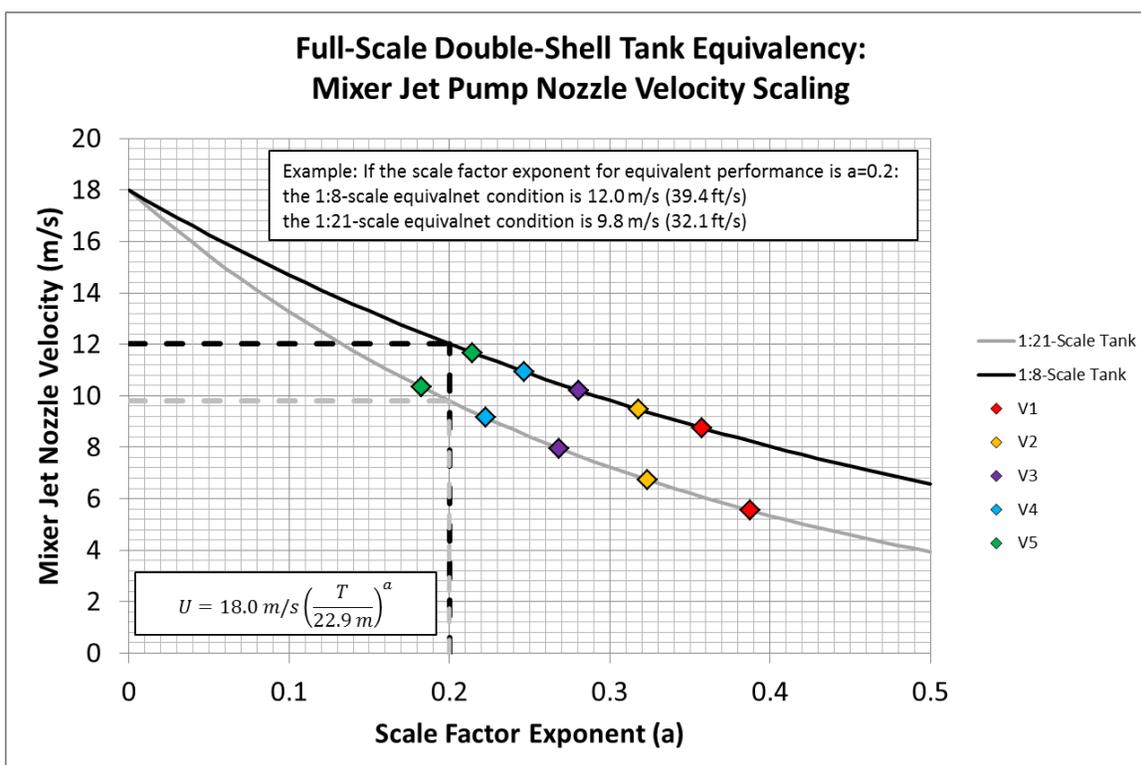


Figure 3: Full-scale equivalency for scaled tank testing

TABLE V. Operational parameters for the transfer pump suction velocities

Transfer Pump Suction Velocity ID	Suction Velocity (m/s)	Suction Velocity (ft/s)
LOW	1.2	<u>3.8</u>
MEDIUM	2.2	<u>7.3</u>
HIGH	3.4	<u>11.3</u>

The test matrix included 26 tests for each scale. The test matrix included four test replicates within the 26 tests. The conditions of each test in the test matrix are identified using a descriptive label when presenting the results. The format of the label is “V=, BS = , SV= , CV= ”. The mixer jet nozzle velocity (V=) is labeled according to the underlined number in Table IV. The solids particulate type (BS=) is labeled according to the underlined letter(s) in Table II. The suspending fluid type (SV=) is labeled according to the underlined letter in Table III. The transfer pump suction velocity (CV=) is labeled according to the underlined numbers in Table V.

### **Sample Collection and Quantification**

During testing, the operating conditions were established, the mixer jet pumps were used to disperse the added solids, and then the tank was mixed at the operating conditions for a minimum of 30 revolutions of the mixer jet pump. Samples of the mixed slurry were collected from the full tank and during each subsequent batch transfer from the tank. All samples were collected from the discharge of the transfer pump. Pre-transfer samples were diverted directly into a sample container. Only one pre-transfer sample subsample was analyzed for each test. Batch transfers from the 1:21-scale tank were diverted into separate subsampling containers. The batch transfer volume was approximately 60 L (16 gallons). Approximately 60 L (1 out of every 20 revolutions of the mixer jet pumps) of each batch transfer from the 1:8-scale tank was diverted into separate subsampling containers; the remainder was discharged to spent simulant holding ponds. The slurry in the subsampling containers was allowed to settle, the clear liquid was decanted, the wet solids were thoroughly mixed, and four wet solids subsamples were collected. An analytical laboratory rinsed and dried the solids and measured the solids content in each subsample. The laboratory then cone and quartered the dried solids, subsampled the material, digested the subsamples, and analyzed the digestate using ICP-AES. The laboratory converted measured concentrations to weight percentages of each component in the simulant. The analytical error (accuracy and precision) depended on solids particulate composition and suspending fluid type. The highest relative variations occurred in the samples with the lowest concentrations. For the subsamples of laboratory controls, the relative error in the subsample average was  $\pm 7\%$  for stainless steel and  $\pm 12.5\%$  for sand [5]. Subsamples of laboratory controls had relative standard deviations up to 30% for stainless steel and 15% for sand [5].

## **ANALYSIS AND DISCUSSION**

For the 26 test pairs, the analytical results, total solids content, volume of the transfer samples, and mass of the transfer samples were used to convert the analytical measurements to component concentrations for the pre-transfer sample and for each batch transfer. The total amount of solids removed from the tank during each transfer and the total amount of each component (gibbsite, sand, zirconium oxide, and stainless steel) were also computed. The results from the tests pairs were compared to evaluate performance equivalency between the two test scales. In addition, ratios comparing the concentrations of the pre-transfer sample and each subsequent transfer batch were also computed and compared.

### **Comparison of Solids Transferred Between Scales**

Figure 4 shows a tank scale comparison for the fraction of solids transferred from the mixing tank during each of the 26 test pairs that were performed. The mass fractions shown are calculated by measuring or estimating the mass of solids transferred and dividing that value by the initial mass of all components added to the test volume. In each figure the test conditions are communicated through the plot marker; the marker color communicates the mixer jet nozzle velocity (red = V1, orange = V2, purple = V3, blue = V4, green = V5), the marker outline communicates the solids particulate type (black outline = TYPICAL, no outline = HIGH), the marker shape communicates the suspending fluid type (square = TYPICAL, diamond = MODIFIED HIGH, and circle = HIGH), and the marker size communicates the transfer pump suction velocity (7 point = LOW, 9 point = MEDIUM, 11 point = HIGH).

Comparing the two tank scales, Figure 4 shows that the fraction of solids transferred was generally greater for the TYPICAL solids particulate than it was for the HIGH solids particulate and for the HIGH solids particulate the fraction of solids transferred increased with increasing mixer jet nozzle velocity. The amount of TYPICAL solids transferred is not sensitive to the test conditions; the fraction of solids transferred is approximately equal to the volume fraction transferred at most test conditions. The TYPICAL solids particulate was 71 weight percent gibbsite particles that were readily suspended at the test velocities and account for at least 71% of the solids that were transferred. The HIGH solids particulate has a much greater proportion of sand and stainless steel; combined these two components account for 89 weight percent of the total solids. Sand and stainless steel are both larger and more dense than the gibbsite in the TYPICAL solids particulate and settle faster than the gibbsite and zirconium oxide particles. The most prevalent particles in the HIGH solids particulate (sand and stainless steel) were more difficult to suspend and transfer than the most prevalent particles in the TYPICAL solids particulate (gibbsite).

In both scales, the lower mixer jet velocities did not provide sufficient energy to suspend the more challenging particles and much of the material was deposited in mounds on the sides of the tanks. As the mixer jet nozzle velocity increased, particle suspension improved, and a greater fraction of solids were transferred from the tank. From Figure 4 it is also concluded that, at the lower mixer jet nozzle velocities, the 1:8-scale tank transferred more of the challenging solids than the 1:21-scale tank. At higher mixer jet pump nozzle velocities, the fraction of solids transferred in each test pair is closer to the line of equality than lower mixer jet pump nozzle velocities. When the performance metric considers the fraction of challenging particles transferred from the tanks, it is concluded that the point of equivalence between the two scaled tanks occurs near the scale factor exponent tested at V-5, 0.12 as listed in Table IV. Test pairs with scale factor exponents greater than 0.25 were further away from operating at the point of equivalency.

Using the same marker symbols from Figure 4, Figure 5 shows parameter sensitivity plots that were used to identify test conditions that influenced the fraction of total solids transferred during a test. For results that do not appear to have a plateau, linear regression trend lines show the trends, or lack thereof, in the data. Separate fit lines are included for each solid particulate type. For data exhibiting a plateau, trend lines are manually added. The two most dominant test parameters affecting the total amount of solids transferred are the solids particulate type, TYPICAL or HIGH, and the mixer jet nozzle velocity. As shown in Figure 5, for both test scales, the fraction of solids transferred is higher for the TYPICAL particulate solids and reaches a plateau with mixer jet nozzle velocity. For the HIGH particulate solids, the fraction of solids transferred continues to increase. The influence of the Newtonian fluid kinematic viscosity and transfer pump suction velocity are much less influential on the amount of solids transferred. Comparing the total solids transfer performance between the two scales, the observed trends are the same: the fraction of solids transferred is higher for the TYPICAL particulate solids than it is for the HIGH particulate solids, the fraction of the TYPICAL particulate solids transferred approaches a plateau that is approximately equal to the volume fraction transferred, the fraction of the HIGH particulate solids transferred continues to increase over the tested mixer jet nozzle velocity ranges, and the sensitivity to the kinematic viscosity and transfer pump suction velocity are not significant.

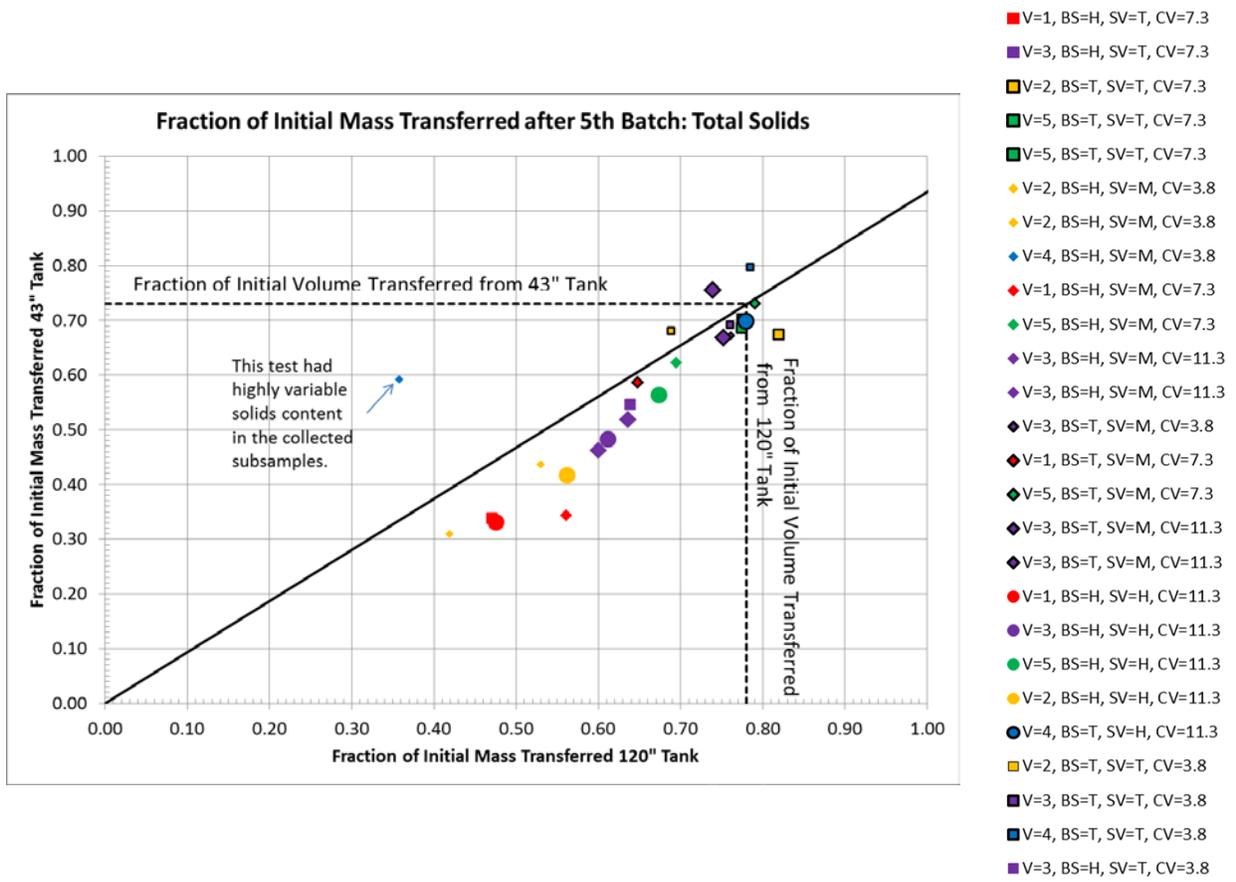


Figure 4. Comparison of the mass fraction of total solids transferred in the two scaled test tanks

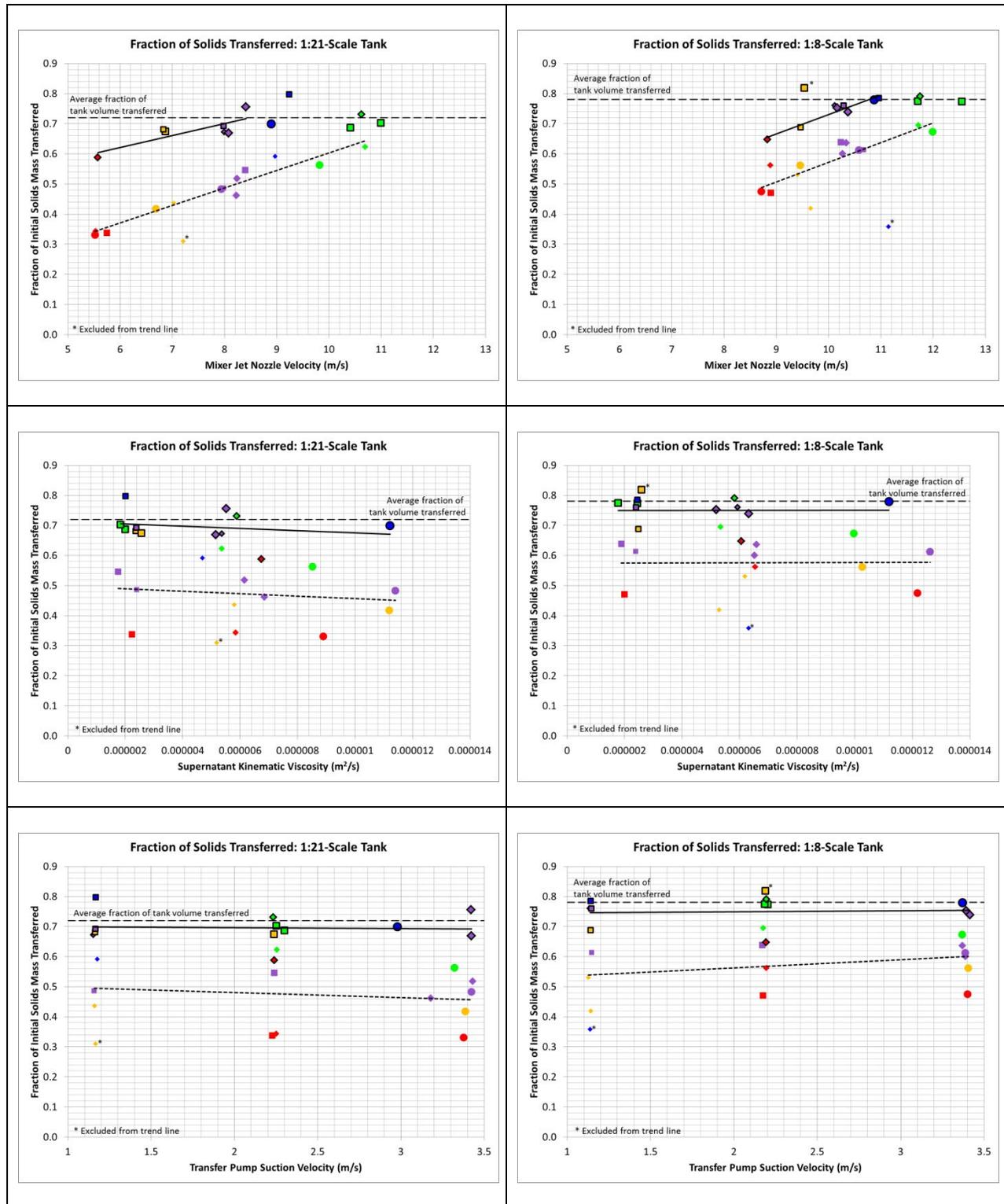


Figure 5. Parameter sensitivity plots for the mass fraction of total solids transferred

Using the same marker symbols from Figure 4, Figure 6 plots the mass fraction of each component transferred during each mixing test. The mass fractions shown are relative to the initial amount of each component added to the test volume. In addition to this comparison by tank scale, least squares regression modeling using the primary test parameters (no polynomial or interaction terms) was performed for each component to evaluate the sensitivity between the mass fractions transferred and the test parameters. The t-ratio for each coefficient in the regression model was computed to test whether the true value of the test parameter coefficient was zero, i.e., the response (mass fraction transferred) was not sensitive to the test parameter. The p-value for the coefficient was also computed; the p-value is the probability of incorrectly stating that the coefficient is different from zero. Test conditions with p-values less than 0.05 were considered influential on the performance result. Table VI provides the responses for each test parameter and component.

As previously discussed and shown in Figure 4, the fraction of total solids transferred is sensitive to the solids particulate type and mixer jet nozzle velocity. The mass fraction of gibbsite and zirconium oxide transferred from the tank are not sensitive to the mixer jet nozzle velocity, but were sensitive to other test parameters. As shown in Figure 6, the fraction of gibbsite transferred is nearly equal to the volume fraction transferred under all test conditions so that the variability in the data is explained by a particular sensitivity to the fluid viscosity and transfer pump suction velocity. Gibbsite was readily suspended in the test tanks so that a direct influence of these two test parameters was not an expected result and is not readily explainable. The fraction of zirconium oxide transferred from the tank is slightly lower for the HIGH particulate solids than it is for the TYPICAL particulate solids. The turbulence caused by the mixer jet pumps is dampened by the greater proportion of faster settling solids in the HIGH particulate solids, thereby reducing the mixing capability of the jets. In addition, larger piles of material were deposited on the sides of the tanks, which could also immobilize more readily suspended components that get buried under the faster settling particles as they are deposited onto the mounds. Because zirconium oxide has a higher particle density than gibbsite, it settled faster than similarly sized gibbsite and may be more susceptible to being immobilized in the mounds. The mass fractions of gibbsite and zirconium oxide were not sensitive to the mixer jet nozzle velocity and therefore are not sensitive to the test scale under the assumed scaling relationship presented in Equation 1.

The mass fraction of sand transferred from the tank is sensitive to the solids particulate type. The sensitivity to the solids type is caused by different sand sizes in the two particulate types (see Table II). The mass fraction of sand and stainless steel transferred is sensitive to mixer jet nozzle velocity. Lower mixer jet nozzle velocities resulted in lower mass fractions of sand and stainless steel transferred from the tank. Although the statistical analysis did not show an influential effect on tank scale, the 1:8-scale tank transferred more of the challenging solids than the 1:21-scale tank. This observation demonstrates that, for the more challenging particles, the two test tanks were not operated equivalently during testing. The mixer jet nozzle velocity ranges for the two tank scales were determined based on an equivalent bottom clearing criterion; the results indicate that the criterion for equal bottom clearing does not also yield equivalent solids transfer performance.

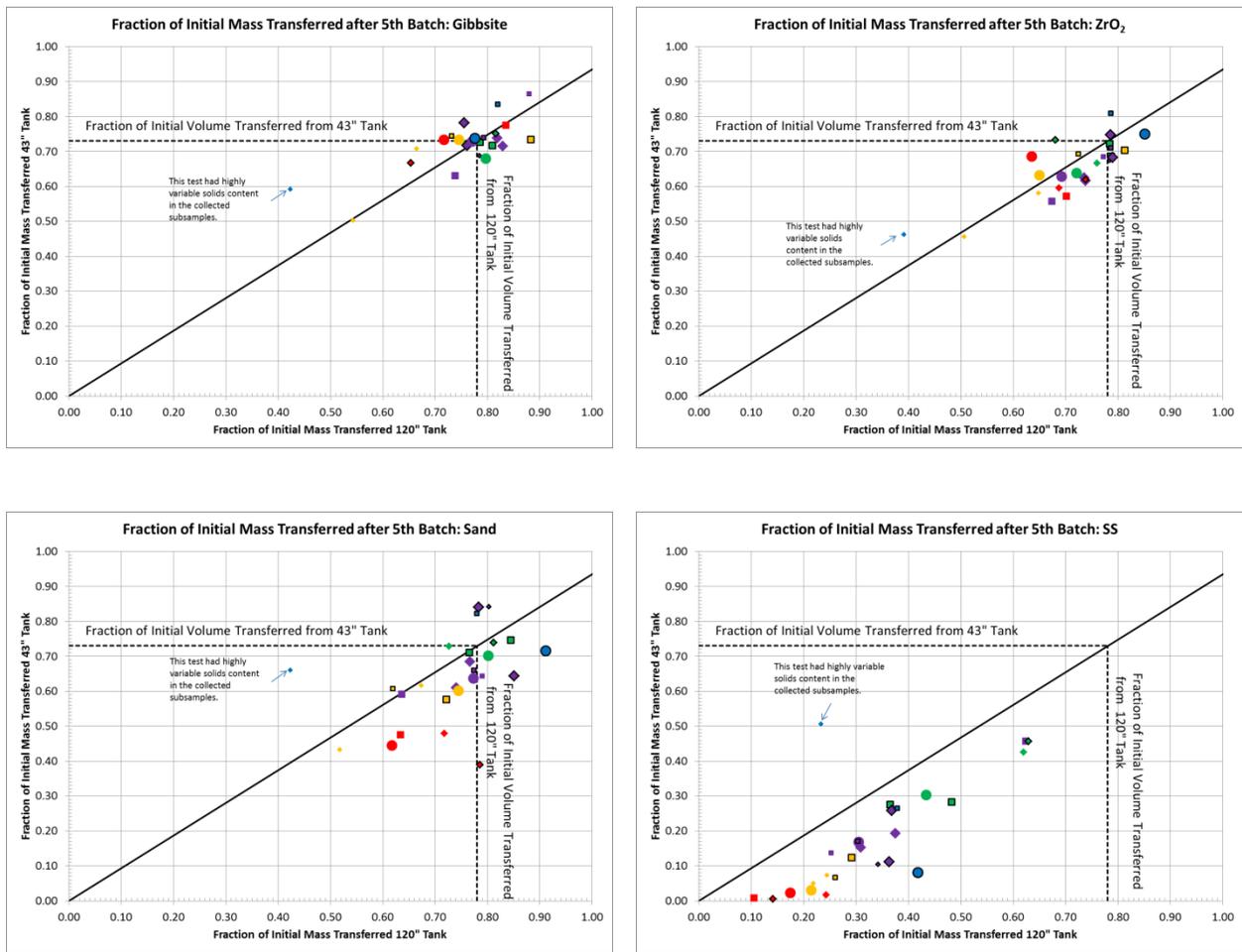


Figure 6. Mass fraction of each component transferred in the two scaled test tanks

TABLE VII. Influence of test condition on the mass fraction of solids transferred from the tank

Component	Influential test parameter				
	Tank Scale	Solids Particulate	Mixer Jet Nozzle Velocity	Suspending Fluid Kinematic Viscosity	Transfer Pump Suction Velocity
Total Solids	No	Yes	Yes	No	No
Gibbsite	No	No	No	Yes	Yes
Zirconium Oxide	Yes	Yes	No	No	Yes
Sand	No	Yes	Yes	No	No
Stainless Steel	No	No	Yes	No	No

## Transfer Consistency Analysis

The anticipated process for demonstrating waste feed acceptability is to sample the transferrable slurry while the tank is being mixed and prior to transferring any tank waste to the WTP. The collected sample will be analyzed and compared to WAC. In a perfectly mixed tank the concentration of the pre-transfer sample and subsequent batch transfers would be equivalent and the acceptability of the pre-transfer sample would translate to acceptability in all subsequent transfers until the tank contents are replenished. When the tank is not perfectly mixed, the pre-transfer sample can only be used to characterize the acceptability of subsequent transfers if a relationship between the pre-transfer sample and subsequent transfers is understood. Data analysis was performed to evaluate the relationship between the concentration of components in the pre-transfer sample and each subsequent transfer batch.

The ratio of the batch concentration and the pre-transfer sample can be used to evaluate consistency. A concentration ratio near one for all subsequent transfers occurs in a well-mixed tank. Concentration ratios less than one occur when a component becomes less concentrated in the transferrable slurry as the tank is emptied. Note that a pre-transfer concentration ratio near 1 for a single batch does not necessarily mean that the tank is well mixed or that all solids are transferred from the tank. If the mixer jet pumps are capable of suspending fast settling solids off the tank bottom but are not capable of fully dispersing the suspended material throughout the tank, a vertical concentration gradient may develop inside the tank. Thus, the pre-transfer concentration ratio for the earliest batches may be close to unity, but the ratio would decrease when a vertical concentration gradient of fast settling solids occurs. In addition, solids deposited in mounds on the sides of the tank are not part of the transferrable slurry that is quantified by the pre-transfer sample. If the mounds persist while the tank is emptied, the solids are not transferred in subsequent batches either. Therefore, quantifying what is transferrable does not equate to quantifying the tank contents.

Evaluating transfer consistency over the range of test conditions is limited to an evaluation of stainless steel; batch transfer consistency analyses for slower settling components (i.e., gibbsite and zirconium oxide) were not very sensitive to the test conditions. The stainless steel concentration ratio for Batch 1 as a function of the mixer jet nozzle velocity is shown in Figure 7. The trend line added to aid in the visualization of the trends is fit to the test results for both solids particulate types. For the 1:8-scale tank the trend line for the mixer jet nozzle velocity comparison was forced to plateau at a value of 1 at mixer jet nozzle velocities greater than 10.5 m/s. The most notable trend is that in the 1:21-scale tank the concentration ratio for Batch 1 increases towards a value of 1 as the mixer jet nozzle velocity increases. In contrast, for the 1:8-scale tank, the concentration ratio for Batch 1 increases towards a value of 1 as the mixer jet nozzle velocity increases up to 10.5 m/s. The concentration ratio did not continue to improve at nozzle velocities above 10.5 m/s.

The trend in the total solids data would suggest that the concentration ratio plateaus at a concentration ratio value of 1, but the data varies around one. There are two test observations that may cause the 1:8-scale tank to deviate from the trend observed in the 1:21-scale tank. The first is that only one pre-transfer sample was collected but each batch transfer concentration is the average of four collected samples. Because only one pre-transfer sample was collected, the concentration of the pre-transfer sample is subject to a greater uncertainty and therefore the concentration ratio is also subject to the same uncertainty. In addition, a flow anomaly that resulted in significant mixer jet pump discharge oscillations was experienced at the two highest mixer jet nozzle velocities tested in the 1:8-scale tank. When high flow rates were combined with high density slurries, the mixer jet discharge rate from one mixer jet pump would increase by 20-50% while the other mixer jet pump experienced an equivalent reduction in discharge flow. These flow imbalances would lead to mixing instability within the tanks. Flow oscillations for other tests in the 1:8-scale tank were typically within 5% of the target flow rate and large flow oscillations were not observed during testing in the 1:21-scale tank at any conditions. If the pre-

transfer sample or batch transfer subsample were collected during a period of tank mixing instability, the samples may not be representative of average flow conditions within the tank and may cause discrepancies between tests that are not susceptible to the flow anomaly. The oscillating flow condition was not discovered until after testing was completed and data analysis had begun. After testing, additional pre-transfer samples that had been collected during testing were analyzed. Comparing the samples with the four highest stainless steel concentrations revealed that pre-transfer samples collected from the same test varied by  $\pm 25\%$ . A correction of  $\pm 25\%$  would result in concentration ratios much closer to one. Reported lessons learned are to ensure that the tank is at a point of stability when tank transfers occur, and collect and analyze multiple samples to provide some measure of accuracy and precision for the reported quantity.

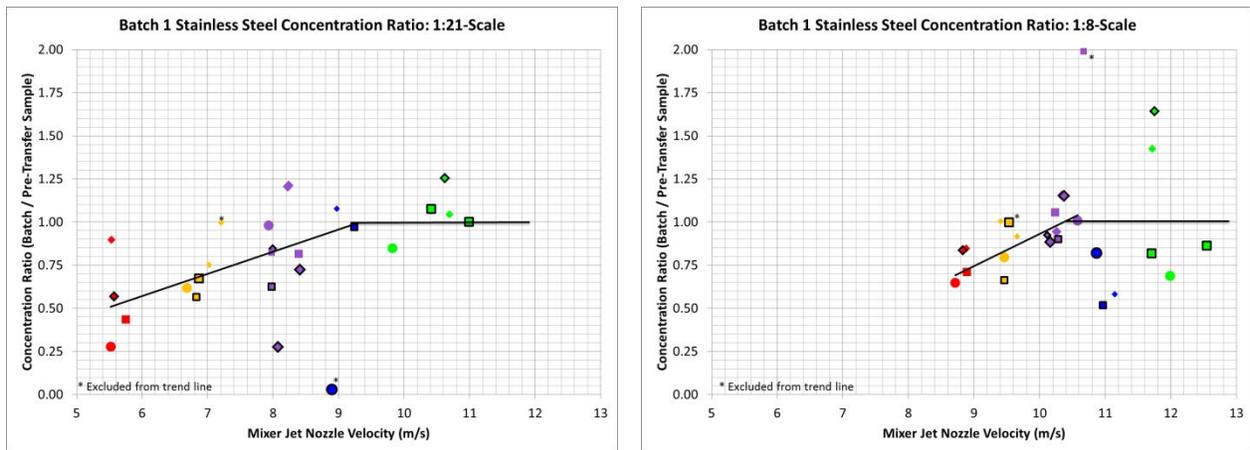


Figure 7. Sensitivity of the batch 1 concentration ratio to the mixer jet nozzle velocity

The plotting analysis was repeated for the supernatant kinematic viscosity and transfer pump suction velocity but the trends were not as strong as with the mixer jet nozzle velocity. The analysis was also repeated for each transfer batch separately, and although the general trends were the same for each batch, the magnitude of the concentration ratio changed with each subsequent batch. The test data for each transfer batch was combined and a least squares regression model using the primary test parameters was performed to quantitatively evaluate the influence of each test parameter on the stainless steel concentration ratio. This statistical analysis was performed to determine the test conditions that had the greatest influence on the concentration ratio. Table VII shows which parameters influenced the concentration ratio when all batch data was combined into the same dataset. The significant effect criterion for identifying the effect in Table VII was a calculated p-value that was less than 0.20. Effects having p-values below 0.05 are emphasized with bold face font. The influence of the Batch Number on the concentration ratio for stainless steel is shown in Figure 8. For the entire test matrix, there is much variability in the concentration ratios. High concentration ratios that are generally consistent across batches are susceptible to having a poorly characterized pre-transfer sample. In addition to oscillating flow conditions that could impact sample collection, variability from the analytical method could also result in pre-transfer sample comparisons that are poorly characterized.

Although there are some exceptions, a general trend in the test data for stainless steel is the concentration ratio decreased with subsequent transfers; the transferrable slurry was less concentrated in stainless steel as the tank was emptied. This result is consistent with previous tests conducted in water [1].

TABLE VIII. Significant test condition effects on the batch transfer concentration ratio for stainless steel

Solids Particulate (BS)	Tank	Observed Effect on the Concentration Ratio			
		Batch Number (BN)	Mixer Jet Nozzle Velocity (U)	Supernatant Kinematic Viscosity (SV)	Transfer Pump Suction Velocity (CV)
TYPICAL	1:21-Scale	↓ as BN ↑	↑ as U ↑	↓ as SV ↑	None
	1:8-Scale	↓ as BN ↑	↑ as U ↑	None	None
HIGH	1:21-Scale	None	↑ as U ↑	↓ as SV ↑	None
	1:8-Scale	↓ as BN ↑	↑ as U ↑	↓ as SV ↑	None

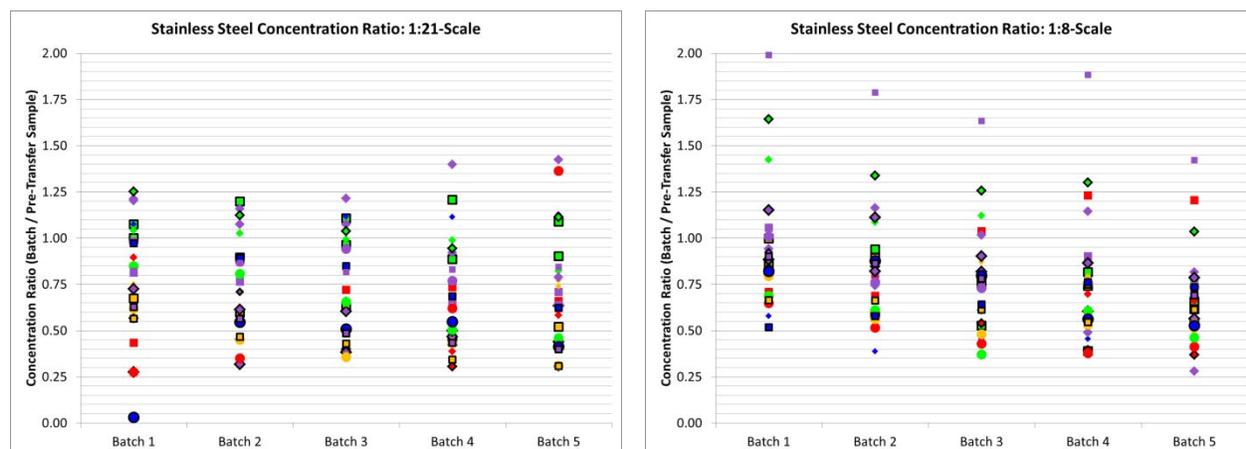


Figure 8. Stainless steel batch consistency comparison in the two scaled tank tests

At the test conditions, mixing with mixer jet pumps did not homogenize the tanks. Stainless steel and other components were deposited in mounds on the sides of the tank. Furthermore, the stainless steel that was suspended was not uniformly suspended in the tanks. When mixing was insufficient to homogenize the tank a concentration gradient was established inside the tank; the concentration at the bottom of the tank was higher than the concentration near the surface. As slurry was pumped from the bottom of the tank, the area of higher concentration, the concentration at the bottom of the tank decreased. As a result each successive transfer had lower stainless steel concentrations. For the most challenging particles, mixing with mixer jet pumps results in the pre-transfer sample over estimating the concentration of subsequent batches with estimates for later transfer batches being overestimated by more than the earlier batches. The observed trend is that with each subsequent batch transfer, the concentration ratio decreases by an average of 3% in the 1:21-scale tank and 6% in the 1:8-scale tank. Therefore, the concentration of stainless steel in the final transfer batch is expected to be between 15 and 25% lower than the stainless steel concentration in the pre-transfer sample.

Exceptions to this general trend were observed when large mounds of unsuspended solids formed on the sides of the tank. As the tank level dropped, the flow conditions in the tank changed and motion at the liquid surface increased. As the tank level approached the top of the mounds, the increased motion caused the shape of the mounds to change. With the changing shape, material was redistributed in the tank resulting in additional material being transferred from the tank.

## Full-Scale Performance Predictions

From Figure 7, the plateau in the stainless steel concentration ratio is reached at about 9.1 m/s in the 1:21-scale tank and at about 10.2 m/s in the 1:8-scale tank. Using Equation 1, the resulting scale factor exponent between these two points is 0.11. This scale factor exponent estimate is consistent with scale factor exponent estimated from the test data. Scale factor exponent estimates based on equivalent stainless steel concentrations in the transfer batches calculated using subsets of the test data ranged from 0 to 0.1 [5, 6] and values up to 0.32 were estimated when the entire data set was modeled [7]. Based on a scale factor exponent value equal to 0.11, it is concluded from Figure 3 that small-scale testing was not performed at scaled nozzle velocities that were equivalent to the full-scale nozzle velocities. The tests performed at the smaller scales were performed at velocities that were lower than full-scale equivalents. Therefore, because it was shown that performance tends to increase with increased mixer jet nozzle velocities, up to a point of a plateau, it is expected that full-scale performance will be better than that observed at small scales or reach the point of the plateau.

## CONCLUSIONS

Testing was performed in two geometrically scaled tanks to evaluate the performance of the planned feed delivery system from the Hanford tank farms to the WTP. Different simulants spanning the range of anticipated tank waste physical properties were used. Based on the testing it was identified that the two test tanks were not operated equivalently during testing. The 1:8-scale tank transferred a greater fraction of solids when the solids particulate contained a greater proportion of fast-settling solids. The amount of solids transferred from the two scales was nearly equivalent when the simulant was predominantly readily suspended material. Scaling analyses based on concentrations of stainless steel transferred from the tanks have been performed [5, 6, 7] to determine the points of equivalency. Through regression modeling it was determined that the point of equivalency has a scale factor exponent that is approximately 0.12. It is concluded from Figure 3 that small-scale testing was performed at scaled velocities that are lower than the scaled equivalent of 18.0 m/s (59 ft/s). Since it was also demonstrated that the batch transfer consistency also improves as mixer jet nozzle velocity increases, it is concluded that batch transfer consistency will be improved over that demonstrated during small-scale testing. Thus although the concentration of fast-settling solids was up to 25% different between the first transfer and the last transfer, it is expected that full-scale performance will be more consistent. Since it was also observed that the fraction of solids transferred from the tank increases with increasing mixer jet nozzle velocity, it is also concluded that full-scale operations will transfer a greater fraction of the fast-settling solids from the tank. As a result of increased solids transfers, the anticipated size of any mounds left on the sides of the tank are expected to be proportionally smaller than those observed during testing.

## REFERENCES

- [1] M. Thien, et. al., “Estimating High-Level Waste Mixing Performance in Hanford Double Shell Tanks”, Proceedings, Waste Management Symposia, (2011).
- [2] D. Greer, M. Thien, “Statistical Evaluation of Small Scale Mixing Demonstration Sampling and Batch Transfer Performance”, Proceedings, Waste Management Symposia, (2012).
- [3] M. Thien, S. Barnes, “A One System Approach to Simulant Selection for Hanford High Level Waste Mixing and Sampling Tests”, Proceedings, Waste Management Symposia, (2013).
- [4] K. Lee, et. al., “Waste Feed Delivery Mixing and Sampling Program Simulant Definition for Tank Farm Performance Testing”, RPP-PLAN-51625, Washington River Protection Solutions (2012).

WM2014 Conference, March 2 – 6, 2014, Phoenix, Arizona, USA

[5] S. Kelly, et. al., “One System Waste Feed Delivery Mixing Performance and Solids Accumulation Test Report”, RPP-RPT-53931, Washington River Protection Solutions (2013).

[6] B. Wells, et. al., “Preliminary Scaling Estimate for Select Small Scale Mixing Demonstration Tests”, PNNL-22737, Pacific Northwest National Laboratory, (2013)

[7] G. Piepel, et. al., “Scaling Relationships Based on Scaled Tank Mixing and Transfer Test Results”, PNNL-22644, Pacific Northwest National Laboratory, (2013)