AVANTech/CH2M ORNL Melton Valley Simulant Tank Waste Mixing Optimization and Technology Maturation Case Study – 22027

Michael Reed *, Tracy Barker *, Ryan Lavisky *, Abram Kolb *, Robert Wilson *
Michael Johnson**
* AVANTech, LLC
** Jacobs

ABSTRACT

AVANTech was selected to provide Technology Readiness Level (TRL) maturation for the Slurry Mixing and Characterization Tank (SMCT) in conjunction with CH2M HILL Constructors Inc. (CH2M) and through DOE-OREM for the Sludge Process Facility Buildout project. AVANTech offers radioactive and industrial water treatment solutions with engineering and fabrication facilities in Columbia, SC; Richland, WA; and Knoxville, TN, near Oak Ridge.

The project demonstrates mixing technology for simulated waste from the Melton Valley Storage Tanks at Oak Ridge National Laboratory in Oak Ridge, TN. An adequately designed mixer is critical for successful operation of the Slurry Mixing and Characterization Tank (SMCT) as part of the Sludge Solidification Center design. The SMCT's objective is to ensure a homogeneously mixed stream that is able to be fed to downstream solidification unit operations. A tall geometric configuration, high solids content, and fast particle settling velocity led the SMCT to be labeled a Critical Technology Element – and thus requires further testing to ensure proper mixer design. Testing entails two phases: 1) laboratory testing with geometrically scaled vessels/mixers, and modeling followed by 2) full-scale testing.

The reduced-scale laboratory testing was completed in 2021. Using rigorous sampling protocols from wall and bottom sample ports, homogeneity of the vessel was assessed for two challenging simulants. Particle size distribution (PSD) proved to be the best indicator for assessing the mixer's ability to achieve whole vessel homogeneity and maintain particle suspension during vessel draining. Key lessons learned included low-level mixing techniques for maximum vessel draining, mixer motor sizing, and homogeneity sampling criteria. The result was a vessel geometry and mixer design that was successfully able to obtain homogeneity with the chosen simulants during reduced-scale testing. The reduced-scale test results were modeled to determine the full-scale SMCT and mixer designs. This provides good confidence in the future success of the full-scale testing.

Lessons learned were incorporated into the full-scale designs. The full-scale SMCT test area is in the fabrication phase, with testing scheduled to start in CY 2022. Full-scale testing will take place at AVANTech's integrated fabrication and testing facility in Columbia, SC. The primary objective is to advance the SMCT towards TRL-6, successful full-scale technology demonstration with two non-radioactive simulated waste streams. In addition to the full-scale SMCT and mixer tests instrumentation and an autosampler will be tested to provide online monitoring of slurry density, flow rate, viscosity, and wt. % total solids. The paper/presentation will describe this Oak Ridge case study and associated lessons learned.

INTRODUCTION

The Melton Valley Storage Tanks at Oak Ridge National Laboratory contain over 300,000 gallons of complex, high solids waste. The disposal of this waste is crucial to protecting the Tennessee Valley and surrounding areas from potential accident or contamination scenarios. Crucial to the effective disposal of the waste is the SMCT, a Critical Technology Element, which will homogeneously suspend and transfer a slurry containing the waste from the Melton Valley Storage Tanks. The focus of this report is to highlight the progression of the SMCT towards demonstrating technology maturation.

Completion of the SMCT reduced scale testing allows for the progression to the next phase of the technology maturation process: successful full-scale technology demonstration with two non-radioactive simulated waste streams. In order to best support the upcoming full-scale testing activities, lessons learned from reduced scale testing must be implemented along with improvements to the design of the full-scale SMCT mixing capabilities.

SIMULANT DESCRIPTION

To properly test the SMCT, development was conducted of non-radiological, representative, and conservative simulant mixture that adequately mimic the physical properties of the actual waste slurries. Simulant development efforts narrowed the list to two simulants.

Simulant 3: Small fraction of large and dense particles up to 1,000 micron
Simulant 4: Large fraction of large and dense particles up to 1,000 micron

The simulants identified for further testing are a diverse and complex set of insoluble and soluble solids. The soluble, supernatant, phase of the simulant is 3 molar sodium nitrate (22 wt.%). The insoluble solids, consisting of 10 wt.% of the slurry mixture consists of alumina trihydrate, calcium carbonate, red iron oxide, magnesium hydroxide, bentonite clay, bismuth metal, bismuth oxide, tungsten oxide, and steel grit. The last four materials (bismuth, bismuth oxide, tungsten oxide, steel grit) are the largest, most dense particles, and the most difficult to suspend.

Characterization of the simulant mixture is crucial to understanding the physical and rheological properties of the simulant and for developing a baseline of comparison for testing the effectiveness of the mixer and sampling design.

Characterization of the simulant involves mass concentration measurement of total solids, total suspended solids, density measurement, PSD analysis, and rheological properties measurements. Reduced scale characterization efforts were performed previously [1]. Simulants 3 and 4 were used in the reduced scale testing and the Computational Fluid Dynamics (CFD) modeling to produce an adequate mixer for full-scale testing of the SMCT.

REDUCED SCALE DEVELOPMENT

Experimental

The mixer developer, Philadelphia Mixing Solutions Ltd. (PMSL), was subcontracted to assist with the reduced scale testing and CFD modeling portions of the SMCT development. The CFD model is developed in two phases. The first phase is a theoretical mixer design based on the characterization of the simulant mixture and previous experience mixing complex slurries. The early CFD work resulted in the design of a 610mm internal diameter (ID) reduced-scale vessel and mixer apparatus [3]. The full-scale vessel will be a torispherical dished, ASME Section VIII vessel that must be able to be transported via freight to its location in Oak Ridge, TN. Figure 1 shows the 610 mm vessel built for the reduced scale testing. It is complete with sampling nozzles along the sides of the vessel, recirculation dip tube, and 4 primary hydrofoil impellers with 1 turbine-style impeller (called a “tickler”) at the bottom of the vessel.

Testing was primarily conducted in a 610mm ID vessel with geometric features similar to that of the proposed full-scale SMCT and mixer. In addition to the 610mm ID vessel, a smaller scale 457mm ID (approximately 1/2 volume of 610mm or 0.75 scale factor with respect to tank ID) vessel was used to determine the scale-up method for the full scale SMCT mixer. Testing of the more difficult of the two simulant (Simulant 4) was repeated at the 457mm scale to determine the scaling exponent for homogeneity so that the proposed full scale SMCT mixer design can be verified.

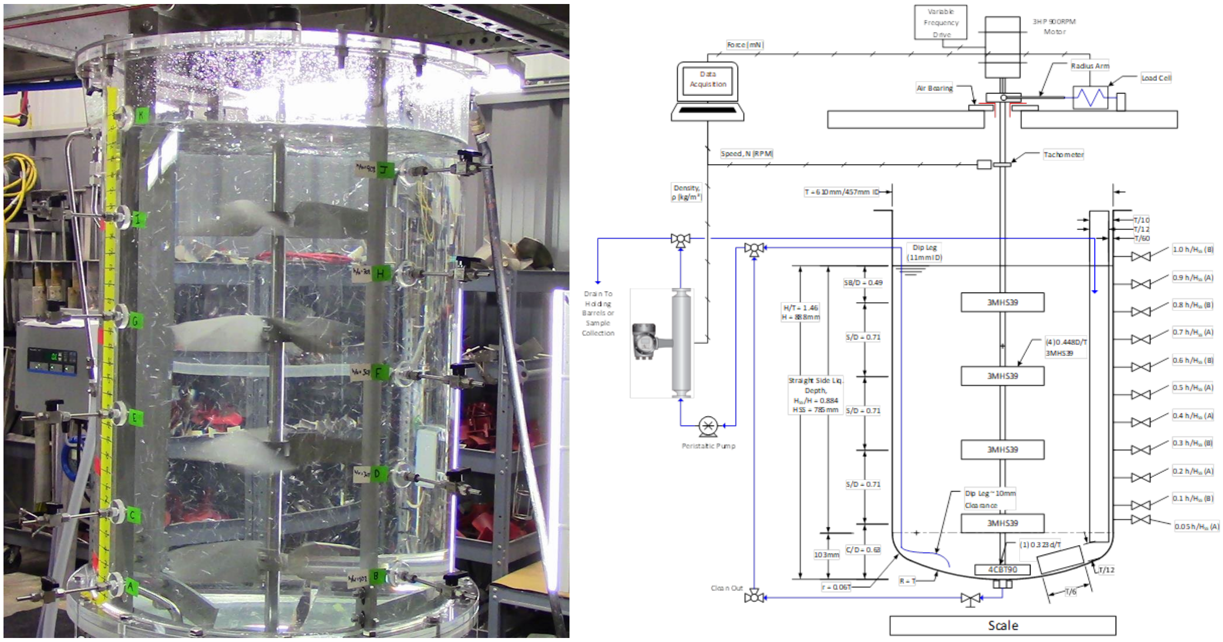

Figure 1 – 610mm scale testing apparatus and test schematic. Picture credit J. Giacomelli, PMSL.

Homogeneity Determination

Homogenous suspension of the slurry mixture is critical to provide as many batches of waste transferred to further treatment and solidification as possible. Specification requirements for determining homogeneity states:

> *For the testing described herein, homogeneity is achieved when the consistency of the concentration, in both the radial and axial directions, of undissolved solids and chemical constituents is within +/-5% of the mean composition in the tank. [5]*

Samples were collected at varying heights from the vessel wall sample ports and from the recirculation dip tube [2]. Mass concentration measurements from these sample ports revealed homogeneity is achieved above the critical mixing condition called the "just suspended" speed, N_{Js}, of the mixer. Below this condition, solid particles are observed settling on the bottom of the vessel. Above this condition, mixing of the vessels is determined to be well-mixed with typical total suspended solids concentrations well within the 5% requirement.

Density measurements taken from an in-line Coriolis flow meter and from samples taken from various vessel locations could not distinguish between a well-mixed or poorly mixed slurry. At speeds below N_{Js}, density measurements are within expected values and above N_{Js}, air entrainment from the rapid mixing disrupts the density measurement and the density is observed to decrease. This indicates that density is not sensitive to the largest, dense particles as these particles are few in number compared to the bulk slurry [2].

Testing indicated that the best description of homogeneity was achieved with PSD analysis. Figure 2 below illustrates the results of obtaining PSD analysis of the slurry from varying heights within reduced scale test system. With PSD analysis, differences in particles size are most clearly observed from differences in the non-cumulative distribution. PSD is more sensitive to the distribution of the largest, dense particles compared to slurry density, and so provides a better indication of a well-mixed slurry.

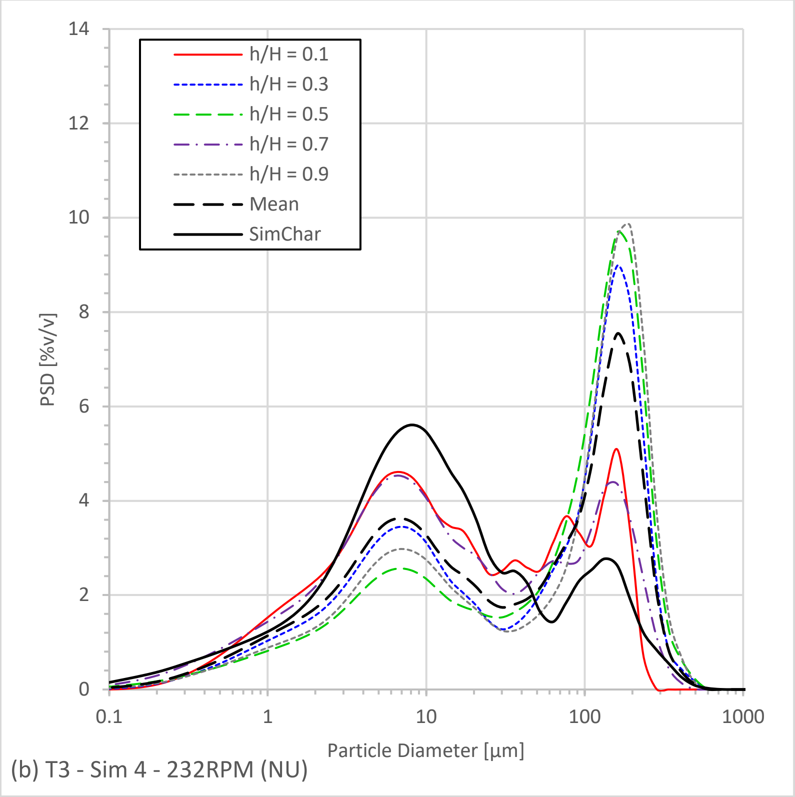

Figure 2 – PSD Analysis of the Reduced Scale test system measured at various levels within the vessel. Picture credit J. Giacomelli, PMSL.

Mixer Restart and Resuspension Testing

Another critical requirement of the SMCT is for the mixer to mobilize the settled bed after an extended power outage of 240 hours and demonstrate homogenous transfers after resuspension. The critical factor affecting the mixer's ability to free itself from the settled sludge layer is the shear strength encountered by the lowest mixer blade. For this purpose, the simulant rheological properties are measured by duplicating the 240-hour settling period on simulant subsamples. Observed shear strength measurements are 94.8 Pa and 126 Pa for simulant 3 and 4, respectively [2].

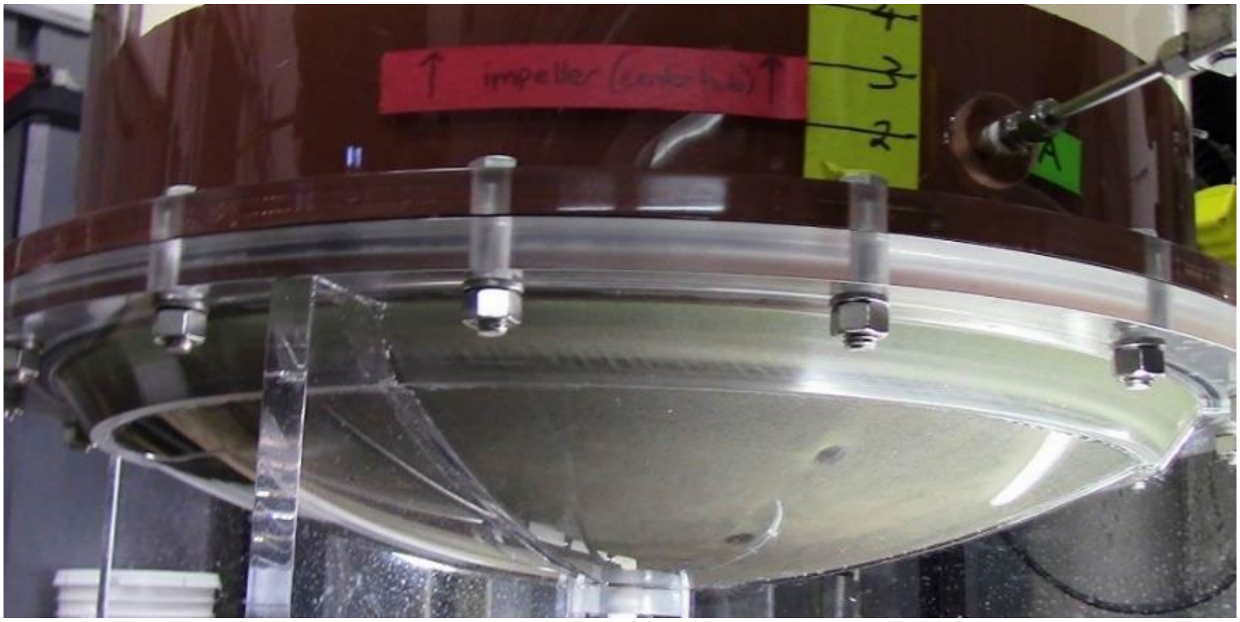

Figure 3 – Solids stratification observed during settled bed test of simulant 4. Picture credit J. Giacomelli, PMSL.

During the settled bed portion of the restart test for reduced scale testing, stratification of the solids is observed with the large, dense particles settling at the bottom while the smaller, fine particles settled more slowly. Further rheological testing of this settled bed revealed that even a "concentrated slurry" of the densest particles as observed above revealed a maximum shear strength of 494 Pa, falling well short of the mixer design value of 7200 Pa [2].

LESSONS LEARNED

Lessons learned from reduced scale testing are implemented for full-scale testing. PSD analysis demonstrated the most effective indicator for determining homogeneity within the SMCT. However, PSD analysis by laser diffraction was not reliable due to the small sample size needed in the analyzer. This was problematic because small sample sizes are partial to obtaining an unrepresentative portion of the simulant's largest particles. Since the simulant's homogeneity is heavily dependent on these large particles, PSD analysis utilizing manual wet sieving was implemented. Sieving the samples in this manner results in a "scalped" sample with only the simulant particles larger than 63 µm (passing the 230 standard mesh). Removing the smaller, easier to suspend particles provides greater resolution for the larger particles and thus the most effective measure of homogeneity for the SMCT mixing performance.

The multiphase CFD report [4], conducted once additional data was obtained during testing, resulted in several modifications to the mixer design to be implemented in full scale testing. Primarily, the 3-blade hydrofoil design was increased to 4-blade so that effective mixing was possible at lower speeds resulting in a lower tip speed of the impellers and less potential erosion concerns of the mixer design. Additionally, testing observed that, as the level of the vessel decreased, faster mixer speeds were required to maintain adequate suspension. To accommodate the higher mixer speeds, the full-scale test system mixer motor power was increased from 200 HP to 250 HP.

Due to success in visually observing the just suspended condition when off-the-bottom suspension is indicated, the full-scale test SMCT will implement additional bottom sight glasses. Figure 4 shows the 3D model of the full-scale SMCT including additions from reduced scale testing lessons learned.

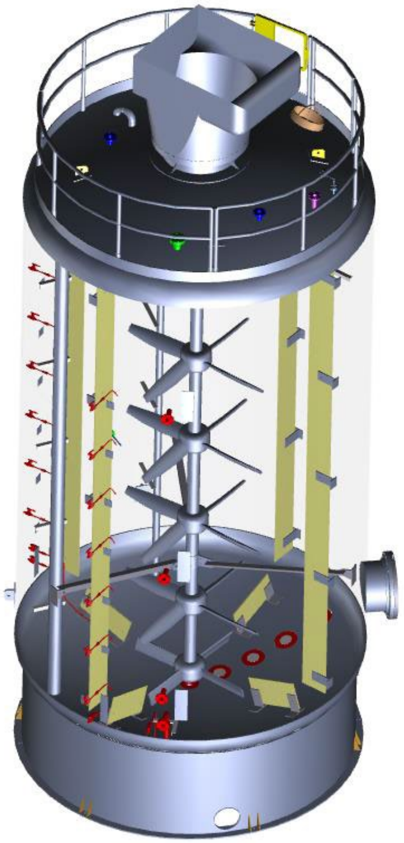

Figure 4 – Full-scale Model of the SMCT design

CONCLUSIONS

Both Simulants 3 and 4, although comprised of challenging slurry components, can be homogeneously mixed with proper impeller and mixer design. Reduced-scale testing results indicate early success in the ability for the SMCT to produce a homogenous slurry mixture for transfer to the downstream solidification process. Implementation of reduced scale testing lessons learned will be crucial to the success of the full-scale test system and advancing the SMCT to TRL–6.

REFERENCES

1. Giacomelli, J., S.J. Johnson. *Slurry Mixing and Characterization Tank (SMCT) Simulant Characterization Report*. Philadelphia Mixing Solutions Ltd. 2020.
2. Giacomelli, J., S.J. Johnson. *Slurry Mixing and Characterization Tank (SMCT) Reduced Scale Agitator Testing*. Philadelphia Mixing Solutions Ltd. 2021.
3. Giacomelli, J. *CFD Analysis Report – Phase I CFD: Analysis of Proposed SMCT Vessel/Agitator*. Philadelphia Mixing Solutions Ltd. 2020.
4. Giacomelli, J., B. Boyer. *CFD Analysis Report – Phase II CFD: Multiphase CFD Model Development*. Philadelphia Mixing Solutions Ltd. 2021.
5. Johnson, M. SLPFB-SPEC-002, revision 2, *Slurry Mixing and Characterization Tank (SMCT): Mixing Test Specification*. CH2M Hill-Jacobs Engineering, 2020.