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F-Canyon Sludge Physical Properties

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ABSTRACT

The Site Deactivation and Decommissioning (SDD) Organization is evaluating options to disposition the 800 underground tanks (including removal of the sludge heels from these tanks). To support this effort, D&D requested assistance from Savannah River National Laboratory (SRNL) personnel to determine the pertinent physical properties to effectively mobilize the sludge from these tanks (Tanks 804, 808, and 809).

SDD provided SRNL with samples of the sludge from Tanks 804, 808, and 809. The authors measured the following physical properties for each tank: particle settling rate, shear strength (i.e., settled solids yield stress), slurry rheology (i.e., yield stress and consistency), total solids concentration in the sludge, soluble solids concentration of the sludge, sludge density, and particle size distribution.

The conclusions from this work follow.

- Tank 804
    - The sludge contained both fast-settling particles (3%) and slow settling particles (77%).
    - The shear strength of the settled sludge samples measured 269 Pa. This large shear strength indicates that the sludge can be difficult to mobilize with conventional agitation systems. Transporting of such materials using centrifugal pumps would be very difficult. Blending the material with a carrier fluid will make transporting it more practical.
    - The insoluble solids concentration of the sludge samples was 55 wt %.
    - The density of the sludge samples was 1.17 g/mL. The calculated density of the sludge particles was 1.36 g/mL.
    - The 10 wt % sludge slurries prepared with this material possess no yield stress. Pipe transport velocities required to maintain particle suspension are 1.6 – 2.7 ft/s.
    - The particle size of the sludge samples varied from 0.14 – 9600 μ. The median particle size (7 μm) was slightly larger than SRS High Level Waste sludge (1 – 5 μm). The particles size distribution varied by five orders of magnitude, which is much greater than that observed in previous analyses of SRS and Hanford High Level Waste Sludge (~ two orders of magnitude). Approximately 1.8% of the particles were larger than 177 μm, which approaches the Defense Waste Processing Facility (DWPF) specification (less than 2% greater than 177 μm).
- Tank 808
    - The sludge contained both fast-settling particles (23%) and slow settling particles (25%).
    - The shear strength of the settled sludge samples measured 796 Pa. This large shear strength indicates that the sludge can be difficult to mobilize with conventional agitation systems. Transporting of such materials using centrifugal pumps would be very difficult. Blending the material with a carrier fluid will make transporting it more practical.
    - The insoluble solids concentration of the sludge samples was 64 wt %.
    - The density of the sludge samples was 1.52 g/mL. The calculated density of the sludge particles was 2.15 g/mL.

- The 10 wt % sludge slurries prepared with this material possess no yield stress. Pipe transport velocities required to maintain particle suspension are 1.8 – 4.4 ft/s.
- The particle size of the sludge samples varied from 0.09 – 2800 μ. The median particle size (17 μm) was slightly larger than SRS High Level Waste sludge (1 – 5 μm). The particles size distribution varied by five orders of magnitude, which is much greater than that observed in previous analyses of SRS and Hanford High Level Waste Sludge (~ two orders of magnitude). Approximately 5.5% of the particles were larger than 177 μm, exceeding the DWPF particle size specification.

- Tank 809
  - The sludge contained both fast-settling particles (4%) and slow settling particles (68%).
  - The shear strength of the settled sludge samples measured 413 Pa. This large shear strength indicates that the sludge can be difficult to mobilize with conventional agitation systems. Transporting of such materials using centrifugal pumps would be very difficult. Blending the material with a carrier fluid will make transporting it more practical.
  - The insoluble solids concentration of the sludge samples measured 74 wt %.
  - The density of the sludge samples was 1.42 g/mL. The calculated density of the sludge particles was 1.66 g/mL.
  - The 10 wt % sludge slurries prepared with this material possess no yield stress. Pipe transport velocities required to maintain particle suspension are 1.6 – 3.4 ft/s.
  - The particle size of the sludge samples varied from 0.02 – 2800 μ. The median particle size (7 μm) was slightly larger than SRS High Level Waste sludge (1 – 5 μm). The particles size distribution varied by five orders of magnitude, which is much greater than that observed in previous analyses of SRS and Hanford High Level Waste Sludge (~ two orders of magnitude). Roughly 2.3% of the particles were larger than 177 μm, slightly exceeding the DWPF particle size specification.

Recommendations:

- Investigate chemical cleaning with materials such as oxalic acid, nitric acid, sodium hydroxide, and hydrogen peroxide to dissolve the sludge and/or reduce its particle size and cohesiveness.
- Consider pilot-scale simulant testing the of proposed sludge retrieval methods prior to retrieval activities.
- Conduct scoping tests with actual tank samples to determine the required mixing energy or vacuum needed to suspend the sludge particles.

INTRODUCTION

The SDD Organization is evaluating options to disposition the 800 underground tanks (including removal of the sludge heels from these tanks) and requested assistance from SRNL personnel to determine the pertinent physical properties to effectively mobilize the sludge from Tanks 804, 808, and 809. This study determined the physical properties to facilitate design of mobilization and transport equipment to remove the sludge from these tanks.

SRNL and SDD personnel agreed on the following program for this task.[1] To determine the requirements for mobilizing sludge in SRS tanks, one must determine whether the slurry (i.e., sludge) is fast-settling or slow-settling. Fast-settling slurry will settle within a few minutes. A slow settling sludge will take hours or days to settle. Fast-settling slurries typically have low concentrations of large (> 100 micron), heavy particles. Slow-settling slurries typically have high concentrations of small (< 10 – 20 micron), slow settling, cohesive particles. These settling characteristics directly influence the effectiveness of sludge mobilization and transfer systems. Consequently, the settling rate of the sludge was measured.

If the slurry is slow settling, the rheology must be measured. If the rheology of the homogenized sludge is determined to be non-Newtonian and modeled as a Bingham Plastic fluid, the Bingham Plastic fluid properties (i.e., yield stress and consistency) provide an indication of the materials resistance to mixing and transport. Materials with large yield stress can be difficult to mix with convention agitation methods and to transport with conventional pumps.[2,3,4]

Since the sludge has been sitting for a long time, another rheological property of interest is the shear strength (i.e., yield stress of the settled solids), which can be determined using a vane. This property can be used to determine startup torque and agitator speed required to mitigate cavern mixing. Materials with large shear strength can be difficult to mobilize with conventional agitation methods.[2,5]

Other needed physical properties are the insoluble solids concentration of the homogenized slurry, the soluble solids concentration in the carrier fluid (or supernate), the density of the homogenized slurry, the carrier fluid density and the carrier fluid viscosity. With this data and the yield stress of the settled solids, a variation of the cavern model[6,7,8] can be used to calculate the target system requirements to mobilize the sludge. The rheological and physical data can also be used to calculate the requirements for transporting the sludge in pipelines.[3,9,10,11,12]

If the slurry is fast settling, one should also measure the particle size distribution and the particle density. With this data and the data described above, one can calculate the requirements to mobilize and maintain mobilization of the slurry and fast settling solids.[2,13] Depending on the type of mixing employed, testing might also be required, particularly for fast settling material. This data can also be used to calculate the requirements for transporting the sludge in pipelines.[13,14,15]

TESTING

SDD provided SRNL with samples of the sludge from Tanks 804, 808, and 809. The authors measured the following physical properties for each tank: particle settling rate, shear strength (i.e., settled solids yield stress), slurry rheology (i.e., yield stress and consistency), total solids concentration in the sludge, soluble solids concentration of the sludge, sludge density, and particle size distribution. This data can be used to determine the size and type of equipment needed to mobilize and transport the sludges. Each of these measurements will be described below.

Particle Settling Rate

SRNL performed the settling rate tests as follows. They placed inhibited water (0.01 M NaOH) in a capped graduated cylinder and added a sample of homogenized sludge. They mixed the vessel and recorded the location of the sludge-supernate interface as a function of time. This approach is based on the method described in previous SRNL testing.[16] They performed tests using approximately 100 g/L of sludge. Personnel performed three replicates of these measurements.

Shear Strength (Yield Stress for Settled Solids)

Personnel measured the settled solids shear strength as follows. They obtained samples of the sludge, which was allowed to settle at room temperature, undisturbed for 96 hours. After the sludge set for 96 hours, they measured the settled solids yield stress using a rotoviscometer equipped with a vane.[17] Personnel performed three replicates of these measurements.

Sludge Solids Measurements

Personnel measured the total solids in the sludge and soluble solids in the supernate from each tank using procedure ADS-2284, “Procedure for Measuring Wt % Total Solids, Soluble Solids, and Insoluble Solids”. They calculated the insoluble solids concentration from the total solids and soluble solids measurements. Personnel performed three replicates of these measurements.

Density Measurements

Personnel measured the sludge density for each tank by placing a sample in a pre-weighed vessel, measuring the mass of the vessel plus the fluid, determining the mass of fluid and dividing this mass by the volume of the vessel. The volume of the measuring vessel was determined using DI water. Personnel performed three replicates of these measurements. Personnel can use the slurry density measurements to calculate the particle density and to convert radionuclide concentrations from Ci/g to Ci/mL.

The samples collected contained insufficient free liquid to measure the carrier fluid density.

They also calculated the density of the sludge particles with equation [1]

$$\rho_{insol} = \frac{X_{insol}\,\rho_{sl}\,\rho_{\mathrm{sup}}}{\rho_{\mathrm{sup}} - X_{\mathrm{sup}}\,\rho_{sl}} \qquad [1]$$

where ρ_{insol} is the density of the solid particles, X_{insol} is the mass fraction of insoluble solids, ρ_{sl} is the density of the slurry, ρ_{sup} is the density of the supernate, and X_{sup} is the mass fraction of supernate. Personnel can use the particle density to calculate the requirements for suspending fast-settling solids and for transporting the fast-settling solids in pipelines.

Flow Curve Measurements to Determine Rheology of the Sludge Slurry

Personnel measured the rheology of each sample with a rotoviscometer. They prepared a 10 wt % insoluble solids sample of each sludge in a 0.01 M NaOH solution. The samples were agitated using a mechanical mixer for at least 1 hour prior to placing the sample in the viscometer cup. Because of the large fast-settling particles in the samples from Tanks 804 and 808, personnel could not measure the flow curves with those samples. Personnel performed three replicates with the sample from Tank 809.

The samples contained insufficient free liquid to measure the carrier fluid viscosity of the as-received sludge.

Particle Size

Personnel measured the sludge particle size with a scanning electron microscope (SEM). They collected a sludge sample, dipped an SEM coupon into the sample, removed the coupon, and submitted it for SEM analysis using procedure ADS-1107, "Procedure for Scanning Electron Microscopy (SEM)". ADS analyzed the sample with the SEM and provided the photographs to the authors. The authors measured the size of the particles on the photographs (~ 500 particles for each sludge sample) and used the scale to calculate the size of a representative sample of particles on each photograph. Personnel have used this method previously to measure the particle size of samples from Hanford waste tanks and found the results to agree.[19-22] Personnel submitted three samples for particle size from each tank. By submitting multiple samples (3 samples for each sludge sample and 10 photographs for each sample) and comparing the results, they tried to account for variations due to non-representative sampling.

RESULTS

Figures 1 shows pictures of the sample from Tank 804. The sample was very thick and contained a slight amount of free liquid. When personnel turned the sample cup on its side, the sample did not run out of the cup. When personnel placed a pipette into the cup, it stood up but was tilted. When they filled the pipette with slurry, it drained very slowly.

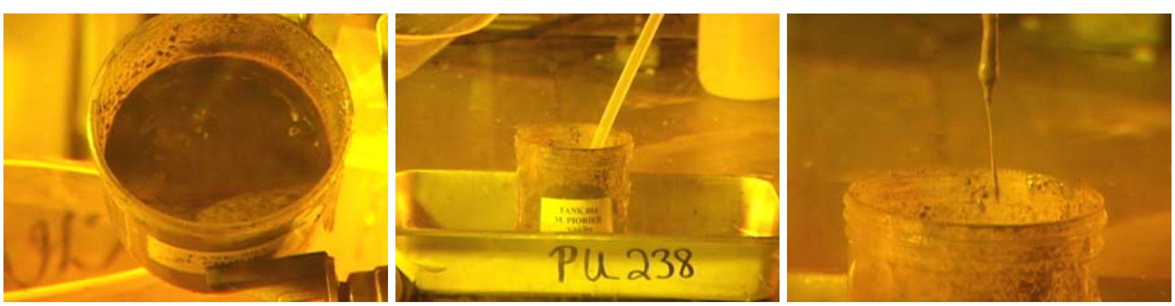

Figure 1. Tank 804 Sludge

Figure 2 shows pictures of the sample from Tank 808. The sample was very thick, as well, and contained little to no free liquid. When personnel turned the sample cup on its side, the sample did not run out of the cup. When personnel placed a pipette into the cup, it stood straight up. When they tilted the cup, the pipette remained straight. When they filled the pipette with slurry, it drained very slowly. These observations indicate the Tank 808 sludge is more viscous than the Tank 804 sludge.

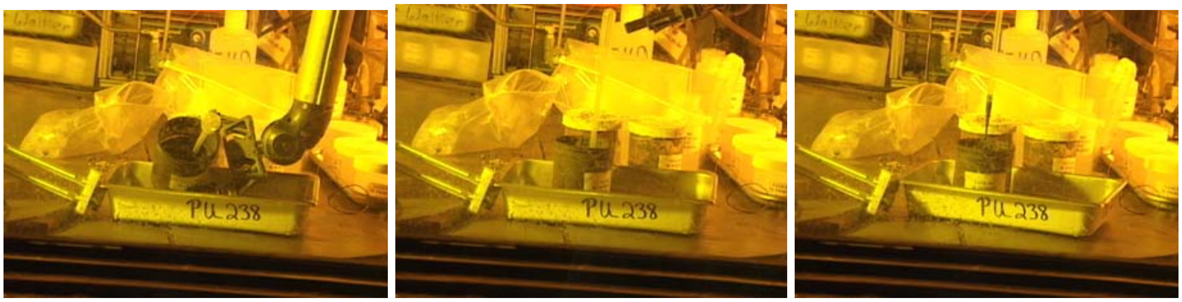

Figure 2. Tank 808 Sludge

Figure 3 shows pictures of the sample from Tank 809. The sample was very thick and contained little to no free liquid. When personnel turned the sample cup on its side, the sample did not run out of the cup. When personnel placed a pipette into the cup, it stood up. When they tilted the cup, the pipette remained straight. When they filled the pipette with slurry, it drained very slowly. Of interest is the photograph in the upper right. Personnel squeezed the pipette with the manipulator to place it in the slurry. After they placed the pipette into the slurry and removed the manipulator, the pipette bulb remained compressed, indicating the viscous nature of the sludge. These observations indicate the Tank 809 sludge is more viscous than the Tank 804 sludge.

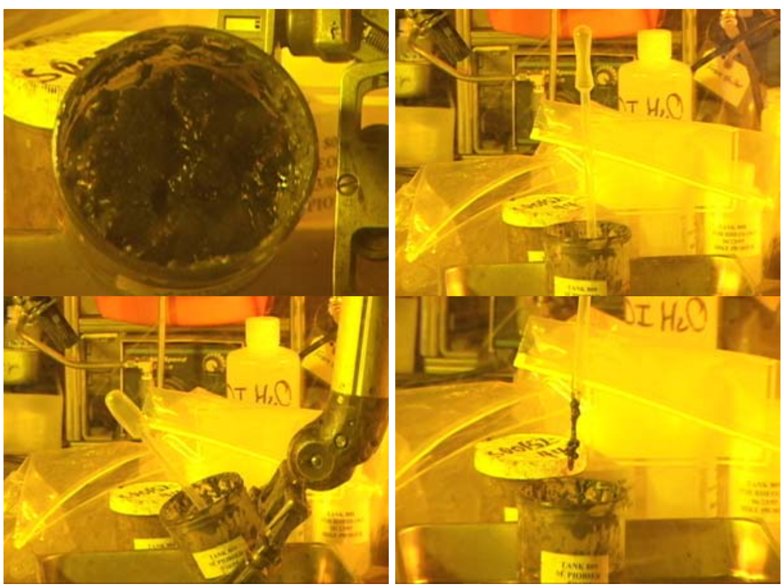

Figure 3. Tank 809 Sludge

Particle Settling Rate

Table 1 shows the measured settling rates for each sample. The large agglomerated particles in the sample settled to the bottom of the vessel very rapidly (within a few seconds). The small particles remained suspended, even after the slurry was allowed to settle overnight. The samples contain both fast-settling and slow-settling particles.

Table 1. Particle Settling Rate

	Settling rate	
Tank	Fast Settling Particles	Slow Settling Particles
804	0.8 ± 0.4 in/s	< 0.01 in/hr
808	2.5 ± 1.8 in/s	< 0.01 in/hr
809	2.0 ± 0.4 in/s	< 0.01 in/hr

Shear Strength (Yield Stress for Settled Solids)

Table 2 shows the shear strength of the settled sludge samples. The shear strength is very large and indicates that the sludge will be very difficult to mobilize with conventional agitation methods. Materials with yield stress less than 10 – 20 Pa pour easily. Materials with yield stress greater than 40 Pa flow poorly, will cleave to walls, and may need pushed to a pump suction.[26] Figure 4 shows the samples, which adhered to the vane rotor, and a typical vane measurement response from that sample. The vane response from the Tank 804 sample indicates that it does not have a typical shear stress versus time response (using the vane), but the fluid seems to have a very viscous component. The largest shear stress was reported for the Tank 804 sample as the shear strength. The Tank 808 and 809 samples have typical vane responses. The samples were allowed to settle for 96 hours prior to the measure, with little to no standing liquid for the Tank 808 and 809 samples. The Tank 804 samples had a slight amount of standing liquid.

Table 2. Slurry Shear Strength

Tank	Shear Strength (Pa)
804	269 ± 23
808	796 ± 77
809	413 ± 79

Analyses performed by the Analytical Development Section (ADS) showed the sludge samples contained a significant fraction of organic constituents.[30] The Tank 804 contained ~ 8 wt % organic constituents (primarily Tributyl Phosphate, Tetradecane, Tridecane). The Tank 808 sludge contained 0.1 wt % organic constituents (primarily Tributyl Phosphate, Bis(2-ethylhexyl) phthalate, DIN). The Tank 809 sludge contained 0.5 wt % organic constituents (primarily Tributyl Phosphate, Tetradecane, DIN).

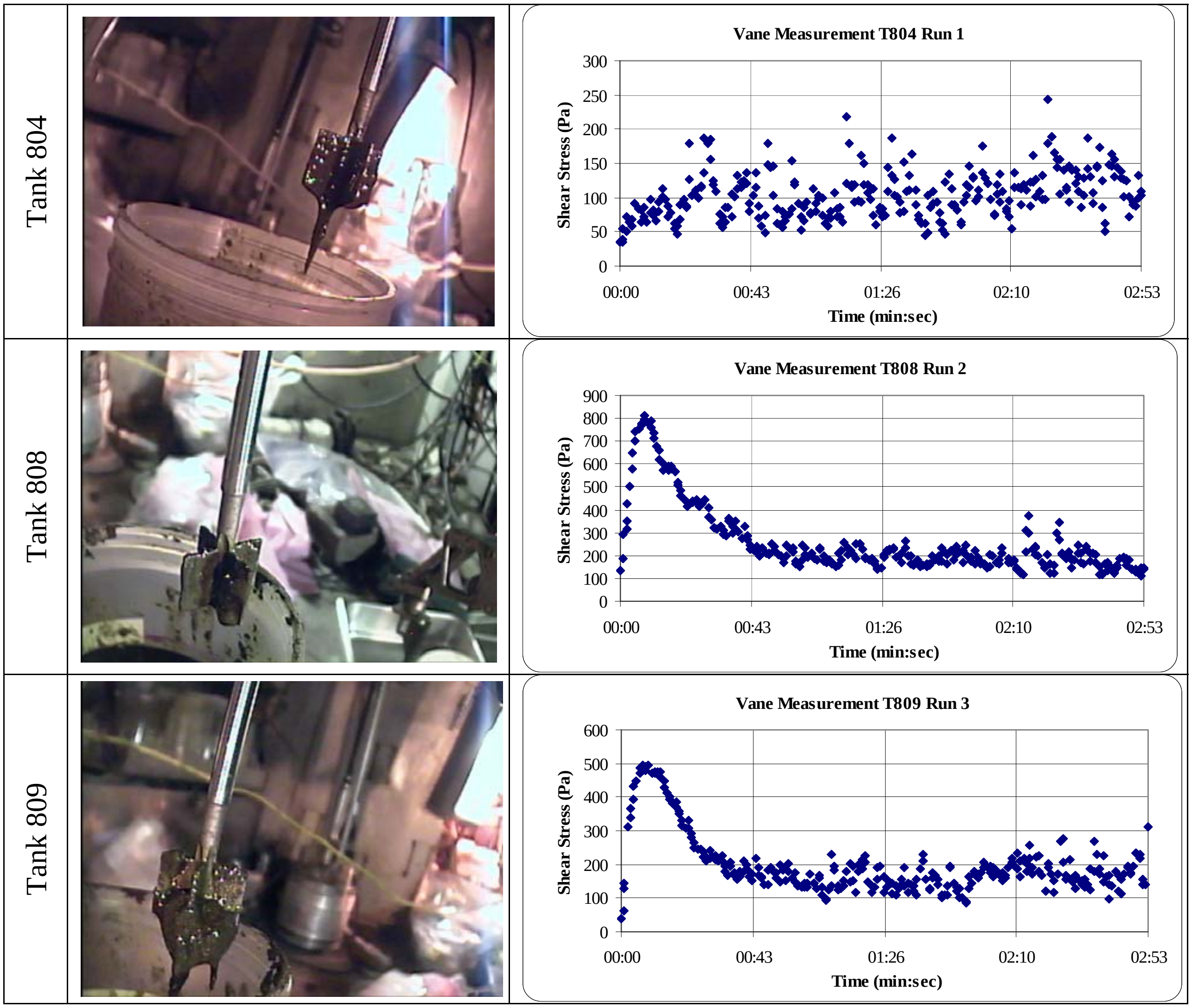

Figure 4. Vane Measure Picture and Typical Results

Sludge Solids Measurements

Table 3 shows the insoluble solids concentration of the samples. The authors measured the total solids in the samples. When they attempted to measure the soluble solids in the samples, they could not obtain more than a drop of filtrate from each sample. After reviewing these results with ADS personnel, they concluded that all of the liquid was bound to the solid particles and that the insoluble solids concentration is equal to the total solids concentration. These high insoluble solids concentrations measured are consistent with a high shear strength material.

Table 3. Solids Measurement

Tank	Insoluble Solids (wt %)
804	55.0 ± 1.5
808	63.8 ± 0.3
809	74.1 ± 0.1

Guidelines for interarea transfers between the waste tank farms require the solids concentration to be 13 – 19 wt % and the yield stress to be 3 – 10 Pa.[27]

Density Measurements

Table 4 shows the measured slurry density, as well as the calculated sludge particle density calculated with equation [1]. The measured densities of the Tank 808 and Tank 809 samples are consistent with insoluble solids concentration measured. The density of the Tank 804 sample appears to be low given that it contains 55 wt % insoluble solids. A likely reason for the low density is that that material contains a large fraction of organic constituents or from air bubbles being entrained in the slurry. This lower density explains why the fast-settling particles in this sludge settled more slowly than the fast-settling particles in the Tank 808 and Tank 809 sludge samples. Chemical analysis of the Tank 804 sludge showed it contained 7.8 wt % organic constituents.[30]

Table 4. Slurry Density Measurement

Tank	Slurry Density (g/mL)	Particle Density (g/mL)
804	1.17 ± 0.02	1.36
808	1.52 ± 0.02	2.15
809	1.42 ± 0.01	1.66

Flow Curve Measurements to Determine Rheology of the Sludge Slurry

Because of the high shear strength of these samples, transporting them with centrifugal pumps will not be practical. One method to make transporting the sludge more practical is to blend it with a carrier fluid to reduce or eliminate the yield stress. To evaluate the effectiveness of this approach, personnel blended the sludge with inhibited water to produce a 10 wt % slurry and measured the flow curve of those slurries.

The samples from Tanks 804, 808 and 809 contained a number of large fast settling particles. As described in the handling of these 10 wt % sludge slurries in inhibited water, the Tank 804 and 808 samples immediately settled out of the clear carrier fluid and flow curve measurements were not performed for these samples. For the Tank 809 sample, the carrier fluid was grayish in color and a decision was made to perform flow curve measurements. The response from the measurement indicated that there was no yield stress. This response indicates that the fluid properties were mostly that of the inhibited water.

Particle Size

Figure 5 shows sample photographs of each of the samples. Table 5 shows the particle size measurements. The table shows the average particle size, the standard deviation, the median particle size, the minimum particle size, and the maximum particle size for each sample. The media particle size is 7 – 17 micron, which is slightly larger than the median particle size of SRS High Level Waste sludge (1 – 5 micron).[18] The particle size variation is about five orders of magnitude, which is much greater than normally observed with SRS and Hanford High Level Waste sludge (~ 2 orders of magnitude).[18,19,20,21,22] The particles shapes observed in the photographs were very irregular. The table also shows the percentage of particles greater than 177 μm. The DWPF limits frit particle size to less than 2% greater than 177 μm.[31] Since these sludge samples a contain significant fraction of particles greater than 177 μm, the particles may need to be size reduced prior to being transported to the DWPF.

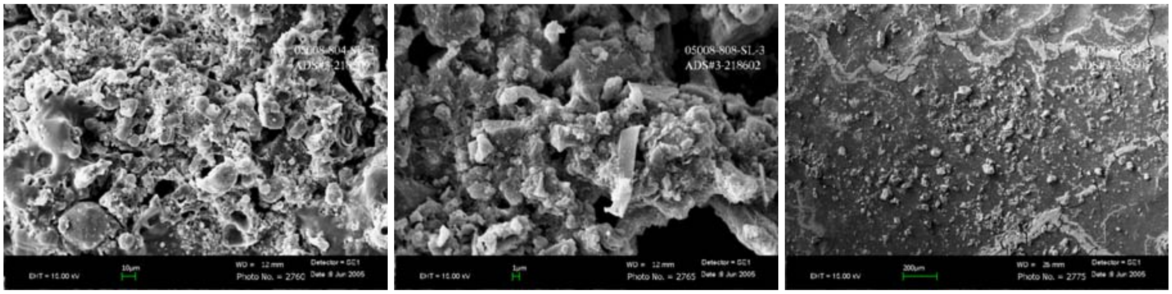

Figure 5. SEM Photographs of Tank 804, 808, and 809 Samples

Table 5. Particle Size

Tank	804	808	809
Particles counted	511	476	526
Average (μm)	54	65	45
Standard Deviation (μm)	479	225	226
Median (μm)	7	17	7
Minimum (μm)	0.14	0.09	0.02
Maximum (μm)	9646	2784	2825
> 177 μm (%)	1.8	5.5	2.3

The particle size data and sludge density can be used to calculate a settling rate. The particle settling velocity is calculated by the following equations[15]

$$v_s = g(s-1)d_p^2/18\nu \qquad \text{for } Re_p < 1.4 \qquad [2]$$

$$v_s = 0.13[g(s-1)]^{0.72}d_p^{1.18}\nu^{-0.45} \qquad \text{for } 1.4 < Re_p < 500 \qquad [3]$$

$$v_s = 1.74[g(s-1)\,d_p]^{0.5} \qquad \text{for } Re_p > 500 \qquad [4]$$

$$Re_p = d_p v_s/\nu \qquad [5]$$

where v_s is the settling velocity, g is the acceleration due to gravity, s is the ratio of particle and fluid densities (s = particle density/fluid density), d_p is the particle diameter, and ν is the fluid kinematic viscosity ($\nu = \mu/\rho$). Table 6 calculates the settling rate for each sample using the various particles size percentiles presented in Table 6.

The calculated settling rate of the largest particles is much larger than the measured settling rate of the samples (4 – 16 X). The difference is likely caused by the particle size in the settling tests being less than the maximum measured. Using the 98th and 99th percentile particle size, the calculated settling rate agrees much better with the measured settling rate for each sample.

Table 6. Calculated Particle Settling Rate

Tank	804	808	809
Particle Size (max)	9646 µm	2784 µm	2825 µm
Particle Size (99%)	673 µm	1062 µm	1474 µm
Particle Size (98%)	170 µm	370 µm	359 µm
Particle Density (g/mL)	1.36	2.15	1.66
Fluid Density (g/mL)	1.0	1.0	1.0
Fluid viscosity (cP)	1.0	1.0	1.0
Measured Settling Rate (in/s)	0.8	2.5	2.0
Predicted Setting Rate - max (in/s)	12.6	12.1	9.3
Predicted Setting Rate – 99% (in/s)	1.1	4.5	4.5
Predicted Setting Rate – 98% (in/s)	0.2	1.3	0.8

Using recommendations in the technical literature, the authors classified the particles in this material as fast-settling (> 0.1 in/s), slow-settling (< 0.005 in/s), or intermediate-settling (0.005 – 0.1 ft/s).[26] Table 7 shows the fraction of particles for each sample that falls in each category.

Figure 7. Categorization of Particle Settling Rates

Tank	804	808	809
Fast-Settling	3 %	23 %	4 %
Intermediate-Settling	20 %	52 %	28 %
Slow-Settling	77 %	25 %	68 %

DISCUSSION

The mobilization equipment that SDD will employ to remove the sludge from the 800 series tanks has not been selected. However, the authors decided to determine the mobilization and transport requirements for material with the same properties as the sludge to provide guidance to SDD.

Tank 804 is 10 ft diameter and 11 ft tall. It contains two flat blade impellers (not working). Given the tank dimensions, the sludge shear strength, assuming the impeller diameter is ¼ the tank diameter, and neglecting the cooling coils, one can calculate the required impeller speed to mix the tank using the cavern model.[6,7,8] The calculated agitator speed is 510 – 550 rpm, which is extremely fast for a 2.5 ft impeller. The required horsepower is 240 hp/1000 gallons, which exceeds common mixing design guidelines by more than an order of magnitude.[2] This approach neglects the cooling coils and other obstructions, which will make the sludge suspension even less effective.

Tanks 808 and 809 are horizontal tanks 36 ft long and 9 ft diameter. SDD has considered using a Gamajet IX to mobilize the sludge in these tanks. The Gamajet IX produces a high pressure jet (e.g., 500 psi, 36 gpm) through a small, rotating nozzle (0.125 – 0.225 in). Using the Churnetski equation[3] and the measured sludge shear strength, one calculates a cleaning radius of 1.5 – 2 ft. This cleaning radius is insufficient to remove the sludge from these tanks.

These calculations of potential mixing requirements for the 800 series tanks show that mobilizing the slurry will likely be difficult. However, previous SRNL testing has shown that given a long time, jets and agitators can mobilize very high shear strength material, by a mechanism similar to erosion.[2,5,23] The ability of agitators and Gamajets to remove material by this mechanism cannot be calculated and can only be determined by pilot-scale testing or plant operating experience.

If SDD can mobilize this sludge, they will need large pumps to transport it to downstream facilities. Equation [6] shows the calculation of the pressure drop needed to overcome the yield stress of a Bingham plastic fluid and begin fluid motion

$$\Delta P = 4L\tau_y/D \qquad [6]$$

where L is pipe length, τ_y is fluid yield stress, and D is pipe diameter. Table 8 shows the required pressure drops needed for several transfer paths. The F – H and H – S paths are for interarea transfers. The Tank 51 – Tank 51 path from a calculation performed to support a pump test in the Tank Farm[29], and provides an estimate of the required pump pressure needed for a tank to tank transfer. The required pressure drops are extremely large and will make transporting this material with centrifugal pumps very difficult. Blending the sludge with a carrier fluid such as inhibited water will reduce or eliminate the yield stress and make transporting the sludge with centrifugal pumps easier.

Table 8. Pressure Drop Needed to Transport 800 Tank Sludge

Path	Distance (ft)	Yield Stress (Pa)	ΔP (psi)
F – H[28]	13,200	269	8,270
F – H	13,200	796	24,470
F – H	13,200	413	12,700
H – S[29]	3650	269	2,286
H – S	3650	796	6,766
H – S	3650	413	3,510
Tank 51 – Tank 51[29]	325	269	203
Tank 51 – Tank 51	325	796	602
Tank 51 – Tank 51	325	413	313

If the sludge is mixed with sufficient liquid to produce slurries with less than 10 wt % insoluble solids, the slurry should have little or no yield stress. However, the large particles produced could require a high transport velocity. Assuming a 3 inch diameter pipe, water as the carrier fluid, and using the 98^{th} – 100^{th} percentile particle size, one calculates a required transport velocity of 1.6 – 4.4 ft/s (35 – 100 gpm).[13,14,15] For example, the required transport velocity for Tank 804 sludge is 1.6 – 2.7 ft/s (35 – 61 gpm). The required transport velocity for Tank 808 sludge is 1.8 – 4.4 ft/s (39 – 100 gpm). The required transport velocity for Tank 809 sludge is 1.6 – 3.4 ft/s (35 – 77 gpm). Guidelines for interarea transfer require flow rates of at least 70 - 100 gpm, so these required velocities are not unreasonable. However, gravity draining of the material will likely see particles settling in the transfer lines.

SDD should consider dissolution of the sludge with a chemical such as oxalic acid (0.5 M), nitric acid (0.5 – 1.0 M), sodium hydroxide, or hydrogen peroxide. Consider pilot-scale simulant testing the of proposed sludge retrieval methods prior to retrieval activities. Conduct scoping tests with actual tank samples to determine the required mixing energy or vacuum needed to suspend the sludge particles.

CONCLUSIONS

The conclusions from this work follow (see Appendix A for summary of physical properties).

- Tank 804
    - The sludge contained both fast-settling particles (3%) and slow settling particles (77%).
    - The shear strength of the settled sludge samples measured 269 Pa. This large shear strength indicates that the sludge can be difficult to mobilize with conventional agitation systems. Transporting of such materials using centrifugal pumps would be very difficult. Blending the material with a carrier fluid will make transporting it more practical.
    - The insoluble solids concentration of the sludge samples was 55 wt %.
    - The density of the sludge samples was 1.17 g/mL. The calculated density of the sludge particles was 1.36 g/mL.
    - The 10 wt % sludge slurries prepared with this material possess no yield stress. Pipe transport velocities required to maintain particle suspension are 1.6 – 2.7 ft/s.
    - The particle size of the sludge samples varied from 0.14 – 9600 μ. The median particle size (7 μm) was slightly larger than SRS High Level Waste sludge (1 – 5 μm). The particles size distribution varied by five orders of magnitude, which is much greater than that observed in previous analyses of SRS and Hanford High Level Waste Sludge (~ two orders of magnitude). Approximately 1.8% of the particles were larger than 177 μm, which approaches the Defense Waste Processing Facility (DWPF) specification (less than 2% greater than 177 μm).
- Tank 808
    - The sludge contained both fast-settling particles (23%) and slow settling particles (25%).
    - The shear strength of the settled sludge samples measured 796 Pa. This large shear strength indicates that the sludge can be difficult to mobilize with conventional agitation systems. Transporting of such materials using centrifugal pumps would be very difficult. Blending the material with a carrier fluid will make transporting it more practical.
    - The insoluble solids concentration of the sludge samples was 64 wt %.
    - The density of the sludge samples was 1.52 g/mL. The calculated density of the sludge particles was 2.15 g/mL.
    - The 10 wt % sludge slurries prepared with this material possess no yield stress. Pipe transport velocities required to maintain particle suspension are 1.8 – 4.4 ft/s.
    - The particle size of the sludge samples varied from 0.09 – 2800 μ. The median particle size (17 μm) was slightly larger than SRS High Level Waste sludge (1 – 5 μm). The particles size distribution varied by five orders of magnitude, which is much greater than that observed in previous analyses of SRS and Hanford High

Level Waste Sludge (~ two orders of magnitude). Approximately 5.5% of the particles were larger than 177 μm, exceeding the DWPF particle size specification.

- Tank 809
    - The sludge contained both fast-settling particles (4%) and slow settling particles (68%).
    - The shear strength of the settled sludge samples measured 413 Pa. This large shear strength indicates that the sludge can be difficult to mobilize with conventional agitation systems. Transporting of such materials using centrifugal pumps would be very difficult. Blending the material with a carrier fluid will make transporting it more practical.
    - The insoluble solids concentration of the sludge samples measured 74 wt %.
    - The density of the sludge samples was 1.42 g/mL. The calculated density of the sludge particles was 1.66 g/mL.
    - The 10 wt % sludge slurries prepared with this material possess no yield stress. Pipe transport velocities required to maintain particle suspension are 1.6 – 3.4 ft/s.
    - The particle size of the sludge samples varied from 0.02 – 2800 μ. The median particle size (7 μm) was slightly larger than SRS High Level Waste sludge (1 – 5 μm). The particles size distribution varied by five orders of magnitude, which is much greater than that observed in previous analyses of SRS and Hanford High Level Waste Sludge (~ two orders of magnitude). Roughly 2.3% of the particles were larger than 177 μm, slightly exceeding the DWPF particle size specification.

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APPENDIX A
PHYSICAL PROPERTIES

Property	Tank 804	Tank 808	Tank 809
Settling Rate (maximum)	0.8 in/s	2.5 in/s	2.0 in/s
Settling Rate (minimum)	< 0.01 in/s	< 0.01 in/s	< 0.01 in/s
Shear Strength	269 Pa	796 Pa	413 Pa
Insoluble Solids	55.0 wt %	63.8 wt %	74.1 wt %
Slurry Density	1.17 g/mL	1.52 g/mL	1.42 g/mL
Particle Density	1.36 g/mL	2.15 g/mL	1.66 g/mL
Median Particle Size	7 μm	17 μm	7 μm
Minimum Particle Size	0.14 μm	0.09 μm	0.02 μm
Maximum Particle Size	9646 μm	2784 μm	2825 μm
Fraction > 177 μm	1.8%	5.5%	2.3%

APPROVAL

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