RHEOLOGY OF SAVANNAH RIVER SITE TANK 51 HLW RADIOACTIVE SLUDGE

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ABSTRACT

Savannah River Site (SRS) Tank 51 HLW radioactive sludge represents a major portion of the first batch of sludge to be vitrified in the Defense Waste Processing Facility (DWPF) at SRS. The rheological properties of Tank 51 sludge will determine if the waste sludge can be pumped by the current DWPF process cell pump design and the homogeneity of melter feed slurries. The rheological properties of Tank 51 sludge and sludge/frit slurries at various solids concentrations were measured remotely in the Shielded Cells Operations (SCO) at the Savannah River Technology Center (SRTC) using a modified Haake Rotovisco viscometer system.

Rheological properties of Tank 51 radioactive sludge/Frit 202 slurries increased drastically when the solids content was above 41 wt%. The yield stresses of Tank 51 sludge and sludge/frit slurries fall within the limits of the DWPF equipment design basis. The apparent viscosities also fall within the DWPF design basis for sludge consistency.

All the results indicate that Tank 51 waste sludge and sludge/frit slurries are pumpable throughout the DWPF processes based on the current process cell pump design, and should produce homogeneous melter feed slurries.

INTRODUCTION

The rheological properties of Savannah River Site (SRS) Tank 51 radioactive sludge waste was investigated in the Shielded Cells Operations at Savannah River Technology Center (SRTC). The results determine if the first radioactive waste sludge batch can be pumped by the current DWPF process cell pump design and also formed a basis for validating experimental data of other studies with simulated sludges.

The high activity radioactive wastes stored as caustic slurries in tanks result from the neutralization of acid waste generated from production of defense nuclear materials. As these wastes settle, they separate into an upper supernate layer and lower sludge layer. In the Defense Waste Processing Facility (DWPF) at SRS, the radionuclides from the sludge and supernate will be immobilized in borosilicate glass for storage and eventual disposal. Prior to transferring from Tank Farm to the DWPF, aluminum in the waste sludge will be dissolved and the sludge will be extensively washed.

In the DWPF, the sludge will initially be processed in the Sludge Receipt and Adjustment Tank (SRAT). The processed sludge slurry will then be transferred to the Slurry Mix Evaporator (SME) where frit will be added to form melter feed. The rheological properties of Tank 51 radioactive sludge which represents a major portion of the first batch of sludge to be processed in the DWPF helped to verify DWPF equipment design basis, particularly process cell pump design. The rheological properties of Tank 51 radioactive sludge also controls mixing of glass frit and sludge to produce a homogeneous melter feed.

This study show that Tank 51 waste sludge and sludge/frit slurries can be pumped and processed throughout the DWPF processes based on the current process cell pump design. And it also produces a homogeneous frit/sludge melter feed slurries.

EXPERIMENTAL

The rheological properties of Tank 51 sludge was measured using a Haake Rotovisco RV-12 with an M150 measuring drive unit and TI sensor system. The shear stress was measured while the shear rate was varied from 0 to 300 sec^{-1} and back to 0 (using a Haake PG 142 programer). The shear stress data of the samples were collected using an Apple Macintosh II containing a Strawberry Tree Computers' data acquisition system and the Strawberry's Analog Connection software. The shear stress and viscosity were calculated using Microsoft Excel spreadsheet software. The Haake viscometer is setup as follow:

Measuring Head:	M150
Sensor System:	TI
Final RPM:	128

Instrument Constants.

$M = 2.34$ cm/min

$G = 412$ pascal.scale-grade.min/10^{-3}

$A = 0.966$ pascal/scale-grade

The Haake viscometer was checked using 48.3 centipoises (cp) and 98.3 cp viscometer standards. The viscosity error was within $\pm 3\%$.

A slurry mixture was prepared by adding known amounts of sludge and frits. The slurry was stirred and then a measurement was made within five minutes at room temperature, 23 ± 1°C. Temperature was monitored by a thermocouple during the experiments and did not increase more than 1°C before and after the measurements during the entire course of the experimental work. The process was repeated at least three times, before measurements of another slurry mixture was attempted. Effects of settling become significant, especially for high solids concentration slurries, 45 wt% solids or more, if the measurements are longer than five minutes.

The yield stress and consistency of the sludge slurries were determined by assuming a Bingham plastic fluid model. The general shape of the sludge slurry flow curves supports the *Bingham plastic* fluid approximation. Yield stress and consistency were determined using the intercept and slope of the flow curves, respectively.

DISCUSSION OF RESULTS

The current design bases for the DWPF slurry properties are shown below (1):

Washed Sludge Slurry (DWPF Feed):

Solids Content, weight %:	13 - 19
Yield Stress, dynes/cm^2:	25 - 100
Consistency, centipoise:	4 - 12

SRAT Slurry:

Solids Content, weight %:	18 - 25
Yield Stress, dynes/cm^2:	15 - 50
Consistency, centipoise:	5 - 12

SME (formatted sludge/frit) Slurry:

Solids Content, weight %:	40 - 50
Yield Stress, dynes/cm^2:	25 - 150
Consistency, centipoise:	10 - 40

Tank 51 rheological properties are measured to ensure that the first DWPF radioactive sludge batch can be pumped, processed and fed through out the DWPF processes with the current design bases.

Rheological properties of Tank 51 radioactive sludge as it would be prior to being transferred from the SRS Tank Farm to the DWPF were measured. At 12, 15, and 18 weight percent solids, the yield stresses of Tank 51 sludge were 5, 11, and 14 dynes/cm^2, respectively. The apparent viscosities were 6, 10 , and 12 cp at 300 sec^{-1} shear rate, respectively. The rheological properties are within the yield stress and viscosity limits of the DWPF process cell pumps design basis.

Rheological properties of SRS Tank 21 radioactive sludge has been studied previously (2). It was found that below 14 wt% insoluble solids, the yield stress of Tank 21 sludge was less than 40 dynes/cm^2, and the consistency was less than 10 cp (2). It was consistent with what has been observed with Tank 51 sludge containing less than 18 wt% total solids.

During sludge processing in the SRAT, formic acid will be added to reduce the yield stress of the sludge slurry so it can be pumped more easily after glass frit is added. To test the worst case scenario at the melter feed tank, it was decided to measure the rheological properties of the frit/sludge mixture as if frit was added directly to the unprocessed (or unformatted) Tank 51 radioactive sludge. The rheological properties of an unformatted sludge/frit melter feed slurry were expected to be very poor due primarily to the high solids content, 45 to 55 wt%, and the fact that the slurries were very caustic (pH = 11 or greater).

The yield stress of a 41 wt% solids slurry, containing 14.3 % Tank 51 sludge and 85.7 % Frit 202, was measured at about 10 to 15 dyne/cm^2. The yield stress of a 57 wt% solids slurry containing 9.3 % Tank 51 sludge and 90.7 % Frit 202 increased to 75 dynes/cm^2. The yield stresses are still within the 25 to 150 dyne/cm^2 range of the DWPF design basis (1) for a 40 to 50 wt% solids melter feed. The apparent viscosities of the 41 and 57 wt% solids sludge/frit slurries were 10 and 100 cp at a shear rate of 300 sec^{-1}, respectively.

The rheological properties of a 55 wt% sludge slurry containing 31.1 wt% unformatted Tank 51 radioactive sludge and 68.9 wt% Frit 202 (3), which is greater than a typical solid composition of the DWPF melter feed, were also measured. This would represent a highly unusual situation when a severe SRAT process upset occurred and could not be remediated for several days. (This is not expected for the DWPF, but represents a potential bounding condition for any process upset.) Normally, samples taken at the DWPF melter feed tank for waste compliance purposes will detect the abnormal condition and prevent the DWPF melter from accepting the sludge/frit slurry. This bounding scenario was looked at to determine, if the DWPF equipment could move the unformatted sludge/frit slurry out of the melter feed tank back to the SRAT and SME for additional processing. The yield stress was observed to increase to 120 - 150 dynes/cm^2, right at the upper yield stress limit of the DWPF design basis (1). The apparent viscosity was 100 cp at a shear rate of 300 sec^{-1}. The DWPF design basis value for consistency of a melter feed ranges from 10 to 40 cp. Thus, even in this bounding scenario, unformatted Tank 51 sludge/frit slurries can still be pumped from the DWPF melter feed tank.

Glass frit is known to dissolve and gel in a very caustic (high Ph) solution and could cause severe increases of yield stress and viscosity. However, frit addition experiments did not show an immediate increase of yield stress of the 41 wt% sludge/frit slurry. Frit dissolution in these very caustic (pH = 11 or higher) sludge/frit slurries seemed to proceed at a very slow rate, probably because of the low temperature of the tests (23 - 24°C). Solids content is a more important factor in determining rheological properties of Tank 51 sludge/frit slurries (see Table I).

Furthermore, the yield stress of the 55 wt% Tank 51 and Frit 202 slurry is higher than the value from a 57 wt% slurry also indicated that rheological properties is effected strongly by the composition of the slurry solid content. The major difference of these two sludge slurries is the 55 wt% solids slurries contained more sludge solids, while the 57 wt% slurry had more glass frit. Frit 202 (3) particle size is probably coarser than those of sludge particles. Its size distribution is also narrower than that of the sludge. These factors caused rheological severity of the slurry not to increase as rapidly when more Frit was added to the slurry, compared to increasing of sludge solids content.

Walker and Fong (2) found that, at 44 wt% solids (or 17 wt% insoluble solids using their terminology), the yield stress of Tank 21 radioactive sludge was in the range of 80 to 120 dynes/cm^2, and the consistency was from 15 to 20 cp. The yield stress results compared very well to those of Tank 51 sludge as reported here. However, the consistency of 15 - 20 cp is lower, but consistent with the DWPF design basis range of 10 - 40 cp for a melter feed.

CONCLUSIONS

Tank 51 radioactive sludge represents a major portion of the first batch of sludge to be processed in the DWPF. The rheological properties of Tank 51 sludge indicated that sludge slurries are pumpable throughout the DWPF processes based on the current process cell pump design, and should produce homogeneous melter feed slurries. The results showed:

TABLE I
Effects of Solid Content on Yield Stress of Tank 51 Sludge Slurry

Wt% Solids	Solid Composition		Yield Stress ($dynes/cm^2$)
	Tank 51 Sludge %	Frit 202 %	
12	100	0	5
15	100	0	11
18	100	0	14
41	14.3	85.7	5
55	31.1	68.9	145
57	9.3	90.7	75

- Rheological properties of Tank 51 aluminum dissolved and washed but unformatted sludge slurry changed drastically when the solid content increases above 41 wt%.
- Frit dissolution in a caustic solution proceeded very slowly at room temperature. No severe increase in yield stress and viscosity was observed when significant amount of frit was added to the sludge slurry.
- The solids content of Tank 51 radioactive sludge has a larger effect on rheological properties than Frit 202. Addition of Frit 202 did not increase the yield stress and viscosity as quite as fast compared to increasing the sludge solid content. It is believed that the finer particle sizes and larger particle size distribution of the sludge is responsible.
- Overall, the yield stresses of Tank 51 sludge slurries fall within the design basis of the DWPF equipment design basis (1). The apparent viscosities also fall within the DWPF design basis for sludge consistency, except for the unformatted sludge/frit melter feed slurry at 55 wt% which was higher than the design basis.

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