Hanford Waste Physical and Rheological Properties: Data and Gaps – 12078

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ABSTRACT

The retrieval, transport, treatment and disposal operations associated with Hanford Tank Wastes involve the handling of a wide range of slurries. Knowledge of the physical and rheological properties of the waste is a key component to the success of the design and implementation of the waste processing facilities. Previous efforts to compile and analyze the physical and rheological properties were updated with new results including information on solids composition and density, particle size distributions, slurry rheology, and particle settling behavior. The primary source of additional data is from a recent series of tests sponsored by the Hanford Waste Treatment and Immobilization Plant (WTP). These tests involved an extensive suite of characterization and bench-scale process testing of 8 waste groups representing approximately 75% of the high-level waste mass expected to be processed through the WTP. Additional information on the morphology of the waste solids was also included. Based on the updated results, a gap analysis to identify gaps in characterization data, analytical methods and data interpretation was completed.

INTRODUCTION

Management of the Hanford Site in Washington State includes 177 underground storage tanks containing approximately 250,000 m^3 of waste generated during past defense reprocessing and waste management operations. These tanks contain a mixture of sludge, saltcake and supernatant liquids. The insoluble sludge fraction of the waste consists of metal oxides and hydroxides and contains the bulk of many radionuclides such as the transuranic components and ^{90}Sr. The saltcake, generated by extensive evaporation of aqueous solutions, consists primarily of dried sodium salts. The supernates consist of concentrated (5-15 M) aqueous solutions of sodium and potassium salts. The 177 storage tanks include 149 single-shell tanks (SSTs) and 28 double-shell tanks (DSTs).

Ultimately the wastes need to be retrieved from the tanks for treatment and disposal. The SSTs contain minimal amounts of liquid wastes, and the Tank Operations Contractor is continuing a program of moving solid wastes from SSTs to interim storage in the DSTs. The Hanford DST system provides the staging location for waste feed delivery to the Department of Energy (DOE) Office of River Protection's (ORP) Hanford Tank Waste Treatment and Immobilization Plant (WTP). The WTP is being designed and constructed to pretreat and then vitrify a large portion of the wastes in Hanford's 177 underground waste storage tanks.

The retrieval, transport, treatment and disposal operations involve the handling of a wide range of slurries. Undissolved solids (UDS)[1] in the slurry have a wide range of particle size, density and chemical characteristics. Depending on the solids concentration the slurries may exhibit a Newtonian or a non-Newtonian rheology.

The extent of knowledge of the physical and rheological properties is a key component to the success of the design and implementation of the waste processing facilities. These properties are used in engineering calculations in facility designs. Knowledge of the waste properties is also necessary for the development and fabrication of simulants that are used in testing at various scales. The expense and hazards associated with obtaining and using actual wastes dictates that simulants be used at many stages in the testing and scale-up of process equipment. The results of the work presented in this paper [1] are useful for estimating process and equipment performance and provide a technical basis for development of simulants for testing.

APPROACH

The purpose of the study [1] was to provide an updated summary of the Hanford waste characterization data pertinent to safe storage, retrieval, transport and processing operations for both the tank farms and the WTP and thereby identify gaps in understanding and data. Important waste parameters for these operations were identified by examining relevant mathematical models of selected phenomena including:

- Pipeline Critical Velocity
- Solid Settling Velocity
- Effective Cleaning Radius
- Vessel Wall/Bottom Erosion
- Critical Suspension Velocity
- Suspended Solid Cloud Height
- Suspended Solid Concentration
- Solid Dissolution and Filtration
- Gas Generation, Retention, and Release

Typical engineering correlations were reviewed and the most important waste parameters identified. The identification was based on the functionality of the parameter in the correlations. The important physical and rheological properties of the waste include:

- Liquid Density and pH
- Liquid Rheology (Viscosity)

[1] UDS; undissolved solids. Those solids, whether soluble or insoluble, that exist as a solid phase and are not dissolved in the liquid phase of the waste.

- UDS Composition and Particle Density
- UDS Primary Particle Size and Shape
- UDS Particle Size Distribution
- UDS Particle Settling
- Slurry Rheology and Shear Strength
- Estimated Particle Size and Density Distributions

Selected parameters from this list are discussed below. The data sets previously presented in Wells et al.(2007) [2] and Poloski et al. (2007) [3] were updated with the data from the additional waste types that have recently been characterized. This recent characterization was performed in response to issue M12 (Undemonstrated Leaching Processes) as identified by the External Flow sheet Review Team (EFRT)[2]. This characterization involved process testing at the bench-scale and provided a significant amount of new data on the waste properties. An analysis of the effect of sample storage was conducted to make sure that the data sets represent equivalent or similar waste conditions. The parameter values were evaluated with *in situ* data pertaining to waste mobilization and UDS settling. The data set is therefore as consistent as possible both internally and with actual waste behavior. Data uncertainties were quantified to the extent possible. Since the current work contains the most extensive data and analyses, it is recommended for use over the prior work for assessing waste properties.

The final step in this effort was to conduct a gap analysis to identify gaps in characterization data, analytical methods, and data interpretation. The primary focus is on data gaps identified by considering the parameters by waste type, percent of waste type volume represented and the uncertainty of the parameter. Gaps in analytical methods and data interpretation are also noted but they do not represent a comprehensive list. This gap analysis will help focus future efforts for waste characterization, method development, and data interpretation.

PRIMARY PARTICLE DENSITY AND SIZE

A summary of the primary particle characteristics for the Hanford tank waste UDS compounds defined in Wells et al. (2011) [1] is presented in Table I. The particle density is based on literature values for the defined compounds, and the particle size identification is based on analysis of samples using various analytical techniques including SEM, XRD and most recently, advanced TEM. The TEM enabled elucidation of the nano-sized particles that dominate many of the Hanford tank sludges. The methodology employed to determine particle size has been to measure individual particles on a calibrated image. A good summary of the mineralogy may be

[2] CCN 132846. 2006. *Comprehensive Review of the Hanford Waste Treatment Plant Flowsheet and Throughput - Assessment Conducted by an Independent Team of External Experts*. Chartered by the Hanford Waste Treatment and Immobilization Plant Project at the Direction of the U.S. Department of Energy, Office of Environmental Management, Washington, DC.

found in Disselkamp (2010) [4]. An expert panel was convened to review and revise the particle size estimates and determine consensus options for those compounds without information.

Table I. Primary Particle Characteristics of Hanford Tank Wastes

Compound	Density (g/mL)	Maximum Spherical Primary Particle Size (μm)	Compound	Density (g/mL)	Maximum Spherical Primary Particle Size (μm)
Ag	10.5	2	$NiC_2O_4•2H_2O$	4.26	1.6
Ag_2O	7.143	2	$Pb(OH)_2$	7.1	5
Bi_2O_3	8.9	3	$Pb_3(PO_4)_2$	7.1	0.4
$BiFeO_3$	7.9	0.1	$PbCO_3$	6.6	5
$Ca(OH)_2$	2.24	9	$Pu(OH)_4$ (co-precipitated with Fe phase)	4.26	0.015
$Ca_5OH(PO_4)_3$	3.14	9	PuO_2	11.43	20
$CaC_2O_4•H_2O$	2.2	9	SiO_2	2.6	100
$CaCO_3$	2.71	55	$Sr_3(PO_4)_2$	3.5	0.065
CaF_2	3.18	15	$SrCO_3$	3.5	0.065
CrOOH	4.11	0.4	ZrO_2	5.68	50
$FePO_4•2H_2O$	3.15	0.02	KNO_3	2.109	2200
FeOOH	4.26	0.015	$Na_2C_2O_4$	2.34	8
Gibbsite ($Al(OH)_3$	2.42	200	$Na_2CO_3•H_2O$	2.25	80
Boehmite (AlOOH)	3.01	0.052	Na_2SO_4	2.68	112
HgO (co-precipitated with Ag_2O phase)	7.143	2	$Na_2SO_4•10H_2O$	1.464	112
$KAlSiO_4$	2.61	8	Na_3FSO_4	2.65	176
$La(OH)_3$	2.3	3	$Na_3NO_3SO_4•H_2O$	2.3	80
$LaPO_4•2H_2O$	6.51	3	$Na_3PO_{4.0}•25NaOH•12 H_2O$	1.62	440
$Mn_3(PO_4)_2$	3.102	8	$Na_3PO_4•8H_2O$	1.8	2200
MnO_2	5.026	10	$Na_4P_2O_7•10H_2O$	1.83	2200
$Na_2(UO_2)_2(PO_4)_2•2 H_2O$	3.5	5	$Na_6(SO_4)_2CO_3$	2.64	32
$Na_2U_2O_7$	5.617	5	NaF	2.78	12
$NaAlCO_3(OH)_2$	2.42	4.2	$Na_7F(PO_4)_2•19H_2O$	1.75	2100
$NaAlSiO_4$	2.365	8	$NaHCO_3$	2.159	328
$Ni(OH)_2$	4.15	0.5	$NaNO_2$	2.168	2200
$Ni_3(PO_4)_2$	3.93	8	$NaNO_3$	2.26	650

The maximum spherical primary particle sizes are shown in Table I. The particles generally have irregular shapes so particle shape factors presented in Wells et al (2011) [1] were used to determine spherical equivalent particle sizes. The particle sizes should be treated as estimates

only because 1) for those compounds where images were specifically identified, a finite set of images are available for the waste from a limited number of tanks, 2) for other compounds, surrogate images are used, wherein the specific UDS phase is not replicated or certain, with similar caveats regarding sample size, and 3) for those compounds with no images available, expert judgment is used to assign the particle characteristics.

PARTICLE SIZE DISTRIBUTIONS

In developing particle size distributions (PSDs), data from a total of 34 tanks were considered. The data are from various instruments, all of which employ a light scattering technique except for one device which used light obscuration. One set of results is based on instruments operated in a flowing unsonicated mode in which the sample is transported through the measurement chamber, typically in turbulent flow. The turbulence tends to break up agglomerates resulting in smaller particles and therefore is probably more indicative of the particles present during turbulent mixing and transport. Another set of results is based on measurements obtained while operating instruments in a no-flow unsonicated mode. In this mode agglomerates are generally not broken up and the particles are larger and likely more representative of low shear environments.

A comparison of the Flowing Unsonicated composite sludge PSDs from the current work is made to the previous results from Wells et al. (2007) [2] and Jewett et al. (2002) [5] in Figure 1. The Sludge, Flowing Unsonicated composite results which are a weighted combination of the PSDs for sludge tanks (solid blue line) are quite similar to the previous results from Wells et al. (2007) [2] (solid black line) and Jewett et al. (2002) [5] (bold dashed black line; PSD composite created via a different methodology with a sub-set of sludge tank data). This suggests that the additional data from the recent characterization work was not substantially different. The Sludge, No-Flow Unsonicated composite results (solid red line) show larger particulate above approximately the 70^{th} percentile by volume probably indicating the presence of agglomerates.

The dashed blue and red lines in Figure 1 are the minimum and maximum measured particle sizes at given percentile values as evidenced in the figure of the PSDs comprising the Sludge, Flowing Unsonicated and Sludge, No-Flow Unsonicated composites respectively. These minimum and maximum values cannot be viewed as confidence bounds. However, they do represent the breath of the PSD data for the characterized waste. Confidence-based interval methods for PSD uncertainty bounds are challenged by limitations in the data and potential violations of the requirements associated with normal statistical theory methods [1].

The differences of the data set and combination methodology between the current work and Jewett et al. (2007) [5] are discussed in [1]. Given these differences, it is of note that the maximum particle size data for the Sludge, Flowing Unsonicated PSD and the 95/95 tolerance limit (TL) PSD from Jewett et al (2002) [5] are shown as approximately equivalent. Substantially larger particle sizes are shown for the Sludge, No-Flow Unsonicated PSDs. In addition to composite PSDs for alternate PSD instrumentation configurations, tank and waste type PSDs for sludge and saltcake wastes are also provided in Wells et al. (2011) [1], whereas Wells et al. (2007) [2] only provided composite results for sludge.

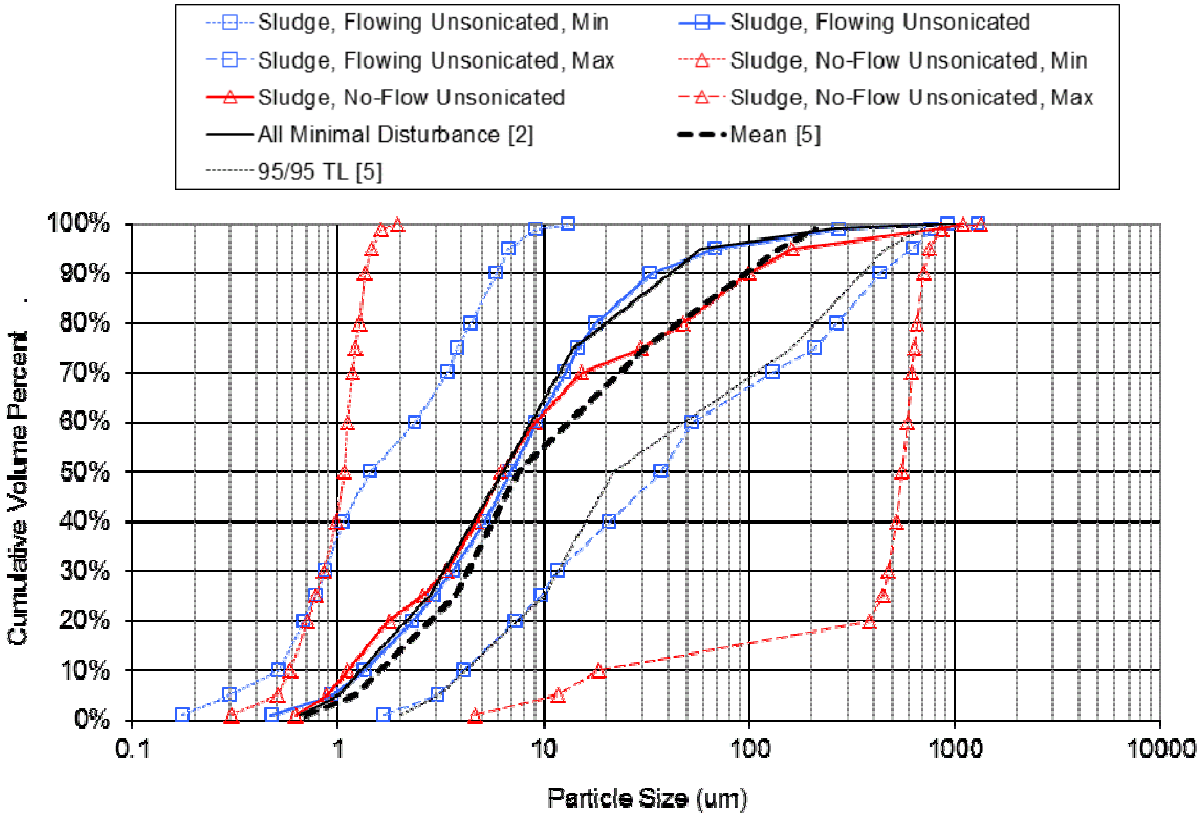

Figure 1. Composite particle size distributions of Hanford Tank Waste Sludge

PARTICLE SIZE AND DENSITY DISTRIBUTIONS

Resulting from the substantial increase of tank, waste type, and composite solid phase compound summaries and PSDs in the current work compared to previous efforts particle size and density distributions (PSDD) are available for sludge and saltcake tanks, waste types, and composites [1]. PSDDs for specific wastes are now also available for a significantly increased fraction of the Hanford waste.

Direct comparison of the Sludge, Flowing Unsonicated, D=3 PSDD is made to the Case 3 PSDD of Wells et al. (2007) [2] in Figure 2. The comparison is made using the computed settling velocity of the particles in water, and the D=3 designation indicates that these PSDDs are computed with a fractal dimension of 3. A fractal dimension of 3 corresponds to an agglomerate with no void space [1]. As with the PSD comparison of Figure 1, there are limited differences for the Flowing Unsonicated case, but the Sludge No-Flow Unsonicated composite results (solid red line) show increased settling velocity above approximately the 70th percentile by volume. Variation of the individual tank PSDDs in comparison to the composites may be found in Wells et al. (2011) [1], and those tanks with the maximum computed settling velocities are shown in Figure 2.

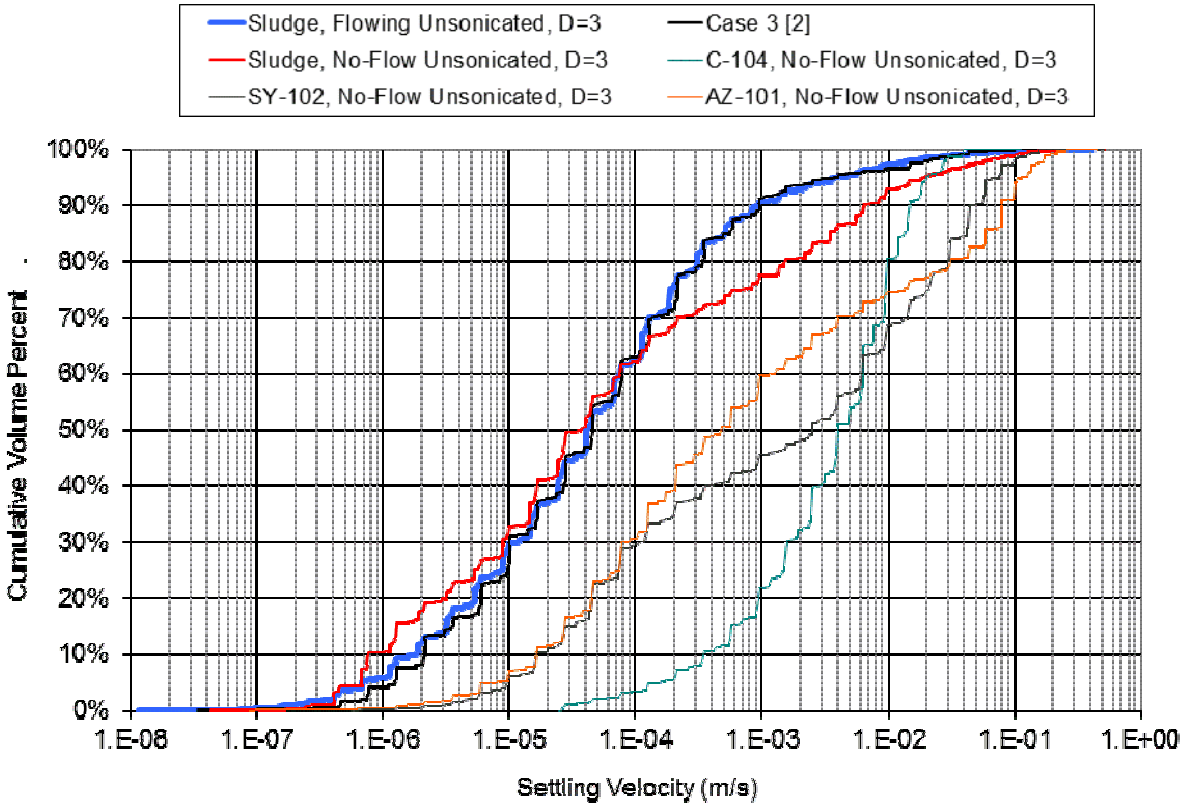

Figure 2. Particle Size and Density Distribution Comparison

RHEOLOGY

Shear-strength measurement techniques employed for Hanford tank waste include:

- Ball Rheometer-*In situ* measurement. The rheology of the waste can be estimated directly from the drag force on a ball as it is moved vertically through the waste at various speeds.
- Waste Extrusion. Video images recorded during the horizontal waste core extrusions after sample retrieval are analyzed to estimate the shear strength. Estimates are based on the extrusion behavior.
- Shear Vane. Laboratory sample measurement. Measured directly by slowly rotating a vane immersed in a sample and recording the resulting torque as a function of time.

Cumulative shear-strength distributions for sludge waste shear vane and waste extrusion data are provided in Figure 3. Ball rheometer measurements were not available for sludge wastes. Not accounted for in these distributions are measurement number, location, representativeness beyond initial sample conditions, the length of time the shear strength has developed, and the relative fraction of Hanford inventory. In some instances, multiple measurements are available throughout the depth and/or at different radial locations in the tank. In others, single measurements were reported. Further, the data set itself represents only a part of the Hanford

inventory. Data availability is also affected by the measurement technique. In addition, some tanks contain significantly greater fractions of the Hanford UDS inventory than others.

The sample history can also have a significant impact on results, and this may vary depending on the waste type. Shear strength is a function of time, and some of the measurements are from sludge material that has been stored undisturbed for decades. High shear strength values that result from long storage times are not likely to represent the shear strength of recently retrieved wastes.

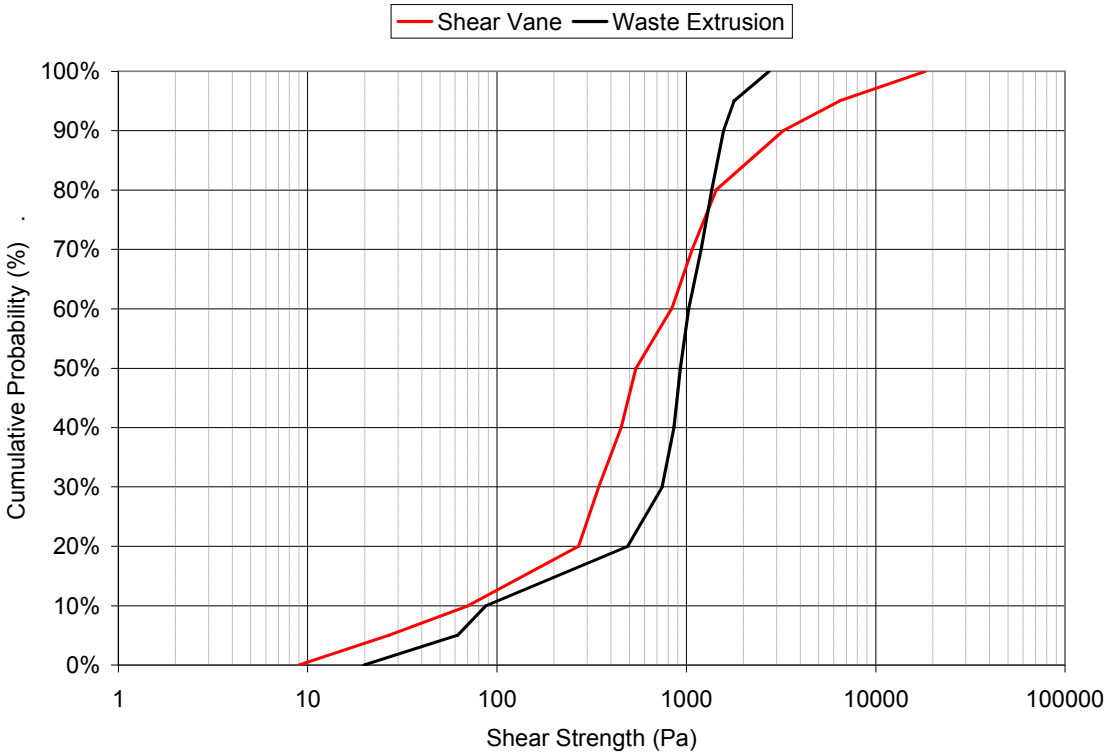

Figure 3. Cumulative shear-strength distributions for sludge waste

Hanford slurries can be characterized rheologically as non-Newtonian, Bingham plastic fluids [3]. The variation of the Bingham parameters as a function of UDS concentration is shown in Figures 4 and 5 for samples from 23 tanks. Sludge and saltcake waste as indicated by the primary waste type are shown separately. The temperature range of the measurements is 20 to 95 ^{o}C. Even for the disparate data set a trend of increasing Bingham parameters with increasing UDS concentration is apparent. At a given mass fraction the Bingham parameters can vary by about two orders of magnitude. This variability makes it difficult to apply a single simple correlation to represent Hanford waste viscosity as a function of UDS concentration.

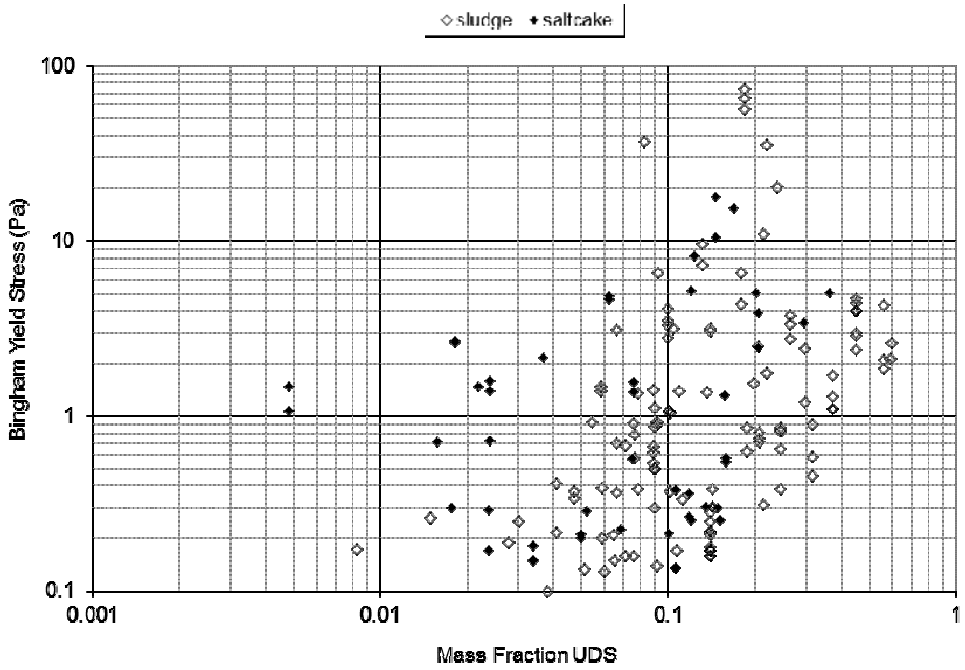

Figure 4. Bingham Yield Stress as a Function of Solids Concentration

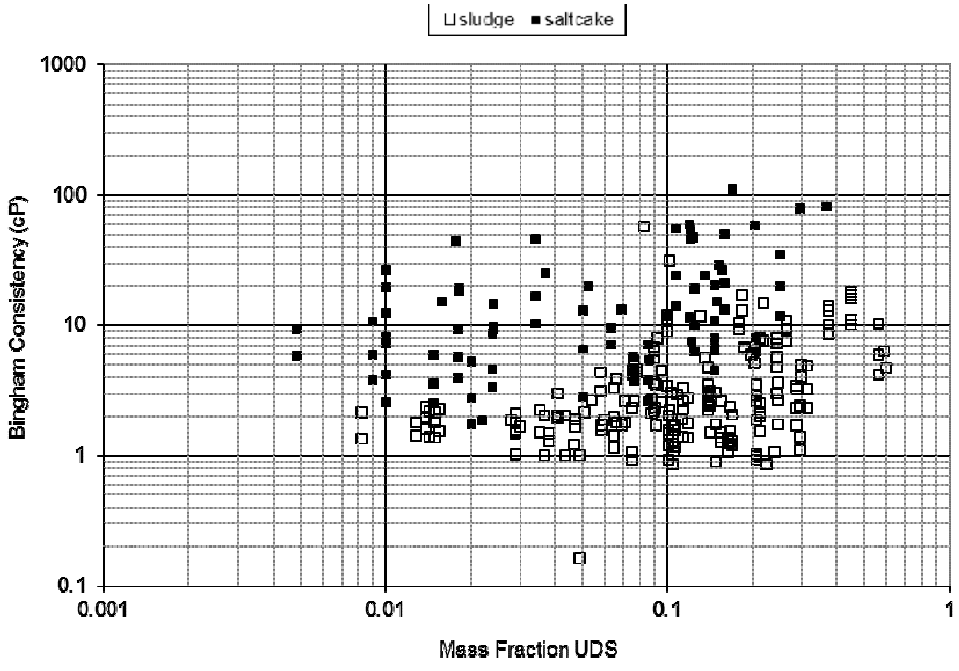

Figure 5. Plastic Viscosity as a function of solids concentration.

DATA GAPS IN PHYSICAL AND RHEOLOGICAL PROPERTIES

While considerable information is available on the physical and rheological properties of the Hanford tank waste there are some gaps in the knowledge that were quantified. The Hanford tank waste has been categorized into 44 different primary waste types. Of these waste types no physical or rheological property data was identified for 21 of the waste types representing approximately 30% of the UDS volume inventory. Most of these waste types represent a small fraction of the overall inventory with 17 of the 21 waste types representing less than 0.7% of the UDS volume. One of the waste types (T2 saltcake) represents 20% of the UDS volume. It should be noted that these values do not reflect some of the information from work sponsored by the WTP. In this work, composite samples consisting of similar waste types were used to represent eight sample groups that consisted of different but similar waste types. The eight groups represented 75% of the HLW mass expected to be processed through the WTP. The composite nature of the samples made it difficult to attribute results to a particular waste type.

Waste property gaps include:

- An expert group assembled to examine information on the composition and morphology of the UDS particles estimated that more than 50% of the particles are amorphous and may be mixtures of phases. The phases present in amorphous particles are not well identified by the X-ray diffraction method most commonly used at the Hanford site.

- The dry solids density is an important parameter used in simulant development and mixing assessments. During the simulant development process for mixing assessments it provides a target for the overall dry particle density for polydisperse simulants.

- Changes in shear strength in settled solids layers with an emphasis on shorter settling times and shear strength as a function of solids depth is not well quantified. An accurate understanding of the shear strength formation is needed so mixing systems are designed to prevent settled solids layers that may exceed the remobilization capabilities.

- The impact of storage on the sample properties has not been systematically quantified. Some of the results presented in this work are based on analysis of samples that were obtained from laboratory archives. In some cases these samples have been stored for up to 15 years. While significant effort is made to minimize the effect of storage, the long storage time may result in altered sample characteristics due to aging and drying.

GAPS IN ANALYTICAL METHODS

Data gaps that may be addressed by new or improved analytical methods are summarized and include PSD characterization, UDS concentration, PSDD characterization, abrasivity, and particle settling rates.

The dominant method for characterizing the PSD of tank wastes is based on light scattering techniques. Due to the nature of the technique and the many potential sources of error, the PSD results from this method are best characterized as an apparent PSD although the technique is arguably adequate to characterize the general particle sizes in the waste. In addition, the method does not provide information on the nature of agglomeration or particle shape and in some applications may underestimate the abundance of large particles. Other methods based on commercially available optical techniques are available that have the potential to provide more direct information on agglomeration and particle shape for individual particles. Results from this type of instrument appear to be more directly applicable to particles in pipeline transport or mixing systems.

The volume fraction of solids is an important parameter used in estimating slurry viscosity and pipeline critical velocity as well as performing hindered settling calculations. To obtain the volume fraction of dry solids in a slurry, it is generally necessary to determine the dry solids density and calculate the volume by dividing by the dry solid mass. Methods currently available to determine dry solids density include the use of gas pycnometers, a displacement method based on the use of dodecane [6], and calculating it as part of the UDS analyses [7]. The small amounts of actual waste sample typically used for the UDS analyses along with the difficulty working in hot cells provide density results that are not accurate enough for practical use. This gap could be addressed by using larger samples or more accurate centrifuge cones. The easiest and most accurate method is gas pycnometry.

Particle size and density distributions for Hanford wastes are important to waste transport and mixing and for developing simulants for evaluating these processes. PSD and particle density data are currently developed with separate analytical techniques. These attributes are combined to provide estimates of particle size and density distributions based on assumptions about the waste properties. Consequently, there is a need for a method that has the capability to determine the particle size and corresponding density of individual particles simultaneously.

One concept is currently under development and sponsored by EM-30. The method uses a settling column in which particulates settle through an appropriate fluid. Cameras obtain images of the settling particles with a sufficient magnification and frame rate to allow a determination of the settling rate. Particle size and shape information is also obtained. From these data, settling correlations can be used to determine the effective particle density for the sample conditions.

The abrasion properties of the waste are expected to have an impact on the erosion rates of processing equipment, but there are little data on the abrasivity of actual wastes. Most of the existing literature on the abrasivity of tanks wastes is based on testing with Hanford tank waste simulants. Only one value for a Miller Number obtained from actual waste was identified [8]. The value provided was a Miller Number of 8.4 obtained from a core sample taken from Tank 241-AZ-101. The lack of data suggests the need for a method to measure abrasivity in a radioactive environment with actual tank waste samples.

The current method of measuring the solids settling rates involves observing the interface of the settling solids and the clarified liquid above the solids. This approach provides a settling rate of

the interface that generally represents the slowest settling solids. The larger, denser particles likely settle at greater rates through the slurry. Data on these particulates are of interest for retrieval and mixing operations since they present a greater challenge. A method that could determine the settling rates over a wide range of particles and densities in concentrated slurries would provide useful data for assessing retrieval and mixing equipment.

GAPS IN SCALE-UP, DATA INTERPRETATION AND ANALYSIS

A common request expressed by end users of PSD results is for some measure of uncertainty to be provided with the PSDs. This desire is driven by the need to use bounding particle sizes for developing simulants or for use in engineering calculations. An understanding of the size of the solid particles in a tank waste sample is crucial in determining sedimentation rates, the ease with which the solids can be filtered, flow behavior of the solids when pumped through a pipe, and the force required to suspend solids and keep the solids suspended in a pipe or tank. One approach to address this issue is to provide an estimate of the uncertainty based on the performance characteristics of the method and instruments. Another approach is to develop tolerance or confidence limits based on the actual samples results. Unfortunately neither approach results in quantifiable, technically defensible uncertainties for the PSDs for the light-scattering methods currently in use.

Non-parametric tolerance interval methods exist that can provide technically defensible estimates of PSD uncertainty but these methods require sample sizes larger than the sample sizes currently available. This suggests that a larger number of samples be analyzed although the number required to attain acceptable confidence levels may be prohibitively large. For example, a random sample of 30 observations would be needed to achieve 95% confidence that the 90^{th} percentile of a population (not necessarily normally distributed) would be less than the maximal value in the sample.

Perhaps the most immediate approach to addressing this gap is to use the range of the actual data combined with knowledge of the wastes and the processes that generated them. For the existing data, the PSDs at a given percentile typically range over a factor of 5-10.

The critical shear stress for erosion is ideally the applied shear stress above which particulate will be removed from a surface or body. This parameter is pertinent to tank farm and WTP mixing and line flushing scenarios and is material dependent.

As described in Wells et al. (2009) [9], the critical shear stress for a given material can be predicted from *in situ* or laboratory erosion measurements. There are different measurement techniques that may be used, but all require multiple data points such that the critical shear stress at zero-erosion (corresponding to the predicted onset of erosion) can be identified. Some of these erosion measurement techniques allow the erosion rate to be determined. For a shear stress beyond the critical shear stress applied to a material, two states of erosion will dominate, surface and bulk erosion. While bulk erosion may be initiated at applied shear stresses below a material's measured shear strength, it will occur if the applied stress is equal to or exceeds the measured shear strength.

Methods for determining the critical shear stress for the onset bulk erosion over a range of cohesive materials have not been successfully developed outside of experimental mapping of the erosion process as a function of applied shear stress for the specific material of interest.

RECOMMENDATIONS

Prioritizing the gaps identified in this study depends on the current state of knowledge, the priority of the applications for which the information is needed, and the timing with which information can be obtained. Recognizing that the authors of this study are not the decision makers' concerning efforts to address the gaps, some guidance is nevertheless offered on where additional efforts should be focused. In developing these observations the focus was on gaps for which relatively small amounts of data are available, data are relatively uncertain, and waste properties are not readily modified by processing (e.g., rheology may be modified by diluting the solids concentration).

While the characterization of the tank wastes is not complete, additional characterization of the waste parameters with the methods currently available may not have a great impact on the average or median properties reported in this document. This suggestion is based on the observation that the results developed in this report are fairly similar to those of previous efforts even though a significant amount of new data has been obtained. Indeed the recent effort sponsored by the WTP characterized samples from eight waste groups representing approximately ~75% of the HLW mass expected to be processed through the WTP. What may be missing from this body of results is information on the outlying properties or extremes. Design and waste processing operations are often controlled by the extreme or most difficult wastes to be processed. Consideration should be given to focusing characterization efforts on samples suspected of having extreme values of the waste properties.

The dry solids density is an important parameter used in simulant development and mixing assessments. During the simulant development process for mixing assessments it provides a target for the overall dry particle density for polydisperse simulants. The dry solids density also has a role in determining the volume fraction of solids, which is an important parameter used in estimating slurry viscosity and pipeline critical velocity as well as performing hindered settling calculations. This gap appears to be relatively easy to fill by using a gas pycnometry method or extending the existing protocols for the determination of undissolved solids fractions. This gap can likely be filled as part of on-going waste characterization efforts.

An accurate understanding of the shear strength formation is needed so mixing systems are designed to prevent settled solids layers that may exceed the remobilization capabilities. Given the small amount of data available on this topic, filling this important gap would allow an assessment of the length of time settled sludge could remain undisturbed before challenging the capability of the mixing and transport systems.

The light-scattering methods currently in use for measuring PSDs have some limitations. Some of these limitations can be overcome by supplementing the light-scattering techniques with

optical-based PSD measurement methods. While this would require the procurement of new instruments, it would offer a direct measurement of the PSDs as well as direct information on the particle and agglomerate shapes.

Particle size and density distributions are important to waste transport and mixing operations and for developing simulants for evaluating these processes. The PSD and particle density data are currently obtained with separate analytical techniques and the separate measurements linked by making assumptions about the waste properties. This approach has several disadvantages that result in considerable uncertainty in the particle size and density distributions. Consequently the development of a new method that has the capability to simultaneously determine the size and corresponding density of individual particles would greatly reduce the uncertainty in the particle size and density distributions. This would likely result in more representative simulants and less-conservative designs for the mixing and transport systems.

The abrasion properties of the waste are expected to have an impact on the erosion rates of processing equipment, but there is little data on abrasivity. This data gap is due to the lack of a developed and accepted method for application to radioactive samples. Given the lack of data on abrasivity of the tank waste, existing methods should be examined to evaluate whether they can be adapted and qualified for radioactive waste samples. Alternatively, a new method may be required.

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ACKNOWLEDGEMENTS

This work was funded by the Office of Technology Innovation and Development (EM-30).