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WTP-RPT-112, Rev. 0

Final Report: Technical Basis for HLW Vitrification Stream Physical and Rheological Property Bounding Conditions

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Prepared for Bechtel National, Inc.
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LEGAL NOTICE

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for W. Tamosaitis 1/5/06
ACCEPTED FOR
WTP PROJECT USE

January 2006

Test specification: 24590-WTP-TSP-RT-01-007, Rev. 0
Test plan: TP-RPP-WTP-205, Rev. 0
Test exceptions: 24590-WTP-TEF-RT-02-070 and 072,
24590-HLW-TEF-RT-05-00005
R&T focus area: Simulant Development
Test Scoping Statement(s): B-87

Battelle—Pacific Northwest Division
Richland, Washington 99352

COMPLETENESS OF TESTING

This report describes the results of work and testing specified by Test Specification 24590-WTP-TSP-RT-01-007, Rev. 0, Test Plan TP-RPP-WTP-205, Rev. 0, and Test Exceptions 24590-WTP-TEF-RT-02-070, 24590-WTP-TEF-RT-02-072, and 24590-HLW-TEF-RT-05-00005. The work and any associated testing followed the quality assurance requirements outlined in the Test Specification/Plan. The descriptions provided in this test report are an accurate account of both the conduct of the work and the data collected. Test plan results are reported. Also reported are any unusual or anomalous occurrences that are different from expected results. The test results and this report have been reviewed and verified.

Approved:

Gordon H. Beeman, Manager
WTP R&T Support Project

1/4/06
Date

Summary

The Hanford Site has 177 single-shell and double-shell tanks containing radioactive waste. The U.S. Department of Energy (DOE) Office of River Protection's (ORP's) Hanford Waste Treatment Plant (WTP) is being designed and built to treat and vitrify these wastes. The tank waste currently stored in the Hanford tank farm has been categorized according to chemical and radiochemical properties into four categories. These categories are referred to as Envelope A, Envelope B, Envelope C, and Envelope D wastes. The two vitrification process streams considered in this report are the pretreated high-level waste (HLW) and the HLW melter feed obtained from the Envelope D wastes.

This document describes the HLW part of the work performed under Battelle Test Plan TP-RPP-WTP-205 Rev 0, *LAW and HLW Actual Waste and Simulant Coordination*. The original draft report, WTP-RPT-075, Rev. 0 (March 2003), combined data for both low-activity waste (LAW) and HLW, but no final report was issued. This draft report was then split into separate reports for LAW and HLW. The LAW report, WTP-RPT-098, titled *Technical Basis for LAW Vitrification Stream Physical and Rheological Property Bounding Conditions*, was issued and accepted for Waste Treatment Project (WTP) project use February 17, 2004. The HLW report, WTP-RPT-100[a], titled *Interim Report: Technical Basis for HLW Vitrification Stream Physical and Rheological Property Bounding Conditions*, was issued within the WTP Project for "Information Only" as all of the planned HLW testing was not complete at the time, and the Project needed a basis for bounding HLW rheological properties etc. for various scopes of work, e.g., the pulse jet mixer (PJM) testing program. This report includes data from all of the planned radioactive HLW testing through fiscal year (FY) 2005.

Objectives

The objective of this work was to develop a set of bounding physical and rheological properties for HLW that likely will be encountered in the WTP vitrification facilities and that can be reasonably processed. To determine the bounding conditions for each unit operation, one must understand what general waste properties are anticipated and how changes in these properties impact process operation. The process bounding conditions are then established at the point where the properties of the material introduce unacceptable risk to plant performance. Hence, one can use this set of bounding physical and rheological properties to determine if a given pretreated waste or melter feed will cause processing problems by forcing the system to operate outside its designed capabilities. See Table S.1.

Table S.1. Summary of Test Objectives and Results

TEST OBJECTIVE	OBJECTIVE MET	DISCUSSION
The objective of this work was to provide the technical basis for a bounding range of physical and	yes	A set of bounding conditions were proposed for both the pretreated HLW sludge and the HLW melter feed. The maximum settled-solids shear strength was determined to be 625 Pa for both

(a) Poloski A, O Bredt, B Calloway, G Smith, and H Smith. 2003b. *Interim Report - Technical Basis for HLW Vitrification Stream Physical and Rheological Property Bounding Conditions*. WTP-RPT-100 Rev. 0, Battelle—Pacific Northwest Division, Richland, WA. (WTP Project Document No. 24590-101-TSA-W000-0004-99-09, Rev. 00D)

TEST OBJECTIVE	OBJECTIVE MET	DISCUSSION
rheological properties for HLW that likely will be encountered in the WTP vitrification facilities and conversely be taken into account when sizing a plant.		streams upon plant upset conditions to allow the solids to be resuspended. The maximum Hedstrom number in 2-in. pipe was determined to be 10^8 for both streams for pumping conditions. The maximum yield stress was proposed to be 30 Pa in both streams with the maximum consistency to be 30 cP in the HLW pretreated sludge and 40 cP in the HLW melter feed for pumping, mixing, erosion, and settling in pipes.
An additional objective was to provide a consensus of testing methods for particle size distribution, heat capacity, thermal conductivity, and particle morphology that are currently unavailable in *Guidelines for Performing Chemical, Physical, and Rheological Properties Measurements* (24590-WTP-GPG-RTD-001 Rev 0).	no	Separated from this work by Test Exception 24590-HLW-TEF-RT-05-00005. NOTE: Disposition of the objective on.. "consensus of testing methods".. will be addressed by WTP issuing a revision of the "Guidelines For Performing Chemical, Physical, and Rheological Properties Measurements" (24590-WTP-GPG-RTD-001 Rev 0) that addresses this objective.

Test Exceptions

Table S.2 describes the test exceptions relevant to the work presented in this report.

Table S.2. Test Exceptions

Test Exceptions	Description
24590-WTP-TEF-RT-02-070	This report shall also contain a section that summarizes the compiled physical property data in a manner requested by Dr. Art Etchells (DuPont mixing expert) in support of modeling of mixing systems for the vitrification streams.
24590-WTP-TEF-RT-02-072	The purpose of this test exception is to document the applicability of NQA-1-1989, Part 1, Basic and Supplementary Requirements and NQA-2a-1990, Part 2.7 requirements that were not specified in the test plan, TP-RPP-WTP-205 Rev 0, *LAW and HLW Actual Waste and Simulant Coordination*, that initiated this work and that QARD/RW-0333P was not necessary.
24590-HLW-TEF-RT-05-00005	The scope associated with defining consensus testing methods for heat capacity, thermal conductivity, and particle morphology was deleted. The consensus testing method for particle size distribution will be included in a revised version of *Guidelines for Performing Chemical, Physical, and Rheological Properties Measurements* (24590-WTP-GPG-RTD-001 Rev 0).

Test Exceptions	Description
	The scope related to test exception 24590-WTP-TEF-RT-02-070, Rev. 0 was deleted.

Results and Performance Against Success Criteria

Table S.3 discusses the test criteria and how they were met. The test criteria mirror the test objectives of proposing bounding conditions for the pretreated HLW sludge and the HLW melter feed.

Table S.3. Summary of Success Criteria

Success Criterion	How the Criterion Was Met
Issue a report documenting a critical review and evaluation of existing chemical, physical and rheological data on actual and simulated wastes relevant to the WTP HLW vitrification processes. The process streams to be addressed include pretreated HLW sludge and HLW melter feed for Envelope D. The report will summarize available information on chemical, physical, and rheological properties as defined in Table 1 in *Guidelines for Performing Chemical Physical, and Rheological Properties Measurements* (24590-WTP-GPG-RTD-001).	Success criterion met. This report addresses the topics of previous work completed in the annotated bibliography and provides an evaluation of the bounding conditions and how they relate to the available data. These bounding conditions are summarized in Tables S.5 and S.6 below.
Include in the report bounding physical and rheological properties for pretreated HLW sludge and HLW melter feeds based upon actual waste and simulant testing.	Success criterion met. A set of bounding conditions was proposed for both the pretreated HLW sludge and the HLW melter feed. The maximum settled solids shear strength was determined to be 625 Pa for both streams upon plant upset conditions to allow the solids to be resuspended. The maximum Hedstrom number in 2-in. pipe was determined to be 10^8 for both streams for pumping conditions. The maximum yield stress was proposed to be 30 Pa in both streams with the maximum consistency to be 30 cP in the HLW pretreated sludge and 40 cP in the HLW melter feed for pumping, mixing, erosion, and settling in pipes. See Tables S.5 and S.6 below.

Quality Assurance Requirements

Application of RPP-WTP Quality Assurance Requirements

Battelle—Pacific Northwest Division’s (PNWD’s) Quality Assurance (QA) Program is based upon the requirements as defined in DOE Order 414.1A, Quality Assurance and 10 CFR 830, Energy/Nuclear Safety Management, Subpart A—Quality Assurance Requirements (a.k.a. the Quality Rule). PNWD has chosen to implement the requirements of DOE Order 414.1A and 10 CFR 830, Subpart A by integrating them into the laboratory's management systems and daily operating processes. The procedures necessary to implement the requirements are documented through PNWD's Standards-Based Management System (SBMS).

PNWD implements the River Protection Project (RPP)-WTP quality requirements by performing work in accordance with the PNWD Waste Treatment Plant Support Project quality assurance project plan (QAPjP) approved by the RPP-WTP QA organization. This work was performed to the quality requirements of NQA-1-1989 Part I, Basic and Supplementary Requirements, and NQA-2a-1990, Part 2.7. These quality requirements are implemented through PNWD's *Waste Treatment Plant Support Project (WTPSP) Quality Assurance Requirements and Description Manual*. The analytical requirements are implemented through WTPSP's Statement of Work (WTPSP-SOW-005) with the Radiochemical Processing Laboratory (RPL) Analytical Service Operations (ASO).

A matrix that cross-references the NQA-1, NQA-2a and Quality Assurance Requirements and Description (QARD) requirements with PNWD's procedures for this work was given in the Test Plan, TP-RPP-WTP-205, *LAW and HLW Actual Waste and Simulant Coordination*. It included justification for those requirements not implemented.

Conduct of Experimental and Analytical Work

Experiments that were not method-specific were performed in accordance with PNWD's procedures QA-RPP-WTP-1101 "Scientific Investigations" and QA-RPP-WTP-1201 "Calibration Control System" verifying that sufficient data were taken with properly calibrated measuring and test equipment (M&TE) to obtain quality results.

As specified in Test Specification, 24590-WTP-TSP-RT-01-007, Rev. 0, BNI's QAPjP, PL-24590-QA00001, is not applicable because the work was not performed in support of environmental/regulatory testing, and the data will not be used as such.

Internal Data Verification and Validation

PNWD addresses internal verification and validation activities by conducting an Independent Technical Review (ITR) of the final data report in accordance with PNWD's Procedure QA-RPP-WTP-604. This review verifies that the reported results are traceable, that inferences and conclusions are soundly based, and that the reported work satisfies the Test Plan objectives. This review procedure is part of PNWD's *WTPSP Quality Assurance Requirements and Description Manual*.

R&T Test Conditions

Table S.4 describes the research and technology (R&T) test conditions and how they were followed in this testing.

Table S.4. R&T Test Conditions

R&T Test Conditions	Test Conditions Followed? Results
1) Existing pretreated waste and melter feed simulants (HLW Pretreated Sludge and HLW Melter Feed) data and preparation procedures from PNWD, Savannah River Technology Center (SRTC), and Vitreous States Laboratory (VSL) will be reviewed and compared to actual radioactive waste measurements. No new testing is planned. Guidelines for reviewing simulant development, definition, and verification methodologies are provided in *Simulant Definition and Verification Methodology* (24590-WTP-RPT-TE-01-003). The report will summarize available information on chemical, physical, and rheological properties as defined Table 1 in *Guidelines for Performing Chemical Physical, and Rheological Properties Measurements* (24590-WTP-GPG-RTD-001). Other waste and simulant property data, including particle morphology, tendency to consolidate into hard-pan clay, some measure of tendency to adhere to stainless steel components, and glass yield, should be provided as available. The viscosity behavior (e.g., Bingham plastic, power law) of wastes and simulants shall be characterized. The quality level of the compiled data shall also be documented. Rheological and physical property data from existing waste feed and melter feed reports will be reviewed, and a set of bounding conditions will be established along with the degree of accuracy required based on the mixing/pump/ transfer system operability limits. This range must be defined to confirm that the mixing and transfer process can be successfully restarted following a downtime of 7 days to support maintenance requirements.	1) Work performed: • Existing pretreated waste and melter feed simulants (HLW Pretreated Sludge and HLW Melter Feed) data and preparation procedures from PNWD, SRTC, and VSL were reviewed and compared to actual radioactive waste measurements. • No new testing was conducted. • Available information on chemical, physical, and rheological properties was summarized per *Guidelines for Performing Chemical Physical, and Rheological Properties Measurements* (24590-WTP-GPG-RTD-001). • Other waste and simulant property data including particle morphology, tendency to consolidate into hard-pan clay, some measure of tendency to adhere to stainless steel components, and glass yield, was provided as available. • A set of bounding physical and rheological properties for waste materials that can be reasonably processed and that likely will be encountered in the WTP HLW vitrification facility is provided. • The evaluation assessed important design considerations, including kinematic viscosity for pump selection and a worst case senario for particle settling. These validation criteria and bounding conditions are based upon engineering design techniques, including dimensional analysis for conventional processing unit operations.
2) Simulant and Waste Characterization Consensus Methods Report Issue a document that provides consensus test	2) Work not performed. Outside present scope. See Test Exception # 24590-HLW-TEF-RT-05-00005.

R&T Test Conditions	Test Conditions Followed? Results
methods for: • particle size distribution • heat capacity • thermal conductivity • particle morphology (scanning electron microscopy [SEM]) for inclusion in the next revision to *Guidelines for Performing Chemical Physical, and Rheological Properties Measurements* (24590-WTP-GPG-RTD-001 Rev 0).	
<u>3) HLW and LAW Waste and Simulant Review Report (Rev 0.)-</u> Rev 0 of the HLW and LAW Waste and Simulant Review Report shall incorporate additional data on recycle streams and other observed waste properties. Information on process and recycle streams should be reviewed, including recycle to the LAW Condensate Recycle Vessel (CRV) from the LAW Submerged Bed Scrubber (SBS) and Wet Electrostatic Precipitator (WESP) and recycle to the HLW CRV from the HLW SBS, WESP, and high efficiency mist eliminator (HEME) as available.	3) The HLW portion of the bounding conditions has focused on updating the interim HLW bounding conditions report with additional data produced by PNWD, SRNL, and VSL. In addition some attention has been given to pretreated HLW slurry particles (types, sizes and densities), expected rheology changes as waste is processed through the plant, the effects of surfactants and anti-foaming agents on rheology of pretreated waste and melter feed, and the question of predicting pretreated HLW and HLW melter feed based on available data.
Other relevant work with simulants including work for the Hanford Waste Vitrification Plant (HWVP), the West Valley Demonstration Project (WVDP), and the Defense Waste Processing Facility (DWPF) should also be considered. Experience with restarting mixing and any changes in properties as a result of down time should also be considered.	Other relevant work with simulants, including work for the Hanford Waste Vitrification Plant (HWVP), the West Valley Demonstration Project (WVDP), and the Defense Waste Processing Facility (DWPF) as well as the Wet Electrostatic Precipitator (WESP) and recycle to the HLW CRV, and a high efficiency mist eliminator (HEME) as available were not included in this report because of programmatic limitations.

Simulant Use

Not applicable.

Results and Performance Against Objectives

The strategy employed in the development of the physical and rheological bounding conditions proposed in this document was based on the identification of correlations between dimensionless groups for specific unit operations performed in the WTP baseline flowsheet. Dimensionless groups are numbers made up of physical-property parameters (e.g., density, flow velocity, yield stress, viscosity) combined in such a way that the units cancel and therefore are "dimensionless." As the WTP will be using standard chemical processing equipment in a lot of their various unit operations, e.g., piping, pumps, and mechanical agitators, correlations for similar equipment that have been developed for standard chemical processing applications are used in this document to help develop correlations relevant to the WTP. Sources for these correlations include various engineering handbooks, engineering textbooks, and peer-reviewed journal articles. In addition, equipment data and calculations for previous vitrification-plant designs are used, including the HWVP and the DWPF. Pulse jet mixer (PJM) studies have been included for reference but not in the analysis reported in this document. Based on these correlations, bounding conditions on the physical and rheological properties are proposed to satisfy equipment selection issues.

Actual and simulated HLW data have been used to tailor the proposed bounding conditions to span the existing actual waste properties. However, not all actual HLW data lie within the proposed bounding conditions, as many HLW materials were tested that possess a wide range of physical and rheological property values. Consequently, the proposed bounding conditions are based upon a general engineering evaluation of process equipment to encompass as many measured values from actual and simulated HLW material as possible.

Bounding conditions criteria were developed for two HLW vitrification streams: HLW pretreated sludge and HLW melter feed. Tables S.5 and S.6 are summary tables of the bounding conditions developed in this document for each vitrification process stream.

Table S.5. Summary of Bounding Conditions HLW Pretreated Sludge

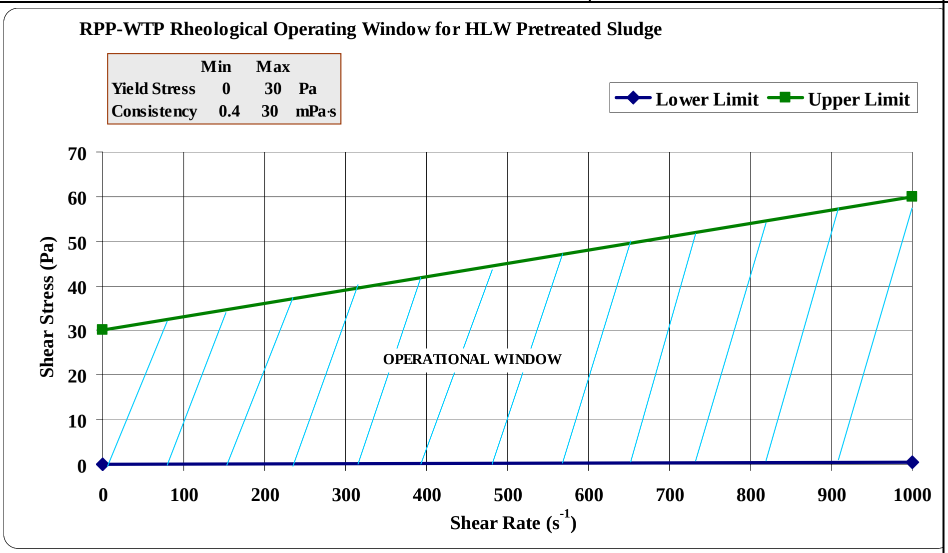
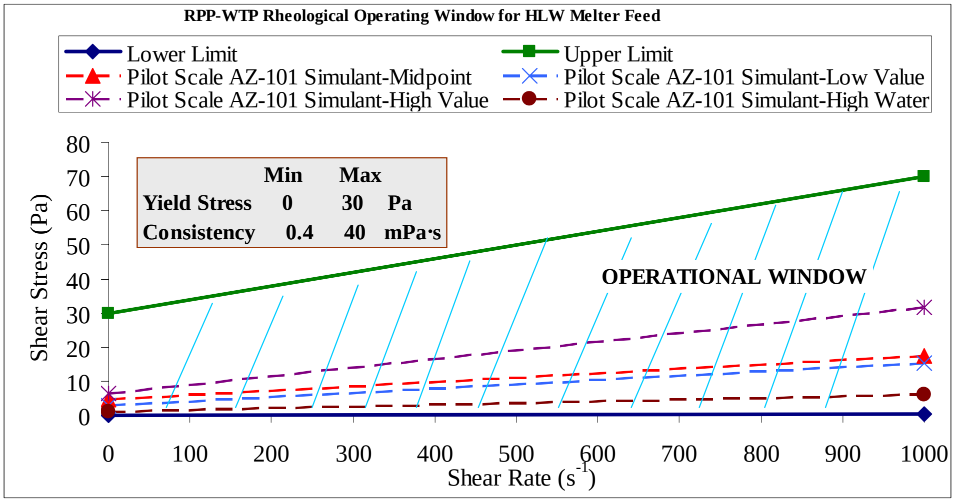
<table>
<tr><th></th><th>Category</th><th>Value</th><th>Application</th></tr>
<tr><td rowspan="3">Bounding Conditions</td><td>Maximum Settled Solids Shear Strength</td><td>< 625 Pa</td><td>Plant Upset Conditions</td></tr>
<tr><td>Maximum Hedstrom Number in 2-in. Pipe
$N_{He} = \dfrac{D^2 \rho \tau_y}{K^2}$</td><td>$< 10^8$</td><td>Pumping</td></tr>
<tr><td colspan="2">
</td><td>Pumping, Mixing, Erosion, Settling in Pipes</td></tr>
</table>

Table S.6. Summary of Bounding Conditions for HLW Melter Feed

	Category	Value	Application
Bounding Conditions	Maximum Settled Solids Shear Strength	< 625 Pa	Plant Upset Conditions
	Maximum Hedstrom Number in 2-in. Pipe $N_{He} = \frac{D^2 \rho \tau_y}{K^2}$	$< 10^8$	Pumping
			Pumping, Mixing, Erosion, Settling in Pipes

As discussed above, the bounding conditions proposed in this document are predicated on 1) actual waste data, 2) theoretical/empirical correlations, and 3) the need for a reduction in plant operational risk. Information from previous actual waste characterization efforts was compiled and compared against the proposed bounding conditions. Several of the actual HLW samples possessed rheological properties outside of these bounding conditions. This is expected because in past characterization efforts, a wide range of solids concentrations was typically analyzed to gauge the effect on physical and rheological properties. An asymptotic relationship between Bingham plastic parameters and undissolved solids (UDS) concentration exists [a] (Slatter 1997; Landel et al. 1965; Dabak and Yucel 1987). At high UDS concentrations, the Bingham plastic parameters can become quite large, and a relatively small amount of dilution can result in a significant decrease. This relationship explains the large rheological ranges observed for the actual HLW materials. However, at least one measurement from each actual HLW sample exists inside the proposed bounding conditions, typically at lower solids concentrations.

(a) The consistency index, K, can be modeled with $K = \mu_f \left(1 - \frac{C}{C_{\max}}\right)^{-m}$ where μ_f is the viscosity of the interstitial liquid; C is the concentration of undissolved solids; $C_{\max}$ and m are fitting parameters. The yield stress, τ_y, can be modeled as $\tau_y = a \frac{C^3}{C_{\max} - C}$ where a is a fitting parameter (Slatter 1997; Landel et al. 1965; Dabak and Yucel 1987).

Bounding conditions for the HLW pretreated sludge and HLW melter feed include a maximum value for the settled solids shear strength of 625 Pa (see Tables S.5 and S.6). This value was established based on a plant-upset condition where restart is attempted with a mechanical agitator immersed in a layer of settled solids. Using design specifications from HWVP, if the settled solids shear strength is above approximately 625 Pa, agitator restart may be difficult. This shear-strength value was also used in an engineering evaluation of another plant-upset condition that involves initiating flow in a 3-m (10-ft) section of pipe containing a plug of settled solids. At a shear strength of 625 Pa, an appreciable pressure drop was required to initiate the flow of a settled-solids plug.

The Hedstrom number upper bounding value of 10^8 was established based on an engineering evaluation of the pumping requirements of several Bingham plastic fluids with pumps specified in the HWVP design. The rheological upper bounds for these vitrification streams were established based on the set of Bingham plastic parameters that would produce a turbulent flow regime in a 2-in. inside diameter (ID) pipe. The premise for this calculation is that heterogeneity during pipeline transport can be significant in the laminar flow regime for settling slurries. Pipeline plugging and slug flow can result during laminar flow. Actual HLW data were compared to a computed set of Bingham plastic parameters that result in turbulent flow while limiting high pipeline velocities to avoid erosion problems. A single point from this set of Bingham plastic parameters for each vitrification stream was selected as the upper Bingham plastic parameter point that encompassed most of the actual waste data. These bounding conditions compared favorably to the DWPF and HWVP melter-feed design ranges. The lower rheological boundaries were selected to be consistent with the settling-velocity calculation discussed above.

Discrepancies and Follow-on Tests

The following recommendations are made based on the findings in this document:
Establish a consensus method of measuring significant properties, such as particle size and particle density.[a] These physical and rheological properties have not been measured or have been measured using different measurement equipment and techniques. Once consensus methods are established for these significant parameters, a coordinated effort to validate simulants is recommended.[b]

About the Appendices

Appendices A, B, and C include an extensive summary of physical property data measured on actual and simulated pretreated HLW and HLW melter feed (Appendix A), a discussion and summary of observed physical property correlations for both actual and simulated pretreated HLW and HLW melter feed

(a) Average particle density can be calculated from the following equation (Shook, Gillies, and Sanders 2002): $\frac{1}{\rho_m} = \frac{C_W}{\rho_s} + \frac{1-C_W}{\rho_f}$ where ρ_m is the slurry density, ρ_s is the average particle density, ρ_f is the interstitial liquid density, and C_W is the mass fraction of undissolved solids in the slurry.

(b) The logic flow behind a coordinated verification/validation effort has been defined in *Simulant Definition and Verification Methodology* (24590-WTP-RPT-TE-01-003, Rev 0) and *Desk Instruction: R&T Simulant Development, Approval, Validation, and Documentation*, RPP-WTP, Effective Date: September 27, 2002.

(Appendix B), and a discussion of physical property variation during HLW pretreatment (Appendix C). Appendix D is a rheology tutorial, and Appendix E provides QA information relating to the measurement and reporting of the data included in this report. Appendices A and B provide detail on the data available on which bounding conditions were set and various ways in which they can affect bounding conditions.

Acronyms

ASO	Analytical Service Operations
BNI	Bechtel National, Inc.
CRV	Condensate Recycle Vessel
CUF	cell unit filter (crossflow ultrafiltration)
DOE	U.S. Department of Energy
DWPF	Defense Waste Processing Facility
ES&H	Environmental Safety and Health
ESP	Environmental Simulation Program
GFC	glass-former chemicals
HEME	high efficiency mist eliminator
HLW	high-level waste
HWVP	Hanford Waste Vitrification Plant
ID	inside diameter
ILAW	immobilized low-activity waste
ITR	Internal Technical Review
LAW	low-activity waste
MFPV	Melter Feed Preparation Vessel
MFV	Melter Feed Vessel
M&TE	measuring and test equipment
MTTR	mean time to repair
NCAW	neutralized current acid waste
OR	Operations Research Model
PJM	pulse jet mixer
PNNL	Pacific Northwest National Laboratory
PNWD	Battelle—Pacific Northwest Division
PSD	particle size distribution

QA	quality assurance
QAPjP	quality assurance project plan
QARD	Quality Assurance Requirements and Description
RPL	Radiochemical Processing Laboratory
RPP	River Protection Project
R&T	research and technology
SBMS	Standards Based Management System
SBS	Submerged Bed Scrubber
SEM	scanning electron microscopy
SIPP	Semi-Integrated Pilot Plant
SOW	Statement of Work
SRNL	Savannah River National Laboratory
SRTC	Savannah River Technology Center
TP	test plan
TRU	Transuranics
TS	total solids
UDS	undissolved solids
UFP2	Ultrafiltration Feed Process-2
VSL	Vitreous States Laboratory
WESP	wet electrostatic precipitator
WLW	wash-leach-wash
WSRC	Westinghouse Savannah River Company
WTP	Waste Treatment Plant
WTPSP	Waste Treatment Plant Support Project

Contents

Figures

Tables

1.0 Introduction

The Hanford Site has 177 single-shell and double-shell tanks containing radioactive waste. The Office of River Protection's (ORP) Hanford Waste Treatment Plant (WTP) is being designed and built to treat and vitrify these wastes. The WTP consists of three primary facilities: a pretreatment facility and two facilities for low-activity and high-level waste vitrification. The pretreatment facility receives waste feed from the Hanford tank farms and separates it into two treated process streams: a high-volume, low-activity, liquid process stream stripped of most solids and radioisotopes and a much smaller volume high-level waste (HLW) slurry containing most of the solids and radioactivity. In the pretreatment facility, solids and radioisotopes are removed from the tank waste by precipitation, filtration, and ion exchange processes to produce the low-activity waste (LAW) streams. The slurry of filtered solids will be blended with ion exchange eluate streams containing soluble radioisotopes to produce the HLW streams. The pretreated HLW mixture routes to the High-Level Waste Vitrification Facility and the pretreated LAW stream routes to the Low-Activity Waste Vitrification Facility. These two vitrification facilities convert these process streams into glass, which is poured directly into stainless steel containers.

The tank waste currently stored in the Hanford tank farm has been categorized according to chemical and radiochemical properties into four categories. These categories are referred to as Envelope A, Envelope B, Envelope C, and Envelope D wastes. The two vitrification process streams considered in this report are the pretreated HLW and the HLW melter feed obtained from the Envelope D wastes.

The unit operations of the pretreatment facility are shown on the process flowsheet presented in Figure 1.1 (Sherwood 2003). The pretreatment process may begin by concentrating the waste through an evaporation-unit operation. One purpose of this step is to minimize the quantity of waste processed through the plant. Figure 1.1 summarizes the number and kinds of waste and recycle (or secondary) process streams that will occur in the pretreatment facility. A solid/liquid separation in a crossflow filter produces a high solids stream that is collected in a feed tank for the HLW vitrification process. The low-solids liquid stream then passes through a series of ion exchange columns to remove the cesium from the stream. The ion exchange columns are then eluted and the eluate from the ion exchange columns is further evaporated and sent to the HLW blend tank for the HLW vitrification process. In this document, the high solids including Sr/TRU precipitates from Envelope C and cesium eluate stream is referred to as "HLW pretreated sludge."

The focus of this document is the streams processed through the HLW Vitrification Facility (see Figure 1.2). This facility receives pretreated HLW waste that includes secondary waste from the pretreatment facilities shown schematically in Figure 1.1. The HLW Vitrification Facility is made up of a series of receipt and mixing tanks with associated pumps and transfer lines. The treated waste is initially transferred from the pretreatment tanks to the Melter-Feed Preparation Vessel (MFPV) where the slurry composition is measured. At this point, appropriate glass-former chemicals (GFCs) are added to the treated waste in the MFPV. The Glass Former Chemical Supply Hopper System illustrated schematically in Figure 1.2 feeds into all of the melter-feed process vessels. Table 1.1 gives the mineral, grade and source of the glass-former materials that will be stored in the Glass Former Chemical Supply Hopper System shown schematically in Figure 1.2. Batches of the GFCs are transferred to the MFPV. With GFCs added, the resulting stream is called "HLW melter feed." The term "HLW melter feed" will be used throughout this document. The subsequent homogenized melter feed is pumped into

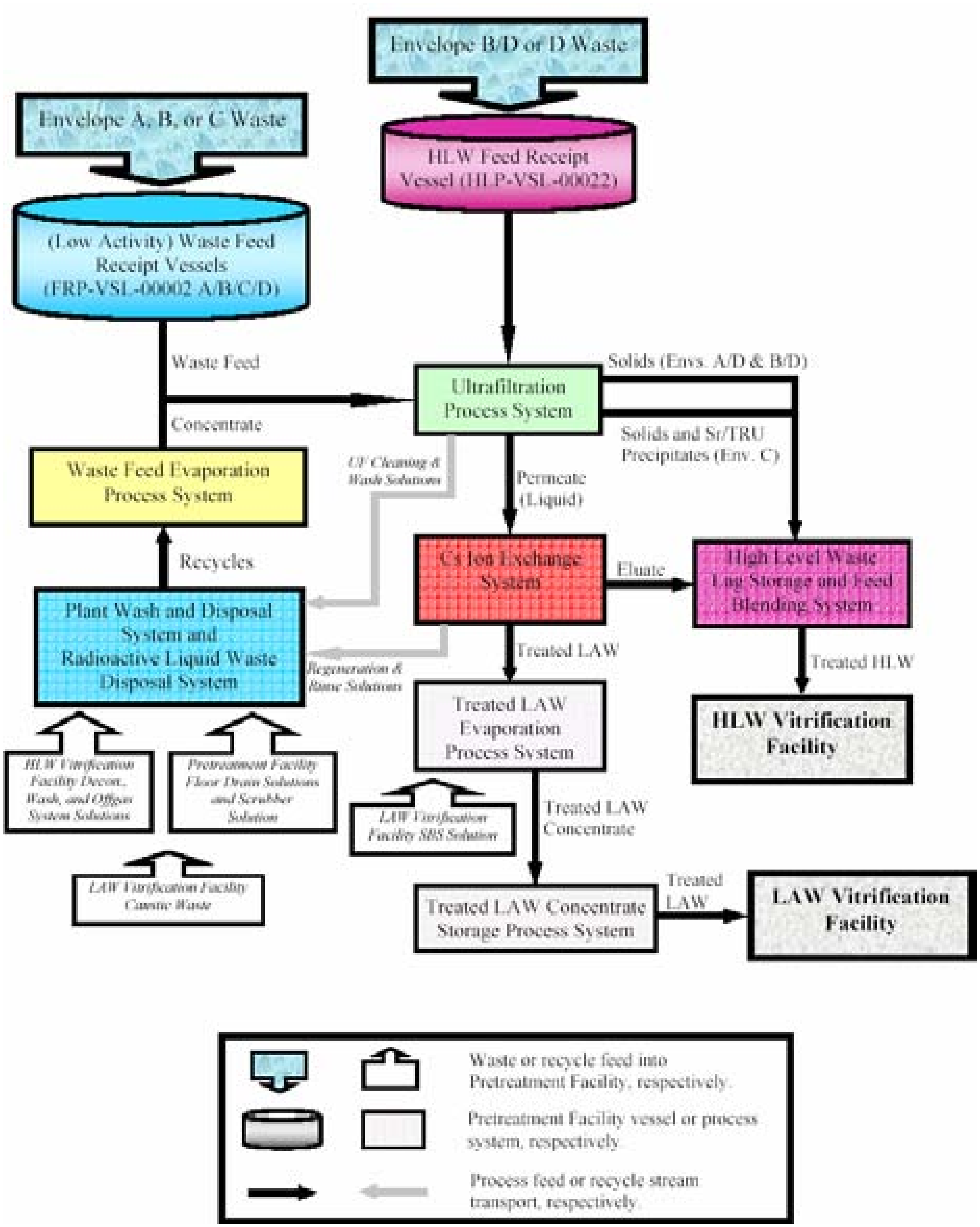


Figure 1.1. Schematic Pretreatment Facility Process Flow

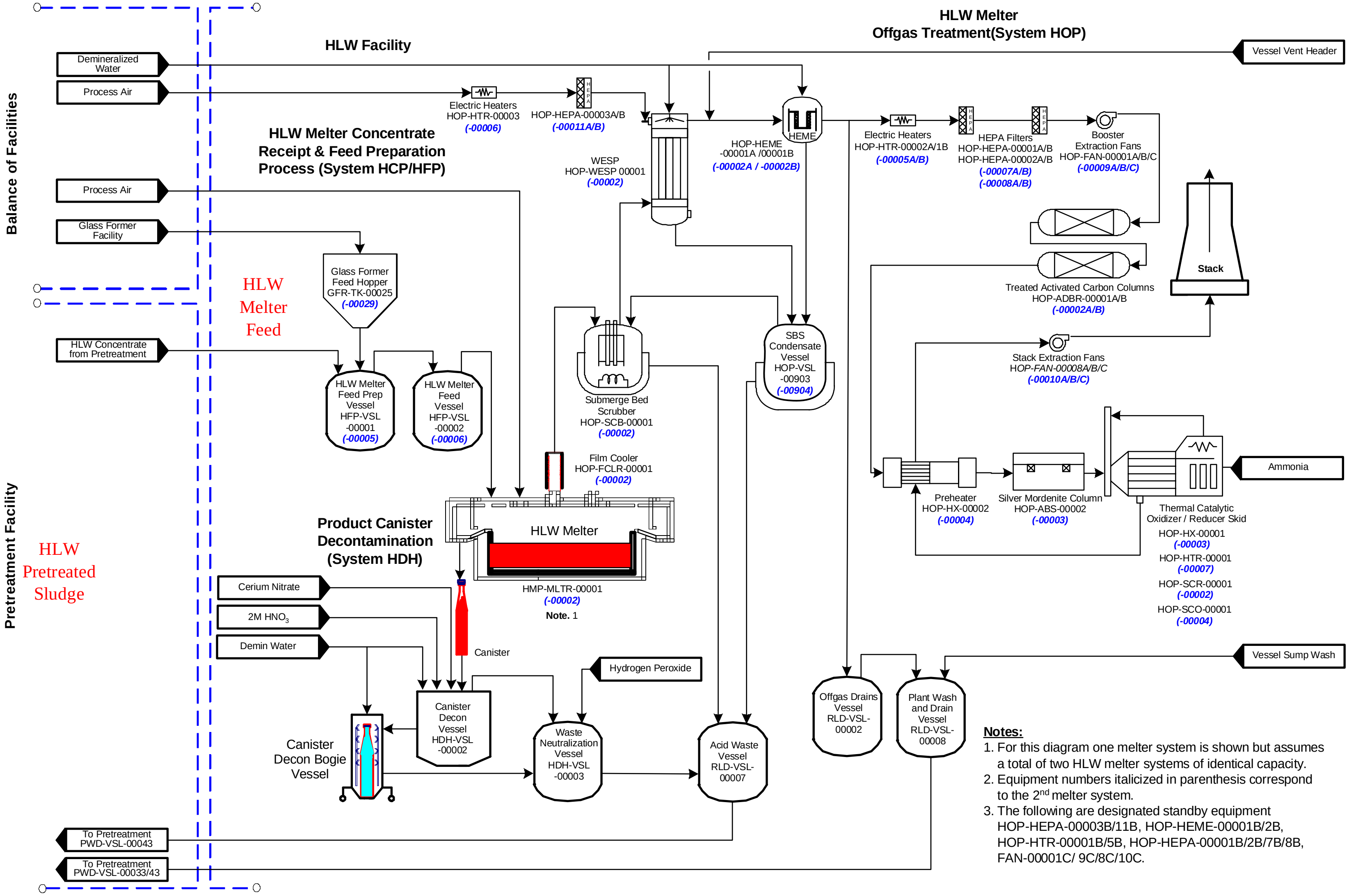


Figure 1.2. Simplified HLW Vitrification Process Diagram

Table 1.1. Glass-Former Chemicals and Minerals

No.	Oxide Added:	Mineral	Grade	Company
1	Al_2O_3	Kyanite Al_2O_3-SiO_2	Raw -325	Kyanite Mining Corp Ddillwyn, VA, 23936 www.kyanite.com
	Alternate	Alumina Al_2O_3	A-2 <325M	Alcoa Alumina Bauxite, AK 72011 www.alunina.alcoa.com
2	B_2O_3	Boric Acid H_3BO_3	Technical Grade-Granular	U.S. Borax Valencia, CA 91355-1847 www.borax.com
3	Na_2O/B_2O_3	10M Borax $Na_2B_4O_7$-$10H_2O$	Technical 10Mole Borax	U.S. Borax Valencia, CA 91355-1847 www.borax.com
4	Na_2O	Na_2CO_3 Anhydrous	Dense Soda Ash	Solvay Minerals Houston TX www.solvayminerals.com
5	CaO	Wollastonite $CaSiO_3$	NYADM325 NWest Mexico	NYCO Wilsboro, NY www.nycominerals.com
6	Fe_2O_3	Fe_2O_3	Fe_2O_3 5001	Prince Mfg. Co. Quincey IL 62306 www.princemfg.com
7	Li_2O	Li_2CO_3	Technical Grade	Chemettal-Foote Kings Mt NC www.chemetalllithium.com
8	MgO	Olivine	#180 Hamilton, WA	Unimin Corp qualityceramics@unimin.com
9	SiO_2	SiO_2	SCS-75 Mill Creek OK	U.S. Silica Berkeley Springs WV www.u-s-silica.com
10	TiO_2	Rutile (Air floated) TiO_2/Fe_2O_3	Air Float Rutile 94 Phil. PA	Chemalloy Co. Bryn Mawr, PA www.chemalloy.com
11	ZnO	ZnO	Kadox 920 Camden, NJ	Zinc Corp Amer. Monaca, PA horseheadinc.com
12	ZrO_2	$ZrSiO_4$	Zircon Flour	Amer. Miner. Inc. Monaca, PA 19406 www.americanminerals.net
13	C	Sugar	Granular Portland OR	Amalgamated Sugar Co. Ogden, UT www.gfhandle/industry

the Melter Feed Vessel (MFV) and then fed to the melter. The remainder of the flowsheet consists of unit operations dedicated to treatment of the melter-generated offgas stream.

The objective of this document is to develop a set of bounding physical and rheological properties for waste materials that can be reasonably processed and that likely will be encountered in the WTP HLW Vitrification Facility. To determine the physical and rheological bounding conditions for each unit operation, one must understand what general waste properties are anticipated and how changes in these properties impact process operation. The process boundaries are then established at the point where the properties of the material introduce unacceptable risk to plant performance. Hence, this set of bounding physical and rheological properties can be used to determine if a given pretreated waste or melter feed will cause processing problems by forcing the system to operate outside its design capabilities. The technical basis for these processing boundaries is established in this document.

2.0 Dimensional Analysis as a Basis for Vitrification Stream Bounding Conditions

The correlations used in the calculation of the bounding physical and rheological conditions are based on dimensionless numbers and dimensional analysis. Given the complexity of the problem and the multiple scenarios where problems arise, dimensional analysis is the only feasible method of determining realistic bounding conditions for the WTP. This section provides the foundation for the determination of the bounding conditions.

In this work, a two-phased approach has been taken. The first phase involved creating a list of physical properties that are believed to have a role in the process flowsheet. The physical-property bounding conditions can be established by simply compiling the actual waste physical-property data into a range of values that account for all the previously measured values. This approach has the advantage of requiring a minimal amount of process-engineering knowledge. However, not considering the engineering knowledge of the flowsheet may lead to a set of bounding conditions that cannot be efficiently processed.

The second phase in developing physical-property bounding conditions involved examining performance correlations for the unit operations described in the process flowsheet. With these correlations, a list of significant physical properties can be developed. The effect on the performance of the equipment by varying the physical properties can be examined with these correlations. These correlations can be used to find limits on the physical properties where equipment performance may drop to unacceptable levels.

The intersection of actual waste measurements (first phase) and bounding conditions based on performance criteria (second phase) was evaluated to establish a set of overall bounding conditions. When engineering design information is needed, Hanford Waste Vitrification Plant (HWVP) and Defense Waste Processing Facility (DWPF) engineering data was used to eliminate conflict with ongoing WTP design efforts.

To begin this process, the unit operations described in the flowsheet needed to be established. The simplified process flowsheet discussed in Section 1.0 consists of several unit operations that involve the following processes:

- fluid flow
  - piping
  - pumps
- fluid mixing
  - mechanical agitators
  - pulse jet mixers (PJMs) with sparging
- vitrification.

In addition, there are several unit operations that precede the vitrification streams that have a direct impact on the physical properties of the vitrification streams. Such unit operations cannot typically be designed completely by theoretical or mathematical methods. One method of attacking a problem for which no mathematical equation can be derived is with empirical correlations. For example, the pressure loss from friction of a Newtonian fluid in a long, round, straight, smooth pipe depends on the following variables:

1. length of the pipe
2. diameter of the pipe
3. flow rate of the liquid
4. density of the liquid
5. viscosity of the liquid.

If one of these variables is changed, the pressure drop also changes. Empirically obtaining an equation relating these factors to pressure drop requires that the effect of each separate variable be determined by systematically varying a single variable while keeping all others constant. The procedure is laborious, and it is difficult to correlate the results obtained into a useful relationship for calculations.

To overcome these difficulties, a method has been developed that is a combination of mathematical and empirical concepts. It is based on the fact that if a theoretical equation does exist among the variables affecting a physical process, that equation must be dimensionally homogeneous (i.e., dimensionless). Therefore, it is possible to group many factors into a smaller number of dimensionless groups of variables. The groups themselves rather than the separate factors appear in the final empirical correlation.

Such dimensional analysis does not yield a numerical equation, and experimentation is usually required to find the correlation between the dimensionless groups. These correlations result in a valuable way for making experimental data suitable for engineering use.

Several dimensionless groups related to fluid flow, heat, and mass transfer are shown in Table 2.1. Note that the terms are also defined in Table 2.1. In designing equipment for these operations, the following correlations (and others) can be found:

- fluid flow
  - $f = \Phi(N_{Re})$
- fluid mixing
  - $N_{Po} = \Phi(N_{Re})$
  - $C_d = \Phi(N_{Re})$
- heat transfer
  - $N_{Nu} = \Phi(N_{Re}, N_{Pr})$
- mass transfer
  - $N_{Sh} = \Phi(N_{Re}, N_{Sc})$.

Table 2.1. Examples of Dimensionless Groups Significant in Fluid Flow, Heat, and Mass Transfer

Name	Symbol	Formula	Special Nomenclature	Proportional to	Where Used
Bingham Number	N_{Bm}	$\tau_y g_c L/KV$	L = characteristic dimension K = consistency index τ_y = Yield Stress V = velocity g_c = gravitational conversion – lbs mass to lbs force	$\frac{\text{Yield Stress}}{\text{Viscous Stress}}$	Flow of Bingham Plastics
Drag Coefficient	C_d	$(\rho-\rho')Lg/\rho V$	ρ = density of object ρ' = density of fluid L = characteristic dimension of object V = velocity g = gravitational accel.	$\frac{\text{Gravitational Force}}{\text{Inertial Force}}$	Free Settling Velocities
Fanning Friction Factor	f	$g_c D(\Delta p_F/\rho)/2V^2L$	$\Delta p_F/\rho$ = friction head D = characteristic diameter of cross section L = length of pipe	Shear Stress at Pipe Wall Expressed as Number of Velocity Heads	Fluid Friction in Conduits
Nusselt Number	N_{Nu}	hL/λ	h = heat transfer coefficient λ = thermal conductivity L = characteristic dimension	$\frac{\text{Characterisitic Length}}{\text{Theorectical Film Thickness}}$	Heat Transfer in Flowing Systems
Power Number	N_{Po}	$Pg_c/L^5\rho n^3$	P = power to agitator L = characteristic dimension of agitator paddle n = rate of rotation	$\frac{\text{Drag Force on Paddle}}{\text{Inertial Force}}$	Power Consumption on Agitated Vessels
Prandtl Number	N_{Pr}	$C_p\mu/\lambda$	C_p = Specific Heat Capacity λ = thermal conductivity	$\frac{\text{Momentum diffusivity}}{\text{Thermal diffusivity}}$	Heat Transfer in Flowing Systems
Reynolds Number	N_{Re}	$LV\rho/\mu$	L = characteristic dimension of the system	$\frac{\text{Inertial Force}}{\text{Viscous Force}}$	Dynamic Similarity
Schmidt Number	N_{Sc}	$\mu/\rho D_{AB}$	D_{AB} = Binary Diffusion Coefficient	$\frac{\text{Momentum diffusivity}}{\text{Mass diffusivity}}$	Mass Transfer in Flowing Systems
Sherwood Number	N_{Sh}	$h_m L/D_{AB}$	h_m = mass transfer coefficient D_{AB} = Binary Diffusion Coefficient	Dimensionless concentration gradient at the surface	Mass Transfer in Flowing Systems

Compiling the parameters that appear in these dimensional groups will provide a list of significant physical properties for this system. Yield stress and viscosity indicate that rheological parameters are significant to these process operations. Parameters such as particle density, bulk density, particle diameter, fluid velocities, and characteristic lengths of processing equipment are also significant to the performance of the equipment. Additionally, operating temperatures, pressures, flow rates, and the concentration of solid particles and chemical species are important in the partial differential equations relevant to fluid flow, heat, and mass-transfer operations. Such partial differential equations include the continuity, momentum, energy, and conservation of mass equations.

A guideline (Smith and Prindiville 2002) has been developed by the RPP-WTP project with the purpose of measuring the parameters significant to simulant development and verification. The properties identified in the guideline document can be found in Table 2.2. One purpose of this report is to compile historical parametric data in Table 2.2 on simulants and actual wastes which will be used to develop physical-properties bounding conditions using many of the dimensionless groups shown in Table 2.1. This compilation of data will be the focus of the next section.

Table 2.2. Physical Properties Considered in Smith and Prindiville (2002) for HLW Pretreated Sludge and Melter Feed

Property	HLW Pretreated Waste	HLW Melter Feed
Chemical Composition	X	X
pH[(a)]	X	X
Particle Size Distribution (PSD)	X	X
Particle (size, shape, and density)	*[(b)]	*
Heat Capacity	*	*
Bulk Density	X	X
Supernatant Liquid Density	X	X
Vol% Settled Solids	X	X
Settling Rate	X	X
Centrifuged Solids Density	X	X
Vol% Centrifuged Solids	X	X
Wt% Centrifuged Solids	X	X
Wt% Oven Dried Solids	*	*
Wt% Total Dried Solids	X	X
Wt% Undissolved Solids	X	X
Shear Stress Versus Shear Rate ambient and 40°C or 50°C	X	X
Shear Strength	X	X
Wt% total oxide	X	X

(a) Only aqueous material below pH 14 will be quantified and reported.
(b) * indicates that this data was not considered to have as high a priority.

3.0 Summary Review of RPP-WTP Project Reports on Actual and Simulated HLW Pretreated Wastes and Melter Feeds

The purpose of Section 3.1 is to briefly review for the reader the relationship between the terms "yield stress" and "shear strength," which are used in Section 3.2 and are taken from Poloski et al. (2004).

In Section 3.2, actual pretreated waste and melter feed characterization data produced by PNWD and SRNL are reviewed in the form of an annotated bibliography summarizing the work considered in this document for samples of actual Hanford tank HLW that were processed through laboratory-scale unit operations. The sources of this data are indicated in Table 3.1. At various stages of laboratory-scale processing, the samples were characterized for multiple properties, including rheological and physical properties. The table indicates the project reports where the detailed information can be found. Global results from these studies have been compiled in Appendices A and B.

In Section 3.3, the kinds of simulated pretreated HLW waste and melter feed characterization data produced by PNWD, SRNL, and VSL are briefly summarized. These data are compiled in Appendices A and B. Other sources of physical simulants are also indicated in Section 3.3 for completeness.

Table 3.1. Documents Reporting Physical and Rheological Measurements of Hanford HLW Pretreated Sludge and Corresponding Melter Feeds

Tank (Envelope)	Actual Waste Data References
AZ-101 (D)	PNWD (WTP-RPT-096, Rev. 0 [Poloski et al. 2003a]) (24590-101-TSA-W000-0004-144-01, Rev. 00B)
AZ-102 (D)	PNWD (WTP-RPT-004 [Bredt et al. 2001] PNNL 13359, PNWD-11025)
C-104 (D)	PNWD (WTP-RPT-004 [Bredt et al. 2001] PNNL 13359, PNWD-11025)
AY102/C106(D)	WSRC-TR-2004-00394, Rev. 0, SRT-RPP-2004-00061, Rev. 0, (Hansen and Crawford 2005) (WTP Project No. SCT-M0SRLE60-00-193-00004 Rev. 00A) (For Information Only)

3.1 Brief Rheological Relationship Review

Steffe (1996) explains that many methods have been developed to evaluate yield stress. These methods produce varying results based on the rheological technique and assumptions used in the evaluation. To explain these variations, the concept of static and dynamic yield stress is introduced. The idea behind static and dynamic yield stress can be explained by assuming that there are two structures that present yield stress-exhibiting fluids. One structure is insensitive to shear rate and defines the dynamic yield stress associated with a flow curve. However, a second, weak structure is also present that forms while the fluid is at rest. This structure is sensitive to shear rate and breaks down as the fluid is sheared. Combined, these two stresses define the static yield stress value (see Figure 3.1).

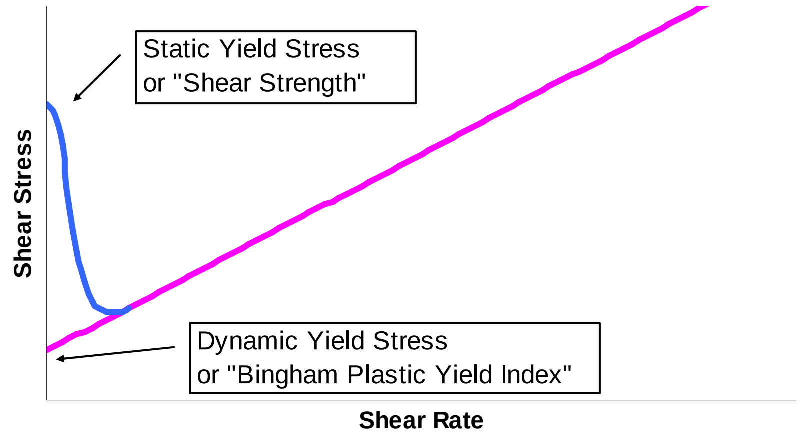


Figure 3.1. Rheogram Illustrating the Concept of Dynamic and Static Yield Stress

The use of static and dynamic yield stress values varies with application. For instance, the dynamic yield stress value extrapolated from a rheogram should be used when performing laminar pipeline head-loss calculations. The static yield stress should be used for process restart applications where the second structure could form while the fluid is at rest. In general, there is no established relationship between the two parameters. Because static yield stress is a cumulative function, the value is always greater than or equal to the dynamic value. The WTP-adopted convention is to refer to the static yield stress as "shear strength." In this report, shear strength is defined by the transition between viscoelastic and fully viscous flow, τ_s. The dynamic yield stress is often referred to as yield stress or yield index. Another term used is "consistency," which can be thought of as the limit of apparent viscosity as shear rate approaches infinity. Apparent viscosity is the shear stress divided by the shear rate the non-Newtonian fluid is experiencing. Other rheology concepts are discussed in Appendix D

3.2 Annotated Bibliography for Envelope-D Process Streams

PNWD (Bredt et al. 2001) conducted rheological and physical-properties testing on actual AZ-102 (Envelope D) and C-104 (Envelope D) pretreated waste samples before adding glass formers and secondary waste products. Analyses were repeated on the C-104 samples after adding simulated Sr/TRU secondary waste. Analyses were repeated again after GFCs were added to both AZ-102 and C-104 samples. The results obtained from these analyses are summarized below:

- The rheology of the AZ-102 and C-104 pretreated wastes was measured at 5-, 15-, 20-, and 25-wt% UDS.
  - The initial 5- and 15-wt% UDS of the C-104 pretreated waste displayed near Newtonian behavior, and the 25-wt% UDS had a small yield stress of ~5 Pa, giving it a slight Bingham plastic behavior.
  - The AZ-102 pretreated waste showed much higher initial consistencies of 12, 530, 900, and 4600 cP for the 5-, 15-, 20-, and 25-wt% UDS.
  - In addition, the AZ-102 pretreated wastes displayed significant hysteresis (non-Newtonian behavior).

- No significant temperature effects on rheological properties were observed for the C-104 or AZ-102 samples measured at 25 and 50°C.

- A mixing and aging study was conducted on the 15-wt% UDS(waste) AZ-102 and 25-wt% UDS(waste) C-104 melter feeds.

  - The yield stress and consistency of the AZ-102 HLW melter feed decreased over a 1-week mixing period during this mixing/aging study.
  - The C-104 HLW melter feed yield stress increased from 28 Pa after 1 hour of mixing to 56 Pa after 1 week of mixing.
  - Over this same time period, the Bingham consistency of the C-104 HLW melter feed increased from 910 cP to 1700 cP at a shear rate of 33 s^{-1}.

- Following the mixing study, the 15-wt% UDS(waste) AZ-102 and 25-wt% UDS(waste) C-104 HLW melter feeds were allowed to settle for 1 week.

  - The 15-wt% UDS AZ-102 sample displayed standing liquid whereas the 25-wt% UDS C-104 sample did not.
  - The 15-wt% UDS AZ-102 sample displayed shear thinning behavior while the 25-wt% UDS C-104 sample continued to thicken.

Morrey et al. (1996) compared the rheological properties of AZ-101 and AZ-102 actual wastes to NCAW simulant made up to the same composition chemically and found that the simulant rheological properties exceeded those of the actual waste. The importance of Morrey et al.'s work was that it compared a carefully made simulant with the actual waste that the simulant was made up to mimic. Brooks et al. (2000a) present work on actual AZ-102 sludge properties before and after it had been through the prescribed pretreatment process.

PNWD (Poloski et al. 2003a) conducted rheological and physical-properties testing on actual AZ-101 (Envelope D) pretreated waste samples before adding glass formers and secondary waste products. A sample of AZ-101 HLW pretreated sludge was received at an initial UDS concentration of 10.3 wt%. The 10.3-wt% UDS sample was concentrated to 22-wt% UDS by decanting the supernate.

The AZ-101 22-wt% UDS sample was diluted to 10- and 15-wt% UDS concentrations so its rheological properties could be studied over a range of UDS concentrations. The results from the testing of the AZ-101 HLW pretreated sludge at 10-, 15-, and 22-wt% UDS concentrations are listed in Table 3.2 and summarized below:

- Flow curves from these samples indicate that the fluid should be characterized as a Bingham-plastic fluid.

  - The maximum measured rheological parameters occurring at 22-wt% UDS were a Bingham consistency of 11 cP and Bingham yield stress of 11 Pa at 25°C.
  - At 40°C, the Bingham-plastic parameters of the 22-wt% UDS pretreated sludge were a Bingham consistency of 7 cP and Bingham yield stress of 10 Pa.
  - The pH of the 22-wt% UDS sample was determined to be 12.1.

- The shear strength behavior of the 22-wt% UDS AZ-101 HLW pretreated sludge sample was determined by agitating (i.e., stirring) the sample and allowing it to sit undisturbed for various periods of time (the periods are also known as "gel time") between measurements.
  - The shear strength appeared to stabilize after approximately 16 hours at approximately 30 Pa.
- GFCs were mixed with an AZ-101 22-wt% UDS HLW pretreated sludge sample to make a melter feed. The melter feed was continuously mixed, and the rheology and pH of the sample were measured at intervals of 1 hour, 1 day, and 1 week.
  - When GFCs were added to the AZ-101 pretreated HLW, the pH of the solution dropped from 12.1 to a range of 9.9 to 10.4. This is most likely because of the relatively large quantity of soluble carbonate species in the melter-feed formulation used for this test.
  - At 10-wt% UDS (waste solids), the AZ-101 HLW melter feed still exhibited Bingham-plastic rheological behavior.

SRNL (Hansen and Crawford 2005) has characterized a sample of AY102/C106 HLW sludge. However, the results were not included in this report because the weight percent solids data for the AY102/C106 HLW sludge were found to be wrong and the resulting melter feed compositions were outside of the envelope of desirable glass batch make-up compositions and therefore were not relevant. Note that because the previous sludge weight percent solids measurements were performed on two different samples which gave different weight percent solids and it is not known if one or both were incorrect, a meaningful back calculation is not possible.

Table 3.2. Summary of AZ-101 Pretreated HLW and Melter Feed Physical and Rheological Property Measurements

Physical Property (unless otherwise noted, data presented are for HLW Melter Feed)	Units	10-wt% UDS[(a)]	15-wt% UDS	22-wt% UDS	22-wt% UDS	22-wt% UDS
Mixing Duration		**1 Hour**	**1 Hour**	**1 Hour**	**1 Day**	**1 Week**
pH (top: melter feed; bottom: pretreated sludge)		10.0 n/a[(b)]	9.9 n/a	10.3 12.1[(c)]	10.3 n/a	10.4 n/a
Bingham Consistency at 25ºC (top: melter feed; bottom: pretreated sludge)	cP	4.1 <10	10.7 5.2	21 10.5[(c)]	9.9 n/a	10.6 21.78[(d)]
Bingham Yield Stress at 25ºC (top: melter feed; bottom: pretreated sludge)	Pa	1.8 0	3.4 2.9	14.7 11.4[(c)]	5.1 n/a	3.6 12.59[(d)]
Bingham Consistency at 40ºC (top: melter feed; bottom: pretreated sludge)	cP	3.8 <10	7.6 3.5	19.3 7.2[(c)]	9.3 n/a	9.0 15.14[(d)]
Bingham Yield Stress at 40ºC (top: melter feed; bottom: pretreated sludge)	Pa	1.9 0	4.9 2.8	18.1 10.3[(c)]	4.7 n/a	4.8 11.77[(d)]
Shear Strength (top: melter feed; bottom: pretreated sludge)	Pa	n/a n/a	n/a n/a	55 31	n/a n/a	23 n/a
Bulk Density	g/mL	1.183 ± 0.082	1.331 ± 0.092	1.506 ± 0.104	n/a	1.402 ± 0.010
vol% Settled Solids	%	55.3% ± 5.5%	76.9% ± 7.6%	96.2% ± 9.5%	n/a	88.9% ± 0.0%
Density of Centrifuged Solids	g/mL	1.370 ± 0.171	1.625 ± 0.202	1.676 ± 0.209	n/a	1.577 ± 0.017
vol% Centrifuged Solids	%	32.5% ± 2.3%	46.0% ± 3.2%	70.5% ± 5.0%	n/a	58.1% ± 0.7%
wt% Centrifuged Solids	%	37.6% ± 3.2%	56.2% ± 4.8%	78.4% ± 6.7%	n/a	65.3% ± 1.0%
Supernatant Density	g/mL	1.063 ± 0.003	1.110 ± 0.003	1.177 ± 0.004	n/a	1.087 ± 0.014
Density of Settled Solids	g/mL	1.28 ± 0.09	1.39 ± 0.10	1.50 ± 0.11	n/a	1.42 ± 0.03
wt% Settled Supernatant	%	62.4% ± 16.3%	43.9% ± 11.5%	21.9% ± 5.7%	n/a	29.7% ± 9.0%
wt% dissolved solids in supernatant	%	8.0% ± 0.2%	10.3% ± 0.3%	10.3% ± 0.3%	n/a	10.5% ± 0.9%
wt% total solids in Centrifuged Sludge	%	48.0% ± 2.5%	51.1% ± 2.7%	53.5% ± 2.8%	n/a	55.7% ± 0.3%
wt% Total Solids	%	23.3% ± 1.1%	33.6% ± 1.6%	44.5% ± 2.1%	n/a	42.1% ± 3.0%
wt% Undissolved Solids	%	16.4% ± 1.5%	25.6% ± 2.4%	37.8% ± 3.5%	n/a	33.0% ± 0.6%

(a) UDS refers only to wt% waste solids in the actual waste slurry component of feed; (b) not measured; (c) pretreated sludge at 22-wt% UDS; (d) melter-feed settled solids.

3.3 Waste, Melter Feeds, and Purely Physical Simulants

This section presents most of the pertinent recent references covering the types and applications of HLW pretreated slurry and melter feed simulants. The data obtained using the chemically similar simulants (as opposed to strictly physical simulants, i.e., PJM simulants) are also included in Appendix A and provide a basis of comparison between the actual wastes and melter feeds and their simulants. The PJM physical simulants are important in that they are environmentally benign in contrast to the "chemically correct" simulants given in Appendix A and can provide important rheological information. Also, a significant amount of older waste treatment studies data have not been included here that originated from the DWPF, HWVP, and West Valley Projects and some even older data originating from simulant work performed at PNWD for the purposes of waste treatment and melter design. Some of these data sources were not completely investigated for this report because of programmatic limitations.

SRNL and VSL have performed extensive studies on simulated wastes and melter feeds modeled after actual wastes. These results are also included in the Appendix A database along with the results for actual pretreated HLW and HLW melter feed. Note also that Appendices B (Physical Property Correlations) and C (Expected HLW Behavior During Pretreatment) are omnibus data comparisons. These appendices each have a reference section that includes references pertaining just to the subject matter of that appendix.

SRNL has focused on developing chemically accurate waste simulants based on measured waste compositions and knowledge of the waste components plus carbon steel passivating agents that were placed in the tanks at Hanford. Reports by Eibling and Nash (2001), Eibling et al. (2003), Hansen and Eibling (2001), and Zamecnik et al. (2004) relate to the fabrication and the rheological and physical properties of chemically accurate waste simulants. Reports by Hansen et al. (2001), Hansen and Schumacher (2003), Hansen and Crawford (2005), Hansen and Williams (2005), Rosencrance et al. (2000), Stone et al. (2003), and Crowder et al. (2004)[a] deal with simulant physical characterization issues with and without glass formers. Duignan et al. (2005)[b] cover the Semi-Integrated Pilot Plant (SIPP) work at SRNL and provide physical property and rheological property data on the simulants used.

VSL has focused on compositionally accurate simulants and melter feeds for supporting various melter tests. Kot et al. (2000) is a good source for the physical and rheological properties of these simulants. Reports by Kot and Pegg (2001) and Kot et al. (2003) provide additional physical and rheological property information. Reports by Matlack et al. (2000a,b,c; 2002a,b; 2003a,b,c,d,e; 2004a,b; 2005)[c] characterize melter feeds used for melter tests.

(a) ML Crowder, EK Hansen, CL Crawford, WE Daniel, Jr., RF Schumacher, PR Burket, and JL Siler. 2004. *Evaporation, Rheology, and Vitrification of a Radioactive Hanford Tank AN-104 Sample Mixed with Recycle.* WSRC-TR-2004-00232, Draft A, SRNL-RPP-2004-00044, Draft A. Westinghouse Savannah River Company, Aiken, SC.

(b) MR Duignan, DJ Adamson, TB Calloway, MD Fowley, ZH Qureshi, JL Steimke, MR Williams, and JR Zamecnik, SRNL. 2005. *Final Report: RPP-WTP Semi-Integrated Pilot Plant.* WSRC-TR-2005-00105, DRAFT B. Westinghouse Savannah River Company, Aiken, SC.

(c) KS Matlack, W Gong, and IL Pegg. 2005. *DuraMelter 100 HLW Simulation Validation Tests with C-106/AY-102 Feeds.* VSL-05R5710-1, Rev. A, Vitreous State Laboratory, The Catholic University of America, Washington, DC.

Additional physical simulant data were generated for the PJM Project sponsored by Bechtel National, Inc. (BNI) and performed by PNWD. For this work, Laponite (a weak silica gel) and a Kaolin-Bentonite clay mixture (80% Kaolin and 20% Bentonite slurry with water) were the principal physical simulants used. These physical simulants were well characterized rheologically over a range of concentrations. Reports giving potentially useful information on these physical waste simulants include Bamberger et al. (2005), Bontha et al. (2000), Enderlin et al. (2003), Poloski et al. (2004, 2005), and Russell et al. (2005).

3.4 Database Summary

Limited data have been acquired on actual wastes, both because of the limited number of tanks sampled and limited quantities of sample available for physical-property characterization. Thus far, only small quantities of three pretreated actual tank wastes have been prepared as melter feeds (AZ-101, AZ-102, and C-104). Data from the reports shown in Table 3.1 have been compiled into a database. This database was designed to present the data in a form compliant with the guideline reporting formation developed by Smith and Prindiville (2002). This database can be found in Appendix A. Additional information from these reports can be found in Appendix B. A high-level summary of the data compiled in Appendices A and B is shown in Tables 3.2 and 3.3.

Table 3.3. Summary of Appendix A Database

Property	HLW Pretreated Waste	HLW Melter Feed
Chemical Composition	varies (see Appendix A)	varies (see Appendix A)
pH	~12[(a)]	7–12[(b)]
PSD[(c)]	<50 μm	<105 μm
Heat Capacity	n/a	n/a
Bulk Density	1.1–1.2	1.1–1.5
Supernatant Liquid Density	~1.0	~1.0
Vol% Settled Solids[(c)]	10%–90%	20%–90%
Settling Rate	n/a	n/a
Centrifuged Solids Density	n/a	n/a
Vol% Centrifuged Solids	n/a	n/a
Wt% Centrifuged Solids	n/a	n/a
Wt% Oven Dried Solids	n/a	n/a
Wt% Total Dried Solids	5%–36%	10%–61%
Wt% Undissolved Solids	6%–35%	38%–54%
Shear Stress Versus Shear Rate ambient and 40°C	Newtonian or Bingham Plastic	Bingham Plastic
Shear Strength	n/a	n/a
Wt% total oxide	7%–15%	25%–40%

n/a not available
(a) expected pH after washing in 0.01 M NaOH
(b) expected pH after boric acid GFC addition
(c) See Appendix B

4.0 Discussion

The purpose of this section is to establish bounding conditions for the data discussed in the previous section and compiled in the database shown as Appendix A. Individual unit operations are examined in an effort to identify parameters significant to plant performance. Bounds are established on these parameters in an effort to verify successful processing of the simulant material during pilot testing. Actual waste data are used to tailor the bounding ranges such that the proposed bounding conditions span the existing actual waste materials at concentrations proposed for use in the WTP. In this regard, the proposed bounding conditions are based upon a general engineering evaluation of process equipment and measured values from actual waste material. When needed, equipment design specifications from the HWVP and DWPF are used. These bounding conditions are evaluated against the data presented in Appendix A. Conclusions and recommendations based on this critical review are documented.

4.1 Development of Bounding Conditions

The strategy employed to establish bounding conditions is to identify correlations between dimensionless groups for specific unit operations performed in the WTP flowsheet. As the WTP will be using standard chemical processing equipment in a lot of their various unit operations, e.g. piping, pumps, and mechanical agitators, correlations for similar equipment that have been developed for standard chemical processing applications are used in this document to help develop correlations relevant to the WTP. Sources for these correlations include Perry's Chemical Engineers Handbook (Perry and Green 1984), various engineering textbooks, and peer-reviewed journal articles. In addition, equipment data and calculations for previous vitrification-plant designs may be used when available. These previous designs include the HWVP and the DWPF. The use of these data and correlations assumes that the equipment selected for use in the WTP will possess similar performance properties to equipment generally used in the chemical processing industry, HWVP, and DWPF. Typically, based on these correlations, engineering judgment determines the overarching percentage variation that can be allowed in a given dimensionless group, e.g., drag coefficient, based on its effect on the unit-operation performance. NOTE: A concise rheology tutorial can be found in Appendix D

4.1.1 Mechanical Mixing (Low-Shear-Rate Viscosity)

Based on the HWVP and DWPF designs, mixing operations considered in this section consist of mechanical agitators in mixing vessels. The WTP design employs mechanical agitators in the MFPV and MFV that will initially contain HLW pretreated sludge (MFPV) and then melter feed (MFPV and MFV). The WTP design employs pulsed jet mixers (PJM) and spargers in the HLW Lag Storage (HLP-VSL-00027A/B), and HLW Blend (HLP-VSL-00028) vessels, which are designed to mix and transfer HLW pretreated sludge. However, as no PJM-specific correlations were initially available for mixing of non-Newtonian slurries, WTP used the set of bounding physical and rheological properties for waste materials presented in the original interim version of this report (Poloski et al. 2003b)[a] as the starting point to

(a) Poloski A, O Bredt, B Calloway, G Smith, and H Smith. 2003b. *Interim Report - Technical Basis for HLW Vitrification Stream Physical and Rheological Property Bounding Conditions*. WTP-RPT-100 Rev. 0, Battelle—Pacific Northwest Division, Richland, WA. (WTP Project Document No. 24590-101-TSA-W000-0004-99-09, Rev. 00D) develop specific PJM correlations. These bounding conditions were used to develop the waste simulants used in the PJM testing program (Poloski et al. 2004). The technical basis for WTP mixing of non-Newtonian fluids using PJMs and scaling was then based on theoretical modeling, dimensional analysis, mixing tests, and scaled prototype testing (Bamberger et al. 2005; Poloski et al. 2005).[a] Dimensional analysis for PJM mixing identified the important dimensionless parameter groups i.e., Strouhal number, yield Reynolds number and the jet Reynolds number.

Consequently, a base assumption in this section is that correlations developed for impeller-based systems can be used for all actual waste efforts. For mechanical-agitator systems, Perry and Green (1984) use dimensional analysis to define an impeller Reynolds number as follows:

$$N_{\mathrm{Re}} = \frac{D_a^2 N \rho}{\mu} \tag{4.1}$$

where N = rotational speed (rev/s)

N_{Re} = impeller Reynolds number

D_a = impeller diameter (m)

ρ = fluid density (kg/m^3)

μ = apparent viscosity (Pa•s).

Using this definition, Perry and Green (1984) describe flow in the tank as turbulent when $N_{Re} > 10{,}000$. When $10 < N_{\mathrm{Re}} < 10{,}000$, the flow is turbulent near the impeller and laminar in remote areas of the vessel. When $N_{\mathrm{Re}} < 10$, the flow is laminar only.

For pseudoplastic and Bingham plastic fluids, Perry and Green (1984) recommend that the following shear rate be used:

$$\dot{\gamma} = 10N \tag{4.2}$$

where $\dot{\gamma}$ is the average shear rate (1/s).

Using a rheogram, the apparent viscosity can be found at this shear rate and used in the impeller Reynolds number equation. Perry and Green (1984) present several correlations between the impeller Reynolds number and the Power number. The Power number (N_{Po}) is defined below.

$$N_{Po} = \frac{P}{\rho N^3 D_a^5} \tag{4.3}$$

where “P” is the motor power (N•m/s).

(a) Meyer PA, DE Kurath, and CW Stewart. 2005. DRAFT: *Overview of the Pulse Jet Mixer Non-Newtonian Scaled Test Program*. WTP-RPT-127 Rev A, Battelle—Pacific Northwest Division, Richland, WA 99352.

Perry and Green (1984) present correlations for several tank geometries. To achieve a homogeneously suspended tank, a turbulent flow regime must be established. As described above, this can occur when $N_{\mathrm{Re}} \geq 10{,}000$. As the power number increases, the power requirement for the mixing motor also increases. Therefore, the correlation that results in efficient mixing was used as a basis for this calculation. At $N_{\mathrm{Re}} = 10{,}000$, a conservative correlation with a given impeller-to-tank diameter ratio, impeller pitch, and number of tank baffles produces $N_{Po} = 0.3$.[a] According to DWPF design specifications (Jones and Peterson 1996), a 100-hp motor with an impeller diameter of 36 in. would be used for homogenization purposes. A value for the bulk density of the fluid is also assumed to be at 1.2 g/mL. Using these parameters, the calculation presented in Figure 4.1 can be performed.

(a) See Perry and Green (1984), Curve 5, Figure 19-13, pg 19-10.

Motor Power: Impeller Diameter: Fluid Density:

$P := 100\ \mathrm{hp}$ $D_a := 36\ \mathrm{in}$ $\rho := 1.2\,\frac{\mathrm{kg}}{\mathrm{L}}$

Turbulent Impeller Reynolds Number: Power Numbe

$N_{Re} := 10000$ $N_{Po} := 0.3$

$$N := \left(\frac{P}{\rho \cdot D_a^{5} \cdot N_{Po}}\right)^{\frac{1}{3}}$$

Rotation Rate of Impeller at 100 hp (rpm)

$N = 412.108 \circ \frac{1}{\mathrm{min}}$

Apparent Viscosity Calculation:

$$\mu := \frac{D_a^{2} \cdot N \cdot \rho}{N_{Re}}$$

$\mu = 0.689 \circ \mathrm{Pa} \cdot \mathrm{s}$

Shear Rate Calculation:

$\gamma := 10 \cdot N$

$\gamma = 68.685 \bullet \mathrm{s}^{-1}$

Figure 4.1. Calculation of Maximum Viscosity for Mixing Operations. Note that a colon before the equal sign means that the equation or value was input, while no colon indicates that the value following the equal sign was the results of the calculation.

The calculation performed in Figure 4.1 indicates that a maximum apparent viscosity of approximately 700 cP at a shear rate of approximately 70 s^{-1} bounds the mixing-operation performance. Based on HWVP and DWPF design specifications and a conservatively low Power number assumption, fluids with an apparent viscosity greater than this value will most likely not result in a homogeneous mixture during mixing operations. This assumes a Bingham plastic media.

4.1.2 Mixing Operations (Maximum Settled-Solids Shear Strength)

The slurries that will be processed through the WTP will typically possess a shear strength. The following calculation assumes a startup scenario involving the impeller being immersed in an undisturbed shear strength slurry. This situation could potentially occur during plant-upset conditions when various systems need to be taken off-line for a period of time, and suspended slurries settle in mixing tanks.

The rheological properties of both HLW sludge and melter feed actual wastes have been measured after settling/standing for 7 days (168 hours) to provide data in relation to understanding mixing and transfer processes following a plant upset condition and the need to restart processing. WTP reliability, availability, and maintainability data for the HLW lag storage and feed blending process system[a] for pretreated waste and for the HLW melter feed process system[b] for melter feed were input to the Operations Research Model (OR) from model run request number MRQ-05-007[c] to determine the mean time to repair (MTTR) in hours for important valves, pumps, and agitators.

The associated valves for the HLW lag storage and feed blending process system have an MTTR of 72 hours. This system contains the HLW lag storage (HLP-VSL-00027A/B) and HLW blend (HLW-VSL-00028) vessels that are designed to mix and transfer HLW pretreated sludge. The transfer pumps have an MTTR of 88 hours for the first two pump repairs with the MTTR increasing to 348 hours for the third pump repair.

The associated agitators for the HLW melter feed process system have an MTTR of 72 hours. This system contains the HLW melter feed preparation (HFP-VSL-00001/5) and HLW melter feed vessels (HFP-VSL-00002/6) that are designed to mix and transfer HLW melter feed. The associated agitators have an MTTR of 72 hours, and the transfer pumps have a MTTR of 156 hours.

Thus, the choice of testing the rheological properties of both HLW pretreated sludge and melter feed actual wastes after settling/standing for 7 days (168 hours) bounds most of the repair estimates except for the third pump repair in the HLP system.

The impeller dimensions defined above and a conservative estimate of a starting torque for the mixing motor of 400 Nm (295 ft·lb) are assumed in this calculation. The equation used for shear-vane calculations (Smith and Prindiville 2002) can be applied to calculate the shear strength of the fluid at the starting torque. The calculation with this equation is performed in Figure 4.2. Based on this calculation, the maximum shear-strength value before the mixing motor stalls appears to be 625 Pa. Figure 4.3 shows this calculation for various impeller diameters.

(a) WTP Project Report 24590-HLW-RPT-PO-05-0001, Rev. 0 "HLW Reliability, Availability, and Maintainability Data Development Report" June 8, 2005.
(b) WTP Project Report 24590-PTF-RPT-PO-05-0001, Rev. 0 "PTF Reliability, Availability, and Maintainability Data Development Report" June 8, 2005.
(c) WTP Project Report 24590-WTP-MRQ-PO-05-0007, Rev. 1 "Integrated OR Run for 80/6 MTD - All Failures with Laboratory Included" May 19, 2005.

Impeller Width:

$$W_i := \frac{D_a}{5}$$

$$W_i = 7.2 \cdot in$$

Assumed 100 hp Mixing Motor Starting Torque:

$$T_m := 400\ newton \cdot m$$

$$T_m = 295 \cdot ft \cdot lbf$$

$$\tau_y := \frac{T_m}{\frac{\pi\ D_a^{\ 3}}{2} \cdot \left(\frac{W_i}{D_a} + \frac{1}{3} \right)}$$

$$\tau_y = 624.5 \cdot Pa$$

Figure 4.2. Maximum Shear-Strength Calculation for Restarting an Impeller in a Gelled Waste. See note for Figure 4.1.

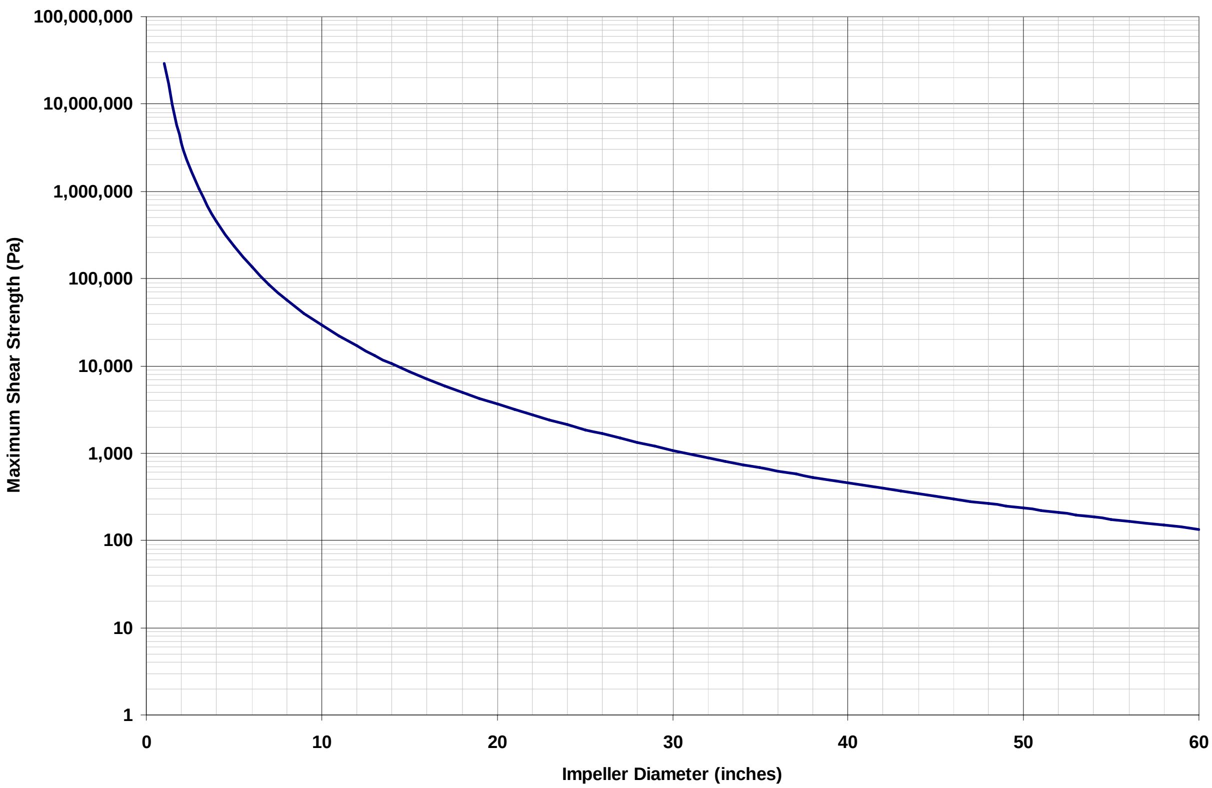


Figure 4.3. Maximum Shear Strength as a Function of Impeller Diameter when Impeller Width is One-Fifth Impeller Diameter, and Mixing Motor Starting Torque is 400 N•m

4.1.3 Mixing Operations (Near Homogeneous Vessel)

Another requirement for mixing operations in the WTP is to achieve a near homogenous slurry. A particle falling under the action of gravity will accelerate until a drag force offsets the gravitational force. At this point, the particle will fall at a constant velocity known as the free-settling velocity. For a spherical particle, the free-settling velocity can be calculated from Equation 4.4:

$$u_t = \sqrt{\frac{4gD_p(\rho_p - \rho)}{3\rho C_d}} \tag{4.4}$$

where u_t = free settling velocity (m/s)
g = acceleration due to gravity (9.81 m/s^2)
D_p = diameter of particle (m)
ρ_p = particle density (kg/m^3)
ρ = fluid density (kg/m^3)
C_d = drag coefficient (dimensionless).

Perry and Green (1984) state that it may be difficult to cause particles with settling velocities above 0.03 m/s (0.1 ft/s) to be suspended uniformly in the top 2 percent of a tank volume. Note that a Newtonian fluid is the worst case scenario in this situation. A relationship between the drag coefficient and the particle Reynolds number exists as shown below:

$$C_d = \Phi(N_{Re}) \tag{4.5}$$

In this case, the particle Reynolds number is defined as follows:

$$N_{\mathrm{Re}} = \frac{D_p u \rho}{\mu} \tag{4.6}$$

where D_p = particle diameter (m)
u = particle speed (m/s)
ρ = fluid density (kg/m^3)
μ = fluid viscosity (Pa•s).

When $0.1 < N_{\mathrm{Re}} < 1000$, the following relationship has been empirically established:

$$C_d = \left(\frac{24}{N_{\mathrm{Re}}}\right)\left(1 + 0.14 \cdot N_{\mathrm{Re}}^{0.70}\right) \tag{4.7}$$

In this calculation, the particle size of the tank waste is assumed to be smaller than the GFCs (see Appendix B). From Table 4.1, rutile appears to be the insoluble melter GFC with the largest particle size. The product data sheet for the "Rutile 94" product from Chemalloy guarantees that 100% of the powder will pass through an 80-mesh sieve (177 μm). However, a sieve analysis of a batch of the "Rutile 94" product shows the first significant amount of material passing through a 140-mesh sieve (105 μm) and collecting in a 200-mesh sieve (74 μm). For the purpose of this analysis, 105 μm is the maximum assumed particle size in the WTP facility. Since particle size dominates particle density in the settling-rate calculation, the properties of the largest diameter material (rutile) should be used for the settling-rate calculations. In this case, the maximum expected particle density would be approximately 4.25 g/mL.

Based on the relationship shown above, a calculation can be performed to find the minimum fluid viscosity required for a 0.03 m/s settling velocity for a spherical particle with a diameter of 105 μm and a particle density of 4.25 g/mL. The resulting fluid viscosity can be found in the calculation shown in Figure 4.4. Note that an equivalent calculation can be performed without iterative solving techniques through the use of a dimensionless group called the Archimedes number (Shook et al. 2002). The calculated minimum viscosity required for homogeneity is 0.4 cP. Because the apparent viscosity of WTP slurries is greater than that of WTP supernate at the low shear rates observed in the mixing vessel, the WTP supernate represents the lower bound on this calculation.

Table 4.1. Settling Information on Glass-Former Chemicals

No.	Name	Particle Size (Mesh; M)	Estimated Particle Density (g/mL)	Free Settling Velocity in Water[(a)] (m/s)	Reference
1	Kyanite	<325 M (44 μm)	3.61	0.0027	http://webmineral.com/data/Kyanite.shtml
	Alumina A2	<325 M (44 μm)	3.7	0.0027	http://www.reade.com/Products/Oxides/alumina.html
2	Boric Acid	>20 M (841 μm)	1.51	0.061	http://www.sqm-mx.com/q_industriales/productos/pdf/boric_acid_msds.pdf
3	10 M Borax	>8 M (2380 μm)	1.71	0.19	http://webmineral.com/data/Borax.shtml
4	Na_2CO_3	<100 M (149 μm)	2.54	0.015	http://webmineral.com/data/Natrite.shtml
5	Wollastonite	<325 M (44 μm)	2.84	0.0018	http://webmineral.com/data/Wollastonite-1A.shtml
6	Fe_2O_3	<325 M (44 μm)	5.3	0.0042	http://webmineral.com/data/Hematite.shtml
7	Li_2CO_3	<200 M (74 μm)	2.11	0.0032	http://www.chemetalllithium.com/
8	Olivine	<200 M (74 μm)	3.32	0.0062	http://www.webmineral.com/data/Olivine.shtml
9	SiO_2	<200 M (74 μm)	2.65	0.0045	http://www.u-s-silica.com/prod_info/PDS/Mill_Creek/MiCSCS752000.PDF
10	Rutile -94	Airfloated <80M (177 μm)	4.25	0.036	http://www.webmineral.com/data/Rutile.shtml
11	ZnO	1 μm	5.6	0.0000025	http://www.zinccorp.com/TD%20for%20Kadox%20920.pdf
12	$ZrSiO_4$	<325 M (44 μm)	4.65	0.0037	http://www.webmineral.com/data/Zircon.shtml
13	Sugar	NA	1.58	NA	http://www.alfa.com/CGI-BIN/LANSAWEB?WEBEVENT+L0422B63C7F078000D26B011+ALF+ENG

(a) Note that the free settling values are calculated values using Equation 4.4.

To illustrate the effect of particle density and size, several of these calculations were performed to create Figure 4.5 and Figure 4.6. These figures demonstrate that a small change in interstitial liquid density (1.0 g/mL to 1.3 g/mL) does not significantly change the required minimum fluid viscosity, and any value over 1.0 g/mL is satisfactory. Based on a calculation to homogenize 105-μm particles with a particle density of 4.25 g/mL in an agitated vessel, the minimum viscosity of interstitial liquid in the WTP slurries should be considered 0.4 cP. For reference, water at 70°C possesses a viscosity of 0.4 cP. At 40°C, water has a viscosity of 0.7 cP.

4.1.4 Material Transfer Operations (Pipeline Flow)

Jones and Peterson (1996) state that solids settling in process lines does not usually occur if the slurry flow is turbulent. Turbulent flow generally exists at high line velocities above 3 to 5 ft/s in 2-in. piping. However, high fluid velocities will cause excessive erosion, and a maximum line velocity of 10 ft/s has been specified for the DWPF (Jones and Peterson 1996). Therefore, the purpose of this section is to find the set of rheological parameters that will create turbulent flow conditions with a maximum superficial velocity of 10 ft/s.

Maximum Free Settling Velocity: $u_t := 0.03 \dfrac{m}{sec}$

Acceleration Due to Gravity: $g = 9.807 \cdot m \cdot s^{-2}$

Maximum Anticipated Particle Size: $D_p := 0.105\,mm$

Maximum Anticipated Particle Density: $\rho_p := 4.25 \dfrac{kg}{L}$

Minimum Anticipated Supernate Density: $\rho := 1.0 \dfrac{kg}{L}$

Drag Coefficient:

$$C_d := \frac{4 \cdot g \cdot D_p \cdot (\rho_p - \rho)}{3 \cdot \rho \cdot u_t^2} \qquad C_d = 4.958$$

Initial Reynolds Number Guess: $N_{Re} := 5$

Correlation for 0.1 < Reynolds Number <1,000

$$\text{Given} \qquad C_d = \left(\frac{24}{N_{Re}}\right) \cdot \left(1 + 0.14 \cdot N_{Re}^{0.7}\right)$$

$$N_{Re} := \text{Find}(N_{Re})$$

$$N_{Re} = 7.659$$

Supernate Viscosity Required to Maintain Max. Settling Velocity:

$$\mu_{min} := \frac{(D_p \cdot u_t \cdot \rho)}{N_{Re}}$$

$$\mu_{min} = 4.113 \cdot 10^{-3} \cdot poise$$

Figure 4.4. Minimum Supernate Viscosity Calculation. See note for Figure 4.1.

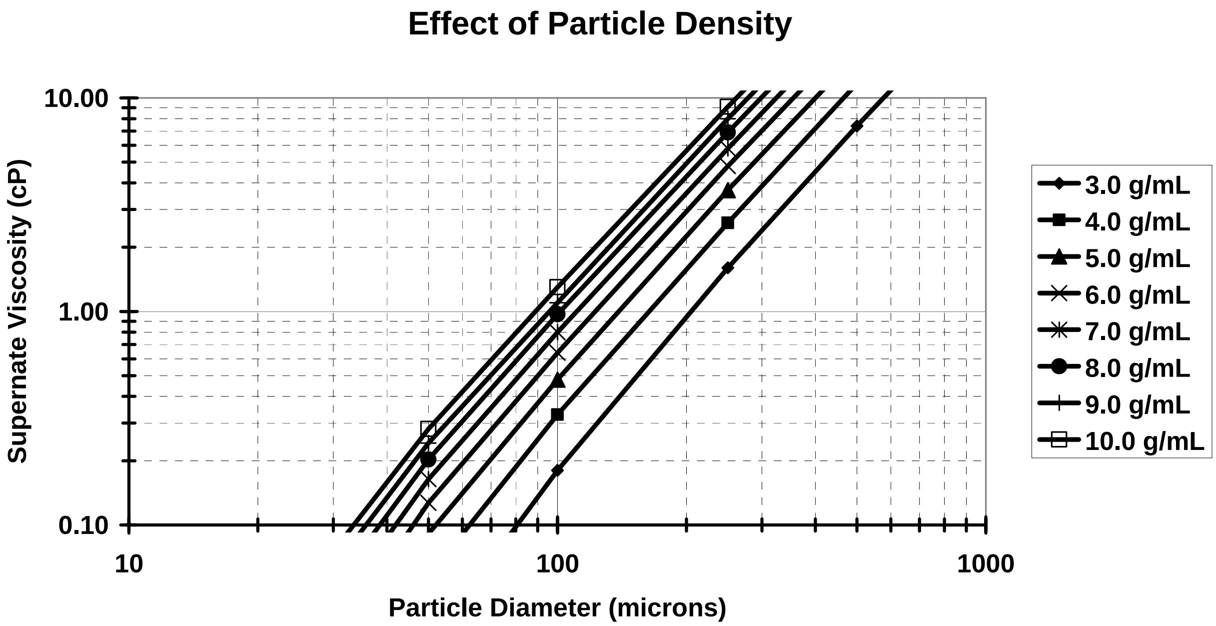


Figure 4.5. Supernate Viscosity Required to Maintain a Free-Settling Velocity of 0.03 m/s as a Function of Particle Diameter and Density in a Suspending Fluid with Density of 1.0 g/mL

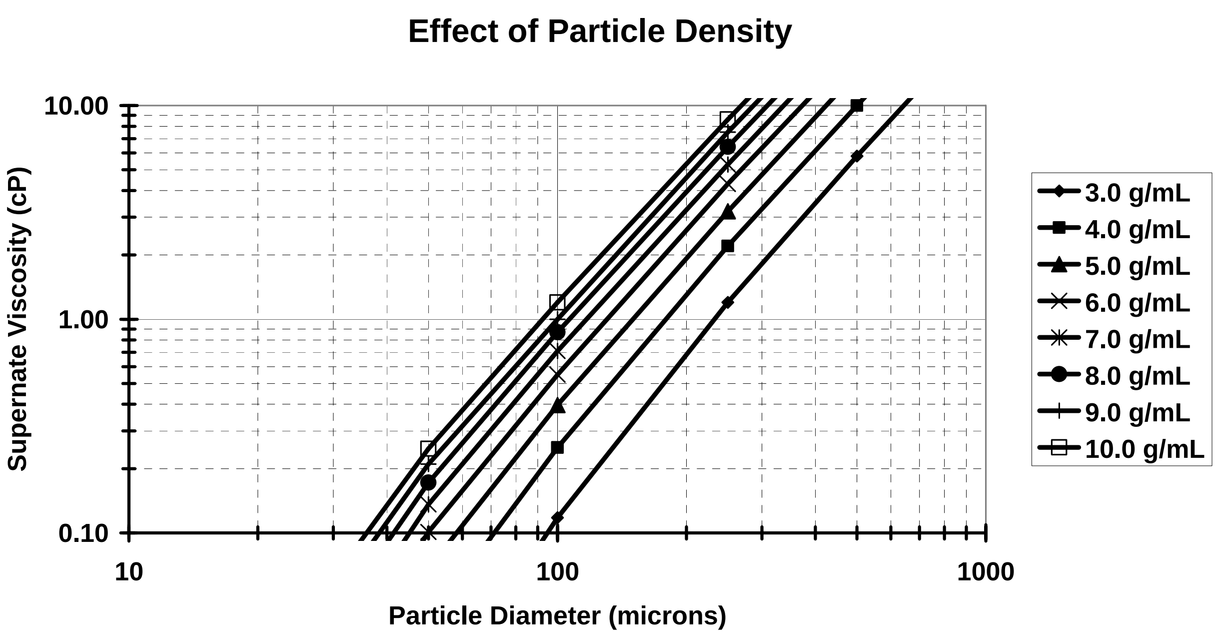


Figure 4.6. Supernate Viscosity Required to Maintain Free-Settling Velocity of 0.03 m/s as a Function of Particle Diameter and Density in a Suspending Fluid with Density of 1.3 g/mL

For Bingham plastic fluids, the first step in this calculation is to calculate the Hedstrom number as shown in Equation 4.8 (Hanks and Dadia 1971; Desouky and Al-Awad 1998; Chang et al. 1999):

$$N_{He} = \frac{D^2 \rho \tau_y}{K^2} \tag{4.8}$$

where N_{He} = Hedstrom number (dimensionless)
D = pipe diameter (m)
ρ = fluid density (kg/m^3)
τ_y = yield stress (Pa)
K = consistency index (Pa•s).

The next step is to perform the following calculation to find the ratio between the yield stress and wall shear stress, ζ_{0c} (Hanks and Dadia 1971; Desouky and Al-Awad 1998; Chang et al. 1999):

$$\frac{\zeta_{0c}}{(1-\zeta_{0c})^3} = \frac{N_{He}}{16{,}800} \tag{4.9}$$

The critical Reynolds Number, $N_{\mathrm{Re}c}$, can then be calculated. This represents the transition from laminar to turbulent flow. The equation for this calculation is shown below (Hanks and Dadia 1971; Desouky and Al-Awad 1998; Chang et al. 1999):

$$N_{\mathrm{Re}c} = N_{He} \frac{\left[1 - \frac{4}{3}\zeta_{0c} + \frac{1}{3}\zeta_{0c}^4\right]}{8 \cdot \zeta_{0c}} \tag{4.10}$$

The velocity of the fluid in the pipe can then be calculated from the definition of the Reynolds Number as shown below:

$$N_{\mathrm{Re}} = \frac{Dv\rho}{K} \tag{4.11}$$

where v is the average velocity of fluid in the pipe (m/s).

These calculations are used to create the plot shown in Figure 4.7. This plot shows fluid properties (bulk density, consistency index, yield stress) required for turbulent flow at a bulk fluid velocity of 10 ft/s. For a fluid with a particular bulk density, turbulent flow will result if the fluid possesses Bingham plastic indices below the corresponding curve. When the yield stress is small (<0.01 Pa), the fluid behaves much like a Newtonian fluid. If one uses a small yield stress, e.g., 0.001 Pa, this turbulent flow criterion can be used to approximate the conditions for Newtonian fluids such as tank supernate. In this case, the consistency index could be considered a Newtonian viscosity.

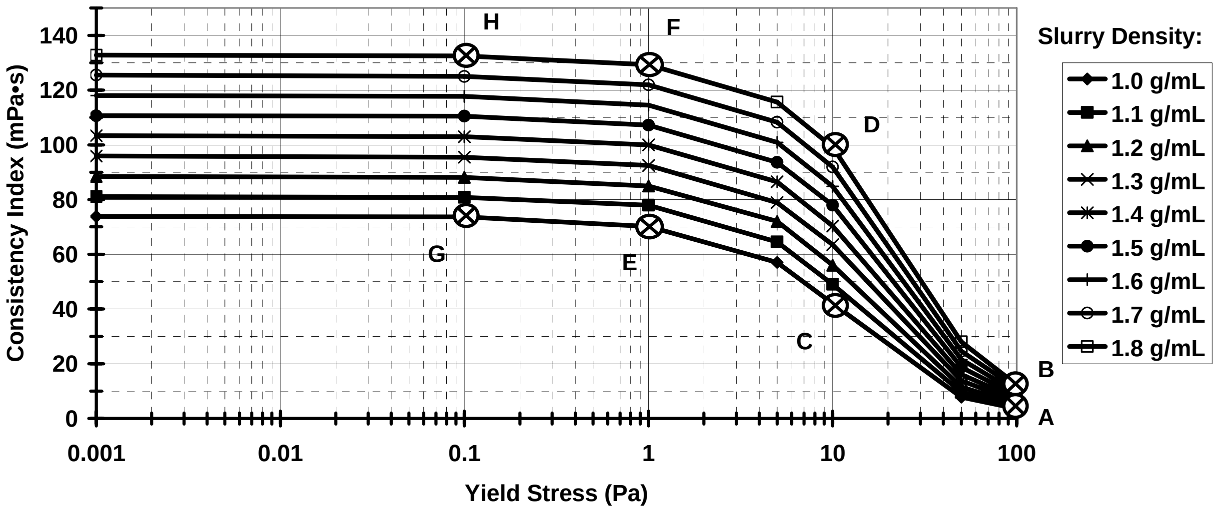


Figure 4.7. Bingham Plastic Parameters Required for Turbulent Flow Regime at 10 ft/s in a 2-in. Pipe

Calculating the pressure drop required to maintain a given flow rate with a Bingham plastic fluid is usually performed through the use of a dimensionless parameter called the Fanning friction factor, (Hanks and Dadia 1971; Desouky and Al-Awad 1998; Chang et al. 1999).

$$f = \frac{DP}{2L\rho v^2} \tag{4.12}$$

where f = Fanning friction factor (dimensionless)
D = pipe diameter (m)
P = pressure drop (Pa)
L = length of pipe (m)
ρ = fluid density (kg/m^3)
v = fluid bulk velocity (m/s).

The following correlations for laminar ($N_{\mathrm{Re}} < N_{\mathrm{Re}c}$) and turbulent ($N_{\mathrm{Re}} > N_{\mathrm{Re}c}$) flow regimes exist between the Fanning friction factor, Hedstrom number, and Reynolds number (see Figure 4.8; Hanks 1978; Chang et al. 1999):

$$f = \begin{cases} \dfrac{16}{N_{\mathrm{Re}}}\left[1 + \dfrac{N_{He}}{6N_{\mathrm{Re}}} - \dfrac{N_{He}^4}{3f^3 N_{\mathrm{Re}}^7}\right] & N_{\mathrm{Re}} < N_{\mathrm{Re}c} \\ 10^c N_{\mathrm{Re}}^{-0.193} & N_{\mathrm{Re}} > N_{\mathrm{Re}c} \\ c = -1.378\left[1 + 0.146\exp\left(-2.9\times10^{-5} N_{He}\right)\right] & \end{cases} \tag{4.13}$$

Correlations similar to these have also been developed for power-law fluids. Hansen[(a)] developed a spreadsheet that uses correlations similar to those presented above to calculate pressure drop in pipes for Bingham plastic, power law, and Newtonian fluids. Using this spreadsheet, the required pressure drop to pump fluids at various flow rates with rheological parameters identified by the points A-H in Figure 4.7 is plotted in Figure 4.9. A pipe diameter of 2 in. and pipe length of 100 ft are assumed in this calculation. These curves are often referred to as system curves. Data from a DWPF pump supplied by Jones and Peterson (1996) for water are also presented to illustrate the likelihood of pumping such material in the WTP. This is often referred to as a pumping curve. Because several of the operating points (points where the pumping and system curves intersect) are in the turbulent flow regime, this plot illustrates that the DWPF pump would be able to pump in the turbulent-flow regime for all fluids except for fluids defined by points A and B. This point represents a high-density, high-yield-strength fluid with a Hedstrom number on the order of 10^7. The remaining fluids have Hedstrom numbers less than 10^6, indicating that fluids with Hedstrom numbers in the 10^7 and greater range will be difficult to pump. Examining Figure 4.8, the friction factor for a Hedstrom number of 10^8 at the laminar/turbulent threshold is approximately 0.03. Depending on the fluid density, at a line velocity of 10 ft/sec in a 2-in.-diameter pipe, the resulting pressure drop for a 100-ft section of pipe for these high Hedstrom number fluids is between 50 to 110 psi. These values exceed the pump performance shown in Figure 4.9, indicating that the transfer of materials with Hedstrom numbers greater than 10^8 may be difficult. For this reason, fluids with Hedstrom numbers above 10^8 are not recommended for cold commissioning.

(a) E Hansen (Westinghouse Savannah River Company)—letter report to H Smith and G Smith (PNWD), Kerry Prindiville (WTP-RPP), and D Crowley (SRNL). 2002. Subject: “Pipe Pressure Drop Calculation for Bingham Plastic, Power Law and Newtonian Fluids.” SRT-RPP-2001-00226, Rev. 1, Westinghouse Savannah River Company, Aiken, SC.

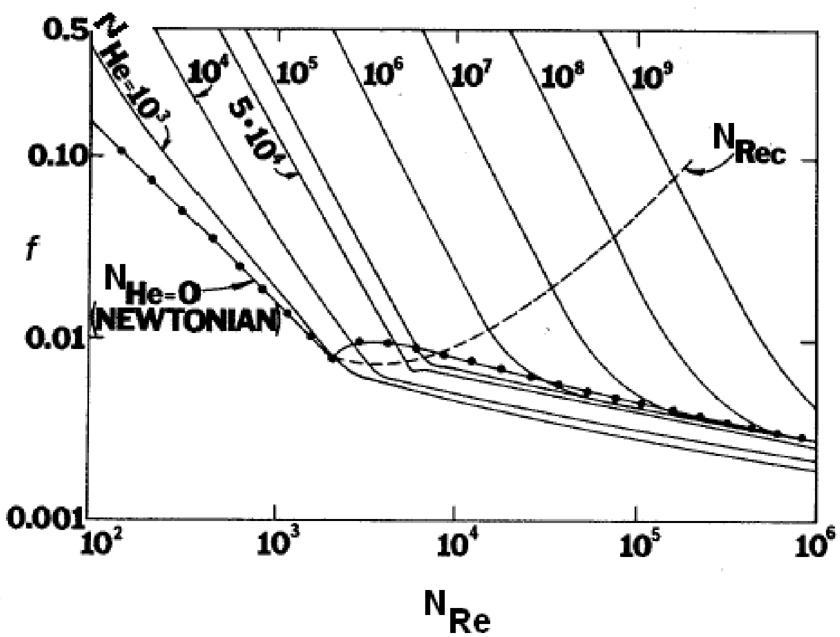


Figure 4.8. Fanning Friction Factor as a Function of Reynolds Number and Hedstrom Number

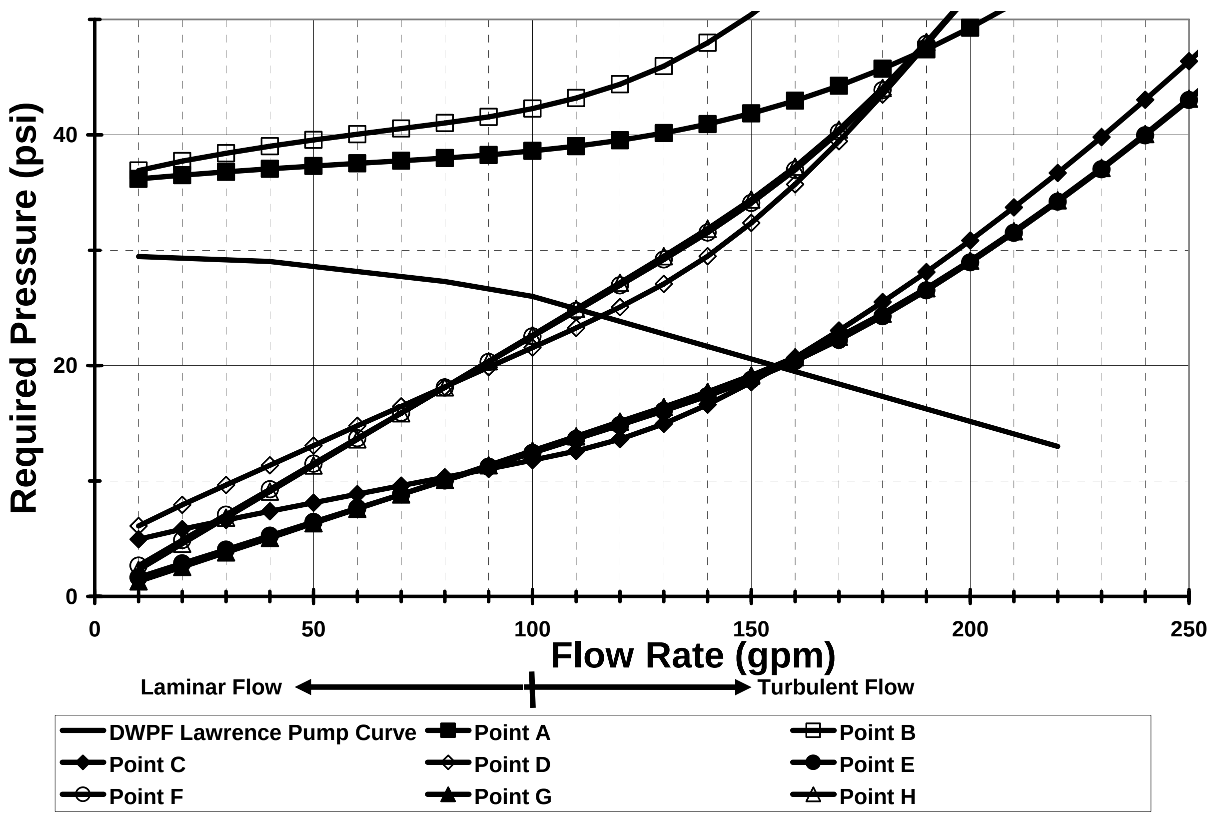


Figure 4.9. System Curves for Fluids with Rheological Properties Defined by Points A-H in Figure 4.7 (100-ft Length of 2-in.-Diameter Pipe)

4.1.5 Material Transfer Operations (Startup Pipeline Flow)

Chang et al. (1999) explain that fluids with shear strength will not flow unless the following condition is met:

$$\tau_w = \frac{DP}{4L} > \tau_y \tag{4.14}$$

where

τ_w = shear stress of the fluid at the pipe wall (Pa)
D = pipe diameter (m)
P = pressure drop (Pa)
L = pipe length (m)
τ_y = shear strength of the fluid (Pa).

Given a 10-ft section of 2-in.-diameter pipe plugged with settled solids, the required pressure to transport the material as a function of shear strength is shown in Figure 4.10. The previously established shear strength value of 625 Pa would result in a pressure of approximately 22 psi to begin flow that appears achievable. This situation would most likely occur during plant upset when systems go offline and solids settle and remain undisturbed until a plant restart is attempted.

4.2 Bounding Conditions Recommendation

Table 4.2 can be constructed if the most restrictive values for the operating boundaries discussed above are taken. This set of operating boundaries represents rheological parameters that should be compatible with many industrial operations of chemical processing units used in the WTP.

It has been demonstrated in Section 4.1.1 that materials with apparent viscosities above 700 cP at low shear conditions (~70 s^{-1}) can lead to difficulties in obtaining homogenous mixing in agitated vessels. Therefore, we wish to restrict the use of material to those with low shear viscosities below 700 cP.

The settled-solids shear strength is a parameter that may be important during plant-upset conditions. When a plant upset occurs, the slurries in vessels and pipes may become motionless, allowing the solids to settle. When the plant is restarted, flow must be reinitiated for the settled solids in pipes and tanks. One such scenario occurs if an impeller in a tank is submerged in settled solids and then restarted. As indicated in Section 4.1.2, a motor with a stall torque of 400 Nm would have difficulty initiating rotation in a fluid with 625 Pa shear strength. One-hundred-horsepower motors typically have stall torques in this range.

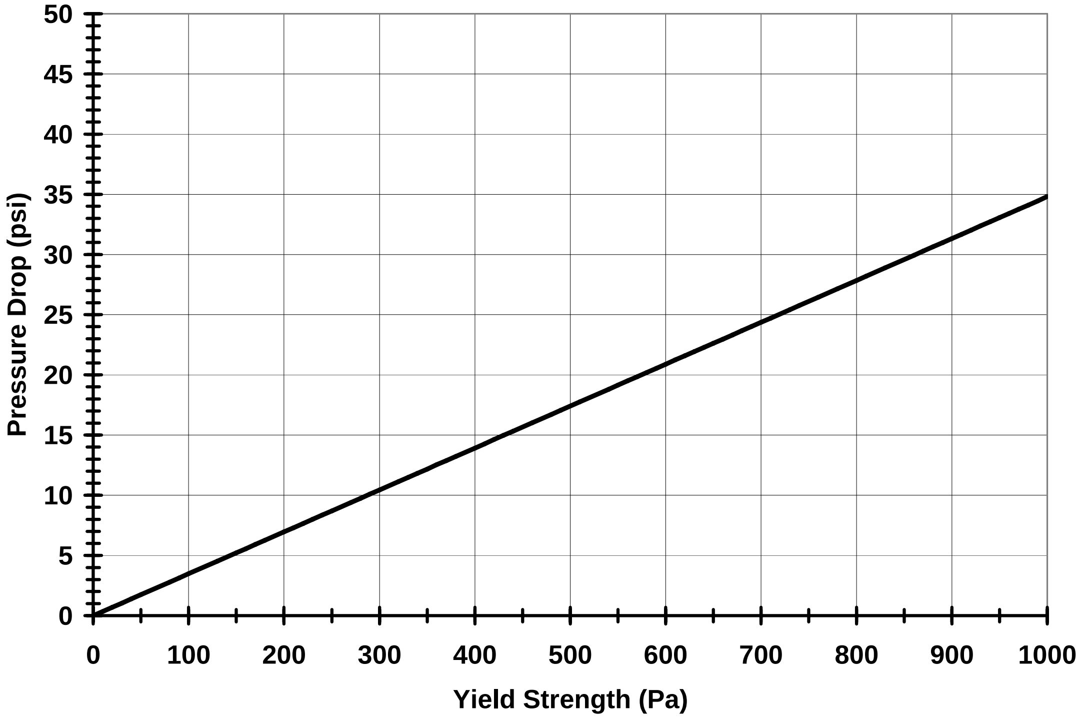


Figure 4.10. Pressure Drop Required to Initiate Flow of a 10-ft Plug of Yield Strength Material in a 2-in. Pipe

Table 4.2. Compilation of Physical-Property Bounding Conditions

Category	Value	Comment
Maximum Apparent Viscosity at Low Shear Rates (~70 s^{-1})	700 cP	Affects power requirements for mixing operations
Maximum Settled Solids Shear Strength	625 Pa	Increases likelihood of successful startup after plant upset
Minimum Supernate Viscosity	0.4 cP	Slows particulate settling during unit operations
Maximum Bingham Plastic Parameters	See Figure 4.7	Increases likelihood that flow will be turbulent in pipeline
Minimum Bingham Plastic Parameters	Consistency Index: 0.4 cP Yield Stress: 0 Pa	Consistent with minimum Newtonian viscosity category
Maximum Hedstrom Number in 2-in. Pipe $N_{He} = \frac{D^2 \rho \tau_y}{K^2}$	10^8	Increases likelihood that the material can be pumped with conventional pumps

It was demonstrated in Section 4.1.3 that 105-μm rutile particles will be difficult to keep homogenized in an agitated vessel with a suspending fluid possessing a viscosity of less than 0.4 cP. Since the insoluble GFCs have rutile particle sizes in this range, it is anticipated that a 0.4-cP suspending medium would be a sufficient minimum viscosity for testing purposes. Suspending fluid density was shown not to be a major concern for this particular combination of fluid viscosity and particle size.

On the basis that particulate settling in pipes is difficult in the turbulent flow regime, a set of Bingham plastic parameters was constructed in Section 4.1.4 that indicates the laminar/turbulent flow threshold in a 2-in. pipe at a fluid velocity of 10 ft/sec. Above this velocity, equipment erosion becomes a concern. These Bingham plastic parameters represent upper boundaries on material and are presented in Figure 4.7. The lower Bingham plastic boundaries were selected to be consistent with the Newtonian viscosity lower boundaries discussed above.

The Hedstrom number appears to have a large impact on the pumping performance of Bingham plastic materials. Using pump performance data from DWPF, it was shown in Section 4.1.4 that fluids with Hedstrom numbers above approximately 10^8 would be difficult to pump in the turbulent flow regime. Consequently, this value was set as an upper bound for the slurry material.

Table 4.2 can be simplified by comparing the bounding conditions to measurements on the actual waste (when available). The resulting sets of bounding conditions developed for each process stream are based on the intersection of the actual waste data and the engineering performance data.

The slurry process streams are expected to behave as Bingham plastic fluids. Using the data compiled in Appendices A and B, estimates of the actual waste data for HLW pretreated sludge and HLW melter feed stream are shown in Table 4.3 and Table 4.4. These data were used to calculate the critical transition velocity for these fluids in a 2-in.-diameter pipe. Several of these critical velocity values are above the 10-ft/s pipe erosion threshold. To define a set of bounding conditions for the vitrification streams, a slurry density of 1.2 g/mL was used as a high characteristic slurry density for the actual pretreated HLW sludge streams, and a slurry density of 1.5 g/mL was used as a high characteristic slurry density for the actual HLW melter feed streams. With these densities, the laminar turbulent transition data in Figure 4.7 were plotted in Figures 4.11 and 4.12. The Bingham plastic parameters that encompass the most actual waste points at these slurry densities (1.2 g/mL or 1.5 g/mL) while maintaining a critical velocity of approximately 10 ft/s were calculated as upper bounding conditions and define the upper right corner of the boundary conditions. Figure 4.11 and Figure 4.12 present the resulting rheological bounding conditions graphically along with the actual waste data (see Tables 4.2, 4.3, and 4.4), the mechanical mixing criterion developed (Section 4.1.1), and the DWPF/HWVP design basis.[a] Note that in each case for mechanical mixers, the low shear mechanical mixing criteria exceed the proposed bounding conditions. This removes the mechanical mixing criteria from further examination. In addition, the proposed bounding conditions generally encompass the DWPF design basis and are comparable to the HWVP design basis.

(a) DWPF Design Basis: DPSTD-80-38-2; Part 10, Item 230, Date 9-82 Rev. 2. HWVP Design Basis: WHC-SD-HWV-DP-01; Section, Item 300 October 1990. HWVP consistency index presented in this document calculated from apparent viscosity design ranges at high and low yield stress design ranges.

Note that several of the actual waste data points lie outside the proposed bounding conditions. This is not unexpected because Bingham plastic parameters are known to increase as undissolved solids content increases asymptotically to the theoretical limit. This asymptotic behavior can result in large rheological changes caused by a small change in solids concentration (Slatter 1997; Landel et al. 1965; Dabak and Yucel 1987). The consistency index, K (cP), has previously been modeled as $K = \mu_f \left(1 - \frac{C}{C_{\max}}\right)^{-m}$ where μ_f is the viscosity of the interstitial liquid, C is the concentration of undissolved solids, and $C_{\max}$ and m are fitting parameters. The yield stress, τ_y (Pa), has been modeled as $\tau_y = a \frac{C^3}{C_{\max} - C}$ where a is a fitting parameter. Using forms similar to these equations, the actual waste data for each vitrification stream were fit to the following three parameter models where *a, b, c, d, e,* and *f* are fitting parameters, and *X* is the weight percent total solids present in the slurry (see Equations 4.15 and 4.16). The resulting model parameters for the actual waste data are shown in Table 4.5.

Table 4.3. Rheological Comparison of Estimated Actual HLW Pretreated Sludge Data to Proposed Operating Envelope at 25°C

Description (Proposed Bounding Conditions)	Wt% Total Solids	Slurry Density	Consistency Index (0.4,30)	Yield Stress (0,30)	Hedstrom Number in 2-in. Pipe ($0,10^8$)	Critical Reynolds Number in 2-in. Pipe	Critical Velocity in 2-in. Pipe (0,10)	Meets Proposed Bounding Conditions?
		g/mL	mPa·s	Pa			ft/sec	Yes/No
Pretreated HLW Sludge AZ101 25°C PNWD	10	1.08	<10	0	0	2,100	1.3	Yes
Pretreated HLW Sludge AZ-101 25°C PNWD	15	1.12	5.2	2.9	3.1E+05	10,000	3.0	Yes
Pretreated HLW Sludge AZ101 25°C PNWD	22	1.19	10.5	11.4	3.2E+05	10,000	5.8	Yes
Pretreated HLW Sludge AZ102 25°C PNWD	15	1.14	30	18.5	6.0E+04	5,700	9.8	Yes
Pretreated HLW Sludge AZ-102 25°C PNWD	20	1.17	34 *	26.3	6.9E+04	6,000	11.3 *	No
Pretreated HLW Sludge AZ102 25°C PNWD	25	1.24	99 *	209.1 *	6.8E+04	6,000	30.8 *	No
Pretreated HLW Sludge C-104 25°C PNWD	5	1.0	3	0.2	5.7E+04	5,600	1.1	Yes
Pretreated HLW Sludge C-104 25°C PNWD	15	1.05	5	0.4	4.3E+04	5,100	1.6	Yes
Pretreated HLW Sludge C-104 25°C PNWD	25	1.12	10	5.8	1.7E+05	8,200	4.7	Yes

* Outside of bounding conditions

Table 4.4. Rheological Comparison of Estimated Actual HLW Melter Feed Data to Proposed Operating Envelope at 25°C

Description (Proposed Bounding Conditions)	Wt% Total Solids	Slurry Density	Consistency Index (0.4,40)	Yield Stress (0,30)	Hedstrom Number in 2-in. Pipe ($0,10^8$)	Critical Reynolds Number in 2-in. Pipe	Critical Velocity in 2-in. Pipe (0,10)	Meets Proposed Bounding Conditions?
		g/mL	mPa·s	Pa			ft/sec	Yes/No
HLW MF AZ-101 PNWD	23.3	1.18	4.1	1.8	3.3E+05	10,000	2.3	Yes
HLW MF AZ-101 PNWD	33.6	1.33	10.7	3.4	1.0E+05	6,900	3.6	Yes
HLW MF AZ-101 PNWD	44.5	1.51	21.0	14.7	1.3E+05	7,500	6.7	Yes
HLW MF AZ-102 PNWD (VSL- HLW98-61)	12.3	1.12	7	0.1	5.9E+03	2,900	1.2	Yes
HLW MF AZ-102 Repeat PNWD (VSL- HLW98-61)	30.3	1.23	25	5.1	2.6E+04	4,400	5.8	Yes
HLW MF C-104 25°C PNWD (VSL- HLW98-51R)	14.1	1.12	4	0.1	1.8E+04	3,900	0.9	Yes
HLW MF C-104 25°C PNWD (VSL- HLW98-51R)	36.8	1.24	16	4.0	5.0E+04	5,400	4.5	Yes
HLW MF C-104 25°C PNWD (VSL- HLW98-51R)	47.3	1.50	41 *	27.8	6.4E+04	5,900	10.4 *	Marginal

* Outside of bounding conditions

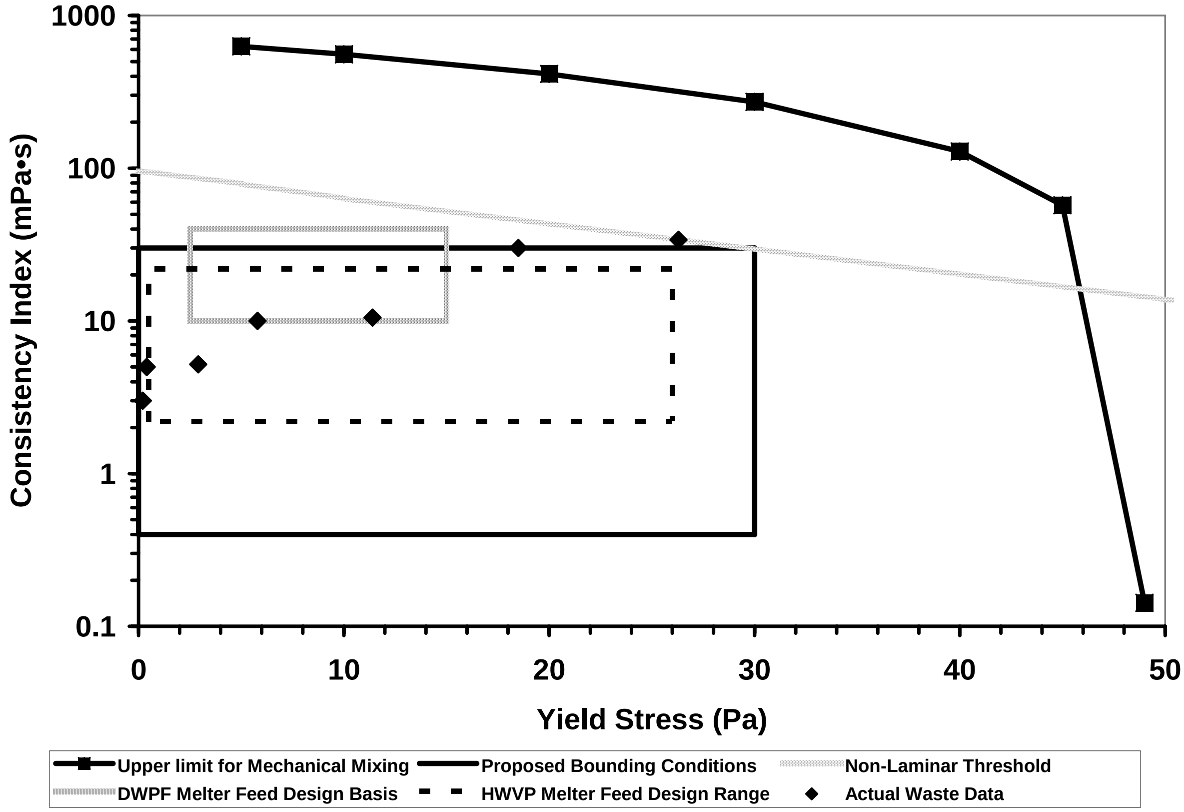


Figure 4.11. Proposed Rheological Operating Envelope for Pretreated HLW Sludge

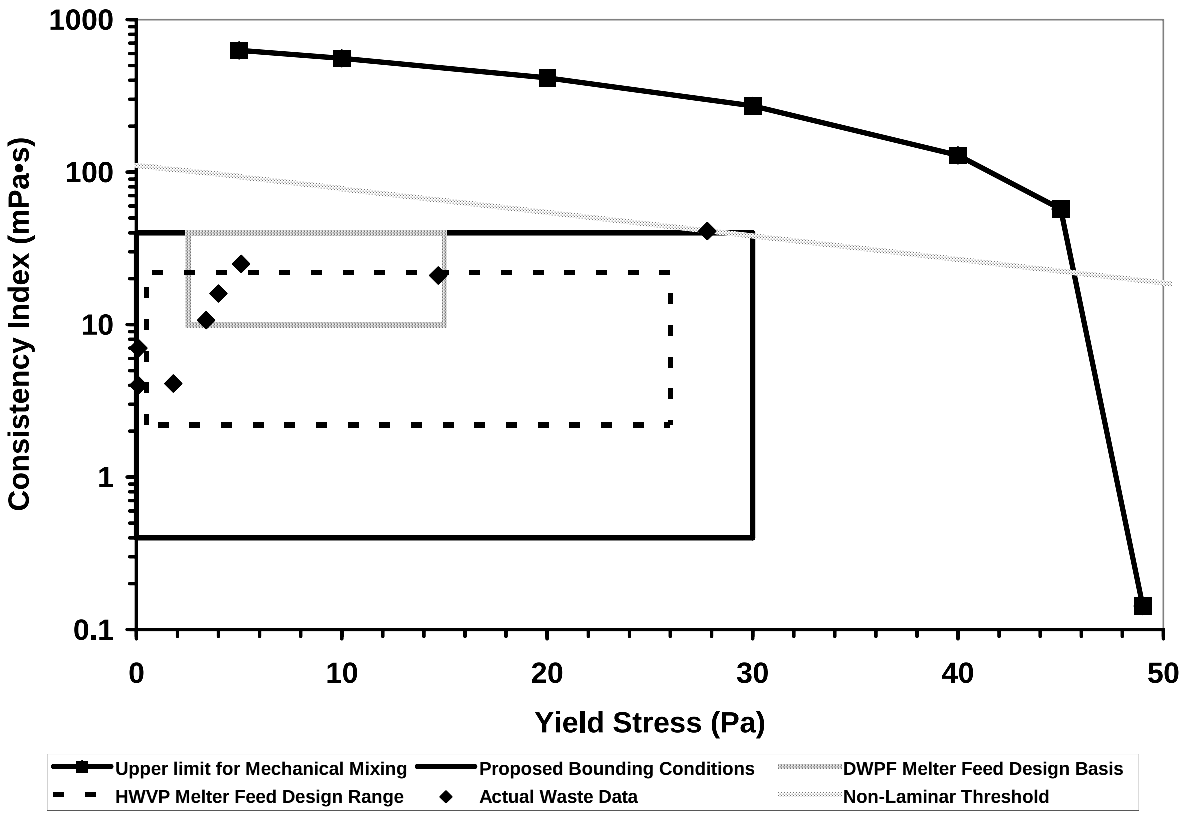


Figure 4.12. Proposed Rheological Operating Envelope for HLW Melter Feed

Table 4.5. Parameters Used to Correlate Bingham Plastic Indices to Total Solids Loading at 25°C

Description	Consistency Index Model Parameters				Yield Index Model Parameters			
	a	b	c	R^2	d	e	f	R^2
AZ-101 HLW Sludge	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
AZ-102 HLW Sludge	23	25.1	0.26	1.00	9.3E-3	100	4.3	0.79
C-104 HLW Sludge	2.4	48.5	2.0	1.00	0.87	100	1.7	0.72
AZ-101 HLW Melter Feed	1.4	100	1.2	0.97	18.9	48.1	0.27	1.00
AZ-102 HLW Melter Feed	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
C-104 HLW Melter Feed	2.1	76.6	3.1	1.00	1.8E-3	51.7	2.9	1.00
(n/a) Not applicable because there are only two data points available for a model fit of a three-parameter model.								

$$K = a\left(1 - \frac{X}{b}\right)^{-c} \tag{4.15}$$

$$\tau_y = d\,\frac{X^f}{e - X} \tag{4.16}$$

The actual waste and model-fit data are displayed graphically as a function of weight-percent total solids in Figure 4.13 through Figure 4.16. These data illustrate the asymptotic effect of solids loading on the rheological properties of the slurry. In many instances, a small change in solids loading can result in a large change in rheological properties. For this reason, some of the slurries previously evaluated with higher solids loadings possess relatively large rheological properties that are likely to result in processing difficulties in the WTP. These slurries are shown outside the operational windows (Figure 4.13 through Figure 4.16). Fortunately, each tank evaluated possesses data within the proposed operational window, and a threshold solids loading for each tank needs to be established before WTP processing. As shown in Figure 4.13, mixing and aging of the slurries for prolonged amounts of time can result in significant rheological changes. Results from mixing and aging tests should also be a factor in determining the threshold solids loading of the WTP process for a particular tank. The proposed operational windows for each vitrification stream are shown in rheogram form (i.e., shear stress versus shear rate) in Figure 4.17 and Figure 4.18.

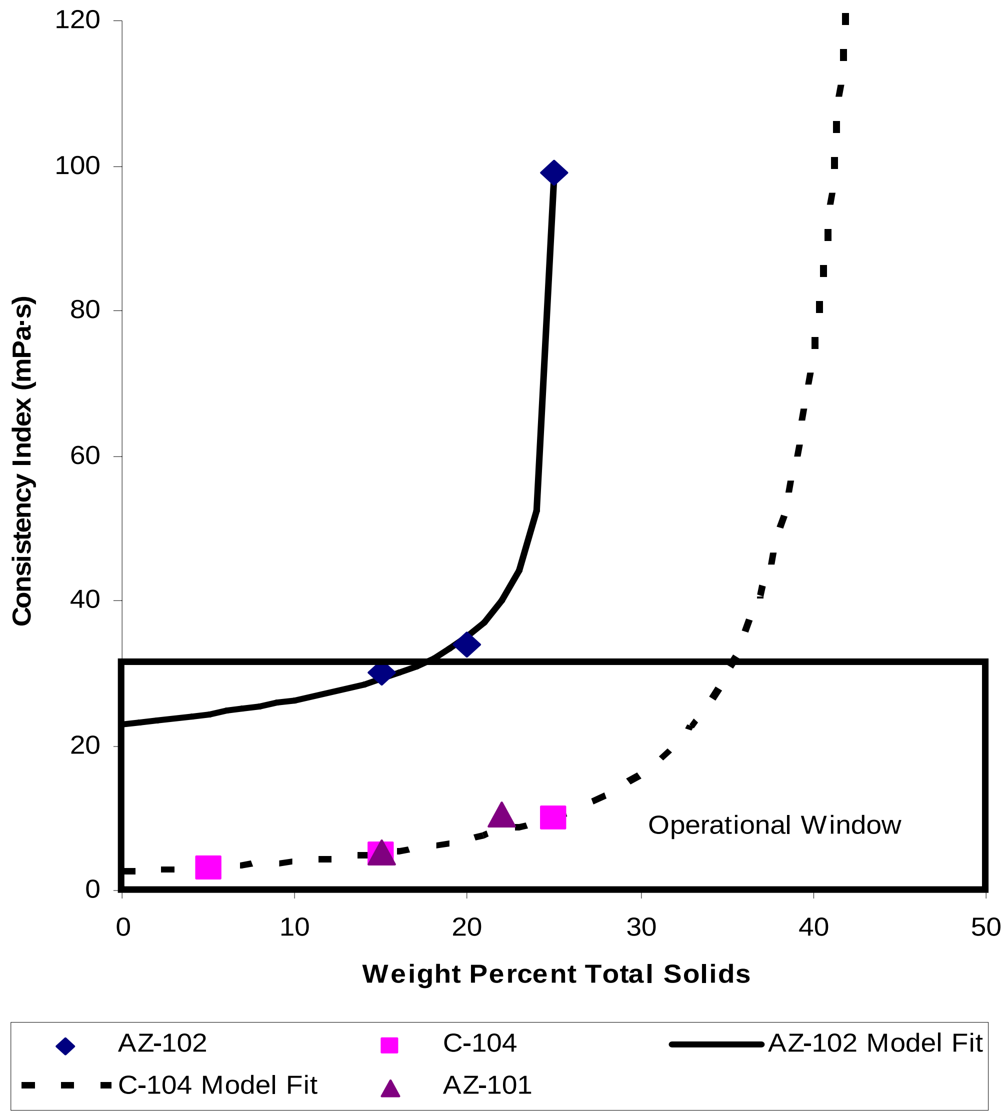


Figure 4.13. Bingham Consistency Index as a Function of Weight-Percent Total Solids for Pretreated HLW Sludge at 25°C

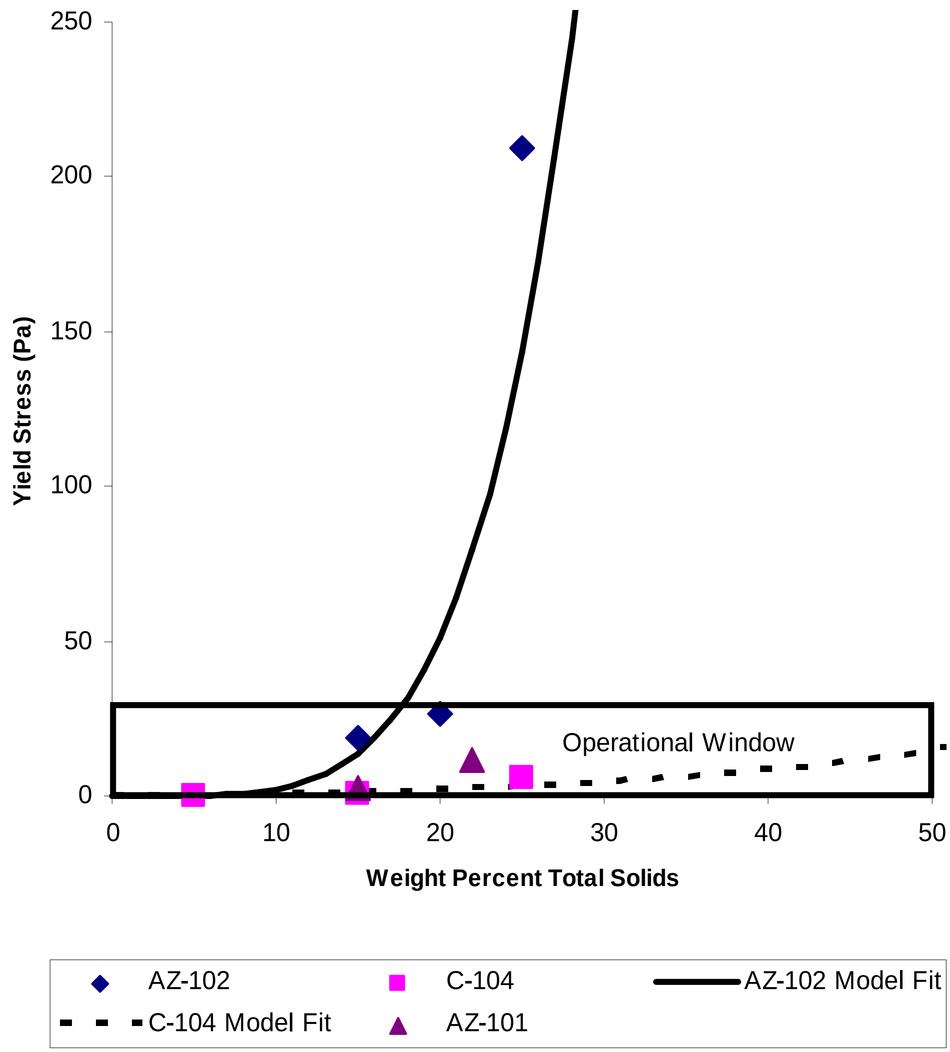


Figure 4.14. Bingham Yield Index as a Function of Weight-Percent Total Solids for Pretreated HLW Sludge at 25°C

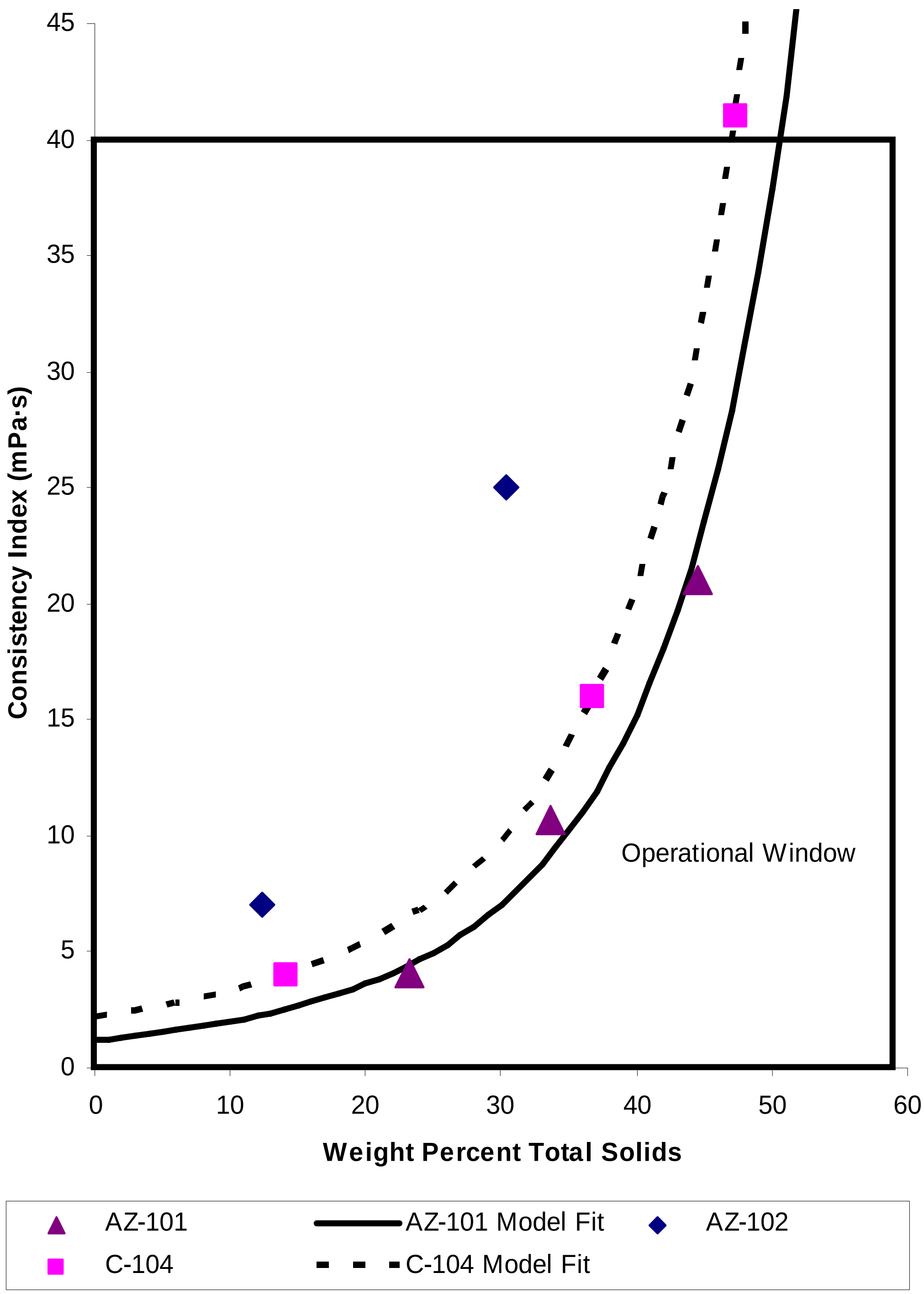


Figure 4.15. Bingham Consistency Index as a Function of Weight-Percent Total Solids for HLW Melter Feed at 25°C

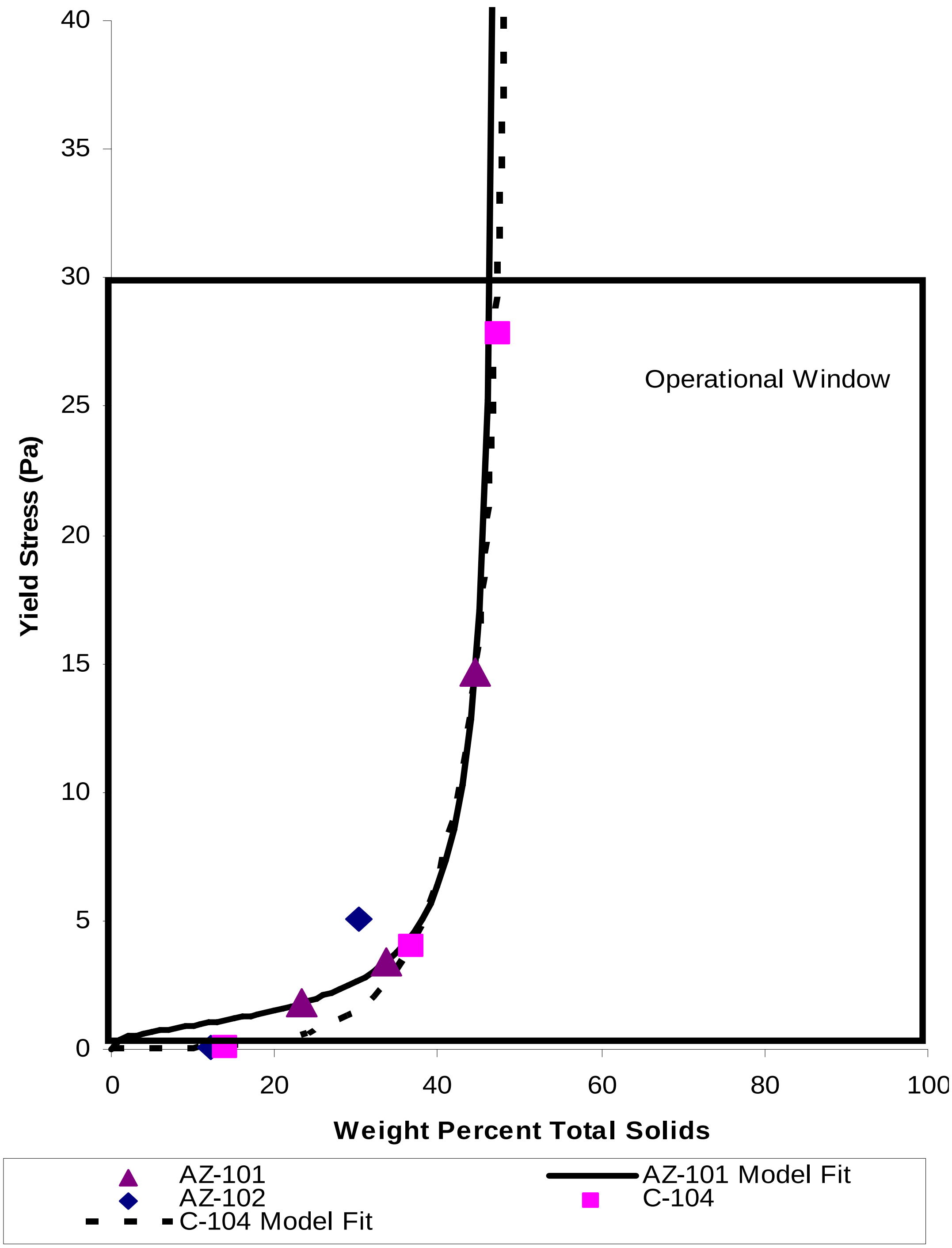


Figure 4.16. Bingham Yield Index as a Function of Weight-Percent Total Solids for HLW Melter Feed at 25°C

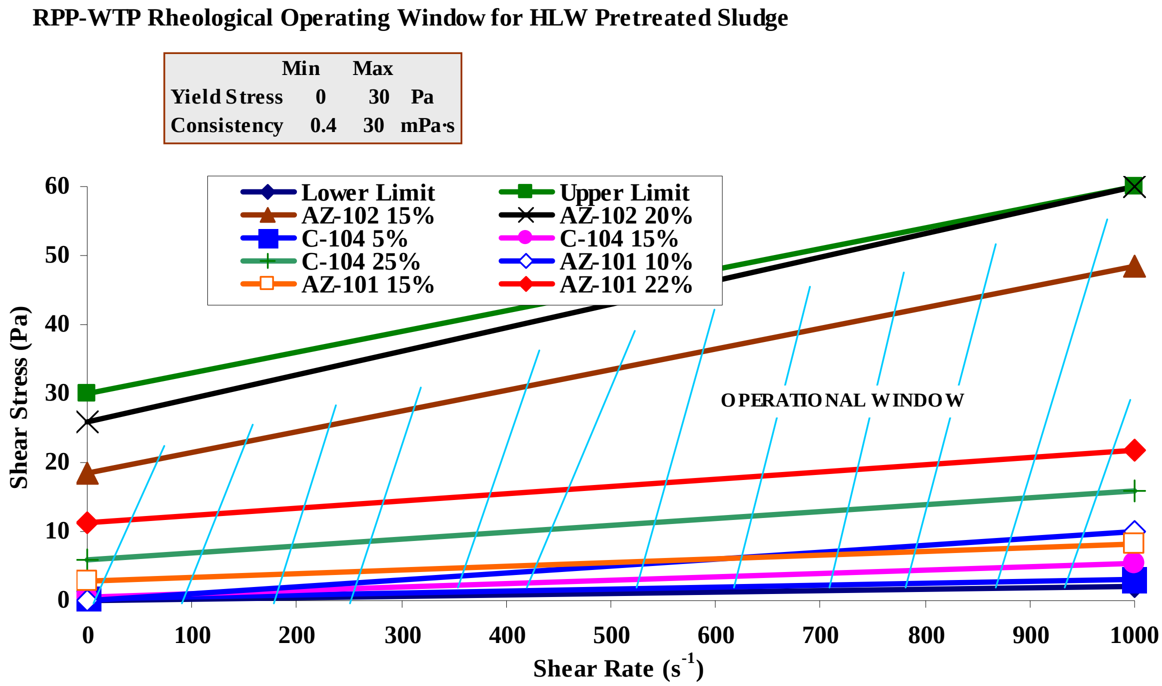


Figure 4.17. Proposed Bounding Conditions for Pretreated HLW Sludge, Including Plots for Pretreated HLW AZ-101, AZ-102, and C-104. Note: percents in the legend refer to weight percent undissolved waste solids.

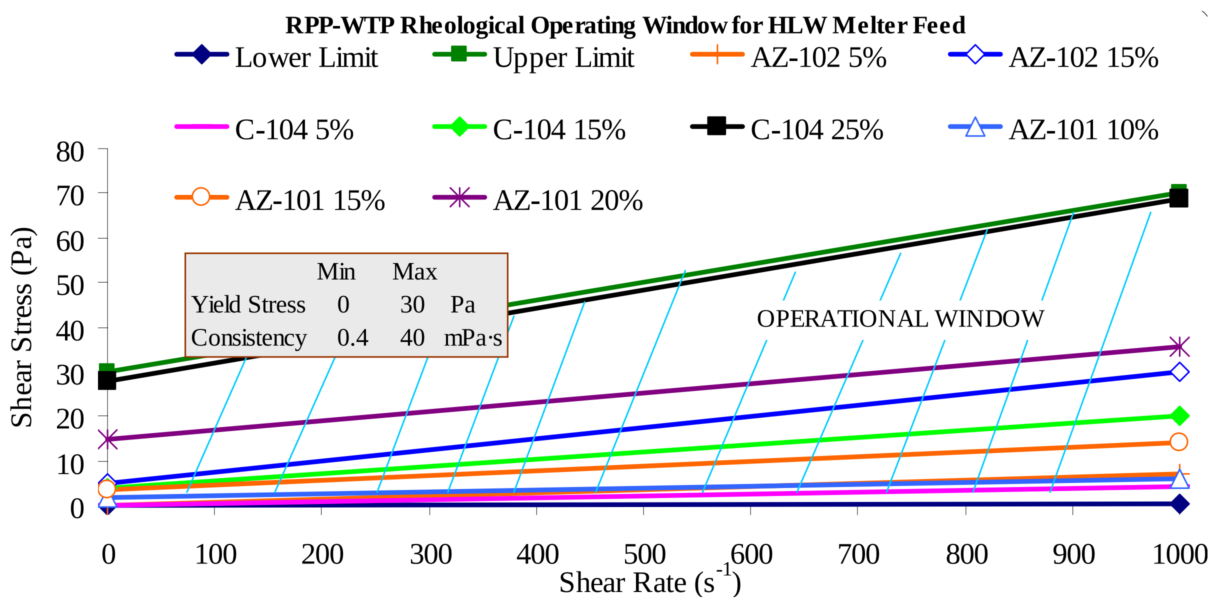


Figure 4.18. Proposed Bounding Conditions for Pretreated HLW Melter Feed, Including Plots for AZ-101, AZ-102, and C-104 HLW Melter Feed. Note: percents in the legend refer to weight percent undissolved waste solids.

4.2.1 Prediction of Yield Stress and Bingham Consistency for Pretreated HLW and HLW Melter Feed

The parameters shown in Table 4.5 for Equations 4.15 and 4.16 provide rheological property predictions for each source waste tank as a function of solids concentration in the slurry. These data indicate that each source waste tank has a different set of rheological parameters that are likely a function of solids concentration, PSD, particle shape, particle composition, aqueous phase composition, etc. Because of this level of complexity, rheological performance curves should be determined for each source tank waste with similar particle properties and constant waste composition.

Tracey et al. (1996), using a Hanford HLW simulant, plotted “Bingham viscosity” and yield stress as a function of solids wt% and found an exponential increase of these physical properties beginning at about 23- to 25-wt% solids. The magnitude of the increase strongly increased with increasing pH. For the HLW melter feed, a rheological upper bound of 40-Pa Bingham yield stress and 30-cP Bingham consistency (a solids loading of 36 wt% total solids) meets the 90% prediction interval for both rheological properties. Note that the HLW melter feed is much better behaved than the pretreated HLW. It is believed that this is because the rheology is dominated by the GFCs in the melter feed whereas the varying solids species in the pretreated waste result in a large amount of statistical variance.

4.3 Selection of a Shear Rate Range to Fit Realistic Boundary Conditions

To define a shear-rate range that should be used when assessing if a material fits within the bounding range, two process operations are considered: pipeline flow and mechanical mixing. These process operations have been previously evaluated as explained below.

4.3.1 Pipe Flow Evaluation

The pipe velocity and diameter are based on the evaluation completed in Section 4.1.4. From that section, Jones and Peterson (1996) state that solids settling in process lines does not usually occur if the slurry flow is turbulent. Turbulent flow generally exists at high line velocities above 3 to 5 ft/s in 2-in. piping. However, high fluid velocities will cause excessive erosion, and a maximum line velocity of 10 ft/s has been specified for the DWPF (Jones and Peterson 1996).

The rheology parameters are established in Section 4.2. Table 4.2 succinctly summarizes those parameters and indicates their importance to pipe flow where appropriate, such as maximum Bingham plastic parameters and the maximum Hedstrom number in 2-in. pipe. The shear stress at the pipe wall is calculated for conditions that produce a maximum shear (equation is taken from Shook et al. [2002]) (Figure 4.19). This result indicates that rheological properties should be measured to at least $800 \cdot sec^{-1}$ to match an estimate of the potential range of service conditions.

4.3.2 Mechanical Mixing Evaluations

Mechanical mixing evaluations were carried out in Section 4.1.1, Mixing Operations (Low-Shear-Rate Viscosity), and 4.1.2, Mixing Operations (Maximum Settled Solids Shear Strength), using the impeller diameter and rotational rate from Section 4.1.1 and assuming that the impeller diameter is 90% of the tank diameter. Reducing the gap between the tank wall and the impeller results in an even higher shear rate, and 90% is a reasonably conservative estimate for typical process operations. The maximum-shear-rate equation for this geometry is found in Steffe (1996) and gives a value for the shear rate at the tank wall of $377 \cdot s^{-1}$ for an impeller rotational rate of 400 rpm (Figure 4.20).

It is concluded that rheological properties should be measured over a shear-rate range of 0 to $800 \cdot s^{-1}$ to include an estimate of the full range of conditions that a slurry might see.

4.4 Application of Boundary Conditions

A stated objective of this report is to develop a set of bounding physical and rheological properties for waste materials that can be reasonably processed and likely encountered in the WTP vitrification facilities. To determine the bounds for each operation, one must understand what general waste properties are anticipated and how changes in those properties can affect process operation. The process bounds are then established at the point where the properties of the material induce unacceptable risk to plant performance. Hence, one can use this set of bounding physical and rheological properties to judge when a given pretreated waste or melter feed may cause transfer or processing problems by causing the system to have to operate outside its design capabilities. In this brief section, examples of HLW pretreated waste or melter feed rheology are discussed with respect to the recommended rheological bounding conditions.

Table 4.6 summarizes the boundary conditions for HLW pretreated waste and melter feed. Figure 4.21 and Figure 4.22 plot these conditions. The pretreated HLW sludge simulant is assumed to display Bingham behavior as the actual low-activity pretreated wastes are observed to do, so in Figure 4.21, the apparent viscosity of a HLW pretreated waste simulant for the asymptotic limit at high shear rates will lay between 0.4 and 30 cP if it is to represent a waste that can be appropriately mixed and transported by a pretreatment facility. The Bingham behavior of the actual high-activity pretreated wastes, and their simulants are anticipated on the basis that they are solutions with significant suspended solid matter. The lower boundary is based on the need to maintain the fastest settling glass-former particles in suspension while the glass formers are being added to the waste to make a melter feed. The upper boundary reflects the fact that HLW melter feed slurries with less than about 50-wt% solids have apparent viscosities less than 30 cP (cf. Figure 4.16).

Pipeline velocity

$v := 10\frac{ft}{sec}$

Pipe Diameter

$D := 2in$

Bingham Plastic Parameters

$\tau_0 := 30Pa$

$K := 0.30poise$

Shear stress at pipe wall

$$\tau_w := \frac{8 \cdot K \cdot v}{D} + \frac{4 \cdot \tau_0}{3}$$

Maximum shear rate at pipe wall

$$\gamma_{pipe} := \frac{\tau_w - \tau_0}{K}$$

$$\gamma_{pipe} = 813s^{-1}$$

Figure 4.19. Basis for Calculating the Maximum Shear Rate at a Pipe Wall. See note for Figure 4.1.

Impeller diameter

$d := 36\ in$

Gap between impeller and tank wall or baffle

$\Delta d := \frac{d}{0.90} - d \qquad \Delta d = 4 \cdot in$

Impeller Rotational Rate

$\Omega := 400 \cdot (2 \cdot \pi)\ min^{-1}$

Maximum Estimated Shear Rate

$\gamma_{tank} := \frac{\Omega \cdot d}{\Delta d} \qquad \gamma_{tank} = 377 \cdot s^{-1}$

Figure 4.20. Basis for Calculating a Maximum Shear Rate in a Mixing Tank. See note for Figure 4.1.

Table 4.6. Boundary Conditions for Pretreated HLW Waste and Melter Feed

Shear Rate (1/s)	10	100	700
PT HLW low—Apparent Viscosity (cP)	0.4	0.4	0.4
PT HLW high—Apparent Viscosity (cP)	2040	240	69
MF HLW low—Apparent Viscosity (cP)	0.4	0.4	0.4
MF HLW high—Apparent Viscosity (cP)	3040	340	83

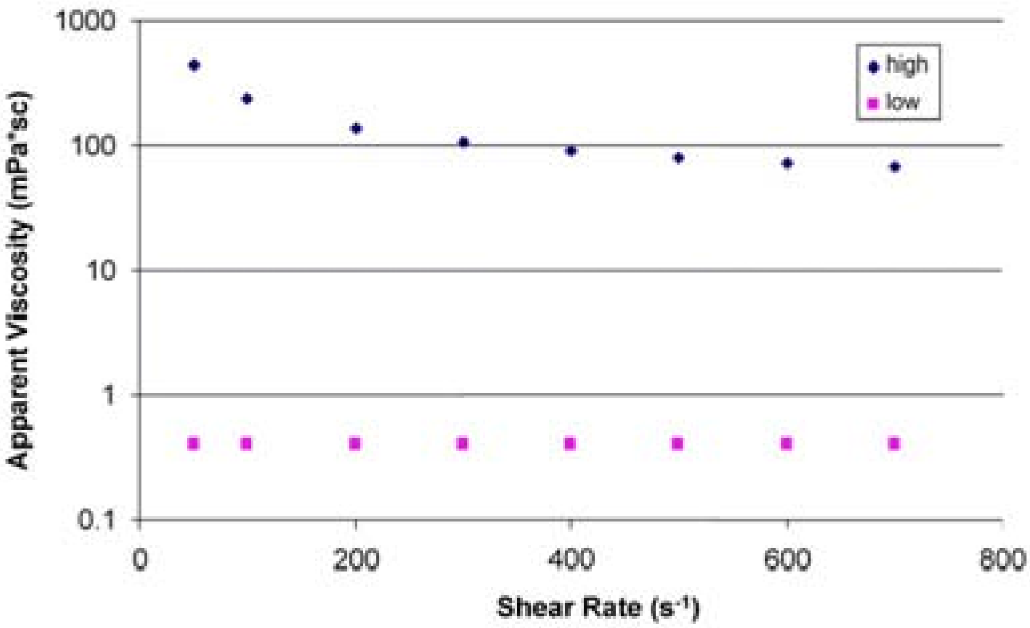


Figure 4.21. Pretreated HLW Rheological Bounding Conditions

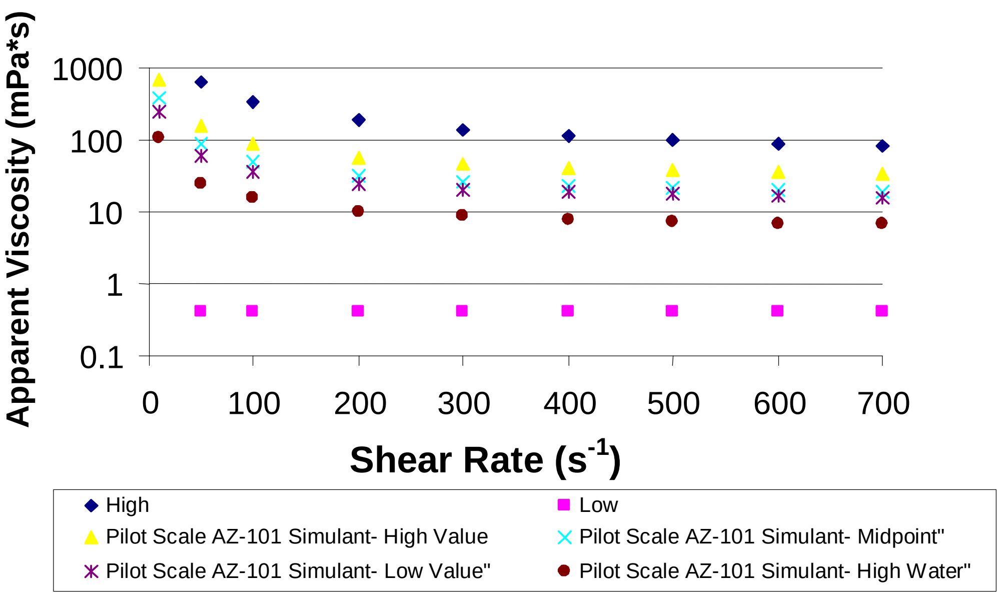


Figure 4.22. HLW Melter Feed Rheological Bounding Conditions

Similarly, Figure 4.22 shows the upper and lower operational boundaries for HLW melter feed. In this case, the lower boundary is also Newtonian and feeds falling near this boundary show little or no shear strength. The lower boundary also has the same requirement as the lower boundary for the pretreated waste, i.e., maintenance of the suspension of the added GFCs and minerals. The upper boundary has been established as the maximum rheological parameters that will allow for turbulent mixing in the pipes while limiting pipe erosion at high velocities. These fall at or below the upper operational boundary for the HLW melter feed processing system. These trends also match the trend displayed by the upper operational boundary, which is based on the Bingham Plastic Rheological model, indicating that they are also well defined by this model.

It is expected that the amount of water in the pretreated waste and the melter feed would be minimized to increase melting efficiency. Hence the examples for both the HLW pretreated waste simulant and the simulated HLW melter feed crowd the upper boundary.

4.5 Rheology Modifier Assessment

Recently, an effort has been undertaken to investigate the use of surfactants, dusting agents, and rheological modifiers for the purpose of minimizing foaming and dusting while adding dry GFCs in addition to lowering the yield stress of the resulting melter feed. The surfactants function by raising or lowering the interfacial tension at the boundary between two phases (Kay et al. 2003). Dusting agents function by agglomerating the dry GFCs into larger particles whereas rheological modifiers alter the particle-particle interaction of particles in a slurry. The impact of all these materials is dependent on the composition of liquid and solid phases, surface-charge effects, pH, and particle size. Even small quantities of these agents have the potential to produce a wide range of rheological effects. For example, in industrial applications, quantities of surfactants and rheological modifiers in the parts per million (ppm) level are typically added to produce desired results.

Kay et al. (2003) have evaluated the rheological effects of several surfactants and rheological modifiers on DWPF simulated melter-feed slurries and RPP-WTP pretreated AZ102 HLW sludge. First, the rheological properties of the simulated melter feeds and pretreated waste sludges were evaluated as an experimental control. Surfactants and rheological modifiers were added to achieve a composition of 1000 ppm (0.1 wt%). The rheological properties of these experimental slurries were then evaluated.

The results from the DWPF simulated-melter-feed slurries emphasize the need for thorough characterization of actual waste with the surfactant before implementation in the WTP. Each of the three surfactants and rheological modifiers investigated increased the yield stress of the slurries by a factor of 1.2 to 3, depending on the surfactant. Such increases could result in slurries that are difficult to process through the WTP unit operations.

The results from adding surfactant and rheological modifiers to simulated AZ-102 HLW pretreated sludge are less dramatic. Eight surfactants and rheological modifiers were investigated. Several of these surfactants decreased the yield stress of the slurry while maintaining or slightly dropping the consistency index. Depending on the surfactant, the yield stress changed by a factor of 0.8 to 1.4, and the consistency index was reduced by a factor of 1.0 to 1.4. The authors attribute the drop in yield stress to dispersion of the particles in the slurry because of the surfactant as opposed to particle agglomeration without the surfactant. Baich et al. (2003) recommended anti-foam Q2-3183A, manufactured by Dow Corning for use in the WTP, based on its chemical and radiolytic stability, and Hassan et al. (2004) have further provided an initial recommendation to add Q2-3183 to a concentration of 350 mg/L to the HLW pretreated sludge. Anti-foam Q2-3183A was not investigated by Kay et al. (2003). Russell et al. (2005) investigated the impact of the Q2-3183A anti-foam on gas holdup in kaolin-bentonite clay and simulated pretreated AZ102 HLW slurries and measured the rheology of each mixture, but rheologies of the same slurries without anti-foam were not measured. There has been no systematic study of the impact of the Q2-3183A anti-foam on rheology, and one is recommended.

Schumacher et al. (2003) have investigated several wetting agents for use in dry GFCs addition to minimize dusting. Of the 11 wetting agents considered, two (water and Van-Gel) were recommended for potential implementation in the WTP.

Adding water is expected to decrease the rheological properties of the resulting melter feeds. The quantities of water added to the GFCs are small, 2.5 wt% for LAW and 5 wt% for HLW. In this amount, adding water to the dry GFCs is not expected to be large enough to significantly lower throughput through the melters.

Van-Gel is the trade name of a bentonite product produced by RT Vanderbilt. Bentonite is a water-swelling clay that has dramatic rheological effects at low solids concentrations. At the concentrations investigated, 1.75 to 2.0 wt% of a 1.85-wt% Van-Gel solution, the effect on the resulting melter feed rheology is expected to be minimal, although bentonite is often used to impart a yield stress in industrial materials at higher concentrations. The rheological properties of the 1.85 wt% Van-Gel solution were small with a yield stress of 0.2 Pa and consistency of 3.0 cP. It should also be noted that the effect of the wetting agent on the rheology of the resulting melter feeds was not considered in this report.

Results from these experiments on simulated vitrification streams show that the use of surfactants, wetting agents, and rheological modifiers may produce beneficial results. However, some surfactants and rheological modifiers have been shown to increase the yield stress and consistency indices of simulated melter feeds and simulated HLW pretreated sludges. Order-of-magnitude changes in rheological properties are not unexpected (Kay et al. 2003), but for slurries with rheological properties near the upper bounding conditions, such increases can produce a slurry that is difficult to process. The rheological effects of adding surfactants, wetting agents, and rheological modifiers should be thoroughly investigated with actual waste samples for each tank before WTP implementation.

4.6 Submerged Bed Scrubber (SBS) Recycle Analysis

A significant issue that has not thoroughly been investigated with actual waste experiments is the recycling of secondary waste streams. The primary recycled secondary waste stream for the HLW vitrification facility consists of an SBS solution that is recycled to the pretreatment facility to an evaporator that is upstream from the crossflow ultrafiltration (CUF) unit (see Figure 4.23). The SBS consisted of a bubbler bed submerged in water. The melter feed offgas is passed through the bubbler bed and through the water. This unit operation is used to cool the melter offgas stream and collect particulates carried over from the melter.

In creating the lower bounding condition of 0.4 cP for the clear liquid (i.e., supernate) viscosity, a particle size of 105 μm was assumed. The particle size of the simulated SBS solution has been measured and can be compared to this assumption. Results indicate that the D_{95} values for SBS fluids from six melter runs were as follows: 1) 24.50 μm, 2) 54.40 μm, 3) 26.39 μm, 4) 4.040 μm, 5) 9.571 μm, and 6) 13.86 μm (Matlack et al. 2002a). The largest particles were detected in the second set of tests and possessed a small quantity of particles (~0.5 vol%) in the 105-μm range. This particle size is consistent with the assumed maximum value 105 μm, and no significant change to the lower viscosity bound is warranted because of SBS particulates.

However, the particle sizes of the solids that precipitate during evaporation have not been measured. These solids may precipitate on the SBS particulates, resulting in larger particles. Large particles that are created during solids precipitation as a result of evaporation of the SBS solution/pretreated LAW mixture may result in fast settling, difficult-to-process slurries. In addition, the solids that precipitated in the simulated mixtures of SBS recycle and pretreated LAW were sodium aluminosilicates. These solids have historically caused processing difficulties in DWPF (Josephs et al. 2003) and may pose a problem in the HLW side of the WTP. The effects of evaporated SBS recycle streams should be evaluated with actual waste experimentation to limit risk to the WTP.

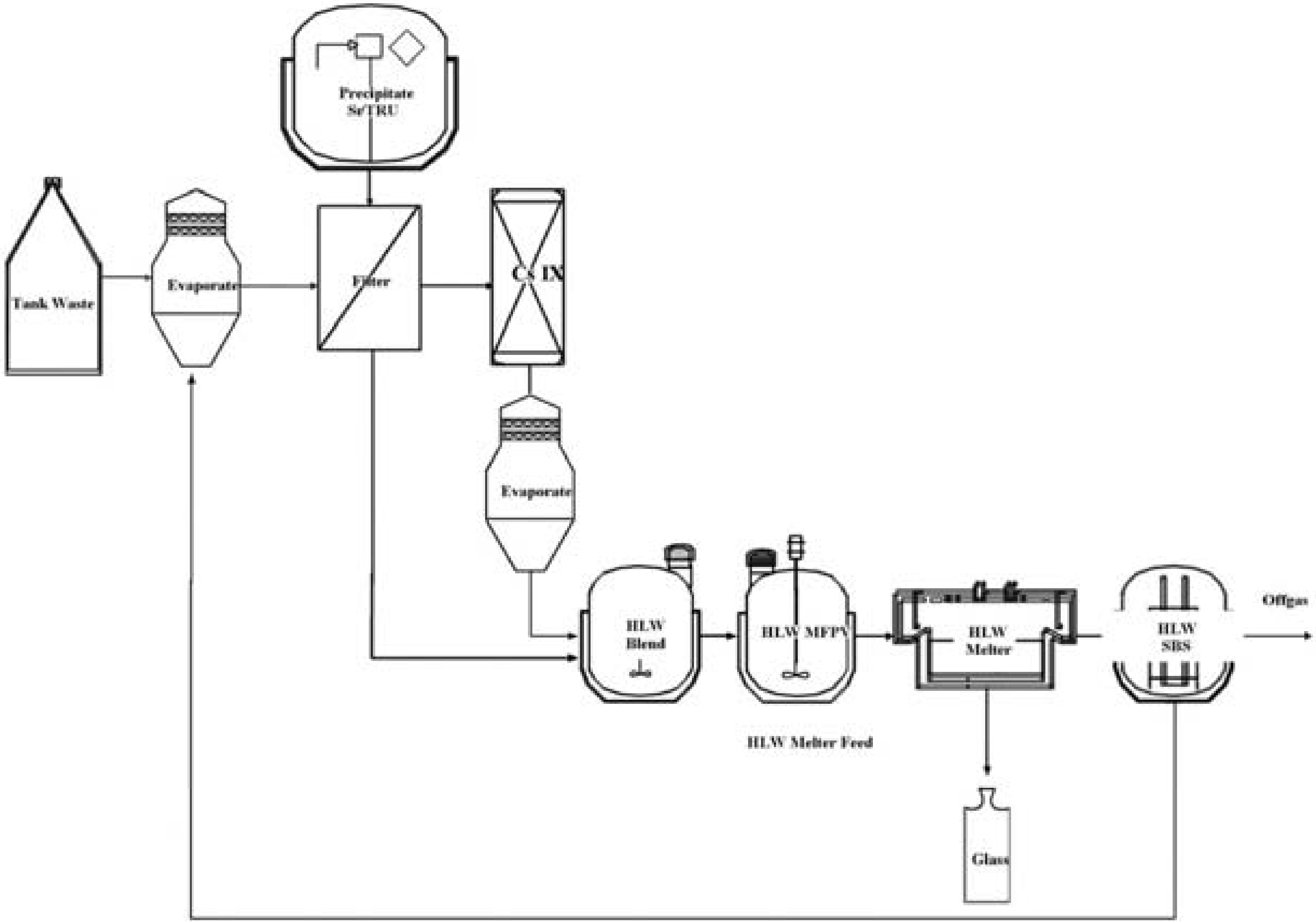


Figure 4.23. Basic HLW SBS Recycle Schematic

5.0 Quality Assurance Requirements

5.1 Application of RPP-WTP Quality Assurance Requirements

The PNWD Quality Assurance Program is based upon the requirements as defined in the U.S. Department of Energy (DOE) Order 414.1A, Quality Assurance and 10 CFR 830, Energy/Nuclear Safety Management, Subpart A—Quality Assurance Requirements (a.k.a. the Quality Rule). PNWD has chosen to implement the requirements of DOE Order 414.1A and 10 CFR 830, Subpart A by integrating them into the laboratory's management systems and daily operating processes. The procedures necessary to implement the requirements are documented through PNWD's Standards-Based Management System (SBMS).

PNWD implements the RPP-WTP quality requirements by performing work in accordance with the PNWD Waste Treatment Plant Support Project quality assurance project plan (QAPjP) approved by the RPP-WTP Quality Assurance (QA) organization. This work was performed to the quality requirements of NQA-1-1989 Part I, Basic and Supplementary Requirements, and NQA-2a-1990, Part 2.7. These quality requirements are implemented through PNWD's *Waste Treatment Plant Support Project (WTPSP) Quality Assurance Requirements and Description Manual*. The analytical requirements are implemented through WTPSP's Statement of Work (WTPSP-SOW-005) with the Radiochemical Processing Laboratory (RPL) Analytical Service Operations (ASO).

A matrix that cross-references the NQA-1, NQA-2a, and Quality Assurance Requirements and Description (QARD) requirements with the PNWD's procedures for this work was given in Test Plan, TP-RPP-WTP-205, *LAW and HLW Actual Waste and Simulant Coordination*. It included justification for those requirements not implemented.

5.2 Conduct of Experimental and Analytical Work

Experiments that were not method-specific were performed in accordance with PNWD's procedures QA-RPP-WTP-1101 "Scientific Investigations" and QA-RPP-WTP-1201 "Calibration Control System," ensuring that sufficient data were taken with properly calibrated measuring and test equipment (M&TE) to obtain quality results.

As specified in Test Specification, 24590-WTP-TSP-RT-01-007, Rev. 0, BNI's QAPjP, PL-24590-QA00001, is not applicable because the work was not performed in support of environmental/regulatory testing, and the data will not be used as such.

5.3 Internal Data Verification and Validation

PNWD addresses internal verification and validation activities by conducting an independent technical review (ITR) of the final data report in accordance with PNWD's Procedure QA-RPP-WTP-604. This review verifies that the reported results are traceable, that inferences and conclusions are soundly based, and that the reported work satisfies the Test Plan objectives. This review procedure is part of PNWD's *WTPSP Quality Assurance Requirements and Description Manual*.

6.0 Summary and Recommendations

Bounding conditions were developed for the HLW pretreated sludge and HLW melter feed. Table 6.1 summarizes the bounding conditions developed for the HLW pretreated sludge, and Table 6.2 summarizes the bounding conditions developed for the HLW melter feed. These data are equipment specific and have been developed for mixing, pumping, and settling applications. The strategy employed in developing the bounding conditions proposed in this document began by identifying correlations between dimensionless groups for specific unit operations performed in the WTP flowsheet. As the WTP will be using standard chemical processing equipment in many of their various unit operations, e.g., piping, pumps, and mechanical agitators, correlations for similar equipment that have been developed for standard chemical processing applications are used in this document to help develop correlations relevant to the WTP. Sources for these correlations included various engineering handbooks, engineering textbooks, and peer-reviewed journal articles. In addition, equipment data and calculations for previous vitrification plant designs were used, including the HWVP and DWPF (Jones and Peterson 1996). Based on these correlations, bounding conditions on the physical and rheological properties are proposed to satisfy equipment-performance issues. Actual waste data are used to tailor the bounding ranges such that the proposed bounding conditions span the existing actual waste materials. In this regard, the proposed bounding conditions are based upon a general engineering evaluation of process equipment and measured values from actual waste material. From this point, a sensitivity analysis on the dimensionless group can be used to determine the variations allowed for physical and rheological properties of the simulant.

Information from previous actual waste-characterization and simulant-development activities was compiled and compared against the proposed bounding conditions (e.g., Figures 4.11 – 4.18, 4.22. See also Appendix A). Several of the actual wastes possessed rheological properties outside of these bounding conditions. However, at lower solids concentrations, at least one measurement from each actual waste data set fell inside the proposed bounding conditions. This may be because of an asymptotic relationship between Bingham plastic parameters and undissolved solids concentration. At high undissolved solids concentrations, the Bingham plastic parameters can become quite large, and a relatively small amount of dilution can result in a significant decrease.

Many of the physical and rheological properties identified in Table 6.1 and Table 6.2 have not been measured or have been measured with varying operating conditions and techniques. Establishing consensus methods for significant properties, such as particle size, particle density,[a] and interstitial liquid (supernate) viscosity, is recommended. Once consensus methods are established for these significant parameters, a coordinated effort to verify and validate simulants of interest is recommended.[b] For these reasons, further testing is recommended to verify future simulants with respect to the criteria established in this document.

(a) Average particle density can be calculated from the following equation (Shook, Gillies, and Sanders 2002): $\frac{1}{\rho_m} = \frac{C_W}{\rho_s} + \frac{1 - C_W}{\rho_f}$ where ρ_m is the slurry density; ρ_s is the average particle density; ρ_f is the interstitial liquid density; and C_W is the mass fraction of undissolved solids in the slurry.

(b) The logic flow behind a coordinated verification/validation effort has been defined in *Simulant Definition and Verification Methodology* (24590-WTP-RPT-TE-01-003, Rev 0) and *Desk Instruction: R&T Simulant Development, Approval, Validation, and Documentation*, RPP-WTP, Effective Date: September 27, 2002.

Table 6.1. Summary of Bounding Conditions for HLW Pretreated Sludge

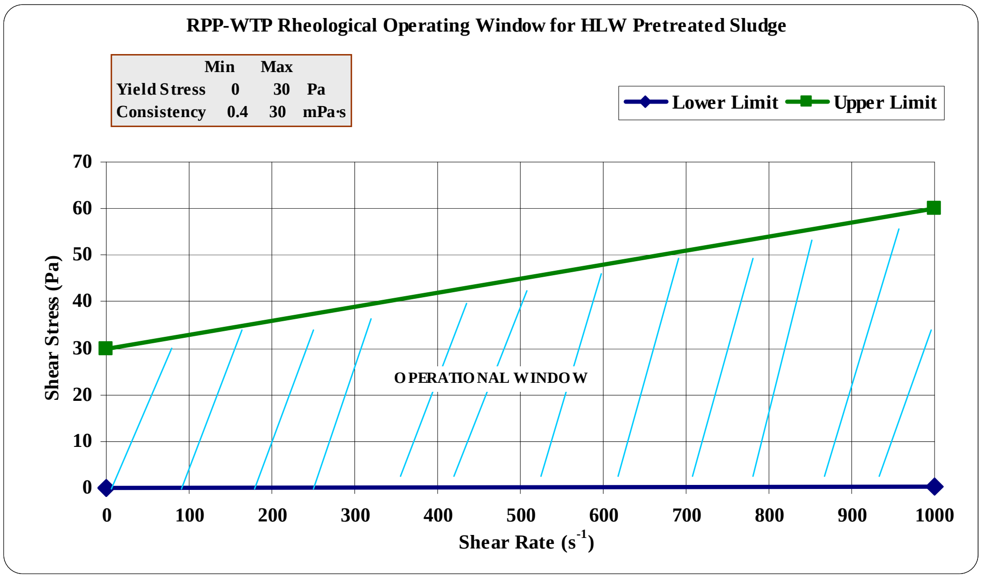
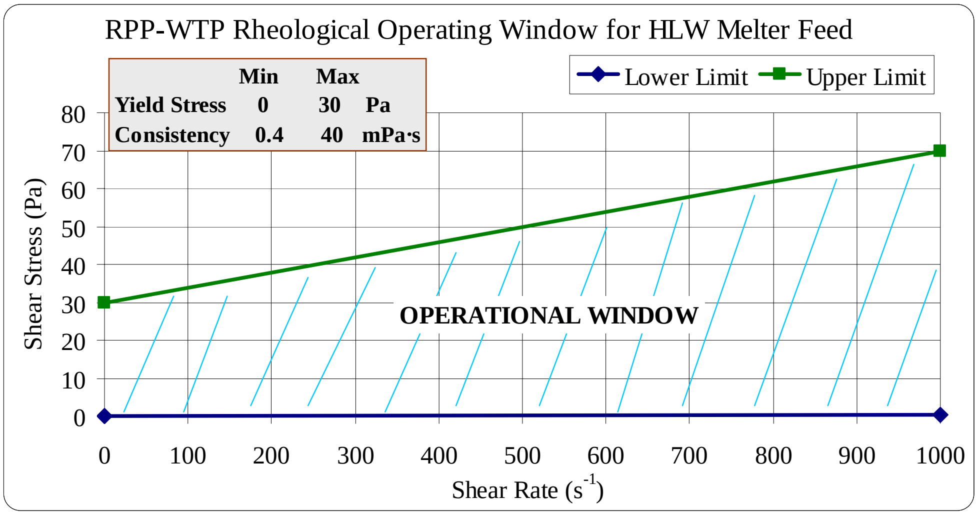
	Category	Value	Application
Bounding Conditions	Maximum Settled Solids Shear Strength	< 625 Pa	Plant Upset Conditions
	Maximum Hedstrom Number in 2-in. Pipe $N_{He} = \dfrac{D^2 \rho \tau_y}{K^2}$	$< 10^8$	Pumping
			Pumping, Mixing, Erosion, Settling in Pipes

Table 6.2. Summary of Bounding Conditions for HLW Melter Feed

<table>
<tr><th></th><th>Category</th><th>Value</th><th>Application</th></tr>
<tr><td rowspan="3">Bounding Conditions</td><td>Maximum Settled Solids Shear Strength</td><td>< 625 Pa</td><td>Plant Upset Conditions</td></tr>
<tr><td>Maximum Hedstrom Number in 2-in. Pipe
$N_{He} = \frac{D^2 \rho \tau_y}{K^2}$</td><td>$< 10^8$</td><td>Pumping</td></tr>
<tr><td>
</td><td></td><td>Pumping, Mixing, Erosion, Settling in Pipes</td></tr>
</table>

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Appendix A

Chemical, Rheological, and Physical Properties Database[a]

(a) Note that Appendices A and B contain data from previous reports on the physical, chemical, and rheological properties of actual and simulated WTP vitrification streams. The data in Appendix A are contained in a spreadsheet that is broken into four worksheets: 1) "**Envelope D Waste Composition**" contains information on the chemical and radiochemical composition of the materials, 2) "**Envelope D Melter Feed Preparation**" contains information on the melter-feed composition and mixing of the melter feed materials, 3) "**Envelope D Waste and Melter Feed Physical Property Data**" contains information on the physical properties of the materials, 4) "**Envelope D Waste and Melter Feed Rheological Property Data**" contains information on the rheological properties of the materials. Note that the sample number is given in the first row of each page of the table to allow the reader to follow the sample data from page to page. A reference for each sample is given on the first page of each the four worksheets of Appendix A. In some cases calculations and approximations of the reported values from the source documents were performed to transform these data to a common reporting basis. If performed, it is described in the reference row of the tables. Entries in the first column of the tables apply to all the other columns of the table. Data from one section of Appendix A relates to data in other sections of Appendix A through the references given in the third row of each section (A.1, A.2, etc). Because of the large amount of data in the source documents, the summarized data in Appendices A and B may not be comprehensive, though that was the original intent. Blank spaces in these tables indicate that relevant data was not identified by the author in the cited reports.

Appendix A: Chemical, Rheological, and Physical Properties Database

Table A.1 Envelope D Waste Composition

Sample Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Sample Description	C-104 (Envelope D) Pretreated Sludge Waste	C-104 (Envelope D) Pretreated Sludge Waste plus Secondary Wastes	Pretreated HLW Sludge C-104 (5 wt% suspended solids) PNNL 25°C	Pretreated HLW Sludge C-104 (15 wt% suspended solids) PNNL 25°C	Pretreated HLW Sludge C-104 (25 wt% suspended solids) PNNL 25°C	AZ102 (Envelope D) Composited Pretreated Sludge Waste	AZ102 (Envelope D) Composited Pretreated Sludge Waste plus Secondary Wastes	Pretreated HLW Sludge AZ102 (15 wt% suspended solids) PNNL 25°C	Pretreated HLW Sludge AZ-102 New Sample (20 wt% suspended solids) PNNL 25°C	Pretreated HLW Sludge AZ102 (25 wt% suspended solids) PNNL 25°C
References and Notes on Data	WTP-RPT-006, Rev. 0, See Table 3.1 for elemental composition and radionuclide activities and Table 3.6 for Oxide wt%. The C-104 (Envelope D) Pretreated Sludge Waste plus Secondary Wastes composition is computed from the first three columns of Table 3.6 taking each waste in the proportions 0.76298 to 0.01486 to 0.22216. For aluminum it is written as =8.723*0.76298+0.01486*2.35+0.22216*1.95 where the wt% secondary waste components are also given in Table 3.6.					WTP-RPT-006, Rev. 0, See Table 3.2 for elemental composition and radionuclide activities , solids content, and equivalent oxide and Table 3.9 for Oxide wt%. Note that the composition of AZ102 (Envelope D) Composited Pretreated Sludge Waste plus Secondary Wastes was computed as for C-104 Pretreated Sludge Waste plus Secondary Wastes.				
Sample History (include washing, leaching, chemical precipitation, mechanical agitation of any kind (time and intensity)										
wt% dry solids	20.00					9.54		~15	~20	~25
Oxides Loading of HLW Sludge or Pretreated Sludge: Total grams oxide/Liter	157.6					73.0				
pH of the Waste										
Analyte (mg/kg HLW)										
Cations										
Ag	1895					442				
Al	36700					101600				
As										
B	52					63				
Ba	426					842				
Be	58					24				
Bi	71					0				
Ca	8547					8258				
Cd	1669					30575				
Ce	1868					1223				
Co	58					140				
Cr	1953					1515				
Cs										
Cu	465					506				
Dy	76					0				

Table A.1 Envelope D Waste Composition

Sample Number	1	2	3	4	5	6	7	8	9	10
Eu	32					0				
Fe	89029					210250				
Hg	32					0				
K	500					0				
La	294					6353				
Li	478					0				
Mg	1066					1805				
Mn	19671					5045				
Mo	31					0				
Na	58529					47700				
Nd	558					4477				
Ni	5664					15000				
P	4290					4985				
Pb	2949					2035				
Pd	0[f]					0				
Pr	124					0				
Pt	< 1					0				
Rb										
Rh	825					0				
Ru	390					0				
S										
Sb										
Se	79					0				
Si	21950					7368				
Sn	1700					3225				
Sr	189					474				
Ta	7					0				
Te										
Th	113043					0				
Ti	301					160				
Tl										
U	99914, 88700					35575				
V	65					51				
W										
Y	74					287				
Zn	815					780				
Zr	112250					27200				
Carbon Analysis										
TIC										
TOC										
Anions										
F										
Cl						196				
Br	< 11					883				
NO_2	100					< 260				
NO_3	320					< 530				
PO_4	525					< 530				
SO_4	65					579				

Table A.1 Envelope D Waste Composition

Sample Number	1	2	3	4	5	6	7	8	9	10
C_2O_4						451				
CO_3						< 530				
CN	14									
NH_3	< 0.8					8				
Free OH										
Total OH										
Oxide wt%										
Ag_2O	0.256	0.198				0.06	0.06			
Al_2O_3	8.723	7.124				25.07	23.02			
As_2O_3										
B_2O_3	0.021	0.055				0.03	0.06			
BaO	0.06	0.057				0.12	0.11			
BeO	0.02	0.015				0.01	0.01			
Bl_2O_3	0.01	0.008								
CaO	1.505	1.379				1.509	1.43			
CdO	0.24	0.183				4.558	4.19			
Cl						0.16	0.17			
CeO_2	0.275	0.245				0.19	0.12			
Co_2O_3	0.009	0.007				0.02	0.02			
Cr_2O_3	0.359	0.418				0.29	0.28			
Cs_2O	0.027	0.188				0.02	0.12			
CuO	0.073	0.075				0.08	0.09			
Dy_2O_3	0.011	0.008								
Eu_2O_3	0.005	0.004								
F						0.04	0.03			
Fe_2O_3	16.013	14.249				39.254	36.39			
HgO	0.004	0.003								
K_2O	0.076	0.169				0	0.08			
La_2O_3	0.043	0.057				0.98	0.89			
Li_2O	0.129	0.098				0	0			
MgO	0.222	0.178				0.39	0.36			
MnO_2	3.195	7.699				0.85	2.76			
MoO_3	0.006	0.007				0	0			
Na_2O	9.925	11.638				8.397	8.93			
Nd_2O_3	0.082	0.134				0.68	0.63			
NO	0.907	0.712				2.489	2.3			
P_2O_3	1.237	0.998				1.499	1.38			
PbO	0.4	0.463				0.29	0.28			
PdO		0.033					0			
Pr_6O_{11}	0.019	0.014								
PtO_2										
Rh_2O_3	0.128	0.098								
RuO_2	0.065	0.050								
SO_3						0.07	0.06			
Sb_2O_5										
SeO_2	0.014	0.011								
SiO_2	5.906	4.800				2.049	1.92			
SnO_2	0.272	0.208				0.54	0.49			
SrO	0.028	10.243				0.07	4.47			

Table A.1 Envelope D Waste Composition

Sample Number	1	2	3	4	5	6	7	8	9	10
Ta_2O_5										
TeO_2										
ThO_2	16.184	12.386					0			
TiO_2	0.063	0.050				0.03	0.03			
UO_2	14.26	10.974				5.278	4.86			
V_2O_3	0.015	0.011								
Y_2O_3	0.012	0.009				0.05	0.04			
ZnO	0.128	0.112				0.13	0.12			
ZrO_2	19.075	14.629				4.798	4.4			
Volatiles (g/100g oxides)										
CO_3										
NO_2										
NO_3										
TOC										
Radioisotopes (µCi/g dry solids)										
H-3	3.20E-03[a]					1.56E+2[a]				
C-14	3.43 E-3					0.00236				
Cr-51										
Fe-59										
Ni-59										
Co-60	0.407					7.4				
Ni-63										
Se-79										
Y-88										
Sr-90	1280					24900				
Sr-90/Y-90										
Nb-94/95	0.241									
Tc-99	0.0421					0.0264				
Ru-103						11.8				
Ru-106										
Sn-113										
Sb-125	0.394					40.3				
Sn-126										
Sb/Sn-126	< 4E-2					< 2.7E-2				
I-127										
I-129	< 7E-05					< 4.4E-8				
C-133										
Cs-134	< 3E-2					< 7E-1				
Cs-135						37				
Cs-137	53.4					169				
Ce-144										
Sm-151										
Ru-152	< 3E-1									
Pa-231	3.92					72.8				
U-233	2.29					134				
U-234										
U-235	0.423									
U-236										
U-238										

Table A.1 Envelope D Waste Composition

Sample Number	1	2	3	4	5	6	7	8	9	10
Np-237										
Pu-236										
Pu-238	0.0099					0.123				
Pu-239						< 0.3				
Pu-240						1.57				
Pu-239/240	12.6									
Pu-241	0.017									
Pu-242						9.83				
Pu-241/Am-241										
Am-241	12.7					175				
Am-241/ Am-243	12.5					203				
Am-242										
Am-243										
Cm-242										
Cm-243										
Cm-244	0.0171									
Cm-243/244	0.171					0.281				
Sum of Alpha (TRU) = Σ (Pu-238, Pu-239, Pu-240, Am-241)										
Total alpha										
Total beta										
Total gamma										
Organic Analytes										
Oxalate										
Citrate										
Fornate										
Gluconate										
Glycolate										
EDTA (ethylenediaminetetraacetic acid)										
HEDTA (N-(2-hydroxyethyl) ethylenediaminetriacetic acid)										
D2EHPA (bis-(2-ethylhexyl)phosphate										
NTA (nitrilotriacetic acid)										
IDA (iminodiacetic acid)										
Succinic Acid										
ED3A (ethylenediaminetriacetic acid)										
Analytes Obtained on an Opportunistic Basis										
a = mCi/g wet slurry										

Table A.1. Envelope D Waste Composition

Sample Number	11	12	13	14	15	16	17	18	19	20	21	22	23
Sample Description	Sim. Pretreated HLW AZ-101 (27.7 wt% total solids) VSL	Sim. Pretreated HLW AZ-102 (27.1 wt% total solids) VSL	Sim. Pretreated HLW C-106/AY-102 (28.8 wt% total solids) VSL	Simulated Waste AZ-101 SRTC	Sim. Pretreated HLW AZ-101 (9 wt% total solids) SRTC 25°C	Sim. Pretreated HLW AZ-101 (11.6 wt% total solids) SRTC 25°C	Sim. Pretreated HLW AZ-101 (16.3 wt% total solids) SRTC 25°C	Sim. Pretreated HLW AZ-101 (20.8 wt% total solids) SRTC 25°C	Simulated Waste AZ-102 SRTC	Sim. Pretreated HLW AZ-102 (10.6 wt% total solids) SRTC 25°C	Sim. Pretreated HLW AZ-102 (12.8 wt% total solids) SRTC 25°C	Sim. Pretreated HLW AZ-102 (15.6 wt% total solids) SRTC 25°C	Sim. Pretreated HLW AZ-102 (20.5 wt% total solids) SRTC 25°C
References and Notes on Data	VSL Report 2520-1, See Tables 2.11, 2.12, 2.13			WSRC-TR-2001-00203, Rev.0 See Table B-1 for AZ-101 and Table B-8 for AZ-102 For oxide weight % see Tables B-6 and B-12									
Sample History (include washing, leaching, chemical precipitation, mechanical agitation of any kind (time and intensity)													
wt% dry solids	27.70	27.10	28.80	15.00	9.00	11.60	16.30	20.80	15.00	10.60	12.80	15.60	20.50
Oxides Loading of HLW Sludge or Pretreated Sludge: Total grams oxide/Liter													
pH of the Waste													
Analyte (mg/kg HLW)													
Cations													
Ag				2235					464				
Al				57907					107000				
As													
B				803					228				
Ba				2114					944				
Be													
Bi													
Ca				9036					1007				
Cd				22295					32120				
Ce				2817					1550				
Co				2860					118				
Cr				2238					1582				
Cs													
Cu				979					5				
Dy													
Eu													
Fe				285023					220560				
Hg													
K				6365									
La				11520					7094				
Li													
Mg				1610					1950				
Mn				6630					5369				
Mo				144									
Na				82976					75100				

Table A.1. Envelope D Waste Composition

Sample Number	11	12	13	14	15	16	17	18	19	20	21	22	23
Nd				7696					233				
Ni				17552					16190				
P													
Pb				3258					62				
Pd													
Pr													
Pt													
Rb													
Rh													
Ru													
S													
Sb													
Se													
Si				14084					7100				
Sn													
Sr				1508					4				
Ta													
Te													
Th													
Ti				274					145				
Tl													
U													
V													
W													
Y													
Zn				865					921				
Zr				95366					32650				
Carbon Analysis													
TIC				7161									
TOC									1625				
Anions													
F				1390					300				
Cl				255					1300				
Br													
NO_2				35942					1750				
NO_3				25238					8350				
PO_4				1678					897				
SO_4				9078					1200				
C_2O_4													
CO_3													
CN													
NH_3													
Free OH													
Total OH													
Oxide wt%													
Ag_2O		0.14	0.46	0.18					0.05				
Al_2O_3	24.27	26.36	21.13	13.6					27.97				
As_2O_3	0.13	0.13											
B_2O_3		0.25											

Table A.1. Envelope D Waste Composition

Sample Number	11	12	13	14	15	16	17	18	19	20	21	22	23
BaO	0.14	0.11	0.13	0.22					0.16				
BeO													
Bl_2O_3													
CaO	0.81	0.82	1.4	0.71					0.22				
CdO	1.22	2.69	0.09	2.64					5.25				
Cl	0.02	0.05	0.05										
CeO_2	0.27	0.15	0.06	0.26					0.2				
Co_2O_3				0.4					0.03				
Cr_2O_3	0.14	0.27	0.32	0.36					0.32				
Cs_2O	0.27	0.31	0.2										
CuO	0.09	0.06		0.13									
Dy_2O_3													
Eu_2O_3													
F	0.12	0.05	0.05										
Fe_2O_3	34.08	38.1	22.99	44.03					45.87				
HgO													
K_2O	0.55	0.18	0.05	0.99									
La_2O_3	1.06	1.07	0.22	1.39					1.2				
Li_2O													
MgO	0.21	0.24	0.43	0.09					0.48				
MnO_2	9.94	4.83	8.7	0.96					1.06				
MoO_3				0.02									
Na_2O	1.96	5.42	16.4	11.06					3.76				
Nd_2O_3				0.92					0.05				
NO	1.76	2.3	0.3	2.42					3.08				
P_2O_3	0.42	0.19	0.3	2.86					1.02				
PbO	0.5	0.24	0.42	0.37									
PdO													
Pr_6O_{11}													
PtO_2													
Rh_2O_3													
RuO_2													
SO_3	0.82	0.09	0.05										
Sb_2O_5	0.69	1.18											
SeO_2	0.49	0.21											
SiO_2	0.07	1.71	11.55	3.37					2.44				
SnO_2													
SrO	7.6	7.75	14.41	0.1					0.07				
Ta_2O_5													
TeO_2	0.47	0.06											
ThO_2													
TiO_2	0.21		0.08										
UO_2													
V_2O_3													
Y_2O_3													
ZnO		0.06		0.13					0.18				
ZrO_2	11.68	5	0.23	12.77					6.08				
Volatiles (g/100g oxides)													
CO_3	3	0.03?	8.24										

Table A.1. Envelope D Waste Composition

Sample Number	11	12	13	14	15	16	17	18	19	20	21	22	23
NO_2	0.91	0.04?	0.002										
NO_3	1.88	0.03?	1.013										
TOC	1.27	0.43?	1.24										
Radioisotopes (µCi/g dry solids)													
H-3													
C-14													
Cr-51													
Fe-59													
Ni-59													
Co-60													
Ni-63													
Se-79													
Y-88													
Sr-90													
Sr-90/Y-90													
Nb-94/95													
Tc-99													
Ru-103													
Ru-106													
Sn-113													
Sb-125													
Sn-126													
Sb/Sn-126													
I-127													
I-129													
C-133													
Cs-134													
Cs-135													
Cs-137													
Ce-144													
Sm-151													
Ru-152													
Pa-231													
U-233													
U-234													
U-235													
U-236													
U-238													
Np-237													
Pu-236													
Pu-238													
Pu-239													
Pu-240													
Pu-239/240													
Pu-241													
Pu-242													
Pu-241/Am-241													
Am-241													
Am-241/ Am-243													

Table A.1. Envelope D Waste Composition

Sample Number	11	12	13	14	15	16	17	18	19	20	21	22	23
Am-242													
Am-243													
Cm-242													
Cm-243													
Cm-244													
Cm-243/244													
Sum of alpha (TRU) = Σ (Pu-238, Pu-239, Pu-240, Am-241)													
Total alpha													
Total beta													
Total gamma													
Organic Analytes													
Oxalate													
Citrate													
Fornate													
Gluconate													
Glycolate													
EDTA (ethylenediaminetetraacetic acid)													
HEDTA (N-(2-hydroxyethyl) ethylenediaminetriacetic acid)													
D2EHPA (bis-(2-ethylhexyl)phosphate													
NTA (nitrilotriacetic acid)													
IDA (iminodiacetic acid)													
Succinic Acid													
ED3A (ethylenediaminetriacetic acid)													
Analytes Obtained on an Opportunistic Basis													

Table A.1. Envelope D Waste Composition

Sample Number	24	25	26	27
Sample Description	Low Bound HLW Pretreated Waste Physical Simulant (20-L)	High Bound HLW Pretreated Waste Physical Simulant (41-H)	HLW Precipitated Hydroxide Simulant	AY102/C106 pretreated sludge
References and Notes on Data	(WSRC-TR-2003-00220, Rev. 0, SRT-RPP-2003-00098, Rev. 0) Note that only the composition of the precipitated hydroxide waste simulant and melter feed simulant are given. The physical simulants are all simplified versions that were developed to match bounding rheological properties and other physical aspects. All of the make up procedures are given in the reference documents.			WSRC-TR-2004-00394, REV. 0 SRT-RPP-2004-00061, REV. 0
Sample History [include washing, leaching, chemical precipitation, mechanical agitation of any kind (time and intensity)]	See recipe in Appendix D of reference.	See recipe in Appendix E of reference.	See recipe in Appendix F of reference. Made up using a washed precipitated hydroxide base.	"It is recommended that future testing be considered to validate the properties of the AY102/C106 pretreated sludge and characterizing a representative melter feed." Section 1.7, Page 12, WSRC-TR-2004-00394, REV. 0, Based on this statement from the report, data on this waste sample is given for information only.
wt% dry solids	14.61	36.37	22.26	32.5 (calc.)
Oxides Loading of HLW Sludge or Pretreated Sludge: Total grams oxide/Liter				
pH of the Waste	12.48	12.81	12.48	11.38
Analyte (mg/kg HLW)				
Cations				
Ag			<280	1139
Al			86659	16953
As				
B			3573	527
Ba			1657	438
Be				
Bi				
Ca			8884	2135
Cd			11098	72
Ce			3444	569
Co			150	
Cr			2344	1001
Cs				
Cu			609	172
Dy				
Eu				
Fe			202384	64267
Hg				
K			2840	57
La			3755	425
Li				119
Mg			1554	567
Mn			5438	14326
Mo			<90	140

Table A.1. Envelope D Waste Composition

Sample Number	24	25	26	27
Na			41630	26130
Nd			3108	
Ni			9970	2127
P			2564	1607
Pb				3287
Pd				22
Pr				520
Pt				
Rb				
Rh			546	52
Ru			947	600
S			666	498
Sb				208
Se				
Si			21558	16229
Sn			1554	308
Sr				937
Ta				31
Te				
Th				
Ti			341	127
Tl				
U				2895
V				60
W				
Y				
Zn			337	163
Zr			60420	2244
Carbon Analysis				
TIC				
TOC			186	
Anions				
F			172	
Cl			443	
Br				
NO_2				
NO_3				
PO_4				
SO_4				
C_2O_4				
CO_3				
CN				
NH_3				
Free OH				
Total OH				
Oxide wt%				
Ag_2O				0.50
Al_2O_3				13.17
As_2O_3				

Table A.1. Envelope D Waste Composition

Sample Number	24	25	26	27
B_2O_3				0.70
BaO				0.20
BeO				
Bi_2O_3				
CaO				1.23
CdO				0.03
Cl				
CeO_2				0.27 (Ce_2O_3)
Co_2O_3				
Cr_2O_3				0.60
Cs_2O				
CuO				0.09
Dy_2O_3				
Eu_2O_3				
F				
Fe_2O_3				37.79
HgO				
K_2O				0.03
La_2O_3				0.20
Li_2O				0.11
MgO				0.39
MnO_2				7.61
MoO_3				0.09
Na_2O				14.48
Nd_2O_3				
NiO				1.11
P_2O_5				1.51
PbO				1.46
PdO				
Pr_6O_{11}				
PtO_2				
Rh_2O_3				
RuO_2				
SO_3				0.51
Sb_2O_5				0.10
SeO_2				
SiO_2				14.28
SnO_2				0.16
SrO				0.46
Ta_2O_5				
TeO_2				
ThO_2				
TiO_2				0.09
UO_2				1.40
V_2O_3				0.04
Y_2O_3				
ZnO				0.08
ZrO_2				1.25
Volatiles (g/100g oxides)				

Table A.1. Envelope D Waste Composition

Sample Number	24	25	26	27
CO_3				
NO_2				
NO_3				
TOC				
Radioisotopes (µCi/g dry solids)				
H-3				
C-14				
Cr-51				
Fe-59				
Ni-59				
Co-60				1.40E-01
Ni-63				
Se-79				
Y-88				
Sr-90				3569
Sr-90/Y-90				
Nb-94/95				
Tc-99				1.45E-02
Ru-103				
Ru-106				
Sn-113				
Sb-125				
Sn-126				
Sb/Sn-126				
I-127				
I-129				
C-133				
Cs-134				
Cs-135				
Cs-137				253
Ce-144				
Sm-151				
Eu-152				
Eu-154				2.19
Eu-155				1.14
Ru-152				
Pa-231				
U-233				1.40E-02
U-234				9.55E-04
U-235				2.91E-05
U-236				4.75E-05
U-238				7.14E-04
Np-237				5.52E-03
Pu-236				
Pu-238				0.29
Pu-239				2.28
Pu-240				0.40
Pu-239/240				
Pu-241				113

Table A.1. Envelope D Waste Composition

Sample Number	24	25	26	27
Pu-242				2.89E-04
Pu-241/Am-241				
Am-241				3.76
Am-241/ Am-243				
Am-242				
Am-243				1.40E-02
Cm-242				
Cm-243				
Cm-244				
Cm-243/244				
Sum of alpha (TRU) = Σ (Pu-238, Pu-239, Pu-240, Am-241)				
Total alpha				46.7
Total beta				9176
Total gamma				
Organic Analytes				
Oxalate				
Citrate				
Fornate				
Gluconate				
Glycolate				
EDTA (ethylenediaminetetraacetic acid)				
HEDTA (N-(2-hydroxyethyl) ethylenediaminetriacetic acid)				
D2EHPA (bis-(2-ethylhexyl)phosphate				
NTA (nitrilotriacetic acid)				
IDA (iminodiacetic acid)				
Succinic Acid				
ED3A (ethylenediaminetriacetic acid)				
Analytes Obtained on an Opportunistic Basis				

Table A.1. Envelope D Waste Composition

Sample Number	28	29	30	31	32	33	34
Sample Description	AZ-101 simulant	AZ-102 simulant	C-104 simulant	C-106/AY-102 Simulant	AZ-101 simulant (later version)	C-106/AY-102 Simulant (later version)	AZ-102 simulant (later version)
References and Notes on Data	HLW Tank Waste plus Pretreatment Products. See Table 2.5 in VSL-01R2540-2				DuraMelter 1200 HLW Pilot Melter System Using AZ-101 HLW Simulants. VSL-02R0100-2, Rev. 1, See Table 2.1. Waste composition used with additive chemicals	DM 1200 Melter Testing of HLW C-106/AY-102 Composition Using Bubblers. VSL-03R3800-1, Rev. 0. See Table 2.1	DM 1200 Melter Testing of HLW AZ-102 Composition Using Bubblers. VSL-03R3800-2, Rev. 0. See Table 2.1
Sample History (include washing, leaching, chemical precipitation, mechanical agitation of any kind (time and intensity)						Blended waste including Recycle, Sr/TRU, Cs- Eluate, and Tc- Eluate.	Blended waste including Recycle, Sr/TRU, Cs- Eluate, and Tc- Eluate.
wt% dry solids							
Oxides Loading of HLW Sludge or Pretreated Sludge: Total grams oxide/Liter							
pH of the Waste							
Analyte (mg/kg HLW)							
Cations							
Ag						6174	1638
Al						84235	156930
As						6568	136
B						1906	8486
Ba						238	316
Be						328	25
Bi						115	207
Ca						9732	8849
Cd						21	5245
Ce						156	237
Co						1376	145
Cr						2403	706
Cs						14	75
Cu						1597	552
Dy						-	-
Eu						-	-
Fe						399329	464819
Hg						1718	43
K						262	1437
La						9329	16972
Li						145	195
Mg						31946	2281
Mn						114765	11940
Mo						264	260
Na						19664	30490
Nd						5846	6311
Ni						6128	18614
P							

Table A.1. Envelope D Waste Composition

Sample Number	28	29	30	31	32	33	34
Pb						6067	3497
Pd						-	209
Pr						-	1194
Pt						-	-
Rb						-	18
Rh						-	126
Ru						-	-
S							
Sb						9664	-
Se						11946	-
Si						43221	25.2
Sn						-	-
Sr						35168	488
Ta						-	-
Te						-	-
Th						-	-
Ti						3819	137
Tl						-	-
U						13	131
V						1	-
W						-	-
Y						-	-
Zn						2557	426
Zr						8725	69510
Carbon Analysis							
TIC						58658	14733
TOC						330	638
Anions							
F						34	180
Cl						4926	76
Br						-	-
NO_2						153	5245
NO_3						9866	24307
PO_4						5725	1797
SO_4						81	2623
C_2O_4						330	638
CO_3						58658	14733
CN						-	-
NH_3						-	-
Free OH						36900	
Total OH						64161	17740
Oxide wt%							
Ag_2O	0.21	0.14	-	0.46	-	-	-
Al_2O_3	23.24	25.59	27.75	20.91	24.27	12.77	23.01
As_2O_3	0.13	0.13	-	-	-	0.69	-
B_2O_3	-	0.24	0.09	-	-	0.49	2.12
BaO	0.13	0.11	0.00	0.13	0.14	-	-
BeO	-	-	-	-	-	-	-
Bi_2O_3	-	-	-	-	-	-	-

Table A.1. Envelope D Waste Composition

Sample Number	28	29	30	31	32	33	34
CaO	0.78	0.80	0.90	1.39	0.81	1.09	0.96
CdO	1.17	2.61	0.18	0.09	1.22	-	0.47
Cl	0.03	0.05	-	0.05	0.02	0.39	-
CeO_2	0.26	0.15	-	0.06	0.27	-	-
Co_2O_3	-	-	0.14	-	-	-	-
Cr_2O_3	0.14	0.26	0.41	0.32	0.14	0.28	-
Cs_2O	0.27	0.30	0.33	0.20	0.27	0.18	0.21
CuO	0.09	0.06	-	-	0.09	0.16	-
Dy_2O_3	-	-	-	-	-	-	-
Eu_2O_3	-	-	-	-	-	-	-
F	0.12	0.05	0.00	0.05	0.12	0.36	0.42
Fe_2O_3	32.63	36.99	11.29	22.76	34.08	45.35	51.58
HgO	-	-	0.03	-	-	-	-
K_2O	0.53	0.18	0.23	0.05	0.55	-	0.13
La_2O_3	1.02	1.04	0.01	0.22	1.06	0.87	1.55
Li_2O	-	0.01	-	-	-	0.02	0.03
MgO	0.20	0.24	0.09	0.43	0.21	4.21	0.30
MnO_2	10.38	4.69	4.92	8.61	9.94	14.41	1.47
MoO_3	-	-	-	-	-	-	-
Na_2O	1.87	5.26	8.58	16.23	1.96	2.11	3.18
Nd_2O_3	-	-	-	-	-	0.54	0.68
NiO	1.69	2.23	0.71	0.30	1.76	0.62	1.84
P_2O_5	0.40	0.18	0.62	0.29	0.42	0.34	0.10
PbO	0.48	0.23	0.16	0.42	0.50	0.52	0.29
PdO	-	-	-	0.01	-	-	-
Pr_6O_{11}	-	-	-	-	-	-	-
PtO_2	-	-	-	-	-	-	-
Rh_2O_3	0.13	0.09	-	0.01	-	-	-
RuO_2	0.26	0.03	-	0.02	-	-	-
SO_3	0.78	0.08	0.00	0.05	0.82	-	0.17
Sb_2O_5	0.66	1.14	-	-	0.69	0.92	-
SeO_2	0.47	0.20	-	-	0.49	1.34	-
SiO_2	0.07	1.66	4.44	11.43	0.07	7.35	4.17
SnO_2	-	-	-	-	-	-	-
SrO	7.28	7.52	5.98	14.26	7.60	3.31	-
Ta_2O_5	-	-	-	-	-	-	-
TeO_2	0.45	0.06	-	-	0.47	-	-
ThO_2	-	-	2.41	-	-	-	-
TiO_2	0.20	-	-	0.08	0.21	0.51	-
UO_2	2.78	2.79	7.36	1.01	-	-	-
V_2O_3	-	-	-	-	-	-	-
Y_2O_3	-	-	-	-	-	-	-
ZnO	-	0.05	0.19	-	-	0.25	0.04
ZrO_2	11.18	4.85	23.18	0.23	11.68	0.93	7.29
Volatiles (g/100g oxides)							
CO_3					3.00		1.145
NO_2					0.95		0.407
NO_3					1.97		1.883
TOC					1.32		0.050

Table A.1. Envelope D Waste Composition

Sample Number	28	29	30	31	32	33	34
Radioisotopes (µCi/g dry solids)							
H-3							
C-14							
Cr-51							
Fe-59							
Ni-59							
Co-60							
Ni-63							
Se-79							
Y-88							
Sr-90							
Sr-90/Y-90							
Nb-94/95							
Tc-99							
Ru-103							
Ru-106							
Sn-113							
Sb-125							
Sn-126							
Sb/Sn-126							
I-127							
I-129							
C-133							
Cs-134							
Cs-135							
Cs-137							
Ce-144							
Sm-151							
Ru-152							
Pa-231							
U-233							
U-234							
U-235							
U-236							
U-238							
Np-237							
Pu-236							
Pu-238							
Pu-239							
Pu-240							
Pu-239/240							
Pu-241							
Pu-242							
Pu-241/Am-241							
Am-241							
Am-241/ Am-243							
Am-242							
Am-243							
Cm-242							

Table A.1. Envelope D Waste Composition

Sample Number	28	29	30	31	32	33	34
Cm-243							
Cm-244							
Cm-243/244							
Sum of alpha (TRU) = Σ (Pu-238, Pu-239, Pu-240, Am-241)							
Total alpha							
Total beta							
Total gamma							
Organic Analytes							
Oxalate							
Citrate							
Fornate							
Gluconate							
Glycolate							
EDTA (ethylenediaminetetraacetic acid)							
HEDTA (N-(2-hydroxyethyl) ethylenediaminetriacetic acid)							
D2EHPA (bis-(2-ethylhexyl)phosphate							
NTA (nitrilotriacetic acid)							
IDA (iminodiacetic acid)							
Succinic Acid							
ED3A (ethylenediaminetriacetic acid)							
Analytes Obtained on an Opportunistic Basis							

Table A.1. Envelope D Waste Composition

Sample Number	35	36	37	38	39	40
Sample Description	C-104/AY-101 Simulant	AZ-101 Simulant	AZ-101 Simulant	C-106/AY-102 Simulant	AZ-101 Simulant	AZ-102 Simulant
References and Notes on Data	DM 1200 Tests with C-104/AY-101 HLW Simulants VSL-03R3800-3, Rev. 0. See Table 2.1 and Table 2.2	DM 1200 Tests with AZ-101 HLW Simulants VSL-03R3800-4, Rev. 0. See Table 2.1 and Table 2.2	DM 1200 Melter Testing of Redox Effects Using HLW AZ-101 and C-106/AY-102 Simulants. VSL-04R4800-1, Rev. 0. See Table 2.1, 2.2, 2.4, and 2.5		DM 1200 Melter Testing of Bubblers Configurations Using HLW AZ-101 Simulants. VSL-04R4800-4, Rev. 0. See Table 2.1	DM 1200 MelterTesting of Redox Effects Using HLW AZ-101 and C-106/AY-102 Simulants: HLW Simulant Verification. VSL-05R5800-1, Rev. A. See Table 2.1.
Sample History (include washing, leaching, chemical precipitation, mechanical agitation of any kind (time and intensity)	Blended waste including Recycle, Sr/TRU, Cs-Eluate, and Tc- Eluate.	Blended waste including Recycle, Sr/TRU, Cs-Eluate, and Tc- Eluate.	Blended waste including Recycle, Sr/TRU, Cs- Eluate, and Tc-Eluate.		Blended waste including Recycle, Sr/TRU, Cs-Eluate, and Tc- Eluate.	Blended waste including Recycle, Sr/TRU, Cs- Eluate, and Tc- Eluate.
wt% dry solids						
Oxides Loading of HLW Sludge or Pretreated Sludge: Total grams oxide/Liter						
pH of the Waste						
Analyte (mg/kg HLW)						
Cations						
Ag	705	84.7	84.7	6174	84.7	1638
Al	48791	113182	113182	84235	113182	156930
As	14	284	284	6568	284	136
B	841	1873	1873	1906	1873	8486
Ba	60	695	695	238	695	316
Be	77	41	41	328	41	25
Bi	138	271	271	115	271	207
Ca	8854	8291	8291	9732	8291	8849
Cd	46	2309	2309	21	2309	5245
Ce	49	345	345	156	345	237
Co	36	182	182	1376	182	145
Cr	1115	220	220	2403	220	706
Cs	1	66	66	14	66	75
Cu	625	1000	1000	1597	1000	552
Dy	-	-	-	-	-	-
Eu	-	-	-	-	-	-
Fe	171399	354545	354545	399329	354545	464819
Hg	218	8	8	1718	8	43
K	256	1142	1142	262	1142	1437
La	3523	14364	14364	9329	14364	16972
Li	1199	411	411	145	411	195
Mg	-	2655	2655	31946	2655	2281
Mn	24711	4455	4455	114765	4455	11940
Mo	11	227	227	264	227	260
Na	30284	35273	35273	19664	35273	30490
Nd	1830	8873	8873	5846	8873	6311
Ni	9401	20000	20000	6128	20000	18614

Table A.1. Envelope D Waste Composition

Sample Number	35	36	37	38	39	40
P						
Pb	2913	1298	1298	6067	1298	3497
Pd	11	-	-	-	-	209
Pr	539	2109	2109	-	2109	1194
Pt	-	-	-	-	-	-
Rb	616	58	58	-	58	18
Rh	28	700	700	-	700	126
Ru	-	-	-	-	-	-
S						
Sb	27	-	-	9664	-	-
Se	-	-	-	11946	-	-
Si	29863	7800	7800	43221	7800	25.2
Sn	-			-		-
Sr	388	3727	3727	35168	3727	488
Ta	3	-	-	-	-	-
Te	-	-	-	-	-	-
Th	97687	-	-	-	-	-
Ti	363	143	143	3819	143	137
Tl	3	-	-	-	-	-
U	58780	111	111	13	111	131
V	105	-	-	1	-	-
W	-	-	-	-	-	-
Y	200	-	-	-	-	-
Zn	386	475	475	2557	475	426
Zr	179811	116545	116545	8725	116545	69510
Carbon Analysis						
TIC	23	1113	1113	58658	1113	14733
TOC	1272	980	980	330	980	638
Anions						
F	3091	1531	1531	34	1531	180
Cl	68	20	20	4926	20	76
Br	-	-	-	-	-	-
NO_2	3375	4327	4327	153	4327	5245
NO_3	15563	23455	23455	9866	23455	24307
PO_4	1367	211	211	5725	211	1797
SO_4	568	3727	3727	81	3727	2623
C_2O_4	1272	980	980	330	980	638
CO_3	23	1113	1113	58658	1113	14733
CN	-	-	-	-	-	-
NH_3	-	-	-	-	-	-
Free OH	-	186900	186900	36900	186900	
Total OH	296530	203636	203636	64161	203636	17740
Oxide wt%						
Ag_2O	0.08	-	-	-	-	-
Al_2O_3	9.71	20.56	20.64	12.77	20.64	23.01
As_2O_3	-	-	-	0.69	-	-
B_2O_3	0.28	0.58	0.58	0.49	0.58	2.12
BaO	-	0.07	0.07	-	0.07	-
BeO	-	-	-	-	-	-

Table A.1. Envelope D Waste Composition

Sample Number	35	36	37	38	39	40
Bi_2O_3	-	-	-	-	-	-
CaO	1.31	1.11	1.11	1.09	1.11	0.96
CdO	-	0.25	0.25	-	0.25	0.47
Cl	-			0.39		-
CeO_2	-	-	-	-	-	-
Co_2O_3	-	-	-	-	-	-
Cr_2O_3	0.17	-	-	0.28	-	-
Cs_2O	-	0.01	0.01	0.18	0.01	0.21
CuO	0.08	0.12	0.12	0.16	0.12	-
Dy_2O_3	-	-	-	-	-	-
Eu_2O_3	-	-	-	-	-	-
F	0.32	0.15	0.15	0.36	0.15	0.42
Fe_2O_3	25.85	48.37	48.56	45.35	48.56	51.58
HgO	-	-	-	-	-	-
K_2O	-	0.13	0.13	-	0.13	0.13
La_2O_3	0.43	1.61	1.62	0.87	1.62	1.55
Li_2O	0.27	0.08	0.08	0.02	0.08	0.03
MgO	-	0.42	0.42	4.21	0.42	0.30
MnO_2	4.12	0.67	0.67	14.41	0.67	1.47
MoO_3	-	-	-	-	-	-
Na_2O	4.30	4.54	4.56	2.11	4.56	3.18
Nd_2O_3	0.29	1.22	1.22	0.54	1.22	0.68
NiO	1.26	2.43	2.44	0.62	2.44	1.84
P_2O_5	0.11	-	-	0.34	-	0.10
PbO	0.33	0.13	0.13	0.52	0.13	0.29
PdO	-	-	-	-		-
Pr_6O_{11}	-	-	-	-		-
PtO_2	-	-	-	-		-
Rh_2O_3	-	-	-	-		-
RuO_2	-	-	-	-		-
SO_3	0.05	0.30	0.30	-	0.30	0.17
Sb_2O_5	-	-	-	0.92	-	-
SeO_2	-	-	-	1.34	-	-
SiO_2	6.70	1.60	1.61	7.35	1.61	4.17
SnO_2	-	-	-	-	-	-
SrO	0.05	0.13	0.13	3.31	0.13	-
Ta_2O_5	-	-	-	-	-	-
TeO_2	-	-	-	-	-	-
ThO_2	11.66	-	-	-	-	-
TiO_2	0.06	-	-	0.51	-	-
UO_2	6.99	-	-	-	-	-
V_2O_3	0.02	-	-	-	-	-
Y_2O_3	0.03	-	-	-	-	-
ZnO	0.05	0.06	0.06	0.25	0.06	0.04
ZrO_2	25.45	15.06	15.12	0.93	15.12	7.29
Volatiles (g/100g oxides)						
CO_3			0.106		0.106	1.145
NO_2			0.414		0.414	0.407
NO_3			2.237		2.237	1.883

Table A.1. Envelope D Waste Composition

Sample Number	35	36	37	38	39	40
TOC			0.093		0.093	0.050
Radioisotopes (µCi/g dry solids)						
H-3						
C-14						
Cr-51						
Fe-59						
Ni-59						
Co-60						
Ni-63						
Se-79						
Y-88						
Sr-90						
Sr-90/Y-90						
Nb-94/95						
Tc-99						
Ru-103						
Ru-106						
Sn-113						
Sb-125						
Sn-126						
Sb/Sn-126						
I-127						
I-129						
C-133						
Cs-134						
Cs-135						
Cs-137						
Ce-144						
Sm-151						
Ru-152						
Pa-231						
U-233						
U-234						
U-235						
U-236						
U-238						
Np-237						
Pu-236						
Pu-238						
Pu-239						
Pu-240						
Pu-239/240						
Pu-241						
Pu-242						
Pu-241/Am-241						
Am-241						
Am-241/ Am-243						
Am-242						
Am-243						

Table A.1. Envelope D Waste Composition

Sample Number	35	36	37	38	39	40
Cm-242						
Cm-243						
Cm-244						
Cm-243/244						
Sum of alpha (TRU) = Σ (Pu-238, Pu-239, Pu-240, Am-241)						
Total alpha						
Total beta						
Total gamma						
Organic Analytes						
Oxalate						
Citrate						
Fornate						
Gluconate						
Glycolate						
EDTA (ethylenediaminetetraacetic acid)						
HEDTA (N-(2-hydroxyethyl) ethylenediaminetriacetic acid)						
D2EHPA (bis-(2-ethylhexyl)phosphate						
NTA (nitrilotriacetic acid)						
IDA (iminodiacetic acid)						
Succinic Acid						
ED3A (ethylenediaminetriacetic acid)						
Analytes Obtained on an Opportunistic Basis						

Table A.1. Envelope D Waste Composition

Sample Number	41	42	43	44	45	46	47
Sample Description	C-106/AY-102 Simulant	C-106/AY-102 Simulant	SIPP Waste Simulant	AZ-101 HLW Simulant	Simulant AY-102	Simulant AY-102 + Ap-101 + recycle	Simulant AY-102+Ap-101+ recycle
References and Notes on Data	DM 1200 MelterTesting of Redox Effects Using HLW AZ-101 and C-106/AY-102 Simulants: HLW Simulant Verification. VSL-05R5800-1, Rev. A. See Table 2.4.	Tank 241-AY-102 Simulant Development, Ultrafiltration, and Washing. WSRTC-TR-2003-00547, Rev.0. Note C-106/AY-102 ≡ AY-102 in this document	DuraMelter 100 HLW Simulant Validation Tests with C-106/AY-102 Feeds. VSL-05R5710-1, Rev. A. See also Final Report: RPP-WTP Semi-Integrated Pilot Plant. WSRC-TR-2005-00105, Draft B, SRNL-RPP-2005-00012 Draft B.	Melter Tests with AZ-101 HLW Simulant Using a DuraMelter 100 Vitrification System. VSL-01R10N0-1	Final Report: RPP-WTP Semi-Integrated Pilot Plant. WSRC-TR-2005-00105, Draft B, SRNL-RPP-2005-00012 Draft B. From Table 34.		
Sample History (include washing, leaching, chemical precipitation, mechanical agitation of any kind (time and intensity)	Blended waste including Recycle, Sr/TRU, Cs- Eluate, and Tc- Eluate. Note that the elemental analysis is the expected value from the blend		SIPP Simulant was provided to VSL by SRNL	Blended waste including Pretreatment Products			
wt% dry solids					36.91	45.37	46.27
Oxides Loading of HLW Sludge or Pretreated Sludge: Total grams oxide/Liter							
pH of the Waste							
Analyte (mg/kg HLW)							
Cations							
Ag	6174	252	975.7		1037	990	1070
Al	85235	9678	15472.1		18117	17550	22158
As	6564	-					
B	1906	4.59	<182		188	<151	-
Ba	238	90.1	480.5		477	444	409
Be	328	-					
Bi	115	4.95					
Ca	9732	495	2360.3		2280	1905	2046
Cd	21	17.5	73.5		63.5	70.6	71.6
Ce	156	126	603.1		516	551	513
Co	1376	4.55	<16.1		59	<15	212
Cr	2403	306	723.9		845	772	799
Cs	14	3.70	<20.3				
Cu	1597	34.5	149.3		129	134	120
Dy	-	-					
Eu	-	-					
Fe	399329	14247	66743.0		58417	55750	53984
Hg	1718	25.6					
K	262	365	3858.9		330	13000	20885
La	9329	88.2	468.4		407	478	477
Li	145	43.7	105.2		0	90.9	91.8
Mg	31946	131	697.2		617	639	618
Mn	114765	3052	14805.0		12650	12300	11669
Mo	264	33.5	<20.3				
Na	19644	66455	33256.0		60800	89230	109462

Table A.1. Envelope D Waste Composition

Sample Number	41	42	43	44	45	46	47
Nd	5846	184	1395.5		1288	1370	1267
Ni	6128	466	2038.7		1750	1840	3135
P		1688	339.2		1263	672	103
Pb	6067	652	3240.0		2793	2625	2507
Pd	-	-					
Pr	-	52.1	373.0				
Pt	-	-					
Rb	-	1.02					
Rh	-	4.14					
Ru	-	44.7					
S		720	593.4		680	862	1857
Sb	9664	-					
Se	11946	-					
Si	43221	4315	17727.4		17983	15821	17999
Sn	-	-	-				
Sr	35168	115	519.4		500	451	454
Ta	-	-					
Te	-	6.12					
Th	-	-					
Ti	3819	-	15.7		22	10.9	66.4
Tl	-	-					
U	13	-					
V	-	3.59					
W	-	115					
Y	-	22.1	109.0				
Zn	2557	29.9	168.7		458	151	178
Zr	8725	509	831.2		797	745	722
Carbon Analysis							
TIC	5.9		5100.0		15133	3347	3456
TOC	0.33		6070.0		15300	5973	13734
Anions							
F	34	137	19.0		39	52	18.4
Cl	4926	125	99.4		98	738	45.9
Br	-	83.9	<27.9		33.3	<29	97.5
NO_2	153	4045	2314.8		3107	14100	10559
NO_3	9866	255	7874.7		224	49700	37079
PO_4	5725	3590			2693	1070	846
SO_4	81	1687			1427	2080	209
C_2O_4	330	10304	6070.0		14133	23800	18351
CO_3	58658	59452	5100.0		75667	16735	17279
CN	-	-					
NH_3	-	-					
Free OH	36900	-					
Total OH	64161	6186					
Oxide wt%							
Ag_2O	-		0.41				
Al_2O_3	12.77		11.57	24.27			
As_2O_3	0.69		-	0.13			
B_2O_3	0.49		-	-			

Table A.1. Envelope D Waste Composition

Sample Number	41	42	43	44	45	46	47
BaO	-		0.21	0.14			
BeO	-		-	-			
Bi_2O_3	-		-	-			
CaO	1.09		1.31	0.81			
CdO	-		0.03	1.22			
Cl	0.39			0.02			
CeO_2	-		0.28	0.27			
Co_2O_3	-		-	-			
Cr_2O_3	0.28		0.42	0.14			
Cs_2O	0.18		-	0.27			
CuO	0.16		0.07	0.09			
Dy_2O_3	-		-	-			
Eu_2O_3	-		-	-			
F	0.36		0.01	0.12			
Fe_2O_3	45.35		37.77	34.08			
HgO	-		-	-			
K_2O	-		1.84	0.55			
La_2O_3	0.87		0.22	1.06			
Li_2O	0.02		0.09	-			
MgO	4.21		0.46	0.21			
MnO_2	14.41		7.57	9.94			
MoO_3	-		-	-			
Na_2O	2.11		17.74	1.96			
Nd_2O_3	0.54		0.64	-			
NiO	0.62		1.03	1.76			
P_2O_3	0.34		0.31	0.42			
PbO	0.52		1.38	0.50			
PdO	-		-	-			
Pr_6O_{11}	-		0.18	-			
PtO_2	-		-	-			
Rh_2O_3	-		-	-			
RuO_2	-		-	-			
SO_3	-		0.59	0.82			
Sb_2O_5	0.92		-	0.69			
SeO_2	1.34		-	0.49			
SiO_2	7.35		15.01	0.07			
SnO_2	-		-	-			
SrO	3.31		0.24	7.60			
Ta_2O_5	-		-	-			
TeO_2	-		-	0.47			
ThO_2	-		-	-			
TiO_2	0.51		0.01	0.21			
UO_2	-		-	-			
V_2O_3	-		-	-			
Y_2O_3	-		0.05	-			
ZnO	0.25		0.08	-			
ZrO_2	0.93		0.44	11.68			
Volatiles (g/100g oxides)							
CO_3			2.018	3.00			

Table A.1. Envelope D Waste Composition

Sample Number	41	42	43	44	45	46	47
NO_2			0.916	0.95			
NO_3			3.117	1.97			
TOC			2.402	1.32			
Radioisotopes (µCi/g dry solids)							
H-3							
C-14							
Cr-51							
Fe-59							
Ni-59							
Co-60							
Ni-63							
Se-79							
Y-88							
Sr-90							
Sr-90/Y-90							
Nb-94/95							
Tc-99							
Ru-103							
Ru-106							
Sn-113							
Sb-125							
Sn-126							
Sb/Sn-126							
I-127							
I-129							
C-133							
Cs-134							
Cs-135							
Cs-137							
Ce-144							
Sm-151							
Ru-152							
Pa-231							
U-233							
U-234							
U-235							
U-236							
U-238							
Np-237							
Pu-236							
Pu-238							
Pu-239							
Pu-240							
Pu-239/240							
Pu-241							
Pu-242							
Pu-241/Am-241							
Am-241							
Am-241/ Am-243							

Table A.1. Envelope D Waste Composition

Sample Number	41	42	43	44	45	46	47
Am-242							
Am-243							
Cm-242							
Cm-243							
Cm-244							
Cm-243/244							
Sum of alpha (TRU) = Σ (Pu-238, Pu-239, Pu-240, Am-241)							
Total alpha							
Total beta							
Total gamma							
Organic Analytes							
Oxalate							
Citrate							
Fornate							
Gluconate							
Glycolate							
EDTA (ethylenediaminetetraacetic acid)							
HEDTA (N-(2-hydroxyethyl) ethylenediaminetriacetic acid)							
D2EHPA (bis-(2-ethylhexyl)phosphate							
NTA (nitrilotriacetic acid)							
IDA (iminodiacetic acid)							
Succinic Acid							
ED3A (ethylenediaminetriacetic acid)							
Analytes Obtained on an Opportunistic Basis							

Table A.1. Envelope D Waste Composition

Sample Number	48	
Sample Description	Pretreated HLW AZ-101	
References and Notes on Data	Hrma, P., J. V. Crum, D. R. Bates, P. R. Bredt, L. R. Greenwood, and H. D. Smith. 2004. *Vitrification and Product Testing of AZ-101 Pretreated High-Level Waste Envelope D Glass.* (WTP-RPT-116, Rev. 0) PNWD-3499, Battelle—Pacific Northwest Division, Richland, WA. See Tables 5.2, 5.3, and 5.4. Geeting, J.G.H., R. T. Hallen, L. K. Jagoda, A. P. Poloski, R. D. Scheele, and D. R. Weier. 2003. *Filtration, Washing, and Caustic Leaching of Hanford Tank AZ-101 Sludge.* PNWD-3206, Rev 1. (WTP-RPT-043, Rev 1) Battelle—Pacific Northwest Division, Richland, WA.	
Sample History (include washing, leaching, chemical precipitation, mechanical agitation of any kind (time and intensity)	See Geeting et al.	
wt% dry solids	13.7	
Oxides Loading of HLW Sludge or Pretreated Sludge: Total grams oxide/Liter	See Geeting et al.	
pH of the Waste	~12	
Analyte (mg/kg HLW)		
Cations		
Ag	902	
Al	99872.5	
As	---	
B	91	
Ba	1510	
Be	26	
Bi	150	
Ca	7505	
Cd	14500	
Ce	5240	
Co	127.5	
Cr	2284.5	
Cs	---	
Cu	583.5	
Dy	---	
Eu	---	
Fe	202384	
Hg	---	

Table A.1. Envelope D Waste Composition

Sample Number	48	
K	2000	
La	5807.5	
Li	115	
Mg	1540	
Mn	5364	
Mo	66.5	
Na	54545	
Nd	4290	
Ni	9992	
P	4505	
Pb	1727.5	
Pd	2300	
Pr	---	
Pt	---	
Rb	---	
Rh	512.5	
Ru	1600	
S	---	
Sb	---	
Se	---	
Si	13055	
Sn	3600	
Sr	3411.5	
Ta	---	
Te	---	
Th	---	
Ti	177.5	
Tl	---	
U	18500	
V	---	
W	---	
Y	385	
Zn	277.5	
Zr	65050	
Carbon Analysis		
TIC	---	
TOC	---	
Anions		

Table A.1. Envelope D Waste Composition

Sample Number	48	
F	390	
Cl	703	
Br	<170	
NO_2	7268	
NO_3	2178	
PO_4	<340	
SO_4	2410	
C_2O_4	518	
CO_3	---	
CN	---	
NH_3	---	
Free OH	---	
Total OH	---	
Oxide wt%		
Ag_2O	0.121	
Al_2O_3	23.661	
As_2O_3	---	
B_2O_3	0.037	
BaO	0.211	
BeO	0.009	
Bi_2O_3	0.021	
CaO	1.317	
CdO	2.077	
Cl	0.088	
CeO_2	0.77 (as Ce_2O_3)	
Co_2O_3	0.02(as CoO)	
Cr_2O_3	0.419	
Cs_2O		
CuO	0.092	
Dy_2O_3		
Eu_2O_3		
F	0.049	
Fe_2O_3	36.277	
HgO		
K_2O	0.302	
La_2O_3	0.854	
Li_2O	0.031	
MgO	0.32	
MnO_2	1.064	
MoO_3	0.01	

Table A.1. Envelope D Waste Composition

Sample Number	48	
Na_2O	9.219	
Nd_2O_3	0.627	
NiO	1.595	
P_2O_5	1.294	
PbO	0.233	
PdO	0.332	
Pr_6O_{11}		
PtO_2		
Rh_2O_3	0.079	
RuO_2	0.248	
SO_3	0.252	
Sb_2O_5		
SeO_2		
SiO_2	3.501	
SnO_2	0.573	
SrO	0.506	
Ta_2O_5		
TeO_2		
ThO_2		
TiO_2	0.037	
UO_2	2.631	
V_2O_3		
Y_2O_3	0.061	
ZnO	0.043	
ZrO_2	11.017	
Volatiles (g/100g oxides)		
CO_3		
NO_2		
NO_3		
TOC		
Radioisotopes (µCi/g dry solids)		
H-3		
C-14		
Cr-51	<5.0	
Fe-59	<0.4	
Ni-59		
Co-60	8.43	
Ni-63		
Se-79		
Y-88	<0.3	
Sr-90	6.1×10^4	
Sr-90/Y-90		
Nb-94/95	<0.3	

Table A.1. Envelope D Waste Composition

Sample Number	48	
Tc-99	2.53	
Ru-103	<0.5	
Ru-106	<3.0	
Sn-113	<0.7	
Sb-125	38.6	
Sn-126	<0.6	
Sb/Sn-126	0.21	
I-127		
I-129	<0.0668	
Cs-133		
Cs-134	<0.3	
Cs-135	641	
Cs-137		
Ce-144	<5.0	
Sm-151		
Eu-152	1.58	
Eu-154	101.2	
Eu-155	119.5	
Pa-231		
Th-232	<1.0	
U-233	0.47	
U-234		
U-235		
U-236		
U-238	1.21×10^4 µg/mL - Σ all U by ICP-MS	
Np-237	192	
Pu-236	<0.2	
Pu-238	1.1	
Pu-239	129	
Pu-240	9.87	
Pu-239/240		
Pu-241		
Pu-242	0.112	
Pu-241/Am-241		
Am-241	165	
Am-241/ Am-243		
Am-242		
Am-243		

Table A.1. Envelope D Waste Composition

Sample Number	48	
Cm-242	0.298	
Cm-243		
Cm-244		
Cm-243/244	0.298	
Sum of alpha (TRU) = Σ (Pu-238, Pu-239, Pu-240, Am-241)		
Total alpha	187.5	
Total beta		
Total gamma		
Organic Analytes		
Oxalate		
Citrate		
Fornate		
Gluconate		
Glycolate		
EDTA (ethylenediaminetetraacetic acid)		
HEDTA (N-(2-hydroxyethyl) ethylenediaminetriacetic acid)		
D2EHPA (bis-(2-ethylhexyl)phosphate		
NTA (nitrilotriacetic acid)		
IDA (iminodiacetic acid)		
Succinic Acid		
ED3A (ethylenediaminetriacetic acid)		
Analytes Obtained on an Opportunistic Basis		

Table A.2. Envelope D Melter Feed Preparation

Sample Number			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Melter Feed Description			HLW MF C-104 (14.1 wt% total solids) PNNL 25°C	HLW MF C-104 (36.8 wt% total solids) PNNL 25°C	HLW MF C-104 (47.3 wt% total solids) PNNL 25°C	HLW MF AZ-102 (12.3 wt% total solids) PNNL 25°C	HLW MF AZ-102 Repeat (30.3 wt% total solids) PNNL 25°C	Sim. HLW MF NOAHF9 AZ-101 (48.4 wt% total solids) VSL	Sim. HLW MF NOAHF11 AZ-101 (46.8 wt% total solids) VSL	AZ101 - NOAHF11A	Sim. HLW MF AZ-102 Melter Feed NOAHF14 (46.2 wt% total solids) VSL	AZ102 - NOAHF14	AZ102 - NOAHF14	AZ102 - NOAHF14	AZ102 - NOAHF14A	Sim. HLW MF Noah F13 (C-106/AY-102)(-325 silica) (42.1 wt% total solids) VSL	C106/AY102 - NOAHF13	C106/AY102 - NOAHF13
References and Notes on Data			WTP-RPT-006, Rev. 0, See Section 3					VSL-R2520-1, Rev0, See Tables 2.14, 2.17, 2.18 for waste density and oxide loading. See Tables 3.5, 3.6, 3.7, 3.9, 3.10, and 3.12 for melter feed make up. The melter feed make up table glass former batching material amounts are based on 100 kg of waste slurry at a given oxide loading per kilogram of waste and are equivalent to grams of glass formers per 100 grams of waste slurry. In the table below all amounts have been recalculated to grams per liter of waste slurry by multiplying by the density to give the equivalent of 100 mL of slurry then multiplying by 10 to bring it up to the equivalent of one liter of waste slurry.										
Pretreatment History (include washing, leaching, chemical precipitation, mechanical agitation of any kind (time and intensity)																		
Sodium Concentration of LAW Pretreated Waste Na Molarity																		
Oxides Loading of HLW Pretreated Sludge - density								1.23	1.23	1.23	1.24	1.24	1.24	1.24	1.24	1.25	1.25	1.25
Total Grams HLW Oxide per Liter								231.2	231.2	231.2	253(See Table 2-17)	253	253	253	253	300	300	300
Actual Mass Added (g) per liter of pretreated waste																		
Source Chemical	**Manufacturer**	**Oxide**																
Kyanite	Kyanite Mining Corp	Al_2O_3																
Alumina A-2	Alcoa Alumina	Al_2O_3																
Boric Acid Technical	U.S. Borax	B_2O_3														50.125	50.125	50.125
10M Borax	U.S. Borax	Na_2O/B_2O_3						208.116	208.116		161.324	161.324	161.324	161.324	161.324	36.5	36.5	36.5
Soda Ash	Solvay Minerals	Na_2CO_3						20.049	20.049	77.982	70.804	70.804	70.804	70.804	70.804			
NaOH																		
Wollastonite	NYCO	CaO																
Fe_2O_3 5001	Prince Mfg. Co.	Fe_2O_3																
$LiOH*H_2O$											139.004	139.004	139.004	139.004				
$LiBO_2$										109.101								
Li_2CO_3	Chemettal-Foote	Li_2O						112.668	128.043	36.039					118.544	66.625	66.625	66.625
Olivine	Unimin Corp	MgO														207.75	207.75	207.75
SCS-75	U.S. Silica	SiO_2						345.999	345.999	345.999	377.704	377.704	377.704	377.704	377.704			
Rutile (Air floated)	Chemalloy Co.	TiO_2																
Kadox	Zinc Corp Amer.	ZnO						15.252	15.252	15.252	16.492	16.492	16.492	16.492	16.492	11.875	11.875	11.875

Table A.2. Envelope D Melter Feed Preparation

Sample Number			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Zircon	Amer. Milner. Inc.	ZrO_2																
Sucrose	Amalgamated Sugar Co.	Sugar																
Mixing Operation Data																		
Processing Scale (lab/bench, pilot, or full)																		
Mixing Activity/Property																		
Order of Chemical Additions																		
Mixing Time																		
Impeller Speed																		
Impeller Diameter																		
Tank Diameter																		
Number of Baffles																		
Size of Baffles																		
Depth of Impeller																		
Comments																		

Table A.2. Envelope D Melter Feed Preparation

Sample Number			17	18	19	20	21	22	23	24	25
Melter Feed Description			Sim. HLW MF 1.3 AZ-101 (39.1 wt% total solids) SRTC	Sim. HLW MF 1.4 AZ-101 (32.5 wt% total solids) SRTC	Sim. HLW MF 1.5 AZ-101 (33.7 wt% total solids) SRTC	Simulated Melter Feed - 2.3	Sim. HLW MF TEST 2.4 AZ-102 (33 wt% total solids) SRTC	Sim. HLW MF TEST 2.5 AZ-102 (33.7 wt% total solids) SRTC	Simulated Melter Feed - 2.9	Sim. HLW MF TEST ADD3 AZ-102 (24.9 wt% total solids) SRTC	Sim. HLW MF TEST ADD4 AZ-102 (28.8 wt% total solids) SRTC
References and Notes on Data			WSRC-TR-2001-00203, Rev.0, The density of the wastes AZ-101 and AZ-102 and grams of oxide per liter of waste were determined from the data in Tables 12 and 13 by calculating the weight of solids in the slurry and multiplying by the appropriate calcine factor. See page 96 for the AZ-101 factor and page 105 for the AZ-102 factor. Note a composite factor was not given but the primary sludge slurries make up ~ 80 % of the blend. The weights of the respective glass former materials for one liter of waste slurry blend were calculated from the information given on pages 114 and 116 for making 100 grams of glass and from the batching sheets on pages 115 and 117 which indicate that the AZ-101 glass is 34.6 wt% waste oxides and that the AZ-102 glass is 33.11 wt% waste oxides.								
Pretreatment History (include washing, leaching, chemical precipitation, mechanical agitation of any kind (time and intensity)											
Sodium Concentration of LAW Pretreated Waste Na Molarity											
Oxides Loading of HLW Pretreated Sludge – density			1.17	1.11	1.13	1.17	1.11	1.11	1.17	1.08	1.05
Total Grams Oxide per Liter			190.35	140.47	150.00	204.64	146.35	150.88	202.40	98.81	116.20
Actual Mass Added (g) per liter of waste											
Source Chemical	**Manufacturer**	**Oxide**									
Kyanite	Kyanite Mining Corp	Al_2O_3									
Alumina A-2	Alcoa Alumina	Al_2O_3									
Boric Acid Technical	U.S. Borax	B_2O_3									
10M Borax	U.S. Borax	Na_2O/B_2O_3	103.09	76.08	81.24	50.64	36.21	37.34	50.08	24.45	28.75
Soda Ash	Solvay Minerals	Na_2CO_3									
NaOH						55.95	40.01	41.25	55.34	27.01	31.77
Wollastonite	NYCO	CaO									
Fe_2O_3 5001	Prince Mfg. Co.	Fe_2O_3									
$LiOH*H_2O$			71.60	52.84	56.43	72.76	52.04	53.65	71.97	35.13	41.32
$LiBO_2$											
Li_2CO_3	Chemettal-Foote	Li_2O									
Olivine	Unimin Corp	MgO									
SCS-75	U.S. Silica	SiO_2	185.10	136.59	145.86	234.07	167.40	172.58	231.51	113.02	132.91
Rutile (Air floated)	Chemalloy Co.	TiO_2									
Kadox	Zinc Corp Amer.	ZnO									
Zircon	Amer. Milner. Inc.	ZrO_2									
Sucrose	Amalgamated Sugar Co.	Sugar									
Mixing Operation Data											
Processing Scale (lab/bench, pilot, or full)											
Mixing Activity/Property											
Order of Chemical Additions											
Mixing Time											
Impeller Speed											
Impeller Diameter											
Tank Diameter											
Number of Baffles											

Table A.2. Envelope D Melter Feed Preparation

Sample Number	17	18	19	20	21	22	23	24	25
Size of Baffles									
Depth of Impeller									
Comments									

Sample Number			26	27	28	29	30
Melter Feed Description			Low Bound HLW Melter Feed Physical Simulant	High Bound HLW Melter Feed Physical Simulant	HLW Precipitated Hydroxide Melter Feed Simulant	Feed to make HLW98-31 Glass	Feed to make HLW98-86 Glass
References and Notes on Data			(WSRC-TR-2003-00220, Rev. 0, SRT-RPP-2003-00098, Rev. 0) Note that only the composition of the precipitated hydroxide waste simulant and melter feed simulant are given. The physical simulants are all simplified versions that were developed to match bounding rheological properties and other physical aspects. All of the make up procedures are given in the reference documents.			DuraMelter 1200 HLW Pilot Melter System Using AZ-101 HLW Simulants. VSL-02R0100-2, Rev. 1, See Table 2.1. Waste composition used with additive chemicals. See Table 2.2	DM 1200 Melter Testing of HLW C-106/AY-102 Composition Using Bubblers. VSL-03R3800-1, Rev. 0. See Table 2.1. Waste composition used with additive chemicals. See Table 2.2
Pretreatment History (include washing, leaching, chemical precipitation, mechanical agitation of any kind (time and intensity)			See recipe in Appendix D	See recipe in Appendix E	See recipe in Appendix F WTP glass forming chemicals added to precipitated hydroxide base simulant	Note that the waste simulant was made by mixing oxides, hydroxides, nitrates, nitrites, carbonates, phosphates, sulfates, salts, and acetic acid	Note that the waste simulant was made by mixing oxides, hydroxides, nitrates, nitrites, carbonates, phosphates, sulfates, salts, and acetic acid
Oxides Loading of HLW Pretreated Sludge – density							
Total Grams Oxide per Liter						119.9	103.7
			Actual Mass Added (g) per liter of waste				
Source Chemical	**Manufacturer**	**Oxide**					
Kyanite	Kyanite Mining Corp	Al_2O_3					17.68
Alumina A-2	Alcoa Alumina	Al_2O_3					
Boric Acid Technical	U.S. Borax	B_2O_3					
10M Borax	U.S. Borax	Na_2O/B_2O_3				155.1	255.91
Soda Ash	Solvay Minerals	Na_2CO_3				14.97	123.20
NaOH							
Wollastonite	NYCO	CaO					
Fe_2O_3 5001	Prince Mfg. Co.	Fe_2O_3					
$LiOH*H_2O$							
$LiBO_2$							
Li_2CO_3	Chemettal-Foote	Li_2O				84.04	76.10
Olivine	Unimin Corp	MgO					
SCS-75	U.S. Silica	SiO_2				257.8	454.55
Rutile (Air floated)	Chemalloy Co.	TiO_2					
Kadox	Zinc Corp Amer.	ZnO				11.33	20.20
Zircon	Amer. Milner. Inc.	ZrO_2					
Sucrose	Amalgamated Sugar Co.	Sugar					
Processing Scale (lab/bench, pilot, or full)							
Order of Chemical Additions							
Mixing Time							
Impeller Speed							
Impeller Diameter							
Tank Diameter							
Number of Baffles							
Size of Baffles							

Sample Number	26	27	28	29	30
Depth of Impeller					
Comments					

Table A.2. Envelope D Melter Feed Preparation

Sample Number			31	32	33	34	35
Melter Feed Description			Feed to make HLW98-80 Glass	Feed to make HLW98-96D Glass	Feed to make HLW98-96D Glass	Feed to make HLW98-77 Glass	Feed to make HLW98-86 Glass
References and Notes on Data			DM 1200 Melter Testing of HLW AZ-102 Composition Using Bubblers. VSL-03R3800-2, Rev. 0. See Table 2.1. See also Tables 2.2 and 2.3	DM 1200 Tests with C-104/AY-101 HLW Simulants VSL-03R3800-3, Rev. 0. See Table 2.1 and Table 2.2. See also Tables 2.3 and 2.4.	DM 1200 Tests with AZ-101 HLW Simulants. VSL-03R3800-4, Rev. 0. See Table 2.3.	DM 1200 Melter Testing of Redox Effects Using HLW AZ-102 and C-106/AY-102 Simulants. VSL-04R4800-1, Rev. 0. See Table 2.3 and Table 2.6.	
Pretreatment History (include washing, leaching, chemical precipitation, mechanical agitation of any kind (time and intensity)			Note that the waste simulant was made by mixing oxides, hydroxides, nitrates, nitrites, carbonates, phosphates, sulfates, salts, and acetic acid	Note that the waste simulant was made by mixing oxides, hydroxides, nitrates, nitrites, carbonates, phosphates, sulfates, salts, and acetic acid	Note that the waste simulant was made by mixing oxides, hydroxides, nitrates, nitrites, carbonates, phosphates, sulfates, salts, and acetic acid	Note that the waste simulant was made by mixing oxides, hydroxides, nitrates, nitrites, carbonates, phosphates, sulfates, salts, and acetic acid	
Oxides Loading of HLW Pretreated Sludge – Density							
Total Grams of waste Oxide per Liter			132.1	149.3	125.5	143.9	149.6
Actual Mass Added (g) per liter of Melter feed							
Source Chemical	**Manufacturer**	**Oxide**					
Kyanite	Kyanite Mining Corp	Al_2O_3					9.52
Alumina A-2	Alcoa Alumina	Al_2O_3					
Boric Acid Technical	U.S. Borax	B_2O_3					
10M Borax	U.S. Borax	Na_2O/B_2O_3	178.9	146.8	155.1	184.4	137.8
Soda Ash	Solvay Minerals	Na_2CO_3	55.0	44.0	43.4	51.6	66.3
NaOH							
Wollastonite	NYCO	CaO					
Fe_2O_3 5001	Prince Mfg. Co.	Fe_2O_3					
$LiOH*H_2O$							
$LiBO_2$							
Li_2CO_3	Chemettal-Foote	Li_2O	44.4	40.6	42.4	50.4	41.0
Olivine	Unimin Corp	MgO					
SCS-75	U.S. Silica	SiO_2	257.2	219.8	226.5	269.4	244.7
Rutile (Air floated)	Chemalloy Co.	TiO_2					
Kadox	Zinc Corp Amer.	ZnO	10.9	10.7	9.64	11.5	10.9
Zircon	Amer. Milner. Inc.	ZrO_2					
Sucrose	Amalgamated Sugar Co.	Sugar					
Mixing Operation Data							
Processing Scale (lab/bench, pilot, or full)							
Mixing Activity/Property							
Order of Chemical Additions							
Mixing Time							
Impeller Speed							
Impeller Diameter							
Tank Diameter							
Number of Baffles							
Size of Baffles							
Depth of Impeller							
Comments							

Table A.2. Envelope D Melter Feed Preparation

Sample Number			36	37	38	39
Melter Feed Description			Feed to make HLW98-77 Glass	Feed to make HLW98-80 Glass	Feed to make HLW98-86 Glass	SIPP Waste Simulant Melter Feed
References and Notes on Data			DM 1200 Melter Testing of Bubblers Configurations Using HLW AZ-101 Simulants. VSL-04R4800-4, Rev. 0. See Table 2.3	DM 1200 MelterTesting of Redox Effects Using HLW AZ-101 and C-106/AY-102 Simulants: HLW Simulant Verification. VSL-05R5800-1, Rev. A. See Table 2.3.	DM 1200 MelterTesting of Redox Effects Using HLW AZ-101 and C-106/AY-102 Simulants: HLW Simulant Verification. VSL-05R5800-1, Rev. A. See Table 2.6.	DuraMelter 100 HLW Simulant Validation Tests with C-106/AY-102 Feeds. VSL-05R5710-1, Rev. A
Pretreatment History (include washing, leaching, chemical precipitation, mechanical agitation of any kind (time and intensity)			Note that the waste simulant was made by mixing oxides, hydroxides, nitrates, nitrites, carbonates, phosphates, sulfates, salts, and acetic acid	Note that the waste simulant was made by mixing oxides, hydroxides, nitrates, nitrites, carbonates, phosphates, sulfates, salts, and acetic acid	Note that the waste simulant was made by mixing oxides, hydroxides, nitrates, nitrites, carbonates, phosphates, sulfates, salts, and acetic acid	
Oxides Loading of HLW Pretreated Sludge – density						
Total Grams Oxide per Liter			143.9	135.1	149.9	
Actual Mass Added (g) per liter of Melter Feed						
Source Chemical	**Manufacturer**	**Oxide**				
Kyanite	Kyanite Mining Corp	Al_2O_3			9.52	
Alumina A-2	Alcoa Alumina	Al_2O_3				
Boric Acid Technical	U.S. Borax	B_2O_3				
10M Borax	U.S. Borax	Na_2O/B_2O_3	184.4	184.8	137.8	143.8
Soda Ash	Solvay Minerals	Na_2CO_3	51.6	56.8	66.3	10.2
NaOH						
Wollastonite	NYCO	CaO				
Fe_2O_3 5001	Prince Mfg. Co.	Fe_2O_3				
$LiOH*H_2O$						
$LiBO_2$						
Li_2CO_3	Chemettal-Foote	Li_2O	50.4	45.9	41.0	33.6
Olivine	Unimin Corp	MgO				
SCS-75	U.S. Silica	SiO_2	269.4	265.7	244.7	212.1
Rutile (Air floated)	Chemalloy Co.	TiO_2				
Kadox	Zinc Corp Amer.	ZnO	11.5	11.2	10.9	5.15
Zircon	Amer. Milner. Inc.	ZrO_2				
Sucrose	Amalgamated Sugar Co.	Sugar				
Mixing Operation Data						
Processing Scale (lab/bench, pilot, or full)						
Mixing Activity/Property						
Order of Chemical Additions						
Mixing Time						
Impeller Speed						
Impeller Diameter						
Tank Diameter						
Number of Baffles						
Size of Baffles						
Depth of Impeller						
Comments						

Table A.2. Envelope D Melter Feed Preparation

Sample Number			40	41	
Melter Feed Description			Pretreated HLW AZ-101 Simulant + Pretreatment Prod. + Glass Formers to make HLW98-31	Pretreated HLW AZ-101 + Pretreatment Prod. + Glass Formers to make HLW98-31	
References and Notes on Data			Melter Tests with AZ-101 HLW Simulant Using a DuraMelter 100 Vitrification System. VSL-01R10N0-1	Poloski AP, PR Bredt, JW Chenault, and RG Swoboda. 2003a. *Rheological and Physical Properties of AZ 101 HLW Pretreated Sludge and Melter Feed.* PNWD-3366, Battelle—Pacific Northwest Division, Richland, WA. See Tables 3.1 and 3.2	
Pretreatment History (include washing, leaching, chemical precipitation, mechanical agitation of any kind (time and intensity)				See Geeting et al.	
Oxides Loading of HLW Pretreated Sludge – density					
Total Grams Oxide per Liter					
Mass Added (g) per liter of melter feed					
Source Chemical	**Manufacturer**	**Oxide**			
Kyanite	Kyanite Mining Corp	Al_2O_3			
Alumina A-2	Alcoa Alumina	Al_2O_3			
Boric Acid Technical	U.S. Borax	B_2O_3			
10M Borax	U.S. Borax	Na_2O/B_2O_3	162.7	167.8 (per kg of pretreated waste, 20 wt% UDS)	
Soda Ash	Solvay Minerals	Na_2CO_3	15.7	39.1(per kg of pretreated waste, 20 wt% UDS)	
NaOH					
Wollastonite	NYCO	CaO			
Fe_2O_3 5001	Prince Mfg. Co.	Fe_2O_3			
$LiOH*H_2O$					
$LiBO_2$					
Li_2CO_3	Chemettal-Foote	Li_2O	88.1	55.8(per kg of pretreated waste, 20 wt% UDS)	
Olivine	Unimin Corp	MgO			
SCS-75	U.S. Silica	SiO_2	270.3	261.1(per kg of pretreated waste, 20 wt% UDS)	
Rutile (Air floated)	Chemalloy Co.	TiO_2			
Kadox	Zinc Corp Amer.	ZnO	11.9	11.8(per kg of pretreated waste, 20 wt% UDS)	
Zircon	Amer. Milner. Inc.	ZrO_2			
Sucrose	Amalgamated Sugar Co.	Sugar			
Mixing Operation Data					
Processing Scale (lab/bench, pilot, or full)				See Poloski et al.	
Mixing Activity/Property					
Order of Chemical Additions				See Poloski et al.	
Mixing Time				See Poloski et al.	
Impeller Speed				See Poloski et al.	
Impeller Diameter				See Poloski et al.	
Tank Diameter				See Poloski et al.	
Number of Baffles				See Poloski et al.	
Size of Baffles				See Poloski et al.	
Depth of Impeller				See Poloski et al.	
Comments				See Poloski et al.	

Table A.3. Envelope D Waste and Melter Feed Physical Property Data

Sample Number	1	2	3	4	5	6	7	8	9	10
Sample Description	C-104 (Envelope D) Pretreated Sludge Waste	C-104 (Envelope D) Pretreated Sludge Waste plus Secondary Wastes	Pretreated HLW Sludge C-104 (5 wt% suspended solids) PNNL 25°C	Pretreated HLW Sludge C-104 (15 wt% suspended solids) PNNL 25°C	Pretreated HLW Sludge C-104 (25 wt% suspended solids) PNNL 25°C	AZ102 (Envelope D) Composited Pretreated Sludge Waste	AZ102 (Envelope D) Composited Pretreated Sludge Waste plus Secondary Wastes	Pretreated HLW Sludge AZ102 (15 wt% suspended solids) PNNL 25°C	Pretreated HLW Sludge AZ-102 New Sample (20 wt% suspended solids) PNNL 25°C	Pretreated HLW Sludge AZ102 (25 wt% suspended solids) PNNL 25°C
References and Notes on Data	WTP-RPT-004, Rev. 0, WTP-RPT-006, Rev. 0 See Test Instructions appended to WTP-RPT-004, Rev. 0 as well as Table 3.1. In WTP-RPT-006, Rev. 0 see Tables 3.1 and 3.2.									
Physical Property										
Sodium concentration of LAW waste or pretreated waste (Molar)										
Oxides loading of HLW sludge or pretreated sludge (total grams oxide/Liter)						76.51				
pH (aging 1day, 1week, 1mo)										
Solid phases present										
Particle size distribution - Mean Vol. Distribution - (µm)										
Particle size distribution - Mean No. Distribution - (µm)										
Density – Bulk slurry (g/mL) (aging 1day, 1week, 1mo)			1	1.05	1.12		1.03	1.15		1.26
Density – settled solids (g/mL)										
Density – centrifuged solids (g/mL)										
Density - supernatant liquid (g/mL)										
Vol. % settled solids after [48 hours] 72 hours (aging 1day, 1week, 1mo)										
Vol. % centrifuged solids										
Wt % total dried solids	20		5	15	25	9.535	5	15	20	25
Wt % centrifuged solids										
Wt % oven dried solids										
Wt % undissolved solids										
Wt % dissolved solids										

Table A.3. Envelope D Waste and Melter Feed Physical Property Data

Waste Type	11	12	13	14	15	16	17
Sample Description	Sim. Pretreated HLW AZ-101 (27.7 wt% total solids) VSL	Sim. Pretreated HLW AZ-102 (27.1 wt% total solids) VSL	Sim. Pretreated HLW C-106/AY-102 (28.8 wt% total solids) VSL	Simulated Waste AZ-101 SRTC	Sim. Pretreated HLW AZ-101 (9 wt% total solids) SRTC 25°C	Sim. Pretreated HLW AZ-101 (11.6 wt% total solids) SRTC 25°C	***Sim. Pretreated HLW AZ-101 (16.3 wt% total solids) SRTC 25°C
References and Notes on Data	VSL Report 2520-1, See Tables 2.14, 2.17, and 2.18.			WSRC-TR-2001-00203, Rev.0, See Tables 4 and 6			
Physical Property							
Sodium concentration of LAW waste or pretreated waste (Molar)							
Oxides loading of HLW sludge or pretreated sludge (total grams oxide/Liter)							
pH (aging 1day, 1week, 1mo)	9	12.66	12.23	10.11			
Solid phases present							
Particle size distribution - Mean Vol. Distribution - (µm)							
Particle size distribution - Mean No. Distribution - (µm)							
Density – Bulk slurry (g/mL) (aging 1day, 1week, 1mo)	1.23	1.24	1.25	1.13			
Density – settled solids (g/mL)							
Density – centrifuged solids (g/mL)		1.41	1.5				
Density - supernatant liquid (g/mL)							
Vol. % settled solids after [48 hours] 72 hours (aging 1day, 1week, 1mo)	93.7	92.1	78.4				
Vol. % centrifuged solids	57.2	56.7					
Wt % total dried solids	24.7	27.4	28.7	14.90	9.00	11.60	16.30
Wt % centrifuged solids							
Wt % oven dried solids							
Wt % undissolved solids							
Wt % dissolved solids							

Table A.3. Envelope D Waste and Melter Feed Physical Property Data

Sample Number	18	19	20	21	22	23	24	25	26
Sample Description	Low Bound HLW Pretreated Waste Physical Simulant (20-L)	Low Bound HLW Melter Feed Physical Simulant	High Bound HLW Pretreated Waste Physical Simulant (41-H)	High Bound HLW Melter Feed Physical Simulant	HLW Precipitated Hydroxide Simulant	HLW Precipitated Hydroxide Melter Feed Simulant	AY102/C106 Pretreated Sludge 20.4	AY102/C106 Pretreated Sludge 27.4	AY102/C106 Pretreated Sludge 32.5
References and Notes on Data	WSRC-TR-2003-00220, Rev. 0, SRT-RPP-2003-00098, Rev. 0						SRT-RPP-2004-00061, Rev. 0		
Physical Property									
Sodium concentration of LAW waste or pretreated waste (Molar)									
Oxides loading of HLW sludge or pretreated sludge (total grams oxide/Liter)									
pH (aging 1day, 1week, 1mo)	12.48		12.81	9.87	12.48	9.34			
Solid phases present									
Particle size distribution - Mean Vol. Distribution - (µm)	2.576	23.9	4.293	19.45	57.68				
Particle size distribution - Mean No. Distribution - (µm)	0.227	0.209	0.315	0.293	0.229				
Density – Bulk slurry (g/mL) (aging 1day, 1week, 1mo)	1.105		1.334		1.197	1.400	1.196	1.288	1.364
Density – settled solids (g/mL)									
Density – centrifuged solids (g/mL)									
Density - supernatant liquid (g/mL)									
Vol. % settled solids after [48 hours] 72 hours (aging 1day, 1week, 1mo)									
Vol. % centrifuged solids									
Wt % total dried solids	14.61	38.75 (calc.)	36.37	60.89	22.26	45.42	20.4	27.4	32.5
Wt % centrifuged solids									
Wt % oven dried solids									
Wt % undissolved solids	12.74		35.27		19.05	37.75			
Wt % dissolved solids	1.87		1.10		3.21	7.68			

Table A.3. Envelope D Waste and Melter Feed Physical Property Data

Sample Number	27	28	29	30	31	32	33	34	35
Sample Description	Melter feed made up with the AZ-101 HLW Simulant (Table 2.2) containing varying amounts of water, nitrate, and frit. The nitrated feed has the lowest pH, while the nominal feed has the highest with the high water or frit containing feed showing intermediate values.								
References and Notes on Data	DuraMelter 1200 HLW Pilot Melter System Using AZ-101 HLW Simulants. VSL-02R0100-2, Rev. 1								
Physical Property									
Oxides loading of HLW sludge or pretreated sludge (total grams oxide/Liter)	120								
Oxide loading melter feed (total grams oxide/Liter)	573	545	382	388	481	427	462	439	593
pH (aging 1day, 1week, 1mo)	9.79	9.73	9.73	9.73	7.33	10.01	8.58	4.94	9.74
Solid phases present									
Particle size distribution - Mean Vol. Distribution - (µm)									
Particle size distribution - Mean No. Distribution - (µm)									
Density – Bulk slurry (g/mL) (aging 1day, 1week, 1mo)	1.44	1.42	1.33	1.32	1.44	1.29	1.32	1.42	1.47
Density – settled solids (g/mL)									
Density – centrifuged solids (g/mL)									
Density - supernatant liquid (g/mL)									
Vol. % settled solids after [48 hours] 72 hours (aging 1day, 1week, 1mo)									
Vol. % centrifuged solids									
Wt % total dried solids									
Wt % centrifuged solids									
Wt % oven dried solids									
Wt % undissolved solids									
Wt % dissolved solids									

Table A.3. Envelope D Waste and Melter Feed Physical Property Data

Sample Number	36	37	38	39	40	41	42	43	44	45	46	47
Sample Description	Feed to make HLW98-86 Glass		Feed to make HLW98-80 Glass		Feed to make HLW98-96D Glass		Feed to make HLW98-77 Glass					
References and Notes on Data	DM 1200 Melter Testing of HLW C-106/AY-102 Composition Using Bubblers. VSL-03R3800-1, Rev. 0. See Table 2.1. Waste composition used with additive chemicals. See Table 2.2 See also Tables 2.3 and 2.4		DM 1200 Melter Testing of HLW AZ-102 Composition Using Bubblers. VSL-03R3800-2, Rev. 0. See Table 2.1. See also Tables 2.2 and 2.3		DM 1200 Tests with C-104/AY-101 HLW Simulants VSL-03R3800-3, Rev. 0. See Table 2.1.		DM 1200 Tests with AZ-101 HLW Simulants. VSL-03R3800-4, Rev. 0. See Table 2.4.					
Physical Property												
Oxides loading of HLW sludge or pretreated sludge (total grams oxide/Liter)	558.3	574.2	544.6	565.7	529.9	522.8	509	269	533	407	387	279
pH (aging 1day, 1week, 1mo)	10.23	10.28	10.53	10.27	10.88	10.89	10.49	10.16	10.71	10.40	10.36	10.25
Solid phases present												
Particle size distribution - Mean Vol. Distribution - (µm)												
Particle size distribution - Mean No. Distribution - (µm)												
Density – Bulk slurry (g/mL) (aging 1day, 1week, 1mo)	1.42	1.46	1.40	1.42	1.41	1.40	1.36	1.22	1.40	1.34	1.30	1.25
Density – settled solids (g/mL)												
Density – centrifuged solids (g/mL)												
Density - supernatant liquid (g/mL)												
Vol. % settled solids after [48 hours] 72 hours (aging 1day, 1week, 1mo)												
Vol. % centrifuged solids												
Wt % total dried solids												
Wt % centrifuged solids												
Wt % oven dried solids												
Wt % undissolved solids												
Wt % dissolved solids												

Table A.3. Envelope D Waste and Melter Feed Physical Property Data

Sample Number	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**
Sample Description	AZ-101 feed with variable amounts of sugar and Ru/Y spike	C-106/AY-102 feed with variable amounts of sugar. No.49 added nitrate. No.50 no sugar.			AZ-101 feed used in Tests 8 and 9.				Feed to make HLW98-80 Glass – Adjusted Rheology		Feed to make HLW98-80 Glass - Nominal	
References and Notes on Data	DM 1200 Melter Testing of Redox Effects Using HLW AZ-102 and C-106/AY-102 Simulants. VSL-04R4800-1, Rev. 0. See Table 2.7				DM 1200 Melter Testing of Bubblers Configurations Using HLW AZ-101 Simulants. VSL-04R4800-4, Rev. 0. See Table 2.5				DM 1200 MelterTesting of Redox Effects Using HLW AZ-101 and C-106/AY-102 Simulants: HLW Simulant Verification. VSL-05R5800-1, Rev. A. See Table 2.10.			
Physical Property												
Oxides loading of HLW sludge, pretreated sludge or melter feed (total grams oxide/Liter)	405		553	549	410	414	419	415	557	453	355	343
pH (aging 1day, 1week, 1mo)	10.42	9.97	10.23	10.09	10.41	10.53	10.62	10.58	10.63	10.60	10.45	10.38
Solid phases present												
Particle size distribution - Mean Vol. Distribution - (µm)												
Particle size distribution - Mean No. Distribution - (µm)												
Density – Bulk slurry (g/mL) (aging 1day, 1week, 1mo)	1.33	1.46	1.42	1.46	1.32	1.32	1.33	1.34	1.45	1.35	1.29	1.29
Density – settled solids (g/mL)												
Density – centrifuged solids (g/mL)												
Density - supernatant liquid (g/mL)												
Vol. % settled solids after [48 hours] 72 hours (aging 1day, 1week, 1mo)												
Vol. % centrifuged solids												
Wt % total dried solids	36.99	45.41	45.80	46.22	36.4	37.8	37.5	36.7	45.3	39.5	32.6	31.4
Wt % centrifuged solids												
Wt % oven dried solids												
Wt % undissolved solids												
Wt % dissolved solids												

Table A.3. Envelope D Waste and Melter Feed Physical Property Data

Sample Number	**60**	**61**	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**
Sample Description	Feed to make HLW98-86 Glass – Adjusted Rheology		Feed to make HLW98-86 Glass – High Waste Loading	AY-102/C-106 Simulant	AY-102/C-106 Actual Slurry. See Table 4.15			SIPP Waste Simulant	AY-102/C-106 Nominal Melter Feed	AY-102/C-106 Adjusted Rheology Feed	SIPP Melter Feed
References and Notes on Data	DM 1200 MelterTesting of Redox Effects Using HLW AZ-101 and C-106/AY-102 Simulants: HLW Simulant Verification. VSL-05R5800-1, Rev. A. See Table 2.10.			Tank 241-AY-102 Simulant Development, Ultrafiltration, and Washing. WSRTC-TR-2003-00547, Rev.0. Note C-106/AY-102 ≡ AY-102 in this document. See Tables 4.7, 4.13, and 4.14				DuraMelter 100 HLW Simulant Validation Tests with C-106/AY-102 Feeds. VSL-05R5710-1, Rev. A, See Table 2.10			
Physical Property											
Oxides loading of HLW sludge or pretreated sludge (total grams oxide/Liter)	509	541	348						411	436	500
pH (aging 1day, 1week, 1mo)	10.28	10.36	10.9	13.4				13.13	10.10	11.34	11.12
Solid phases present											
Particle size distribution - Mean Vol. Distribution - (µm)				See Figure 4.5							
Particle size distribution - Mean No. Distribution - (µm)				See Figure 4.5							
Density – Bulk slurry (g/mL) (aging 1day, 1week, 1mo)	1.41	1.44	1.28	1.212	1.226	1.226	1.226	1.13	1.26	1.34	1.38
Density – settled solids (g/mL)											
Density – centrifuged solids (g/mL)											
Density - supernatant liquid (g/mL)											
Vol. % settled solids after [48 hours] 72 hours (aging 1day, 1week, 1mo)				68.1	68.53	68.03	67.49				
Vol. % centrifuged solids				27.78							
Wt % total dried solids	43.3	44.0	30.5	21.56	22.58	22.70	22.67	27.67	38.1	38	41.7
Wt % centrifuged solids				31.29							
Wt % oven dried solids											
Wt % undissolved solids				5.90	7.38	7.50	7.49	19.00			
Wt % dissolved solids								8.67			

Table A.3. Envelope D Waste and Melter Feed Physical Property Data

Sample Number	71	72	73	74	75	76	77	78	79	80	81	82	83
Sample Description	12/00	12/12/00	12/18/00	1/4/01	1/17/01	1/19/01	2/3/01	10-wt% UDS	15-wt% UDS	22-wt% UDS	10-wt% UDS	15-wt% UDS	22-wt% UDS
References and Notes on Data	Melter Tests with AZ-101 HLW Simulant Using a DuraMelter 100 Vitrification System. VSL-01R10N0-1. See Table 2.3. Used Sampling Date from Table 2.3 to identify each sample							Pretreated AZ-101 HLW - Poloski AP, PR Bredt, JW Chenault, and RG Swoboda. 2003a. *Rheological and Physical Properties of AZ 101 HLW Pretreated Sludge and Melter Feed.* PNWD-3366, Battelle—Pacific Northwest Division, Richland, WA			AZ-101 HLW Melter Feed - Poloski AP, PR Bredt, JW Chenault, and RG Swoboda. 2003a. *Rheological and Physical Properties of AZ 101 HLW Pretreated Sludge and Melter Feed.* PNWD-3366, Battelle—Pacific Northwest Division, Richland, WA		
Physical Property													
Oxides loading of HLW sludge or pretreated sludge (total grams oxide/Liter)	537	406	421	562	350	311	542						
pH (aging 1day, 1week, 1mo)	10.3	10.1	5.0	10.0	10.0	10.0	10.1			12.1	10.0	9.9	10.3,10.3,10.4
Solid phases present													
Particle size distribution - Mean Vol. Distribution - (µm)													
Particle size distribution - Mean No. Distribution - (µm)													
Density – Bulk slurry (g/mL) (aging 1day, 1week, 1mo)	1.41	1.30	1.37	1.46	1.26	1.23	1.41				1.183±0.082	1.331±0.092	1.506 ± 0.104
Density – settled solids (g/mL)											1.28 ± 0.09	1.39 ± 0.10	1.50 ± 0.11
Density – centrifuged solids (g/mL)											1.370±0.171	1.625±0.202	1.676 ± 0.209
Density - supernatant liquid (g/mL)											1.063±0.003	1.110 ±0.003	1.177 ± 0.004
Vol. % settled solids after [48 hours] 72 hours (aging 1day, 1week, 1mo)											55.3%±5.5%	76.9%±7.6%	96.2%±9.5%
Vol. % centrifuged solids											32.5% ± 2.3%	46.0% ± 3.2%	70.5% ± 5.0%
Wt % total dried solids	47.0	37.5	45.7	46.9	34.3	30.9	47				23.3% ± 1.1%	33.6% ± 1.6%	44.5% ± 2.1%
Wt % centrifuged solids													
Wt % oven dried solids													
Wt % undissolved solids											16.4% ± 1.5%	25.6% ± 2.4%	37.8% ± 3.5%
Wt % dissolved solids											8.0% ± 0.2%	10.3% ± 0.3%	10.3% ± 0.3%

Table A.4. Envelope D Waste and Melter Feed Rheological Property Data

Sample Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Sample Description	C-104 (Envelope D) Pretreated Sludge Waste (5 wt% suspended solids)	C-104 (Envelope D) Pretreated Sludge Waste (15 wt% suspended solids)	C-104 (Envelope D) Pretreated Sludge Waste (25 wt% suspended solids)	C-104 (Envelope D) Pretreated Sludge Waste plus Secondary Wastes	AZ102 (Envelope D) Composited Pretreated Sludge Waste (5 wt% suspended solids)	AZ102 (Envelope D) Composited Pretreated Sludge Waste (15 wt% suspended solids)	AZ102 (Envelope D) Composited Pretreated Sludge Waste (20 wt% suspended solids)	AZ102 (Envelope D) Composited Pretreated Sludge Waste (25 wt% suspended solids)	AZ102 (Envelope D) Composited Pretreated Sludge Waste plus Secondary Wastes
References and Notes on Data	WTP-RPT-004, Rev. 0, See Table 3.3. Note that values given below were taken at the temperature reported after aging the slurry for the times stated. If only one value is stated it is after aging for one hour unless indicated otherwise. See reference for further details.								
Flow Curve Summary Report									
Steady State Shear									
Flow Curve (10-S) (cP) 20°C (aging 1hr, 1day, 1week)									
Flow Curve (10-S) (cP) 25°C (aging 1hr, 1day, 1week)									
40°C									
Flow Curve (33-S) ave. ascending -decending (cP) 25°C (aging 1hr, 1day, 1week)	9.8	15.4	164.9		12.1	525.2	903.8	4597	200
40°C									
50°C									
Flow Curve (100-S) ave. ascending -decending (cP) 25°C	3.8	14.6	193.8		11.7	556.2			
40°C									90
50°C									
Flow Curve (150-S) ave. ascending -decending (cP) 25°C	5.2	6.2	45.5		5.7	144.1	233.1	1263.5	
50°C	4.1	5.4	49.2		4.7	148.3			
Flow Curve (200-S) ave. ascending -decending (cP) 20°C									
Flow Curve (200-S) ave. ascending -decending (cP) 25°C									
40°C									
Flow Curve (300-S) ave. ascending -decending (cP) 25°C	4.7	5.7	25.9		5.2	78.7	128.6	702.6	60
40°C									
50°C	3.2	4.9	26.7		4.3	81.3			
Flow Curve (350-S) ave. ascending -decending (cP) 25°C									

Table A.4. Envelope D Waste and Melter Feed Rheological Property Data

Sample Number	1	2	3	4	5	6	7	8	9
Flow Curve (500-S) ave. ascending -decending (cP) 25°C									
50°C									
newtonian 25°C									
50°C									
Yield Stress (Pa) - 25°C (aging 1hr, 1day, 1week)	<1	<1	~5		<1	~14	~20	~190	3
Yield Stress (Pa) - 40°C									5
Yield Stress (Pa) - 50°C	<1	<1	~8		<1	~17			

Table A.4. Envelope D Waste and Melter Feed Rheological Property Data

Waste Type	10	11	12
Sample Description	Sim. Pretreated HLW AZ-101 (27.7 wt% total solids) VSL	Sim. Pretreated HLW AZ-102 (27.1 wt% total solids) VSL	Sim. Pretreated HLW C-106/AY-102 (28.8 wt% total solids) VSL
References and Notes on Data	VSL Report 2520-1, See Table C-1 for yield stress data. See Figures C-1 to C-3 for viscosity versus shear rate curves for AZ-101. See Figures C-18 to C-21 for AZ-102 data. See Figure C-37 for C-106/AY-102 data. Note that values given below were taken at the temperature reported after aging the slurry for the times stated. If only one value is stated it is after aging for one hour unless indicated otherwise. See reference for further details.		
Flow Curve Summary Report			
Steady State Shear			
Flow Curve (10-S) (cP) 20°C (aging 1hr, 1day, 1week)			
Flow Curve (10-S) (cP) 25°C (aging 1hr, 1day, 1week)			
40°C			
Flow Curve (33-S) ave. ascending -decending (cP) 25°C (aging 1hr, 1day, 1week)	300	200	60.00
40°C			
50°C			
Flow Curve (100-S) ave. ascending -decending (cP) 25°C		170	
40°C	150	90	18.60
50°C		75	
Flow Curve (150-S) ave. ascending -decending (cP) 25°C			
50°C			
Flow Curve (200-S) ave. ascending -decending (cP) 20°C			
Flow Curve (200-S) ave. ascending -decending (cP) 25°C		62	9.30
40°C		50	
Flow Curve (300-S) ave. ascending -decending (cP) 25°C	70		6.70
40°C			
50°C			
Flow Curve (350-S) ave. ascending -decending (cP) 25°C			
Flow Curve (500-S) ave. ascending -decending (cP) 25°C			
50°C			
newtonian 25°C			
50°C			
Yield Stress (Pa) - 25°C (aging 1hr, 1day, 1week)	1.9	3.8	
Yield Stress (Pa) - 40°C	2.6	7	
Yield Stress (Pa) - 50°C			

Table A.4. Envelope D Waste and Melter Feed Rheological Property Data

Sample Number	13	14	15	16	17	18	19	20	21
Sample Identification	Low Bound HLW Pretreated Waste Physical Simulant (20-L)	Low Bound HLW Melter Feed Physical Simulant	High Bound HLW Pretreated Waste Physical Simulant (41-H)	High Bound HLW Melter Feed Physical Simulant	HLW Precipitated Hydroxide Simulant	HLW Precipitated Hydroxide Melter Feed Simulant	AY102/C106 Pretreated Sludge 20.4	AY102/C106 Pretreated Sludge 27.4	AY102/C106 Pretreated Sludge 32.5
References and Notes on Data	WSRC-TR-2003-00220, Rev. 0, SRT-RPP-2003-00098, Rev. 0, Note that values given below were taken at the temperature reported after aging the slurry for the times stated. If only one value is stated it is after aging for one hour unless indicated otherwise. See reference for further details.						SRT-RPP-2004-00061, Rev. 0, Note that values given below were taken at the temperature reported after aging the slurry for the times stated. If only one value is stated it is after aging for one hour unless indicated otherwise. See reference for further details.		
Flow Curve Summary									
Steady State Shear									
Flow Curve (10-S) (cP) 20°C (aging 1hr, 1day, 1week)									
Flow Curve (10^{-S}) (cP) 25°C (aging 1hr, 1day, 1week)									
40°C									
Flow Curve (33^{-S}) ave. ascending -decending (cP) 25°C (aging 1hr, 1day, 1week)									
40°C									
50°C									
Flow Curve (100^{-S}) ave. ascending -decending (cP) 25°C									
40°C									
50°C									
Flow Curve (150^{-S}) ave. ascending -decending (cP) 25°C									
50°C									
Flow Curve (200^{-S}) ave. ascending -decending (cP) 20°C									
Flow Curve (200^{-S}) ave. ascending -decending (cP) 25°C									
40°C									
Flow Curve (300^{-S}) ave. ascending -decending (cP) 25°C									
40°C									
50°C									
Flow Curve (350^{-S}) ave. ascending -decending (cP) 25°C									
Flow Curve (500^{-S}) ave. ascending -decending (cP) 25°C									
50°C									
Flow Curve ($50\text{-}750^{-S}$) ave. ascending -decending (cP) 25°C							4.7		
40°C									
Flow Curve ($50\text{-}950^{-S}$) ave. ascending -decending (cP) 25°C								11.18	
40°C									
Flow Curve ($100\text{-}1000^{-S}$) ave. ascending -decending (cP) 25°C									18.95
40°C									19.03
newtonian 25°C	2.0								
50°C									

Table A.4. Envelope D Waste and Melter Feed Rheological Property Data

Sample Number	13	14	15	16	17	18	19	20	21
Yield Stress (Pa) - 25°C (aging 1hr, 1day, 1week)							0	20.4	
Yield Stress (Pa) - 40°C									
Yield Stress (Pa) - 50°C									
Bingham Model Yield Stress (Pa) - 25°C	0		27.9	29.8	12.5	18.9	1.62	11.99	60.99
Bingham Model Yield Stress (Pa) - 40°C					13.7	15.7			49.76
Bingham Model Consistency (mPa.s) - 25°C	2.0		10.6	39.7	11.0	28.5			
Bingham Model Consistency (mPa.s) - 40°C					10.4	20.2			

Table A.4. Envelope D Waste and Melter Feed Rheological Property Data

Sample Number	22	23	24	25	26	27	28	29	30
Sample Identification	Melter feed made up with the AZ-101 HLW Simulant (Table 2.2) containing varying amounts of water, nitrate, and frit. The nitrated feed has the lowest pH, while the nominal feed has the highest with the high water or frit containing feed showing intermediate values.								
References and Notes on Data	DuraMelter 1200 HLW Pilot Melter System Using AZ-101 HLW Simulants. VSL-02R0100-2, Rev. 1, Note that values given below were taken at the temperature reported after aging the slurry for the times stated. If only one value is stated it is after aging for one hour unless indicated otherwise. See reference for further details.								
Flow Curve Summary									
Steady State Shear (1/sec) - cP	2310	4290	800	700	900	530	400	180	2860
Steady State Shear (10/sec) - cP	280	610	99	80	96	70	53	7	430
Flow Curve (10-S) (cP) 20°C (aging 1hr, 1day, 1week)									
Flow Curve (10^{-S}) (cP) 25°C (aging 1hr, 1day, 1week)									
40°C									
Flow Curve (33^{-S}) ave. ascending -decending (cP) 25°C (aging 1hr, 1day, 1week)									
40°C									
50°C									
Flow Curve (100^{-S}) ave. ascending -decending (cP) 25°C									
40°C									
50°C									
Flow Curve (150^{-S}) ave. ascending -decending (cP) 25°C									
50°C									
Flow Curve (200^{-S}) ave. ascending -decending (cP) 20°C									
Flow Curve (200^{-S}) ave. ascending -decending (cP) 25°C									
40°C									
Flow Curve (300^{-S}) ave. ascending -decending (cP) 25°C									
40°C									
50°C									
Flow Curve (350^{-S}) ave. ascending -decending (cP) 25°C									
Flow Curve (500^{-S}) ave. ascending -decending (cP) 25°C									
50°C									
Flow Curve ($50\text{-}750^{-S}$) ave. ascending -decending (cP) 25°C									
40°C									
Flow Curve ($50\text{-}950^{-S}$) ave. ascending -decending (cP) 25°C									
40°C									
Flow Curve ($100\text{-}1000^{-S}$) ave. ascending -decending (cP) 25°C									
40°C									
newtonian 25°C									
50°C									
Yield Stress (Pa) - 25°C (aging 1hr, 1day, 1week)	2.0	7.7	1.8	1.8	1.2	1.0	0.7	-	6.3
Yield Stress (Pa) - 40°C									
Yield Stress (Pa) - 50°C									
Bingham Model Yield Stress (Pa) - 25°C									
Bingham Model Yield Stress (Pa) - 40°C									

Table A.4. Envelope D Waste and Melter Feed Rheological Property Data

Sample Number	22	23	24	25	26	27	28	29	30
Bingham Model Consistency (mPa.s) - 25°C									
Bingham Model Consistency (mPa.s) - 40°C									

Table A.4. Envelope D Waste and Melter Feed Rheological Property Data

Sample Number	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**
Sample Identification	Feed to make HLW98-86 Glass		Feed to make HLW98-80 Glass		Feed to make HLW98-96D Glass		Feed to make HLW98-77 Glass					
References and Notes on Data	DM 1200 Melter Testing of HLW C-106/AY-102 Composition Using Bubblers. VSL-03R3800-1, Rev. 0. See Table 2.1.		DM 1200 Melter Testing of HLW AZ-102 Composition Using Bubblers. VSL-03R3800-2, Rev. 0. See Table 2.1. See also Tables 2.2 and 2.3.		DM 1200 Tests with C-104/AY-101 HLW Simulants VSL-03R3800-3, Rev. 0. See Table 2.5.		DM 1200 Tests with AZ-101 HLW Simulants. VSL-03R3800-4, Rev. 0. See Table 2.4.					
Flow Curve Summary												
Steady State Shear (1/sec) - cP	2328	2589	4674	3171	3060	3290	3370	1870	3820	912	1210	100
Steady State Shear (10/sec) - cP	262	313	598	477	475	511	475	380	549	124	152	21
Steady State Shear (100/sec) - cP	42	49	92	67	66	70	66	9	74	21	25	7
Flow Curve (10-S) (cP) 20°C (aging 1hr, 1day, 1week)												
Flow Curve (10^{-S}) (cP) 25°C (aging 1hr, 1day, 1week)												
40°C												
Flow Curve (33^{-S}) ave. ascending -decending (cP) 25°C (aging 1hr, 1day, 1week)												
40°C												
50°C												
Flow Curve (100^{-S}) ave. ascending -decending (cP) 25°C												
40°C												
50°C												
Flow Curve (150^{-S}) ave. ascending -decending (cP) 25°C												
50°C												
Flow Curve (200^{-S}) ave. ascending -decending (cP) 20°C												
Flow Curve (200^{-S}) ave. ascending -decending (cP) 25°C												
40°C												
Flow Curve (300^{-S}) ave. ascending -decending (cP) 25°C												
40°C												
50°C												
Flow Curve (350^{-S}) ave. ascending -decending (cP) 25°C												
Flow Curve (500^{-S}) ave. ascending -decending (cP) 25°C												
50°C												
Flow Curve ($50\text{-}750^{-S}$) ave. ascending -decending (cP) 25°C												
40°C												
Flow Curve ($50\text{-}950^{-S}$) ave. ascending -decending (cP) 25°C												
40°C												
Flow Curve ($100\text{-}1000^{-S}$) ave. ascending -decending (cP) 25°C												
40°C												
newtonian 25°C												
50°C												
Yield Stress (Pa) - 25°C (aging 1hr, 1day, 1week)	5.5	5.5	8.8	9.6	5.0	5.9	5.5	1.1	6.1	0.8	1.9	1.1

Table A.4. Envelope D Waste and Melter Feed Rheological Property Data

Sample Number	31	32	33	34	35	36	37	38	39	40	41	42
Yield Stress (Pa) - 40°C												
Yield Stress (Pa) - 50°C												
Bingham Model Yield Stress (Pa) - 25°C												
Bingham Model Yield Stress (Pa) - 40°C												
Bingham Model Consistency (mPa.s) - 25°C												
Bingham Model Consistency (mPa.s) - 40°C												

Table A.4. Envelope D Waste and Melter Feed Rheological Property Data

Sample Number	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**
Sample Identification	AZ-101 feed with variable amounts of sugar and Ru/Y spike	C-106/AY-102 feed with variable amounts of sugar. No.44 added nitrate. No.45 no sugar.			AZ-101 feed used in Tests 8 and 9.				Feed to make HLW98-80 Glass – Adjusted Rheology		Feed to make HLW98-80 Glass - Nominal	
References and Notes on Data	DM 1200 Melter Testing of Redox Effects Using HLW AZ-102 and C-106/AY-102 Simulants. VSL-04R4800-1, Rev. 0. See Table 2.7. Note that values given below were taken at the temperature reported after aging the slurry for the times stated. If only one value is stated it is after aging for one hour unless indicated otherwise. See reference for further details.				DM 1200 Melter Testing of Bubblers Configurations Using HLW AZ-101 Simulants. VSL-04R4800-4, Rev. 0. See Table 2.5. Note that values given below were taken at the temperature reported after aging the slurry for the times stated. If only one value is stated it is after aging for one hour unless indicated otherwise. See reference for further details.				DM 1200 MelterTesting of Redox Effects Using HLW AZ-101 and C-106/AY-102 Simulants: HLW Simulant Verification. VSL-05R5800-1, Rev. A. See Table 2.11. Note that values given below were taken at the temperature reported after aging the slurry for the times stated. If only one value is stated it is after aging for one hour unless indicated otherwise. See reference for further details.			
Flow Curve Summary												
Steady State Shear (1/sec) - cP	983	11500	2328	6300	1606	1802	1627	1627				
Steady State Shear (10/sec) - cP	134	1524	262	1451	207	230	209	195	5705	2215	59	59
Steady State Shear (100/sec) - cP	23	265	42	180	33	37	35	33	756	292	13	12
Steady State Shear (1000/sec) - cP									108	48	6	6
Flow Curve (10-S) (cP) 20°C (aging 1hr, 1day, 1week)												
Flow Curve (10^{-S}) (cP) 25°C (aging 1hr, 1day, 1week)												
40°C												
Flow Curve (33^{-S}) ave. ascending -decending (cP) 25°C (aging 1hr, 1day, 1week)												
40°C												
50°C												
Flow Curve (100^{-S}) ave. ascending -decending (cP) 25°C												
40°C												
50°C												
Flow Curve (150^{-S}) ave. ascending -decending (cP) 25°C												
50°C												
Flow Curve (200^{-S}) ave. ascending -decending (cP) 20°C												
Flow Curve (200^{-S}) ave. ascending -decending (cP) 25°C												
40°C												
Flow Curve (300^{-S}) ave. ascending -decending (cP) 25°C												
40°C												
50°C												
Flow Curve (350^{-S}) ave. ascending -decending (cP) 25°C												
Flow Curve (500^{-S}) ave. ascending -decending (cP) 25°C												
50°C												
Flow Curve ($50\text{-}750^{-S}$) ave. ascending -decending (cP) 25°C												
40°C												
Flow Curve ($50\text{-}950^{-S}$) ave. ascending -decending (cP) 25°C												

Table A.4. Envelope D Waste and Melter Feed Rheological Property Data

Sample Number	43	44	45	46	47	48	49	50	51	52	53	54
40°C												
Flow Curve (100-1000^{-S}) ave. ascending -decending (cP) 25°C												
40°C												
newtonian 25°C												
50°C												
Yield Stress (Pa) - 25°C (aging 1hr, 1day, 1week)	1.9	12.3	5.5	11.2	3.7	3.0	2.4	2.2	57.0	25.8	1.5	1.6
Yield Stress (Pa) - 40°C												
Yield Stress (Pa) - 50°C												
Bingham Model Yield Stress (Pa) - 25°C												
Bingham Model Yield Stress (Pa) - 40°C												
Bingham Model Consistency (mPa.s) - 25°C												
Bingham Model Consistency (mPa.s) - 40°C												

Table A.4. Envelope D Waste and Melter Feed Rheological Property Data

Sample Number	55	56	57	58	59	60	61	62	63	64
Sample Identification	Feed to make HLW98-86 Glass – Adjusted Rheology		Feed to make HLW98-86 Glass – High Waste Loading	AY-102/C-106 Simulant	AY-102/C-106 Actual Slurry. See Table 4.15			Nominal Melter Feed	Adjusted Rheology Feed	SIPP Melter Feed
References and Notes on Data	DM 1200 MelterTesting of Redox Effects Using HLW AZ-101 and C-106/AY-102 Simulants: HLW Simulant Verification. VSL-05R5800-1, Rev. A. See Table 2.11.			Tank 241-AY-102 Simulant Development, Ultrafiltration, and Washing. WSRTC-TR-2003-00547, Rev.0. Note C-106/AY-102 ≡ AY-102 in this document. See Tables 4.7, 4.13, and 4.14				DuraMelter 100 HLW Simulant Validation Tests with C-106/AY-102 Feeds. VSL-05R5710-1, Rev. A, See Table 2.10		
Flow Curve Summary										
Steady State Shear (1/sec) - cP										
Steady State Shear (10/sec) - cP	2672	2604	67					358	1740	1140
Steady State Shear (100/sec) - cP	368	352	13					41	164	164
Steady State Shear (1000/sec) - cP	58	58	7					22	28	34
Flow Curve (10-S) (cP) 20°C (aging 1hr, 1day, 1week)										
Flow Curve (10^{-S}) (cP) 25°C (aging 1hr, 1day, 1week)										
40°C										
Flow Curve (33^{-S}) ave. ascending -decending (cP) 25°C (aging 1hr, 1day, 1week)										
40°C										
50°C										
Flow Curve (100^{-S}) ave. ascending -decending (cP) 25°C										
40°C										
50°C										
Flow Curve (150^{-S}) ave. ascending -decending (cP) 25°C										
50°C										
Flow Curve (200^{-S}) ave. ascending -decending (cP) 20°C										
Flow Curve (200^{-S}) ave. ascending -decending (cP) 25°C										
40°C										
Flow Curve (300^{-S}) ave. ascending -decending (cP) 25°C										
40°C										
50°C										
Flow Curve (350^{-S}) ave. ascending -decending (cP) 25°C										
Flow Curve (500^{-S}) ave. ascending -decending (cP) 25°C										
50°C										
Flow Curve ($50\text{-}750^{-S}$) ave. ascending -decending (cP) 25°C										
40°C										
Flow Curve ($50\text{-}950^{-S}$) ave. ascending -decending (cP) 25°C										
40°C										
Flow Curve ($100\text{-}1000^{-S}$) ave. ascending -decending (cP) 25°C										
40°C										
newtonian 25°C										

Table A.4. Envelope D Waste and Melter Feed Rheological Property Data

Sample Number	55	56	57	58	59	60	61	62	63	64
50°C										
Yield Stress (Pa) - 25°C (aging 1hr, 1day, 1week)	28.0	29.9	3.2	0.38	1.24	1.22	1.26			
Yield Stress (Pa) - 40°C										
Yield Stress (Pa) - 50°C										
Bingham Model Yield Stress (Pa) - 25°C										
Bingham Model Yield Stress (Pa) - 40°C										
Bingham Model Consistency (mPa.s) - 25°C				5.3	6.64	6.63	6.59			
Bingham Model Consistency (mPa.s) - 40°C										

Table A.4. Envelope D Waste and Melter Feed Rheological Property Data

Sample Number	65	66	67	68	69	70	71	72	73	74	75	76	77
Sample Identification	12/00	12/12/00	12/18/00	1/4/01	1/17/01	1/19/01	2/3/01	10-wt% UDS	15-wt% UDS	22-wt% UDS	10-wt% UDS	15-wt% UDS	22-wt% UDS
References and Notes on Data	Melter Tests with AZ-101 HLW Simulant Using a DuraMelter 100 Vitrification System. VSL-01R10N0-1. See Table 2.3. Used Sampling Date from Table 2.3 to identify each sample. Note that values given below were taken at the temperature reported after aging the slurry for the times stated. If only one value is stated it is after aging for one hour unless indicated otherwise. See reference for further details.							Pretreated AZ-101 HLW - Poloski AP, PR Bredt, JW Chenault, and RG Swoboda. 2003a. *Rheological and Physical Properties of AZ 101 HLW Pretreated Sludge and Melter Feed.* PNWD-3366, Battelle—Pacific Northwest Division, Richland, WA. Note that values given below were taken at the temperature reported after aging the slurry for the times stated. If only one value is stated it is after aging for one hour unless indicated otherwise. See reference for further details.			AZ-101 HLW Melter Feed - Poloski AP, PR Bredt, JW Chenault, and RG Swoboda. 2003a. *Rheological and Physical Properties of AZ 101 HLW Pretreated Sludge and Melter Feed.* PNWD-3366, Battelle—Pacific Northwest Division, Richland, WA. Note that values given below were taken at the temperature reported after aging the slurry for the times stated. If only one value is stated it is after aging for one hour unless indicated otherwise. See reference for further details.		
Flow Curve Summary													
Steady State Shear (1/sec) - cP	1800	700	700	3000	350	700	5200						
Steady State Shear (10/sec) - cP	187	75	82	274	42	77	600						
Steady State Shear (100/sec) - cP	35	15	15	46	10	13	90						
Steady State Shear (1000/sec) - cP													
Flow Curve (10-S) (cP) 20°C (aging 1hr, 1day, 1week)													
Flow Curve (10^{-S}) (cP) 25°C (aging 1hr, 1day, 1week)													
40°C													
Flow Curve (33^{-S}) ave. ascending -decending (cP) 25°C (aging 1hr, 1day, 1week)													
40°C													
50°C													
Flow Curve (100^{-S}) ave. ascending -decending (cP) 25°C													
40°C													
50°C													
Flow Curve (150^{-S}) ave. ascending -decending (cP) 25°C													
50°C													
Flow Curve (200^{-S}) ave. ascending -decending (cP) 20°C													
Flow Curve (200^{-S}) ave. ascending -decending (cP) 25°C													
40°C													
Flow Curve (300^{-S}) ave. ascending -decending (cP) 25°C													
40°C													
50°C													

Table A.4. Envelope D Waste and Melter Feed Rheological Property Data

Sample Number	65	66	67	68	69	70	71	72	73	74	75	76	77
Flow Curve (350^{-S}) ave. ascending -decending (cP) 25°C													
Flow Curve (500^{-S}) ave. ascending -decending (cP) 25°C													
50°C													
Flow Curve ($50\text{-}750^{-S}$) ave. ascending -decending (cP) 25°C													
40°C													
Flow Curve ($50\text{-}950^{-S}$) ave. ascending -decending (cP) 25°C													
40°C													
Flow Curve ($100\text{-}1000^{-S}$) ave. ascending -decending (cP) 25°C													
40°C													
newtonian 25°C													
50°C													
Yield Stress (Pa) - 25°C (aging 1hr, 1day, 1week)													
Yield Stress (Pa) - 40°C													
Yield Stress (Pa) - 50°C													
Bingham Model Yield Stress (Pa) - 25°C	0.4	0.4	newtonian	0.7	newtonian	newtonian	0.8	0	2.9	11.4,nr*,12.6	1.8	3.4	14.7,5.1,3.6
Bingham Model Yield Stress (Pa) - 40°C								0	2.8	10.3,nr,11.8	1.9	4.9	18.1,4.7,4.8
Bingham Model Consistency (mPa.s) - 25°C								<10	5.2	10.5,nr,21.8	4.1	10.7	21,9.9,10.6
Bingham Model Consistency (mPa.s) - 40°C								<10	3.5	7.2,nr,15.1	3.8	7.6	19.3,9.3,9.0

* nr ≡ not reported

Appendix B

Physical-Property Correlations and Discussions

Appendix B: Physical-Property Correlations and Discussions

B1. Settling-Rate Characteristics HLW Melter Feeds and HLW Pretreated Waste Sludge

The settling of suspended solids in pretreated waste sludge and in melter-feed slurries is significant because it relates directly to the ease of maintaining a homogenous slurry during processing. Homogeneity is a compliance criterion because the quality control of the glass product is directly affected by the degree of homogeneity during processing. The historical settling-rate information discussed in this section relates to the height of the supernate/settled solids interface as a function of time. This interface represents the slow-settling portion of the slurry and is directly related to particle-size distribution, particle-density distribution, particle shape, slurry aging, temperature, size of the measurement container, degree of flocculation, etc. A comparison of these data across multiple laboratories with different measurement techniques will vary these parameters and be difficult.

In Figure B1.1, the settled volume percent of the initial volume occupied by the suspended solids of HLW sludge and melter feeds is plotted as a function of bulk density. The dissolved-solids concentration of these streams is low. Hence, it is expected that the density will be proportional to the suspended-solids loading and will relate to the settling data in a similar way as the previous section. The HLW pretreated sludge and melter feeds show decreasing amounts of settling as the amount of suspended solids, i.e., bulk density, increases. It is observed that adding glass-former minerals appears to increase the settling rate. This is most likely due to the addition of large/dense particles from glass formers. As a result, the melter feeds show similar settling behavior to the HLW pretreated sludges, only shifted to a higher density.

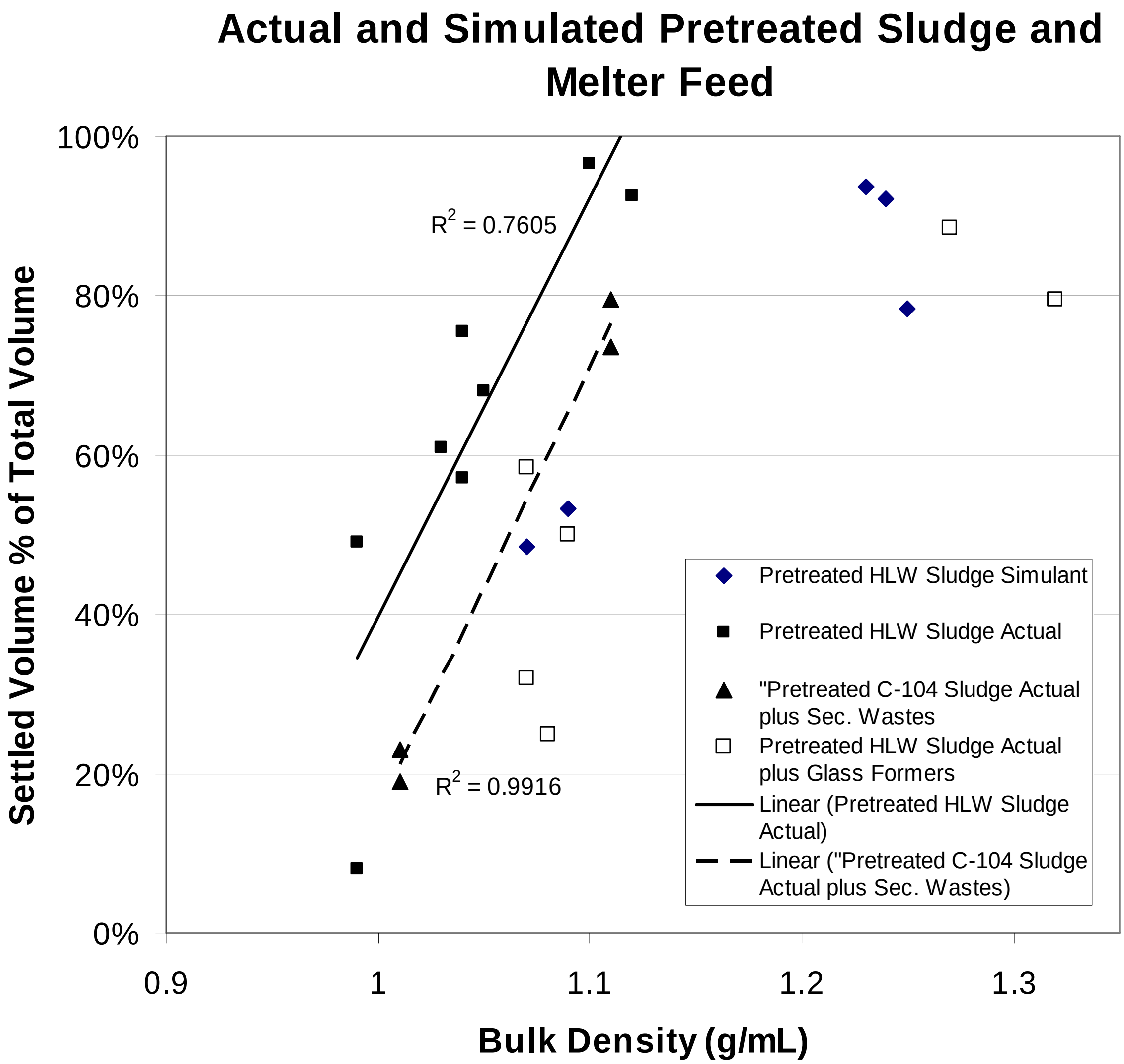

Figure B1.1. HLW Sludge and HLW Melter Feed Settling Characteristic (Settling time 48 hrs.)

B2. Correlation of Bulk Density to Weight Percent Solids and Oxide Loading

Figure B2.1 indicates that the bulk density of pretreated wastes and melter feeds and their simulants correlate well with concentration parameters such as weight percent total solids or the total gram oxides per liter. Figure B2.1 shows the relationship between bulk density and both weight percent total solids and the related total gram oxides per liter recalculated as weight-percent oxides. The percentage difference between these values is the amount of material that volatizes at high temperatures.

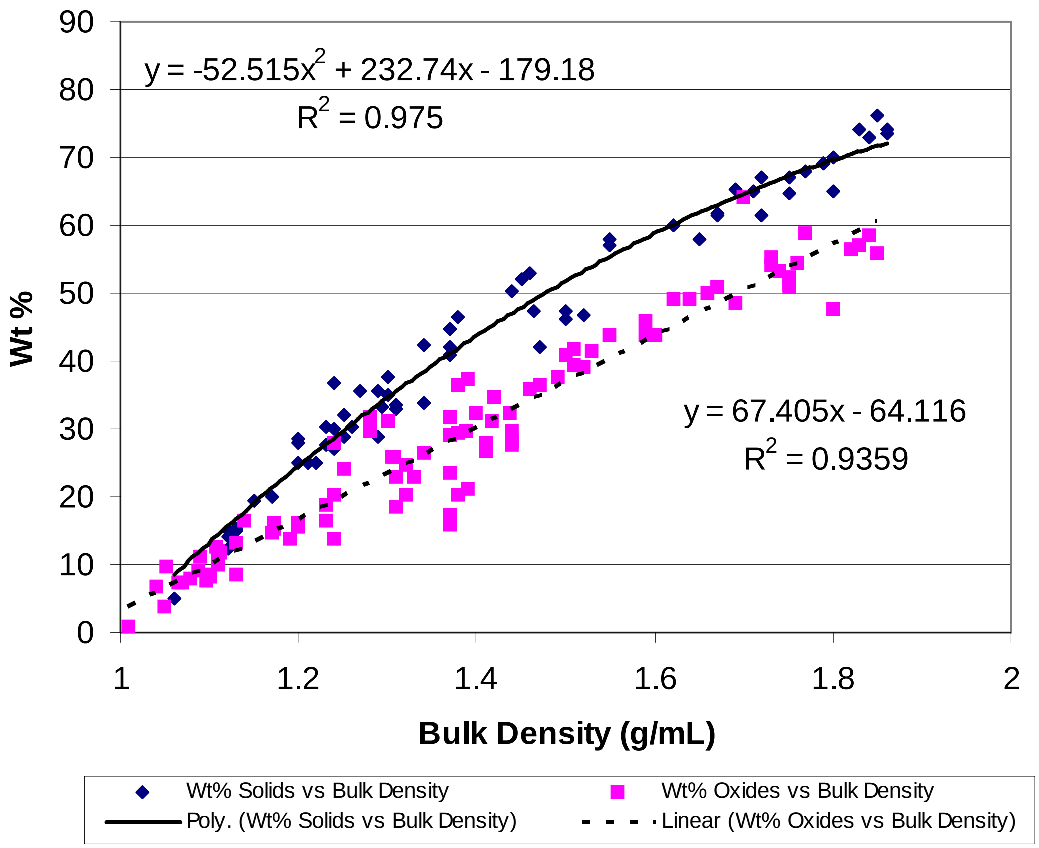

Figure B2.1. Weight Percent Total Solids and Weight Percent Oxides as a Function of Bulk Density for Pretreated LAW, HLW Sludge, and LAW and HLW Melter Feed and Their Simulants

Figures B2.2 and B2.3 indicate that the bulk density correlates system by system with the percent total solids and the related total gram oxides per liter recalculated as weight percent oxides, all in a similar way.

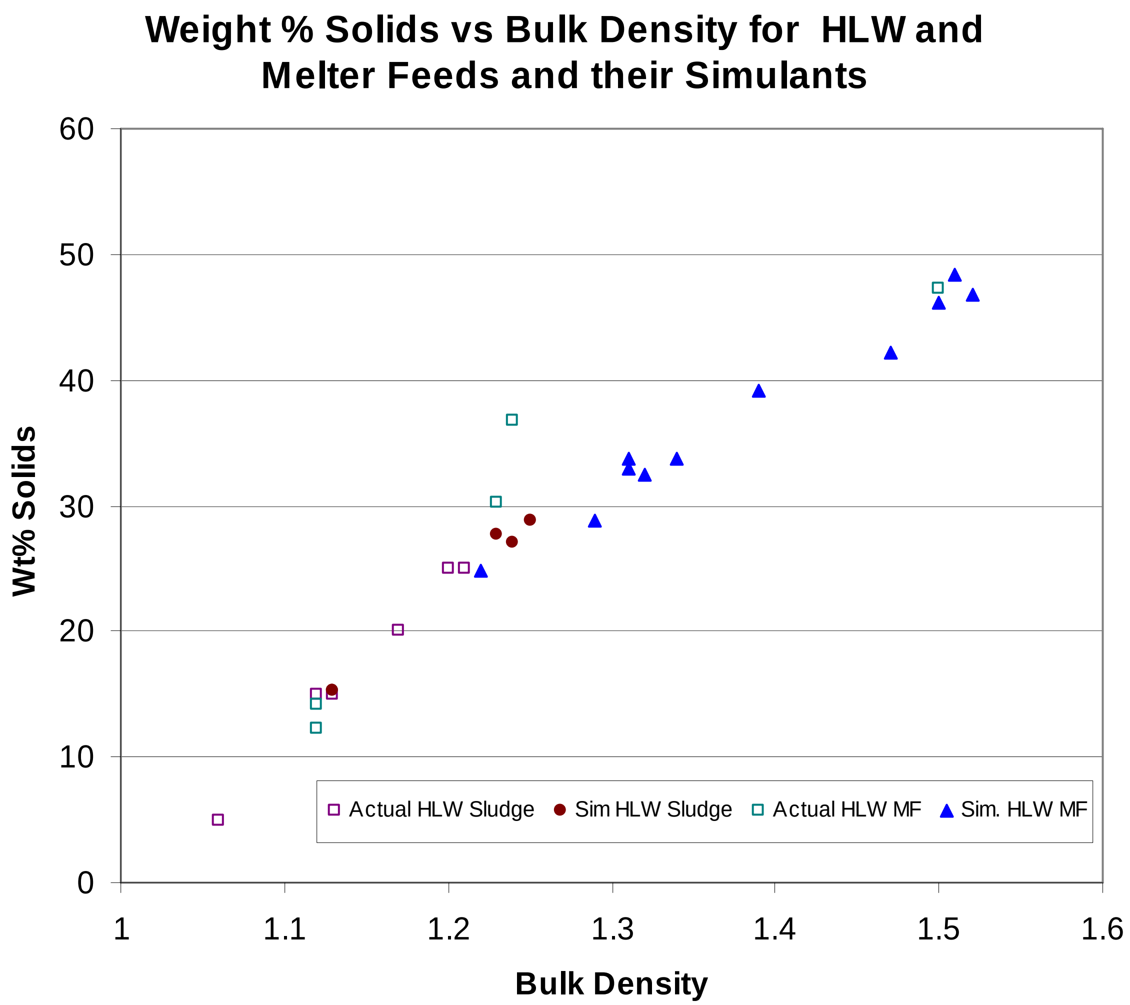

Figure B2.2. Observed Weight Percent Total Solids as a Function of Bulk Density for HLW Sludge and HLW Melter Feed.

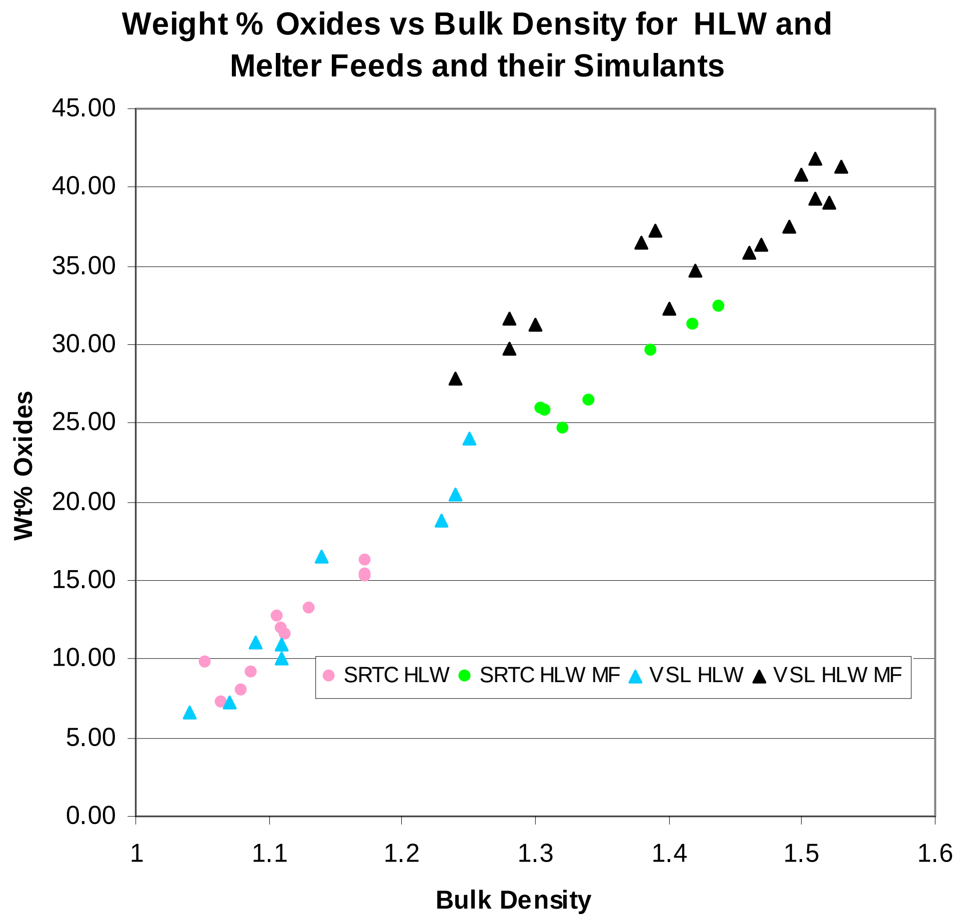

Figure B2.3. Observed Weight Percent Oxides as a Function of Bulk Density for HLW Sludge and HLW Melter Feed.

Table B2.1. Source References for Data

Waste Type	Sample Description	Density – Bulk slurry (g/mL)	Wt % total dried solids	Source Reference for Data
D	C-104 (Envelope D) Pretreated Sludge Waste		20	WTP-RPT-004, Rev. 0, WTP-RPT-006, Rev. 0 See Test Instructions appended to WTP-RPT-004, Rev. 0 as well as Table 3.1. In WTP-RPT-006, Rev. 0 see Tables 3.1 and 3.2.
D	C-104 (Envelope D) Pretreated Sludge Waste plus Secondary Wastes			
D	Pretreated HLW Sludge C-104 (5 wt% suspended solids) PNNL 25°C	1	5	
D	Pretreated HLW Sludge C-104 (15 wt% suspended solids) PNNL 25°C	1.05	15	
D	Pretreated HLW Sludge C-104 (25 wt% suspended solids) PNNL 25°C	1.12	25	
D	AZ102 (Envelope D) Composited Pretreated Sludge Waste		9.535	
D	AZ102 (Envelope D) Composited Pretreated Sludge Waste plus Secondary Wastes	1.04	5	
D	Pretreated HLW Sludge AZ102 (15 wt% suspended solids) PNNL 25°C	1.14	15	
D	Pretreated HLW Sludge AZ-102 New Sample (20 wt% suspended solids) PNNL 25°C		20	
D	Pretreated HLW Sludge AZ102 (25 wt% suspended solids) PNNL 25°C	1.24	25	
D	Sim. Pretreated HLW AZ-101 (27.7 wt% total solids) VSL	1.23	24.7	VSL Report 2520-1, See Tables 2.14, 2.17, and 2.18.
D	Sim. Pretreated HLW AZ-102 (27.1 wt% total solids) VSL	1.24	27.4	
D	Sim. Pretreated HLW C-106/AY-102 (28.8 wt% total solids) VSL	1.25	28.7	
D	Simulated Waste AZ-101 SRNL	1.13	14.90	WSRC-TR-2001-00203, Rev.0. See Tables 4 and 6
D	Sim. Pretreated HLW AZ-101 (9 wt% total solids) SRNL 25°C	1.07	9.00	
D	Sim. Pretreated HLW AZ-101 (11.6 wt% total solids) SRNL 25°C	1.08	11.60	
D	Sim. Pretreated HLW AZ-101 (16.3 wt% total solids) SRNL 25°C	1.13	16.30	
D	Sim. Pretreated HLW AZ-101 (20.8 wt% total solids) SRNL 25°C	1.18	20.80	
D	Simulated Waste AZ-102 SRNL	1.11		
D	Sim. Pretreated HLW AZ-102 (10.6 wt% total solids) SRNL 25°C	1.07	10.60	
D	Sim. Pretreated HLW AZ-102 (12.8 wt% total solids) SRNL 25°C	1.09	12.80	
D	Sim. Pretreated HLW AZ-102 (15.6 wt% total solids) SRNL 25°C	1.11	15.60	

D	Sim. Pretreated HLW AZ-102 (20.5 wt% total solids) SRNL 25°C	1.17	20.50	
D	C-104(25 wt% solids) w GF Mixing and Aging Study Measured at 25°C			WTP-RPT-004, Rev. 0. See Table 3.1 (incomplete)
D	HLW MF C-104 (14.1 wt% total solids) PNNL 25°C	1.12	14.4	
D	HLW MF C-104 (36.8 wt% total solids) PNNL 25°C	1.24	36.8	
D	HLW MF C-104 (47.3 wt% total solids) PNNL 25°C	1.5	47.3	
D	AZ-102(15 wt% waste solids with both secondary wastes and glass formers) Mixing and Aging Study Measured at 25°C		31.3	
D	HLW MF AZ-102 (12.3 wt% total solids) PNNL 25°C	1.12	12.3	
D	HLW MF AZ-102 Repeat (30.3 wt% total solids) PNNL 25°C	1.23	30.3	
D	Sim. HLW MF NOAHF9 AZ-101 (48.4 wt% total solids) VSL	1.51	48.43	VSL-R2520-1, Rev0. See Tables 3.5, 3.6, 3.7, 3.9, 3.10, and 3.12 for melter feed properties.
D	Sim. HLW MF NOAHF11 AZ-101 (46.8 wt% total solids) VSL	1.52	46.8	
D	AZ101 - NOAHF11A	1.51	49.14	
D	Sim. HLW MF AZ-102 Melter Feed NOAHF14 (46.2 wt% total solids) VSL	1.5	46.18	
D	AZ102 - NOAHF14	1.38	41	
D	AZ102 - NOAHF14	1.3	35	
D	AZ102 - NOAHF14	1.24	31.3	
D	AZ102 - NOAHF14A	1.53	50.57	
D	Sim. HLW MF Noah F13 (-325 silica) (42.1 wt% total solids) VSL	1.47	42.06	
D	C106/AY102 - NOAHF13			
D	C106/AY102 - NOAHF13			
D	Sim. HLW MF 1.3 AZ-101 (39.1 wt% total solids) SRNL	1.387	39.05	WSRC-TR-2001-00203, Rev.0, See Tables 16 and 18.
D	Sim. HLW MF 1.4 AZ-101 (32.5 wt% total solids) SRNL	1.321	32.47	
D	Sim. HLW MF 1.5 AZ-101 (33.7 wt% total solids) SRNL	1.308	33.66	
D	Simulated Melter Feed - 2.3	1.418	39.82	
D	Sim. HLW MF TEST 2.4 AZ-102 (33 wt% total solids) SRNL	1.305	32.96	
D	Sim. HLW MF TEST 2.5 AZ-102 (33.7 wt% total solids) SRNL	1.341	33.65	
D	Simulated Melter Feed - 2.9	1.438	41.39	
D	Sim. HLW MF TEST ADD3 AZ-102 (24.9 wt% total solids) SRNL	1.22	24.9	
D	Sim. HLW MF TEST ADD4 AZ-102 (28.8 wt% total solids) SRNL	1.29	28.8	

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Kot WK, H Gan, and IL Pegg. 2000. *Physical and Rheological Properties of Waste Simulants and Melter Feeds for RPP-WTP HLW Vitrification.* VSL-00R2520-1, Vitreous States Laboratory, The Catholic University of America, Washington D.C.

Matlack KS, WK Kot, and IL Pegg. 2000. *Screening Tests on DuraMelter™10 with C-106/AY-102 Simulant in Support of DuraMelter™1000 Throughput Tests.* VSL-00R2501-2, Rev. 0, Vitreous States Laboratory, The Catholic University of America, Washington DC.

Matlack KS, WK Kot, F Perez-Cardenas, and IL Pegg. 2000. *Tests on DuraMelter™10 with AZ-101 Simulant in Support of DuraMelter™1000 Throughput Tests.* VSL-00R2501-1, Rev. 0, Vitreous States Laboratory, The Catholic University of America, Washington D.C.

Rosencrance SW, WD King, and C Nash. 2000. *Physical Characterization for Hanford Tank Waste Samples AN-102, AN-103, and AZ-102.* WSRC-TR-2000-00352, Westinghouse Savannah River Company, Aiken, SC. (SCT-M0SRLE60-00-83-01A

B3. Rheological Comparison of HLW Pretreated Wastes and Associated Melter Feeds

Figure B3.1 compares the actual and simulants of the AZ-102 HLW sludge at an insoluble solids loading range of 5 to 25 wt%. Note that the total solids in a pretreated HLW sludge are almost totally insoluble because the waste sludge is produced from the raw waste by a washing process that removes almost all of the soluble chemical compounds, so it can be said with reasonable confidence that a sludge with 15 wt% suspended solids is about 85 wt% water. The principle observation to be made is that the waste simulant made by the hydroxide precipitation method (SRNL) has rheological properties closer to the actual HLW AZ-102 than that made by just mixing the appropriate hydroxide chemicals (VSL). Note that this relationship between the actual and simulated waste materials was reported by Morrey et al. (1996). The melter feed made with the "hydroxide precipitation and wash method" simulant is slightly more concentrated than the feed made with actual HLW sludge (67 wt% water vs 69 wt% water). Again, the "mixing the appropriate hydroxide chemicals method" for producing a simulant resulted in a simulated melter-feed system with a significantly lower viscosity for the same water concentration.

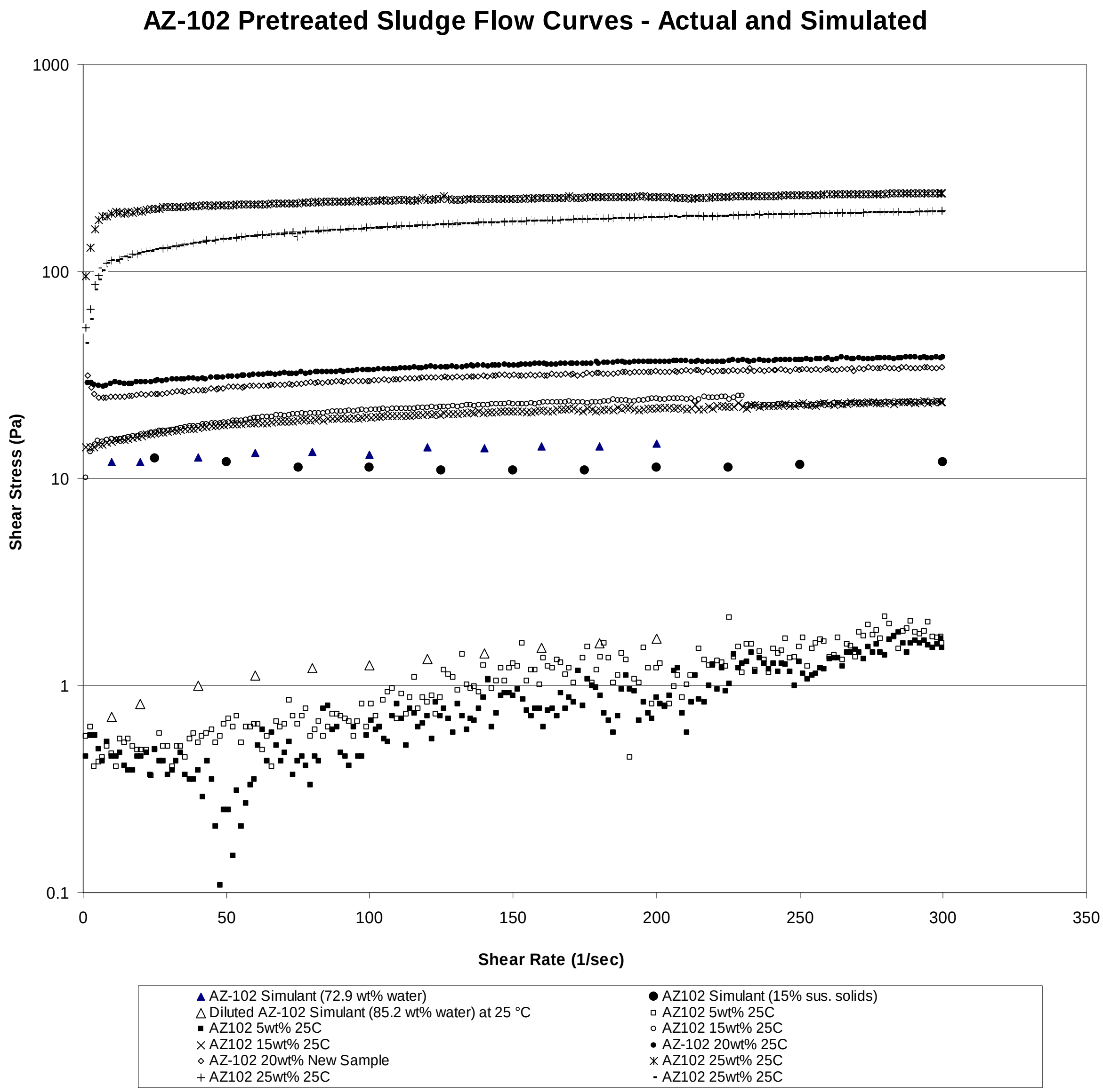

Figure B3.1. Rheology of Simulated and Actual AZ-102 HLW Sludge

Figure B3.2 illustrates the anomalous behavior of the slurry rheology observed between the actual AZ-102 melter feed and the actual AZ-102 pretreated HLW sludge. It was expected that these slurries would show similar behavior to that observed for the C-104 system discussed below, i.e., the melter feed would be thicker than the pretreated HLW slurry itself.

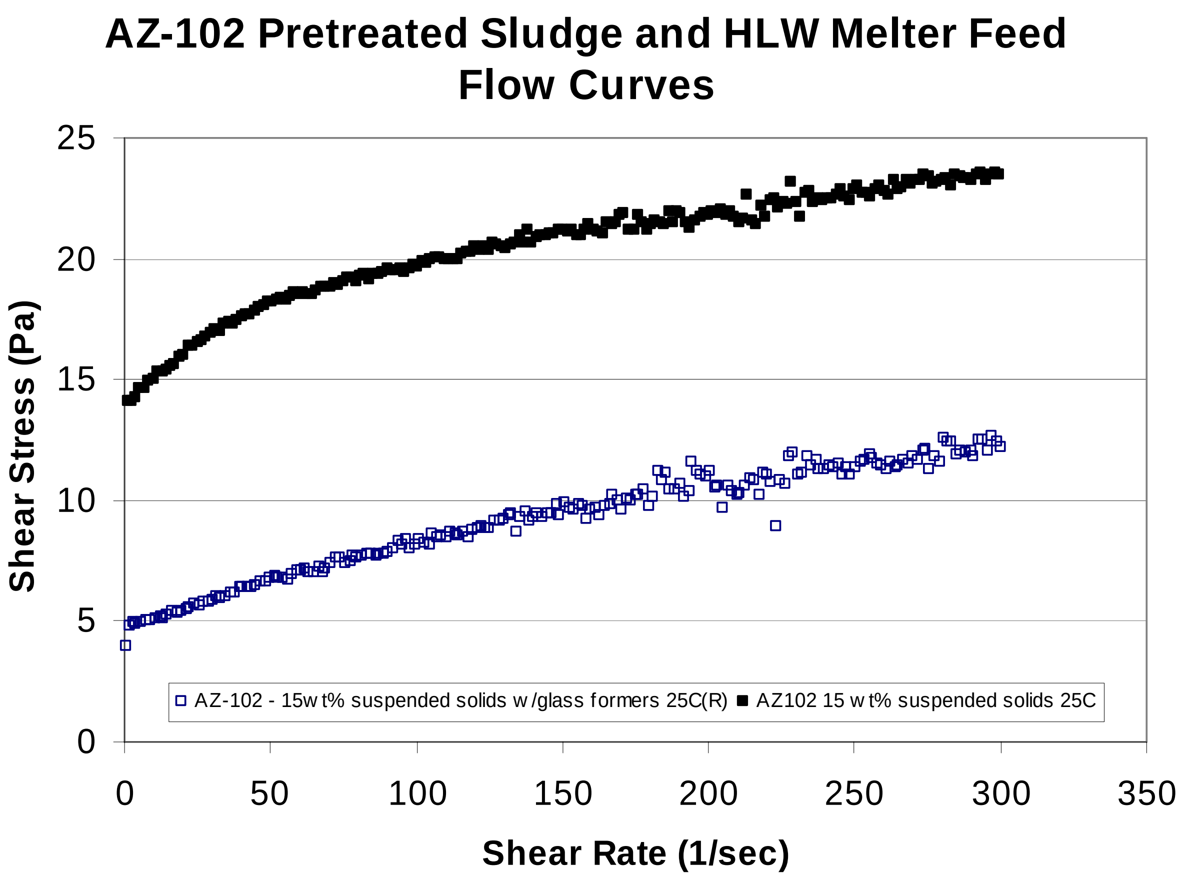

Figure B3.2. The Addition of Glass Formers to the AZ-102 Actual Waste is Observed to Lower the Viscosity of the Slurry by more than a Factor of Two

Figures B3.3 and B3.4 summarize the effects of temperature and water concentration on the viscous behavior of C-104 actual sludge and melter feed. Note the considerable increase in viscosity when glass-former additives are added to C-104 pretreated sludge.

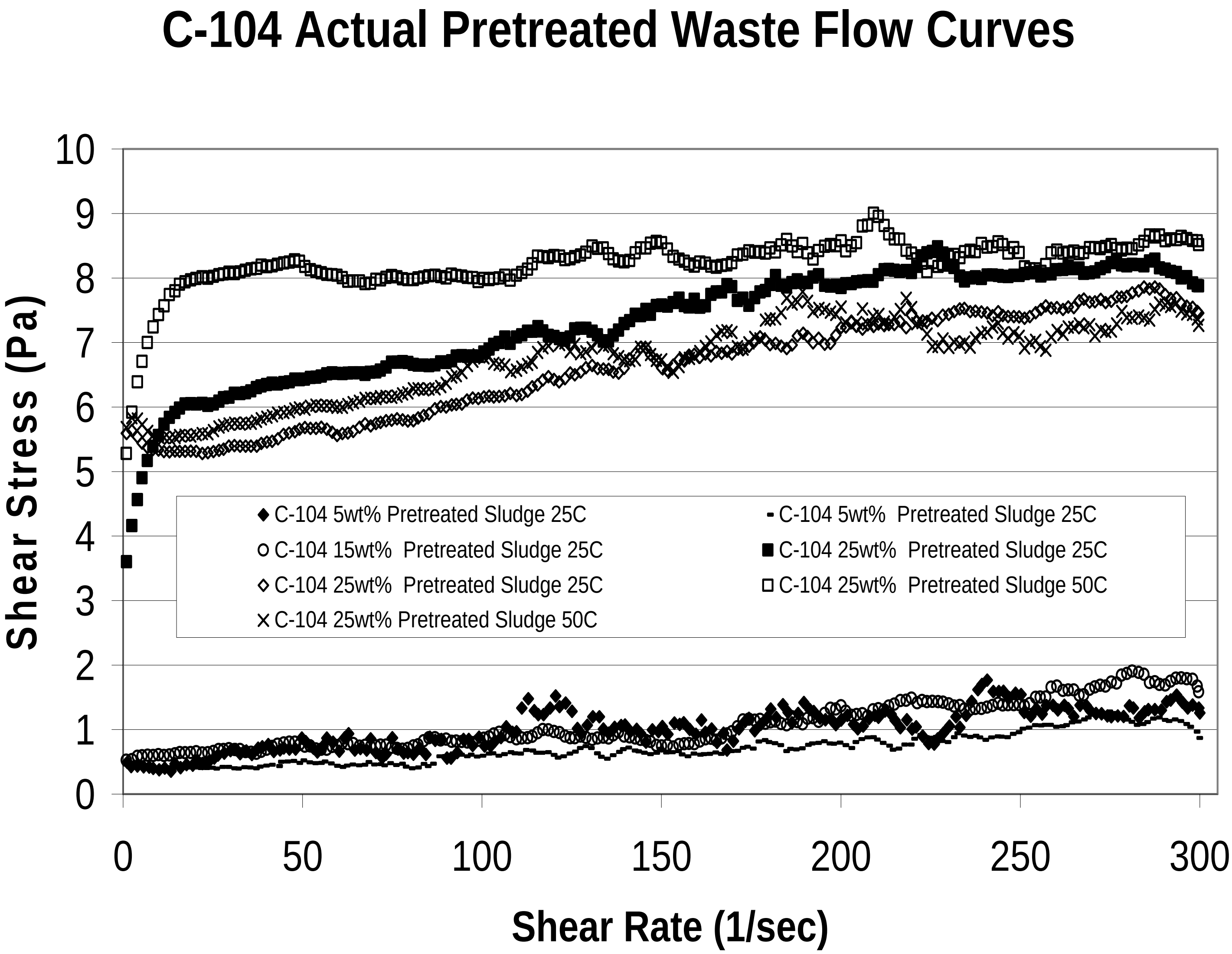

Figure B3.3. C-104 HLW Pretreated Sludge Rheology

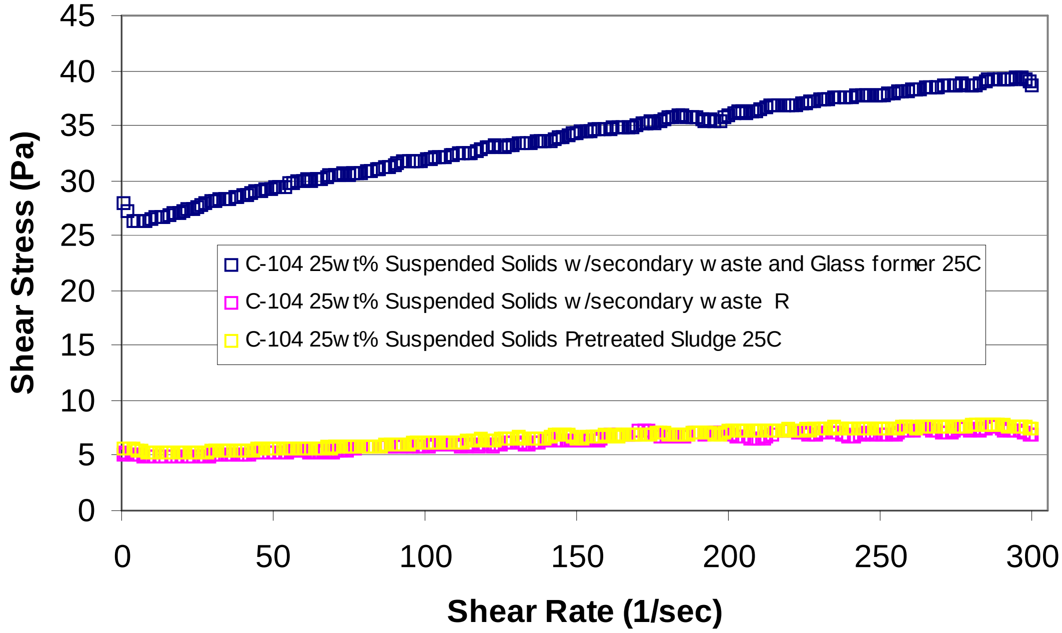

Figure B3.4. Flow curves for C-104 HLW Pretreated Sludge and Melter Feed

Figure B3.5 provides an overall summary plot of the observed shear stress versus shear rate of the HLW sludges and melter feeds for AZ-102 and C-104.

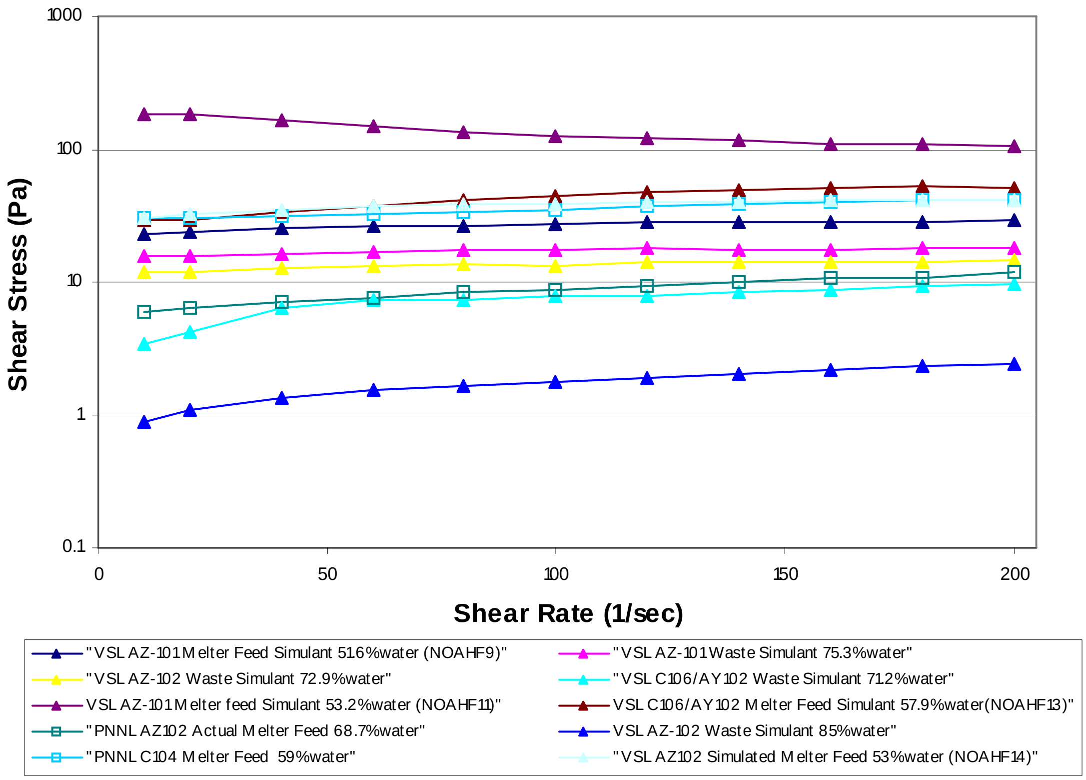

Figure B3.5. Rheograms of HLW Envelope D Actual and Simulated Sludge and Melter Feed

Data Sources

Bredt PR, LK Jagoda, and DE Rinehart. 2001. *Rheological Studies on Pretreated Feed and Melter Feed from C-104 and AZ-102.* WTP-RPT-004 (PNNL-13359), Pacific Northwest National Laboratory, Richland, WA.

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Hansen EK, RE Eibling, and TB Calloway, Jr. 2001. *Mixing Envelope D Sludge with LAW Intermediate Products with and without Glass Formers.* WSRC-TR-2001-00203, Rev. 0, Westinghouse Savannah River Company, Aiken, SC.

Kot WK, H Gan, and IL Pegg. 2000. *Physical and Rheological Properties of Waste Simulants and Melter Feeds for RPP-WTP HLW Vitrification.* VSL-00R2520-1, Vitreous States Laboratory, The Catholic University of America, Washington DC.

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Matlack KS, WK Kot, F Perez-Cardenas, and IL Pegg. 2000. *Tests on DuraMelter™ 10 with AZ-101 Simulant in Support of DuraMelter™ 1000 Throughput Tests.* VSL-00R2501-1, Rev. 0, Vitreous States Laboratory, The Catholic University of America, Washington D.C.

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B4. Particle-Size and Particle-Size Distribution

B4.1. Introduction

Particle size is a significant factor in the processing of the four WTP vitrification streams considered in this document. The pretreated LAW stream is expected to be solids free (i.e., less than 2 wt% undissolved solids as specified in the WTP contract). The remaining vitrification streams (AZ-101, AZ-102, C-104) are expected to contain a significant quantity of undissolved solids. Consequently, these three streams are the focus of this section.

The HLW pretreated sludge contains the solids-rich process stream that results from crossflow ultrafiltration (CUF) and sludge washing/leaching. Battelle has performed testing with a crossflow ultrafiltration unit on actual Hanford tank wastes. These Envelope D tank wastes include AZ-101 (Geeting et al. 2002), AZ-102 (Brooks et al. 2000b), and C-104 (Brooks et al. 2000a). Particle-size distributions of the final washed/leached slurries are shown in Figure B4.1. These distributions indicate that greater than 90% of the particle volume of these slurries is made up of particles less than 10 μm in diameter, and 100% of the particle volume of these slurries is made up of particles less than 44 μm in diameter. These data indicate that relatively small particles (less than 50 μm) should be expected in the HLW pretreated sludge portions of the WTP process stream. However, this conclusion is only based on results from three tanks, and larger particles are possible due to tank-to-tank variability and solids-rich recycle streams from other portions of the WTP.

The maximum particle size of the insoluble glass-former chemicals (GFCs) is expected to be in the 74-μm to 177-μm range (see Table 4.1, page 4.8 of this report). Because the pretreated LAW is expected to be solids free and the HLW pretreated sludge is expected to contain particles less than 50 μm, the maximum particle size of the LAW and HLW melter feed streams should be dominated by GFCs. The particle size of actual AP-101 LAW melter feed[a] is shown in Figure B4.2. These data indicate particle sizes in the 2-μm to 40-μm range. No particles in the 74-μm to 177-μm range were observed. A possible explanation for the lack of larger particles includes dissolution of the GFCs in the highly caustic pretreated LAW. Another possible explanation is precipitation of undissolved solids from the pretreated LAW due to boric acid addition, which could bias the particle-size distribution to smaller sizes. The particle-size distribution of the AP-101 GFC mix (LAWA-126) in deionized water is also shown in Figure B4.2. This particle-size distribution shows particles in the 74-μm to 120-μm range and illustrates that particles of this size are possible in the LAW and HLW melter-feed streams.

(a) PR Bredt, AP Poloski, and RG Swoboda. 2002. *Rheological and Physical Properties of AP-101 Pretreated LAW and Melter Feed.* WTP-RPT-064, Rev. A, Battelle—Pacific Northwest Division, Richland, WA.

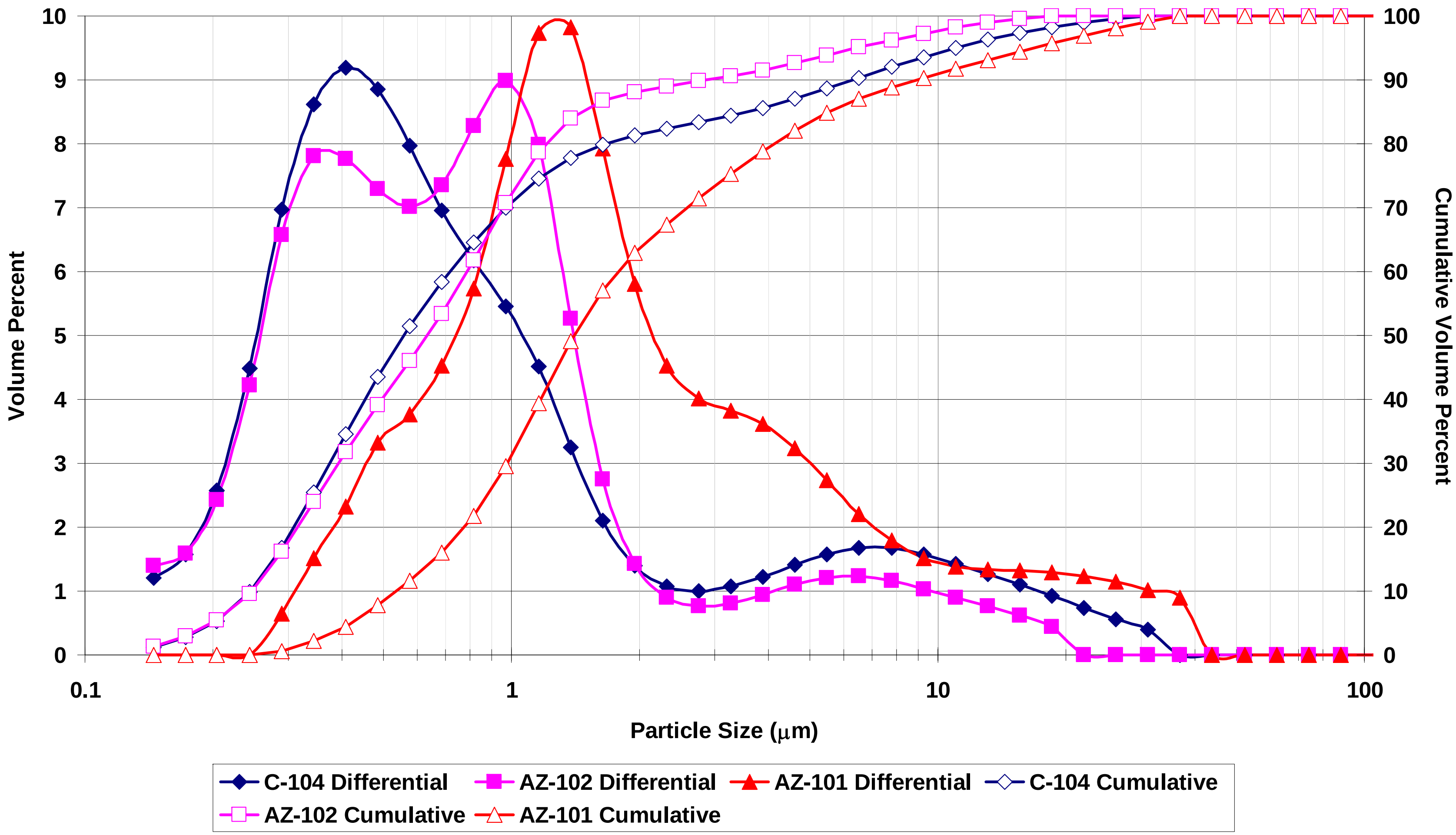

Figure B4.1. Particle-Size Distribution of Actual HLW Pretreated Sludge Streams

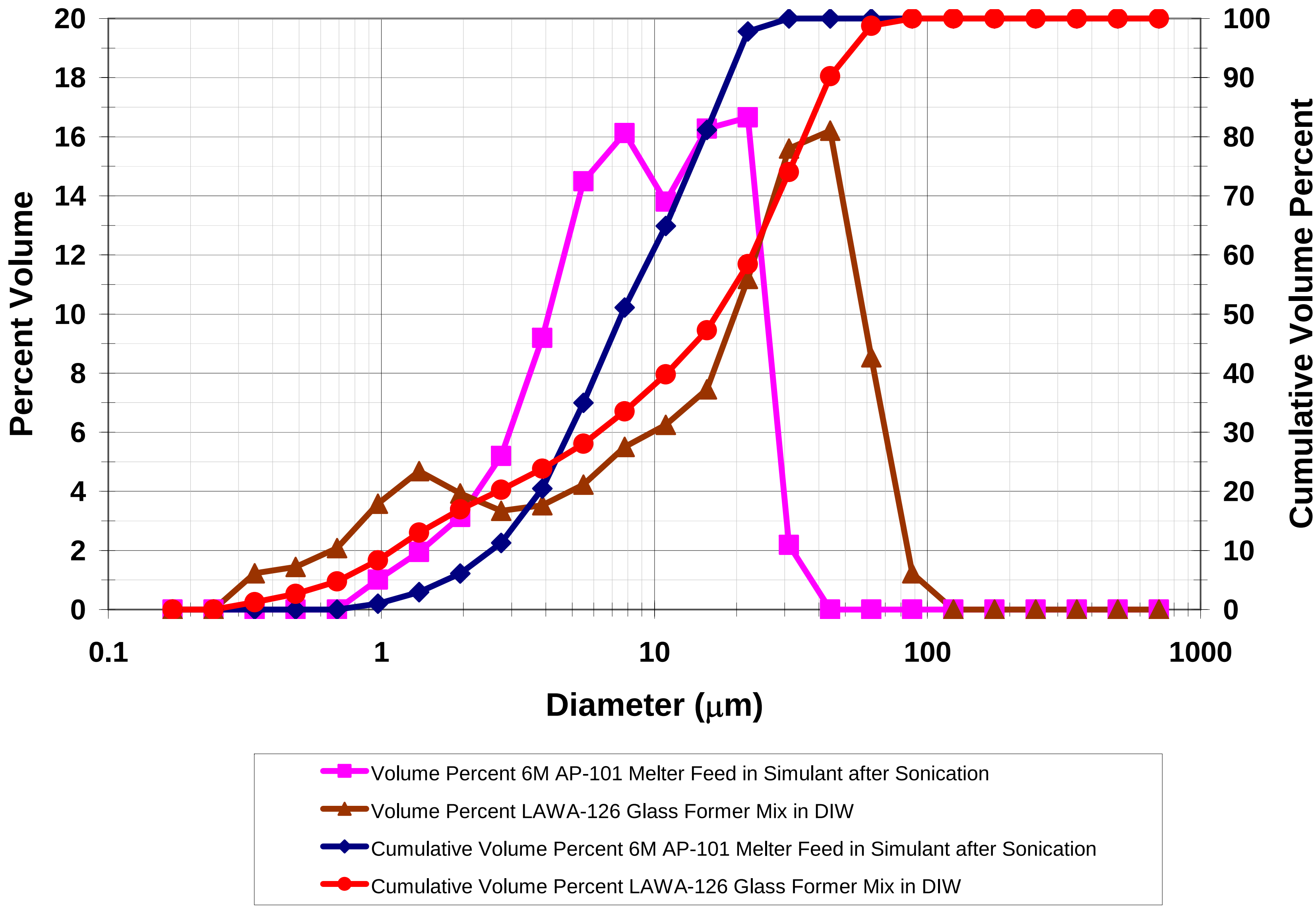

Figure B4.2. Particle-Size Distribution of Actual AP-101 Melter-Feed and Glass-Former Chemical Mix

B4.2. High-Level Waste Solid Phase Characteristics—Discussion

Hanford HLWs are a multiphase, multi-component, high-ionic strength, and highly basic mixture of liquids, solids, and possibly gases. They consist of widely varying chemical and physical characteristics. Solids can be primary particles or agglomerates with varying particle sizes and shapes (Jewett et al. 2002). Main primary solids of HLW include $Al(OH)_3$, FeO(OH), $Na_2C_2O_4$, ZrO_2, and $NaAlCO_3(OH)_2$, but vary from tank to tank (Jewett et al. 2002; Onishi et al. 2003). Table B4.2.1 (Jewett et al. 2002) shows major solid constituents in eight HLW tanks predicted by the chemical code, Environmental Simulation Program (ESP).(3) The smallest particles are hydrous oxides, e.g., goethite (FeOOH) with approximately 3- to 6-nm diameters (see Table B4.2.1 and Table B4.2.2 for various chemical forms). Intermediate size particles in a 0.1~1-μm range include boehmite (AlOOH) and apatite. These submicron primary particles typically form agglomerates with 1~10-μm diameters, but their sizes can reach 100 μm or more. Some of the largest primary particles include gibbsite ($Al(OH)_3$), whose size can exceed 20 μm. Trisodium phosphate hydrates ($Na_3(PO_4)\cdot 12H_2O$), if formed, have a needle-like shape and exceed 100 μm in length (Onishi et al. 2002).

Table B4.2.1. Major Constituents in the Dry-Basis Compositions (weight percent) of the Solids in Eight HLW Tanks (Jewett et al. 2002)

Compound	Tanks							
	AW-103	AY-101	AY-102	AZ-101	AZ-102	C-104	C-107	SY-102
$Al(OH)_3$	9.0	26.4	30.6	57.8	46.9	39.6	25.4	53.6
Bi_2O_3							5.9	
Cr_2O_3								9.2
FeO(OH)		27.9	37.4	26.1	33.6	7.5	17.5	7.3
$KAlSiO_4$					6.1			
$Mn(OH)_2$			8.2					
$Na_2C_2O_4$		13.7						
$Na_2U_2O_7$	11.4					12.1		
$Na_7F(PO_4)_2\cdot 19H_2O$							30.6	19.3
$NaAlCO_3(OH)_2$		9.3	15.1					
$NaAlSiO_4$		14.9				8.5	15.2	
NaF	36.5					9.4		
ZrO_2	36.4			7.3		14.9		

There is considerable uncertainty regarding the HLW particle sizes, depending on many factors, e.g., sample preparation, flocculation/agglomeration, waste agitation, and particle size measurement instrumentation (Jewett et al. 2002; Schlosser et al. 2002; Onishi et al. 2005). For example, the average median particle diameter (volume basis) of HLW wastes in seven tanks (AW-103, AY-101, AY-102, AZ-102, C-104, C-107, SY-102) were reported as 1) equal to or less than 275 µm (Jewett and Jensen 2000) and 2) 7.5 µm (Jewett et al. 2002). The wide variation between these two studies may be attributed to the preparation of waste samples and measurement instrumentation. Table B4.2.2 shows the particle sizes on which the Slurry Transfer Expert Panel (Schlosser et al. 2002) agreed should be used for Hanford tank waste. Note that the

(3) Environmental Simulation Program (ESP) is a registered trademark of OLI Systems, Morris Plains, NJ.

percentiles in Table B4.2.2 are like the cumulative volume percentages given in Figures B4.1 and B4.2.

Pretreated HLW consists of the solids of HLW that have undergone a wash-leach-wash process that reduces the solids mass by removing nonradioactive components (e.g., aluminum and sodium compounds) that are solubilized by the process (see Table B4.2.3). In addition, Sr/TRU precipitates from Envelope C wastes and Cs IX eluates are added reducing the load of radionuclides in the LAW. The Sr/TRU precipitates add solids to the pretreated HLW, but the eluates do not.

Table B4.2.2. Particle Size Distributions of the HLW in Seven Tanks (Schlosser et al. 2002)

Tank	Percentile	1%	5%	25%	50%	75%	95%	99%
AW-103	Mean,µm	0.7	1.1	3.4	6.9	29.9	194.0	268.0
	S.D.*, µm	0.6	0.8	0.4	2.0	49.1	223.7	284.5
AY-101	Mean,µm	0.6	1.2	5.0	9.0	15.3	260.7	393.2
	S.D., µm	0.1	0.1	0.3	0.5	1,6	136.2	95.8
AY-102	Mean,µm	0.7	0.9	1.3	2.4	5.3	11.5	16.2
	S.D., µm	0.0	0.0	0.1	0.2	1.2	3.2	4.5
AZ-102	Mean,µm	1.4	2.4	7.0	15.6	113.0	181.9	240.6
	S.D., µm	0.1	0.5	2.6	8.7	175.1	236.5	310.5
C-104	Mean,µm	0.2	0.5	2.8	7.3	31.8	188.1	332.0
	S.D., µm	0.0	0.1	0.1	0.5	6.4	54.1	76.8
C-107	Mean,µm	0.9	1.3	3.4	6.6	10.2	16.2	21.0
	S.D., µm	0.0	0.0	0.1	0.3	0.8	1.9	2.7
SY-102	Mean,µm	0.3	1.0	2.7	4.6	8.7	130.7	187.4
	S.D., µm	0.0	0.0	0.2	0.6	2.5	166.1	237.3

* S.D. ≡ standard deviation

Table B4.2.3. Solubility of AZ-102 Sludge Key Components in 0.01 M NaOH and 3 M NaOH (Brooks et al. 2000a)

Component	Fraction Removed in Water Washes (%)	Fraction Removed in Caustic Leaches (%)	Fraction in Solids Residue (%)
Al	2.5	61.2	36.3
Cr	44.1	14.2	41.7
Fe	0.006	0.02	99.97
Na	80.2	-nd-	11.2
P	6.7	45.6	47.7
^{90}Sr	0.003	0.007	99.99
^{137}Cs	61.2	32.7	6.1
-nd- : Not determined because of difficulty in distinguishing leached sodium from added sodium. The fraction Na in the solids residue may be that added during the caustic leaching rather than that initially present in the sludge.			

The effects of caustic washing of HLW are shown in Table B4.2.3 reported by Brooks et al. (2000a). Tanks, such as 241-SY-102, contain plutonium particles with a size range of approximately 1 to > 36 µm (Callaway and Cooke 2004). Rapko et al. (1996) report that most aluminum oxide, hydroxide, and phosphate phases are removed by caustic leaching but not aluminosilicates in wastes from Tanks B-111, BX-107, C-103, S-104, SY-103, T-104, and T-111. Other phosphate- and chromium-containing phases were reduced in amount. Note that Rapko et al.'s (1996) findings are consistent with the results given in Table B4.2.3. Table B4.2.4 summarizes the phase characterization results of Buck et al. (2003) for two washed HLW tanks.

Table B4.2.5 gives the accepted densities for most of the phases that have been identified in pretreated HLW. Most of the sodium- and aluminum-rich phases have densities in the 2- to 3-g/cc range. The heavy metal-containing phases are considerably denser. For example, ZrO_2 and pure PuO_2 have densities of 5.89 and 11.4 g/mL, respectively. Note that these densities are not for agglomerates, which are collections of finer particles adhering to one another. In that case the densities are on the order of 40% to 60% of the densities stated here.

Table B4.2.4. Identified Phases in Washed Solids from Hanford Tanks 241-AN-102 and 241-AZ-101 (Buck et al. 2003)

Element	AZ-101 WS	Size (µm)	AN-102 WS	Size (µm)
Al	Gibbsite	2-3	Boehmite,	ND
Al	Boehmite	ND	Zeolite	5-20
Al	Zr-Fe phase	0.5-2	Na aluminate	<1
Ca	Calcite	5	Zeolite, calcite	5-20
Cd	Cd-Sn phase	4-8	ND	NA
Ce	ND	NA	Cerianite	10
Cr	Chromite	ND	Chromite	10
Cu	Fe-Zr phase, chromite	0.5-2	ND	NA
Fe	Hematite	1-3	Chromite	10
Fe	Fe-Zr phase	0.5-2	Hematite	NA
K	Mn-clay	0.3-0.5	Zeolite	5-20
La	Fe-Zr phase	0.5-2	ND	NA
Mn	Mn-clay	0.3-0.5	ND	NA
Na	$NaNO_3$	NA	Zeolite	5-10
Na	NA	NA	Na aluminate	<1
Nd	Fe-Zr phase	0.5-2	ND	NA
Ni	Fe-Zr phase	0.5-2	Chromite	10
Si	Fe-Zr phase	0.5-2	Zeolite	5-20
SO_4	Na sulfate	NA	Na sulfate	NA
Sn	Cd-Sn phase	4-8	ND	NA
U	U(VI)-oxide	5-20	U(VI) oxide	5-10
V	ND	NA	Wakefieldite	5
Y	ND	NA	Wakefieldite	5
Zr	Fe-Zr phase	0.5-2	ND	NA

WS = washed solids, NA = not applicable
ND = not detected
Particle diameter based on scanning electron microscopy observations of individual particles.
Note: Some elements are listed more than once because they were present in more than one phase.

As indicated above, pretreatment changes the waste chemistry and physical properties (e.g., particle sizes, shapes and density, sludge viscosity and shear stress, and density and viscosity of the liquid). The major concern in regard to mixing, transport, re-suspension, etc. for pretreated HLW is the size, shape, and density of the particles making up the waste slurry. These properties will determine the conditions required to achieve near homogenous mixing and transport of the waste slurry to meet WTP process flow sheet requirements. The bounding conditions for such mixing will be set by the fastest settling-rate particles in the slurry. This is discussed in more detail in Section 4.1.3 of the report.

However, of concern as well is what happens if the slurry is allowed to settle during a plant upset condition such as a power outage or an equipment failure. The energy to remobilize settled slurry is significantly larger than that necessary to keep it in suspension once mobilized, so if the plant is designed only to maintain already mobilized slurry it will not have the capability to remobilize settled slurry (Vanoni 1975). For example, solids suspension in mechanically stirred tanks is characterized by the "just suspended" criteria developed by Zwietering (1958; Atiemo-Obeng 2003). The Zwietering correlations show that the minimum velocity to pick up solids is a weak function of solids fraction and particle size and mainly depends on the density difference between the solids and the liquid. Hence, attention should be paid to the presence of high-density-material particles, such as the uranium and plutonium oxides, in the waste. The correlations also indicate that the larger the particle size, the greater the minimum velocity to erode and suspend the solids. This is true for non-cohesive solids that do not stick to each other, but behave as individual separate particles.

Table B4.2.5. Density of HLW Waste Phases

Phase	**Expected Density**
Gibbsite $Al(OH)_3$	2.42
Boehmite $AlO(OH)$	3.01
Calcite $CaCO_3$	2.71
Cd-Sn phase (Sn,Cd)O	6–7
Chromite $(Fe,Mg)(Cr,Fe)_2O_4$	4.1–4.9
Fe-Zr phase (mahlmoodite) $FeZr(PO_4)\cdot 4(H_2O)$	2.88
Hematite Fe_2O_3	5.24
Mn-clay	3.25
$NaNO_3$	2.26
Na_2SO_4	2.68
U(VI)-oxide UO_3	7.29
Zeolites— e.g., $(Ca,Na)_{2\text{-}3}Al_3(Al,Si)_2Si_{13}O_{36}\cdot 12H_2O$, $(K_2Na_2Ca)(Al_2Si_4)O_{14}\cdot 4\text{-}5H_2O$, $Na(AlSi_2O_6)\cdot H_2O$, $(Na, K, Ca)_{2\text{-}3}Al_3(Al, Si)_2Si_{13}O_{36}\cdot 12H_2O$,	~2.2
Na aluminate $Na_2Al_2O_4$	>1.5
Cerianite CeO_2	7.1
Wakefieldite YVO_4	4.76
ZrO_2	5.89
Zircon $ZrSiO_4$	4.68–4.70

Plutonium Oxide PuO_2	11.5

On the other hand, cohesive solids coagulate with each other; thus, the force required to erode or scour cohesive solids are generally greater than those of noncohesive solids with about the same particle sizes. Moreover, for cohesive solids, smaller particles tend to require greater force and velocity to mobilize the solids (Vanoni 1975). The Shields diagram (see Figure B4.2.1), shows a relationship between the critical shear stress (minimum shear stress needed to mobilize solids by an overlying flow) and the boundary Reynolds number when fluid flow is moving over a solid layer. In this figure, d_s = solid diameter, g = gravitational acceleration, U_* = shear velocity, γ and γ_s = specific gravities of liquid and solid, respectively, ν = kinematic viscosity of the liquid, and τ_0 = shear stress acting on the solid. This figure shows that the smaller the solid size, the greater the required shear stress to erode the solids when the boundary Reynolds number R_* is roughly below 10. For a solid with density of 2.65 g/mL and a liquid with a density of 1 g/mL and a viscosity of 1 cP, the corresponding velocity to begin mobilizing this settled particle in water is shown in Figure B4.2.2 (Vanoni 1975). This figure shows that the required critical velocity increases with decreasing solid sizes for particles below approximately 100 to 200 µm, corresponding to the $R_* < 10$ range shown in Figure B4.2.1. Most Hanford wastes have particle sizes of less than 100 µm. Thus, they fall into this range. How much shear stress or velocity is needed to mobilize settled solids depends on many factors, including particle size, cohesiveness, waste chemistry, solid compaction, time solids have been undisturbed, and weight imposed on the solids.

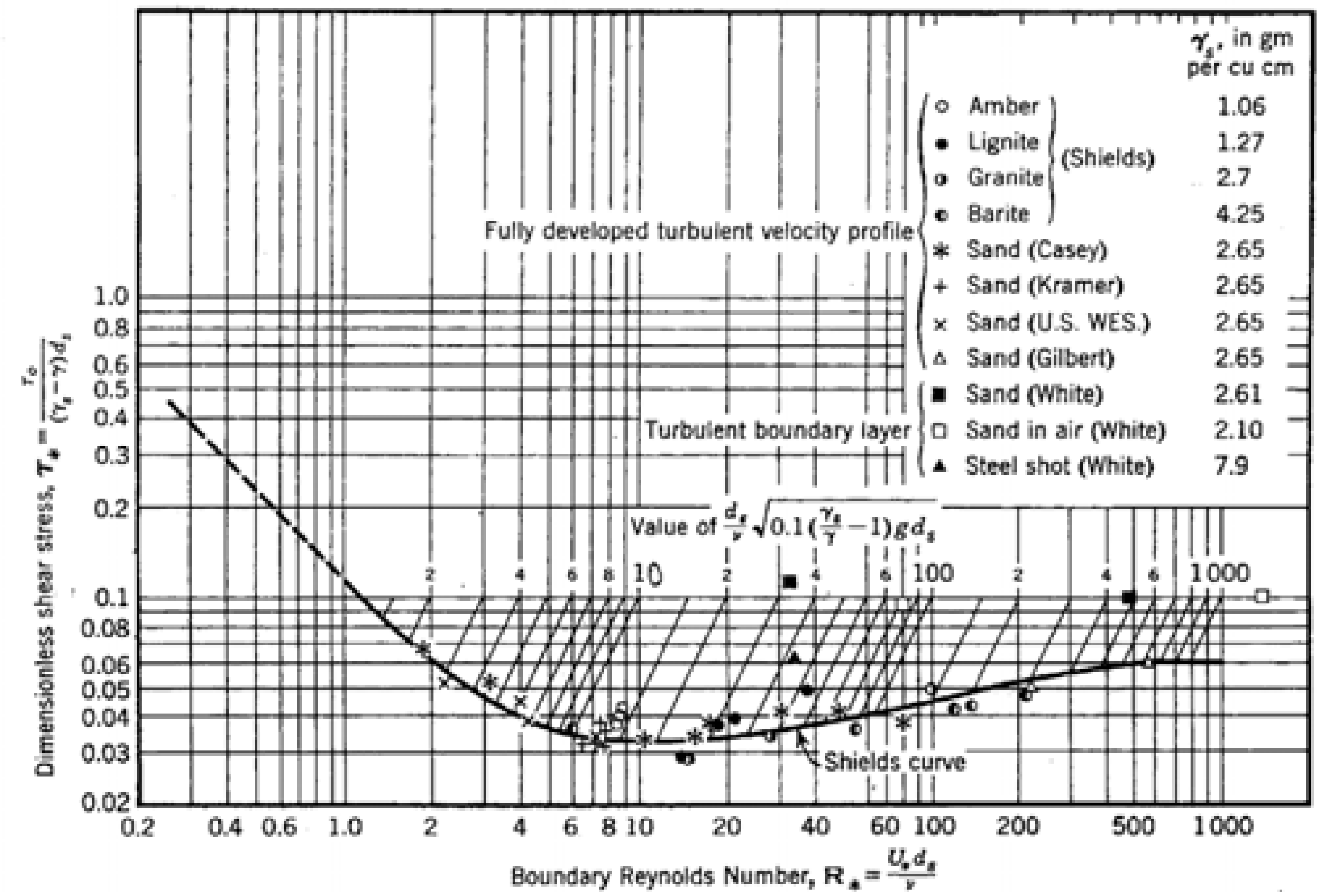

Figure B4.2.1. Minimum Shear Stress Required to Mobilize Solids (Vanoni 1975)

When a jet resuspends settled solids by impinging a solid layer (by the jet initially burrowing into the solid layer), the solids are mobilized when the jet forces acting on the solid layer are greater than the shear strength of the solid layer. This mechanism is used for sludge erosion modeling (Onishi et al. 2000, 2003).

In conclusion, as with rheological conditions, it is the extremes (of the particle size and density distribution) that can cause problems with respect to mixing and transport. Small dense particles can form packed layers that are difficult to remobilize if they are allowed to form because of loss of power or equipment failure. At the other end of the continuum, there are particle size and density limits above which the particles will not be suspended at all or at best not homogeneously. Note that the concept of an average should not be used in this context because it conveys a distorted sense of reality with respect to extremes. One can estimate the permissible limits of these particle properties over the lifetime of the system by estimating the number of events that would occur that would allow deposits of a maximum permissible depth to form (fine compact layers) and including the amount of oversize dense particles that will not be suspended and simply collect at the bottom of the processing vessel. Model calculations should be made to determine when a problem might arise in the WTP because of pretreated HLW particle waste characteristics.

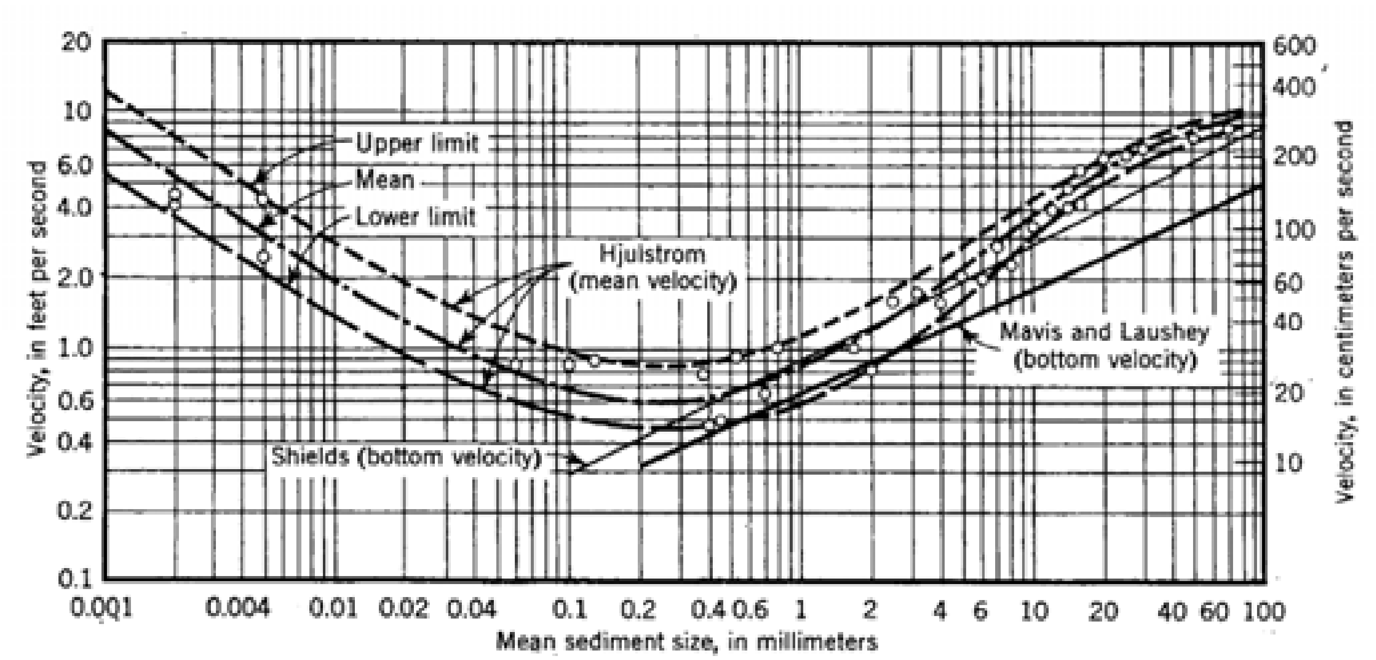

Figure B4.2.2. Water Velocity to Start to Mobilize the Quartz Solid (Vanoni 1975)

Appendix C

Expected HLW Behavior During Pretreatment

Appendix C: Expected HLW Behavior During Pretreatment

Expected HLW Behavior During Pretreatment

A number of tests were performed at the Savannah River Site using HLW samples from tanks there. One set of tests evaluated the yield stress of slurry samples from Tank 8 over a wide range of solids contents. Figure C.1 provides the data from this testing and the equation parameters are given in Table C.1. Also provided in Figure C.1 is a fit to the data using Equation C.1. Literature (Johnson et al. 1999) provides another form for the yield stress that also provides an adequate fit. Equation C.2 is the same as Equation 4.16 from this report.

$$\tau_y = a \cdot e^{mX} \tag{C.1}$$

$$\tau_y = d \frac{X^f}{e - X} \tag{C.2}$$

where a and m are fitting parameters and X is the weight percent solids. The fits are shown in Figure C.1.

Table C.1. Parameter Values for Equations C.1 and C.2 Corresponding to the Plots shown in Figure C1.

Equation C.1		Equation C.2 (Equation 4.16)	
a	0.36	f	3.131
m	0.15	d	0.062
na	na	e	107.129

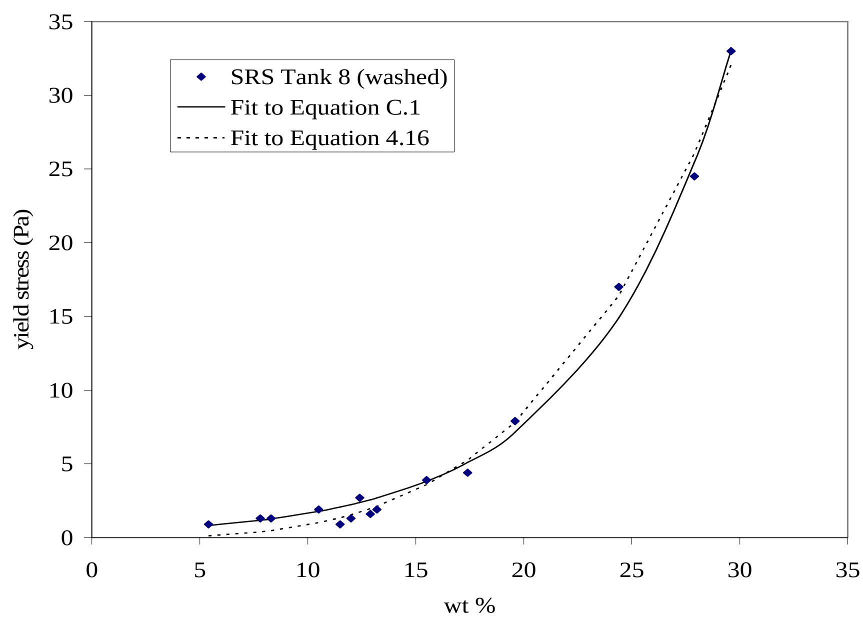

Figure C.1. Measured Yield Stress of Washed HLW Samples from Tank 8 Savannah River Site

Since these fits are nearly identical, Equation C.1 will be used since it employs one less fitting parameter and thus will allow for easier extrapolation of data from limited data sets. Because limited data are available for other tank waste, an assumption will be made for this analysis that the pre-exponential factor is nearly the same for all the data sets of interest. Thus, a value of 0.36 will be used in the estimates that follow. Data from C-104, AZ-102 and AZ-101 (before and after leaching) were fit using Equation C.1 and an assumed value for “a” of 0.36. These are summarized in Table C.2. Note that the value for “m” is assumed to change with leaching of the waste. Leaching causes significant dilution of the waste and can change the PSD significantly. Therefore, an assumption has been made that rheology is changed significantly by leaching.

Table C.2. Parameter Estimates for Tanks of Interest

Tank Conditions	m
AZ-101 before leaching	0.13
AZ-101 after leaching	0.16
AZ-102 before leaching	0.17
AZ-102 after leaching	0.25
C-104 before leaching	0.18
C-104 after leaching	0.11

These parameter fits can then be used to estimate the yield stress during planned pretreatment operations. Note that this exercise involves a significant amount of extrapolation from a limited data set, but can provide some insight into the operations to be seen in WTP. Figure C.2 summarizes these estimates.

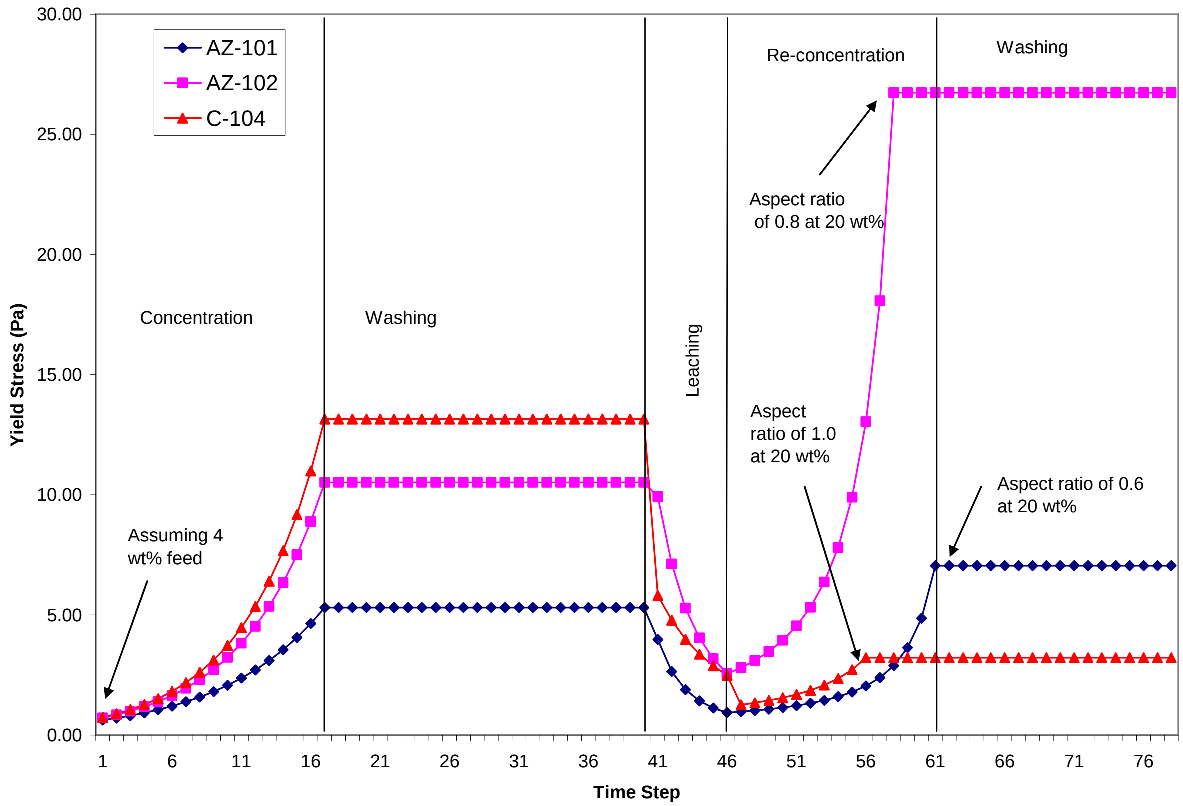

Figure C.2. Anticipated Rheology Behavior of C-104, AZ-101, and AZ-102 in Ultrafiltration Feed Process-2 (UFP2) Vessel

This figure is based on the following set of assumptions.

- That the feed is initially concentrated to 20 wt% UDS at 17,000 gallons
- That washing has little impact on yield stress
- That 5,000 gallons is added during leaching
- That the changes in rheology caused by leaching occur immediately, before any significant solids dissolution occurs
- That all the observed dissolution occurs during the leaching process
- That the waste is concentrated to 20 wt% UDS after leaching.

Inspection of Figure C.2 provides some interesting insights. Primary among these is that the bounding rheological condition (relative to a tank dimension aspect ratio of 1.4 W/D) involves the material before leaching. The primary cause for this is that a significant quantity of the material dissolves upon leaching. Thus, the solids content after leaching at the 17,000 gallon tank level is significantly lower. When the material is concentrated to a level below 17,000 gallons after leaching, the yield stress continues to increase.

A second observation is that AZ-102 does not necessarily define the bounding rheology for the pretreatment system. In fact, the rheology of C-104 appears to be more bounding for the bulk of pretreatment operations at higher aspect ratios.

Figure C.2 indicates that for C-104 waste, the rheology improves significantly after leaching. This improvement is at least in some way associated with the near complete dissolution of aluminum from the sludge during leaching. There is also evidence that leaching resulted in a bi-modal PSD containing a significant (>30%) amount of 10-micron sized material (Brooks et al. 2000b). Note that this material resulted in the highest yield stress for un-leached material.

Figure C.2 indicates that leaching is anticipated to result in a slight increase in the rheology of AZ-101 tank waste. As noted previously, the washed and leached material actually demonstrated a slightly larger PSD than the washed material. However, leaching may have affected other attributes of this material, resulting in the slight difference in measured rheological properties between leached and unleached AZ-101 materials.

Figure C.2 indicates a significant increase in rheology during leaching for AZ-102 waste. This is likely attributed to the decrease in PSD as a result of leaching and may also be affected by the change in residual alumina crystalline phase as a result of leaching. This material clearly results in the highest yield stress after leaching of the three HLW tanks assessed.

Since rheology data are available for only a limited number of tanks under WTP processing conditions, a natural question is how representative these data are of the broader tank farm. As indicated above, settling behavior can provide insight into the agglomerate behavior and by inference the rheology of HLW solids. Consider the case of two similar waste samples. Suppose Sample A settles to 10-wt% solids, and Sample B settles to 15-wt% solids. If both samples were concentrated through filtration to 12-wt% solids, Sample A would likely have a higher yield stress (since Sample B is still readily settling, the particle-particle interactions that lead to yield stress are not as strong). Similarly, consider that if the samples were concentrated to 15 wt %, Sample A would still likely have a higher yield stress (because in Sample B, the solids are just starting to interact). Thus, the inference that the lower the final settled solids content (i.e., the less a sample settles), the higher the yield stress at a given solids concentration.

Whereas significant WTP flowsheet specific rheology data are only available for three HLW tanks, more extensive settling data are available for a wide range of HLW tanks. Figure C.3 summarizes the settled solids wt% for 16 different HLW samples. Inspection of this figure indicates that the majority of these tanks (~70+%) reach settled solids contents of 10 wt% or greater. Note that this correlates reasonably well to the onset of non-Newtonian behavior for the three tanks measured. Each of these three tanks begins to exhibit significant yield stresses at above 10 wt%. This result infers that some fraction (perhaps 20 to 30%) of the HLW tanks may have more extreme rheological properties than those observed in the three tanks measured to date. Note that redilution of a pretreated waste slurry can always be performed to produce a pretreated waste slurry that has rheological properties in a range acceptable for the WTP processing system.

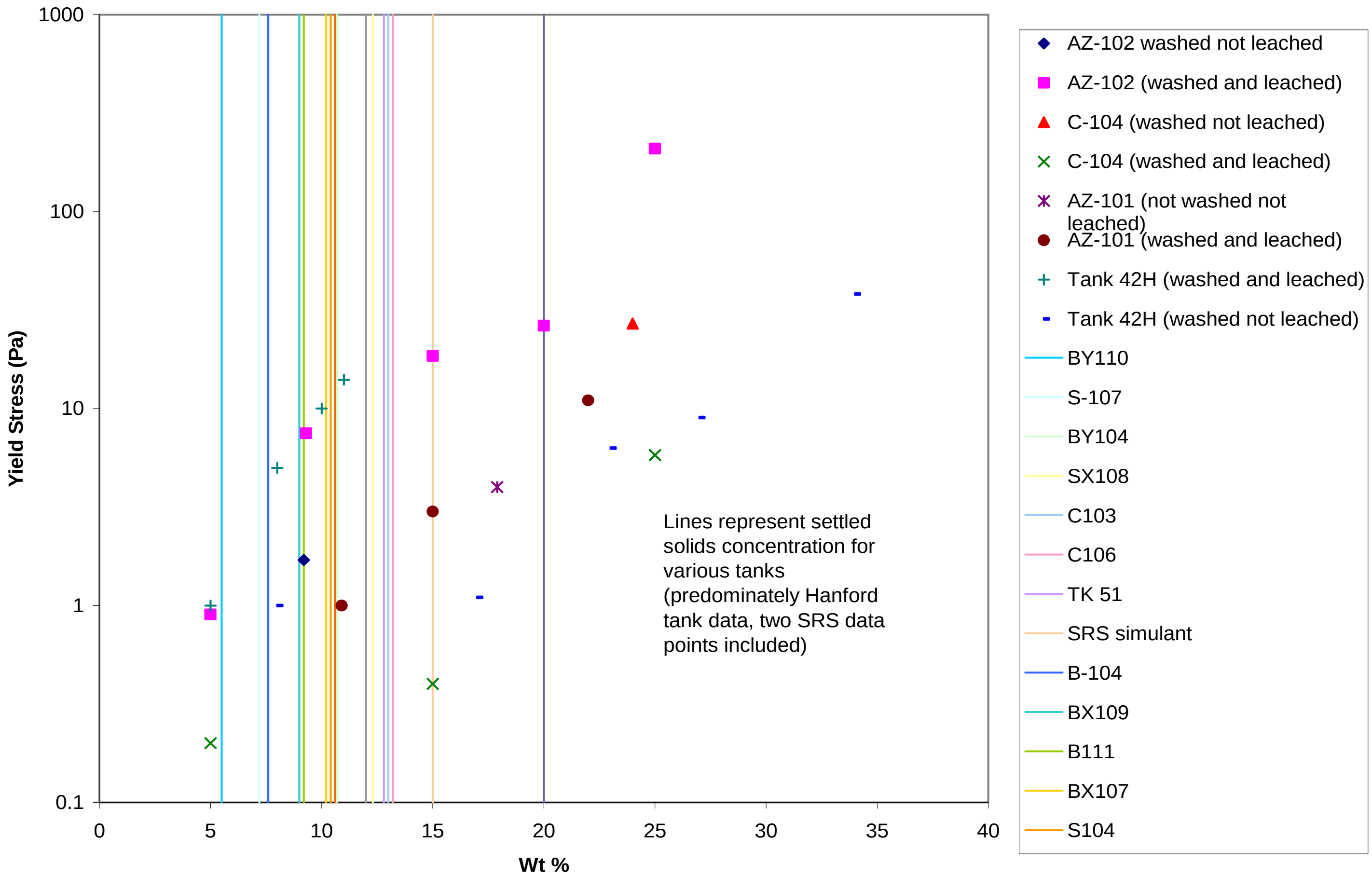

Figure C.3. Settled Solids Content for Various HLW Tanks with Rheology Data for Selected HLW Tanks

Appendix D

Rheology Primer[(a)]

([a]) Much of the information in this Appendix was derived from JF Steffe. 1996. *Rheological Methods in Food Process Engineering*. 2nd Edition, Freeman Press. An online version of this book can be downloaded from http://www.egr.msu.edu/~steffe/freebook/offer.html.

Appendix D: Rheology Primer

Rheology is the study of the flow of matter. When a force (i.e., stress) is placed on an object, the object deforms or strains. Many relationships have been found relating stress to strain for various fluids. Flow behavior of a fluid can generally be explained by considering a fluid placed between two plates of thickness x (see Figure D.1). The lower plate is held stationary while a force, F, is applied to the upper plate of area, A, that results in the plate moving at velocity, v. If the plate moves a length, ΔL, the strain, γ, on the fluid is can be defined by Equation D.1.

$$\gamma = \frac{\Delta L}{\mathrm{x}} \tag{D.1}$$

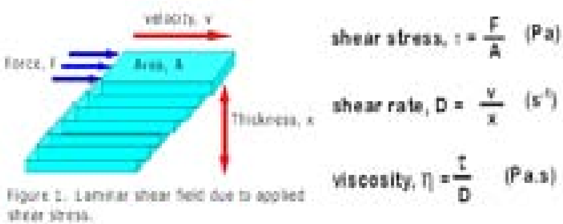

Figure D.1. Diagram of Fluid Flow Between Stationary and Moving Plates

The rate of change of strain (also called shear rate), $\dot{\gamma}$, can be defined by Equation D.2. Since the shear rate is defined as the ratio of a velocity to a length, the units of the variable are the inverse of time, typically s^{-1}.

$$\dot{\gamma} = \frac{d\gamma}{dt} = \frac{d}{dt}\left(\frac{\Delta L}{\mathrm{x}}\right) = \frac{\mathrm{v}}{\mathrm{x}} \tag{D.2}$$

Typical shear rates of food-processing applications can be seen in Table D.1. Depending on the application, shear rates in the range of 10^{-6} to 10^{7} s^{-1} are possible.

Table D.1. Typical Shear Rates in Food-Processing Applications

Situation	Shear Rate Range (1/s)	Typical Applications
Sedimentation of Particles in a Suspending Liquid	$10^{-6} – 10^{-3}$	Medicines, paints, spices in salad dressing
Leveling due to surface tension	$10^{-2} – 10^{-1}$	Frosting, paints, printing inks
Draining under gravity	$10^{-1} – 10^{1}$	Vats, small food containers
Extrusion	$10^{0} – 10^{3}$	Snack and pet foods, toothpaste, cereals, pasta, polymers
Calendering	$10^{1} – 10^{2}$	Dough sheeting
Pouring from a Bottle	$10^{1} – 10^{2}$	Foods, cosmetics, toiletries
Chewing and Swallowing	$10^{1} – 10^{2}$	Foods
Dip Coating	$10^{1} – 10^{2}$	Paints, confectionery
Mixing and Stirring	$10^{1} – 10^{3}$	Food processing
Pipe Flow	$10^{0} – 10^{3}$	Food processing, blood flow
Rubbing	$10^{2} – 10^{4}$	Topical application of creams and lotions
Brushing	$10^{3} – 10^{4}$	Brush painting, lipstick, nail polish
Spraying	$10^{3} – 10^{5}$	Spray drying, spray painting, fuel atomization
High speed coating	$10^{4} – 10^{6}$	Paper
Lubrication	$10^{3} – 10^{7}$	Bearings, gasoline engines

The shear stress applied to the fluid can be found by Equation D.3. Since the shear stress is defined as the ratio of a force to an area, the units of the variable are pressures, typically Pa (N/m^2).

$$\tau = \frac{F}{A} \tag{D.3}$$

The apparent viscosity of the fluid is defined as the ratio of the shear stress to shear rate (see Equation D.4). Since the viscosity is defined as the ratio of shear stress to shear rate, the units of the variable are Pa•s. Typically, viscosity is reported in units of centipoise (cP) where 1 cP = 1 mPa•s.

$$\eta(\dot{\gamma}) = \frac{\tau(\dot{\gamma})}{\dot{\gamma}} \tag{D.4}$$

For Newtonian fluids, the apparent viscosity is independent of shear rate (see Equation D.5). Examples of the viscosity of common Newtonian materials can be seen in Table D.2.

$$\tau = \eta\dot{\gamma} \qquad \text{(D.5)}$$

where τ is the shear stress, η is the Newtonian viscosity, and $\dot{\gamma}$ is the shear rate.

Table D.2. Viscosities of Several Common Newtonian Fluids

Material	Viscosity at 20°C (mPa•s)
Acetone	0.32
Water	1.0
Ethanol	1.2
Mercury	1.6
Ethylene Glycol	20
Corn Oil	71
Glycerin	1,500

Fluids that do not behave as Newtonian fluids are referred to as non-Newtonian fluids. Rheograms or plots of shear stress versus shear rate are typically used to characterize non-Newtonian fluids. Examples of typical rheograms can be seen in Figure D.2.

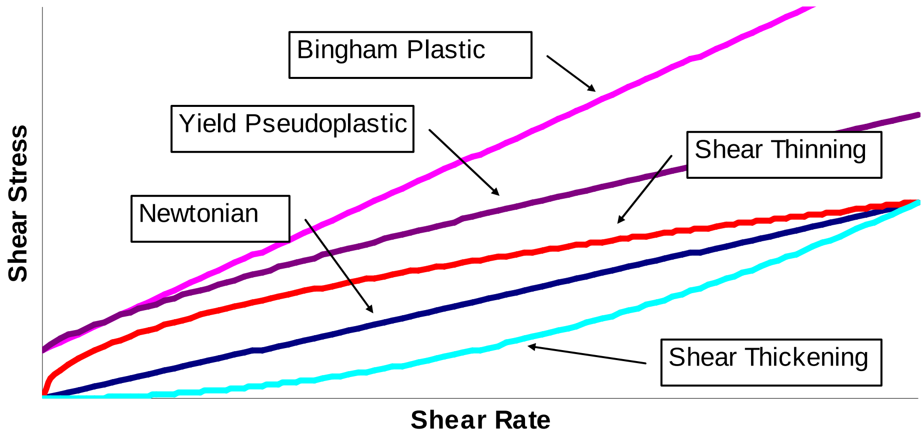

Figure D.2. Rheograms of Various Fluid Types

Shear-thinning and shear-thickening fluids can be modeled by the Ostwald equation (see Equation D.6). If n<1, then the material is referred to as pseudoplastic (shear thinning). If n>1, that material is referred to as dilatant (shear thickening). These fluids exhibit decreasing or increasing apparent viscosities as shear rate increases, depending on whether the fluid is shear thinning or shear thickening, respectively. Since shear-thickening flow behavior is rare, shear-thickening behavior is often an indication of possible secondary flow patterns or other measurement errors.

$$\tau = m\dot{\gamma}^{n} \tag{D.6}$$

where *m* is the power-law consistency coefficient, *n* is the power-law exponent, and $\dot{\gamma}$ is the shear rate.

A Bingham plastic rheogram does not necessarily pass through the origin. When a rheogram has a non-zero y-intercept, that fluid is said to posses a yield stress. A yield stress is a shear-stress threshold that defines the boundary between solid-like behavior and fluid-like behavior. The fluid will not begin to flow until the yield stress threshold is exceeded. For Bingham plastic materials, once enough force has been applied to exceed the yield stress, the material approaches Newtonian behavior at high shear rates (see Equation D.7). Since Bingham plastic behavior is used throughout this document, a Bingham plastic model was fit to rheological data for many common types of materials (see Table D.3). Note that many of these materials would not typically be classified as Bingham plastic materials. The purpose of the Bingham plastic model fits is to provide the reader with a relative understanding of the magnitude of Bingham plastic values used in this document to common materials. Human perception is typically based on a shear rate of approximately 60 s^{-1}.

$$\tau = \tau_O^B + \eta_P \gamma \tag{D.7}$$

where τ_O^B is the Bingham yield stress, η_p is the plastic viscosity, and γ is the shear rate.

Table D.3. Bingham Plastic Model Fit to Various Common Materials

Material	**Consistency (mPa•s)**	**Yield Stress (Pa)**	**R^2**
Squeeze Margarine	49	11	0.80
Ketchup	190	38	0.81
Whipped Desert Topping	190	45	0.80
Tub Margarine	320	125	0.77
Mustard	400	50	0.84
Mayonnaise	610	130	0.80
Whipped Butter	660	350	0.75
Stick Butter	690	240	0.77
Stick Margarine	860	350	0.77
Whipped Cream Cheese	910	480	0.75
Peanut Butter	1,200	570	0.75
Apple Butter	1,600	300	0.82
Canned Frosting	1,900	450	0.79
Honey	15,000	5.3	1.00
Marshmallow Cream	23,000	1,200	0.92

Fluids that exhibit a non-linear rheogram with a yield stress are modeled by the three-parameter Herschel-Bulkley equation (see Equation D.8). Again, shear-thickening behavior is uncommon, and typically the Hershel-Bulkley power-law exponent is less than unity.

$$\tau = \tau_O^H + k\gamma^b \tag{D.8}$$

where

τ_O^H = yield stress

k = Herschel-Bulkley consistency coefficient

b = Hershel-Bulkley power-law exponent

γ = shear rate.

Many methods have been developed to evaluate yield stress. These methods produce varying results based on the rheological technique and assumptions used in the evaluation. To explain these variations, the concept of static and dynamic yield stress is introduced. The idea behind static and dynamic yield stress can be explained by assuming that there are two structures that present yield-stress exhibiting fluids. One structure is insensitive to shear rate and defines the dynamic yield stress associated with a flow curve. However, a second weak structure is also present that forms while the fluid is at rest. The second structure is sensitive to shear rate and breaks down as the fluid is sheared. Combined, these two stresses define the static yield-stress value (see Figure D.3).

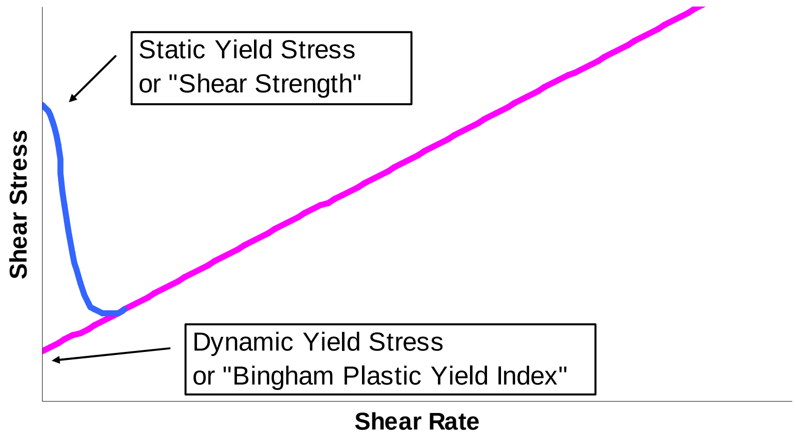

Figure D.3. Rheogram Illustrating the Concept of Dynamic and Static Yield Stress

The use of the static and dynamic yield-stress values varies with application. For instance, the dynamic yield-stress value extrapolated from a rheogram should be used when performing pipeline-head-loss calculations. The static yield stress should be used for process restart applications where the second structure could form while the fluid is at rest.

A common method of measuring the static shear strength of a fluid is with a device called a shear vane. A WTP procedure for measuring the static yield stress of a fluid was provided in 24590-WTP-

GPG-RTD-001 Rev 0. The WTP-adopted convention is to refer to the static yield stress as “shear strength.” The dynamic yield stress is often referred to as “yield stress” or “yield index.”

Since shear-strength values are discussed throughout this document, values of shear strength for common food items as measured by the vane method are given in Table D.4. Note that yield-stress values are given in Table D.3. These tables should provide a reference point for the magnitude of shear-strength and yield-stress values discussed in this document.

Table D.4. Shear Strength of Various Common Materials

Material	Shear Strength (Pa)
Baby food, peaches	22.9 ± 3.4
Spaghetti sauce, Brand B	24.8 ± 3.4
Spaghetti sauce, Brand A	26.3 ± 4.5
Tomato puree, Brand B	30.0 ± 4.2
Baby food, pears	31.8 ± 5.0
Tomato puree, Brand A	34.4 ± 3.7
Tomato ketchup, Brand B	43.2 ± 3.4
Apple sauce, Brand B	48.2 ± 4.7
Tomato ketchup, Brand A	51.3 ± 5.0
Baby food, carrots	64.0 ± 4.0
Apple sauce, Brand A	77.3 ± 0.0
Mustard, Brand A	82.5 ± 5.3
Mustard, Brand B	103.8 ± 5.0
Mayonnaise, Brand B	163.8 ± 4.2
Mayonnaise, Brand A	204.4 ± 5.0

The shear vane must be immersed in the test material such that wall and end effects are negligible. Figure D.4 shows an accepted material testing geometry to minimize wall and end effects (Dzuy and Boger 1985). These geometry requirements were confirmed before material testing.

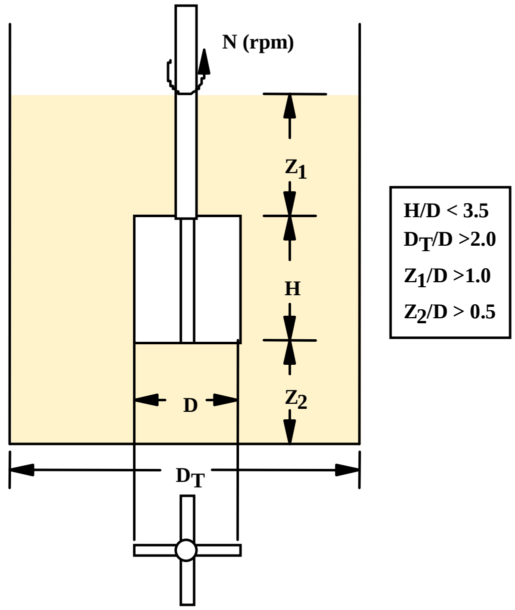

Figure D.4. Geometrical Requirements of a Shear Vane

Figure D.5 shows a typical stress-time profile. The profile shows an initial linear region followed by a nonlinear region, a stress maximum, and a stress decay region. The shape of the stress time profile can be explained from a consideration of the network bonds within the material. The initial linear region represents the elastic deformation of the network bonds. The nonlinear region represents viscoelastic flow (also called creep flow), where the network bonds are stretched beyond their elastic limit and some of the bonds begin to break. At the maximum stress point on the curve, the majority of the bonds are broken and the material begins to flow as a fully viscous fluid. The network typically collapses, and stress decay is observed. This peak on the curve is defined as the shear strength, and it indicates the minimum force required to cause material deformation or flow.

From this response, two shear strengths can be defined, one corresponding to the transition between elastic and viscoelastic flow and the other corresponding to the transition between viscoelastic and fully viscous flow, τ_s. Most researchers regard the transition between viscoelastic and fully viscous flow as the definitive shear strength of the material. In this report, shear strength is defined by the transition between viscoelastic and fully viscous flow, τ_s.

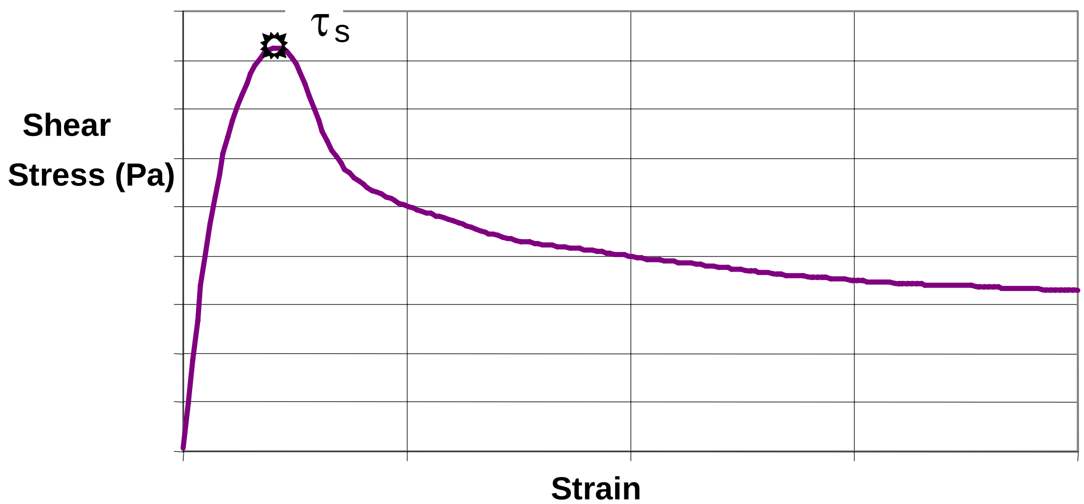

Figure D.5. Typical Response of a Shear Vane

Another term used is “consistency,” which can be thought of as the limit of apparent viscosity as shear rate approaches infinity. Apparent viscosity is the shear stress divided by the shear rate the non-Newtonian fluid is experiencing.

Appendix E

Quality Level Summary

Appendix E: Quality Level Summary

This Section identifies the Quality Assurance levels applied to reviews and reports prepared for the Waste Treatment Plant (WTP) based on completion of Research and Technology activities that were performed under British Nuclear Fuels Limited (BNFL), CH2M Hill Hanford Group (CHG) and Bechtel National, Inc. (BNI), Battelle (PNWD), Catholic University of America - Vitreous State Laboratory (VSL), and Savannah River National Laboratory (SRNL) since 2000.

The various Quality Assurance Program Plans had different requirements under the different contractors. These differences should be programmatic in nature and should not impact data quality. However, an evaluation to determine the nature of these differences is outside the scope of this document.

Table E.1. Review of Physical and Rheological Measurements on Hanford LAW, HLW Pretreated Waste and Corresponding Melter Feeds Supporting Documents Quality-Assurance Level

Reference	Quality Information Found
24590-101-TSA-W0000004-114-00016, REV 00A (WTP-RPT-113 Rev 0) (Bamberger et al. 2005) *Technical Basis for Testing Scaled Pulse Jet Mixing Systems for Non-Newtonian Slurries.*	PNWD implements the River Protection Project (RPP) WTP quality requirements by performing work in accordance with the PNWD Waste Treatment Plan Support Project Quality Assurance Project Plan (QAPjP) approved by the RPP-WTP Quality Assurance (QA) organization. This work was performed for the quality requirements of NQA-1-1989 Part I, Basic and Supplementary Requirements, and NQA-2a-1990, Part 2.7 and DOE/RW-0333 Rev 13, Quality Assurance Requirements and Description (QARD). These quality requirements were implemented through PNWD's *Waste Treatment Plant Support Project (WTPSP) Quality Assurance Requirements and Description Manuel*. The analytical requirements were implemented through WTPSP's Statement of Work (WTPSP-SOW-005) with the Radiochemical Processing Laboratory (RPL) Analytical Service Operations (ASO). Experiments that were not method-specific were performed in accordance with PNWD's procedures QA-RPP-WTP-1101, "Scientific Investigations," and QA-RPP-WTP-1201, "Calibration Control System," to ensure that sufficient data were taken with properly calibrated measuring and test equipment (M&TE) to obtain quality results. PNWD addresses internal verification and validation activities by conducting an independent technical review of the final data in accordance with PNWD's procedure QA-RPP-WTP-604. This review verifies that the reported results are traceable, that inferences and conclusions are soundly based, and that the reported work satisfies the Test Plan objectives. This review procedure is part of PNWD's *WTPSP Quality Assurance Requirements and Description Manual*. SRNL work was conducted in accordance with the RPP-WTP-QA requirements specified for work conducted by SRNL as identified in DOE IOW M0SRLE60 (Wilson et al. 2004).
BNFL-RPT-048, Rev. 0. (PNWD-3054) (Bontha et al. 2000). *Demonstration and Optimization of BNFL.s Pulsed Jet Mixing and RFD Sampling Systems Performance Using NCAW Simulant*.	Not stated.

WTP-RPT-004, Rev. 0 (PNNL-13359) (Bredt et al. 2001) *Rheological Studies on Pretreated Feed and Melter Feed from C-104 and AZ-102*	QA requirements as directed by test specifications TS-W375HV-PR00011 and TS-W375HV-PR00012 and state, "*The contractor shall have a quality system in compliance with applicable elements of DOE/RW/0333P for work in connection with High Level Waste Form.*
WTP-RPT-038, Rev 1 (Brooks et al. 2000a). *Characterization, Washing, Leaching, and Filtration of AZ-102 Sludge*.	The results presented in this report are based on work conducted under Test Plans TP-29953-069 and TP-29953-075, test instruction TP-29953-076, and Procedure TP-29953-020, Rev 1. Some data are recorded in Laboratory Record Book (LRB) #13745. Conditions for conducting these tests were given in the "AZ-102 Dewatering and Caustic Leach Test Specification," TSP-W375-99-014, Rev 0.
BNFL-RPT-030, Rev 0 (PNWD-3024) (Brooks et al. 2000b). *Characterization, Washing, Leaching, and Filtration of C-104 Sludge*.	Not stated.
24590-101-TSA-W0000004-134-01, Rev. 00C (WTP-RPT-076, Rev. 0) (Buck 2003.) *Identification of Washed Solids from Hanford Tanks 241-AN-102 and 241-AZ-101 with X-ray Diffraction, Scanning Electron Microscopy, and Light-Scattering Particle Analysis*.	PNWD implemented the RPP-WTP quality requirements by performing work in accordance with the quality assurance project plan (QAPjP) approved by the RPP-WTP Quality Assurance (QA) organization. This work was conducted to the quality requirements of NQA-1-1989 and NQA-2a-1990, Part 2.7, as instituted through PNWD's *Waste Treatment Plant Support Project Quality Assurance Requirements and Description* (WTPSP) manual. All of the instruments used in this study were checked where possible with National Institute of Standards and Technology (NIST) standards, as well as other internal standards, at the time of the analysis. NIST standards were not available for all instrumentation. For example, both the calibration of the infrared spectrometer and x-ray energy dispersive spectrometer was checked with various compounds. PNWD addressed verification activities by conducting an Independent Technical Review of the final data report in accordance with procedure QA-RPP-WTP-604. This review verified that the reported results were traceable, that inferences and conclusions were soundly based, and that the reported work satisfied the Test Plan objectives.

WSRC-TR-2000-00338, (SRT-RPP-2000-00017) (Eibling and Nash 2001). *Hanford Waste Simulants Created to Support the Research and Development on the River Protection Project – Waste Treatment Plant.*	This report documents the simulants developed to support the Savannah River Technology Center programs in support of the RPP-WTP. The research described in this report was conducted under task plan BNF-003-98-011, rev 0. Additional simulants described in this report were also developed under task plan BNF-003-98-0079A.
SCT-M0SRLE60-00-193-02, REV 00A (WSRC-TR 2003-00220, REV. 0) (Eibling et al. 2003). *Development of Simulants to Support Mixing Tests for High Level Waste and Low Activity Waste.*	This work was conducted in accordance with the RPP-WTP QA requirements specified for work conducted by SRTC as identified in DOE IWO M0SRLE60. SRTC has provided matrices to WTP demonstrating compliance of the SRTC QA program with the requirements specified by WTP. Specific information regarding the compliance of the SRTC QA program with RW-0333P, Revision 10, NQA-1 1989, Part 1, Basic and Supplementary Requirements and NQA-2a 1990, Part 2.7 is contained in these matrices. The simulant development program supports agitator design testing and mixing studies planned for LAW and HLW feeds. The task plan covering the simulant development is WSRC-TR-2002-00468, Task Technical and Quality Assurance Plan for Development of Simulants to Support Mixing tests for High Level Waste and Low Activity Waste.
24590-101-TSA-W0000004-72-08, Rev 00B (PNWD-3360) (WTP-RPT-078 Rev. 0). (Enderlin et al. 2003). *Results of Small-Scale Particle Cloud Tests and Non-Newtonian Fluid Cavern Tests*	PNWD implements the RPP-WTP quality requirements by performing work in accordance with the Waste Treatment Plant Support Project quality assurance project plan (QAPjP) approved by the RPP-WTP Quality Assurance (QA) organization. This QA manual is a web-based manual managed by the PNWD WTP QA engineer. This work was performed to the quality requirements of NQA-1-1989 Part I, "Basic and Supplementary Requirements," and NQA-2a-1990, Part 2.7. These quality requirements were implemented through PNWD's *Waste Treatment Plant Support Project (WTPSP) Quality Assurance Requirements and Description Manual*. The analytical requirements are implemented through PNWD's *Conducting Analytical Work in Support of Regulatory Programs*. For calculating the cloud and cavern height dimensions, independent measurements were performed by two individuals. PNWD addressed verification activities by conducting an independent technical review of the final data report in accordance with procedure QA-RPPWTP-604. This review verified that the reported results were traceable, that inferences and conclusions were soundly based, and the reported work satisfied the test plan objectives. The review procedure is part of PNWD's WTPSP Manual.

24590-101-TSA-W0000004-87-09, Rev 00C (Geeting et al. 2003). (PNWD-3206, Rev 1.) (WTP-RPT-043, Rev 1) *Filtration, Washing, and Caustic Leaching of Hanford Tank AZ-101 Sludge.*	Quality control information can be found in Section 2.0 "Test Conditions" and in Appendices A through H.
SRT-RPP-2001-00008 (Hansen and Eibling 2001). *Status Report for Mixing Envelope D Sludge with LAW Intermediate Products with and without Glass Formers.*	The simulants/data will be reported as sectioned in the experimental section of the "Task Technical and Quality Assurance Plan for Mixing Envelope D Sludge with LAW Intermediate Products (Sr/TRU Precipitate and Cs/Tc Eluate) with and without Glass Formers" document. Listed below is the introduction and Task description as stated in the task plan. (Hansen, E. K., Eibling, R. E., and Calloway, T. B. "Task Technical and Quality Assurance Plan for Mixing Envelope D Sludge with LAW Intermediate Products (Sr/TRU Precipitate and Cs/Tc Eluate with and without Glass Formers", WSRC-RP-2000-00731, October 3, 2000)
24590-TRPT- 01-00001, Rev. 0 (WSRC-TR-2001-00203, Rev. 0) (SRT-RPP-2001-00051, Rev. 0) (Hansen et al. 2001). *Mixing Envelope D Sludge with LAW Intermediate Products with and without Glass Formers.*	Not stated

WTP Project No. SCT-M0SRLE60-00-193-00004 REV 00A (WSRC-TR-2004-00394, Rev. 0) (SRT-RPP-2004-00061, Rev. 0) (Hansen and Crawford 2005). Hanford HLW AY102/C106 Pretreated Sludge Physical and Chemical Properties Prior to Melter Feed Processing (U).	This work was conducted in accordance with the RPP-WTP Quality Assurance (QA) requirements specified for work conducted by SRNL as identified in DOE IWO M0SRLE60. SRNL has provided matrices to WTP indicating application of the SRNL QA program with the requirements specified by WTP. The Task Technical and Quality Assurance Plan (Ref. 0) provided the quality requirements for this work. NQA Specific information regarding the compliance of the SRNL QA program with RW-0333P, Revision 13, NQA-1 1989, Part 1, Basic and Supplementary Requirements and NQA-2a 1990, Subpart 2.7 is contained in these matrices.
SCT-M0SRLE60-00-211-00001 REV 00A (WSRC-TR-2005-00035, Rev. 0) (SRNL-RPP-2005-00003, Rev. 0) (Hansen and Williams 2005). *Physical Characterization of Vitreous State Laboratory AY102/C106 and AZ102 High Level Waste Melter Feed Simulants (u).*	This work was conducted in accordance with the RPP-WTP QA requirements specified for work conducted by SRNL as identified in DOE IWO M0SRLE60. SRNL has provided matrices to WTP demonstrating compliance of the SRNL QA program with the requirements specified by WTP. Specific information regarding the compliance of the SRNL QA program with RW-0333P, Revision 13, NQA-1 1989, Part 1, Basic and Supplementary Requirements and NQA-2a 1990, Subpart 2.7 is contained in these matrices. The Task Technical and Quality Assurance Plan used to conduct this work are specified in Hansen, E. K., *General Support: SRNL Physical and Chemical Measurements for WTP Simulants Task.* WSRC-TR-2004-00388, Rev. 0 & SRT-RPP-2004-00057, Rev. 0, Westinghouse Savannah River Company, Aiken, South Carolina, August 2004.
SCT-M0SRLE60-00-199-00001, Rev. 00A (WSRC-TR-2004-00387) (Hassan et al. 2004.) *Evaluation of Foaming / Antifoaming in WTP Tanks Equipped with Pulse Jet Mixers and Air Spargers*.	This work was conducted in accordance with the RPP-WTP QA requirements specified for work conducted by SRTC as identified in DOE IWO M0SRLE60. SRTC has provided matrices to WTP demonstrating compliance of the SRTC QA program with the requirements specified by WTP. Specific information regarding the compliance of the SRTC QA program with RW-0333P, Revision 10, NQA-1 1989, Part 1, Basic and Supplementary Requirements and NQA-2a 1990, Subpart 2.7 is contained in these matrices.

24590-101-TSA-W0000004-150-00004, Rev. 00A. (WTP-RPT-116, Rev. 0) (PNWD-3499) (Hrma et al. 2004). *Vitrification and Product Testing of AZ-101 Pretreated High-Level Waste Envelope D Glass.*	PNWD implements the River Protection Project Waste Treatment Plant (RPP-WTP) quality requirements by performing work in accordance with the PNWD Waste Treatment Plant Support Project quality assurance project plan (QAPjP) approved by the RPP-WTP Quality Assurance (QA) organization. This work was performed to the quality requirements of NQA-1-1989 Part I, Basic and Supplementary Requirements, and NQA-2a-1990, Part 2.7. These quality requirements are implemented through PNWD's *Waste Treatment Plant Support Project (WTPSP) Quality Assurance Requirements and Description Manual.* The analytical requirements are implemented through WTPSP's Statement of Work (WTPSP-SOW-005) with the Radiochemical Processing Laboratory (RPL) Analytical Service Operations (ASO). A matrix that cross-references the NQA-1 and 2a requirements with the PNWD's procedures for this work is given in test plan TP-RPP-WTP-190, Rev 0, Table 5. (Applicable Quality Assurance Procedures) It includes justification for those requirements not implemented. For activities with the HLW the additional quality requirements of DOE/RW-0333P, Rev 13, *Quality Assurance Requirements and Descriptions* shall be met. **Conduct of Experimental and Analytical Work** Experiments that were not method-specific were performed in accordance with PNWD's procedures QA-RPP-WTP-1101 "Scientific Investigations" and QA-RPP-WTP-1201 "Calibration Control System," ensuring that sufficient data were taken with properly calibrated measuring and test equipment (M&TE) to obtain quality results. The work was conducted as specified in Test Specification 24590-LAW-TSP-RT-02-009, Rev 0. BNI's QAPjP, PL-24590-QA00001, Rev 0, is applicable to the TCLP activities since the work might be used in support of environmental/regulatory compliance. The applicable quality control (QC) parameters for chemical analysis are delineated in Test Plan TP-RPP-WTP-190, Rev 0, Table 3 and 7. TCLP Results for AZ-101 Envelope D Glass are summarized in Appendix D. **Internal Data Verification and Validation** PNWD addresses internal verification and validation activities by conducting an independent technical review of the final data report in accordance with PNWD's procedure QA-RPP-WTP-604. This review verifies that the reported results are traceable, that inferences and conclusions are soundly based, and that the reported work satisfies the Test Plan objectives. This review procedure is part of PNWD's *WTPSP Quality Assurance Requirements and Description Manual*.

SCT-M0SRLE60-00-184-01, Rev.00B; -184-01, Rev. 00C (cleared) (WSRC-TR-2003-00119, Rev. 0) (Josephs 2003). *Treated LAW feed evaporation: physical properties and solubility determination.*	This work was conducted in accordance with the RPP-WTP QA requirements specified for work conducted by SRTC as identified in DOE IWO MOSRLE60. SRTC has provided matrices to WTP demonstrating compliance of the SRTC QA program with the requirements specified by WTP. Specific information regarding the compliance of the SRTC QA program with RW-0333P, Revision 10, NQA-1 1989, Part 1, Basic and Supplementary Requirements and NQA-2a 1990, Subpart 2.7 is contained in these matrices.
24590-101-TSA-W0000010-06-04A (VSL-01R2540-2) (Kot and Pegg 2001). *Final Report: Glass Formulation and Testing with RPP-WTP HLW Simulants*.	This work was conducted under an NQA-1 based quality assurance program that is in place at VSL. The program has been reviewed and audited by Duratek and representatives of the RPP-WTP Project. This program is supplemented by a Quality Assurance Project Plan for RPP-WTP work that is conducted at VSL, which includes the correlation of the VSL QA program with the contractually imposed 10-CFR-831.120.
(VSL-00R2520-1) (Kot et al. 2000). *Physical and Rheological Properties of Waste Simulants and Melter Feeds for RPP-WTP HLW Vitrification.*	This work was conducted under an NQA-1 based quality assurance program that is in place at VSL. The program has been reviewed and audited by GTS Duratek and representatives of the RPP-WTP Project. This program is supplemented by a Quality Assurance Project Plan for RPP-WTP work that is conducted at VSL, which includes the correlation of the VSL QA program with the contractually imposed 10-CFR-831.120.

24590-101-TSA-W000-0009-82-02, REV 00B (VSL-03R3760-2) (Kot et al. 2003). *Glass Formulation to Support Melter Runs with HLW Simulants.*	This work was conducted under an NQA-1 (1989) and NQA-2a (1990 Part 2.7) based quality assurance program that is in place at the Vitreous State Laboratory (VSL). This program is supplemented by a Quality Assurance Project Plan for RPP-WTP work performed at VSL [11]. Test and procedure requirements by which the testing activities are planned and controlled are also defined in that plan. The program is supported by VSL standard operating procedures for this work [12]. The following specific areas of this work are also subject to the Quality Assurance Requirements and Description (QARD) Document (DOE/RW-0333P, Rev.10) [13]: __ Glass preparation __ Glass compositional analysis __ PCT leach testing __ Glass transition temperature determination. TCLP analyses used to support environmental and regulatory requirements have been conducted according to the requirements of the QAPjP [14]. This has been accomplished by contracting with a Washington State certified laboratory to perform TCLP analyses of glass compositions selected for melter tests, according to SW-846 methods, with samples supplied by VSL. TCLP data not generated in accordance with SW-846 methods and QAPjP requirements are clearly identified as such in this report.
24590-101-TSA-W000-00009-106-00021, Rev.00A (VSL-05R5710-1) (Matlack et al. 2005). *DuraMelter 100 HLW Simulant Validation Tests with C-106/AY-102 Feeds.*	This work was conducted under a quality assurance program based on NQA-1 (1989) and NQA-2a (1990) Part 2.7 that is in place at the VSL. This program is supplemented by a VSL Quality Assurance Project Plan (QAPP) for RPP-WTP work. Test and procedure requirements by which the testing activities are planned and controlled are also defined in this plan. The program is supported by VSL standard operating procedures that were used for this work. This work was not subject to DOE/RW-0333P or the WTP QAPjP for environmental regulatory data.
VSL-05R5800-1 (Matlack et al. 2005). *Final Report Integrated DM1200 Melter Testing using AZ-101 and C-106/AY-102 HLW Simulants: HLW Simulant Verification.*	This work was conducted under a quality assurance program that is in place at the VSL that is based on NQA-1 (1989) and NQA-2a (1990) Part 2.7. This program is supplemented by a Quality Assurance Project Plan for RPP-WTP work that is conducted at VSL. Test and procedure requirements by which the testing activities are planned and controlled are also defined in this plan. The program is supported by VSL standard operating procedures that were used for this work. This work was not subject to DOE/RW-0333P or the requirements of the RPP-WTP QAPjP for environmental testing.

24590-101-TSA-W000-000911800009, REV 00A (VSL-04R4800-1) (Matlack et al. 2004a). *Final Report DM1200 Melter Testing of Redox Effects using HLW AZ-101 and C-106/AY-102 Simulants.*	This work was conducted under an NQA-1 (1989) and NQA-2a (1990) Part 2.7 based quality assurance program that is in place at the VSL. This program is supplemented by a Quality Assurance Project Plan for RPP-WTP work that is conducted at VSL. Test and procedure requirements by which the testing activities are planned and controlled are also defined in this plan. The program is supported by VSL standard operating procedures that were used for this work. This work was not subject to DOE/RW-0333P or the requirements of the RPP-WTP QAPjP for environmental testing.
24590-101-TSA-W000-0009-158-00001, REV 00A (VSL-04R4800-4) (Matlack et al. 2004b). *Final Report: Integrated DM1200 Melter Testing of Bubbler Configurations Using HLW AZ-101 Simulants.*	This work was conducted under a quality assurance program that is in place at the VSL that is based on NQA-1 (1989) and NQA-2a (1990) Part 2.7. This program is supplemented by a Quality Assurance Project Plan for RPP-WTP work that is conducted at VSL. Test and procedure requirements by which the testing activities are planned and controlled are also defined in this plan. The program is supported by VSL standard operating procedures that were used for this work. This work was not subject to DOE/RW-0333P or the requirements of the RPP-WTP QAPjP for environmental testing.
24590-101-TSA-W000-0009-144-02, REV 00B (VSL-03R3800-2) (Matlack et al. 2003a). *Final Report Integrated DM1200 Melter Testing of HLW AZ-102 Composition Using Bubblers.*	This work was conducted under an NQA-1 (1989) and NQA-2A (1990) Part 2.7 based quality assurance program that is in place at the VSL. This program is supplemented by a Quality Assurance Project Plan for RPP-WTP work that is conducted at VSL. Test and procedure requirements by which the testing activities are planned and controlled are also defined in this plan. The program is supported by VSL standard operating procedures that were used for this work. This work did not generate data to support waste form quality qualification activities; nor did it generate data to support environmental regulatory data to support permitting activities. Therefore, this work was not subject to DOE/RW-0333P or the WTP QAPjP for environmental and regulatory data.

24590-101-TSA-W000-0009-144-01, REV 00B (VSL-03R3800-1) (Matlack et al. 2003b). *Final Report Integrated DM1200 Melter Testing of HLW AZ-101 and C-106/AY-102 Composition Using Bubblers.*	This work was conducted under an NQA-1 (1989) and NQA-2A (1990) Part 2.7 based quality assurance program that is in place at the VSL. This program is supplemented by a Quality Assurance Project Plan for RPP-WTP work that is conducted at VSL. Test and procedure requirements by which the testing activities are planned and controlled are also defined in this plan. The program is supported by VSL standard operating procedures that were used for this work. This work did not generate data to support waste form quality qualification activities; nor did it generate data to support environmental regulatory data to support permitting activities. Therefore, this work was not subject to DOE/RW-0333P or the WTP QAPjP for environmental and regulatory data.
24590-101-TSA-W000-0009-98-07, REV 00B (VSL-03R3800-3) (Matlack et al. 2003d). *DM1200 Tests with C-104/AY-101 HLW Simulants.*	This work was conducted under an NQA-1 (1989) and NQA-2A (1990) Part 2.7 based quality assurance program that is in place at the VSL. This program is supplemented by a Quality Assurance Project Plan for RPP-WTP work that is conducted at VSL. Test and procedure requirements by which the testing activities are planned and controlled are also defined in this plan. The program is supported by VSL standard operating procedures that were used for this work. This work did not generate data to support waste form quality qualification activities; nor did it generate data to support environmental regulatory data to support permitting activities. Therefore, this work was not subject to DOE/RW-0333P or the WTP QAPjP for environmental and regulatory data.
24590-101-TSA-W000-0009-144-00005, REV 00A (VSL-03R3800-4) (Matlack et al. 2003e). *Final Report DM1200 Tests with AZ-101 HLW Simulants.*	This work was conducted under an NQA-1 (1989) and NQA-2A (1990) Part 2.7 based quality assurance program that is in place at the VSL. This program is supplemented by a Quality Assurance Project Plan for RPP-WTP work that is conducted at VSL. Test and procedure requirements by which the testing activities are planned and controlled are also defined in this plan. The program is supported by VSL standard operating procedures that were used for this work. This work did not generate data to support waste form quality qualification activities; nor did it generate data to support environmental regulatory data to support permitting activities. Therefore, this work was not subject to DOE/RW-0333P or the WTP QAPjP for environmental and regulatory data.

24590-101-TSA-W000-0009-48-01, REV 00C (VSL-01R10NO-1, Rev.1) (Matlack et al. 2002b). *Melter Tests with AZ-101 HLW Simulant Using a DuraMelter 100 Vitrification System.*	This work was conducted under an NQA-1 based quality assurance program that is in place at VSL. This program is supplemented by a VSL Quality Assurance Project Plan (QAPP) for RPP-WTP work. Per RPP-WTP Project direction, the program was revised during the performance of this work. Accordingly, work performed before 8/1/01 was performed under an NQA-1 (1994) program and corresponding Quality Assurance Project Plan (QAPP) for RPP-WTP work [12], while work performed after that date was performed under an NQA-1 (1989) and NQA-2a (1990) Part 2.7 based quality assurance program and corresponding QAPP [13]. The program is supported by VSL standard operating procedures that were used for this work [14]. This work was not subject to DOE/RW-0333P.
VSL-00R2501-2, Rev. 0 (Matlack et al. 2000a). *Screening Tests on DuraMelter™10 with C-106/AY-102 Simulant in Support of DuraMelter™ 1000 Throughput Tests.*	This work was conducted under an NQA-1 based quality assurance program that is in place at VSL. The program has been frequently audited by representatives of GTS Duratek and various DOE sites and contractors over many years. This program is supplemented by a Quality Assurance Project Plan for RPP-WTP B1 work that is conducted at VSL, which includes the correlation of the VSL QA program with the contractually imposed 10-CFR-831.120.
VSL-00R2501-1, Rev. 0 (Matlack et al. 2000b). *Tests on DuraMelter™10 with AZ-101 Simulant in Support of DuraMelter™1000 Throughput Tests.*	This work was conducted under an NQA-1 based quality assurance program that is in place at VSL. The program has been frequently audited by representatives of GTS Duratek and various DOE sites and contractors over many years. This program is supplemented by a Quality Assurance Project Plan for RPP-WTP B1 work that is conducted at VSL, which includes the correlation of the VSL QA program with the contractually imposed 10-CFR-831.120.
VSL-00R2590-1, Rev. 0 (Matlack et al. 2000c). *Determination of the Processing Rate of RPP-WTP Simulants Using a DuraMelter™1000 Vitrification System.*	This work was conducted under an NQA-1 based quality assurance program that is in place at VSL. The program has been frequently audited by representatives of GTS Duratek and various DOE sites and contractors over many years and, most recently, by BNFL, Inc. This program is supplemented by a Quality Assurance Project Plan for RPP-WTP-B1 work that is conducted at VSL, which includes the correlation of the VSL QA program with the contractually imposed 10-CFR-831.120.

VSL-02R0100-2 Rev. 1 (Matlack et al. 2002a). *Tests on the DuraMelter 1200 HLW Pilot Melter System Using AZ-101 HLW Simulants.*	This work was conducted under an NQA-1 based quality assurance program that is in place at VSL. This program is supplemented by a VSL Quality Assurance Project Plan (QAPP) for RPP-WTP work. Per RPP-WTP Project direction, the program was revised during the performance of this work. Accordingly, work performed before 8/1/01 was performed under an NQA-1 (1994) program and corresponding Quality Assurance Project Plan (QAPP) for RPP-WTP work [12], while work performed after that date was performed under an NQA-1 (1989) and NQA-2a (1990) Part 2.7 based quality assurance program and corresponding QAPP [13]. The program is supported by VSL standard operating procedures that were used for this work [14]. This work was not subject to DOE/RW-0333P.

24590-101-TSA-W000-0004-144-01, REV 00B (WTP-RPT-096, Rev. 0) (Poloski et al. 2003a). *Rheological and Physical Properties of AZ 101 HLW Pretreated Sludge and Melter Feed.*	PNWD implements the RPP-WTP quality requirements by performing work in accordance with the PNWD Waste Treatment Plant Support Project quality assurance project plan (QAPjP) approved by the RPP-WTP Quality Assurance (QA) organization. This work was performed to the quality requirements of NQA-1-1989 Part I, Basic and Supplementary Requirements, and NQA-2a-1990, Subpart 2.7. These quality requirements are implemented through PNWD's *Waste Treatment Plant Support Project (WTPSP) Quality Assurance Requirements and Description Manual*. The analytical requirements are implemented through PNWD's *Conducting Analytical Work in Support of Regulatory Programs*. For activities with the HLW, the additional QA requirements of DOE/RW-0333P, Rev. 11, *Quality Assurance Requirements and Description*, were met. A listing of the procedures implementing the DOE/RW-0333P QA requirements is included in Test Plan, TP-RPP-WTP-188 Rev 0, *AZ-101 (Envelope D) Melter Feed Rheology Testing.* A matrix that cross references the NQA-1 and 2a requirements with PNWD's procedures for this work is given in the Test Plan, TP-RPP-WTP-188 Rev 0, *AZ-101 (Envelope D) Melter Feed Rheology Testing*. It includes justification for those requirements not implemented. Experiments that are not method-specific were performed in accordance with PNWD's procedures QA-RPP-WTP-1101 "Scientific Investigations" and QA-RPP-WTP-1201 "Calibration Control System," assuring that sufficient data were taken with properly calibrated measuring and test equipment (M&TE) to obtain quality results. As specified in Test Specification, 24590-HLW-TSP-RT-02-009 Rev 0, Bechtel National Inc.'s (BNI's) QAPjP, 24590-QA-0001, is not applicable since the work was not performed in support of environmental/regulatory testing, and the data will not be used as such. PNWD addresses internal verification and validation activities by conducting an Independent Technical Review of the final data report in accordance with PNWD's procedure QA-RPP-WTP-604. This review verifies that 1) the reported results are traceable, 2) inferences and conclusions are soundly based, and 3) the reported work satisfies the Test Plan objectives. This review procedure is part of PNWD's *WTPSP Quality Assurance Requirements and Description Manual*.

24590-101-TSA-W000-0004-99-09, Rev. 00D (WTP-RPT-100 Rev. 0) (Poloski et al. 2003b). *Interim Report - Technical Basis for HLW Vitrification Stream Physical and Rheological Property Bounding Conditions*.	Battelle—Pacific Northwest Division (PNWD) implements the River Protection Project (RPP)-WTP quality requirements by performing work in accordance with the PNWD Waste Treatment Plant Support Project quality assurance project plan (QAPjP) approved by the RPP-WTP Quality Assurance (QA) organization. This work was performed to the quality requirements of NQA-1-1989 Part I, Basic and Supplementary Requirements, and NQA-2a-1990, Part 2.7. These quality requirements are implemented through PNWD's *Waste Treatment Plant Support Project (WTPSP) Quality Assurance Requirements and Description Manual*. The analytical requirements are implemented through PNWD's *Conducting Analytical Work in Support of Regulatory Programs*. For activities with the HLW, the additional quality assurance requirements of DOE/RW-0333P, Rev. 11, *Quality Assurance Requirements and Description*, were met. A listing of the procedures implementing the DOE/RW-0333P quality assurance requirements is included in Test Plan, TP-RPP-WTP-205, *LAW and HLW Actual Waste and Simulant Coordination*. A matrix that cross-references the NQA-1 and 2a requirements with the PNWD's procedures for this work is given in Test Plan, TP-RPP-WTP-205, *LAW and HLW Actual Waste and Simulant Coordination*. It includes justification for those requirements not implemented. As specified in Test Specification, 24590-WTP-TSP-RT-01-007, Rev. 0, Bechtel National, Incorporated's (BNI's) QAPjP, PL-24590-QA00001, is not applicable since the work was not performed in support of environmental/regulatory testing, and the data will not be used as such. PNWD addresses internal verification and validation activities by conducting an Independent Technical Review of the final data report in accordance with PNWD's Procedure QA-RPP-WTP-604. This review verifies that the reported results are traceable, that inferences and conclusions are soundly based, and that the reported work satisfies the Test Plan objectives. This review procedure is part of PNWD's *WTPSP Quality Assurance Requirements and Description Manual*.

24590-101-TSA-W000-0004-99-00010, REV00A; -99-00010, REV 00B (published) (PNWD-3495). (WTP-RPT-111 Rev 0) (Poloski et al. 2004). *Non-Newtonian Slurry Simulant Development and Selection for Pulse Jet Mixer Testing*	PNWD implemented the RPP-WTP quality requirements by performing work in accordance with the PNWD Waste Treatment Plant Support Project quality assurance project plan (QAPjP) approved by the RPP-WTP Quality Assurance (QA) organization. This work was performed to the quality requirements of NQA-1-1989 Part I, Basic and Supplementary Requirements, and NQA-2a-1990, Part 2.7. These quality requirements were implemented through PNWD's *Waste Treatment Plant Support Project (WTPSP) Quality Assurance Requirements and Description Manual*. The analytical requirements were implemented through WTPSP's Statement of Work (WTPSP-SOW-005) with the Radiochemical Processing Laboratory (RPL) Analytical Service Operations (ASO). Experiments that were not method-specific were performed in accordance with PNWD's procedures QA-RPP-WTP-1101, "Scientific Investigations," and QA-RPP-WTP-1201, "Calibration Control System," ensuring that sufficient data were taken with properly calibrated measuring and test equipment (M&TE) to obtain quality results. As specified in Test Specification 24590-WTP-TSP-RT-03-008 Rev. 0, "Development of Scaled Performance Data for PJM Mixers in the Ultrafiltration Feed and Lag Storage/Blend Tanks," BNI's QAPjP, PL-24590-QA00001, was not applicable because the work was not performed in support of environmental/regulatory testing, and the data will not be used as such. PNWD addressed internal verification and validation activities by conducting an Independent Technical Review of the final data report in accordance with PNWD's procedure QA-RPP-WTP-604. This review verified that the reported results were traceable, that inferences and conclusions were soundly based, and the reported work satisfied the Test Plan objectives. This review procedure is part of PNWD's *WTPSP Quality Assurance Requirements and Description Manual*.

24590-101-TSA-W000-0004-160-00001 REV 00A (PNWD-3541). (WTP-RPT-129 Rev 0) (Poloski et al. 2005). *Technical Basis for Scaling of Air Sparging Systems for Mixing in Non-Newtonian Slurries*,	Battelle - Pacific Northwest Division (PNWD) implements the RPP-WTP quality requirements by performing work in accordance with the PNWD Waste Treatment Plant Support Project quality assurance project plan (QAPjP) approved by the RPP-WTP Quality Assurance (QA) organization. This work was performed to the quality requirements of NQA-1-1989 Part I, Basic and Supplementary Requirements, and NQA-2a-1990 Part 2.7. These quality requirements are implemented through PNWD's Waste Treatment Plant Support Project (WTPSP) Quality Assurance Requirements and Description Manual. Experiments that were not method-specific were performed in accordance with PNWD's procedures QA-RPP-WTP-1101, "Scientific Investigations," and QA-RPP-WTP-1201, "Calibration Control System," ensuring that sufficient data were taken with properly calibrated measuring and test equipment (M&TE) to obtain quality results. As specified in Test Specification 24590-WTP-TSP-RT-03-010 Rev. 0, "Pulse Jet Mixer Gas Hold-Up and Release Testing," BNI's QAPjP, PL-24590-QA-00001, was not applicable because the work was not performed in support of environmental/regulatory testing, and the data will not be used as such. PNWD addresses internal verification and validation activities by conducting an Independent Technical Review of the final data in accordance with PNWD's procedure QA-RPP-WTP-604. This review verifies that the reported results are traceable, that inferences and conclusions are soundly based, and the reported work satisfies the Test Plan objectives. This review procedure is part of PNWD's WTPSP Quality Assurance Requirements and Description Manual.
SCT-M0SRLE60-00-83-01A (WSRC-TR-2000-00352) (Rosencrance et al. 2000). *Physical Characterization for Hanford Tank Waste Samples AN-102, AN-103, and AZ-102.*	This work was requested by the customer[1] and the experimental details and Quality Assurance requirements were specified in a Task Plan.[2]

24590-101-TSA-W000-0004-153-00002 REV 00B (PNWD-3552). (WTP-RPT-114 Rev. 1) (Russell et al. 2005). *Final Report: Gas Retention and Release in Hybrid Pulse Jet Mixed Tanks Containing Non-Newtonian Waste Simulants*	Battelle - Pacific Northwest Division (PNWD) implements the RPP-WTP quality requirements by performing work in accordance with the PNWD Waste Treatment Plant Support Project quality assurance project plan (QAPjP) approved by the RPP-WTP Quality Assurance (QA) organization. This work was performed to the quality requirements of NQA-1-1989 Part I, Basic and Supplementary Requirements, and NQA-2a-1990 Part 2.7. These quality requirements are implemented through PNWD's Waste Treatment Plant Support Project (WTPSP) Quality Assurance Requirements and Description Manual. Experiments that were not method-specific were performed in accordance with PNWD's procedures QA-RPP-WTP-1101, "Scientific Investigations," and QA-RPP-WTP-1201, "Calibration Control System," ensuring that sufficient data were taken with properly calibrated measuring and test equipment (M&TE) to obtain quality results. As specified in Test Specification 24590-WTP-TSP-RT-03-010 Rev. 0, "Pulse Jet Mixer Gas Hold-Up and Release Testing," BNI's QAPjP, PL-24590-QA-00001, was not applicable because the work was not performed in support of environmental/regulatory testing, and the data will not be used as such. PNWD addresses internal verification and validation activities by conducting an Independent Technical Review of the final data in accordance with PNWD's procedure QA-RPP-WTP-604. This review verifies that the reported results are traceable, that inferences and conclusions are soundly based, and the reported work satisfies the Test Plan objectives. This review procedure is part of PNWD's WTPSP Quality Assurance Requirements and Description Manual.
CCN 066843 (Sherwood 2003). *Execution Strategy for Research & Technology Department Pretreatment Integration Program.*	Not stated
WSRC-TR-2001-00252 (SRT-RPP-2001-00068) (Schumacher et al. 2002) *Final Report for Crucible Scale Vitrification of Waste Envelope D (C-106).*	The preparation of the individual HLW feed streams (cesium eluates and sludge powder) was documented in a previous status report document,[a] and all details concerning weights, compositions, and techniques were included. A basic review of these feed preparation steps will be presented in this report. The original data sheets and procedures can be found in WSRC Laboratory Notebooks.[b,c,d]

SCT-M0SRLE60-00-154-06, REV 00B; -154-06 REV 00C (cleared) (WSRC-TR-2003-00212, Rev. 0) (SRT-RPP-2003-0094, Rev. 0) (Stone et al. 2003). *Waste Feed Evaporation: Physical Properties and Solubility Determination.*	This work was conducted in accordance with the RPP_WTP Quality Assurance requirements specified for work conducted by SRTC as identified in DOE IWO MOSRLE60. Researchers followed the WSRC QA program, which has been approved by WTP, and the WSRC QA Management Plan (WSRC-RP-92-225). The program applied the appropriate QA requirements for this task, as indicated by the QA Plan Checklist in section IX of the Task Technical and Quality Assurance Plan. Analytical sample labeling and tracking complied with established procedures (WSRC Manual L1, Procedure 7.15). The SRTC Analytical Development Section (ADS) conducted all analyses using the routine level QA program. The Task Technical & QA Plan provided the quality requirements for this work. NQA-! 1989, part 1, Basic and Supplementary Requirements and NQA-2a 1990, Part 2.7 were applied as appropriate.

SCT-M0SRLE60-00-110-00023, REV 00A (WSRC-TR-2003-00547, Rev. 0) (SRT-RPP-2003-00240, Rev. 0) (Zamecnik et al. 2004). *Tank 241-AY-102 Simulant Development, Ultrafiltration, and Washing.*	**1.4 QUALITY REQUIREMENTS** The following quality assurance requirements were specified in the Task Plan.1 Researchers will follow the WSRC Quality Assurance Program, which has been approved by WTP, and the WSRC Quality Assurance Management Plan (WSRC-RP-92-225). Tests will be performed in accordance with the following quality assurance requirements established in NQA-1 (1989) and NQA-2a (1990) Subpart 2.7 as indicated by the QA Plan Checklist in Section VIII. This task will not generate data that will be used for environmental regulatory purposes. Therefore, per the "Quality Assurance Project Plan (QAPjP) for Testing Programs Generating Environmental Regulatory Data", PL-24590-QA00001, Rev. 0, the quality control (QC) for analytical data specified in the aforementioned QAPjP are not applicable. Thus, an exception to the QC specified in the Test Specifications (“AY-102/C-106 Simulant Ultrafiltration and Washing Test Specification”, 24590-PTF-TSP-RT-02-009, Rev 01 and “AY-102/C-106 Simulant Definition Test Specification”, 24590-WTP-TSP-RT-02-009, Rev 02) will be taken and the following analytical protocol will be followed for this task. The determination of the non-applicability of this work for environmental regulatory purposes and the approach to institute quality controls as specified below was agreed to by the RPPWTP customer (Washington Group International). SRTC personnel will conduct this filtration activity in accordance with this approved Task Technical and QA plan. The additional RW-0333P, rev. 10 QA requirements do not apply to this task. Measuring and test equipment used in the course of this task complied with the SRTC QA program as delineated in the Task Plan.1 A list of the M&TE used in the ultrafiltration section is in lab notebook WSRC-NB-2003-00190.2 Simulant development data was recorded in laboratory notebooks WSRC-NB-2003-00085, -00137, -00174, and -00229. **1.4.1 Analytical Quality Assurance** Analyses will be provided by SRTC’s Analytical Development Section (ADS) on a "Routine" QA/QC level. Routine Level is for general R&D support. ADS maintains a written method or instrument procedure for all Routine Level analyses, and the results for most methods are recorded in LIMS. Quality Control (QC) is addressed through ADS’s Measurement Control Program (MCP) for analytical services. Quality Control data is routinely tracked and evaluated. The ADS Quality Control (QC) program tracks long term system performance of the Measurement Systems. These systems include instruments, standards and personnel (laboratory technicians and chemists). These records are available and auditable, but will not be submitted with sample analysis results evaluated. The ADS Quality Control (QC) program tracks long term system performance of the Measurement Systems. These systems include instruments, standards and personnel (laboratory technicians and chemists). These records are available and auditable, but will not be submitted with sample analysis results.

(a) R. F. Schumacher, C. L. Crawford, and N. E. Bibler, *Status Report for Crucible Scale Vitrification of Waste Envelope D (C-106).* SRT-RPP-2001-00003, January 2001.
(b) Laboratory Notebook WSRC-NB-2000-00159, BNFL Part B.1, D Envelope, Vol. 1.
(c) Laboratory Notebook WSRC-NB-2000-00160, BNFL Part B.1, D Envelope, Vol. 2.
(d) Laboratory Notebook WSRC-NB-2001-00106, RPP Part B.1, D Envelope, Vol. 3.

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