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DEVELOPMENT OF SIMULANTS TO SUPPORT MIXING TESTS FOR HIGH LEVEL WASTE AND LOW ACTIVITY WASTE

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SRS savannah river site ™

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LIST OF ACRONYMS

AA	Atomic Absorption Spectrophotometry
cP	centipoise
CMC	Sodium Carboxymethylcellulose
CRV	Concentrate Receipt Vessel
GFCs	Glass Forming Chemicals
HLW	High Level Waste
IC	Ion Chromatography
ICPES	Inductively Coupled Plasma Emission Spectrophotometry
ICPMS	Inductively Coupled Plasma Mass Spectrometry
IS	Insoluble Solids
IX	Ion Exchange
LAW	Low Activity Waste
MFPV	Melter Feed Preparation Vessel
mPa·s	milliPascal-seconds
NM	Not Measured
Pa	Pascals
RPM	revolutions per minute
RPP	River Protection Project
RTD	Resistance Thermometer Detector
SS	Soluble Solids
TIC	Total Inorganic Carbon
TOC	Total Organic Carbon
TS	Total Solids
Wt%	Weight Percent
WTP	Waste Treatment Plant
XRD	X-ray Diffraction analysis

1.0 SUMMARY OF TESTING

1.1 OBJECTIVES

The objectives of this study were to develop two different types of simulants to support vendor agitator design studies and mixing studies. The initial simulant development task was to develop rheologically-bounding physical simulants and the final portion was to develop a nominal chemical simulant which is designed to match, as closely as possible, the actual Envelope D sludge from tank 241-AZ-101.

The physical simulants to be developed included a lower and upper rheologically bounded:

- pretreated low activity waste (LAW) physical simulant.
- LAW melter feed physical simulant.
- pretreated high level waste (HLW) physical simulant.
- HLW melter feed physical simulant.

The bounding rheological conditions were specified in RPP Task Specification 24590-WTP-TSP-RT-01-004, Rev.1 and revised in subsequent test exceptions.[1, 2, 3]

The nominal chemical simulant, hereafter referred to as the HLW Precipitated Hydroxide simulant, is designed to represent the chemical/physical composition of the actual washed and leached AZ-101 sludge sample characterized by Battelle.[5] The objective was to produce a simulant which matches not only the chemical composition but also the physical properties of the actual waste sample. The HLW Precipitated Hydroxide simulant could then be used for mixing tests to validate mixing, homogeneity and representative sampling and transferring issues. The HLW Precipitated Hydroxide simulant may also be used for integrated nonradioactive testing of the WTP prior to radioactive operation.

1.2 CONDUCT OF TESTING

The development of the LAW physical simulants was based upon preparing a simplified LAW formulation derived from the composition of AP-101 supernate.[6] This composition was then tested rheologically from 2 molar sodium to 11 molar sodium concentrations. The upper and lower bound rheological conditions for LAW pretreated feed were encompassed by these concentrations. The pretreated feeds were then mixed with the appropriate amount of project-approved glass former chemicals (GFCs) producing LAW melter feed and the rheological properties were measured.[13] Using this technique, the lower bound rheological LAW melter feed condition was satisfied. However, none of the LAW melter feeds, derived by varying the Na concentration of the pretreated waste, were capable of reaching the yield stress of the upper bound LAW melter feed. Tests were performed with rheology modifiers to identify a modifier capable of achieving the necessary yield stress needed for the LAW upper bounding melter feed.

A cesium ion exchange evaporator concentrate simulant was developed for use in producing the pretreated HLW feed for both the physical and Precipitated Hydroxide simulants described below.

The development of the HLW physical simulants was based on the use of four major HLW components (Al, Fe, Si and Zr) as hydroxides or as oxides with known particle properties (density and size). Tests were conducted on various combinations of these particle properties while maintaining a general composition derived from AZ-101 washed, leached sludge.[5] The tests varied the total solids loading from 15 to 35 weight % in order to match the upper and lower bounds for the pretreated HLW feed and for the HLW melter feed. Additional tests with rheology modifiers were also conducted so that an upper bound condition could be obtained without exceeding 25 weight % total solids.

The HLW Precipitated Hydroxide nominal simulant was developed to reproduce the chemical and physical properties of the radioactive AZ-101 HLW sample processed by Battelle.[17] The simulant production method (precipitation) was based upon the previous SRTC work on Envelope D simulants.[7, 8] The HLW Precipitated Hydroxide simulant was then combined with the cesium ion exchange evaporator concentrate simulant to produce a pretreated HLW concentrate receipt vessel (CRV) feed. The HLW Precipitated Hydroxide melter feed simulant was produced from the pretreated HLW Precipitated Hydroxide CRV simulant by the addition of appropriate GFCs.[1] The physical and chemical properties of the simulants were then measured and compared to the actual waste properties.

1.3 RESULTS AND PERFORMANCE AGAINST OBJECTIVES

The following bounding simulants were developed and recipes provided as part of this study:

- Lower Bound LAW Pretreated Waste physical simulant and Lower Bound LAW Melter Feed physical simulant (recipe in Appendix A).
- Upper Bound LAW Pretreated Waste physical simulant (recipe in Appendix B).
- Upper Bound LAW Melter Feed physical simulant (recipe in Appendix C).
- Lower Bound HLW Pretreated Waste physical simulant and Lower Bound HLW Melter Feed physical simulant (recipe in Appendix D).
- Upper Bound HLW Pretreated Waste physical simulant and Upper Bound HLW Melter Feed physical simulant (recipe in Appendix E).
- Nominal AZ-101 HLW Precipitated Hydroxide simulant that provides physical and chemical properties that are representative of the actual radioactive AZ-101 Envelope D waste (recipe in Appendix F).

All of the objectives stated in the RPP test specification and the subsequent test exceptions were satisfied. Table 1 compares the rheological values of the bounding physical simulants to the rheological limits for each simulant.

Table 1 Summary of Bounding Simulant Results

	Bingham Plastic Yield Stress	Bingham Plastic Consistency	Yield Stress from WTP-RPT-075	Consistency from WTP-RPT-075	Yield Stress from 24590-WTP-TEF-RT-03-021	Consistency from 24590-WTP-TEF-RT-03-021
Simulant	**Pascal**	**mPa.s**	**Pascal**	**mPa.s**	**Pascal**	**mPa.s**
Low Bound LAW Pretreated Waste	0	1.7	0	2	NA	NA
High Bound LAW Pretreated Waste	0.5	15.1	0	15	NA	NA
Low Bound LAW Melter Feed	0	2.8	0	2	NA	NA
High Bound LAW Melter Feed	14.6	57	12	92	NA	NA
Low Bound HLW Pretreated Waste	0	2	0	2	0	0.4
High Bound HLW Pretreated Waste	17.5	9.9	20	37	20	40
Low Bound HLW Melter Feed	0	4	0	2	0	0.4
High Bound HLW Melter Feed	30	40	28	41	30	40

1.4 QUALITY REQUIREMENTS

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.[4]

1.5 ISSUES

The development of the physical simulants for LAW and HLW pretreated CRV feeds and LAW/HLW melter feeds has not identified any issues for design or operation of the River Protection Project – Waste Treatment Plant (RPP-WTP)**.** Development of the nominal HLW Precipitated Hydroxide simulants has not identified any issues for design or operation of the RPP-WTP**.** Application of these simulants may identify design or process issues, but application of the simulants is beyond the scope of this study.

2.0 CD-ROM ENCLOSURES

The enclosed CD-ROM contains additional data not included in this report. An electronic copy of the report is also included on the CD-ROM.

The CD-ROM should start automatically within 30 seconds when placed in your CD-ROM drive on an IBM compatible PC. If it does not, then do the following:

1. Double-left-click on My Computer icon on your desktop
2. Right-click on your CD drive icon
3. Left-click on AutoPlay

The recommended minimum computer system is as follows:

- Pentium II running at 233 MHz
- 32 MB ram
- Windows 95 or later.

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3.0 DISCUSSION

The objectives of this task were to develop two different types of simulants to support vendor agitator tests and mixing studies. The first two portions of this discussion will focus on the development of rheologically-bounding physical simulants for LAW and HLW pretreated wastes and melter feeds. The final portion of the discussion will cover development of a chemical simulant (HLW Precipitated Hydroxide simulant) which is designed to match, as closely as possible, the actual radioactive Envelope D sludge from tank 241-AZ-101.

The rheological limits that the physical simulants must meet are shown in Figures 1 through 4. These limits were obtained from RPP-WTP.[9] Two definitions are important when discussing the rheological properties of the Hanford waste slurries. The first definition is for yield stress and the second is for consistency. Yield stress is the minimum force required to initiate flow. Consistency is a measure of the degree of fluidity of a slurry after it has begun to flow.

For pretreated LAW feed the lower limit is a fluid which has Newtonian fluid properties (no yield stress and a linear dependence of the shear stress on the shear rate under laminar conditions) with a viscosity of 2 milliPascal·seconds (mPa·s). A milliPascal·seconds is equal to one centipoise. The upper limit is a fluid which has Newtonian fluid properties and a viscosity of 15 mPa·s. After addition of GFCs, the lower limit for LAW melter feed is also a Newtonian fluid with a viscosity of 2 mPa·s. The upper limit for LAW melter feed is a non-Newtonian fluid with a yield stress of 12 Pa and a consistency of 92 mPa·s.

For HLW Pretreated Waste (CRV feed) the lower limit is a fluid which has Newtonian fluid properties with a viscosity of 0.4 mPa·s. For comparison purposes, the viscosity of water at 40 ° C is 0.653 mPa·s.[10] The upper limit for pretreated HLW CRV feed is a non-Newtonian fluid with a yield stress of 20 Pa and a consistency of 40 mPa·s. The lower limit for the HLW melter feed is a fluid which has Newtonian fluid properties with a viscosity of 0.4 mPa·s. The upper limit for HLW melter feed is a non-Newtonian fluid with a yield stress of 30 Pa and a consistency of 40 mPa·s. The basis for these rheological limits was based upon a review of existing rheology data for simulants and actual waste samples.[9]

Viscosity for fluids is generally an inverse function of temperature. As the temperature increases, the viscosity decreases. Therefore, the upper bounds will be based upon rheology measurements at 25 ° C. The lower bounds will be based upon either a 25 or 40 ° C temperature.

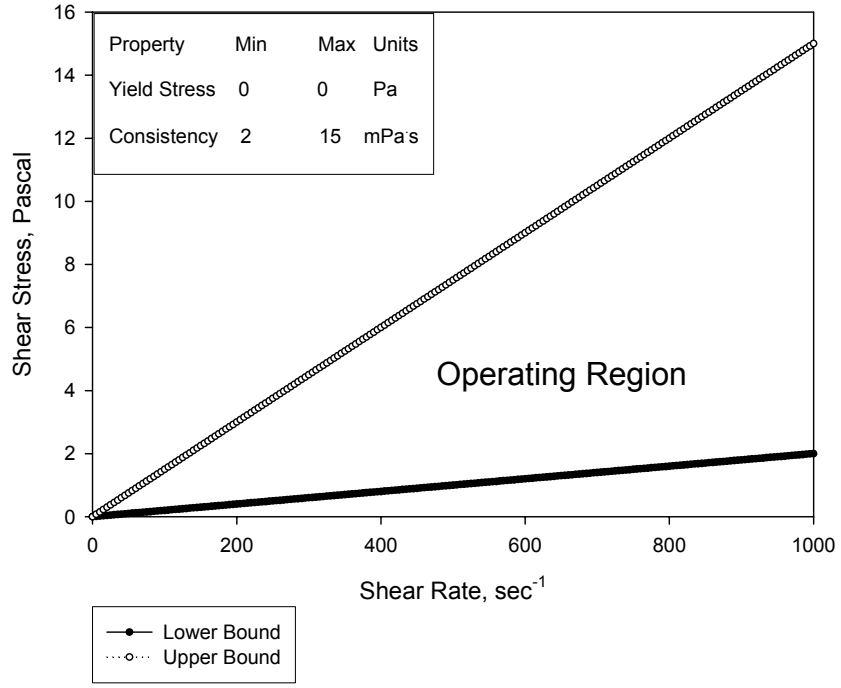

Figure 1 Rheological Operating Limits for LAW Pretreated Waste

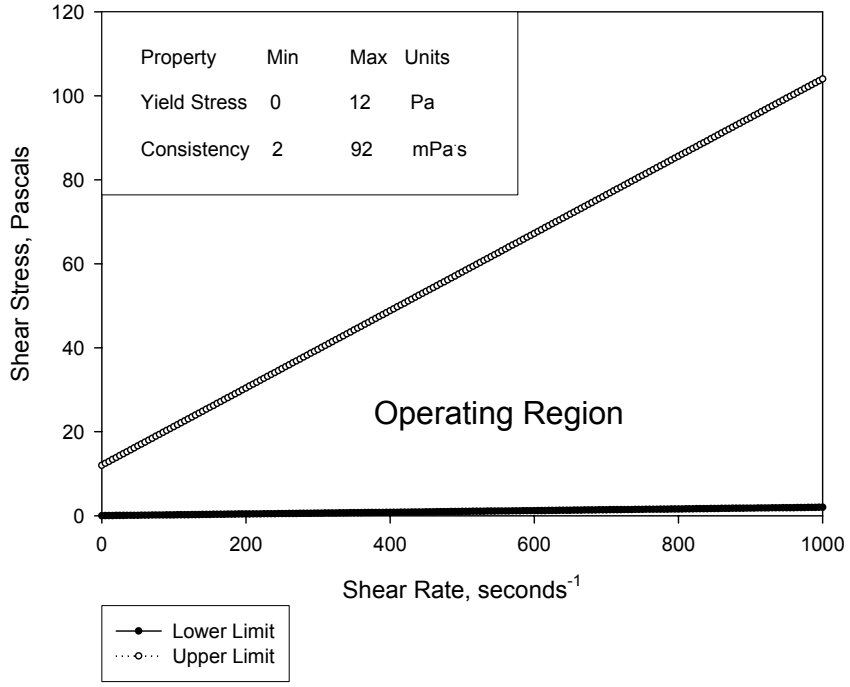

Figure 2 Rheological Operating Limits for LAW Melter Feed

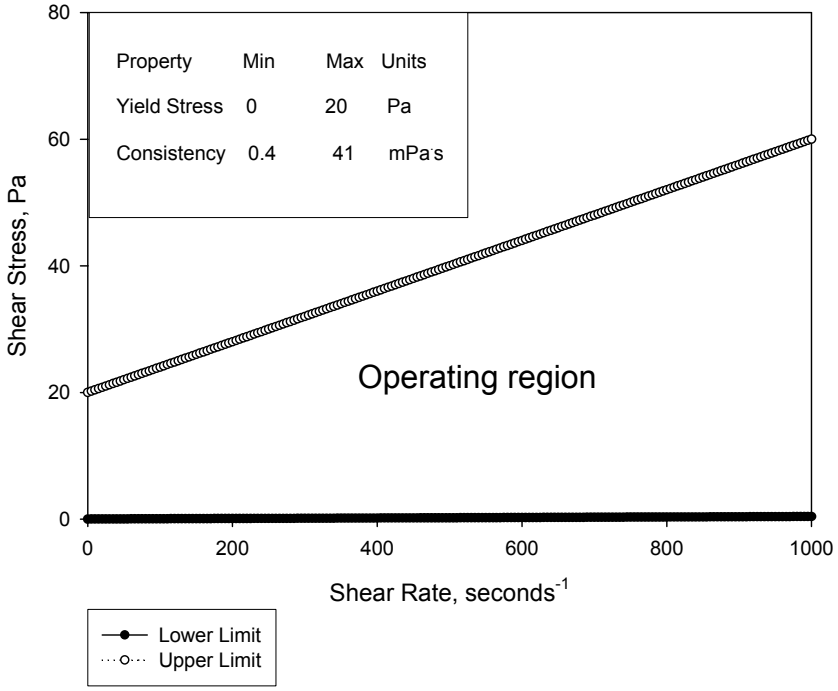

Figure 3 Rheological Limits for HLW Pretreated Waste

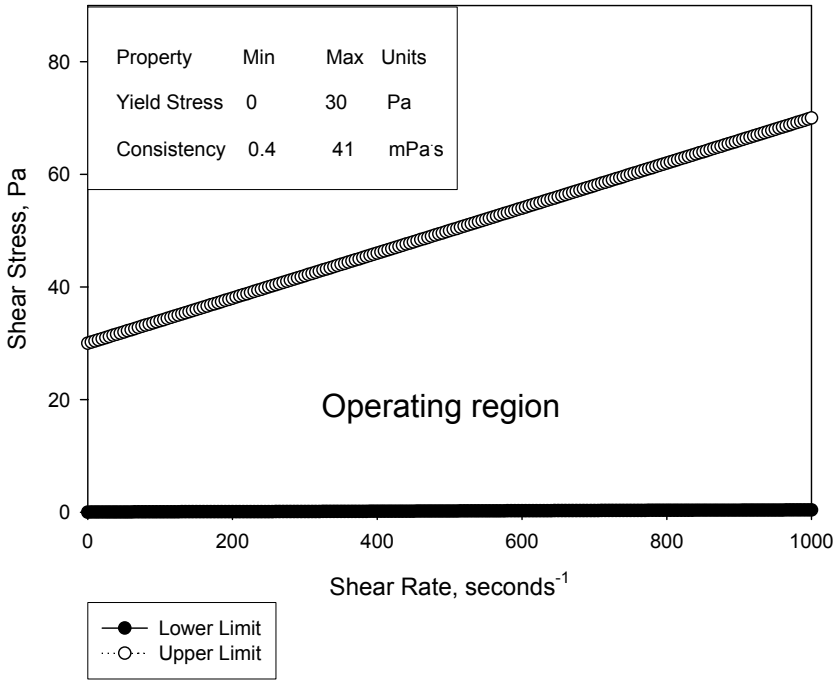

Figure 4 Rheological Limits for HLW Melter Feed

Supernate and slurry rheology (flow curves) were characterized using a Haake RS600 rheometer and a Haake RS150 rheometer based upon RPP guidance for rheology measurements.[18] Both rheometers are Searle type measuring systems, where both the speed and torque are measured at the rotating shaft. The RS150 and RS600 rheometers can be controlled using either the controlled rate or controlled stress modes. In this study, only the controlled rate mode was used. The measuring geometries used included the cylindrical bob and cup (Z38, Z41 and DG41) and the cone and plate. Flow curves were obtained from 0 to 1000 seconds^{-1} shear at 25 and 40 ° C. The resulting flow curves were fitted to the following rheological models: Newtonian, Bingham Plastic, Ostwald (power law), and Herschel-Bulkley (power law with an intercept). The Bingham Plastic fit values were used in determining compliance with the rheology limits for non-Newtonian slurries. The range of fitted shear rates was adjusted to avoid problems with nonlaminar flow conditions.

The shear strengths for settled, undisturbed samples were measured using the Haake rheometers and the vane method. The sensor used was the FL-22 vane (diameter 22 mm, height 16 mm) and the rotation rate was set to 0.03 radians/second (equivalent to 0.3 RPM). Samples were generally run in duplicate while paying close attention to the required measuring geometry.[11]

Chemical analysis methods used in the characterization of the HLW Precipitated Hydroxide simulant included inductively coupled plasma emission spectrophotometry (ICPES), inductively coupled plasma mass spectrometry (ICPMS), atomic absorption spectrophotometry (AA), ion chromatography (IC), and total inorganic carbon/total organic carbon analyzer (TIC/TOC). Samples of solids were prepared by microwave dissolution and by sodium peroxide fusion. Solids were analyzed by x-ray diffraction (XRD) to identify the crystalline phases present. Particle size measurements were made by a MicroTrac-X100 particle analyzer based upon laser diffraction analysis.

The weight percent solids were determined using a Mettler Toledo HR73P Halogen Moisture Analyzer. The HR73P is programmed to heat the sample to 105 ° C and monitor the weight of the sample until the change in weight is less than or equal to 1 mg in 130 sec. The advantage of this method is that a weight percent solids analysis can be run in less than 20 minutes while a complete analysis of total, soluble and insoluble solids can take less than an hour. The homogenous sample (slurry or liquid) is placed on a glass fiber pad and the pad placed in the HR73P. The HR73P weighs the sample. The mass of the sample used is considered as the total mass (m_{tt}). The sample is then heated by the Halogen irradiator to 105 ° C to drive off all the water and the resulting remaining mass is the total solids (m_{ts}) in the sample. The weight percent (wt %) total solids (TS) was determined using equation [1].

$$\text{wt}\%_{ts} = \frac{m_{ts}}{m_{tt}} \times 100\% \qquad [1]$$

A sample of the slurry is centrifuged (at 4332 gravities) to obtain the supernate. The resulting supernate is then processed through a 0.45 μm filter. Any particle smaller than 0.45 μm is assumed to be part of the supernate. A sample of this supernate is then placed on a glass fiber pad and placed in the HR73P and weighed. The mass of sample used is considered as the total mass of the supernate (m_{st}). The sample is then heated by the Halogen irradiator to 105 ° C to drive off all the water and the resulting remaining mass is the total dissolved solids (m_{ds}) in the supernate. The weight percent of total dissolved solids in the supernate is determined using equation [2]. Again, this analysis assumes that all the solids in the resulting supernate are dissolved.

$$wt\%_{ds} = \frac{m_{ds}}{m_{st}} \times 100\% \qquad [2]$$

The weight percent of insoluble solids (IS) and soluble solids (SS) of the slurry can then be determined by the following conservation of mass relationships, equations [3] and [4] respectively.

$$wt\%_{is} = \frac{wt\%_{ts} - wt\%_{ds}}{100\% - wt\%_{ds}} \cdot 100\% \qquad [3]$$

$$wt\%_{ss} = wt\%_{ts} - wt\%_{is} \qquad [4]$$

Settling rate measurements were obtained by placing a sample in a 15 mL graduated centrifuge tube and measuring the settled volume as a function of time.

3.1 DEVELOPING THE LAW PHYSICAL SIMULANTS

The LAW physical simulant is derived from the composition of 241-AP-101 supernate. The supernate from this Hanford tank has been previously simulated and the formulation for the physical simulant was obtained by modifying this simulant recipe.[6] The basis for the physical simulant to be tested was obtained by using the AP-101 supernate waste components that exceeded 0.01 moles per liter in concentration. Species below 0.01 molar were not considered to have much effect on the rheology of the supernate for AP-101 compositions. Varying simulant compositions were obtained by either mathematically diluting or concentrating the simplified 5 molar simulant to obtain sodium concentrations from 2 to 11 molar.

Test solutions were prepared by following the basic procedure given in Appendix A for LAW concentrations varying from 2 to 11 molar Na. The physical properties and the rheological properties of these test solutions are shown in Table 2 and Table 3.

Table 2 Physical Properties of LAW Pretreated Waste Simulants

Na Concentration	Density at 25	Total Solids	Insoluble Solids	Soluble Solids
Moles/Liter	g/mL	Weight %	Weight %	Weight %
2	1.106	13.30	0	13.30
3	1.158	19.00	0	19.00
3.5	1.187	22.00	0	22.00
4	1.210	24.50	0	24.50
5	1.252	29.09	0.05	29.04
6	1.298	33.59	0.24	33.35
7	1.341	38.06	0.53	37.53
8	1.384	42.24	0.71	41.53
9	1.393	43.15	1.19	41.96
10	1.459	49.94	7.26	42.68
10.5	1.489	52.10	8.10	44.00
11	1.499	53.45	9.70	43.80

Table 3 Rheology of LAW Pretreated Waste Simulants

Na Concentration	Rheology at 25 ° C			Rheology at 40 ° C		
	Yield Stress	Consistency or Viscosity	Flow Curve Type	Yield Stress	Consistency or Viscosity	Flow Curve Type
Moles/Liter	Pascal	milliPascal-seconds		Pascal	milliPascal-seconds	
2	0	1.3	Newtonian	0	1.0	Newtonian
3	0	1.7	Newtonian	0	1.2	Newtonian
4	0	2.1	Newtonian	NM	NM	NM
5	0	2.8	Newtonian	0	2.0	Newtonian
6	0	3.7	Newtonian	0	2.5	Newtonian
7	0	4.9	Newtonian	0	3.3	Newtonian
8	0	6.8	Newtonian	0	4.3	Newtonian
9	0	7.8	Newtonian	0	4.8	Newtonian
10	0	9.3	Newtonian	0	5.6	Newtonian
10.5	0.5	15.1	Non-Newtonian*	0.4	9.2	Non-Newtonian*
11	0.9	20	Non-Newtonian*	0.7	11.3	Non-Newtonian*

*Non-Newtonian – these were best described by a Power Law (Ostwald) fit but could still adequately be described by a Newtonian equation. NM – indicates not measured.

The LAW simulants below 5 molar in Na did not have any measurable amounts of insoluble solids. The LAW Simulants, which were 5 molar and greater in Na, had increasing amounts of insoluble solids. This observation confirms previously reported work on the AP-101 simulant and also on actual pretreated AP-101 waste feed.[6, 12] The density also compares very well with the values observed in actual pretreated AP-101 waste as shown in Table 4.

Table 4 Comparison of LAW Physical Simulant Density to AP-101 Actual Pretreated Waste

Na Concentration	Density (g/mL) at 25 °C		% Comparison
Moles/Liter	LAW Simulant	AP-101 Actual Pretreated Waste[12]	
4.9	NM	1.259	NM
5	1.252	NM	NM
6	1.298	1.325	97.9
8	1.384	1.399	98.9
10	1.459	1.461	99.8

The flow curves for all of the LAW pretreated waste simulants from 2 to 10 molar in Na were linear starting from 0 seconds^{-1} up to the maximum reported shear rate for laminar flow and were therefore Newtonian fluids. The flow curves above 10 molar in Na show some curvature and give a better fit to a Power Law rheology model (Ostwald). However, the departure from linearity is minor and the curve can be adequately described using a Newtonian fit. The yield stress values given in Table 3 are obtained from a fit to a Bingham Plastic rheology model of the up flow curve from 50 to 1000 sec^{-1}. While a better fit is obtained to a power law rheology model, the Bingham Plastic fit is used for comparison with the bounding rheology limits. Figure 5 shows a comparison of the viscosity of the physical simulant with the actual pretreated AP-101 supernate.[12]

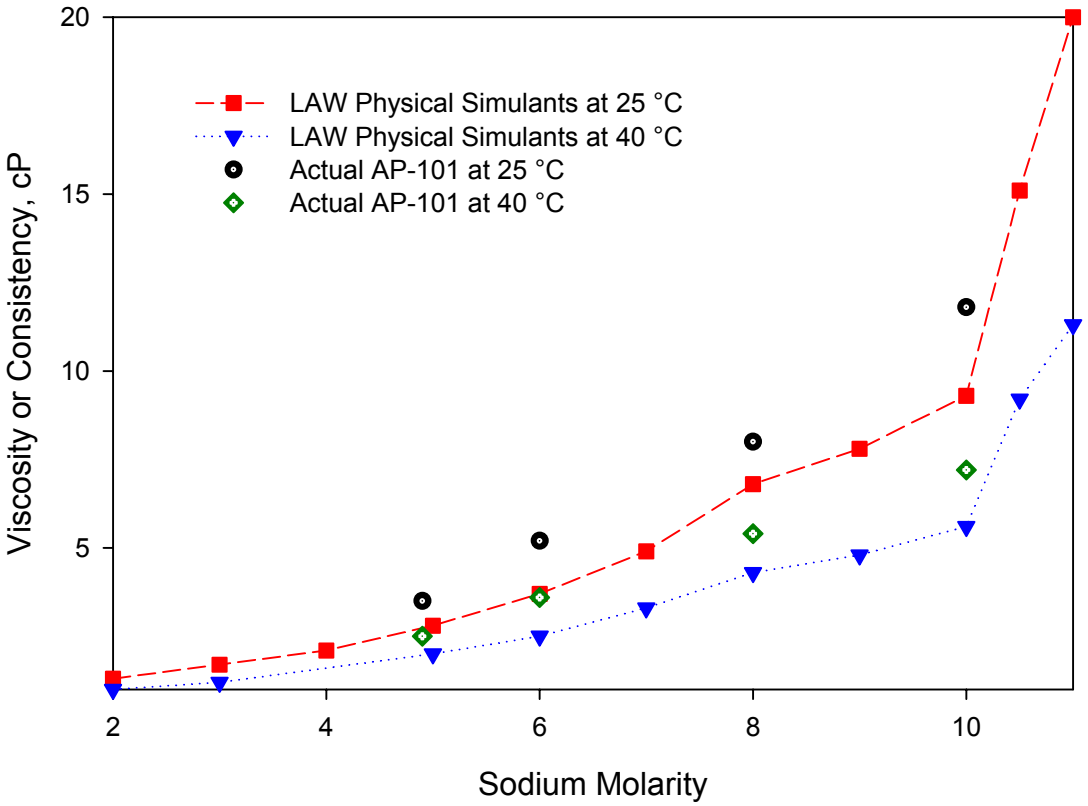

Figure 5 Viscosity of the LAW Physical Simulants compared to the Viscosity of Actual AP-101 Supernate

The pretreated LAW physical simulants were then converted to LAW melter feed physical simulants by the addition of the approved glass forming chemicals (GFCs).[13] The GFCs used in this study for LAW melter feed production are shown in Table 5. The mass of GFCs to use per liter of pretreated Feed was obtained from RPP[1] and was calculated by dividing the pretreated LAW feed Na concentration by 5 molar Na and multiplying by the masses for each of the GFCs shown in Table 6.

Table 5 Glass Former Chemicals and Minerals for LAW Melter Feeds[13]

Oxide Added	Mineral	Grade	Company	Bulk Density (pcf) Particle Density (g/cc^3)	Screen Analysis (mesh) Particle Size (μm)
Al2O3	Kyanite Al2O3-SiO2	Raw -325	Kyanite Mining Corp Ddillwyn, VA, 23936 www.kyanite.com	65.5 3.61	<325M 44
B2O3	Boric Acid H3BO3	Technical Grade-Granular	U.S. Borax Valencia, CA 91355-1847	56.8 1.51	>20M 841
CaO	Wollastonite CaSiO3	NYADM325 NWest Mexico	NYCO Wilsboro, NY www.nycominerals.com	45.6 2.84	<325M 44
Fe2O3	Fe2O3	Fe2O3 5001	Prince Mfg. Co. Quincey IL 62306 www.princemfg.com	120 5.3	<325M 44
MgO	Olivine	#180 Hamilton, WA	Unimin Corp qualityceramics@unimin.com	96.7 3.32	<200M 74
SiO2	SiO2	SCS-75 Mill Creek OK	U.S. Silica Berkeley Springs WV www.u-s-silica.com	59.3 2.65	<200M 74
TiO2	Rutile (Air floated) TiO2/Fe2O3	Air Float Rutile 94 Phil. PA	Chemalloy Co. Bryn Mawr, PA www.chemalloy.com	 4.25	Air Floated 177
ZnO	ZnO	Kadox 920 Camden, NJ	Zinc Corp Amer. Monaca,PA horseheadinc.com	41.2 5.6	1 micron 1
ZrO2	ZrSiO4	Zircon Flour	Amer. Miner.Inc. Monaca,PA 19406 www.americanminerals.net	103 4.65	<325M 44

Table 6 Amount of GFCs to Add to Pretreated LAW Feed to Make LAW Glass

Oxides	Additives	Amount of Raw Minerals to Add to AP-101 Waste Slurry, g/Liter of 5 Molar Na Feed
Al_2O_3	Kyanite (Al_2SiO_5) 325 Mesh	59.45
B_2O_3	H_3BO_3 (Technical - Granular)	146.09
CaO	Wollastonite NYAD 325 Mesh	35.26
Fe_2O_3	Fe_2O_3 (-325 Mesh)	45.34
MgO	Olivine (Mg_2SiO_4) 325 Mesh (#180)	25.83
SiO_2	SiO_2 (Sil-co-Sil 75)	306.05
TiO_2	TiO_2 (Rutile - Airfloated)	17.53
ZnO	ZnO (K-920)	24.98
ZrO_2	Zircon $ZrSiO_4$ (Flour) 325 Mesh	37.78
	Total	698.31

*Note: Derived from actual pretreated LAW (AP-101) supplied for glass fabrication: 364 mL at 1.258 g/mL or 457.9 g AP-101 feed at 4.85 moles/L sodium. Reference 1

The melter feed simulant was prepared by mixing the dry GFCs together and then slowly adding this dry mix to a well stirred batch of the pretreated LAW physical simulant. This dry blending process followed by addition to liquid varies somewhat from the planned WTP process. The planned WTP process will add a small amount of water (3-7 wt % of the GFCs mass) to the GFC blend to prevent dusting before addition to the feed. However, the water addition can be accounted for in the simulant liquid phase preparation and was not deemed significant in terms of impacting the development of or properties for an appropriate bounding physical simulant. The resulting melter feed mixture was mixed for a minimum of 1 hour at ambient lab conditions (20-25 ° C). The melter feed test mixtures were then left unagitated at ambient lab conditions until ready for rheology measurements. The rheology samples were agitated by shaking or stirring before each rheology measurement was made. The 40 ° C rheology measurements were performed on a small portion of the test mixture using the temperature control features of the Haake rheometers. Each sample had the rheology measurement performed twice on two separate subsamples. The measured physical properties are shown in Table 7 and the rheological properties in Table 8.

Table 7 Physical Properties of LAW Melter Feed Simulants

Na Concentration	Density at 25 ° C	pH	Total Solids	Insoluble Solids	Soluble Solids
Moles/Liter	g/mL		Weight %	Weight %	Weight %
2	1.380	9.58	39.8	32.5	7.3
3	1.382	11.01	37.8	21.7	16.1
6	1.620	11.49	56.2	32.2	24.0
7	1.688	11.64	60.5	34.6	25.9
8	1.753	11.83	64.3	36.8	27.5
9	1.799	11.95	66.7	37.6	29.1
10	1.877	12.21	70.5	39.5	30.9
10.5	1.903	12.31	72.1	40.4	31.7
11	1.924	12.75	73.2	41.6	31.6

Table 8 Rheology of LAW Melter Feed Simulants

Na Concentration	Rheology at 25 ° C			Rheology at 40 ° C		
	Yield Stress	Consistency or Viscosity	Flow Curve Type	Yield Stress	Consistency or Viscosity	Flow Curve Type
Moles/Liter	Pascal	milliPascal-seconds		Pascal	milliPascal-seconds	
2	*	*	Settles	*	*	Settles
3	0	2.8	Newtonian	0	2.1	Newtonian
3.5	0	3.5	Newtonian	0	2.5	Newtonian
6	0	9.9	Newtonian	0	6.2	Newtonian
7	0	16.4	Newtonian	0	10.1	Newtonian
8	0	28.5	Newtonian	0	16.0	Newtonian
9	2.5	44.3	Non-Newtonian	NM	NM	NM
10	4.6	74.7	Non-Newtonian	NM	NM	NM
10.5	5.4	91.9	Non-Newtonian	3.0	48.4	Non-Newtonian
11	6.2	110.4	Non-Newtonian	2.6	61.0	Non-Newtonian

* - The melter feed simulant settles too quickly to measure rheology. NM – indicates not measured.

The 2 molar Na LAW melter feed simulant was very difficult to handle due to the excessively fast settling property of the melter feed solids. The odd results for weight percent total solids and insoluble solids reflect the rapid settling characteristic of this simulant. Since the weight percent soluble solids value is calculated from the total solids value and insoluble solids value as described earlier, the value reported for weight percent soluble solids at 2 molar Na should be considered unreliable. Measuring the rheological properties by producing a flow curve was also impossible for the 2 molar Na melter feed under standard flow curve conditions due to the extremely rapid settling within the rheometer. This occurred whether using the cylindrical bob and cup, cone and plate or plate to plate measuring sensors.

A quick review of the rheology data in Table 3 and in Table 8 shows that sufficient information exists for choosing the three bounding LAW conditions that are based upon Newtonian fluid properties. The most cost effective method of meeting the Low Bound limits for LAW pretreated waste and for LAW melter feed is for the same LAW physical simulant to be used for both. Therefore, by comparing the data for the 3 molar through 4 molar mixtures the best candidate was the 3 molar LAW simulant. The viscosity of the low bounding LAW Pretreated Waste physical simulant was 1.7 mPa·s at 25 ° C (within 20% of the low bound) and 1.2 mPa·s at 40 ° C. The viscosity of the low bounding LAW Melter Feed physical simulant is 2.8 mPa·s at 25 ° C and 2.1 mPa·s at 40 ° C. Figure 6 shows how closely both of the physical simulants meet the desired 2 centipoise target viscosity at 25 ° C.

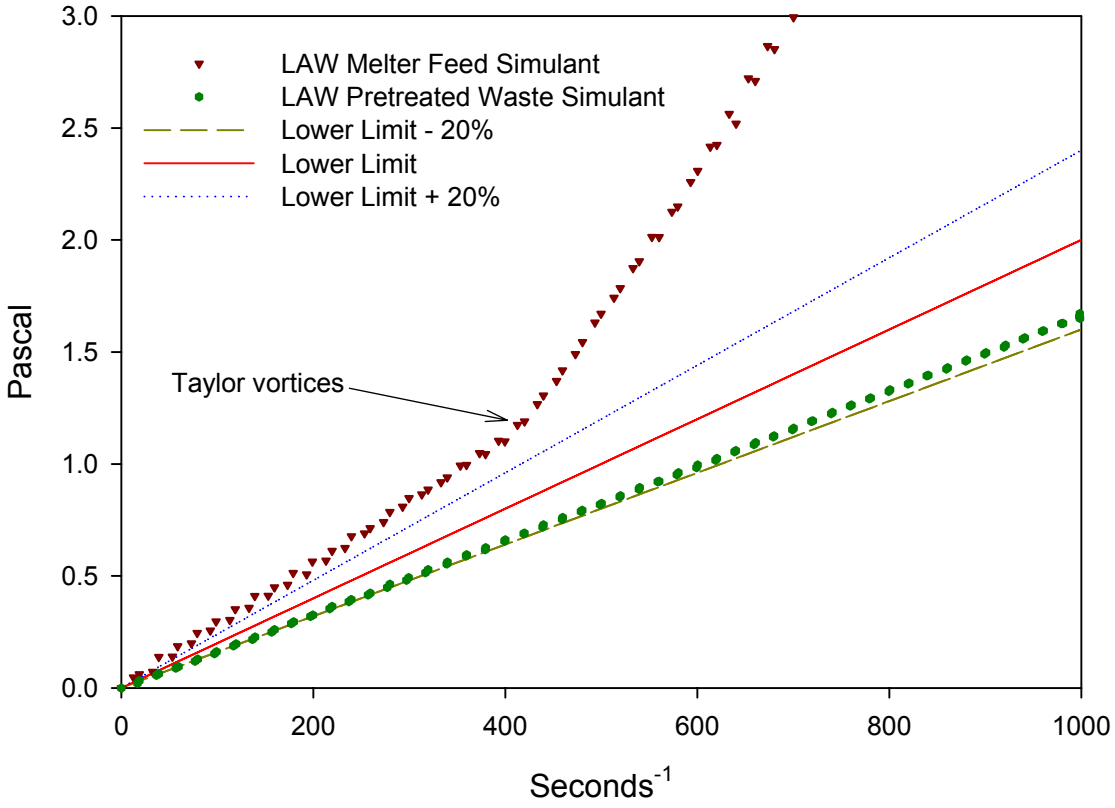

Figure 6 Comparison of the 3 Molar Na LAW Pretreated Simulant and 3 Molar Na LAW Melter Feed Simulant with the Lower Rheology Bounds at 25 ° C

The value for the melter feed exceeds the boundary but is still reasonably close and meets the needs for the lower bound limits at the higher temperature. The abrupt rise in the flow curve above 400 seconds^{-1} for the LAW melter feed simulant is due to Taylor vortices, which is a function of the rheometer sensor gap size and the fluid density. Use of a narrower gap to extend the flow curve data to higher shears was not possible due to the insoluble GFC particles in the melter feed. The flow curve for the 3 M Na pretreated LAW simulant does not show the rise because it was measured using a different sensor.

The upper bound viscosity limit for LAW pretreated waste is 15 mPa·s, as previously stated. Comparing this upper limit to Table 3 identifies the 10.5 molar Na pretreated LAW physical simulant as the closest match to the upper limit. The 10.5 molar Na LAW simulant does deviate slightly from Newtonian behavior and is best fit on the up curve to a power law function. However, the curve is well represented by the Newtonian upper limit line given the allowable 20 % error on the measurement. A comparison of the upper limit and error allowance with the flow curve of the 10.5 molar Na physical simulant is shown in Figure 7. The viscosity of the high bounding LAW Feed physical simulant was 15.1 mPa·s at 25 ° C (101% of the high bound) and 9.2 mPa·s at 40 ° C based upon the application of a Bingham curve fit from 50 to 1000 sec^{-1} to the up flow curve.

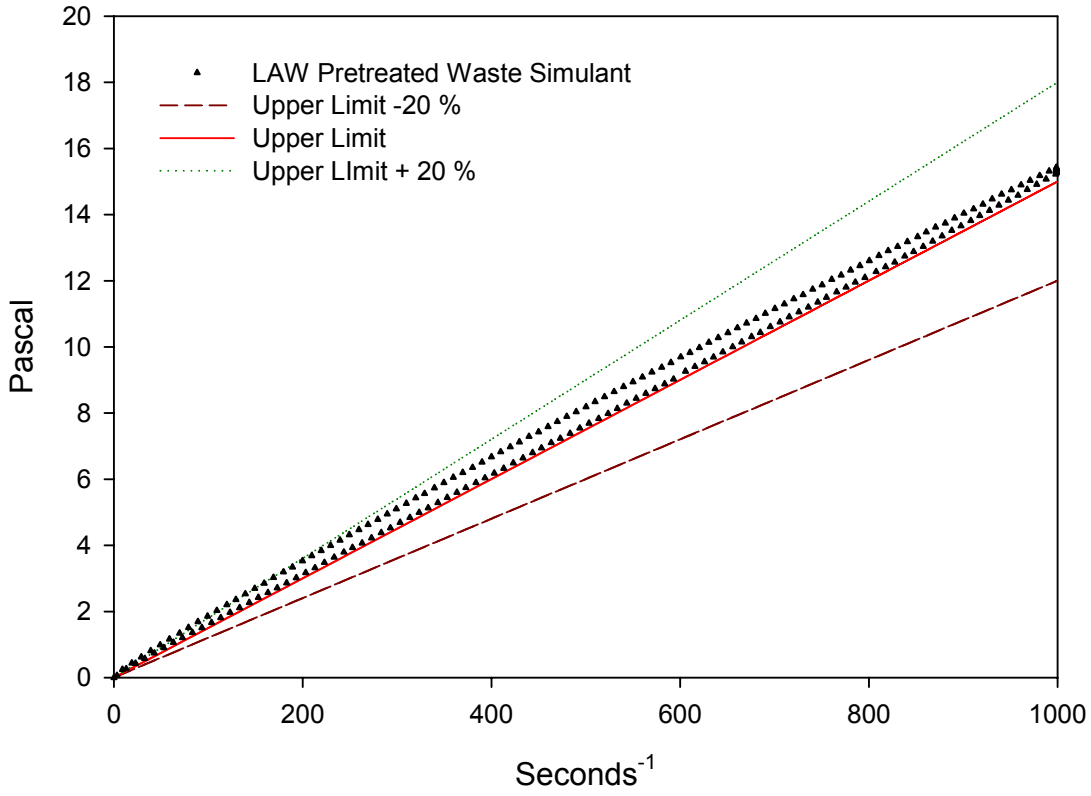

Figure 7 Flow Curve of the Upper Bound LAW Pretreated Waste Physical Simulant Compared to the Upper Bound Rheology Limits at 25 ° C

The procedures for producing the lower bound 3 molar Na pretreated LAW physical simulant and the upper bound 10.5 molar Na pretreated LAW physical simulant are given in Appendix A and Appendix B respectively. Table 9 compares the actual AP-101 supernate composition (adjusted to the same Na concentration) with each of the pretreated LAW bounding physical simulant target compositions.[6] The slight difference in Na and nitrate concentrations is due to the absence of the minor species in the physical simulants.

Table 9 Calculated Compositions of Actual AP-101 Supernate Compared to LAW Physical Simulants

Species	3 Molar Na AP-101 LAW Feed	3 Molar Na LAW Physical Simulant	10.5 Molar Na AP-101 LAW Feed	10.5 Molar Na LAW Physical Simulant
	Moles/Liter	Moles/Liter	Moles/Liter	Moles/Liter
Acetate	0.0148	0.0148	0.0519	0.0519
Aluminum	0.155	0.155	0.543	0.543
Barium	0.00000126	NA	0.00000422	NA
Beryllium	0.000078	NA	0.000273	NA
Boron	0.000792	NA	0.00277	NA
Cadmium	0.0000095	NA	0.0000322	NA
Calcium	0.000103	NA	0.000359	NA
Carbonate	0.2676	0.2676	0.9366	0.9366
Cesium	0.000027	NA	0.000095	NA
Chloride	0.0245	0.0245	0.0859	0.0859
Chromium	0.00175	NA	0.00614	NA
Copper	0.000013	NA	0.000047	NA
Fluoride	0.00169	NA	0.0059	NA
Formate	0.0142	0.0142	0.0498	0.0498
Hydroxide	1.788	1.788	6.258	6.258
Iron	0.000024	NA	0.000083	NA
Lead	0.000039	NA	0.000135	NA
Lithium	0.000026	NA	0.000091	NA
Molybdenum	0.000081	NA	0.00028	NA
Nickel	0.000072	NA	0.00025	NA
Nitrate	1.009	1.008	3.531	3.528
Nitrite	0.424	0.424	1.485	1.485
Oxalate	0.0107	0.0107	0.0374	0.0374
Phosphate	0.0075	0.0075	0.0261	0.0261
Potassium	0.427	0.427	1.495	1.495
Rubidium	0.000025	NA	0.000087	NA
Silicon	0.0026	0.0026	0.0091	0.0091
Sodium	3.000	2.98	10.501	10.46
Sulfate	0.0224	0.0224	0.0783	0.0783
Tungsten	0.000072	NA	0.000251	NA
Zinc	0.000046	NA	0.00016	NA

The upper rheology limit for LAW melter feed requires a non-Newtonian fluid which has a yield stress of 12 Pa and a consistency of 92 mPa·s based upon a Bingham Plastic rheology model. A review of the information in Table 8 indicates that none of the pretreated LAW physical simulants can approach the upper limit of the yield stress (± 35% of target) for melter feed through the addition of the appropriate amount of GFCs. Therefore, the use of rheology modifiers to modify one of the high Na concentration melter feeds was tested.

The initial rheology modifiers considered were xanthan gum, sodium carboxymethylcellulose and smectite clay (Van Gel), which is a magnesium aluminum silicate. Initial scoping tests showed that the smectite clay did not have any effect on the rheology of the high sodium concentration solutions. Apparently, the high ionic strength of the LAW feed prevented or delayed the generation of the structure which the smectite clays normally produce to thicken materials. The sodium carboxymethylcellulose is a thickener that does not impart much yield stress value and was not tested with the LAW simulants.

The initial tests with the xanthan gum did show an increase in yield strength and in consistency. Xanthan gum (CAS 11138-66-2) is an anionic polysaccharide (formula $(C_{35}H_{49}O_{29})_n$) with a molecular weight of approximately $2x10^6$. It is produced through fermentation by the bacterium *Xanthomonas campestris*.[14] The long chain structure of the gum imparts the rheology modifier properties of the material into the solution with which it is blended. Xanthan gum adds yield stress value to aqueous systems and is stable at high salt concentrations such as those existing in the LAW melter feed. Figure 8 shows a standard flow curve for one wt % xanthan gum in a one wt % potassium chloride solution. As can be seen from the flow curve, the gum provides significant yield stress, shows very little thixotropic characteristics and is shear thinning.

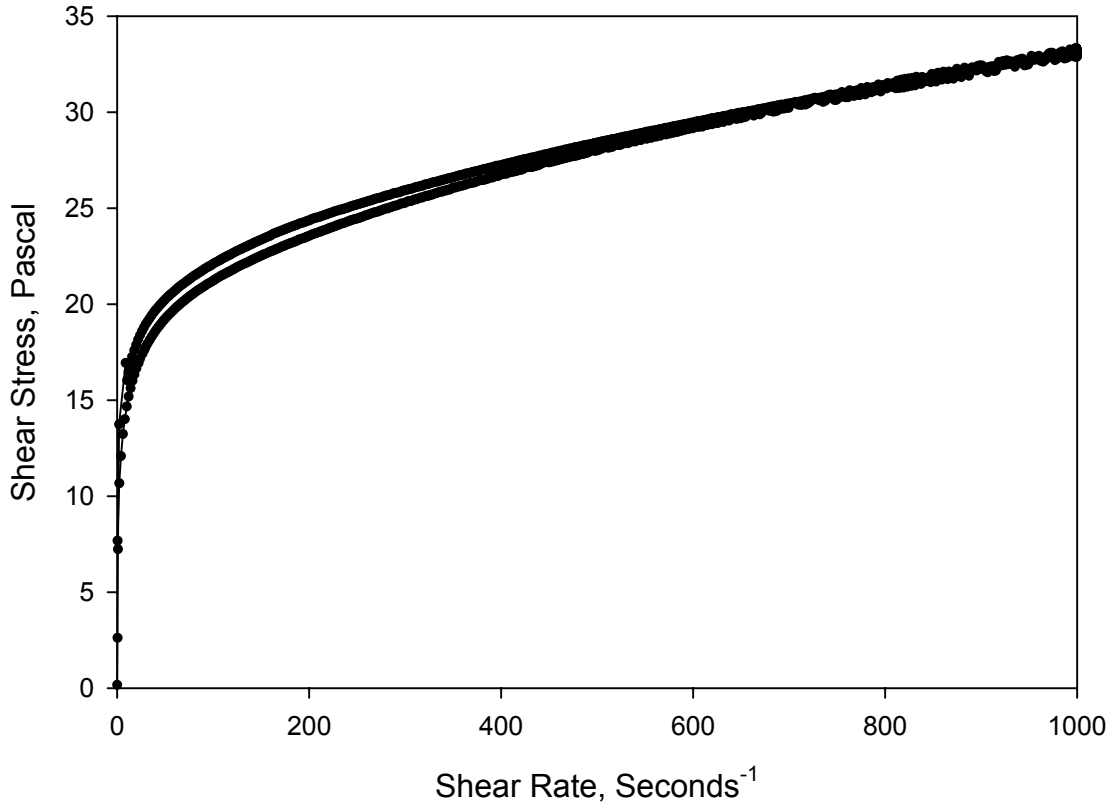

Figure 8 One Wt % Xanthan Gum in One Wt % KCl Solution Flow Curve at 25 ° C

The initial tests with xanthan gum were performed using a 9 molar Na pretreated LAW physical simulant. The 9 molar solution was chosen to minimize the amount of xanthan gum needed to reach the bounding conditions. The melter feed simulant was prepared first and then the xanthan gum was added and mixed for one hour. Initial testing of the xanthan gum was made at concentrations ranging from 0.1 wt % to 1.0 wt % in the melter feed. Table 10 and Table 11 list the rheology results of the 9 molar Na LAW melter feed at 25 and 40 ° C. All of the yield stress and consistency values were obtained by applying a Bingham Plastic model fit to the flow curve recorded in increasing shear from 50 to 1000 sec^{-1}. Excluding the data from 0 to 50 sec^{-1} minimizes the contribution of the values close to zero shear and conservatively values (over estimates) the yield stress without distorting the consistency. The square of the linear correlation coefficient (r^2) value in the last column of the rheology tables indicates the degree of fit to the Bingham equation. The negative values for yield stress shown in Table 10 are indicative of problems with the shape of the flow curve and should not be used in engineering calculations. The extreme variability observed in the 40 ° C rheology shown in Table 10 are also a result of the poorly shaped flow curves and will be discussed later. The physical property measurements for the 9 molar Na LAW Melter feed with xanthan gum are listed in Table 12.

Table 10 Rheology of 9 Molar Na LAW Melter Feed at 25 ° C with and without Xanthan Gum

Xanthan Gum	Yield Stress	Consistency			
weight %	Pascal	milliPascal-seconds	Prep Date	Measurement Date	Bingham fit r^2
0	2.7	45.1	2/5/2003	2/13/2003	0.9970
0	2.8	44.9	2/5/2003	2/13/2003	0.9972
0	1.6	39.3	3/18/2003	3/19/2003	0.9984
0	1.7	39.8	3/18/2003	3/19/2003	0.9982
0	1.7	42.7	3/18/2003	3/25/2003	0.9984
0	2.6	45.5	2/5/2003	3/25/2003	0.9980
0.1	3.2	48.6	3/10/2003	3/11/2003	0.9974
0.1	3.3	49.3	3/10/2003	3/11/2003	0.9972
0.1	4.0	53.1	3/10/2003	3/25/2003	0.9988
0.2	4.0	52.1	3/10/2003	3/11/2003	0.9986
0.2	4.2	52.8	3/10/2003	3/11/2003	0.9964
0.2	4.9	56.5	3/10/2003	3/25/2003	0.9988
0.5	7.4	74.6	3/10/2003	3/11/2003	0.9958
0.5	7.5	76.2	3/10/2003	3/11/2003	0.9958
0.5	10.1	78.8	3/10/2003	3/25/2003	0.9930
0.6	5.7	86.6	3/18/2003	3/19/2003	0.9986
0.6	5.8	85.2	3/18/2003	3/19/2003	0.9978
0.6	32.7	161	3/18/2003	3/24/2003	0.9904
0.6	37.6	172	3/18/2003	3/24/2003	0.9912
0.7	8.0	100.6	3/18/2003	3/19/2003	0.9976
0.7	8.0	102.2	3/18/2003	3/19/2003	0.9978
0.7	38.4	190	3/18/2003	3/24/2003	0.9914
0.7	47.7	210	3/18/2003	3/24/2003	0.9924
0.8	10.4	119	3/18/2003	3/19/2003	0.9980
0.8	10.6	119	3/18/2003	3/19/2003	0.9978
0.8	59.5	227	3/18/2003	3/24/2003	0.9912
0.8	71.1	232	3/18/2003	3/24/2003	0.9952
1	30.0	167	3/10/2003	3/10/2003	0.9962
1	30.5	166	3/10/2003	3/10/2003	0.9962
1	42.0	184	3/10/2003	3/10/2003	0.9960

Note Bingham Model fit applied to up curve from 50 to 1000 sec^{-1}.

Table 11 Rheology of 9 Molar Na LAW Melter Feed at 40 ° C with or without Xanthan Gum

Xanthan Gum	Yield Stress	Consistency			
weight %	Pascal	milliPascal-seconds	Prep Date	Measure-ment Date	Bingham fit r^2
0	2.3	43.4	2/5/2003	2/14/2003	0.9976
0	2.1	43.6	2/5/2003	2/14/2003	0.9982
0	0.8	20.8	3/18/2003	3/19/2003	0.9988
0	0.8	21.9	3/18/2003	3/19/2003	0.9988
0.1	2.0	29.4	3/10/2003	3/11/2003	0.9990
0.1	2.0	29.6	3/10/2003	3/11/2003	0.9992
0.2	0.8	39.8	3/10/2003	3/11/2003	0.9996
0.2	0.9	39.8	3/10/2003	3/11/2003	0.9998
0.5	-9.8	125	3/10/2003	3/11/2003	0.9882
0.5	-13.4	138	3/10/2003	3/11/2003	0.9813
0.6	2.9	86.5	3/18/2003	3/19/2003	0.9990
0.6	11.6	108.9	3/18/2003	3/19/2003	0.9988
0.7	-1.2	116	3/18/2003	3/19/2003	0.9932
0.7	0.9	133	3/18/2003	3/19/2003	0.9924
0.8	-2.9	157	3/18/2003	3/19/2003	0.9850
0.8	-3.3	191	3/18/2003	3/19/2003	0.9801

Note Bingham Model fit applied to up curve from 50 to 1000 sec^{-1}.

Table 12 Physical Properties of 9 Molar Na LAW Melter Feed with and without Xanthan Gum

Na Concentration	Xanthan Gum	Density at 25 ° C	pH	Total Solids	Insoluble Solids	Soluble Solids
Moles/Liter	weight %	g/mL		Weight %	Weight %	Weight %
9	0	1.813	NM	67.5	38.21	29.28
9	0	1.799	11.95	66.7	37.6	29.1
9	0.6	NM	NM	67.79	38.68	29.11
9	0.7	NM	NM	67.81	38.56	29.25
9	0.8	NM	NM	67.22	38.02	39.21

A review of the yield stress values versus the date prepared and the date collected seemed to indicate that the rheological properties of the melter feed were time dependent. The time dependence could potentially be worse than indicated since these tests were performed under static conditions (sample was allowed to sit undisturbed). Dynamic conditions such as continuous mixing could potentially accelerate the chemical reactions that are taking place. Additional measurements were also made of the LAW melter feeds without xanthan gum which had previously been measured. An example of an LAW melter feed which has changed as it ages is shown in Figure 9. The LAW melter feeds at 8 molar Na and less did not show significant change. The 11 molar Na LAW melter feed could not be removed from its container to measure the rheology after little more than one week of aging. The 11 molar Na LAW melter feed had hardened to a nearly rock-like state and could not be mixed.

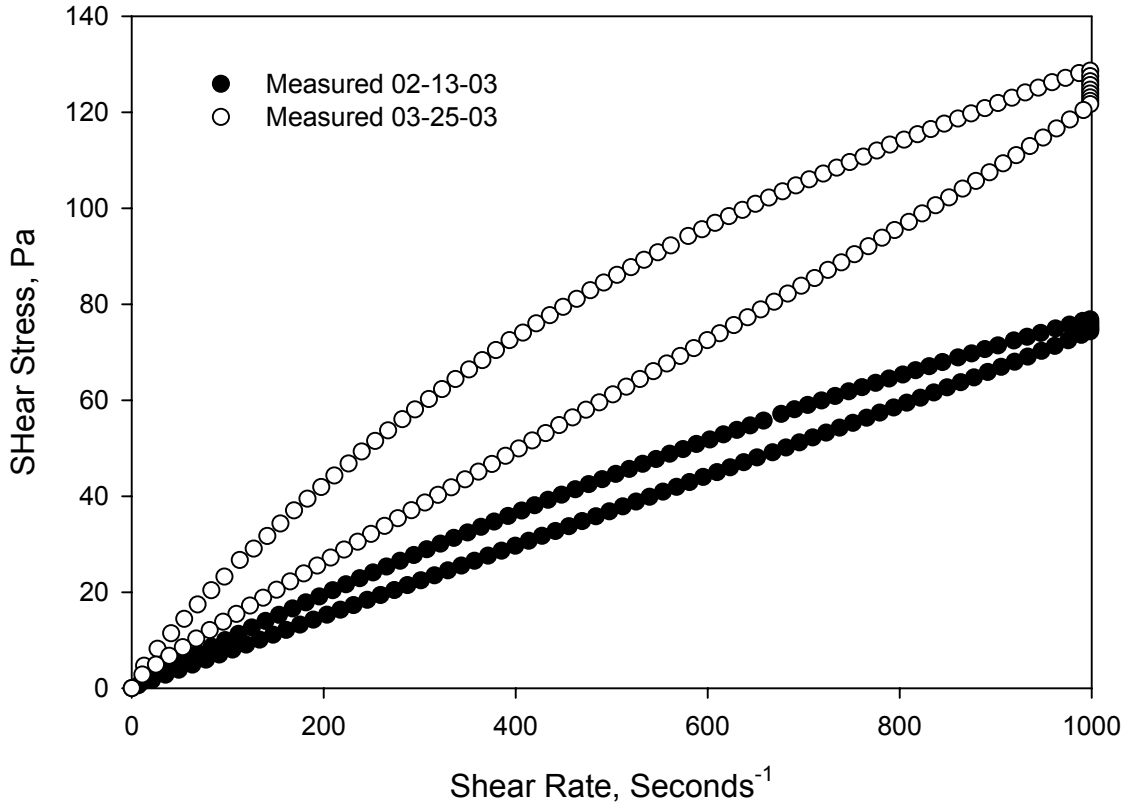

Figure 9 Time Effects in the 25 ° C Slurry Rheology of 10 Molar Na LAW Melter Feed Simulant

The rheology results for LAW melter feeds at 8 molar or less Na did not vary much while those above 8 molar were progressively more time dependent. Based upon the effect of time, the remaining tests of xanthan gum were made at 8 M Na. The rheology results of the 8 M Na tests are listed in Table 13 and Table 14 and the physical property measurements in Table 15.

Table 13 Rheology of 8 Molar Na Pretreated LAW Melter Feed Physical Simulant at 25 ° C with and without Xanthan Gum Rheology Modifier

Xanthan Gum	Yield Stress	Consistency or Viscosity				
weight %	Pascal	milliPascal-seconds	Prep Date	Measure-ment Date	Bingham fit r^2	Purpose of Experiment
0	1.3	27.7	4/1/2003	4/2/2003	0.9976	Gum Added after GFCs
0	1.7	28.0	4/1/2003	4/2/2003	0.9958	Gum Added after GFCs
0	2.0	27.7	4/1/2003	4/7/2003	0.9980	Gum added immediately before GFCs
0	2.1	27.6	4/1/2003	4/7/2003	0.9984	Gum added immediately before GFCs
0	2.1	20.9	6/25/2003	6/25/2003	0.9914	Substituted NO_3 for some OH
0	1.2	21.0	6/25/2003	6/25/2003	0.9976	Substituted NO_3 for some OH
0	47.2	181	7/8/2003	7/8/2003	0.9399	Added 50 % more GFCs, Curve suggests settling
0	43.8	173	7/8/2003	7/8/2003	0.9276	Added 50 % more GFCs, Curve suggests settling
0.1	2.5	40.6	5/13/2003	5/14/2003	0.9976	Heated at 40 ° C for 18 Hours
0.1	1.6	42.1	5/13/2003	5/14/2003	0.9988	Heated at 40 ° C for 18 Hours
0.2	4.4	56.9	5/13/2003	5/14/2003	0.9974	Heated at 40 ° C for 18 Hours
0.2	5.3	57.8	5/13/2003	5/14/2003	0.9966	Heated at 40 ° C for 18 Hours
0.3	11.5	91.6	5/13/2003	5/14/2003	0.9940	Heated at 40 ° C for 18 Hours
0.3	10.5	85.4	5/13/2003	5/14/2003	0.9938	Heated at 40 ° C for 18 Hours
0.3	3.1	46.9	5/20/2003	5/21/2003	0.9954	Heated at 40 ° C for 18 Hours, New Lot of Gum
0.3	0.3	43.7	5/20/2003	5/21/2003	1.0000	Heated at 40 ° C for 18 Hours, New Lot of Gum
0.3	1.6	46.0	5/20/2003	5/21/2003	0.9994	Heated at 40 ° C for 18 Hours, New Lot of Gum
0.3	0.3	41.1	5/20/2003	5/21/2003	1.0000	Heated at 40 ° C for 18 Hours, New Lot of Gum
0.3	8.9	84.8	5/29/2003	5/30/2003	0.9952	18 Hour Heat at 40 ° C + Lot#2799
0.3	9.3	82.4	5/29/2003	5/30/2003	0.9946	18 Hour Heat at 40 ° C + Lot#2799
0.3	0.7	42.4	5/29/2003	5/30/2003	0.9996	18 Hour Heat at 40 ° C + Aldrich
0.3	0.8	41.0	5/29/2003	5/30/2003	0.9998	18 Hour Heat at 40 ° C + Aldrich
0.3	162	318	6/19/2003	6/23/2003	0.9759	Substituted NO_3 for some OH, Gum Lot #2799
0.3	2.7	28.7	6/25/2003	6/26/2003	0.9974	Substituted NO_3 for some OH, Gum Lot #3485
0.3	1.8	34.2	6/25/2003	6/26/2003	0.9984	Substituted NO_3 for some OH, Gum Lot #3485

Xanthan Gum	Yield Stress	Consistency or Viscosity				
weight %	Pascal	milliPascal-seconds	Prep Date	Measure-ment Date	Bingham fit r^2	Purpose of Experiment
0.3	1.3	23.1	6/25/2003	6/26/2003	0.9986	Substituted NO_3 for some OH, Gum Lot #2799
0.3	0.7	24.1	6/25/2003	6/26/2003	0.9998	Substituted NO_3 for some OH, Gum Lot #2799
0.3	8.4	77.9	7/1/2003	7/7/2003	0.9958	Gum Lot #2799, mixed with GFCs
0.3	8.2	76.9	7/1/2003	7/7/2003	0.9958	Gum Lot #2799, mixed with GFCs
0.3	2.3	47.7	7/1/2003	7/7/2003	0.9982	Gum Lot #3485, Mixed with GFCs
0.3	2.2	46.4	7/1/2003	7/7/2003	0.9982	Gum Lot #3485, Mixed with GFCs
0.3	2.7	38.8	6/9/2003	6/11/2003	0.9974	Lot#2799 after GFCs, Heat at 40 ° C for 18 Hrs
0.3	6.9	49.0	7/9/2003	7/15/2003	0.9946	Boric Acid added before Gum, Lot #2799
0.3	6.5	49.0	7/9/2003	7/15/2003	0.9948	Boric Acid added before Gum, Lot #2799
0.3	2.9	42.9	7/9/2003	7/15/2003	0.9974	Boric Acid added before Gum, Lot #3485
0.3	2.7	43.2	7/9/2003	7/15/2003	0.9978	Boric Acid added before Gum, Lot #3485
0.3	2.8	41.0	6/9/2003	6/11/2003	0.9972	Lot#2799 after GFCs, Heat at 40 ° C for 18 Hrs
0.3	1.1	32.2	6/9/2003	6/11/2003	0.9988	Lot# 3485 after GFCs, Heat at 40 ° C for 18 Hrs
0.3	1.1	33.3	6/9/2003	6/11/2003	0.9990	Lot# 3485 after GFCs, Heat at 40 ° C for 18 Hrs
0.4	26.4	131	5/13/2003	5/14/2003	0.9896	Heated at 40 ° C for 18 Hours
0.4	24	126	5/13/2003	5/14/2003	0.9898	Heated at 40 ° C for 18 Hours
0.5	4.7	60.7	3/31/2003	4/2/2003	0.9964	Gum Added after GFCs
0.5	9.4	68.0	3/31/2003	4/8/2003	0.9984	Gum Added after GFCs
0.5	7.0	65.5	3/31/2003	4/8/2003	0.9972	Gum Added after GFCs
0.5	3.9	61.5	4/1/2003	4/2/2003	0.9988	Gum added immediately before GFCs
0.5	3.9	60.5	4/1/2003	4/2/2003	0.9988	Gum added immediately before GFCs
0.5	3.8	57.9	4/1/2003	4/2/2003	0.9990	Gum Added after GFCs
0.5	2.6	49.1	4/1/2003	4/7/2003	0.9990	Gum added immediately before GFCs
0.5	2.8	51.9	4/1/2003	4/7/2003	0.9990	Gum added immediately before GFCs
0.5	68.6	195	5/7/2003	5/9/2003	0.9746	Heated at 40 ° C for 18 Hours
0.5	67.9	196	5/7/2003	5/9/2003	0.9756	Heated at 40 ° C for 18 Hours
0.5	5.5	71.4	7/1/2003	7/7/2003	0.9970	Gum Lot #3485, Mixed with GFCs
0.5	5.8	74.6	7/1/2003	7/7/2003	0.9972	Gum Lot #3485, Mixed with GFCs

Xanthan Gum	Yield Stress	Consistency or Viscosity				
weight %	Pascal	milliPascal-seconds	Prep Date	Measure-ment Date	Bingham fit r^2	Purpose of Experiment
0.5	35.7	151	7/1/2003	7/7/2003	0.9894	Gum Lot #2799, Mixed with GFCs
0.5	34.7	149	7/1/2003	7/7/2003	0.9894	Gum Lot #2799, Mixed with GFCs
0.5	50.2	154	7/9/2003	7/15/2003	0.9825	Boric Acid added before Gum, Lot #2799
0.5	52.7	158	7/9/2003	7/15/2003	0.9816	Boric Acid added before Gum, Lot #2799
0.5	7.9	71.4	7/9/2003	7/15/2003	0.9952	Boric Acid added before Gum, Lot #3485
0.5	7.4	69.4	7/9/2003	7/15/2003	0.9954	Boric Acid added before Gum, Lot #3485
0.6	6.4	83.7	4/1/2003	4/2/2003	0.9990	Gum added immediately before GFCs
0.6	5.0	70.8	4/1/2003	4/2/2003	0.9986	Gum added immediately before GFCs
0.6	2.0	61.0	4/1/2003	4/2/2003	0.9998	Gum Added after GFCs
0.6	1.8	61.5	4/1/2003	4/2/2003	0.9998	Gum Added after GFCs
0.6	5.3	68.7	4/1/2003	4/7/2003	0.9984	Gum added immediately before GFCs
0.6	5.2	66.4	4/1/2003	4/7/2003	0.9982	Gum added immediately before GFCs
0.6	5.7	70.9	4/1/2003	4/8/2003	0.9992	Gum Added after GFCs
0.6	5.0	66.7	4/1/2003	4/8/2003	0.9994	Gum Added after GFCs
0.6	5.3	102.6	4/29/2003	4/30/2003	0.9994	Gum added to LAW day before GFCs
0.6	5.4	102.5	4/29/2003	4/30/2003	0.9994	Gum added to LAW day before GFCs
0.6	168.5	241	5/7/2003	5/9/2003	0.9740	Heated at 40 ° C for 18 Hours
0.6	170.4	239	5/7/2003	5/9/2003	0.9736	Heated at 40 ° C for 18 Hours
0.65	8.5	127	4/29/2003	4/30/2003	0.9994	Gum added to LAW day before GFCs
0.65	9.0	133	4/29/2003	4/30/2003	0.9996	Gum added to LAW day before GFCs
0.7	1.8	73.3	4/1/2003	4/2/2003	0.9998	Gum Added after GFCs
0.7	2.4	84.7	4/1/2003	4/2/2003	0.9992	Gum Added after GFCs
0.7	6.1	86.5	4/1/2003	4/2/2003	0.9992	Gum added immediately before GFCs
0.7	6.0	86.2	4/1/2003	4/2/2003	0.9990	Gum added immediately before GFCs
0.7	8.7	84.9	4/1/2003	4/7/2003	0.9976	Gum added immediately before GFCs
0.7	8.5	83.9	4/1/2003	4/7/2003	0.9976	Gum added immediately before GFCs
0.7	5.2	73.6	4/1/2003	4/8/2003	0.9994	Gum Added after GFCs
0.7	5.1	74.0	4/1/2003	4/8/2003	0.9990	Gum Added after GFCs

Xanthan Gum	Yield Stress	Consistency or Viscosity				
weight %	Pascal	milliPascal-seconds	Prep Date	Measure-ment Date	Bingham fit r^2	Purpose of Experiment
0.7	249	270	5/7/2003	5/9/2003	0.9681	Heated at 40 ° C for 18 Hours
0.7	232	299	5/7/2003	5/9/2003	0.9594	Heated at 40 ° C for 18 Hours
0.7	11.0	79.4	6/9/2003	6/11/2003	0.9940	Lot #2799 after GFCs, Heat at 40 ° C for 18 Hrs
0.7	11.2	84.6	6/9/2003	6/11/2003	0.9936	Lot #2799 after GFCs, Heat at 40 ° C for 18 Hrs
0.7	8.7	140	4/29/2003	4/30/2003	0.9996	Gum added to LAW day before GFCs
0.7	8.5	146	4/29/2003	4/30/2003	0.9998	Gum added to LAW day before GFCs
0.7	120	272	7/1/2003	7/7/2003	0.9720	Gum Lot #2799, Mixed with GFCs
0.7	120	275	7/1/2003	7/7/2003	0.9710	Gum Lot #2799, Mixed with GFCs
0.7	16.2	112	7/1/2003	7/7/2003	0.9942	Gum Lot #3485, Mixed with GFCs
0.7	16.2	114	7/1/2003	7/7/2003	0.9940	Gum Lot #3485, Mixed with GFCs
0.75	6.1	87.0	4/10/2003	4/11/2003	0.9992	Gum added immediately before GFCs
0.75	6.3	86.6	4/10/2003	4/11/2003	0.9990	Gum added immediately before GFCs
0.75	12.7	101.8	4/10/2003	4/11/2003	0.9984	Gum added immediately before GFCs
0.75	11.1	107.3	4/10/2003	4/11/2003	0.9986	Gum added immediately before GFCs
0.75	2.2	103.2	4/10/2003	4/11/2003	0.9998	Gum added immediately before GFCs
0.75	2.4	101.6	4/10/2003	4/11/2003	0.9998	Gum added immediately before GFCs
0.8	22.0	143	4/1/2003	4/2/2003	0.9984	Gum added immediately before GFCs
0.8	23.2	151	4/1/2003	4/2/2003	0.9986	Gum added immediately before GFCs
0.8	3.2	76.6	4/1/2003	4/2/2003	0.9998	Gum Added after GFCs
0.8	3.5	81.9	4/1/2003	4/2/2003	0.9998	Gum Added after GFCs
0.8	33.0	138	4/1/2003	4/8/2003	0.9968	Gum added immediately before GFCs
0.8	34.0	142	4/1/2003	4/8/2003	0.9972	Gum added immediately before GFCs
0.8	4.3	56.8	4/1/2003	4/8/2003	0.9986	Gum Added after GFCs
0.8	5.1	61.4	4/1/2003	4/8/2003	0.9980	Gum Added after GFCs
1	27.8	212	4/1/2003	4/2/2003	0.9990	Gum added immediately before GFCs
1	25.4	206	4/1/2003	4/2/2003	0.9990	Gum added immediately before GFCs
1	8.8	120	4/1/2003	4/3/2003	0.9992	Gum Added after GFCs
1	7.9	120	4/1/2003	4/3/2003	0.9994	Gum Added after GFCs

Xanthan Gum	Yield Stress	Consistency or Viscosity				
weight %	**Pascal**	**milliPascal-seconds**	**Prep Date**	**Measure-ment Date**	**Bingham fit r^2**	**Purpose of Experiment**
1	37.1	194	4/1/2003	4/8/2003	0.9980	Gum added immediately before GFCs
1	39.5	201	4/1/2003	4/8/2003	0.9982	Gum added immediately before GFCs
1	10.0	105	4/1/2003	4/8/2003	0.9986	Gum Added after GFCs
1	10.3	108	4/1/2003	4/8/2003	0.9984	Gum Added after GFCs

Table 14 Selected Rheology of 8 Molar Na Pretreated LAW Melter Feed Physical Simulant at 40 ° C with and without Xanthan Gum Rheology Modifier

Xanthan Gum	Yield Stress	Consistency or Viscosity				
weight %	Pascal	milliPascal-seconds	Prep Date	Measurement Date	Bingham fit r^2	Purpose of Experiment
0	0.7	15.0	4/1/2003	4/3/2003	0.9996	
0	0.7	15.2	4/1/2003	4/3/2003	0.9998	
0	0.8	11.7	6/25/2003	6/25/2003	0.9970	Substituted NO_3 for some OH
0	0.8	10.0	6/25/2003	6/25/2003	0.9950	Substituted NO_3 for some OH
0.1	1.0	22.8	5/13/2003	5/14/2003	0.9992	Heated at 40 ° C for 18 Hours
0.1	1.0	23.0	5/13/2003	5/14/2003	0.9992	Heated at 40 ° C for 18 Hours
0.2	1.5	37.9	5/13/2003	5/14/2003	0.9998	Heated at 40 ° C for 18 Hours
0.2	1.6	38.0	5/13/2003	5/14/2003	0.9996	Heated at 40 ° C for 18 Hours
0.3	4.0	65.2	5/13/2003	5/14/2003	0.9992	Heated at 40 ° C for 18 Hours
0.3	4.2	67.1	5/13/2003	5/14/2003	0.9992	Heated at 40 ° C for 18 Hours
0.3	4.3	25.3	6/25/2003	6/26/2003	0.9914	Substituted NO_3 for some OH, Gum Lot #3485
0.3	3.4	24.8	6/25/2003	6/26/2003	0.9942	Substituted NO_3 for some OH, Gum Lot #3485
0.3	2.7	19.2	6/25/2003	6/26/2003	0.9756	Substituted NO_3 for some OH, Gum Lot #2799
0.3	0.4	25.3	6/25/2003	6/26/2003	0.9972	Substituted NO_3 for some OH, Gum Lot #2799
0.4	13.3	116	5/13/2003	5/14/2003	0.9954	Heated at 40 ° C for 18 Hours
0.4	11.6	110	5/13/2003	5/14/2003	0.9960	Heated at 40 ° C for 18 Hours
0.5	-0.5	49.4	4/1/2003	4/4/2003	0.9994	Gum added immediately before GFCs
0.5	53.6	167	5/7/2003	5/9/2003	0.9677	Heated at 40 ° C for 18 Hours
0.5	56.2	163	5/7/2003	5/9/2003	0.9628	Heated at 40 ° C for 18 Hours
0.6	-19.1	203	4/29/2003	4/30/2003	0.9914	Gum added to LAW day before GFCs
0.6	93.2	305	5/7/2003	5/9/2003	0.9841	Heated at 40 ° C for 18 Hours
0.6	128.6	214	5/7/2003	5/9/2003	0.9536	Heated at 40 ° C for 18 Hours
0.7	-14.7	131	4/1/2003	4/7/2003	0.9602	Gum Added after GFCs
0.7	-18.2	142	4/1/2003	4/7/2003	0.9532	Gum Added after GFCs

Xanthan Gum	Yield Stress	Consistency or Viscosity				
weight %	Pascal	milliPascal-seconds	Prep Date	Measurement Date	Bingham fit r^2	Purpose of Experiment
0.8	-11.7	108	4/1/2003	4/7/2003	0.9681	Gum Added after GFCs
0.8	-13.3	116	4/1/2003	4/7/2003	0.9635	Gum Added after GFCs
1	-94.0	487	4/1/2003	4/7/2003	0.8957	Gum Added after GFCs
1	-105	531	4/1/2003	4/7/2003	0.8951	Gum Added after GFCs

Note Bingham Model fit applied to up curve from 50 to 1000 sec^{-1}.

Table 15 Physical Properties of 8 Molar Na Pretreated LAW Melter Feeds with and without Xanthan Gum

Xanthan Gum	Density at 25 ° C	pH	Total Solids	Insoluble Solids	Soluble Solids	Purpose of Experiment
weight %	g/mL		Weight %	Weight %	Weight %	
0	1.753	11.83	64.30	36.80	27.50	Initial LAW Melter Feed
0	1.764	NM	65.10	37.64	27.46	Gum added immediately before GFCs
1	1.764	NM	64.55	36.50	28.05	Gum added immediately before GFCs
0.5	1.768	NM	64.62	36.78	27.84	Gum added immediately before GFCs
0.6	1.767	NM	64.75	36.99	27.76	Gum added immediately before GFCs
0.7	1.766	NM	64.77	36.96	27.81	Gum added immediately before GFCs
0.8	1.756	NM	64.81	37.06	27.75	Gum added immediately before GFCs
1	1.768	NM	64.25	36.06	28.19	Gum Added after GFCs
0.5	1.765	NM	64.55	36.63	27.92	Gum Added after GFCs
0.6	1.766	NM	64.57	36.49	28.08	Gum Added after GFCs
0.7	1.762	NM	64.47	36.65	27.82	Gum Added after GFCs
0.8	1.776	NM	64.38	36.35	28.03	Gum Added after GFCs
0.75	1.764	NM	64.99	37.11	27.88	Gum added immediately before GFCs
0.75	1.743	NM	64.52	36.44	28.08	Gum added immediately before GFCs
0.75	1.758	NM	64.90	36.88	28.02	Gum added immediately before GFCs
0.6	1.755	NM	64.74	36.23	28.51	Gum added to LAW day before GFCs
0.65	1.762	NM	64.98	36.55	28.43	Gum added to LAW day before GFCs
0.7	1.765	NM	65.25	36.95	28.30	Gum added to LAW day before GFCs
0.5	1.667	12.17	64.76	NM	NM	Heated at 40 ° C for 18 Hours
0.6	1.757	12.16	62.23	NM	NM	Heated at 40 ° C for 18 Hours
0.7	NM	12.17	65.10	NM	NM	Heated at 40 ° C for 18 Hours
0.1	1.761	11.9	64.59	36.34	28.25	Heated at 40 ° C for 18 Hours
0.2	1.761	11.99	64.49	35.56	28.93	Heated at 40 ° C for 18 Hours
0.3	1.762	12.03	64.55	35.99	28.56	Heated at 40 ° C for 18 Hours
0.4	1.762	12.06	64.30	NM	NM	Heated at 40 ° C for 18 Hours
0.3	1.742	11.96	64.41	36.65	27.76	Heated at 40 ° C for 18 Hours
0.3	1.758	12.02	64.28	36.02	28.26	Heated at 40 ° C for 18 Hours
0.3	1.744	NM	64.35	36.49	27.86	18 Hour Heat at 40 ° C + Aldrich
0.3	1.752	NM	63.37	34.30	29.07	18 Hour Heat at 40 ° C + Lot#2799
0.3	1.751	NM	64.14	36.19	27.95	18 Hour Heat at 40 ° C + Lot#3485

Xanthan Gum	Density at 25 ° C	pH	Total Solids	Insoluble Solids	Soluble Solids	Purpose of Experiment
weight %	g/mL		Weight %	Weight %	Weight %	
0.3	NM	9.84	64.35	40.84	23.51	Substituted CO_3 for OH
0.3	NM	9.85	65.21	43.05	22.16	Substituted CO_3 for OH
0.3	NM	9.81	65.53	43.21	22.32	Substituted CO_3 for OH
0	1.751	7.36	68.08	35.86	32.22	Substituted NO_3 for some OH
0.3	1.768	7.37	67.06	34.92	32.14	Substituted NO_3 for some OH
0.3	1.774	7.34	68.05	35.51	32.54	Substituted NO_3 for some OH
0.3	1.773	7.41	68.01	37.76	30.25	Substituted NO_3 for some OH
0.5	1.732	12.21	64.03	NM	NM	Gum added with dry GFCs
0.7	1.751	12.33	64.21	NM	NM	Gum added with dry GFCs
0.3	1.748	12.35	64.60	36.99	27.61	Gum added with dry GFCs
0.5	1.751	12.31	64.33	36.62	27.71	Gum added with dry GFCs
0.7	1.747	12.18	64.13	35.06	29.07	Gum added with dry GFCs
0.3	1.754	12.24	64.25	35.80	28.45	Gum added with dry GFCs
0.3	1.543	NM	64.95	37.45	27.50	Boric Acid added before Gum
0.5	1.686	NM	64.12	35.62	28.50	Boric Acid added before Gum
0.3	1.645	NM	64.70	37.19	27.51	Boric Acid added before Gum
0.5	1.68	NM	64.60	37.14	27.46	Boric Acid added before Gum
0	1.807	NM	69.18	48.58	20.60	Added 50 % more GFCs

The large number of test runs at 8 molar Na show inconsistent results which were identified to be due to several different variables. The first two variables identified were time and temperature dependence for the xanthan gum to produce a consistent result. The strange negative yield stress values reported for some of the early 9 and 8 molar Na runs at 40 ° C were due to the production of a flow curve which implied that the slurry was thickening as the shear rate increased. Figure 10 shows such a flow curve. The implication of the strange sample results when the sample is raised to 40 ° C to measure the rheology is that a reaction or structural modification of the xanthan gum occurs during the rheology measurement due to the elevated temperature. Further tests demonstrated that heating the LAW melter feed containing Xanthan gum to 40 ° C for 18 hours produced considerably higher yield stress and consistency values. After heating, the flow curves measured at 40 ° C returned to more normal shear thinning behavior. This delayed development of the ultimate rheological properties differs from the technical data supplied by xanthan gum manufacturers. The optimal heating time was not developed in this study since additional variation in rheological properties was still observed after establishing a consistent heating period. The additional variation in rheological properties implied that additional variables were yet to be identified.

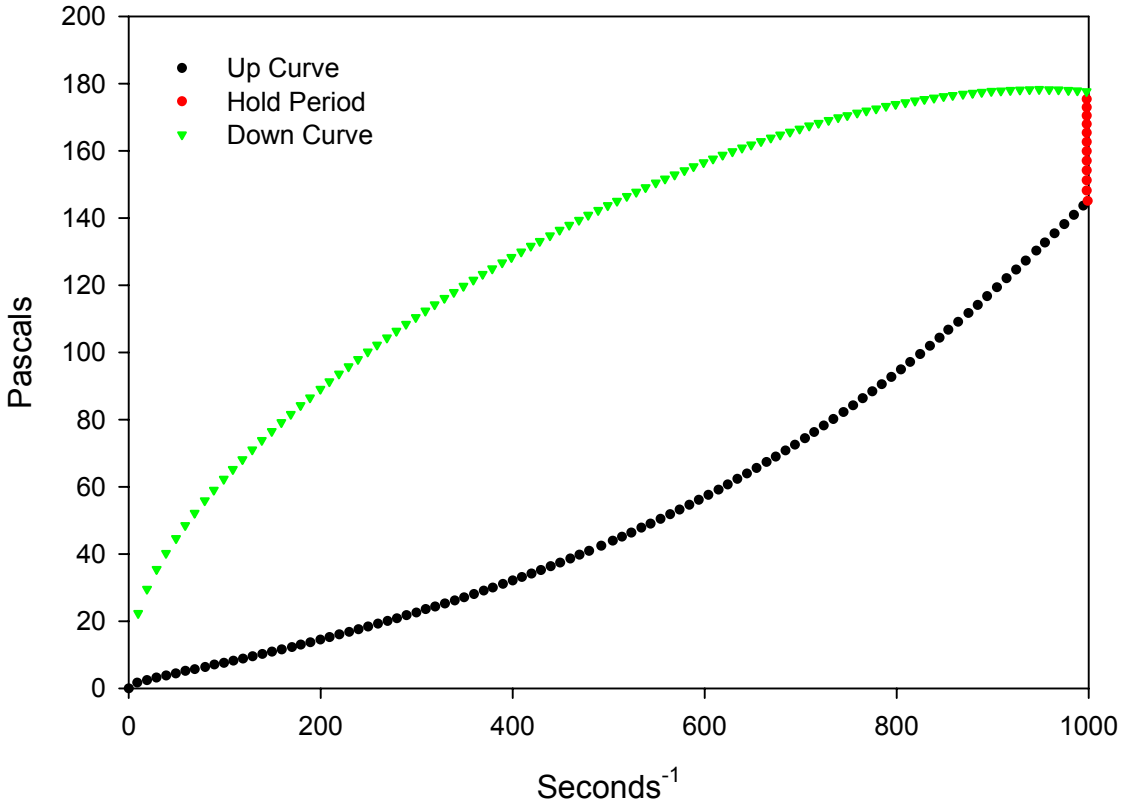

Figure 10 Flow Curve at 40 ° C for 8 Molar Na LAW Melter Feed with 0.7 Wt % Xanthan Gum

Another possible variable that produced inconsistent data on the rheological properties was xanthan gum from different vendors and also different lot numbers from a specific vendor. After testing the addition method and the effect of hydroxide on the melter feed, the problem was demonstrated to be due to the hydroxide (including aluminate) concentration, not vendor or lot variability. Several alternative methods were tested unsuccessfully to minimize the xanthan gum exposure to the hydroxide. Tests that added the gum directly to the pretreated LAW feed (maximum base concentration) never effectively thickened. However, lot to lot comparisons using a salt solution without hydroxide species showed that all of the xanthan gums were equivalent. Therefore, the decision was made to produce an upper bound melter feed physical simulant which only contained 8 molar $NaNO_3$.

The rheology results using the 8 molar $NaNO_3$ are listed in Table 16 and in Table 17 and the physical property results in Table 18. All of the test mixtures rapidly thickened upon addition of the xanthan gum. The slurry did not require heating as had previously been observed with the high hydroxide melter feeds. The 40 ° C rheology measurements were as expected without any unusual behavior in the flow curves.. The smooth variation in yield stress as a function of the xanthan gum concentration is shown in Figure 11. The upper bound yield stress limit of 12 Pascals appears to match the 0.15 wt % xanthan gum fairly well.

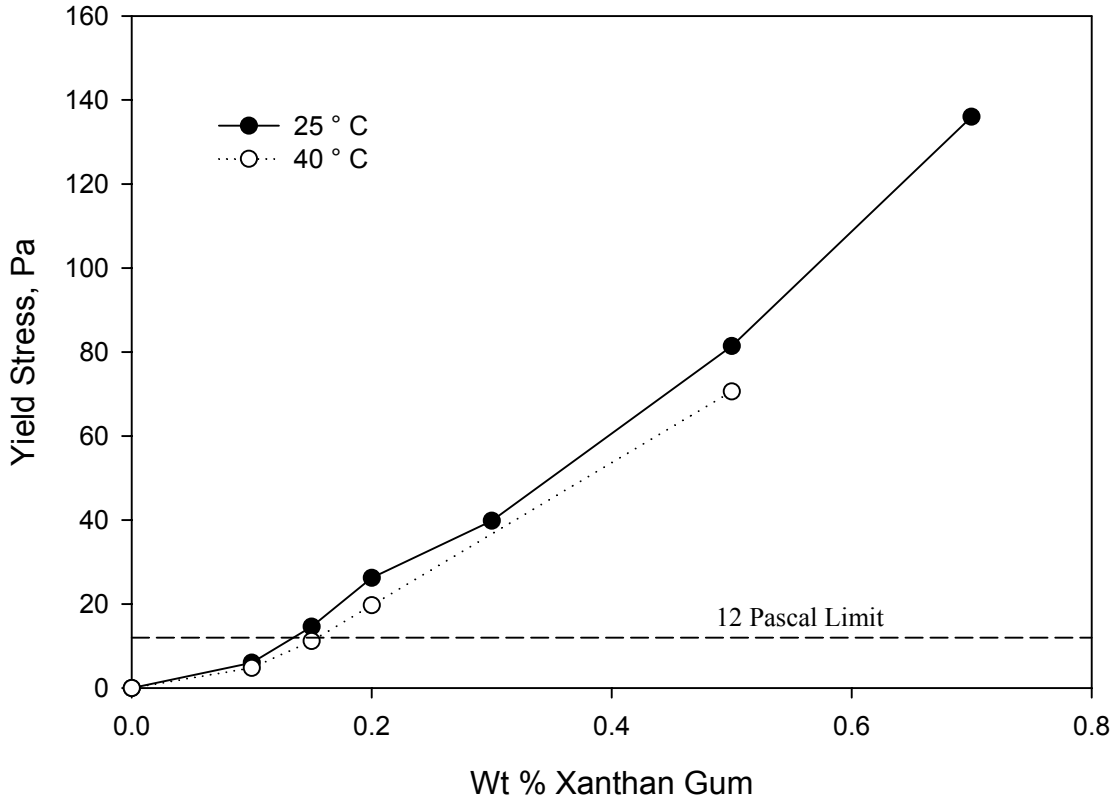

Figure 11 Yield Stress Variation in the 8 Molar $NaNO_3$ Melter Feed Physical Simulant

Table 16 Rheology at 25 ° C of the 8 Molar Sodium Nitrate LAW Physical Simulant

Xanthan Gum	Yield Stress	Consistency or Viscosity				
Weight %	Pascal	milliPascal-seconds	Prep Date	Measurement Date	Bingham fit r^2	Xanthan Gum Lot Number
0.1	6.1	46.6	7/15/2003	7/16/2003	0.9898	Lot #2799
0.1	6.0	45.9	7/15/2003	7/16/2003	0.9974	Lot #2799
0.15	14.7	58.1	7/15/2003	7/16/2003	0.9898	Lot #2799
0.15	14.4	55.7	7/15/2003	7/16/2003	0.9864	Lot #2799
0.2	25.9	68.3	7/15/2003	7/17/2003	0.9757	Lot #2799
0.2	26.6	70.2	7/15/2003	7/17/2003	0.9779	Lot #2799
0.3	39.6	88.7	7/9/2003	7/10/2003	0.9659	Lot #2799
0.3	40.0	88.2	7/9/2003	7/10/2003	0.9677	Lot #2799
0.5	83.7	120	7/9/2003	7/10/2003	0.9789	Lot #2799
0.5	84.6	122	7/9/2003	7/10/2003	0.9712	Lot #2799
0.5	82.5	124	7/9/2003	7/10/2003	0.9740	Lot #3485
0.5	74.9	134	7/9/2003	7/10/2003	0.9902	Lot #3485
0.7	137	138	7/9/2003	7/10/2003	0.9561	Lot #2799
0.7	135	137	7/9/2003	7/10/2003	0.9514	Lot #2799

Table 17 Rheology at 40 ° C of the 8 Molar Sodium Nitrate LAW Physical Simulant

Xanthan Gum	Yield Stress	Consistency or Viscosity				
Weight %	Pascal	milliPascal-seconds	Prep Date	Measurement Date	Bingham fit r^2	Xanthan Gum Lot Number
0.1	4.6	33.1	7/15/2003	7/17/2003	0.9974	Lot #2799
0.1	4.9	31.6	7/15/2003	7/17/2003	0.9964	Lot #2799
0.15	11.2	39.0	7/15/2003	7/17/2003	0.9862	Lot #2799
0.15	11.2	38.4	7/15/2003	7/17/2003	0.9862	Lot #2799
0.2	20	49.0	7/15/2003	7/17/2003	0.9785	Lot #2799
0.2	19.4	49.8	7/15/2003	7/17/2003	0.9797	Lot #2799
0.5	69.8	97.0	7/9/2003	7/10/2003	0.9807	Lot #2799
0.5	71.4	98.9	7/9/2003	7/10/2003	0.9769	Lot #2799

Table 18 Physical Properties of the 8 Molar Na Nitrate Melter Feed

Xanthan Gum	Density at 25 ° C	pH	Total Solids	Insoluble Solids	Soluble Solids	Xanthan Gum Lot Number
Weight %	g/mL		Weight %	Weight %	Weight %	
0	1.3916	5.78	46.93	0	46.93	LAW only, No GFCs, No Xanthan Gum
0	1.386	NM	NM	NM	NM	LAW only, No GFCs, No Xanthan Gum
0.1	1.713	4.24	67.55	36.92	30.63	Lot #2799
0.15	1.713	4.4	67.43	NM	NM	Lot #2799
0.2	1.708	4.38	67.89	NM	NM	Lot #2799
0.3	1.707	4.9	67.93	NM	NM	Lot #2799
0.5	1.692	6.07	68.30	NM	NM	Lot #2799
0.5	1.661	4.45	68.20	NM	NM	Lot #3485
0.7	1.706	4.86	68.54	NM	NM	Lot #2799

The yield stress of the high bounding LAW Melter Feed physical simulant based upon a Bingham Plastic model fit of the up flow curve from 50 to 1000 sec^{-1} is 14.6 Pascals at 25 ° C (122 % of the upper bound yield stress of 12 Pascals). At 40 ° C, the yield stress is 11 Pascals (92% of the upper bound yield stress). The consistency of the up flow curve from 50 to 1000 sec^{-1} is 57 mPa·s at 25 ° C (62 % of the upper bound consistency of 92 mPa·s). At 40 ° C, the consistency is 39 mPa·s, showing the effect due to an increase in temperature. The rheogram of the high bounding LAW Melter Feed physical simulant indicates that the material is a non-Newtonian slurry with pseudoplastic properties. Figure 12 compares the flow curve for the high bounding LAW Melter Feed physical simulant to the upper bound rheology conditions for the melter feed preparation vessel (MFPV).

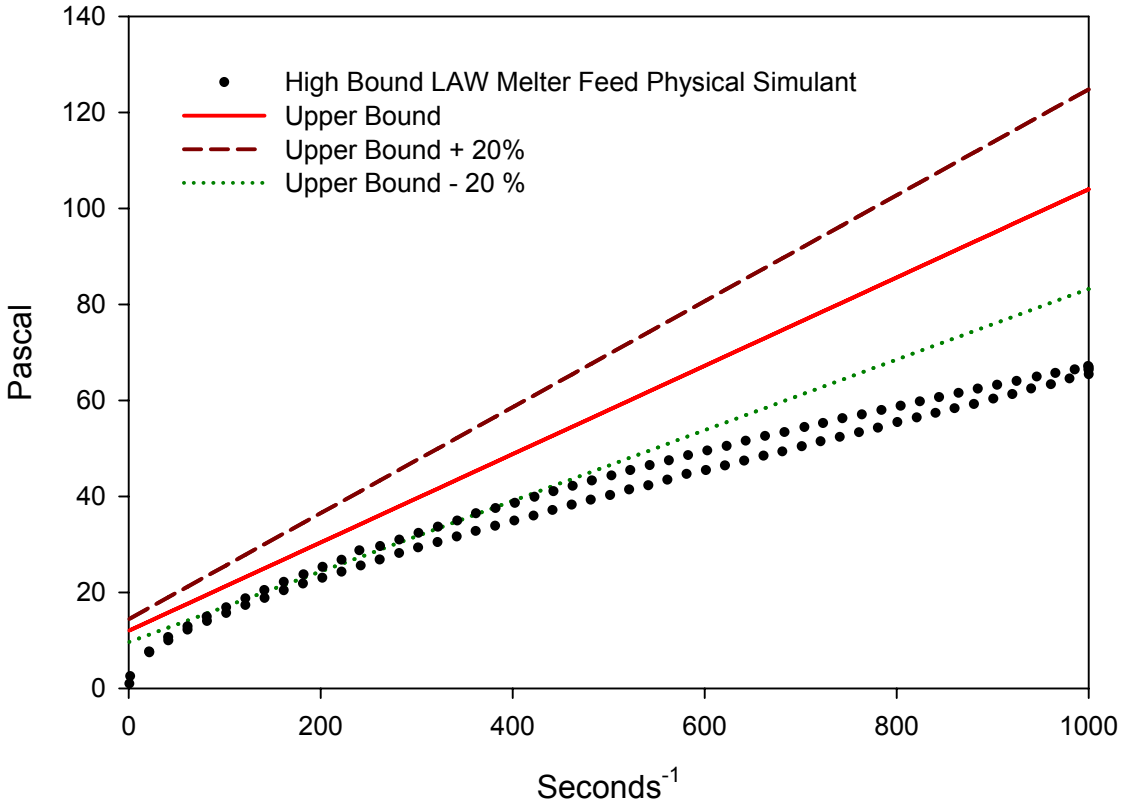

Figure 12 High Bound LAW Melter Feed Physical Simulant Compared to the Required Rheology Limits

The recipe for the high bound LAW melter feed physical simulant is in Appendix C. Due to the time dependence seen in many of the LAW melter feed tests, with and without xanthan gum, the high bound LAW melter feed physical simulant should be prepared and used within a week. Any delay beyond this period could produce rheological properties that exceed the upper bound conditions.

Another rheology limit of concern for application of the LAW physical simulants is the settled shear strength. The settled shear strength has the same technical description as yield stress except it applies to settled material. For the LAW CRV and MFPV, the maximum expected down time for the vessel agitation is expected to be 168 hours.[1] Therefore, a simulant that has settled for up to 168 hours must not have a yield stress that exceeds 625 Pa.[1] The settled shear strengths were measured for the LAW melter feed simulants only. Table 19 shows that the settled shear strength after 168 hours did not exceed the maximum allowed. The value at 48 hours for the high bound LAW melter feed is probably in error. There was evidence that the container was not well sealed and that drying had occurred in the upper layer of material. Note that the high bound LAW melter feed does not settle measurably in the 168 hour period of this test hence the relatively small settled shear strength. The much higher settled shear strength for the low bound melter feed could be an indication of chemical reactions between the GFCs and the supernate after settling. However, the value is still less than the maximum limit.

Table 19 Settled Shear Strengths of LAW Melter Feeds

Hours	Low Bound 3 Molar LAW Melter Feed	High Bound 8 Molar LAW Melter Feed
	τ_{vane} (Pa)	τ_{vane} (Pa)
0	0.2	4.0
48	5.8	1046
168	225	32

The particle size distributions for the low bound LAW melter feed simulant and for the high bound LAW melter feed simulant were measured on a Microtrac X100 particle size analyzer. Table 20 lists the data on these two simulants.

Table 20 Particle Size Data for LAW Melter Feed Simulants

Simulant	Low Bound LAW Melter Feed	High Bound LAW Melter Feed
Percentiles$_{vol}$	**Particle Size, micrometers**	**Particle Size, micrometers**
10	2.147	3.021
20	4.734	8.825
25	5.916	12.69
40	10.8	27.22
50	16.62	35.54
60	23.53	42.93
70	31.75	50.6
75	36.67	54.99
90	60.43	76.36
95	80.67	95.38
Mean$_{vol}$	26.09	39.4
Mean$_{num}$	0.444	0.764
Mean$_{area}$	4.858	7.909

Since the solid particles in both these simulants come from the GFCs added to the simulant, it would be expected that the particle size distribution would be similar. However, the low bound LAW melter feed simulant shows a bimodal particle distribution and may be reflecting the enhanced dissolution of the GFCs by the hydroxide in the simulant. The high bound LAW melter feed does not have any hydroxide and would not be capable of dissolution due to hydroxide reactions.

The settling rates of the solids interface of the low bound LAW melter feed and high bound pretreated LAW feed were also measured. Table 21 displays the normalized settling rates of the solids interface obtained for the low and high bounding simulants. The average volume % column in these tables is volume % of the solids layer relative to the total sample volume. The standard deviation (Std. Dev.) column lists the one standard deviation value for the average of three measurements.

Table 21 Settling Rate Data for LAW Physical Simulants

Low Bound LAW Melter Feed			High Bound Pretreated LAW Feed		
Minutes	**Average Vol. %**	**Std Dev**	**Minutes**	**Average Vol. %**	**Std Dev**
0	100.0	0.0	0	100.0	0.0
5	92.6	1.2	5	99.2	0.0
10	87.4	1.6	10	99.2	0.0
15	81.3	2.9	15	99.2	0.0
21	76.7	2.9	20	99.2	0.0
31	66.2	5.5	30	99.2	0.0
42	55.9	6.4	41	98.7	0.4
54	47.9	6.0	55	98.5	0.0
62	45.1	5.7	61	93.6	0.4
133	35.6	4.2	120	90.5	0.4
183	34.9	4.2	180	86.2	0.8
243	32.6	3.9	240	82.6	1.9
302	31.3	3.9	300	79.0	3.1
361	30.8	3.8	360	75.9	3.1
2987	30.8	3.8	2860	47.2	1.2
4532	30.8	3.8	4570	41.0	1.9

Figure 13 shows that the low bound LAW melter feed settles very quickly as expected based upon its rheological properties. The settling rate of the high bound pretreated LAW feed is initially slower due to the high viscosity of the supernate. The high bound LAW melter feed does not settle within the time period of this test. The error bars represent one standard deviation in the value of that measurement.

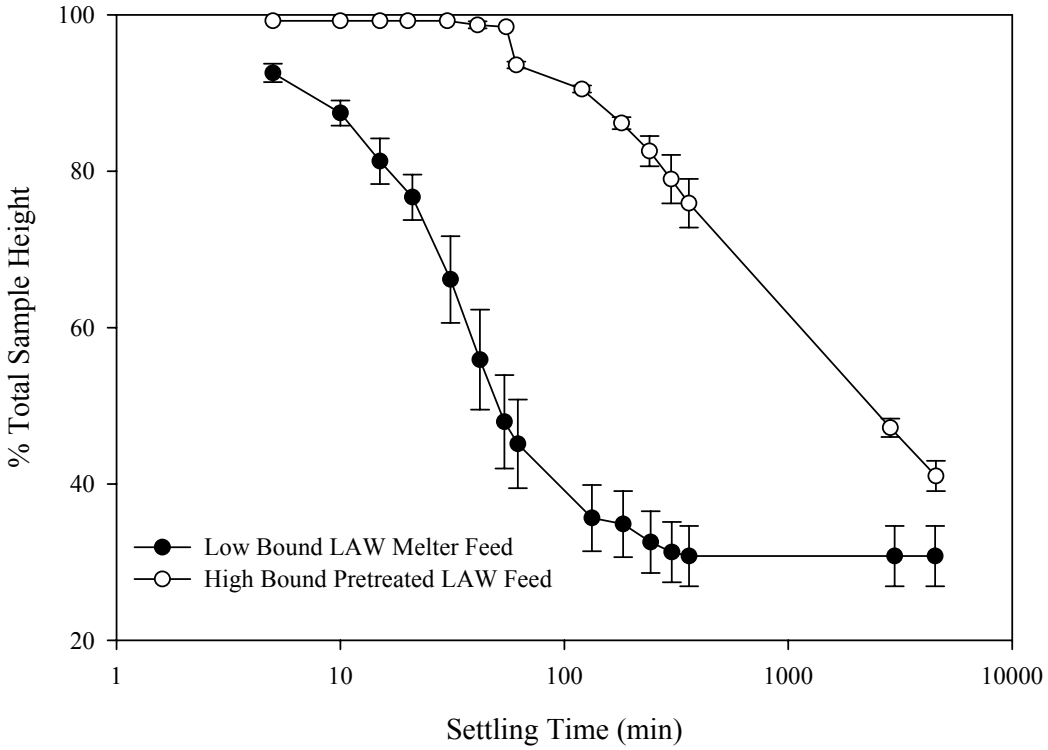

Figure 13 Settling Rates of LAW Physical Simulants

During preparation of the LAW melter feed simulants by addition of GFCs to pretreated LAW simulants, it was observed that the temperature of the melter feed slurries increased. This temperature rise was presumably due to the reaction of one of the GFCs (boric acid) with the hydroxide in the LAW simulant. At the request of the RPP-WTP R&T, the temperature of the LAW melter feed simulant was monitored as the GFCs were incorporated. These melter feeds were prepared in an insulated bucket with provision for agitation, a addition port for GFCs and a resistance thermometer detector (RTD) measuring device for monitoring the temperature. One liter of pretreated LAW feed simulant was placed in the bucket, agitation started, and the temperature recorded for approximately 20 minutes (data taken every five minutes). The GFCs were then added over a 15 to 20 minute period while the temperature measurements were continued. After that GFC addition was complete, the temperature measurements were continued for approximately another 20 minutes. Three LAW feed simulants were tested by this process. The low bound pretreated LAW melter feed physical simulant (3 molar Na AP-101 basis) was measured to produce a 6 ° C temperature rise when the GFCs were added over a 20 minute period. The high bound LAW melter feed physical simulant was also prepared by this procedure and only a decline in temperature (2 ° C) was measured. This simulant does not have any hydroxide to react with the GFCs so that the only thing observed was the heat of solution for the soluble GFCs. An additional test was run with 8 molar Na LAW feed to get the maximum temperature rise possible assuming that LAW feeds above this hydroxide level are unlikely. The maximum temperature rise observed was 14 ° C for a 20 minute addition period for the 8 molar Na LAW feed.

3.2 DEVELOPING THE HLW PHYSICAL SIMULANTS

The lower rheological limits for pretreated HLW CRV feed and for HLW melter feed require that these slurries have no yield stress and that the consistency is only 0.4 mPa·s. Therefore, a physical simulant chosen to match this lower bound must be a Newtonian fluid with a viscosity of 0.4 mPa·s. However, the viscosity of water at 25 ° C is 0.89 mPa·s and at 40 ° C is 0.653 mPa·s.[10] It will not be possible to make an aqueous simulant which has a viscosity lower than water. Accordingly, the lower bound for the purposes of this study is taken to be based on a Newtonian slurry with a viscosity of 2 mPa·s at 25 ° C. In order to minimize the number of simulants, the physical lower bound simulant will be chosen based on its fluid properties and on its properties after adding the GFCs.

The upper rheology limit for pretreated HLW CRV feed requires a fluid which is non-Newtonian, has a yield stress of 20 Pa and a consistency of 41 mPa·s.[3] After the addition of GFCs to the HLW CRV feed, the resulting HLW melter feed rheology limit increases to a yield stress of 30 Pa and a consistency of 41 mPa·s.[3] Again the ideal HLW physical simulant should meet both requirements.

The composition of HLW that the physical simulant should represent was based on the radioactive Hanford tank 241-AZ-101 sample analyzed by Battelle. Table 22 lists the composition of the washed and leached Envelope D solids from tank AZ-101. This was combined with the desired low bound weight % solids goal of 15 wt % solids and an estimated sludge density of 1.13 g/mL to produce a sludge composition in mg/Liter.

Table 22 Composition of Washed, Leached AZ-101 Envelope D Solids

Species	µg/g dry waste	Species	µg/g dry waste	Species	µg/g dry waste
Ag	902	La	5808	Sn	3600
Al	99872.5	Li	115	Sr	3412
B	91	Mg	1540	Ti	178
Ba	1510	Mn	5364	U	18500
Be	26	Mo	66.5	Y	385
Bi	150	Na	54545	Zn	278
Ca	7505	Nd	4290	Zr	65050
Cd	14500	Ni	9992	F	390
Ce	5240	P	4505	Br	<170
Co	128	Pb	1728	NO_2	7268
Cr	2284	Pd	2300	NO_3	2178
Cu	584	Rh	512	PO_4	<340
Fe	202384	Ru	1600	SO_4	2410
K	2000	Si	13055	C_2O_4	518

The physical HLW simulants were based upon using only the four major species that were easily obtained in nonhazardous, insoluble forms: Fe, Al, Si and Zr, to represent the complete sludge. The relative amount of each of the four major species was maintained constant while the total amount was varied to represent the total amount of insoluble solids in the sludge. The supernate portion was based on the soluble species in Table 22 with the addition of 2.66 grams/Liter of hydroxide anion (0.156 molar) and sufficient carbonate anion to charge balance the supernate (0.063moles/liter).[7] The charge balance calculation is shown in Table 23.

Table 23 Charge Balance Calculation for HLW Supernate

Cations				Anions			
Species	**Charge**	**Moles/Liter**	**Charge, moles/Liter**	**Species**	**Charge**	**Moles/Liter**	**Charge, moles/Liter**
Sodium	1	4.02E-01	4.02E-01	Boron	-3	1.43E-03	4.28E-03
Potassium	1	8.67E-03	8.67E-03	Carbonate	-2	6.31E-02	1.26E-02
Total Plus Charge			0.41067	Chloride	-1	3.36E-03	3.36E-03
				Fluoride	-1	3.48E-03	3.48E-03
				Hydroxide	-1	1.56E-01	1.56E-01
				Nitrate	-1	5.95E-03	5.95E-03
				Nitrite	-1	2.68E-02	2.68E-02
				Oxalate	-2	9.98E-04	2.0E-03
				Phosphate	-3	2.47E-02	7.4E-02
				Sulfate	-2	4.25E-03	9.5E-03
				Total Minus Charge			-0.4116

The initial goal was to base the low bounding HLW physical simulant on a 15 wt % total solids feed and the high bounding HLW physical simulant on a 25 wt % or higher total solids feed. The supernate in both simulants would be the same (i.e. the high is produced from the lower by concentrating through a filter). The HLW supernate simulant composition used is shown in Table 24. The density of the HLW supernate at 25 ° C is 1.019 g/mL.

Table 24 Composition of HLW Physical Simulant Supernate

Compound	Formula	Grams/Liter
Boric acid	H_3BO_3	0.09
Sodium Chloride	NaCl	0.2
Sodium Fluoride	NaF	0.15
Sodium Sulfate	Na_2SO_4	0.6
Sodium Hydroxide	NaOH	6.43
Sodium Phosphate	$Na_3PO_4 \bullet 12H_2O$	9.37
Sodium Oxalate	$Na_2C_2O_4$	0.13
Sodium Carbonate	Na_2CO_3	6.68
Sodium Nitrate	$NaNO_3$	0.51
Potassium Nitrite	KNO_2	0.74
Sodium Nitrite	$NaNO_2$	1.25
Water	H_2O	992.85

The four major species were added as one of the following compounds: Fe_2O_3 or FeOOH, $Al(OH)_3$, SiO_2, and ZrO_2 or $Zr(OH)_4$. These compounds were obtained as industrial grade compounds of known particle size ranges and densities. Table 25 lists the Fe compounds, Table 26 lists the Al compounds and Table 27 lists the Zr compounds tested for the HLW physical simulant. The silicon was added as SiO_2 obtained from Alfa Aesar® as Silicon (IV) Oxide, 99.5% Catalog #13024. The properties of the SiO_2 include -400 mesh solids, 2 micron average particle size, and 2 m^2/g surface area.

Table 25 Materials Tested for Fe_2O_3 in HLW Physical Simulants

Material Name	Material Supplier	Oxide Formula	Purity wt%	Particle Size Dist.	Range microns	Chemical Composition Fe2O3	Al2O3	SiO2	MgO	CaO	P	Mn
Prince 5001	Prince Mfg. Co. Quincey, IL	Fe_2O_3	97.0	99%-325M (-44 micron) (-150 micron)	-100	97.00	1.50	1.35	0.10	0.04	0.12	0.09
Prince 5052	Prince Mfg. Co. Quincey, IL	Fe_2O_3	97.0	99.9%-325M (~2 micron)		97.00	0.85	0.46	0.02	0.01	0.05	0.09
Prince 07-3752	Prince Mfg. Co. Quincey, IL	Fe_2O_3	78.7	99.99%-325 M (~2 micron avg)	2	78.70	9.00	2.90	1.10	0.50	0.10	0.36
Prince 07-3728	Prince Mfg. Co. Quincey, IL	Fe_2O_3										
Bayferrox 130C Agglomerate	Bayer Chemical	Fe_2O_3	92.0	(100 Mesh) (-150 micron)		>92.0						
Bayferrox 130	Bayer Chemical	Fe_2O_3 spherical	96.0	Red Pigment (~0.17 micron)		>95.0						
Bayferrox 180M	Bayer Chemical	Fe_2O_3		Red Pigment								
Bayferrox 820 Yellow	Bayer Chemical	FeO(OH)	N.A.	Yellow Pigment 0.1-0.7 micron		FeOOH						

Table 26 Materials Tested for $Al(OH)_3$ in HLW Physical Simulants

Material Name	Material Supplier	Oxide Formula	Purity wt%	Particle Size Dist.	Range microns	Al2O3	Fe2O3	Na2O	SiO2
C-30	Alcoa	Al(OH)3	65.0	99%-100 M (-150 micron)	(-100m)	~65	0.01	0.12	0.01
FlameGard ATH	Alcoa	Al(OH)3	65.0	Coarse Powder (22 to 26 micron med)					
Hydral 716	Alcoa	Al(OH)3	65.0	1-5 micron		~65	0.01	0.24	0.01
C-231 Gran.Hy.	Alcoa	Al(OH)3	65.0	97%-325M 14 micron avg.	0.25-14	~65	0.01	0.17	0.00
S-11 Spacerite	Alcoa	Al(OH)3	65.0	(-1 micron) 0.25 micron avg					
S-23 Spacerite	Alcoa	Al(OH)3	65.0	(-400 mesh) 7.5 micron avg.					

Table 27 Materials Tested for Zr in HLW Physical Simulants

Material Name	Material Supplier	Oxide Formula	Purity wt%	Particle Size Dist.	Range microns
DK-1	Zirconia Sales	ZrO_2 (m)	99.5	0.9 micron avg.	0.9
Zr(OH)4 Fzo 922/01	Mag.Elec.Inc.	$Zr(OH)_4$			

The WTP will combine the HLW washed or washed/leached sludge with concentrated Cs ion exchange eluant. The Cs ion exchange eluant concentrate (Cs IX eluant concentrate) is strongly acidic (~5.8 molar nitric acid) and is added in sufficient quantities to change the pH and rheology of the sludge simulant. The basis for the composition of the Cs IX eluant concentrate is the estimated eluant that formed part of the basis for the glass composition planned for the actual AZ-101 sludge sample. The estimated eluant was based on a blend of AP-101 and AZ-101 eluants. This eluant composition was provided to an OLI Cs Eluant Evaporator model to calculate the composition of the Cs IX eluant concentrate. Appendix G documents the results of the OLI model. The Cs eluant composition provided to the model is shown in Table 28 compared to the actual radioactive AP-101 Cs eluant. The eluant composition used provides a good bounding composition.

Table 28 Cesium Ion Exchange Eluant Composition

Species	Cs Eluant Basis mg/L	AP-101 Cs Eluant[5] mg/L
Al	20	12
Ba	3	0.3
B	90	49
Cd	5	1.8
Ca	79	32
Cs	37	37
Cl	170	<63
Cr	54	14
Cu	5	2.8
Fe	16	5.9
Pb	10	6.1
Ni	3	1.9
NO_3	29250	29250
K	183	110
Si	167	100
Na	2164	844
SO_4	283	<125
C_2O_4	160	<125
H	423*	455*

* Hydrogen ion calculated based upon charge balance

The resulting Cs IX eluant concentrate simulant was prepared based on the output from the OLI evaporator model. The Cs IX eluant concentrate is characterized by a high nitric acid concentration, 4.88 moles/Liter, and a density of 1.31 g/mL at 25 ° C. A simplified version of the simulant was produced that did not include the hazardous metal: Cd, Cr, Ni and Pb. The composition of the simplified Cs IX eluant Concentrate is shown in Table 29.

Table 29 Simplified Cs IX Eluant Concentrate

Compound	Formula	Grams/Liter
Aluminum Nitrate	$Al(NO_3)_3 \bullet 9H_2O$	8.19
Sodium Borate	$Na_2B_4O_7 \bullet 10H_2O$	23.39
Calcium Nitrate	$Ca(NO_3)_2 \bullet 4H_2O$	13.72
Cesium Nitrate	$CsNO_3$	1.60
Copper Nitrate	$Cu(NO_3)_2 \bullet 2.5H_2O$	0.54
Ferric Nitrate	$Fe(NO_3)_3 \bullet 9H_2O$	3.41
Potassium Nitrate	KNO_3	13.943
Sodium Chloride	NaCl	2.77
Sodium Sulfate	Na_2SO_4	12.33
Oxalic Acid	$HO_2CCO_2H \bullet 2H_2O$	9.65
Nitric Acid	HNO_3, 70 wt %	434.49
Sodium meta-silicate	$Na_2SiO3 \bullet 9\ H_2O$	0.52
Sodium Nitrate	$NaNO_3$	206.21
Water	H_2O	579.25

The amount of Cs IX eluant concentrate to add to produce the pretreated HLW sludge is 6 grams of Cs IX eluant concentrate solids per 94 grams of dried, washed, leached HLW solids as specified by the test specification.[1]

The GFCs to be used in producing the AZ-101 HLW glass are listed in Table 30.

Table 30 Glass Former Chemicals and Minerals for HLW Melter Feeds[13]

Oxide Added	Mineral	Grade	Company	Bulk Density (pcf) Particle Density (g/cc^3)	Screen Analysis (mesh) Particle Size (μm)
Na2O/B2O3	10M Borax Na2B4O7-10H2O	Technical 10Mole Borax	U.S. Borax Valencia, CA 91355-1847 www.borax.com	1.71	2380
Na2O	Na2CO3 Anhydrous	Dense Soda Ash	Solvay Minerals Houston TX www.solvayminerals.com	63 2.54	<100M 149
Li2O	Li2CO3	Technical Grade	Chemettal-Foote Kings Mt NC www.chemetalllithium.com	50 2.11	<200M 74
SiO2	SiO2	SCS-75 Mill Creek OK	U.S. Silica Berkeley Springs WV www.u-s-silica.com	59.3 2.65	<200M 74
ZnO	ZnO	Kadox 920 Camden, NJ	Zinc Corp Amer. Monaca,PA horseheadinc.com	41.2 5.6	1 micron 1

The amount of each GFC required is based on the amount of waste oxides in the HLW. The amount of each GFC and of HLW oxides to produce 100 grams of HLW glass is listed in Table 31.[1]

Table 31 Amount of GFCs and HLW Waste Oxides for 100 Grams HLW Glass[1]

Material	**Formula or Source**	**Grams/100 grams glass**
Borax	$Na_2B_4O_7.10H_2O$	29.049
Lithium Carbonate	Li_2CO_3	9.512
Sodium Carbonate	Na_2CO_3	6.609
Silica	SiO_2	43.939
Zinc Oxide	ZnO	2.02
HLW Oxides	Pretreated HLW Feed	31.75

The initial work on the HLW physical simulant focused on establishing a basis for the low bounding simulant based on a total solids loading of 15 wt%. The initial tests examined the rheology of a starting sludge composition as a function of the oxides available for Fe, Al and Zr. Table 32 describes the composition of the first 20 test mixtures which were aimed primarily at the low bound rheology limits. Table 33 lists the test mixtures which were aimed at producing a high bounding HLW physical simulant and associated melter feed. The rheology results for both sets of tests are listed in Table 34 and Table 35. The physical properties measured for these test mixtures are listed in Table 36 and in Table 37.

Table 32 Composition of Low Bounding HLW Test Mixtures

Test	Component 1	Grams	Component 2	Grams	Component 3	Grams	Component 4	Grams	Component 5	Grams	Component 6	Grams	Component 7	Grams	Component 8	Grams
1-L	Fe_2O_3, Prince 3752	48.52	$Al(OH)_3$, Alcoa S-11	63.28	SiO2, Alfa Aesar	4.68	ZrO_2, DK-1	14.74	HLW Supernate Simulant	999.0						
2-L	Fe_2O_3, Prince 3728	48.52	$Al(OH)_3$, Alcoa S-23	63.28	SiO2, Alfa Aesar	4.68	$Zr(OH)_4$, MEI	14.74	HLW Supernate Simulant	999.0						
3-L	Fe_2O_3, Prince 3752	38.816	Fe_2O_3, Prince 5001	9.704	$Al(OH)_3$, Alcoa S-11	50.628	$Al(OH)_3$, Alcoa C231	12.654	SiO2, Alfa Aesar	4.68	$Zr(OH)_4$, MEI	14.74	HLW Supernate Simulant	999.0		
4-L	Fe_2O_3, Bayferrox 130	38.816	Fe_2O_3, Bayferrox 130C	9.704	$Al(OH)_3$, Hydral 716	50.624	$Al(OH)_3$, Alcoa C30	4.68	SiO2, Alfa Aesar	4.68	$Zr(OH)_4$, MEI	14.74	HLW Supernate Simulant	999.0		
5-L	Fe_2O_3, Prince 5001	29.112	Fe_2O_3, Prince 3752	19.408	$Al(OH)_3$, Alcoa C231	31.64	$Al(OH)_3$, Alcoa S-23	18.98	$Al(OH)_3$, Alcoa S-11	12.66	SiO2, Alfa Aesar	4.68	$Zr(OH)_4$, MEI	14.74	HLW Supernate Simulant	999.0
6-L	Fe_2O_3, Prince 3752	48.6	$Al(OH)_3$, Alcoa S-11	63.2	SiO2, Alfa Aesar	4.6	$Zr(OH)_4$, MEI	14.8	HLW Supernate Simulant	999.0						
7-L	Fe_2O_3, Bayferrox 820	48.6	$Al(OH)_3$, Alcoa S-11	63.2	SiO2, Alfa Aesar	4.6	$Zr(OH)_4$, MEI	14.8	HLW Supernate Simulant	999.2						
8-L	Fe_2O_3, Prince 3752	48.6	$Al(OH)_3$, Alcoa S-11	63.2	SiO2, Alfa Aesar	4.6	$Zr(OH)_4$, MEI	14.8	HLW Supernate Simulant	999.0						
9-L	Fe_2O_3, Prince 3752	48.6	$Al(OH)_3$, Alcoa S-11	63.2	SiO2, Alfa Aesar	4.6	$Zr(OH)_4$, MEI	14.8	Van Gel B, RT Vanderbilt	10	HLW Supernate Simulant	999.0				
10-L	Fe_2O_3, Prince 3752	48.6	$Al(OH)_3$, Alcoa S-11	63.2	SiO2, Alfa Aesar	4.6	$Zr(OH)_4$, MEI	14.8	Na CMC, Kraft Chemical	10	HLW Supernate Simulant	999.2				
11-L	Fe_2O_3, Bayferrox 130	48.6	$Al(OH)_3$, Flamegard ATH	63.2	SiO2, Alfa Aesar	4.6	$Zr(OH)_4$, MEI	14.8	HLW Supernate Simulant	999.0						
12-L	Fe_2O_3, Bayferrox 130	38.8	Fe_2O_3, Prince 5001	9.8	$Al(OH)_3$, Alcoa S-23	63.2	SiO2, Alfa Aesar	4.6	$Zr(OH)_4$, MEI	14.8	HLW Supernate Simulant	999.0				
13-L	Fe_2O_3, Prince 3728	52.773	$Al(OH)_3$, Alcoa S-23	52.663	SiO2, Alfa Aesar	5.095	$Zr(OH)_4$, MEI	20.714	HLW Supernate Simulant	998.9						
14-L	Fe_2O_3, Bayferrox 130	42.221	Fe_2O_3, Bayferrox 130C	10.552	$Al(OH)_3$, Hydral 716	42.134	$Al(OH)_3$, Alcoa C30	10.53	SiO2, Alfa Aesar	5.092	$Zr(OH)_4$, MEI	20.711	HLW Supernate Simulant	998.9		

Test	Component 1	Grams	Component 2	Grams	Component 3	Grams	Component 4	Grams	Component 5	Grams	Component 6	Grams	Component 7	Grams	Component 8	Grams
15-L	Fe_2O_3, Bayferrox 130	52.771	$Al(OH)_3$, Flamegard ATH	52.661	SiO2, Alfa Aesar	5.091	$Zr(OH)_4$, MEI	20.714	HLW Supernate Simulant	998.9						
16-L	Fe_2O_3, Bayferrox 130	42.2	Fe_2O_3, Prince 5001	10.6	$Al(OH)_3$, Alcoa S-23	52.7	SiO2, Alfa Aesar	5.1	$Zr(OH)_4$, MEI	20.7	HLW Supernate Simulant	998.9				
17-L	Fe_2O_3, Prince 3752	52.8	$Al(OH)_3$, Alcoa S-11	52.7	SiO2, Alfa Aesar	5.1	$Zr(OH)_4$, MEI	20.7	Van Gel B, RT Vanderbilt	10	HLW Supernate Simulant	998.9				
18-L	Fe_2O_3, Prince 3752	52.8	$Al(OH)_3$, Alcoa S-11	52.7	SiO2, Alfa Aesar	5.1	$Zr(OH)_4$, MEI	20.7	Na CMC, Kraft Chemical	10	HLW Supernate Simulant	998.9				
19-L	Fe_2O_3, Bayferrox 130	46.12	Fe_2O_3, Bayferrox 130C	11.531	$Al(OH)_3$, Hydral 716	46.021	$Al(OH)_3$, Alcoa C30	11.5	SiO2, Alfa Aesar	5.56	$Zr(OH)_4$, MEI	22.619	HLW Supernate Simulant	986.6		
20-L	Fe_2O_3, Bayferrox 130	50.73	Fe_2O_3, Bayferrox 130C	12.681	$Al(OH)_3$, Hydral 716	50.62	$Al(OH)_3$, Alcoa C30	12.65	SiO2, Alfa Aesar	6.12	$Zr(OH)_4$, MEI	24.889	HLW Supernate Simulant	986.6		

Table 33 Composition of High Bounding HLW Test Mixtures

Test	Component 1	Grams	Component 2	Grams	Component 3	Grams	Component 4	Grams	Component 5	Grams	Component 6	Grams	Component 7	Grams
21-H	Fe_2O_3, Prince 3752	112.133	$Al(OH)_3$, Alcoa S-11	111.892	SiO2, Alfa Aesar	10.821	$Zr(OH)_4$, MEI	44.010	HLW Supernate Simulant	941.100				
22-H	Fe_2O_3, Prince 3752	123.350	$Al(OH)_3$, Alcoa S-11	123.081	SiO2, Alfa Aesar	11.910	$Zr(OH)_4$, MEI	48.412	HLW Supernate Simulant	913.300				
23-H	Fe_2O_3, Prince 3752	123.352	$Al(OH)_3$, Alcoa S-11	123.081	SiO2, Alfa Aesar	11.909	$Zr(OH)_4$, MEI	48.409	HLW Supernate Simulant	913.300	Xanthan Gum	10.003		
24-H	Fe_2O_3, Prince 3752	123.348	$Al(OH)_3$, Alcoa S-11	123.082	SiO2, Alfa Aesar	11.913	$Zr(OH)_4$, MEI	48.408	HLW Supernate Simulant	913.300	Na CMC, Kraft Chemical	10.000		
25-H	Fe_2O_3, Prince 3752	123.349	$Al(OH)_3$, Alcoa S-11	123.078	SiO2, Alfa Aesar	11.900	$Zr(OH)_4$, MEI	48.416	HLW Supernate Simulant	913.300	Na CMC, Kraft Chemical	10.000		
26-H	Fe_2O_3, Prince 3752	123.351	$Al(OH)_3$, Alcoa S-11	123.083	SiO2, Alfa Aesar	11.906	$Zr(OH)_4$, MEI	48.412	HLW Supernate Simulant	913.300	Bentonite, GPG-30, Kraft	10.004		
27-H	Fe_2O_3, Prince 3752	123.348	$Al(OH)_3$, Alcoa S-11	123.082	SiO2, Alfa Aesar	11.910	$Zr(OH)_4$, MEI	48.410	HLW Supernate Simulant	913.300	Van Gel B, R T Vanderbilt	10.003		
28-H	Fe_2O_3, Prince 3752	123.352	$Al(OH)_3$, Alcoa S-11	123.081	SiO2, Alfa Aesar	11.914	$Zr(OH)_4$, MEI	48.412	HLW Supernate Simulant	913.300	VeeGum, R T Vanderbilt	10.004		
29-H	Fe_2O_3, Prince 3752	123.354	$Al(OH)_3$, Alcoa S-11	123.100	SiO2, Alfa Aesar	11.912	$Zr(OH)_4$, MEI	48.413	HLW Supernate Simulant	913.300	Xanthan Gum	2.001		
30-H	Fe_2O_3, Prince 3752	123.353	$Al(OH)_3$, Alcoa S-11	123.100	SiO2, Alfa Aesar	11.914	$Zr(OH)_4$, MEI	48.414	HLW Supernate Simulant	913.300	Xanthan Gum	4.002		
31-H	Fe_2O_3, Prince 3752	123.351	$Al(OH)_3$, Alcoa S-11	123.100	SiO2, Alfa Aesar	11.911	$Zr(OH)_4$, MEI	48.412	HLW Supernate Simulant	913.300	Xanthan Gum	6.003		
32-H	Fe_2O_3, Prince 3752	123.351	$Al(OH)_3$, Alcoa S-11	123.100	SiO2, Alfa Aesar	11.910	$Zr(OH)_4$, MEI	48.413	HLW Supernate Simulant	913.300	Xanthan Gum	8.002		
33-H	Fe_2O_3, Prince 3752	123.353	$Al(OH)_3$, Alcoa S-11	123.081	SiO2, Alfa Aesar	11.911	$Zr(OH)_4$, MEI	48.410	HLW Supernate Simulant	913.300	Xanthan Gum	5.002	Na CMC, Kraft Chemical	5.000

Test	Component 1	Grams	Component 2	Grams	Component 3	Grams	Component 4	Grams	Component 5	Grams	Component 6	Grams	Component 7	Grams
34-H	Fe_2O_3, Prince 3752	123.351	$Al(OH)_3$, Alcoa S-11	123.081	SiO2, Alfa Aesar	11.913	$Zr(OH)_4$, MEI	48.411	HLW Supernate Simulant	913.300	Xanthan Gum	5.004	Na CMC, Kraft Chemical	4.005
35-H	Fe_2O_3, Prince 3752	123.350	$Al(OH)_3$, Alcoa S-11	123.084	SiO2, Alfa Aesar	11.911	$Zr(OH)_4$, MEI	48.413	HLW Supernate Simulant	913.260	Xanthan Gum	4.001	Na CMC, Kraft Chemical	5.001
36-H	Fe_2O_3, Prince 3752	123.350	$Al(OH)_3$, Alcoa S-11	123.080	SiO2, Alfa Aesar	11.910	$Zr(OH)_4$, MEI	48.410	HLW Supernate Simulant	913.300				
37-H	Fe_2O_3, Prince 3752	123.350	$Al(OH)_3$, Alcoa S-11	123.080	SiO2, Alfa Aesar	11.910	$Zr(OH)_4$, MEI	48.410	Xanthan Gum	5.004	Na CMC, Kraft Chemical	4.005	HLW Supernate Simulant	913.300
38-L+H	Fe_2O_3, Bayferrox 130 $Zr(OH)_4$, MEI	50.728 48.409	Fe_2O_3, Bayferrox 130C HLW Supernate Simulant	12.680 913.300	Fe_2O_3, Prince 3752	60.152	$Al(OH)_3$, Hydral 716	50.622	$Al(OH)_3$, Alcoa C30	12.653	$Al(OH)_3$, Alcoa S-11	59.810	SiO2, Alfa Aesar	11.912
39-H	Fe_2O_3, Prince 3752	123.352	$Al(OH)_3$, Alcoa S-11	123.082	SiO2, Alfa Aesar	11.910	$Zr(OH)_4$, MEI	48.410	Xanthan Gum, Kraft Chem.	5.002	Na CMC, Kraft Chemical	4.002	HLW Supernate Simulant	913.200
40-H	Fe_2O_3, Prince 3752	155.640	$Al(OH)_3$, Alcoa S-11	155.300	SiO2, Alfa Aesar	15.020	$Zr(OH)_4$, MEI	61.080	HLW Supernate Simulant	873.000				
41-H	Fe_2O_3, Prince 3752	192.794	$Al(OH)_3$, Alcoa S-11	192.380	SiO2, Alfa Aesar	18.610	$Zr(OH)_4$, MEI	75.661	HLW Supernate Simulant	840.600				
42-H	Fe_2O_3, Prince 3752	152.872	$Al(OH)_3$, Alcoa S-11	152.543	SiO2, Alfa Aesar	14.760	$Zr(OH)_4$, MEI	60.002	HLW Supernate Simulant	879.800				
43-H	Fe_2O_3, Prince 3752	188.640	$Al(OH)_3$, Alcoa S-11	188.232	SiO2, Alfa Aesar	18.210	$Zr(OH)_4$, MEI	74.043	HLW Supernate Simulant (modified OH level)	850.900				
44-H	Fe_2O_3, Prince 5052	192.700	$Al(OH)_3$, Alcoa S-11	192.400	SiO2, Alfa Aesar	18.612	$Zr(OH)_4$, MEI	75.661	HLW Supernate Simulant	840.600				

Table 34 Low Bounding HLW Physical Simulant Rheology at 25 ° C

Test #	Derived From Test:	Sludge Volume mL	Cs IX added grams	Yield Stress Pascals	Consistency mPa.s	Type of Rheology	Purpose of experiment
1-L	Scoping	1000	NA	0.6	2.8	Non-Newtonian	Scoping Particle size and type for effect on rheology
2-L	Scoping	1000	NA	0	1.3	Newtonian	Scoping Particle size and type for effect on rheology
3-L	Scoping	1000	NA	0.5	2.6	Non-Newtonian	Scoping Particle size and type for effect on rheology
4-L	Scoping	1000	NA	0	1.9	Newtonian	Scoping Particle size and type for effect on rheology
5-L	Scoping	1000	NA	0	1.5	Newtonian	Scoping Particle size and type for effect on rheology
6-L	Scoping	1000	NA	0.7	2.9	Non-Newtonian	Scoping Particle size and type for effect on rheology
7-L	Scoping	1000	NA	2.8	4.8	Non-Newtonian	Scoping Particle size and type for effect on rheology
8-L	Scoping	1000	NA	0.8	3.0	Non-Newtonian	Scoping Particle size and type for effect on rheology
9-L	Scoping	1000	NA	4.0	4.2	Non-Newtonian	Scoping Particle size and type for effect on rheology
10-L	Scoping	1000	NA	4.8	26.8	Non-Newtonian	Scoping Particle size and type for effect on rheology
11-L	Scoping	1000	NA	0	1.4	Newtonian	Scoping Particle size and type for effect on rheology
12-L	Scoping	1000	NA	0	1.3	Newtonian	Scoping Particle size and type for effect on rheology
13-L	2-L	1000	NA	0	1.4	Newtonian	Repeat of 2-L
CRV-13-L	13-L	500	11.965	0	1.5	Newtonian	Effect of IX eluate on rheology
14-L	4-L	1000	NA	0	1.7	Newtonian	Repeat of 4-L

Test #	Derived From Test:	Sludge Volume mL	Cs IX added grams	Yield Stress Pascals	Consistency mPa.s	Type of Rheology	Purpose of experiment
CRV-14-L	14-L	500	11.965	0	1.8	Newtonian	Effect of IX eluate on rheology
15-L	11-L	1000	NA	0	1.6	Newtonian	Repeat of 11-L
CRV-15-L	15-L	500	11.965	0	1.6	Newtonian	Effect of IX eluate on rheology
16-L	12-L	1000	NA	0	1.5	Newtonian	Repeat of 12-L
CRV-16-L	16-L	500	11.965	0	1.7	Newtonian	Effect of IX eluate on rheology
17-L	9-L	1000	NA	2.7	4.0	Non-Newtonian	Retest of candidate for base composition to get upper bound rheology
18-L	10-L	1000	NA	3.9	26.7	Non-Newtonian	Retest of candidate for base composition to get upper bound rheology
19-L	14-L	1000	NA	0	1.8	Newtonian	Initial adjustment to get 15 wt % total solids loading
20-L	14-L	1000	NA	0	2.0	Newtonian	Final adjustment to obtain 15 wt % total solids loading = success.

Note: Yield Stress and consistency based upon a Bingham model curve fit from 50 to 1000 sec^{-1} on the up flow curve.

Table 35 High Bound HLW Rheology Tests at 25 ° C

Test #	Derived From Test:	Sludge Volume mL	Cs IX added grams	Yield Stress Pascals	Consistency mPa.s	Purpose of experiment
21-H	17-L	1000	NA	4.3	4.7	Initial Attempt at 25 wt % total solids loading. Still Short
22-H	17-L	1000	NA	7.7	6.9	Adjusted 17 -L to get 25 wt % total solids loading = success.
23-H	22-H	1000	NA	43.6	44.1	Test Mix 22-H + Xanthan Gum
24-H	22-H	1000	NA	16.3	46.4	Test Mix 22-H + Na Carboxymethylcellulose from Kraft Chemical
25-H	22-H	1000	NA	2.6	12.3	Test Mix 22-H + Na Carboxymethylcellulose from KIC
26-H	22-H	1000	NA	9.8	6.6	Test Mix 22-H + GPG-30
27-H	22-H	1000	NA	25.6	6.9	Test Mix 22-H + Van Gel B
28-H	22-H	1000	NA	28.0	8.6	Test Mix 22-H + VeeGum
29-H	22-H	1000	NA	6.5	11.4	Test Mix 22-H + 2 g/L Xanthan Gum
30-H	22-H	1000	NA	12.3	15.1	Test Mix 22-H + 4 g/L Xanthan Gum
31-H	22-H	1000	NA	20.8	17.5	Test Mix 22-H + 6 g/L Xanthan Gum
32-H	22-H	1000	NA	31.4	22.2	Test Mix 22-H + 8 g/L Xanthan Gum
33-H	22-H	1000	NA	27.2	35.9	Test Mix 22-H + 5 g/L Xanthan Gum + 5 g/L CMC Kraft
34-H	22-H	1000	NA	20.8	32.2	Test Mix 22-H + 5 g/L Xanthan Gum + 4 g/L CMC Kraft
HLW-CRV-34	34-H	250	11.89	19.1	30	Pretreated HLW Feed (34-H) Recommended for a Modifier CRV Feed
HLW-MFPV-34	HLW-CRV-34	250	11.8864	76.9	99.8	Melter Feed Produced from the Recommended Pretreated HLW Feed with modifier
35-H	22-H	1000	NA	17.5	34.1	Test Mix 22-H + 4 g/L Xanthan Gum + 5 g/L CMC Kraft

Test #	Derived From Test:	Sludge Volume mL	Cs IX added grams	Yield Stress Pascals	Consistency mPa.s	Purpose of experiment
36-H	22-H	1000	NA	8.0	6.6	Test 22-H Repeat
HLW-CRV-36	36-H	250	11.8862	4.1	5.5	Treated HLW Feed from 36-H
HLW-MFPV-36	HLW-CRV-36	250	11.885	7.4	12.9	Melter Feed Product from 36-H
37-H	34-H	1000	NA	NM	NM	Repeat of Test mix 34-H
HLW-CRV-37	37-H	1000	47.542	18.0	30.9	Treated HLW Feed from 37-H
HLW-MFPV-37-17.5	HLW-CRV-37	250	From CRV-37	13.6	27.5	Treated HLW Feed from 37-H Diluted to 17.5 wt % total solids then made into Melter Feed
HLW-MFPV-37-20	HLW-CRV-37	250	From CRV-37	20.8	38.1	Treated HLW Feed from 37-H Diluted to 20 wt % total solids then made into Melter Feed
HLW-MFPV-37-22.5	HLW-CRV-37	200	From CRV-37	32.5	56.1	Treated HLW Feed from 37-H Diluted to 22.5 wt % total solids then made into Melter Feed
38-(L+H)	20-L + 22-H	1000	NA	NM	NM	Initial 15 wt% total solids based on 20-L then the remaining sludge mass based on the 22-H physical simulant
HLW-MFPV-38-(L+H) Vis Mod	38-(L+H)	250	11.8864	48.2	85.5	Initial 15 wt% total solids based on 20-L then the remaining sludge mass based on the 22-H physical simulant then into melter feed with viscosity modifier
39-H	34-H	2000	NA	24.6	33.2	Repeat of 34-H mixture
HLW-CRV-39	39-H	1000	47.542	NM	NM	Treated HLW Feed from 39-H
HLW-CRV-Dil-39-22	HLW-CRV-39	500	From CRV-39	10.6	18.1	Treated HLW Feed from 39-H Diluted to 22 wt % total Solids
HLW-MFPV-39-22	HLW-CRV-Dil-39-22	500	From CRV-39	34.0	52.6	Treated 22 wt % total solids from 39-H converted to Melter Feed. Recommended for a Visc. Mod. HLW Melter Feed Physical Simulant
40-H	22-H	1000	NA	14.4	7.8	Initial attempt at 30 wt % total solids Washed sludge, No Vis. Modifier.

Test #	Derived From Test:	Sludge Volume mL	Cs IX added grams	Yield Stress Pascals	Consistency mPa.s	Purpose of experiment
HLW-40-CRV	40-H	500	29.576	5.9	6.6	Treated HLW Feed at 30 wt % total solids
HLW-40-MFPV	HLW-40-CRV	250	From 40-CRV	14.5	20.6	HLW Melter Feed produced from 30 wt % total solids Treated HLW Feed
41-H	22-H	1000	NA	27.9	10.6	Initial attempt at 35 wt % total solids Washed sludge, No Vis. Modifier.
HLW-41-CRV	41-H	500	36.277	17.5	9.9	Treated HLW Feed at 35 wt % total solids
HLW-41-MFPV	HLW-41-CRV	250	From 41-CRV	29.8	39.7	HLW Melter Feed produced from 35 wt % total solids Treated HLW Feed
42-H	40-H	1000	NA	17.7	8.1	30 wt % total solids Washed sludge Increased Base in supernate, No Vis. Modifier.
HLW-CRV-42	42-H	500	29.474	12.7	8.5	Treated HLW Feed with increased base at 30 wt % total solids
HLW-MFPV-42	HLW-CRV-42	250	From CRV-42	13.3	21.1	HLW Melter Feed produced from 30 wt % total solids Treated HLW Feed with increased base
43-H	41-H	1000	NA	14.3	8.1	Initial attempt at 35 wt % total solids Washed sludge with increased base, No Vis. Modifier.
HLW-CRV-43	43-H	500	36.112	19.7	10.6	Treated HLW Feed with increased base at 35 wt % total solids and no modifier
HLW-MFPV-43	HLW-CRV-43	250	From CRV-43	29.4	33.2	HLW Melter Feed produced from 35 wt % total solids Treated HLW Feed with increased base, no modifier.

Note: Yield Stress and consistency based upon a Bingham model curve fit from 50 to 1000 sec^{-1} on the up flow curve.

Table 36 Low Bounding HLW Physical Simulant Physical Properties

Test #	Total Solids Wt %	Soluble Solids in Supernate Wt %	Soluble Solids Wt %	Insoluble Solids Wt %	pH	Density g/mL
1-L	13.37	2.33	2.07	11.30	12.03	1.105
2-L	11.11	2.14	1.95	9.16	12.03	1.089
3-L	13.04	2.18	1.94	11.10	12.01	1.103
4-L	11.90	2.17	1.95	9.95	12.01	1.101
5-L	12.21	2.17	1.95	10.26	12.00	1.130
6-L	12.67	2.33	2.08	10.59	12.69	1.101
7-L	12.36	2.15	1.92	10.44	12.67	1.087
8-L	13.21	2.10	1.86	11.35	12.59	1.101
9-L	13.73	2.04	1.80	11.94	12.74	1.096
10-L	13.50	2.96	2.64	10.86	12.60	1.107
11-L	11.88	2.04	1.84	10.04	12.67	1.080
12-L	12.85	2.05	1.82	11.02	12.68	1.104
13-L	11.59	2.14	1.93	9.65	12.18	1.107
CRV-13-L	11.95	2.87	2.61	9.35	12.14	1.110
14-L	12.26	2.01	1.80	10.45	12.25	1.108
CRV-14-L	12.48	2.92	2.64	9.85	12.19	1.121
15-L	12.57	2.04	1.82	10.74	12.31	1.104
CRV-15-L	12.18	3.12	2.82	9.36	12.23	1.111
16-L	12.92	2.08	1.85	11.07	12.41	1.114
CRV-16-L	13.19	2.96	2.65	10.55	12.30	1.131
17-L	13.63	2.13	1.88	11.75	12.31	1.105
18-L	13.28	2.51	2.23	11.04	12.37	1.106
19-L	13.41	2.03	1.80	11.62	12.56	1.097
20-L	14.61	2.14	1.87	12.74	12.48	1.105

Table 37 High Bounding HLW Physical Properties

Test #	Total Solids Wt %	Soluble Solids in Supernate Wt %	Soluble Solids Wt %	Insoluble Solids Wt %	pH	Density g/mL
21-H	23.72	1.84	1.43	22.29	13.05	1.192
22-H	25.80	1.83	1.38	24.42	13.10	1.212
23-H	26.21	NM	NM	NM	12.45	1.216
24-H	25.97	2.73	2.08	23.89	12.39	1.222
25-H	26.82	2.68	2.02	24.80	12.36	1.199
26-H	26.38	2.01	1.58	24.80	12.53	1.171
27-H	26.31	1.99	1.50	24.81	12.62	1.132
28-H	26.33	1.93	1.45	24.88	12.56	1.198
29-H	25.90	2.27	1.72	24.18	14.00	1.216
30-H	25.89	NM	NM	NM	14.00	1.218
31-H	25.97	NM	NM	NM	14.00	1.217
32-H	26.23	NM	NM	NM	14.00	1.218
33-H	26.16	NM	NM	NM	12.25	NM
34-H	25.77	NM	NM	NM	12.29	1.220
HLW-CRV-34	NM	NM	NM	NM	9.55	NM
HLW-MFPV-34	NM	NM	NM	NM	9.29	NM
35-H	26.06	NM	NM	NM	12.43	1.218
36-H	25.89	1.95	1.47	24.42	12.33	1.179
HLW-CRV-36	26.28	3.36	2.56	23.72	9.46	1.218
HLW-MFPV-36	50.36	12.10	6.83	43.53	9.16	1.482
37-H	26.81	NM	NM	NM	12.29	NM
HLW-CRV-37	26.81	NM	NM	NM	NM	1.222
HLW-MFPV-37-17.5	38.19	NM	NM	NM	9.39	NM
HLW-MFPV-37-20	41.74	NM	NM	NM	9.43	1.392
HLW-MFPV-37-22.5	45.32	NM	NM	NM	9.49	1.436
38-(L+H)	26.16	2.09	1.57	24.59	12.72	1.223
HLW-MFPV-38-(L+H) Vis Mod	50.28	NM	NM	NM	9.40	1.080
39-H	26.33	NM	NM	NM	12.96	1.213
HLW-CRV-39	25.06	NM	NM	NM	9.93	1.207
HLW-CRV-Dil-39-22	21.44	NM	NM	NM	10.14	1.154
HLW-MFPV-39-22	44.58	NM	NM	NM	9.74	1.419
40-H	30.84	1.83	1.29	29.56	12.85	1.272
HLW-40-CRV	31.13	3.82	2.74	28.39	8.93	1.270
HLW-40-MFPV	56.15	13.86	7.06	49.10	9.87	1.552
41-H	36.37	1.70	1.10	35.27	12.81	1.334
HLW-41-CRV	36.03	4.10	2.75	33.28	6.82	1.310
HLW-41-MFPV	60.89	15.66	7.26	53.63	9.87	1.642
42-H	30.91	2.63	1.87	29.05	13.37	1.271
HLW-CRV-42	31.04	4.32	3.11	27.93	11.60	1.261
HLW-MFPV-42	55.86	14.52	7.5.0	48.37	10.04	1.569
43-H	35.06	1.09	0.72	34.34	11.93	1.317

Test #	Total Solids Wt %	Soluble Solids in Supernate Wt %	Soluble Solids Wt %	Insoluble Solids Wt %	pH	Density g/mL
HLW-CRV-43	34.98	3.99	2.70	32.28	4.27	1.144
HLW-MFPV-43	60.33	15.00	7.00	53.33	9.76	1.414

The initial tests identified test mixtures 2-L, 4-L, 11-L and 12-L as being close to the desired limits for a low bounding HLW simulant (Newtonian and 2 mPa.s). Further tests evaluated the impact of the Cs IX concentrate addition on the slurry rheology (CRV-14-L with a very minor shift in viscosity) and increased the solids loading to obtain the 15 wt% total solids level for the simulant. Test 20-L defined the composition of the low bounding HLW feed physical simulant before addition of the Cs IX concentrate.

The viscosity of the low bounding Pretreated HLW Waste physical simulant was 2.0 mPa·s at 25 ° C (within 100% of the low bound) and 1.8 mPa·s at 40 ° C. The viscosity of the low bounding HLW Melter Feed physical simulant is 4.0 mPa·s at 25 ° C and 3.7 mPa·s at 40 ° C. Figure 14 compares the low bound pretreated HLW physical simulant and associated HLW melter feed to the lower rheological limits.

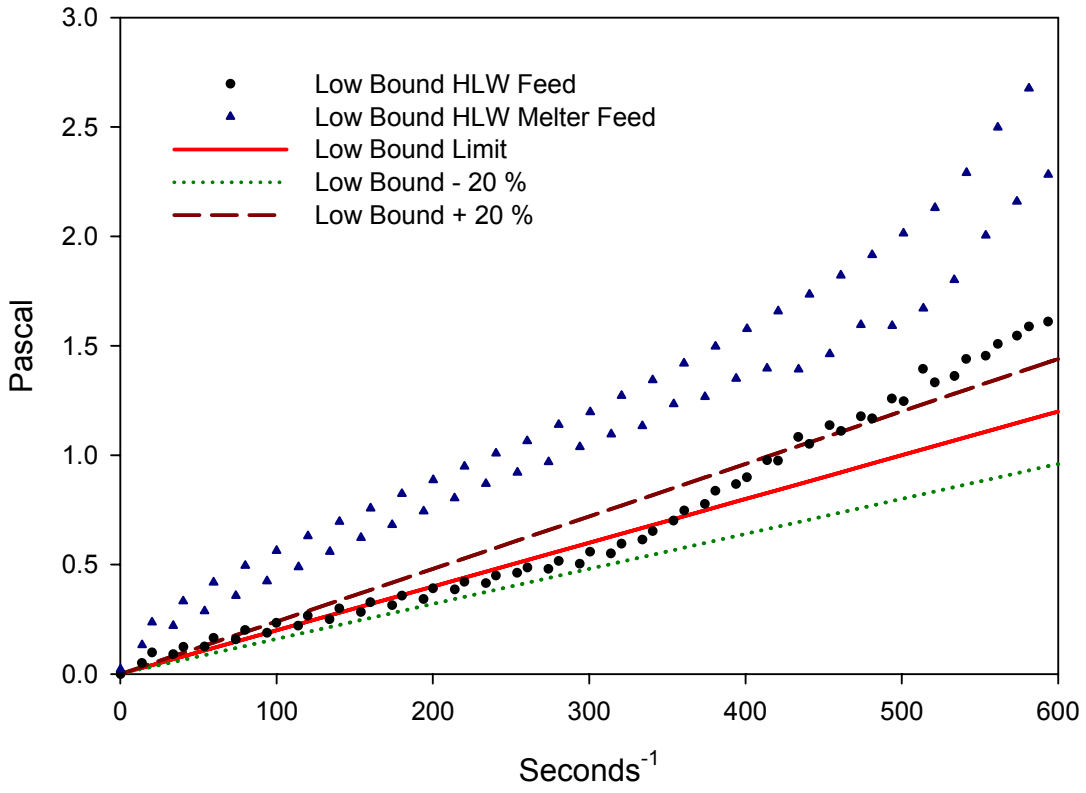

Figure 14 Low Bound Pretreated HLW Physical Simulant and Low Bound HLW Melter Feed Physical Simulant Compared to the Low Rheological Limits

The match to the limit is excellent for the pretreated feed through 350 s^{-1}. At that point Taylor vortices occur due to the gap size of the rheology sensor applied to this sample. The melter feed simulant produced from the low bounding pretreated HLW feed is sufficiently close to the lower limit to be used as a bounding melter feed test mixture. The very slight deviation from pure Newtonian flow properties will not prevent use of this material as the low bound HLW melter feed simulant. The recipes for the low bound pretreated HLW feed physical simulant and the low bound HLW melter feed simulant are given in Appendix D.

Test mixtures 9-L and 10-L appeared to be good candidates for the starting point for developing the high bound HLW physical simulant based on the yield stresses listed in Table 34. However, mixture 10-L is better fit to a Power Law rheology model and does not have a yield stress. Therefore, the high bound HLW simulant was initially derived from test mixture 9-L. Test mixture 9-L included a rheology modifier. Since the high bound HLW mixtures were initially targeted at a total solids loading of 25 wt %, the initial high bounding tests, 21-H and 22-H, used the basic composition of 9-L at a higher solids loading without a rheology modifier. The shapes of these two flow curves were excellent (rapid rise in shear stress at the start of the curve) but the yield stress values were insufficient to meet the required rheology limit (see Figure 15). Therefore, either higher solids loading would be required or the use a rheology modifier would be necessary.

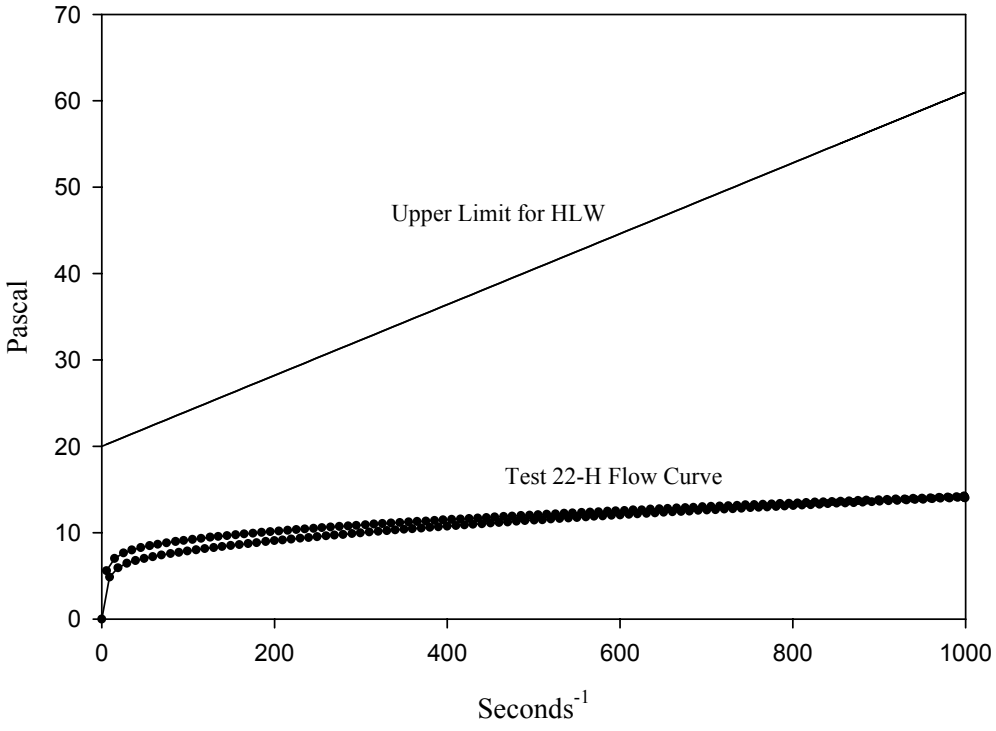

Figure 15 Flow Curve of Test Mixture 22-H at 25 ° C Compared to Upper HLW Rheology Limit

Rheology modifiers can increase/decrease a yield value or increase/decrease the consistency of the material being modified. The modifiers tested with the HLW physical simulant are listed in Table 38.

Table 38 Rheology Modifiers Tested with HLW Physical Simulants

Material Name	Material Supplier	Formula or Grade
Xanthan Gum	Kraft Chemical Co.	Food Grade
Na Carboxymethylcellulose	KIC	Detergent Grade
Na Carboxymethylcellulose	Kraft Chemical Co.	Aqualon 7M
Bentonite GPG-30	Kraft Chemical Co.	VolClayGPG30
VanGel B	R.T. Vanderbilt	MgAlSiO (OH)
VeeGum	R.T. Vanderbilt	MgAlSiO (OH)

The xanthan gum and bentonite-type (smectite, MgAlSiO(OH)) modifiers add yield value to aqueous systems. The sodium carboxymethylcellulose adds consistency to aqueous systems. Tests with the HLW physical simulant based on 22-H showed that xanthan gum was sufficient to raise the yield stress to the required 20 Pascal level. However, the consistency for the HLW physical simulant remained low (see test mixture 31-H in Table 35). Mixtures of xanthan gum and sodium carboxymethylcellulose (CMC) increased yield stress and consistency (see test mixtures 33-H, 34-H, and 35-H). Test mixture 34-H matched fairly well to the upper rheology limit as shown in Figure 16.

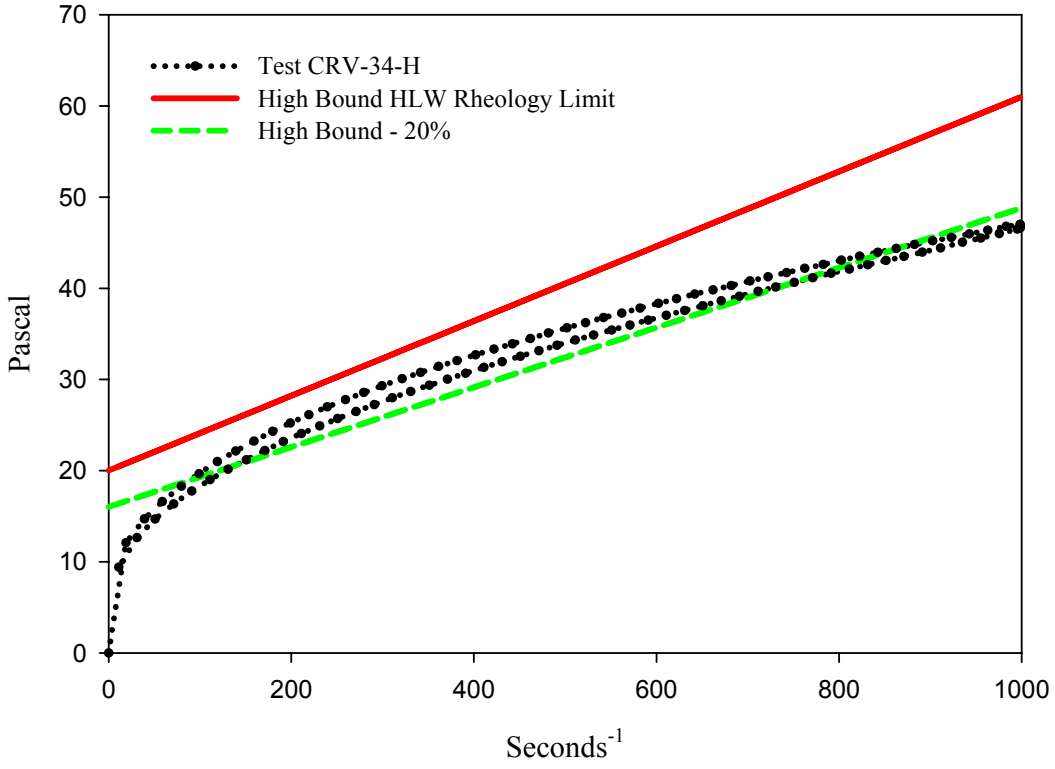

Figure 16 Test CVR-34-H compared to High Bound HLW Rheology Limit

The tests with the rheology modifiers did not show any odd properties such as were observed with the xanthan gum blended with the LAW feed simulants. The use of the combined modifier could be used to meet the upper bound HLW rheology needs. Addition of GFCs to the 34-H pretreated HLW feed produced a melter feed which clearly exceeded the upper bounds for HLW melter feed (77.9 Pa versus 30 Pa yield stress and 99.8 mPa·s versus 41 mPa·s).

The emphasis of the later HLW physical simulant tests focused on determining the required solids loading which could produce an acceptable upper bound HLW physical simulant without the use of a viscosity modifier. Tests 40-H to 43-H increased the solids loading while continuing to use the basic simulant composition as in test 22-H. Previous SRS and WTP studies of simulated HLW slurry rheology observed that the yield stress from a Bingham Plastic fit was an exponential function of the simulants solids content.[8,15,16] Figure 17 shows the same dependence for the HLW physical simulants.

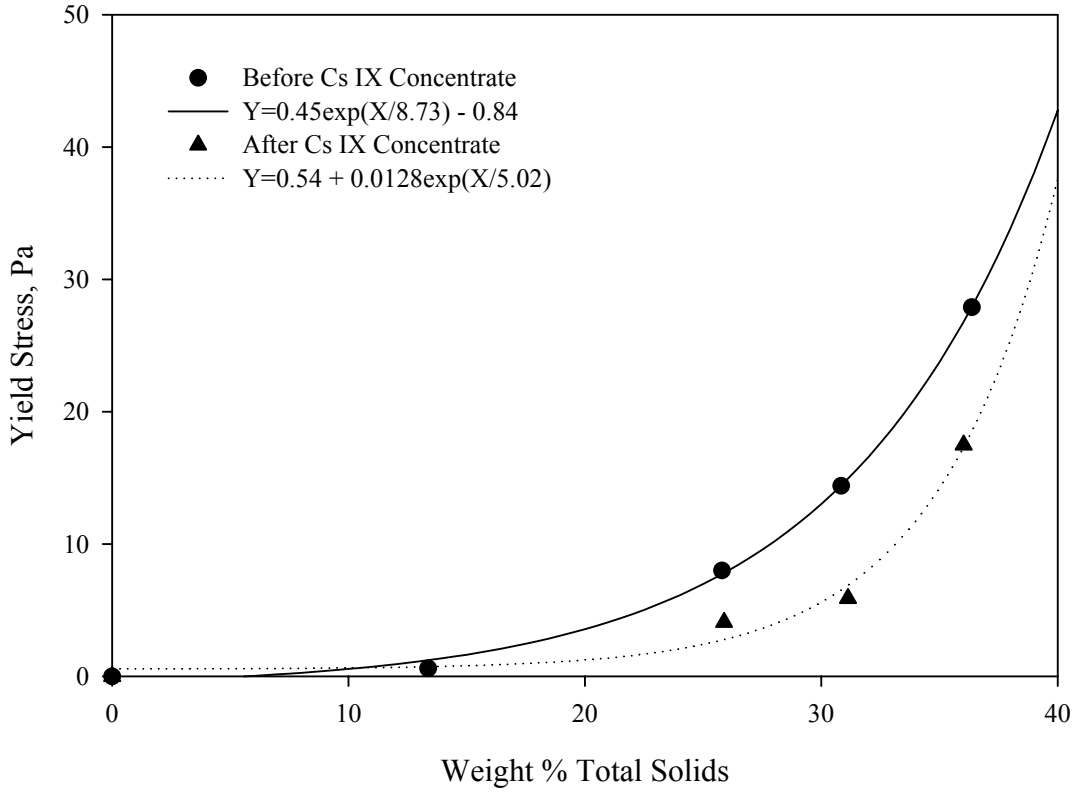

Figure 17 Yield Stress as a Function of Wt % Total Solids for HLW Physical Simulant

Examination of the results for tests 41-H demonstrate that HLW-41-CRV meets the required yield stress for the upper bound rheology limit for pretreated HLW feed but does not meet the consistency requirement. However, the addition of GFCs to the test mixture produces a melter feed which meets the requirements for the upper bound for HLW melter feed. Therefore, the composition based on test 41-H is recommended as the upper bound simulant for the upper limits for HLW CRV and MFPV. Comparisons of the 41-H tests with the upper limits are given below.

The recipes for producing the high bound pretreated HLW feed simulant and the associated HLW melter feed simulant are given in Appendix E.

The yield stress of the high bounding pretreated HLW feed physical simulant was 17.5 Pascals at 25 ° C and 15.3 Pascals at 40 ° C based upon a Bingham Plastic model fit for the up flow curve from 50 to 1000 sec^{-1}. The consistency of the high bounding pretreated HLW feed physical simulant was 9.9 mPa·s at 25 ° C (24% of the high bound limit of 41 mPa·s) and 9.8 mPa·s at 40 ° C also based upon the Bingham Plastic model fit. Figure 18 shows a comparison of the limits to the high bound pretreated HLW physical simulant.

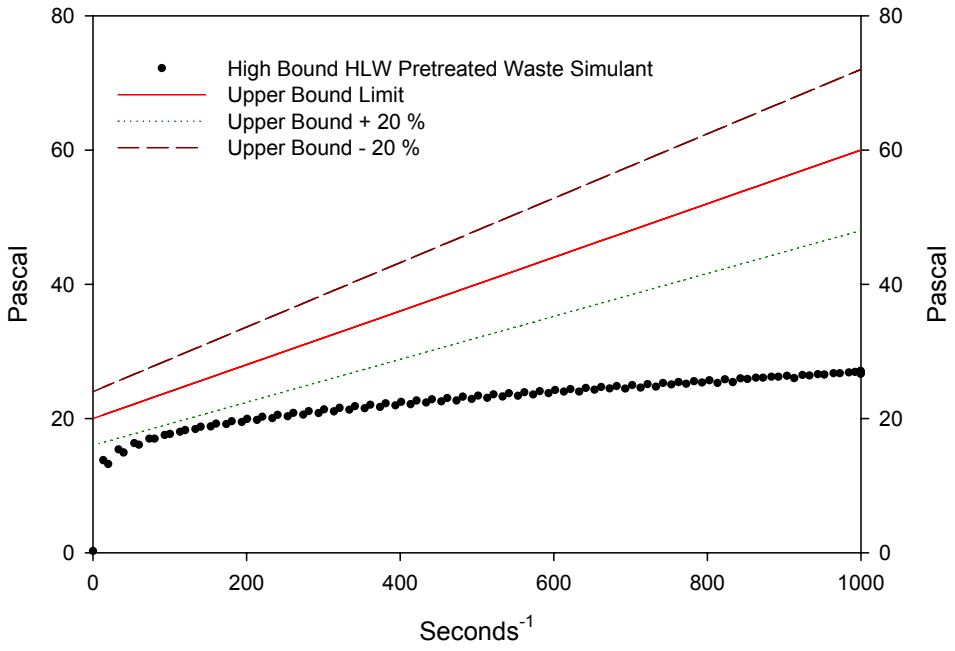

Figure 18 High Bound Pretreated HLW Physical Simulant Compared to the Upper Rheological Limits

The yield stress of the high bounding HLW melter feed physical simulant was 30 Pa at 25 ° C and 29.4 Pa at 40 ° C based upon a Bingham Plastic model fit for the up flow curve from 50 to 1000 sec^{-1}. The consistency of the high bounding HLW melter feed physical simulant was 40 mPa·s at 25 ° C (within 98% of the high bound) and 32 mPa·s at 40 ° C also based upon the Bingham Plastic model fit. The Herchel-Bulkey rheology model provided a better fit (r^2 closer to one) in both temperature cases, but generated a lower yield stress value as expected. Figure 19 compares the high bounding HLW melter feed physical simulant flow curve to the HLW melter feed upper rheology limits.

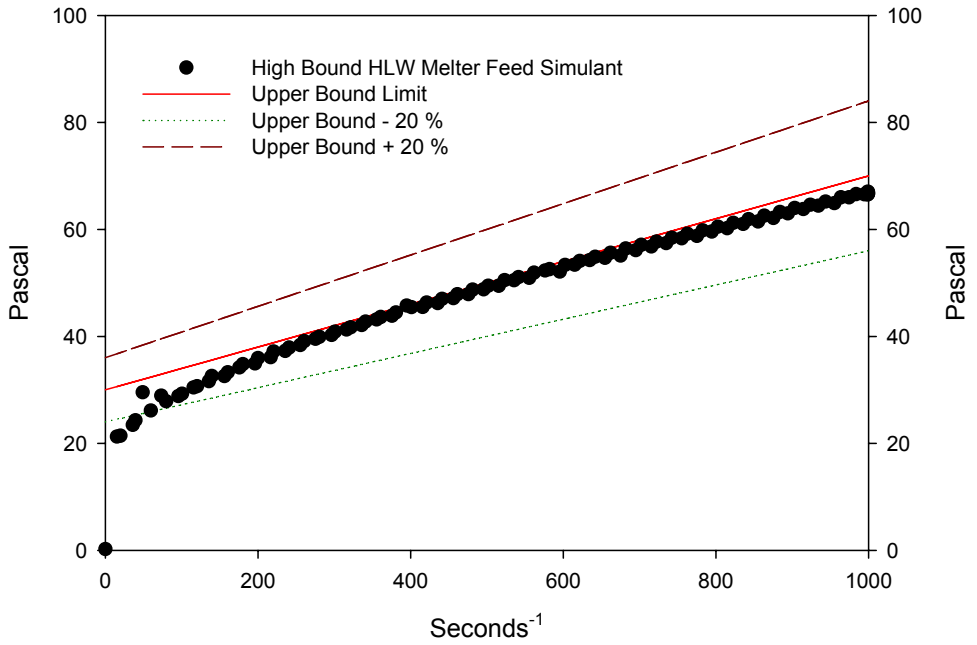

Figure 19 High Bound HLW Melter Feed Physical Simulant Compared to the Upper Rheological Limits

Another rheology property of concern for application of the HLW physical simulants is the settled shear strength. For the HLW CRV and MFPV, the maximum expected down time for the vessel agitation is expected to be 192 hours. Therefore, a simulant that has settled for up to 192 hours must not have a yield stress that exceeds 625 Pa.[1] The settled shear strengths were measured for the high bound simulants only using the vane method previously described. Table 39 shows that the settled shear strength after 288 hours did not exceed the maximum allowed.

Table 39 Settled Shear Strengths for the High Bound Pretreated HLW Feed and High Bound HLW Melter Feed

Hours	High Bound Pretreated HLW Feed	High Bound HLW Melter Feed
	τ_{vane} (Pa)	τ_{vane} (Pa)
0	10	23
48	16	37
192	NM	NM
288	26	75

The settling rates of the solids interface of the low bound and high bound simulants were also measured. Table 40 and Table 41 show the normalized settling rates of the solids interface obtained for the low and high bounding simulants respectively. The average volume % column in these tables is volume % of the solids layer relative to the total sample volume. The Std. Dev. column lists the one standard deviation for the average of three normalized measurements.

Table 40 Average Settling Rate Data for Low Bound HLW Simulants

Low Bound Pretreated HLW Feed			Low Bound HLW Melter Feed		
Minutes	**Average Vol %**	**Std Dev**	**Minutes**	**Average Vol %**	**Std Dev**
0	100.0	0.0	0	100.0	0.0
5	61.5	0.0	5	88.2	0.4
10	49.5	0.4	10	80.8	0.0
16	46.2	0.8	15	73.1	0.0
21	43.1	0.8	21	65.1	0.4
31	40.8	0.8	31	60.8	1.3
41	37.7	0.8	41	57.2	0.9
53	35.9	0.9	52	55.4	1.3
61	34.9	0.4	60	53.3	0.9
132	30.3	0.9	130	47.9	1.9
182	28.2	0.4	181	45.9	1.6
241	27.2	0.9	240	45.1	1.6
301	26.4	0.9	300	44.9	1.9
361	25.9	1.2	360	44.1	1.9
2987	25.9	1.2	2986	44.1	1.9
4532	25.9	1.2	4531	44.1	1.9

Table 41 Average Settling Rate Data for High Bound HLW Simulants

High Bound Pretreated HLW Feed			High Bound HLW Melter Feed		
Minutes	**Average Vol %**	**Std Dev**	**Minutes**	**Average Vol %**	**Std Dev**
0	100.0	0.0	0	100.0	0.0
5	100.0	0.0	5	100.0	0.0
10	100.0	0.0	10	100.0	0.0
15	100.0	0.0	15	100.0	0.0
24	100.0	0.0	24	100.0	0.0
33	99.5	0.4	33	100.0	0.0
45	99.0	0.4	45	100.0	0.0
54	98.5	0.0	55	100.0	0.0
65	98.5	0.0	65	99.5	0.4
144	97.7	0.0	145	98.7	0.4
186	97.7	0.0	186	98.7	0.4
243	96.9	0.0	244	98.2	0.9
308	96.1	0.0	309	98.2	0.9
366	95.9	0.5	368	97.3	0.7
1459	91.2	0.4	1460	95.4	0.7
3350	88.1	0.4	3355	94.6	0.7
4325	88.1	0.4	4325	94.4	0.9

Figure 20 shows that the low bound simulant with a low viscosity readily settles while the more viscous high bound simulant barely settles. The error bars represent one standard deviation for the % of total sample height.

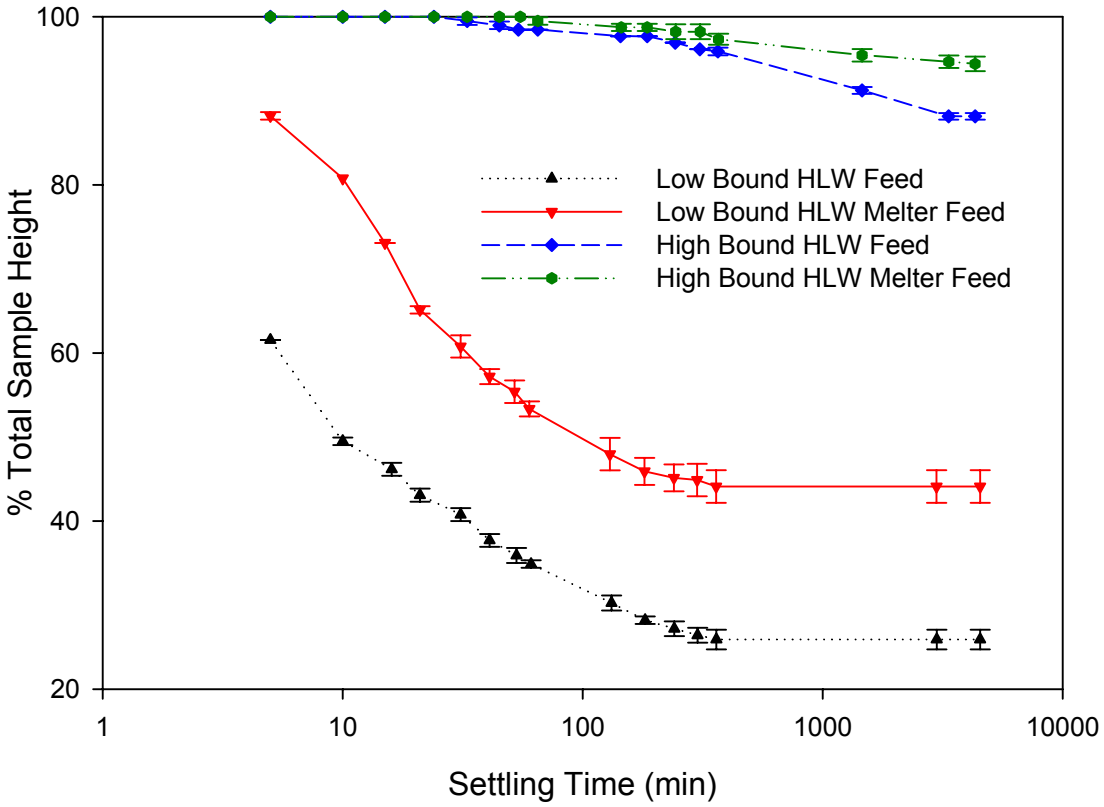

Figure 20 Settling Rate of High and Low Bound HLW Physical Simulants

The particle size data for the bounding HLW physical simulants is shown in Table 42. The difference in properties of these simulants is not obvious based upon the particle size distribution. During the analysis of these samples, differences were observed that seemed to correlate with how the sample was prepared for analysis (degree of dilution, sonication time, etc). This could be an indication that agglomerates may be dominating the measurements. Additional work in this area might make for better physical simulants if needed.

Table 42 Particle Size Distribution for the Bounding HLW Simulants

Simulant	Low Bound HLW Feed	Low Bound HLW Melter Feed	High Bound HLW Feed	High Bound HLW Melter Feed
$Percentiles_{vol}$	Particle Size, micrometers	Particle Size, micrometers	Particle Size, micrometers	Particle Size, micrometers
10	0.271	0.391	0.333	0.434
20	0.406	0.883	0.513	0.848
25	0.524	1.12	0.631	1.13
40	0.902	2.171	0.976	3.788
50	1.17	3.73	1.255	7.698
60	1.599	9.584	1.817	14.89
70	2.314	21.2	3.429	23.63
75	2.743	27.28	4.724	28.56
90	5.049	61.29	13.8	50.95
95	10.52	107	19.98	69.53
$Mean_{vol}$	2.576	23.9	4.293	19.45
$Mean_{num}$	0.227	0.209	0.315	0.293
$Mean_{area}$	0.699	1.204	0.872	1.452

Testing for a temperature rise upon GFC addition (added over a 20 minute period as done for the LAW melter feeds) did not find more than a degree or two increase. This is consistent with the composition of the HLW GFCs and the low level of hydroxide in the HLW simulants.

3.3 DEVELOPING THE HLW PRECIPITATED HYDROXIDE SIMULANT

The nominal AZ-101 chemical simulant (HLW Precipitated Hydroxide simulant) developed as a part of this study is planned for waste form compliance mixing tests. The HLW Precipitated Hydroxide simulant is based on the chemical composition of AZ-101 Envelope D sludge as shown in Table 43.

Table 43 Composition of AZ-101 Envelope D Washed, Leached Sludge[5]

AZ-101 Env. D, Washed, Leached		AZ-101 Env. D, Washed, Leached	
Species	µg/g dry waste	Species	µg/g dry waste
Ag	902	Ni	9992
Al	99872.5	P	4505
B	91	Pb	1728
Ba	1510	Pd	2300
Be	26	Rh	512
Bi	150	Ru	1600
Ca	7505	Si	13055
Cd	14500	Sn	3600
Ce	5240	Sr	3412
Co	128	Ti	178
Cr	2284	U	18500
Cu	584	Y	385
Fe	202384	Zn	278
K	2000	Zr	65050
La	5808	F	390
Li	115	Br	<170
Mg	1540	NO_2	7268
Mn	5364	NO_3	2178
Mo	66.5	PO_4	<340
Na	54545	SO_4	2410
Nd	4290	C_2O_4	518

The HLW Precipitated Hydroxide simulant was prepared based upon a process designed to mimic the manner in which the original waste was generated. The precipitation process used is similar to the precipitation process used previously for generated Envelope D sludges.[8] The process consists of the following steps:

1. Generate hydrated manganese dioxide by reacting permanganate ion and manganese (II) ion.
2. Add the transition metals, lanthanides and alkaline earth metals as nitrates or chlorides to the hydrated manganese dioxide solids.
3. Add 8 molar sodium hydroxide to the slurry to precipitate the metal ions until the pH is greater than 10. Continuous mixing must be maintained to prevent locally higher pH values
4. Add a 0.6 molar sodium carbonate solution to enable conversion of the more soluble hydroxides to less-soluble carbonates, such as the conversion of calcium hydroxide to calcium carbonate.

5. Wash the insoluble solids with inhibited water (0.01 molar NaOH and 0.01 molar $NaNO_2$) to reduce the nitrate concentration in the aqueous phase to less than 1000 mg/L.
6. Decant or dewater the precipitated slurry to approximately 10-11 wt % total solids.
7. Add hydroxide-reactive insoluble species of known particle size to the 11 wt % solids slurry. Measure the total and insoluble solids of the slurry.
8. Place the slurry in a heated vessel with a condenser and boil the slurry at atmospheric conditions (temperature 102-103 ° C) for 6-7 hours to remove sufficient condensate to raise the total solids content to approximately 20 weight percent.
9. Measure the volume of the slurry and add the soluble salts to reach the final desired concentration.

Appendix F describes the complete process thoroughly and Table F-2 gives the details of the recipe. The preparation of the HLW Precipitated Hydroxide simulant in this study used batch washing with gravity settling in step 5. However, it should be possible to use continuous or batch washing with filtration to remove the soluble nitrate ion. The initial slurry after steps 3 and 4 had solids that are dark brown-black in color. After heat-treating/dewatering the slurry in step 8, the color of the insoluble solids changed to a red color similar to that of ferric oxide. An analysis of the precipitated solids before the heat treatment by x-ray diffraction (XRD) did not detect any Fe_2O_3 in the solids. The solids after heat treatment did show the presence of Fe_2O_3 in the XRD analysis. Based on this information, the form of the iron in the initial precipitate was probably amorphous $Fe(OH)_3$ which then dehydrated and crystallized to the Fe_2O_3 observed by XRD.

The HLW Precipitated Hydroxide simulant was converted to the pretreated HLW Precipitated Hydroxide simulant by the addition of Cs IX concentrate produced as detailed in Table F-3 in Appendix F. The only difference between the Cs IX concentrate used for the HLW Precipitated Hydroxide and that used for the HLW physical simulants (Table 29) is the addition of the hazardous species Cd, Cr, Ni and Pb. The amount of Cs IX concentrate added is specified in Table F-2. The chemical analysis of the pretreated HLW Precipitated Hydroxide simulant compared to the starting AZ-101 sludge basis is shown in Table 44.

Table 44 Chemical Analysis of Pretreated HLW Precipitated Hydroxide Compared to Radioactive Washed, Leached AZ-101 Sludge Solids

Species	Pretreated HLW Precipitated Hydroxide µg/gram solids	Radioactive AZ-101 Washed, Leached µg /gram solids	% of Target	Analysis Method
Ag	<280	902	<31	ICPES
Al	86659	99872	87	ICPES*
B	3573	91	3927	ICPES*
Ba	1657	1510	110	ICPES
C_2O_4	186	518	36	IC
Ca	8158	7505	109	ICPES
Ca	9609	7505	128	ICPES*
Cd	11265	14500	78	ICPES
Cd	10930	14500	75	ICPES*
Ce	3444	5240	66	ICPES
Cl	443	703	63	IC
Co	150	128	117	ICPES
Cr	2344	2284	103	ICPES
Cu	609	584	104	ICPES
F	172	390	44	IC
Fe	202384	202384	100	ICPES
Fe	202384	202384	100	ICPES*
K	3172	2000	159	ICPES
K	2508	2000	125	AA
La	3755	5808	65	ICPES
Mg	1554	1540	101	ICPES
Mn	5438	5364	101	ICPES
Mo	<90	66	<139	ICPES
Na	41047	54545	75	ICPES
Na	42212	54545	77	AA
Nd	3108	4290	72	ICPES
Ni	9970	9992	100	ICPES
NO_2	4623	7268	64	IC
NO_3	48686	2178	2235	IC
P	2564	4505	57	ICPES
PO_4	627	<340	NA	IC
Rh	546	512	107	ICPMS
Ru	947	1600	59	ICPMS
Si	27321	13055	209	ICPES
Si	15794	13055	121	ICPES*
Sn	1554	3600	43	ICPES
SO_4	1997	2410	83	IC
Ti	341	178	191	ICPES

Species	Pretreated HLW Precipitated Hydroxide µg/gram solids	Radioactive AZ-101 Washed, Leached µg /gram solids	% of Target	Analysis Method
Zn	337	278	121	ICPES
Zr	61505	65050	95	ICPES
Zr	59334	65050	91	ICPES*

* Different sample preparation method used. Na_2O_2 fusion instead of HNO_3/HF microwave dissolution

The values given for the pretreated HLW Precipitated Hydroxide simulant solids were normalized based upon the value for Fe to put the results on the same basis as the radioactive AZ-101 results. An alternative comparison was also made without the normalization by converting the measured HLW Precipitated Hydroxide simulant concentration and the radioactive AZ-101 values to a wt % oxides basis and comparing those values. The results were essentially the same as the percent of target values shown above. The large nitrate concentration in the pretreated HLW Precipitated Hydroxide simulant is due to the addition of the Cs IX concentrate. Some of the low values for some of the metals could be reflecting the solubility of the hydroxide form of that metal.

Addition of the GFCs to the pretreated HLW Precipitated Hydroxide simulant is made based upon the amount of waste oxides in the pretreated HLW Precipitated Hydroxide simulant as reflected in the calcine factor. The calcine factor is calculated as the wt % calcine solids divided by the wt % total solids. The wt % calcine solids are determined by heating a measured mass of slurry to 1050 ° C for thirty minutes to calcine the simulant and then measuring the final mass after cooling in a dessicator. The HLW Precipitated Hydroxide melter feeds tested in this report were based upon an estimated calcine factor of 0.765 which fit well with previous precipitated sludge simulants.[8] After the HLW Precipitated Hydroxide melter feeds had been made, the calcine factor was measured at 0.887, which is considerably higher than expected. The estimate for the pretreated HLW physical simulant calcine factor of 0.784 compared very nicely with the measured calcine factor of 0.808. The result of using the estimated calcine factor is that the HLW Precipitated Hydroxide melter feed in this task contains 14 % less GFCs than necessary to make the AZ-101 HLW glass composition. This variance will be discussed during the rheological discussion for the HLW Precipitated Hydroxide simulants. The measured HLW Precipitated Hydroxide melter feed composition is compared in Table 45 to the planned composition for the melter feed. The concentration values reported for the HLW Precipitated Hydroxide melter feed is the average of triplicate analyses and the Std Dev column reports the standard deviation for the average.

Table 45 Composition of HLW Precipitated Hydroxide Melter Feed Compared to Planned Composition

Species	Concentration mg/L	Std Dev	Target mg/L	% of Target	Analysis Method
Ag	<50	NA	1	NA	ICPES
Al	10260	270	11800	87	ICPES*
B	9870	270	9060	109	ICPES*
Ba	200	10	180	111	ICPES
$C_2O_4^{-2}$	20	1	80	25	IC
Ca	1000	70	920	109	ICPES
Ca	1240	20	920	135	ICPES*
Cd	1310	110	1720	76	ICPES
Cd	1310	20	1720	76	ICPES*
Ce	510	80	620	82	ICPES
Cl^-	70	1	70	100	IC
Co	20	3	20	100	ICPES
Cr	270	30	290	93	ICPES
Cs	30	1	15	200	AA
Cu	70	4	70	100	ICPES
F^-	20	2	25	80	IC
Fe	24000	1800	24000	100	ICPES
Fe	23900	230	24000	100	ICPES*
K	430	70	300	143	ICPES
K	310	25	300	103	AA
La	550	110	690	80	ICPES
Mg	190	10	190	100	ICPES
Mn	640	70	640	100	ICPES
Mo	<20	NA	10	NA	ICPES
Na	22600	1170	22600	100	ICPES
Na	22300	1330	21800	102	AA
Nd	440	50	510	86	ICPES
Ni	1190	110	1190	100	ICPES
NO_2^-	560	20	300	187	IC
NO_3^-	6060	310	5910	102	IC
P	350	30	290	121	ICPES
PO_4^{-3}	30	3	890	3	IC
Rh	60	10	60	100	ICPMS
Ru	130	40	190	68	ICPMS
Si	50500	5400	58100	87	ICPES
Si	59500	680	58100	102	ICPES*
Sn	190	50	430	44	ICPES
SO_4^{-2}	280	2	250	112	IC
Ti	40	3	20	200	ICPES
TIC	6300	780	13300	47	TIC/TOC
Zn	4570	400	4500	102	ICPES
Zr	7310	620	7720	95	ICPES

Species	Concentration mg/L	Std Dev	Target mg/L	% of Target	Analysis Method
Zr	7070	60	7720	92	ICPES*

* Different sample preparation method used. Na_2O_2 fusion instead of HNO_3/HF microwave dissolution

The pretreated HLW Precipitated Hydroxide simulant was prepared at 22.3 wt % total solids. The HLW Precipitated Hydroxide melter feed simulant was prepared from the pretreated HLW Precipitated Hydroxide simulant by adding the appropriate amount of GFCs based upon the estimated calcine factor cited earlier. Dilutions of the pretreated HLW Precipitated Hydroxide simulant were made with deionized water to produce lower solids loading pretreated HLW Precipitated Hydroxide simulants. The same amount of dilution water was also added to an appropriate amount of HLW Precipitated Hydroxide melter feed to produce HLW Precipitated Hydroxide melter feeds produced from lower solids loading simulants. The physical properties of these simulants are listed in Table 46. The rheological properties of these simulants were measured at 25 and 40 ° C and the results are shown in Table 47. The wt % calcine solids for the pretreated HLW Precipitated Hydroxide simulant was 19.75 wt %. The calcine factor is 0.887.

Table 46 Physical Properties of HLW Precipitated Hydroxide Simulants

Material	Total Solids, Wt %	Soluble Solids in Supernate, Wt %	Soluble Solids, Wt %	Insoluble Solids, Wt %	pH	Density at 25 ° C, g/mL
HLW Precipitated Hydroxide Blend	20.48	0.26	0.21	20.27	13.01	1.164
11.5 Wt % Pretreated HLW Precipitated Hydroxide	11.53	1.73	1.56	9.97	12.16	1.094
17.7 Wt % Pretreated HLW Precipitated Hydroxide	17.69	1.63	1.38	16.31	12.63	1.147
Pretreated HLW Precipitated Hydroxide	22.26	3.97	3.21	19.05	12.48	1.197
11.5 Wt % HLW Precipitated Hydroxide + GFCs	28.62	8.12	6.31	22.31	10.25	1.256
17.7 Wt % HLW Precipitated Hydroxide + GFCs	39.07	10.89	7.44	31.63	9.95	1.361
HLW Precipitated Hydroxide Melter Feed	45.42	12.33	7.68	37.75	9.34	1.400

Table 47 Rheology of HLW Precipitated Hydroxide Simulants

Material	Rheology at 25 ° C				Rheology at 40 ° C			
	Yield Stress Pascal	Consistency or Viscosity milliPascal-seconds	Bingham Plastic Model Fit r^2	Bingham Plastic Model Fit Range s^{-1}	Yield Stress Pascal	Consistency or Viscosity milliPascal-seconds	Bingham Plastic Model Fit r^2	Bingham Plastic Model Fit Range s^{-1}
HLW Precipitated Hydroxide Blend	14.0	11.0	0.9960	Up 50-1000	16.0	11.0	0.9874	Up 50-1000
Pretreated HLW Precipitated Hydroxide	12.0	11.7	0.9430	Up 0-1000	13.2	11.2	0.9025	Up 0-1000
Pretreated HLW Precipitated Hydroxide	12.5	11	0.9967	Up 50-1000	13.7	10.4	0.9971	Up 50-1000
11.5 Wt % Pretreated HLW Precipitated Hydroxide	0.6	2.6	0.9972	Up 50-600	0.6	2.2	0.9949	Up 50-550
17.7 Wt % Pretreated HLW Precipitated Hydroxide	3.6	5.2	0.9953	Up 50-1000	3.8	5.0	0.9912	Up 50-1000
HLW Precipitated Hydroxide Melter Feed	18.9	28.5	0.992	Up 50-1000	15.7	20.2	0.9975	Up 50-1000
11.5 Wt % HLW Precipitated Hydroxide + GFCs	0.7	4.0	0.9990	Up 50-700	0.7	3.2	0.9985	Up 50-650
17.7 Wt % HLW Precipitated Hydroxide + GFCs	3.6	11.2	0.9986	Up 50-1000	2.7	10.7	0.9940	Up 50-1000

The rheology of the pretreated HLW Precipitated Hydroxide simulant at 22.26 wt % total solids compares very favorably with the actual AZ-101 sludge at 22 wt % undissolved solids. Figure 21 shows the pretreated HLW Precipitated Hydroxide and the HLW Precipitated Hydroxide blend compared to the actual AZ-101 sludge rheology data. Within the data range that the actual waste data was collected the values for yield stress and consistency are within a few percent of the radioactive AZ-101 Bingham Plastic model fit values.

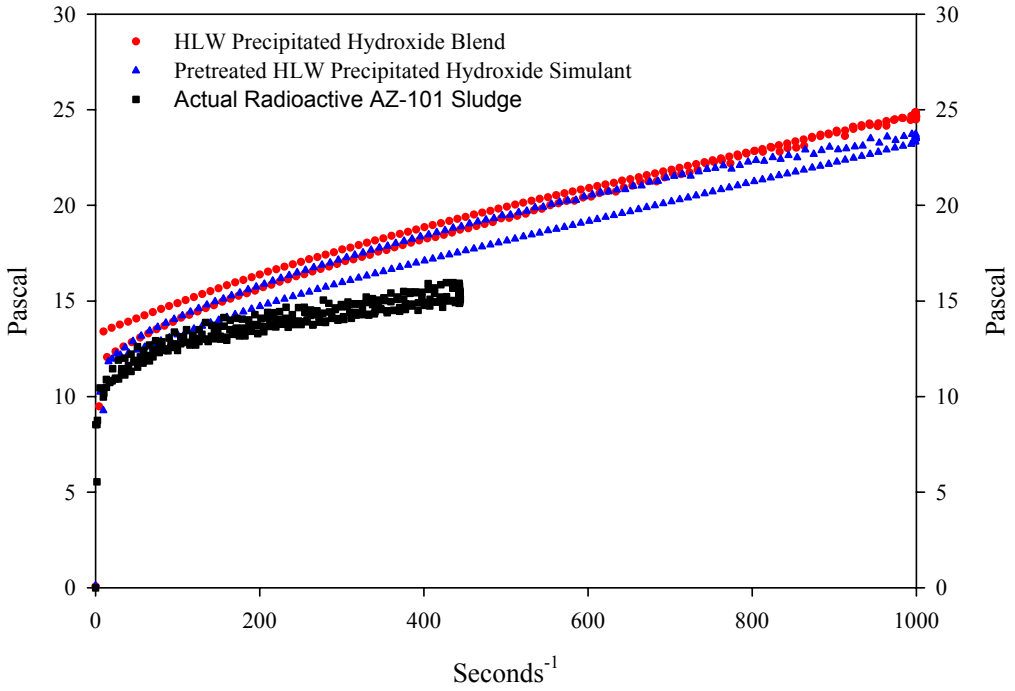

Figure 21 Rheology of Pretreated HLW Precipitated Hydroxide Simulant and HLW Precipitated Hydroxide Blend Compared to Actual AZ-101 Sludge Data

Addition of the GFCs did not appreciably increase the yield stress value but did increase the consistency for the highest solids loading by a larger amount. Neither the pretreated HLW Precipitated Hydroxide simulant rheology nor the HLW Precipitated Hydroxide melter feed rheology approached the bounding limits for this solids loading. However, the substantial increase in the yield stress and consistency in going from 17.7 wt % solids to 22.3 wt % solids suggest that the exponential growth curve observed for the HLW physical simulant (Figure 17) has a parallel situation in a more realistic waste. Additional data points at high solids loadings would help to define the sensitivity of the curve to increasing solids above 22 wt %. It is also clear that the sludge particles determine the rheology more than the GFCs by comparing the yield stresses of the pretreated HLW Precipitated Hydroxide simulant to the yield stresses of the HLW Precipitated Hydroxide melter feed produced from it.

Another rheology property of concern for application of the HLW Precipitated Hydroxide simulants is the settled shear strength. For the HLW CRV and MFPV, the maximum expected down time for the vessel agitation is expected to be 192 hours. Therefore, a simulant that has settled for up to 192 hours must not have a shear strength that exceeds 625 Pa.[1] The settled shear strengths were measured for the HLW Precipitated Hydroxide simulants at maximum solids loading using the vane method previously described. Table 48 shows that the settled shear strength after 192 hours did not exceed the maximum allowed.

Table 48 Settled Shear Strengths for the pretreated HLW Precipitated Hydroxide Simulant and HLW Precipitated Hydroxide Melter Feed Simulant

Hours	Pretreated HLW Precipitated Hydroxide at 22 wt % TS	HLW Precipitated Hydroxide Melter Feed at 22 wt% HLW
	τ_{vane} (Pa)	τ_{vane} (Pa)
0	11.1 ± 0.2	12.6 ± 0.5
48	25.6 ± 1.2	40.2 ± 0.8
192	30.8 ± 0.7	45.5± 1.7

The settling rates of the solids interface of the pretreated HLW Precipitated Hydroxide simulants and HLW Precipitated Hydroxide melter feed simulants at different solids loadings were also measured. Table 49 and Table 50 show the normalized settling rates of the solids interface obtained for the pretreated HLW Precipitated Hydroxide simulants and HLW Precipitated Hydroxide melter feed simulants respectively. The average volume % column in these tables is the volume of the solids layer relative to the total sample volume. The Std Dev columns give the error in terms of one standard deviation on the measured volume.

Table 49 Average Settling Rate Data for Pretreated HLW Precipitated Hydroxide Simulants

11.7 Wt % Total Solids Pretreated HLW Precipitated Hydroxide Simulant			17.5 Wt % Total Solids Pretreated HLW Precipitated Hydroxide Simulant			22.3 Wt % Total Solids Pretreated HLW Precipitated Hydroxide Simulant		
Minutes	**Average Vol %**	**Std Dev**	**Minutes**	**Average Vol %**	**Std Dev**	**Minutes**	**Average Vol %**	**Std Dev**
0	100.0	0.0	0	100.0	0.0	0	100.0	0.0
5	100.0	0.0	5	100.0	0.0	5	100.0	0.0
10	93.3	0.4	10	100.0	0.0	10	100.0	0.0
15	91.5	0.8	15	100.0	0.0	15	100.0	0.0
24	88.5	0.8	24	96.2	1.3	23	100.0	0.0
33	86.7	1.2	33	95.9	0.9	33	100.0	0.0
42	85.5	1.1	43	95.1	0.9	45	100.0	0.0
50	84.4	0.4	50	94.6	1.3	53	99.7	0.4
62	83.6	0.4	63	94.6	1.3	64	99.7	0.4
143	78.5	0.8	144	93.8	1.3	144	99.2	0.8
184	76.4	0.4	185	93.3	1.2	186	98.9	0.4
240	74.1	0.4	240	92.1	0.9	242	98.6	0.6
300	72.6	0.4	300	91.3	1.6	306	98.2	0.5
360	71.0	0.4	360	91.3	1.6	366	98.2	0.5
1453	65.9	0.4	1455	85.9	1.2	1458	97.2	0.9
3345	64.1	0.9	3345	85.4	1.3	3350	96.7	0.5
4320	63.5	0.7	4320	85.4	1.3	4324	96.7	0.5

Table 50 Average Settling Rate Data for HLW Precipitated Hydroxide Melter Feeds

11.5 Wt % Total Solids Pretreated HLW Precipitated Hydroxide + GFCs			17.5 Wt % Total Solids Pretreated HLW Precipitated Hydroxide + GFCs			22.3 Wt % Total Solids Pretreated HLW Precipitated Hydroxide + GFCs		
Minutes	**Average Vol %**	**Std Dev**	**Minutes**	**Average Vol %**	**Std Dev**	**Minutes**	**Average Vol %**	**Std Dev**
0	100.0	0.0	0	100.0	0.0	0	100.0	0.0
5	98.5	0.0	5	100.0	0.0	5	100.0	0.0
10	96.9	0.0	10	100.0	0.0	10	100.0	0.0
15	96.2	0.0	15	100.0	0.0	15	100.0	0.0
24	95.4	0.0	24	96.7	0.9	24	100.0	0.0
30	94.7	0.8	32	96.4	1.2	33	100.0	0.0
40	92.3	1.5	41	96.2	0.8	44	99.2	0.0
50	90.5	1.9	50	95.4	0.8	53	99.2	0.0
60	88.7	1.6	61	95.4	0.8	63	99.2	0.0
140	82.8	1.2	142	94.9	1.2	144	99.2	0.0
182	80.3	0.9	183	94.4	1.2	186	99.2	0.0
240	77.9	0.9	240	93.8	0.8	241	99.2	0.0
300	76.2	0.8	300	93.1	0.8	305	99.0	0.4
360	74.9	0.9	360	93.1	0.8	365	98.7	0.4
1450	66.2	0.8	1452	87.7	0.8	1456	97.2	0.4
3345	64.1	0.9	3345	84.6	0.8	3350	96.4	0.4
4320	64.1	0.9	4320	84.4	1.2	4322	96.2	0.0

Figure 22 and Figure 23 show that the normalized settling rate of the solids interface for the pretreated HLW Precipitated Hydroxide feed simulant and for the melter feed simulant are a strong function of solids loading.

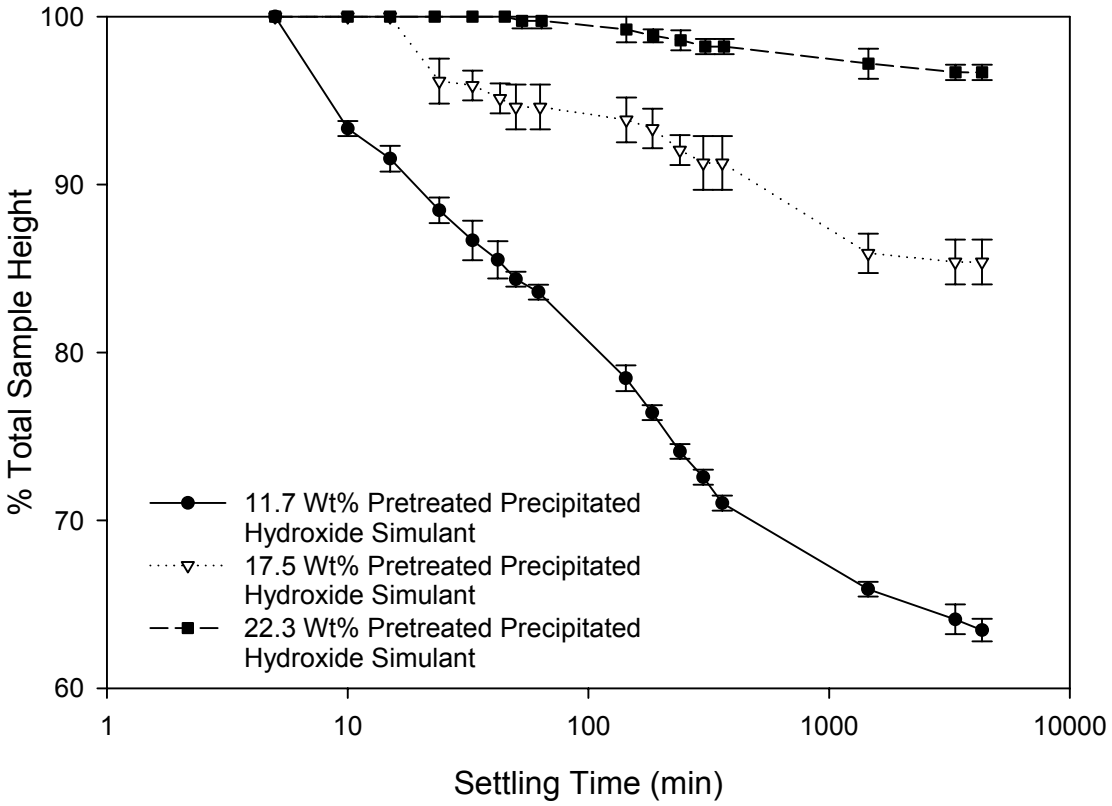

Figure 22 Settling Rate for Pretreated HLW Precipitated Hydroxide Feed Simulant

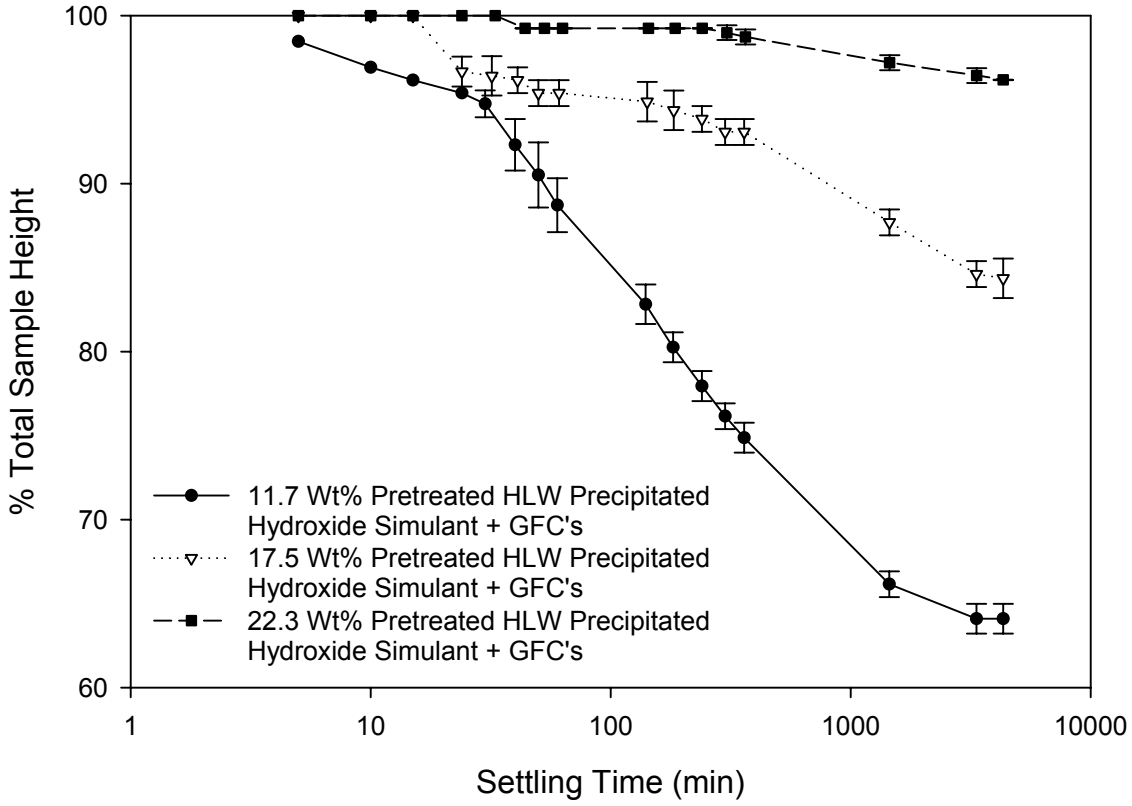

Figure 23 Settling Rate of HLW Precipitated Hydroxide Melter Feed

Four samples from the production of the HLW Precipitated Hydroxide simulant were submitted for particle size data. These samples were the initial settled, washed precipitated simulant from Step 7 (see page 76) labeled as Initial HLW Precipitated Hydroxide simulant, a sample after Step 8 (see page 76) labeled as HLW Precipitated Hydroxide-4 Concentrate, HLW Precipitated Hydroxide Blend represents the simulant before Cs IX concentrate addition, and the pretreated HLW Precipitated Hydroxide simulant at 22.3 wt % total solids. Table 51 displays the particle size distribution for these four samples and Appendix H shows the raw data and plots of distribution.

Table 51 Particle Size Distribution Data for HLW Precipitated Hydroxide Simulants

Simulant	Initial HLW Precipitated Hydroxide Solids	HLW Precipitated Hydroxide-4 Concentrate	HLW Precipitated Hydroxide Blend	Pretreated HLW Precipitated Hydroxide
Percentiles$_{vol}$	Particle Size, micrometers	Particle Size, micrometers	Particle Size, micrometers	Particle Size, micrometers
10	5.24	2.95	0.773	0.584
20	8.078	5.921	3.014	2.476
25	9.719	7.588	4.231	3.657
40	16.41	15.45	8.946	8.239
50	22.97	24.62	14.61	14.45
60	33.08	43.09	24.48	26.76
70	49.12	80.48	47.76	60.84
75	61.89	108	67.09	84.52
90	175.1	211.4	157.3	185.6
95	259	266.4	239.2	248.4
Mean$_{vol}$	58.96	70.76	53.95	57.68
Mean$_{num}$	2.798	0.386	0.22	0.229
Mean$_{area}$	12.68	5.715	2.131	1.947

A comparison of the initial distribution to the distribution after boiling shows a significant change in the particles that make up the simulant. The average for the particle number distribution is shifted toward more small particles, but the mean volume had increased. At the 10 percentile level the heat-treated HLW Precipitated Hydroxide simulant is at 2.95 micrometers while the initial HLW Precipitated Hydroxide simulant is at 5.2 micrometers. The appearance of the distribution has also changed from bimodal to trimodal (see Appendix H). Addition of the soluble species and then of the Cs IX concentrate modifies the material further toward more small particles while still having a broad distribution of sizes.

Testing for a temperature rise upon GFC addition to the HLW Precipitated Hydroxide simulant (as done for the LAW and HLW melter feeds) did not find more than a one degree increase when the GFCs are added over a twenty minute period. This is consistent with the composition of the HLW GFCs and the low level of hydroxide in the HLW Precipitated Hydroxide simulants.

4.0 FUTURE WORK

Additional work with the bounding simulants should focus in three areas:

- Time dependence for LAW melter feed simulants (especially if much work is planned with the viscosity modifiers added to a LAW simulant).
- The impact of insoluble solids loading on the HLW physical simulant should be examined in case the rheology limits are modified.
- Determining the impact of dissolved solids on HLW consistency could be the key to improve the Upper Bound HLW physical simulant.

The HLW Precipitated Hydroxide simulant should also be studied further to provide an understanding of the impact of increasing the insoluble solids loading on rheology.

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APPENDIX A

1. APPENDIX A. LOW BOUNDING PRETREATED LAW FEED PHYSICAL SIMULANT WITH AND WITHOUT GLASS FORMERS

1. Simulant Designation

The low bounding pretreated LAW physical simulant with and without glass formers is designed to represent pretreated LAW waste and LAW melter feed with rheological properties close to the low bound conditions of the LAW Chemical Receipt Vessel (CRV) and the LAW Melter Feed Process Vessel (MFPV). The simulant is intended for mixing and agitator tests for the CRV and MFPV vessels. The simulant is designed to reproduce the physical interactions expected for LAW feeds combined with the planned LAW glass formers.

2. Simulant Waste Stream Composition and Unit Operation Usage

2.1. CHARACTERIZATION DATA DESCRIPTION

The compositional basis of the physical simulant was derived from the characterization of AP-101 supernate and the development of an AP-101 supernate simulant (Russell, 2003). Only those species at concentrations greater than 0.01 molar were retained in the simulant formulation. Table A-1 compares the composition of the Battelle AP-101 simulant (adjusted to a 3 molar Na Basis) with the Low Bounding LAW Pretreated Waste Physical Simulant.

Table A- 1 Comparison of low bounding LAW Pretreated Waste Physical simulant composition to Battelle AP-101 Supernate Simulant

	Battelle AP-101 Original Basis	Battelle AP-101 3 M Na Basis	Low Bound LAW Pretreated Waste Physical Simulant
Species	**Moles/Liter**	**Moles/Liter**	**Moles/Liter**
Acetate	0.0247	0.0148	0.0148
Aluminum	0.259	0.155	0.155
Barium	2.1E-6	1.26E-6	NA
Beryllium	1.3E-4	7.8E-5	NA
Boron	0.00132	0.00079	NA
Cadmium	1.58E-5	9.5E-6	NA
Calcium	1.71E-4	1.03E-4	NA
Carbonate	0.446	0.268	0.268
Cesium	4.5E-5	2.7E-5	NA
Chloride	0.0409	0.0245	0.0245
Chromium	0.00292	0.00175	NA
Copper	2.2E-5	1.3E-5	NA
Fluoride	0.00281	0.00169	NA
Formate	0.0237	0.0142	0.0142
Hydroxide	2.98	1.788	1.788
Iron	4E-5	2.4E-5	NA
Lead	6.4E-5	3.9E-5	NA
Lithium	4.3E-5	2.6E-5	NA
Molybdenum	1.34E-4	8.1E-5	NA
Nickel	1.2E-4	7.2E-5	NA
Nitrate	1.68	1.009	1.009
Nitrite	0.707	0.424	0.424
Oxalate	0.0178	0.0107	0.0107
Phosphate	0.0124	0.00746	0.00746
Potassium	0.712	0.427	0.427
Rubidium	4.1E-5	2.5E-5	NA
Silicon	0.00434	0.00260	0.0026
Sodium	5.00	3.00	2.98
Sulfate	0.0373	0.0224	0.0224
Tungsten	1.19E-4	7.2E-5	NA
Zinc	7.6E-5	4.6E-5	NA

2.2. FLOWSHEET OPERATION FOR WHICH THE SIMULANT WAS DEVELOPED

The low bounding pretreated LAW physical simulant was developed to support mixing, sampling and waste transfer studies to aid in verifying adequate design of these systems. Since the composition of simulant does not completely match the composition of AP-101 pretreated waste supernate, it should not be used to represent AP-101 waste.

3. Actual Simulant Preparation Procedure

3.1. CHEMICALS TO USE

Development of the physical simulant used reagent grade chemicals. However, technical grade chemicals should be sufficient for producing larger scale quantities of the simulant. These technical grade chemicals should be at least 97 % pure. Cost, chemical availability, and ease of scale up were considered in choosing which compounds to use. Many of the salts used in the simulant include waters of hydration and the specific form to be used is shown in Table A-2. Care must be taken in storing and using some of these compounds due to their tendency to readily absorb water. Using a salt, which has obviously absorbed excess water, will lead to missing the target value for that compound. When necessary, a solution of the compound can be used. However, the water additions shown in Table A-2 will have to be appropriately reduced to account for the water in the solution of the compound.

The low bound LAW melter feed physical simulant is prepared from the low bound LAW pretreated waste feed physical simulant by the addition of the appropriate amount of approved glass formers as specified by the Waste Treatment Plant (WTP) Project. The composition of glass formers shown in Table A-3 is based on the composition specified for the AP-101 supernate sample (Prindiville, 2002 and Bredt, 2002).

3.2. CHEMICAL ADDITION ORDER

The order of chemical addition to produce the supernate simulant is shown in Table A-2 and is based upon the following logical steps:

- Prepare a solution of acid stable salts.
- Convert solution from acid to base by addition of sodium hydroxide and selected basic salts.
- Add base-stable.

These steps produce the desired composition expected in the waste simulant while avoiding the acid-induced decomposition of carbonate or nitrite.
The water used for the simulant should be deionized water to limit the addition of other uncontrolled species. The mass of water added in each step is based upon producing a simulant solution with a total Na concentration of 3 molar and a solution density of 1.158 g/mL at 25 ° C based on previous preparations of this simulant.

Table A-2 Chemical Addition Order and Amounts for Producing One Liter of the Low Bound LAW Pretreated Waste Feed Physical Simulant

Low Bound LAW Pretreated Waste Feed Physical Simulant at 3 M Na		
Volume of Feed	**1**	**Liters**
Target Density	**1.1576**	**g/mL**
To the Simulant Preparation Vessel	**grams**	
Water	150	
Next add the following while maintaining good mixing		
Compounds	**Formula**	**Mass Needed, grams**
Sodium Acetate	$NaCH_3COO \bullet 3H_2O$	2.02
Sodium Oxalate	$Na_2C_2O_4$	1.43
Aluminum Nitrate	$Al(NO_3)_3 \bullet 9H_2O$	58.23
Sodium Chloride	NaCl	1.43
Sodium Dihydrogen Phosphate	$NaH_2PO_4 \bullet H_2O$	1.03
Sodium Sulfate	Na_2SO_4	3.18
Sodium Nitrate	$NaNO_3$	36.0
Potassium Nitrate	KNO_3	12.01
Mix thoroughly to dissolve solids. Then add the following while mixing.	**Formula**	**Mass Needed, grams**
Sodium Hydroxide (50 wt % solution)	NaOH	143.04
Sodium meta-silicate	$Na_2SiO_3 \bullet 9H_2O$	0.74
Sodium Formate	HCOONa	0.97
Sodium Nitrite	$NaNO_2$	29.27
Sodium Carbonate	Na_2CO_3	12.02
Potassium Carbonate	K_2CO_3	21.31
Water	H_2O	684.9
Mix thoroughly.		
Continue agitation for 24 hours to completely dissolve as much as possible. No appreciable solids should remain.		

The addition of glass formers to the LAW Pretreated Waste Feed should be made as a single continuous addition by premixing the dry glass formers as the first step. The combined glass formers are then added with good mixing to a stirred batch of the low bounding LAW Pretreated Waste Feed physical simulant. The amounts of the glass formers required for one liter of the LAW Pretreated Waste Feed to produce LAW Melter Feed is shown in Table A-3.

Table A-3 Glass Formers required for One Liter of Low Bound LAW Pretreated Waste Feed Physical Simulant to produce the Low Bound LAW Melter Feed Physical Simulant

Blend together the following glass formers	grams
Kyanite (Al_2SiO_5) 325 Mesh	35.67
Boric Acid, H_3BO_3 (Technical - Granular)	87.65
Wollastonite NYAD 325 Mesh	21.16
Ferric Oxide, Fe_2O_3 (-325 Mesh) Prince 5001	27.21
Olivine (Mg_2SiO_4) 325 Mesh (#180)	15.50
Silica, SiO_2 (Sil-co-Sil 75)	183.63
Titanium Dioxide, TiO_2 (Rutile - Airfloated)	10.52
Zinc Oxide, ZnO (K-920)	14.99
Zircon $ZrSiO_4$ (Flour) 325 Mesh	22.67

The addition of the glass formers produces 1.14 liters of the low bound LAW Melter Feed physical simulant with a density of 1.382 g/mL at 25 ° C.

3.3. PRECAUTIONS

- Material Safety Data Sheets (MSDS) should be reviewed for all of the compounds in the simulant formulation.
- Appropriate safety apparel (acid-resistant gloves, etc) should be worn when working with chemicals as specified in the MSDS.
- Addition of the transition metal nitrates to the initial solution will produce a very acidic solution.
- Addition of the NaOH solution results in significant heat generation. The NaOH can be added slowly allowing heat to dissipate, or the mixing container can be cooled by use of an external or internal cooling system (ice bath, cooling coils, etc).
- During the initial stages of sodium hydroxide addition, significant Al solids form. Mixing may become difficult at this point. The Al solids will return to solution when pH ~9 is exceeded.
- The carbonate salts are added after the NaOH to avoid carbonate decomposition.
- Addition of sodium nitrite must be made after the addition of sodium hydroxide to avoid generation of NO_x vapors.
- The addition of the glass formers will also produce heat as a result of the reaction between hydroxide ion and the boric acid. For a one liter batch of the LAW pretreated waste feed physical simulant, a temperature increase of 6 degrees C has been measured using a glass former addition period of 15 minutes.

3.4. OTHER CONSIDERATIONS

- The stability of the low bound LAW feed simulant is not an issue since it has been based upon a previous simulant with good stability (Russell 2003).
- Preliminary tests combined with other LAW melter feed studies suggest that the low bound LAW melter feed simulant does not have stability problems.
- The low bound LAW Feed simulant should not be stored in glass or glass-lined containers since etching of the glass will occur which could impact the rheological properties of the simulant.

4. Key Characteristics and Limitations of the Low Bound LAW Pretreated Waste Feed and LAW Melter Feed Physical Simulants

4.1. KEY CHARACTERISTICS

The simulant composition is designed to match the major constituents of actual AP-101 waste diluted to 3 Molar Na. Of specific concern are the constituents that can interact with the glass formers to modify the physical properties of the simulant. These constituents include the Na, Al, OH^-, and CO_3^{-2} concentrations. Solution density and viscosity are process-affecting and result from the concentration of the previously mentioned species.

4.2. LIMITATIONS

The physical simulants described in this document were primarily designed to support process studies that only involve physical properties. The simulants should not be used for process chemistry studies, waste acceptance or environmental impact studies.

5. Validation of the Simulant

Validation of a simulant is normally based upon comparison of the simulant with actual waste measurements for the waste that the simulant is designed to duplicate. However, these two simulants are instead designed to match the lower limits for the processes that will use the simulants. Therefore, validation of this simulant is based upon comparison with the physical properties (rheology) required of a bounding simulant. Actual waste measurements are therefore not needed for comparison. The bounding rheological properties required of the low bound physical simulant were as specified in the test specification (Prindiville 2002):

- The LAW feed simulant must be Newtonian (no measurable yield stress).
- The viscosity (consistency) of the LAW feed simulant must be 2 milliPascal-seconds (mPa·s) (±20%).
- The LAW melter feed simulant must be Newtonian (no measurable yield stress).
- The viscosity (consistency) of the LAW melter feed simulant must be 2 mPa·s (±20%).

5.1. CHEMICAL COMPOSITION

Chemical composition is not a required feature for a physical simulant. However, the low bounding LAW pretreated waste feed physical simulant is based on the major species (>0.01 Molar) in the AP-101 waste when the waste supernate has been diluted to 3 molar in sodium.

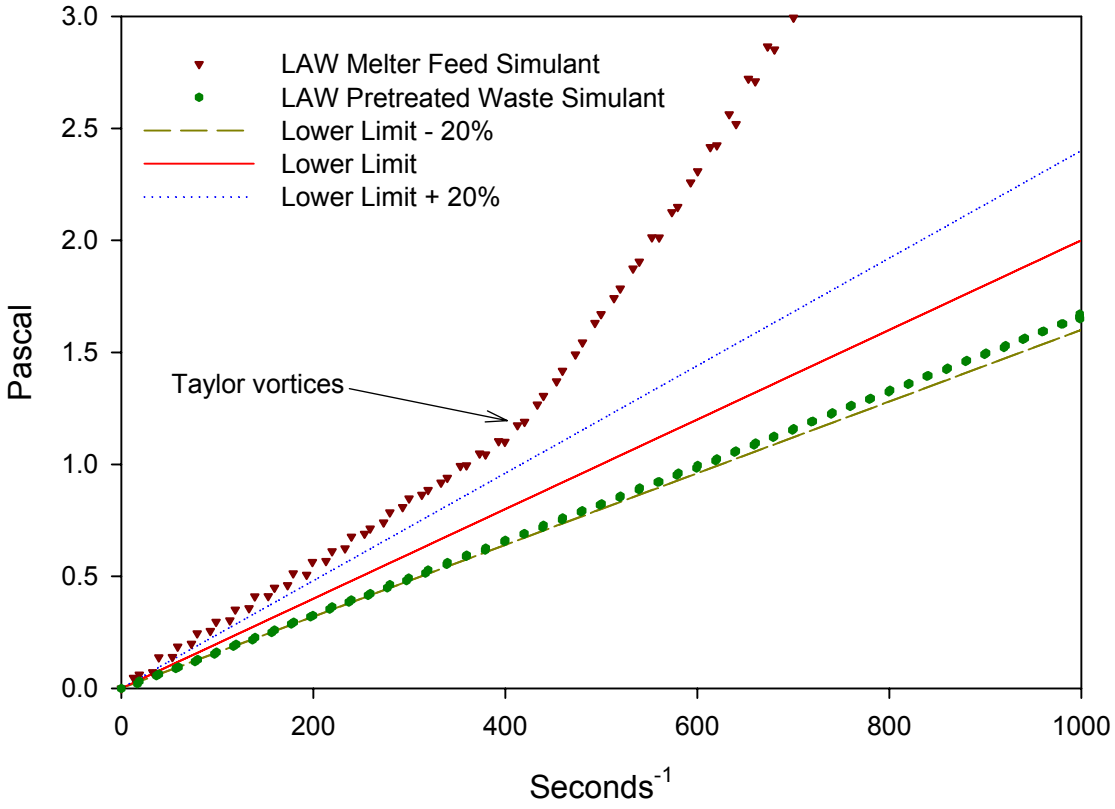
5.2. CHARGE BALANCING

The physical simulant was derived from the composition of the AP-101 supernate simulant. (Russell, 2003) Since the AP-101 simulant had already addressed the charge balancing issue, additional work on this was unnecessary.

6. Simulant Properties Compared to Bounding Waste Properties

The rheograms of the LAW feed and LAW melter feed physical simulants indicate that the fluids are Newtonian in behavior since they are linear with the shear rate versus shear stress relationship passing through the origin. Figure A-1 shows both simulants compared to the lower rheological limits.

Figure A-1 Comparison of the LAW Physical Simulants to the Lower Rheological Limit



Note that the LAW pretreated waste feed simulant was measured on the Haake RS-150 with the DG41 sensor. Because of the glass former solids in the LAW melter feed simulant, the melter feed was measured using the Z41 sensor. This sensor only produces valid data up to the shear rate that leads to the production of Taylor vortices as indicated in Figure A-1. The viscosity of the low bounding LAW feed physical simulant was 1.7 mPa·s at 25 ° C (within 20% of the low bound) and 1.2 mPa·s at 40 ° C. The viscosity of the low bounding LAW melter feed physical simulant is 2.8 mPa·s at 25 ° C and 2.1 mPa·s at 40 ° C.

7. Simulant Development Organization

The low bound LAW pretreated waste feed physical simulant and low bound LAW melter feed physical simulant were developed at Westinghouse Savannah River Company, Savannah River Technology Center. The primary contact for the simulant development work is:

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8. References

Russell, R. L., Fiskum, S. K., Jagoda, L. K. and A. P. Poloski. **AP-101 Diluted Feed (Envelope A) Simulant Development Report**. WTP-RPT-057, Battelle Pacific Northwest Division, Richland, WA, February 2003.

Kerry Prindiville. **Test Specification: Development of Simulants to Support Mixing Tests for High Level Waste and Low Activity Waste**. 24590-WTP-TSP-RT-01-004, Rev. 1, River Protection Project, Waste Treatment Plant, Richland, WA, 99352, November 2002.

Bredt, P. R., Poloski, A. P., Swoboda, R. G., Buck, C., Arey, W., Jenson, D., and K. McNamara. **Rheological and Physical Properties of AP-101 LAW Pretreated Waste and Melter Feed.** Battelle Pacific Northwest Division, Richland, WA, December 2002.

APPENDIX B

APPENDIX B: HIGH BOUND LAW PRETREATED WASTE PHYSICAL SIMULANT

1. Simulant Designation

The high bound LAW pretreated waste physical simulant is designed to represent LAW pretreated waste with rheological properties close to the high bound conditions of the LAW Chemical Receipt Vessel (CRV) and the LAW Melter Feed Process Vessel (MFPV). The simulant is intended for mixing and agitator tests for the CRV and MFPV vessels. The simulant is designed to reproduce the physical interactions expected for LAW feeds

2. Simulant Waste Stream Composition and Unit Operation Usage

2.1. CHARACTERIZATION DATA DESCRIPTION

The compositional basis of the physical simulant was derived from the characterization of AP-101 supernate and the development of an AP-101 supernate simulant (Russell, 2003). Only those species at concentrations greater than 0.01 molar were retained in the simulant formulation. Table B-1 compares the composition of the Battelle AP-101 simulant (adjusted to a 10.5 molar Na Basis) with the high Bounding LAW Pretreated Waste Physical Simulant.

Table B-1 Comparison of the high bound LAW pretreated waste physical simulant composition to Battelle AP-101 supernate simulant

	Battelle AP-101 Original Basis	Battelle AP-101 10.5 M Na Basis	High Bound LAW Pretreated Waste Physical Simulant
Species	**Moles/Liter**	**Moles/Liter**	**Moles/Liter**
Acetate	0.0247	0.0519	0.0519
Aluminum	0.259	0.543	0.543
Barium	2.1E-6	4.4E-6	NA
Beryllium	1.3E-4	2.7E-4	NA
Boron	0.00132	0.00277	NA
Cadmium	1.58E-5	3.3E-5	NA
Calcium	1.71E-4	3.6E-4	NA
Carbonate	0.446	0.9366	0.9366
Cesium	4.5E-5	9.5E-5	NA
Chloride	0.0409	0.0859	0.0859
Chromium	0.00292	0.00614	NA
Copper	2.2E-5	4.7E-5	NA
Fluoride	0.00281	0.0059	NA
Formate	0.0237	0.0498	0.0498
Hydroxide	2.98	6.258	6.258
Iron	4E-5	8.4E-5	NA
Lead	6.4E-5	1.4E-4	NA
Lithium	4.3E-5	9.1E-5	NA
Molybdenum	1.34E-4	2.8E-4	NA
Nickel	1.2E-4	2.5E-4	NA
Nitrate	1.68	3.531	3.528
Nitrite	0.707	1.485	1.485
Oxalate	0.0178	0.0374	0.0374
Phosphate	0.0124	0.0261	0.0261
Potassium	0.712	1.495	1.495
Rubidium	4.1E-5	8.7E-5	NA
Silicon	0.00434	0.00911	0.00911
Sodium	5.00	10.5	10.46
Sulfate	0.0373	0.0783	0.0783
Tungsten	1.19E-4	2.5E-4	NA
Zinc	7.6E-5	1.6E-4	NA

2.2. FLOWSHEET OPERATION FOR WHICH THE SIMULANT WAS DEVELOPED

The high bound LAW melter feed physical simulant was developed to support mixing, sampling and waste transfer studies to aid in verifying adequate design of these systems. Since the composition of simulant does not completely match the composition of AP-101 supernate, it should not be used to represent AP-101 waste.

3. Actual Simulant Preparation Procedure

3.1. CHEMICALS TO USE

Development of the physical simulant used reagent grade chemicals. However, technical grade chemicals should be sufficient for producing larger scale quantities of the simulant. Cost, chemical availability, and ease of scale up were considered in choosing which compounds to use.

Many of the salts used in the simulant include waters of hydration and the specific form to be used is shown in Table B-2. Care must be taken in storing and using some of these compounds due to their tendency to readily absorb water. Using a salt, which has obviously absorbed excess water, will lead to missing the target value for that compound. When necessary, a solution of the compound can be used. However, the water additions shown in Table B-2 will have to be appropriately reduced to account for the water in the solution of the compound.

The high bound LAW melter feed physical simulant is not prepared from the LAW feed physical simulant due to the low stability of melter feed prepared at this level of sodium concentration and the lack of necessary bounding properties.

3.2. CHEMICAL ADDITION ORDER

The order of chemical addition to produce the supernate simulant is shown in Table B-2 and is based upon the following logical steps:

- Prepare a solution of acid stable salts.
- Convert solution from acid to base by addition of sodium hydroxide and selected basic salts.
- Add base-stable compounds.

These steps produce the desired composition expected in the waste simulant while avoiding the acid-induced decomposition of carbonate or nitrite.

The water used for the simulant should be deionized water to limit the addition of other uncontrolled species. The mass of water added in each step is based upon producing a simulant solution with a total Na concentration of 10.5 molar and a solution density of 1.489 g/mL at 25 ° C based upon previous tests of the simulant.

Table B-2 Chemical Addition Order and Amounts for Producing One Liter of the High Bound LAW Pretreated Waste Feed Physical Simulant

High Bound LAW Pretreated Waste Feed Physical Simulant at 10.5 Molar Na		
Volume of Feed	**1**	**Liter**
Target Density	**1.489**	**g/mL**
To the Simulant Preparation Vessel add	**grams**	
Water	300	
Next add the following while maintaining good mixing		
Compounds	**Formula**	**Mass Needed**
Sodium Acetate	$NaCH_3COO \bullet 3H_2O$	7.07
Sodium Oxalate	$Na_2C_2O_4$	5.01
Aluminum Nitrate	$Al(NO_3)_3 \bullet 9H_2O$	203.81
Sodium Chloride	NaCl	5.02
Sodium Dihydrogen Phosphate	$NaH_2PO_4 \bullet H_2O$	3.60
Sodium Sulfate	Na_2SO_4	11.13
Sodium Nitrate	$NaNO_3$	126.01
Potassium Nitrate	KNO_3	42.04
Mix to thoroughly dissolve the solids. Then add the following slowly with good mixing.	**Formula**	**Mass Needed**
Sodium Hydroxide (50 wt % solution)	NaOH	500.64
Sodium meta-silicate	$Na_2SiO_3 \bullet 9H_2O$	2.59
Sodium Formate	HCOONa	3.39
Sodium Nitrite	$NaNO_2$	102.44
Sodium Carbonate	Na_2CO_3	42.07
Potassium Carbonate	K_2CO_3	74.59
Water	H_2O	59.6
Mix thoroughly.		
Agitate for 24 hours to completely dissolve as much as possible. Note that considerable undissolved solids will remain. Do not filter to remove the solids.		

The high bound LAW pretreated waste physical simulant will have considerable amount of undissolved solids in the solution. This is consistent with observations made during the development of the AP-101 complete simulant (Russell 2003).

3.3. PRECAUTIONS

- Material Safety Data Sheets (MSDS) should be reviewed for all of the compounds in the simulant formulation.
- Appropriate safety apparel (acid-resistant gloves, etc) should be worn when working with chemicals as specified in the MSDS.
- Addition of the transition metal nitrates to the initial solution will produce a very acidic solution.
- Addition of the NaOH solution results in significant heat generation. The NaOH can be added slowly allowing heat to dissipate, or the mixing container can be cooled by use of an external or internal cooling system (ice bath, cooling coils, etc).
- During the initial stages of sodium hydroxide addition, significant Al solids form. Mixing will become difficult at this point. The Al solids will return to solution when pH ~9 is exceeded.
- The carbonate salts are added after the NaOH to avoid carbonate decomposition.
- Addition of sodium nitrite must be made after the addition of sodium hydroxide to avoid generation of NO_x vapors.

3.4. OTHER CONSIDERATIONS

- The stability of the high bound LAW pretreated waste simulant is not an issue since it has been based upon a previous simulant with good stability. Note that some insoluble solids are expected in this simulant and the presence of these solids was also observed in the actual AP-101 supernate at this concentration (Bredt 2002).
- The high bound LAW pretreated waste simulant should not be stored in glass or glass-lined containers since etching of the glass will occur which could impact the rheological properties of the simulant and modify the silicon content of the simulant.

4. Key Characteristics and Limitations of the High Bound LAW Pretreated Waste Feed Physical Simulants

4.1. KEY CHARACTERISTICS

The simulant composition is designed to match the major constituents of actual AP-101 waste concentrated to 10.5 Molar Na. Of specific concern are the constituents that can interact with the glass formers to modify the physical properties of the simulant. These constituents include the Na^+, Al, OH^-, and CO_3^{-2} concentrations. Solution density and viscosity are process-affecting and result from the concentration of the previously mentioned species.

4.2. LIMITATIONS

The physical simulants described in this document were primarily designed to support process studies that only involve physical properties. The simulants should not be used for process chemistry studies, waste acceptance or environmental impact studies.

5. Validation of the Simulant

Validation of this simulant is based upon comparison with the physical properties (rheology) required of a bounding simulant. The bounding rheological properties required of the high bound physical simulant were:

- The LAW pretreated waste simulant must be Newtonian (no measurable yield stress) (Prindiville 2002)
- The viscosity (consistency) of the LAW waste simulant must be 15 milliPascal-seconds (mPa·s) (±20%) (Prindiville 2002).

5.1. CHEMICAL COMPOSITION

Chemical composition is not a required feature for a physical simulant. However, the high bound LAW pretreated waste physical simulant is based on the major species (>0.01 Molar) in the AP-101 waste when the waste supernate has been concentrated to 10.5 molar in sodium.

5.2. CHARGE BALANCING

The physical simulant was derived from the composition of the AP-101 supernate simulant. (Russell, 2003) Since the AP-101 simulant had already addressed the charge balancing issue, additional work on this was unnecessary

6. Simulant Properties Compared to Bounding Waste Properties

The rheogram of the high bounding LAW pretreated waste physical simulant indicate that the fluid is very nearly Newtonian in behavior since the rheograms are nearly linear with the shear rate versus shear stress relationship passing through the origin. Figure B-1 shows the flow curve for the simulant compared to the bounding upper limits for slurry rheology.

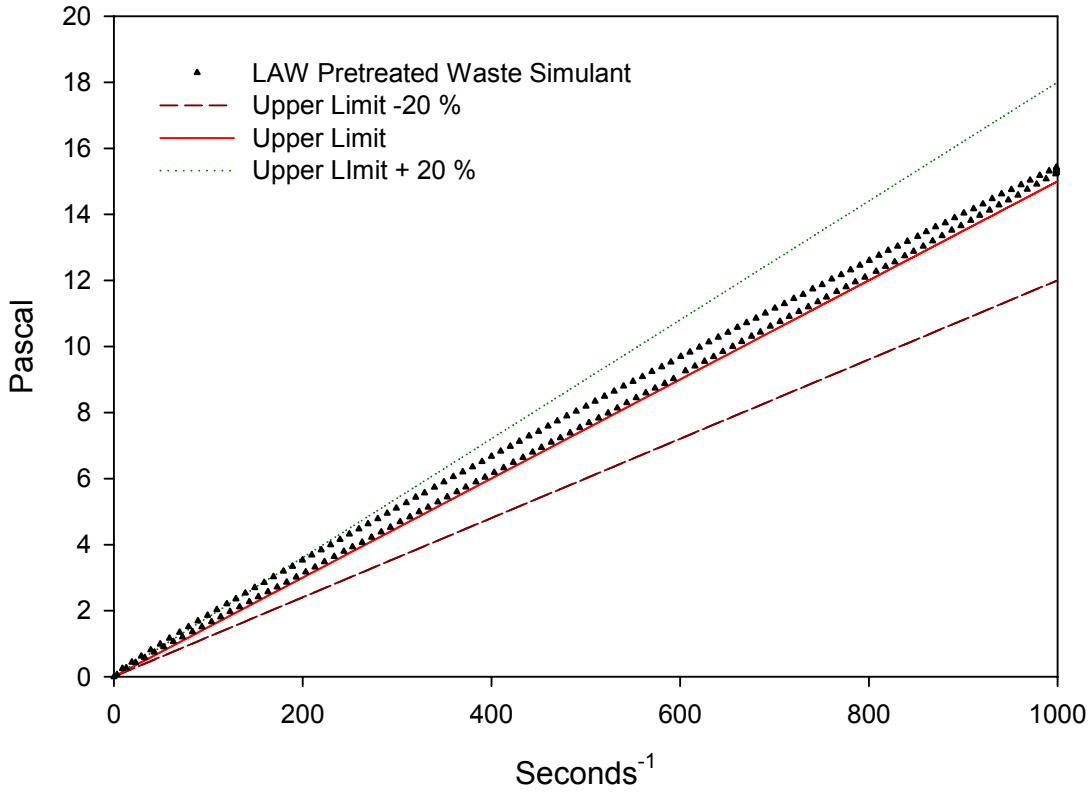

Figure B-1 Flow Curve of the high bound LAW pretreated waste physical simulant compared to the Upper Bound Rheology limits at 25 ° C

The 10.5 molar Na LAW simulant does deviate slightly from Newtonian and is best fit on the up curve to a power law function. However, the curve is well represented by the Newtonian line given the allowable 20 % error on the measurement. The viscosity of the high bound LAW feed physical simulant was 15.1 mPa·s at 25 ° C (101% of the high bound) and 9.2 mPa·s at 40 ° C based upon the application of a Bingham curve fit from 50 to 1000 sec^{-1} to the up flow curve. The down flow curve suggests that settling had occurred during the measurement and that the viscosity of the supernate is 15 mPa·s at 25 ° C.

7. Simulant Development Organization

The high bound LAW pretreated waste feed physical simulant was developed at Westinghouse Savannah River Company, Savannah River Technology Center. The primary contact for the simulant development work is:

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8. References

Russell, R. L., Fiskum, S. K., Jagoda, L. K. and A. P. Poloski. **AP-101 Diluted Feed (Envelope A) Simulant Development Report**. WTP-RPT-057, Battelle Pacific Northwest Division, Richland, WA, February 2003.

Bredt, P. R., Poloski, A. P., Swoboda, R. G., Buck, C., Arey, W., Jenson, D., and K. McNamara. **Rheological and Physical Properties of AP-101 LAW Pretreated Waste and Melter Feed**. WTP-RPT-064, Rev. B, Battelle Pacific Northwest Division, Richland, WA, December 2002.

Kerry Prindiville. **Test Specification: Development of Simulants to Support Mixing Tests for High Level Waste and Low Activity Waste**. 24590-WTP-TSP-RT-01-004, Rev. 1, River Protection Project, Waste Treatment Plant, Richland, WA, 99352, November 2002.

APPENDIX C

APPENDIX C: HIGH BOUND LAW MELTER FEED PHYSICAL SIMULANT

1. Simulant Designation

The high bound LAW melter physical simulant is designed to represent LAW melter feed with rheological properties close to the high bound conditions of the LAW Melter Feed Process Vessel (MFPV). The simulant is intended for mixing and agitator tests for the MFPV vessel only. The simulant is designed to produce the upper bounding physical properties (rheology, density) expected for LAW melter feeds.

2. Simulant Waste Stream Composition and Unit Operation Usage

2.1. CHARACTERIZATION DATA DESCRIPTION

This simulant is a purely physical simulant and does not aim to reproduce any specific chemical composition or chemical properties other than density for an 8 Molar Na LAW melter feed

2.2. FLOWSHEET OPERATION FOR WHICH THE SIMULANT WAS DEVELOPED

The high bound LAW melter feed physical simulant was developed to support mixing, sampling and waste transfer studies to aid in verifying adequate design of these systems. Since the composition of simulant does not represent any specific LAW waste it should be used for no other purposes.

3. Actual Simulant Preparation Procedure

3.1. CHEMICALS TO USE

Initial development of the physical simulant used reagent grade chemicals. However, technical grade chemicals should be sufficient for producing larger scale quantities of the simulant. Cost, chemical availability, and ease of scale up were considered in choosing which compounds to use.

The high bound LAW melter feed physical simulant is prepared by preparing an 8 molar $NaNO_3$ solution (Table C-1) followed by the addition of the appropriate amount of approved glass formers as specified by the Vitreous State Laboratory at Catholic University for a 5 Molar AP-101 sample scaled to 8 molar.. The composition of glass formers shown in Table C-2 is based on the composition specified for the AP-101 supernate sample.

3.2. CHEMICAL ADDITION ORDER

The only significant issue for the order of addition is that the viscosity modifier, xanthan gum, should be mixed into the glass formers and added with them to insure ease of addition and mixing. The water used for the simulant should be deionized water to limit the addition of other uncontrolled species. The mass of water added in each step is based upon producing a simulant solution with a total Na concentration of 8 molar and a solution density of 1.38 g/mL at 25 ° C.

Table C- 1 Chemical Addition Order and Amounts for Producing One Liter of the 8 Molar Sodium Nitrate Solution

High Bounding LAW Feed Physical Simulant at 8 Molar Na		
Volume of Feed	**One**	**Liter**
Target Density	**1.39**	**g/mL**
To the Simulant Preparation Vessel add	**grams**	
Water	710.1	
Next add the following while maintaining good mixing		
Compounds	**Formula**	**Mass, grams**
Sodium Nitrate	$NaNO_3$	679.9
Mix thoroughly.		
Agitate for 24 hours to completely dissolve as much as possible		

The high bound rheology conditions require the use of a viscosity modifier to achieve the thick rheology conditions at reasonable Na concentrations. Tests with higher Na concentrations for LAW simulants derived from AP-101 composition did not produce stable melter feeds when combined with the glass formers. The viscosity modifier chosen for the LAW physical simulants is xanthan gum, food grade, obtained from Kraft Chemical Co. Xanthan gum is a high molecular weight, water-soluble polysaccharide produced by the bacterium Xanthomonas campestris. The gum adds yield value and thickening to aqueous systems that are ionic.

The addition of glass formers to the LAW Feed should be made as a single continuous addition by combining the dry glass formers and the xanthan gum as the first step. And then, adding the combined glass formers in a continuous addition with good mixing to a stirred batch of the 8 molar Na NO_3 LAW feed physical simulant. The amounts of the glass formers required for one liter of the LAW Feed is shown in Table C-2.

Table C- 2 Glass Formers plus Viscosity Modifier required for One Liter of 8 Molar Sodium Nitrate Solution

Blend together the following glass formers	Supplier	grams
Kyanite (Al_2SiO_5) 325 Mesh	Kyanite Mining Corp.	95.12
Boric Acid, H_3BO_3 (Technical - Granular)	U. S. Borax	233.74
Wollastonite NYAD 325 Mesh	NYCO	56.42
Ferric Oxide, Fe_2O_3 (-325 Mesh) Prince 5001	Prince Manufacturing Co.	72.55
Olivine (Mg_2SiO_4) 325 Mesh (#180)	Unimin Corp.	41.33
Silica, SiO_2 (Sil-co-Sil 75)	U. S. Silica	489.68
Titanium Dioxide, TiO_2 (Rutile - Airfloated)	Chemalloy Co.	28.05
Zinc Oxide, ZnO (K-920)	Zinc Corp. America	39.97
Zircon $ZrSiO_4$ (Flour) 325 Mesh	American Minerals Inc.	60.45
Xanthan Gum, Food Grade	Kraft Chemical Co.	3.77

Preparation of the melter feed simulant using the glass formers listed in Table C-2 is described by Table C-3.

Table C- 3 Preparation of High Bounding LAW Melter Feed Simulant

Add 8 Molar $NaNO_3$ solution to mixing vessel
Apply agitation to insure good mixing
Add Glass Former mixture from Table C-2
Mix the melter feed for 1 hour.

The addition of the glass formers to one liter of 8 molar $NaNO_3$ solution produces 1.47 liters of high bound LAW melter feed physical simulant with a density of 1.713 g/mL at 25 ° C and a total weight % solids content of 67.4 wt %. A temperature rise was not observed for the addition of the glass formers to the supernate.

3.3. PRECAUTIONS

- Material Safety Data Sheets (MSDS) should be reviewed for all of the compounds in the simulant formulation.
- Appropriate safety apparel (acid-resistant gloves, etc) should be worn when working with chemicals as specified in the MSDS.

3.4. OTHER CONSIDERATIONS

- Long term stability of the high bound LAW melter feed physical simulant with rheology modifier is an issue. Vane measurements of the yield stress of the undisturbed melter feed after 168 hours gave a yield strength of 32 Pascals. The melter feed simulant should therefore be used within a couple of days of production (1-5 days).
- Settling of the melter feed slurry is not an issue since the viscosity modifier prevents settling.
-

4. Key Characteristics and Limitations of the High Bound LAW Melter Feed Physical Simulant

4.1. KEY CHARACTERISTICS

The key characteristics of the LAW melter feed physical simulant is the density of the simulant and the rheological properties of the simulant.

4.2. LIMITATIONS

The physical simulant described in this document were designed to support process studies that only involve physical properties. The simulant should not be used for process chemistry studies, waste acceptance or environmental impact studies.

5. Validation of the Simulant

Validation of this simulant is based upon comparison with the physical properties (rheology) required of a bounding simulant. The bounding rheological properties required of the high bound physical simulant were:

- The LAW melter feed simulant must be non-Newtonian (pseudoplastic) in rheological properties. The yield stress as determined by application of the Bingham Plastic model shall be 12 Pascals (±20%). (Prindiville 2002)
- The consistency of the LAW melter feed simulant from application of the Bingham Plastic model must be 92 mPa·s (±20%).(Prindiville 2002)

5.1. CHEMICAL COMPOSITION

Chemical composition is not a required feature for a physical simulant. The only composition of significance in this simulant are the glass formers.

5.2. CHARGE BALANCING

As a purely physical simulant, the simulant required no charge balancing while developing the simulant.

6. Simulant Properties Compared to Bounding Waste Properties

The rheogram of the high bound LAW melter feed physical simulant indicate that the material is a non-Newtonian slurry with pseudoplastic properties. Figure C-1 compares the flow curve for the high bound LAW melter feed physical simulant to the upper bound rheology conditions for the MFPV.

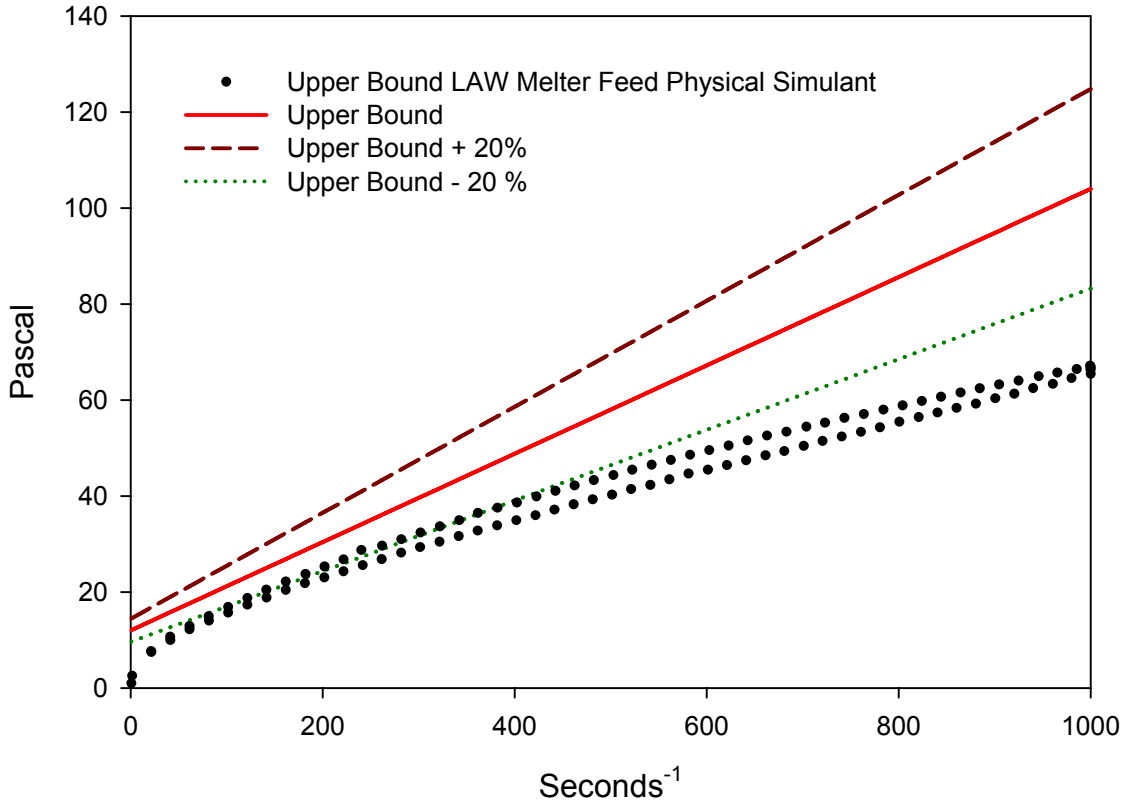

Figure C- 1 Flow curve of High Bound LAW Melter Feed physical simulant versus Limits

The yield stress of the high bound LAW melter feed physical simulant based upon a Bingham Plastic model fit of the up flow curve from 50 to 1000 sec-1 is 14.6 Pascals at

25 ° C (122 % of the upper bound yield stress). At 40 ° C, the yield stress is 11 Pascals. The consistency based upon a Bingham Plastic model fit of the up flow curve from 50 to 1000 sec-1 is 57 mPa·s at 25 ° C (62 % of the upper bound consistency). At 40 ° C, the consistency is 39 mPa·s showing the drop that is expected with an increase in temperature.

7. Simulant Development Organization

The high bound LAW melter feed physical simulant was developed at Westinghouse Savannah River Company, Savannah River Technology Center. The primary contact for the simulant development work is:

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Email: russell.eibling@srs.gov

8. References

Kerry Prindiville. **Test Specification: Development of Simulants to Support Mixing Tests for High Level Waste and Low Activity Waste**. 24590-WTP-TSP-RT-01-004, Rev. 1, River Protection Project, Waste Treatment Plant, Richland, WA, 99352, November 2002.

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APPENDIX D

APPENDIX D: LOW BOUND HLW PRETREATED WASTE PHYSICAL SIMULANT WITH AND WITHOUT GLASS FORMERS

1. Simulant Designation

The low bound HLW pretreated waste physical simulant with and without glass formers is designed to represent HLW pretreated waste and HLW melter feed with rheological properties close to the lower bound conditions of the HLW Chemical Receipt Vessel (CRV) and the HLW Melter Feed Process Vessel (MFPV). The simulant is intended for mixing and agitator tests for the CRV and MFPV vessels. The simulant is designed to reproduce the physical interactions expected for HLW feeds combined with the planned HLW glass formers.

2. Simulant Waste Stream Composition and Unit Operation Usage

2.1. CHARACTERIZATION DATA DESCRIPTION

The compositional basis of the HLW physical simulant was derived from the characterization of AZ-101 sludge (Beeman 2002). Only four major species (Al, Fe, Si and Zr) were included in the physical simulant. The relative amounts of these four species were kept constant as the amount of the species was increased to represent the rest of the mass of the sludge.

2.2. FLOWSHEET OPERATION FOR WHICH THE SIMULANT WAS DEVELOPED

The low bound HLW physical simulant was developed to support mixing, sampling and waste transfer studies to aid in verifying adequate design of these systems. Since the composition of simulant does not completely match the composition of AZ-101 pretreated waste sludge, it should not be used to represent AZ-101 sludge waste

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3. Actual Simulant Preparation Procedure

3.1. CHEMICALS TO USE

Development of the physical simulant used reagent grade chemicals and specific oxides/hydroxides of known particle sizes. The specific metal oxides and their sources are listed in Table D-1. However, technical grade chemicals should be sufficient for replacing the reagent grade chemicals when producing larger scale quantities of the simulant. These technical grade chemicals should be at least 97 % pure. Substitutions for the specific oxides/hydroxides should not be made. Cost, chemical availability, and ease of scale up were considered in choosing which compounds to use.

Table D-1 Metal Oxides/Hydroxides Used in Simulant

Material	Product Name	Material Supplier
Ferric Oxide, Fe_2O_3	Bayferrox 130	Bayer Chemical
Ferric Oxide, Fe_2O_3	Bayferrox 130C	Bayer Chemical
Aluminum Trihydroxide, $AL(OH)_3$	Hydral 716 or Hydral 717	Alcoa
Aluminum Trihydroxide, $AL(OH)_3$	C-30	Alcoa
Silica, SiO_2	Silicon(IV) Oxide, 99.5% -400 mesh, Cat #13024	Alfa Aesar
Zirconium Hydroxide, $Zr(OH)_4$	FZO922/1	Magnesium Elektron, Inc., Flemington, N.J.

Many of the salts used in the simulant include waters of hydration and the specific form to be used is shown in Table D-2 and Table D-3. Care must be taken in storing and using some of these compounds due to their tendency to readily absorb water. Using a salt, which has obviously absorbed excess water, will lead to missing the target value for that compound. When necessary, a solution of the compound can be used. However, the water additions shown in Table D-2 will have to be appropriately reduced to account for the water in the solution of the compound.

The low bound HLW melter feed physical simulant is prepared from the low bound HLW pretreated waste feed physical simulant by the addition of the appropriate amount of approved glass formers as specified by the Waste Treatment Plant (WTP) Project. The composition of glass formers shown in Table D-4 is based on the composition specified for the AZ-101 sludge sample (Prindiville, 2002).

3.2. CHEMICAL ADDITION ORDER

The order of chemical addition to produce the simulant is shown in Table D-2 and is based upon the following logical steps:

- Prepare a solution of acid stable salts.
- Convert solution from acid to base by addition of sodium hydroxide and selected basic salts.
- Add base-stable.
- Add the specific metal oxides/hydroxides
- Add Cesium Ion Exchange Concentrate simulant (Table D-3)

These steps produce the desired composition expected in the waste simulant while avoiding the acid-induced decomposition of carbonate or nitrite prior to the addition of the acidic Ion Exchange concentrate. Some destruction of the basic salts is expected when the acidic Cesium Ion Exchange Concentrate is added to the mixture. Such reactions are expected to occur in Pretreatment in producing the HLW pretreated waste feed.

The water used for the simulant should be deionized water to limit the addition of other uncontrolled species. The mass of water added in each step is based upon producing a simulant solution with a specific target density and containing 15 weight % solids.

Table D-2 Chemical Addition Order and Amounts for Producing One Liter of the Low Bound HLW Pretreated Waste Feed Physical Simulant

Low Bound HLW Pretreated Waste Feed Physical Simulant at 15 wt % HLW Solids		
Volume of Feed	**1**	**Liters**
Target Density	**1.105**	**g/mL**
To the Simulant Preparation Vessel	**grams**	
Water	200	
Next add the following while maintaining good mixing		
Compounds	**Formula**	**Mass, grams**
Boric Acid	H_3BO_3	0.084
Sodium Chloride	NaCl	0.187
Sodium Fluoride	NaF	0.139
Sodium Sulfate	Na_2SO_4	0.576
Mix thoroughly to dissolve solids. Then add the following while mixing.	**Formula**	**Mass, grams**
Sodium Hydroxide (50 wt % solution)	NaOH	12.266
Sodium Phosphate	$Na_3PO_4 \bullet 12H_2O$	8.942
Sodium Oxalate	$Na_2C_2O_4$	0.128
Water	H_2O	200
Mix thoroughly. Then add the following while mixing.	**Formula**	**Mass, grams**
Sodium Carbonate	Na_2CO_3	6.377
Sodium Nitrate	$NaNO_3$	0.483
Potassium Nitrite	KNO_2	0.704
Sodium Nitrite	$NaNO_2$	1.192
Water	H_2O	300
Mix thoroughly to dissolve solids. Then add the following while mixing.	**Formula**	**Mass, grams**
Bayferrox 130, Ferric Oxide	Fe_2O_3	50.73
Bayferrox 130C, Ferric Oxide	Fe_2O_3	12.68
Hydral 716, Aluminum Trihydroxide	$Al(OH)_3$	50.62
C-30, Aluminum Trihydroxide	$Al(OH)_3$	12.65
Silica, Alfa Aesar, -400 mesh, 2 Micron APS	SiO_2	6.12
Zirconium Oxide, MEI $Zr(OH)_4$	$Zr(OH)_4$	24.89
Water	H_2O	241
Mix thoroughly. Finally Add	**Formula**	**Mass, grams**
Add **Cesium Ion Exchange Concentrate simulant**	See Table D-3	26.025
Mix for 1 Hour.		

The recipe for preparing the Cesium Ion Exchange Concentrate is given in Table D-3.

Table D-3 Preparation of Cesium Ion Exchange Concentrate Simulant

Cesium Ion Exchange Concentrate Simulant		
Volume of Feed	1000	mL
Target Density	1.31	g/mL
In a Hood, in a tared	2	Liter Poly
Add the following Compounds	**Formula**	**Mass, grams**
Water	H_2O	200
Aluminum Nitrate	$Al(NO_3)_3 \bullet 9H_2O$	8.19
Sodium Borate	$Na_2B_4O_7 \bullet 10H_2O$	23.39
Calcium Nitrate	$Ca(NO_3)_2 \bullet 4\ H_2O$	13.72
Cesium Nitrate	$CsNO_3$	1.60
Copper Nitrate	$Cu(NO_3)_2 \bullet 2.5\ H_2O$	0.54
Ferric Nitrate	$Fe(NO_3)_3 \bullet 9\ H_2O$	3.41
Potassium Nitrate	KNO_3	13.943
Sodium Chloride	NaCl	2.77
Sodium Sulfate	Na_2SO_4	12.33
Oxalic Acid	$HO_2CCO_2H \bullet 2\ H_2O$	9.65
Nitric Acid	HNO_3, 70 wt %	434.49
Mix to thoroughly dissolve the solids. Next add the following slowly with good mixing.		
Compounds	**Formula**	**Mass, grams**
Sodium meta-silicate	$Na_2SiO_3 \bullet 9\ H_2O$	0.52
Sodium Nitrate	$NaNO_3$	206.21
Water	H_2O	379.25
Agitate for 24 hours to completely dissolve as much as possible.		

The addition of glass formers to the low bound HLW pretreated waste feed should be made as a single continuous addition by premixing the dry glass formers as the first step. The combined glass formers are then added with good mixing to a stirred batch of the low bound HLW pretreated waste feed physical simulant. The amounts of the glass formers required for one liter of the HLW pretreated waste feed to produce the low bound HLW melter feed is shown in Table D-4.

Table D-4 Glass Formers required for One Liter of Low Bound HLW Pretreated Waste Feed Physical Simulant to produce the Low Bound HLW Melter Feed Physical Simulant

Blend together the following glass formers	grams
10 Mole Borax,	136.98
Lithium Carbonate	44.86
Sodium Carbonate	31.17
Silica, SiO_2 (Sil-co-Sil 75)	207.20
Zinc Oxide, ZnO (K-920)	9.53

The addition of the glass formers produces 1.16 liters of the low bound HLW melter feed physical simulant with a density of 1.324 g/mL at 25 ° C. The addition of the glass formers to the low bounding HLW feed did not cause a rise in temperature.

3.3. PRECAUTIONS

- Material Safety Data Sheets (MSDS) should be reviewed for all of the compounds in the simulant formulation.
- Appropriate safety apparel (acid-resistant gloves, etc) should be worn when working with chemicals as specified in the MSDS.
- Addition of the transition metal nitrates to the initial solutions will produce a very acidic solution.
- Addition of the NaOH solution results in significant heat generation. The NaOH can be added slowly allowing heat to dissipate, or the mixing container can be cooled by use of an external or internal cooling system (ice bath, cooling coils, etc).
- The carbonate salts are added after the NaOH to avoid carbonate decomposition.
- Addition of sodium nitrite must be made after the addition of sodium hydroxide to avoid generation of NO_x vapors.
- Good mixing is necessary when adding the Cesium Ion Exchange Concentrate simulant to prevent creating local regions of the slurry with excessively acidic conditions. If mixing is not adequate, the potential exists for generation of CO_2 and NOx gases.
- The addition of the glass formers will also produce heat as a result of the reaction between hydroxide ion and the boric acid. For a one liter batch of the low bound HLW pretreated waste feed physical simulant, a temperature increase of less than one ° C has been measured using a glass former addition period of 15 minutes.

3.4. OTHER CONSIDERATIONS

- The stability of the low bounding HLW pretreated waste feed simulant is good within the normal process time period for the HLW vitrification facility.
- Preliminary tests combined with other HLW melter feed studies suggest that the low bound HLW melter feed simulant does not have stability problems within the normal process time period for the HLW vitrification facility.
- The low bound HLW pretreated waste feed simulant should not be stored in glass or glass-lined containers since etching of the glass could occur which could impact the rheological properties of the simulant.

4. Key Characteristics and Limitations of the Low Bound HLW Pretreated Waste Feed and HLW Melter Feed Physical Simulants

4.1. KEY CHARACTERISTICS

The physical simulant composition is designed to match four of the major constituents of actual AZ-101 sludge. Modification of the physical simulant to improve the degree of chemical simulation of the AZ-101 waste is possible since the relative proportions of the four main insoluble constituents were set to allow such an action. Of specific concern are the constituents that can interact with the glass formers to modify the physical properties of the simulant. These constituents include the Fe, Si, Zr, Na, Al, OH^-, and CO_3^{-2} concentrations. Solution density and viscosity are process-affecting and result from the concentration of the previously mentioned species.

4.2. LIMITATIONS

The physical simulants described in this document were primarily designed to support process studies that only involve physical properties. The simulants should not be used for process chemistry studies, waste acceptance or environmental impact studies without adding additional species and additional simulant research and development.

5. Validation of the Simulant

Validation of a simulant is normally based upon comparison of the simulant with actual waste measurements for the waste that the simulant is designed to duplicate. However, these two simulants are instead designed to match the lower limits for the processes that will use the simulants. Therefore, validation of this simulant is based upon comparison of the simulants physical properties with the physical properties (rheology) required of a bounding simulant. Actual waste measurements are therefore not needed for comparison. The bounding rheological properties required of the low bound physical simulant were as specified in the test specification (Prindiville 2002):

- The HLW feed simulant must be Newtonian (no measurable yield stress).

- The viscosity (consistency) of the HLW feed simulant must be 5-10 milliPascal-seconds (mPa·s) (±20%).
- The HLW melter feed simulant must be Newtonian (no measurable yield stress).
- The viscosity (consistency) of the HLW melter feed simulant must be 5-10 mPa·s (±20%).

5.1. CHEMICAL COMPOSITION

Chemical composition is not a required feature for a physical simulant. However, the low bound HLW pretreated waste feed physical simulant is based on four of the major species in the AZ-101 sludge waste after leaching and washing.

5.2. CHARGE BALANCING

The only portion of the physical simulant that required charge balancing was the supernate and the Cesium Ion Exchange Concentrate simulant.

6. Simulant Properties Compared to Bounding Waste Properties

The rheograms of the low bound HLW pretreated waste feed and low bound HLW melter feed physical simulants indicate that the fluids are Newtonian in behavior since they are linear with the shear rate versus shear stress relationship passing through the origin. Figure D- 1 shows a comparison of the limit with the low bound feed and melter feed.

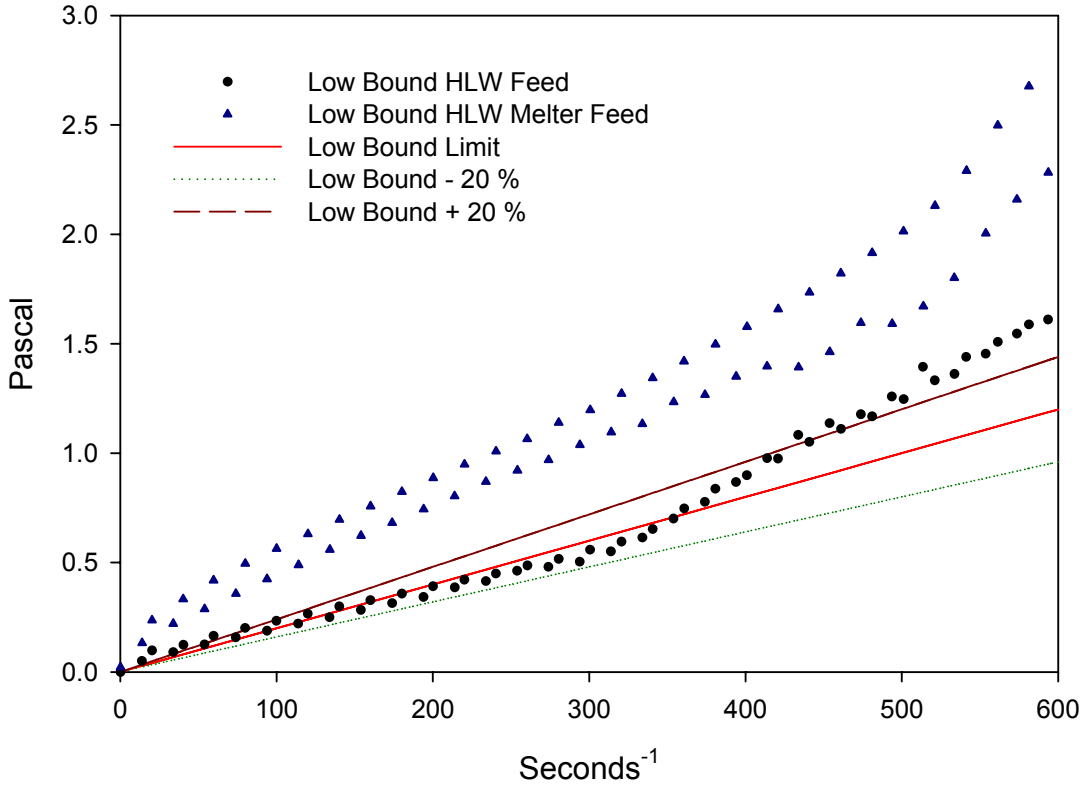

Figure D- 1 Comparison of Limit with Rheograms of HLW Pretreated Waste Simulant and HLW Melter Feed Simulant

The viscosity of the low bound HLW pretreated waste feed physical simulant was 2.0 mPa·s at 25 ° C (within 100% of the low bound) and 1.8 mPa·s at 40 ° C. The viscosity of the low bound HLW melter feed physical simulant is 4.0 mPa·s at 25 ° C and 3.7 mPa·s at 40 ° C.

7. Simulant Development Organization

The low bound HLW pretreated waste feed physical simulant and low bound HLW melter feed physical simulant were developed at Westinghouse Savannah River Company, Savannah River Technology Center. The primary contact for the simulant development work is:

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8. References

Kerry Prindiville. **Test Specification: Development of Simulants to Support Mixing Tests for High Level Waste and Low Activity Waste**. 24590-WTP-TSP-RT-01-004, Rev. 1, River Protection Project, Waste Treatment Plant, Richland, WA, 99352, November 2002.

G. H. Beeman. **Composition of AZ-101 Envelope D and Associated Wastes**. RPP-WTP-02-168, RPP-WTP-02-184, RPP-WTP-02-199, Battelle – Pacific Northwest Division, Richland, WA 99352 (June 21, 2002),(July 31, 2002), (September 5, 2002).

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APPENDIX E

APPENDIX E: HIGH BOUND HLW PRETREATED FEED PHYSICAL SIMULANT WITH AND WITHOUT GLASS FORMERS

1. Simulant Designation

The high bound HLW pretreated waste physical simulant with and without glass formers is designed to represent HLW pretreated waste and HLW melter feed with rheological properties close to the upper bound conditions of the HLW Chemical Receipt Vessel (CRV) and the HLW Melter Feed Process Vessel (MFPV). The simulant is intended for mixing and agitator tests for the CRV and MFPV vessels. The simulant is designed to reproduce the physical interactions expected for HLW feeds combined with the planned HLW glass formers.

2. Simulant Waste Stream Composition and Unit Operation Usage

2.1. CHARACTERIZATION DATA DESCRIPTION

The compositional basis of the HLW physical simulant was derived from the characterization of AZ-101 sludge (Beeman 2002). Only four major species (Al, Fe, Si and Zr) were included in the physical simulant. The relative amounts of these four species were kept constant as the amount of the species was increased to represent the rest of the mass of the sludge. Physical properties were adjusted by varying the insoluble solids loading of the physical simulant.

2.2. FLOWSHEET OPERATION FOR WHICH THE SIMULANT WAS DEVELOPED

The high bound HLW physical simulant was developed to support mixing, sampling and waste transfer studies to aid in verifying adequate design of these systems. Since the composition of simulant does not completely match the composition of AZ-101 pretreated waste sludge, it should not be used to represent AZ-101 sludge waste

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3. Actual Simulant Preparation Procedure

3.1. CHEMICALS TO USE

Development of the physical simulant used reagent grade chemicals and specific oxides/hydroxides of known particle sizes. The specific metal oxides and their sources are listed in Table E- 1. Substitutions for the specific oxides/hydroxides should not be made. However, technical grade chemicals should be sufficient for replacing the reagent grade chemicals when producing larger scale quantities of the simulant. These technical grade chemicals should be at least 97 % pure. Cost, chemical availability, and ease of scale up were considered in choosing which compounds to use.

Table E- 1 Metal Oxides/Hydroxides Used in Simulant

Material	**Product Name**	**Material Supplier**
Ferric Oxide, Fe_2O_3	Prince 3752	Prince Manufacturing Co.
Aluminum Trihydroxide, $AL(OH)_3$	S-11	Alcoa
Silica, SiO_2	Silicon(IV) Oxide, 99.5% -400 mesh, Cat #13024	Alfa Aesar
Zirconium Hydroxide, $Zr(OH)_4$	FZO922/1	Magnesium Elektron, Inc., Flemington, N.J.

Many of the salts used in the simulant include waters of hydration and the specific form to be used is shown in Table E-2 and Table E-3. Care must be taken in storing and using some of these compounds due to their tendency to readily absorb water. Using a salt, which has obviously absorbed excess water, will lead to missing the target value for that compound. When necessary, a solution of the compound can be used. However, the water additions shown in Table E-2 will have to be appropriately reduced to account for the water in the solution of the compound.

The high bound HLW melter feed physical simulant is prepared from the high bound HLW pretreated waste physical simulant by the addition of the appropriate amount of approved glass formers as specified by the Waste Treatment Plant (WTP) Project. The composition of glass formers shown in Table E-4 is based on the composition specified for the AZ-101 sludge sample (Prindiville, 2002).

3.2. CHEMICAL ADDITION ORDER

The order of chemical addition to produce the simulant is shown in Table E-2 and is based upon the following logical steps:

- Prepare a solution of acid stable salts.
- Convert solution from acid to base by addition of sodium hydroxide and selected basic salts.
- Add base-stable.
- Add the specific metal oxides/hydroxides
- Add Cesium Ion Exchange Concentrate simulant (Table E-3)

These steps produce the desired composition expected in the waste simulant while avoiding the acid-induced decomposition of carbonate or nitrite prior to the addition of the acidic Ion Exchange concentrate. Some destruction of the basic salts is expected when the acidic Cesium Ion Exchange Concentrate is added to the mixture. Such reactions are expected to occur in Pretreatment in producing the HLW pretreated waste feed.

The water used for the simulant should be deionized water to limit the addition of other uncontrolled species. The mass of water added in each step is based upon producing a simulant solution with a specific target density and containing 35 weight % solids.

Table E-2 Chemical Addition Order and Amounts for Producing One Liter of the High Bound HLW Pretreated Waste Feed Physical Simulant

High Bound HLW Pretreated Waste Feed Physical Simulant at 35 wt % HLW Solids		
Volume of Feed	**1**	**Liters**
Target Density	**1.32**	**g/mL**
To the Simulant Preparation Vessel	**grams**	
Water	200	
Next add the following while maintaining good mixing		
Compounds	**Formula**	**Mass, grams**
Boric Acid	H_3BO_3	0.073
Sodium Chloride	NaCl	0.162
Sodium Fluoride	NaF	0.121
Sodium Sulfate	Na_2SO_4	0.498
Mix thoroughly to dissolve solids. Then add the following while mixing.	**Formula**	**Mass, grams**
Sodium Hydroxide (50 wt % solution)	NaOH	10.604
Sodium Phosphate	$Na_3PO_4 \bullet 12H_2O$	7.73
Sodium Oxalate	$Na_2C_2O_4$	0.11
Water	H_2O	200
Mix thoroughly.	**Formula**	**Mass, grams**
Sodium Carbonate	Na_2CO_3	5.513
Sodium Nitrate	$NaNO_3$	0.417
Potassium Nitrite	KNO_2	0.609
Sodium Nitrite	$NaNO_2$	1.031
Water	H_2O	300
Mix thoroughly to dissolve solids. Then add the following while mixing.	**Formula**	**Mass, grams**
Prince 3752, Ferric Oxide	Fe_2O_3	192.79
Alcoa S-11, Aluminum Trihydroxide	$Al(OH)_3$	192.38
Silica, Alfa Aesar, -400 mesh, 2 Micron APS	SiO_2	18.61
Zirconium Oxide, MEI $Zr(OH)_4$	$Zr(OH)_4$	75.66
Water	H_2O	113.7
Mix thoroughly. Finally Add	**Formula**	**Mass, grams**
Add **Cesium Ion Exchange Concentrate simulant**	See Table E-3	72.55
Mix for 1 Hour.		

The recipe for preparing the Cesium Ion Exchange Concentrate is given in Table E-3.

Table E-3 Preparation of Cesium Ion Exchange Concentrate Simulant

Cesium Ion Exchange Concentrate Simulant		
Volume of Feed	1000	mL
Target Density	1.31	g/mL
In a Hood, in a tared	2	Liter Poly
Add the following Compounds	**Formula**	**Mass, grams**
Water	H_2O	200
Aluminum Nitrate	$Al(NO_3)_3 \bullet 9H_2O$	8.19
Sodium Borate	$Na_2B_4O_7 \bullet 10H_2O$	23.39
Calcium Nitrate	$Ca(NO_3)_2 \bullet 4\ H_2O$	13.72
Cesium Nitrate	$CsNO_3$	1.60
Copper Nitrate	$Cu(NO_3)_2 \bullet 2.5\ H_2O$	0.54
Ferric Nitrate	$Fe(NO_3)_3 \bullet 9\ H_2O$	3.41
Potassium Nitrate	KNO_3	13.943
Sodium Chloride	NaCl	2.77
Sodium Sulfate	Na_2SO_4	12.33
Oxalic Acid	$HO_2CCO_2H \bullet 2\ H_2O$	9.65
Nitric Acid	HNO_3, 70 wt %	434.49
Mix to thoroughly dissolve the solids. Next add the following slowly with good mixing.		
Compounds	**Formula**	**Mass, grams**
Sodium meta-silicate	$Na_2SiO_3 \bullet 9\ H_2O$	0.52
Sodium Nitrate	$NaNO_3$	206.21
Water	H_2O	379.25
Agitate for 24 hours to completely dissolve as much as possible.		

The addition of glass formers to the high bound HLW pretreated waste feed should be made as a single continuous addition by premixing the dry glass formers as the first step. The combined glass formers are then added with good mixing to a stirred batch of the high bound HLW pretreated waste feed physical simulant. The amounts of the glass formers required for one liter of the HLW pretreated waste feed to produce the high bound HLW melter feed is shown in Table E-4.

Table E-4 Glass Formers required for One Liter of High Bound HLW Pretreated Waste Feed Physical Simulant to produce the High Bound HLW Melter Feed Physical Simulant

Blend together the following glass formers	**grams**
10 Mole Borax,	383.38
Lithium Carbonate	125.54
Sodium Carbonate	87.22
Silica, SiO_2 (Sil-co-Sil 75)	579.9
Zinc Oxide, ZnO (K-920)	26.66

The addition of the glass formers produces 1.58 liters of the high bound HLW melter feed physical simulant with a density of 1.642 g/mL at 25 ° C.

3.3. PRECAUTIONS

- Material Safety Data Sheets (MSDS) should be reviewed for all of the compounds in the simulant formulation.
- Appropriate safety apparel (acid-resistant gloves, etc) should be worn when working with chemicals as specified in the MSDS.
- Addition of the transition metal nitrates to the initial solutions will produce a very acidic solution.
- Addition of the NaOH solution results in significant heat generation. The NaOH can be added slowly allowing heat to dissipate, or the mixing container can be cooled by use of an external or internal cooling system (ice bath, cooling coils, etc).
- The carbonate salts are added after the NaOH to avoid carbonate decomposition.
- Addition of sodium nitrite must be made after the addition of sodium hydroxide to avoid generation of NO_x vapors.
- Good mixing is necessary when adding the Cesium Ion Exchange Concentrate simulant to prevent creating local regions of the slurry with excessively acidic conditions. Gas evolution (presumably CO_2) has been observed when preparing a 4 liter batch of the simulant. If mixing is not adequate, the potential exists for generation of NOx gases.
- The addition of the glass formers will also produce heat as a result of the reaction between hydroxide ion and the boric acid. For a one liter batch of the HLW pretreated waste feed physical simulant, a temperature increase of 3 degrees C has been measured using a glass former addition period of 20 minutes.

3.4. OTHER CONSIDERATIONS

- The stability of the high bound HLW pretreated waste feed simulant is good within the normal process time period for the HLW vitrification facility.
- Preliminary tests combined with other HLW melter feed studies suggest that the high bound HLW melter feed simulant does not have stability problems within the normal process time period for the HLW vitrification facility.
- The high bound HLW pretreated waste feed simulant should not be stored in glass or glass-lined containers since etching of the glass could occur which could impact the rheological properties of the simulant.

4. Key Characteristics and Limitations of the High Bound HLW Pretreated Waste Feed and HLW Melter Feed Physical Simulants

4.1. KEY CHARACTERISTICS

The physical simulant composition is designed to match four of the major constituents of actual AZ-101 sludge. Modification of the physical simulant to improve the degree of chemical simulation of the AZ-101 waste is possible since the relative proportions of the four main insoluble constituents were set to allow such an action. Of specific concern are the constituents that can interact with the glass formers to modify the physical properties of the simulant. These constituents include the Fe, Si, Zr, Na, Al, OH^-, and CO_3^{-2} concentrations. Solution density and viscosity are process-affecting and result from the concentration of the previously mentioned species.

4.2. LIMITATIONS

The physical simulants described in this document were primarily designed to support process studies that only involve physical properties. The simulants should not be used for process chemistry studies, waste acceptance or environmental impact studies without adding additional species and additional simulant research and development.

5. Validation of the Simulant

Validation of a simulant is normally based upon comparison of the simulant with actual waste measurements for the waste that the simulant is designed to duplicate. However, these two simulants are instead designed to match the lower limits for the processes that will use the simulants. Therefore, validation of this simulant is based upon comparison of the simulants physical properties with the physical properties (rheology) required of a bounding simulant. Actual waste measurements are therefore not needed for comparison. The bounding rheological properties required of the high bound physical simulant were as specified in the test specification (Prindiville 2002) and subsequent test exceptions:

- The HLW feed simulant must be non-Newtonian and have a yield stress of 20 Pascals.
- The viscosity (consistency) of the HLW feed simulant must be 20 milliPascal-seconds (mPa·s) (±20%).
- The HLW melter feed simulant must be non-Newtonian and have a yield stress of 30 Pascals..
- The viscosity (consistency) of the HLW melter feed simulant must be 40 mPa·s (±20%).

5.1. CHEMICAL COMPOSITION

Chemical composition is not a required feature for a physical simulant. However, the high bound HLW pretreated waste physical simulant is based on four of the major species in the AZ-101 sludge waste after leaching and washing.

5.2. CHARGE BALANCING

The only portion of the physical simulant that required charge balancing was the supernate and the Cesium Ion Exchange Concentrate simulant. The OLI software used to model the Cesium Ion Exchange Eluant evaporator automatically performs a charge balance.

6. Simulant Properties Compared to Bounding Waste Properties

The rheograms of the HLW pretreated waste and HLW melter feed physical simulants indicate that the fluids are non-Newtonian in behavior since they are not a linear function of the shear. Figure E-1 and Figure E-2 compare the high bound simulants to the upper rheology limits for HLW.

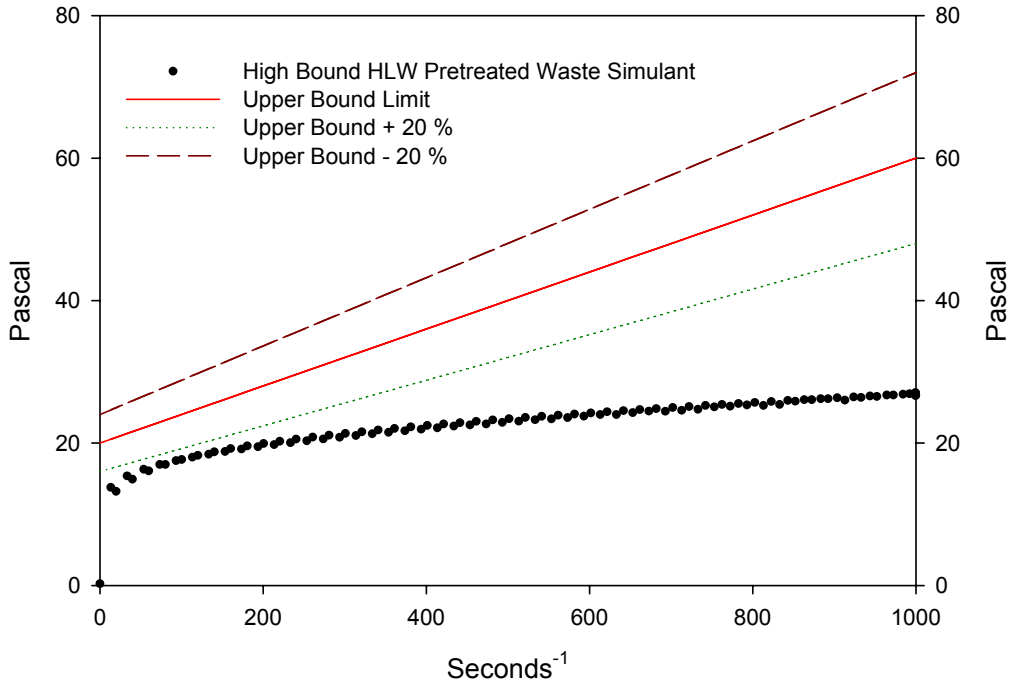

Figure E-1 Rheogram for high bound HLW pretreated waste physical simulant compared to limits

The yield stress of the high bound pretreated HLW feed physical simulant was 17.5 Pascals at 25 ° C and 15.3 Pascals at 40 ° C based upon a Bingham Plastic model fit for up flow curve from 50 to 1000 sec^{-1}. The consistency of the high bound pretreated HLW feed physical simulant was 9.9 mPa·s at 25 ° C (25% of the high bound) and 9.8 mPa·s at 40 ° C also based upon the Bingham Plastic model fit.

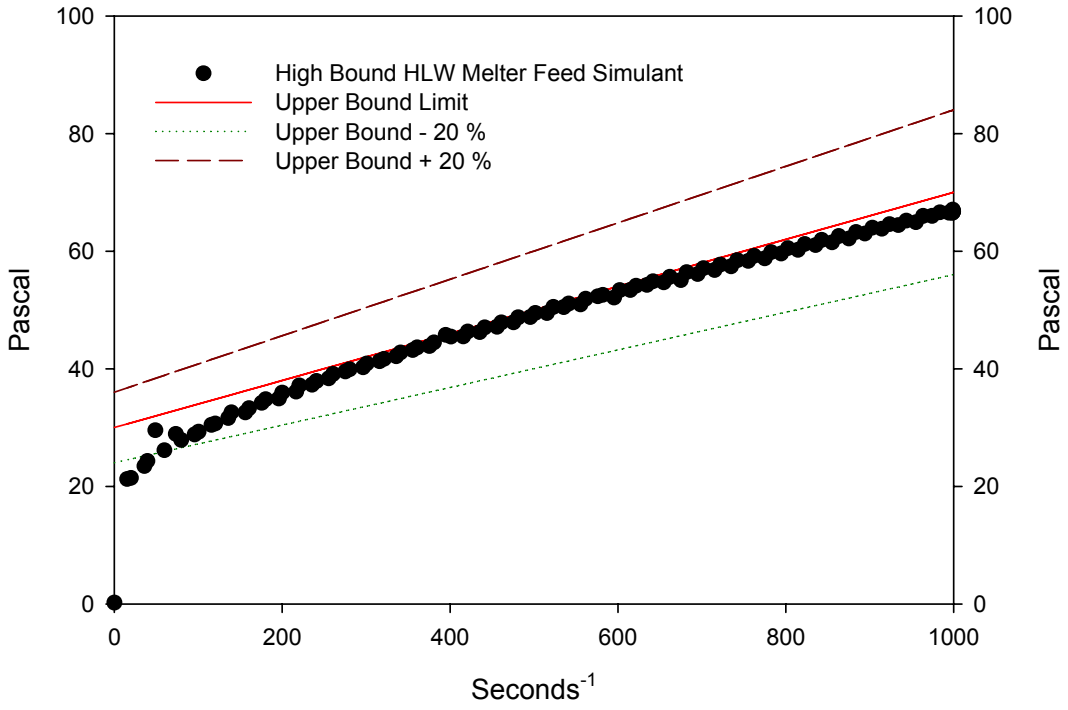

Figure E-2 Rheogram of HLW Melter Feed Simulant compared to Upper Rheology Limit

The yield stress of the high bound HLW melter feed physical simulant was 30 Pascals at 25 ° C and 29.4 Pascals at 40 ° C based upon a Bingham Plastic model fit for the up flow curve from 50 to 1000 sec^{-1}. The consistency of the high bound HLW melter feed physical simulant was 40 mPa·s at 25 ° C (within 100% of the high bound) and 32 mPa·s at 40 ° C also based upon the Bingham Plastic model fit. In both cases a better model fit was obtained using power law with intercept (Herschel-Bulkey) model.

7. Simulant Development Organization

The high bound HLW pretreated waste feed physical simulant and high bound HLW melter feed physical simulant were developed at Westinghouse Savannah River Company, Savannah River Technology Center. The primary contact for the simulant development work is:

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8. References

Kerry Prindiville. **Test Specification: Development of Simulants to Support Mixing Tests for High Level Waste and Low Activity Waste**. 24590-WTP-TSP-RT-01-004, Rev. 1, River Protection Project, Waste Treatment Plant, Richland, WA, 99352, November 2002.

G. H. Beeman. **Composition of AZ-101 Envelope D and Associated Wastes**. RPP-WTP-02-168, RPP-WTP-02-184, RPP-WTP-02-199, Battelle – Pacific Northwest Division, Richland, WA 99352 (June 21, 2002),(July 31, 2002), (September 5, 2002).

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APPENDIX F

APPENDIX F: HLW PRECIPITATED HYDROXIDE SIMULANT WITH AND WITHOUT GLASS FORMERS

1. Simulant Designation

The HLW Precipitated Hydroxide Simulant with and without glass formers is designed to represent HLW pretreated feed and HLW melter feed with a composition which duplicates the actual AZ-101 pretreated sludge. The simulant is intended for tests requiring a simulant as realistic as possible for both chemical properties and physical properties. The simulant is designed to reproduce the physical interactions expected for HLW feeds combined with the planned HLW glass formers.

2. Simulant Waste Stream Composition and Unit Operation Usage

2.1. CHARACTERIZATION DATA DESCRIPTION

The compositional basis of the HLW Precipitated Hydroxide simulant was derived from the characterization of AZ-101 sludge (Beeman 2002). The simulant includes all measured species that are not radioactive. Physical properties were adjusted by varying the insoluble solids loading of the HLW Precipitated Hydroxide simulant and by thermal processing of the simulant.

2.2. FLOWSHEET OPERATION FOR WHICH THE SIMULANT WAS DEVELOPED

The HLW Precipitated Hydroxide simulant can be used for process studies involving the HLW Concentrate Receipt Vessel (CRV) and the HLW Melter Feed Process Vessel (MFPV) and subsequent vitrification processing. It can be used in rheological studies, process chemistry studies and possibly environmental studies.

3. Actual Simulant Preparation Procedure

3.1. CHEMICALS TO USE

Development of the HLW Precipitated Hydroxide simulant used reagent grade chemicals and specific oxides/hydroxides of known particle sizes. The specific metal oxides and their sources are listed in Table F-1. Substitutions for the specific oxides/hydroxides should not be made without additional studies. However, technical grade chemicals may be sufficient for replacing the reagent grade chemicals when producing larger scale quantities of the simulant. These technical grade chemicals should be at least 97 % pure. Care in choosing the technical grade chemicals are necessary to prevent the trace contaminants in the technical grade from swamping the intended concentration of minor waste species.
Cost, chemical availability, and ease of scale up were considered in choosing which compounds to use.

Table F- 1 Metal Oxides/Hydroxides Used in Simulant

Material	Product Name	Material Supplier
Aluminum Oxide, 99.5%	Fine Powder, Cat #12553	Alfa Aesar
Silica, SiO_2	Silicon(IV) Oxide, 99.5% -400 mesh, Cat #13024	Alfa Aesar
Tin (IV) Oxide	Tin (IV) Oxide,-325 Mesh, 99.9%, Cat #24465-1	Sigma-Aldrich
Titanium Dioxide	Titanium(IV) Oxide, powder, <5 micron, 99.9+%, Cat #22422-7	Sigma-Aldrich

Many of the salts used in the simulant include waters of hydration and the specific form to be used is shown in Table F-2 and Table F-3. Care must be taken in storing and using some of these compounds due to their tendency to readily absorb water. Using a salt, which has obviously absorbed excess water, will lead to missing the target value for that compound. When necessary, a solution of the compound can be used. However, the water additions shown in Table F-2 will have to be appropriately reduced to account for the water in the solution of the compound.

The HLW Precipitated Hydroxide melter feed simulant is prepared from the HLW Precipitated Hydroxide feed simulant by the addition of the appropriate amount of approved glass formers as specified by the Waste Treatment Plant (WTP) Project. The composition of glass formers shown in Table F-4 is based on the composition specified for the AZ-101 sludge sample (Prindiville, 2002).

3.2. CHEMICAL ADDITION ORDER

The order of chemical addition to produce the simulant is shown in Table F-2 and is based upon the following logical steps:

1. Generate hydrous MnO_2 by reacting Manganous nitrate, $Mn(NO_3)_2$ with potassium permanganate, $KMnO_4$.
2. Add Alkaline earth and transition metal nitrates.
3. Convert solution from acid to base by addition of sodium hydroxide to precipitate metal oxides/hydroxides.
4. Add sodium carbonate solution to convert slightly soluble hydroxides to more insoluble carbonates.
5. Wash the slurry to remove excess Na^+ and NO_3^- and CO_2^- ions.
6. Add the specific metal oxides/hydroxides
7. Concentrate the sludge to the appropriate target insoluble solids concentration by boiling the sludge for 6-7 hours and removing the condensate.
8. Measure the sludge volume and density.
9. Add soluble species for the supernate phase
10. Add Complete Cesium Ion Exchange Concentrate simulant (Table F-3)

These steps produce the desired composition expected in the waste simulant while avoiding the acid-induced decomposition of carbonate or nitrite prior to the addition of the acidic Ion Exchange concentrate. Some destruction of the basic salts is expected when the acidic Cesium Ion Exchange Concentrate is added to the mixture. Such reactions are expected to occur in Pretreatment in producing the HLW pretreated waste feed.

The water used for the simulant should be deionized water to limit the addition of other uncontrolled species. The mass of water added in each step is based upon producing a mixable precipitated sludge.

Table F- 2 Chemical Addition Order and Amounts for Producing the HLW Precipitated Hydroxide Feed Simulant

HLW Precipitated Hydroxide Feed Simulant		
Volume of Feed	**1**	**Liters**
Step 1. To the Simulant Preparation Vessel Add	**grams**	
Water	1000	
Next add the following while maintaining good mixing		
Compounds	**Formula**	**Mass,**
Potassium Permanganate	$KMnO_4$	1.913
Mix to completely dissolve		
Add to the vessel	**Formula**	**Mass,**
Manganese Nitrate Solution, 50 wt %	$Mn(NO_3)_2$	6.50
Mix thoroughly. Will produce fine black solids.		
Step 2. Then add the following while mixing	**Formula**	**Mass, grams**
Ferric Nitrate	$Fe(NO_3)_3 \cdot 9H_2O$	453.86
Nickel Nitrate	$Ni(NO_3)_2 \cdot 6H_2O$	15.348
Zirconyl Nitrate	$ZrO(NO_3)_2 \cdot xH_2O$, X~6	75.012
Cerium Nitrate	$Ce(NO_3)_3 \cdot 6H_2O$	5.034
Lanthanum nitrate	$La(NO_3)_3 \cdot 6H_2O$	5.612
Neodymium Nitrate	$Nd(NO_3)_3 \cdot 6H_2O$	4.042
Barium Nitrate	$Ba(NO_3)_2$	0.891
Calcium Nitrate	$Ca(NO_3)_2 \cdot 4H_2O$	13.708
Cadmium Nitrate	$Cd(NO_3)_2 \cdot 4H_2O$	12.335
Chromium Nitrate	$Cr(NO_3)_3 \cdot 9H_2O$	5.450
Cobalt Nitrate	$Co(NO_3)_2 \cdot 6H_2O$	0.195
Cupric Nitrate	$Cu(NO_3)_2 \cdot 2.5H_2O$	0.662
Magnesium Nitrate	$Mg(NO_3)_2 \cdot 6H_2O$	5.036
Lead Nitrate	$Pb(NO_3)_2$	0.856
Rhodium Nitrate	$Rh(NO_3)_3$ Soln, 4.933wt% Rh	3.221
Ruthenium Trichloride	$RuCl_3$ 41.74wt% Ru	1.188
Strontium Nitrate	$Sr(NO_3)_2$	2.554
Zinc Nitrate	$Zn(NO_3)_2 \cdot 6H_2O$	0.391
Silver Nitrate	$AgNO_3$	0.004
Mix thoroughly to completely dissolve everything except the fine black solids of MnO2.		
Step 3. Standardize a pH electrode with pH 4, 7 and 10 buffers.		
Place the pH electrode in the precipitation vessel with the metal nitrates and measure the pH.		
pH	Record pH	

With the nitrate solution agitating, slowly add 8 molar NaOH, until the pH reaches 10		
pH	Record final pH value	
Continue mixing for 1 Hour and then recheck pH.		
pH	Record pH value	
Step 4. Next add 400 mL of a 0.6 molar Na_2CO_3 solution.		
Thoroughly mix the slurry to insure good mixing.		
pH	Record pH value	
Allow the slurry to settle overnight or over a weekend.		
Decant the supernate .		
Step 5. Wash the settled solids with a 0.01 M NaOH and 0.01 M NaNO2 Solution until the supernate *is less than 1000 mg/L Nitrate*		
Washing can be accomplished by multiple dilutions with gravity settling or by continuous crossflow filtration.		
Measure Final Volume	Final Volume	Milliliters
Step 6. Final Insoluble Compounds Addition		
Compounds	**Formula**	**Mass, grams**
Titanium dioxide	TiO_2	0.092
Silica	SiO_2	8.66
Tin (IV) Oxide	SnO_2	1.42
Aluminum Oxide	Al_2O_3	58.50
Mix thoroughly for 30 minutes.		
Step 7. Concentrate the washed solids by boiling at atmospheric pressure (T=101-103 ° C) for 6-7 hours and removing the condensate.		
Step 8. Measure Final Volume	Final Volume	Milliliters
Measure Density	Density	g/mL
Step 9. Final Soluble Compound Addition		
Compounds	**Formula**	**Mass, grams/mL**
Potassium Nitrate	KNO_3	1.560
Potassium Molybdate	K_2MoO_4	0.051
Boric Acid	H_3BO_3	0.088
Sodium Chloride	NaCl	0.196
Sodium Fluoride	NaF	0.146
Sodium Sulfate	Na_2SO_4	0.604
Sodium Phosphate	$Na_3PO_4 \cdot 12H_2O$	9.37
Sodium Hydroxide	NaOH	6.43
Sodium Carbonate	Na_2CO_3	6.68
Sodium Nitrate	$NaNO_3$	0.000
Sodium Nitrite	$NaNO_2$	1.17
Mix thoroughly for an hour.		

Measure Weight % Solids, density and volume		
Step 10. Calculate the mass of Cesium Ion Exchange Concentrate to add using the following equation: Volume * Density * (Weight% solids/100)*0.1461		
Add **Cesium Ion Exchange Concentrate simulant**	See Table E-3	See above equation
Mix thoroughly for an hour.		

The recipe for preparing the Cesium Ion Exchange Concentrate is given in Table F- 3.

Table F- 3 Preparation of Cesium Ion Exchange Concentrate Simulant

Cesium Ion Exchange Concentrate Simulant		
Volume of Feed	1000	mL
Target Density	1.31	g/mL
In a Hood, in a tared	2	Liter Poly
Add the following Compounds	**Formula**	**Mass, grams**
Water	H_2O	200
Aluminum Nitrate	$Al(NO_3)_3 \bullet 9H_2O$	8.19
Sodium Borate	$Na_2B_4O_7 \bullet 10H_2O$	23.39
Cadmium Nitrate	$Cd(NO_3)_2 \bullet 4H_2O$	0.404
Calcium Nitrate	$Ca(NO_3)_2 \bullet 4H_2O$	13.72
Cesium Nitrate	$CsNO_3$	1.60
Copper Nitrate	$Cu(NO_3)_2 \bullet 2.5H_2O$	0.54
Ferric Nitrate	$Fe(NO_3)_3 \bullet 9H_2O$	3.41
Lead Nitrate	$Pb(NO_3)_2$	0.471
Nickel Nitrate	$Ni(NO_3)_2 \bullet 6H_2O$	0.438
Potassium Nitrate	KNO_3	13.943
Sodium Chloride	NaCl	2.77
Sodium Sulfate	Na_2SO_4	12.33
Oxalic Acid	$HO_2CCO_2H \bullet 2H_2O$	9.65
Nitric Acid	HNO_3, 70 wt %	434.49
Mix to thoroughly dissolve the solids. Next add the following slowly with good mixing.		
Compounds	**Formula**	**Mass, grams**
Sodium meta-silicate	$Na_2SiO_3 \bullet 9H_2O$	0.52
Sodium Chromate	Na_2CrO_4	4.957
Sodium Nitrate	$NaNO_3$	206.21
Water	H_2O	379.25
Agitate for 24 hours to completely dissolve as much as possible.		

The addition of glass formers to the HLW Precipitated Hydroxide pretreated feed simulant should be made as a single continuous addition by premixing the dry glass formers as the first step. The combined glass formers are then added with good mixing to a stirred batch of the HLW Precipitated Hydroxide pretreated feed simulant. The density of the feed simulant and the weight % calcine solids is needed to calculate the amounts of glass formers to make the melter feed. The amounts of the glass formers required for one liter of the HLW Precipitated Hydroxide pretreated feed simulant at 20 weight % solids, a calcine factor of 0.781, and a density of 1.204 to produce the HLW Precipitated Hydroxide melter feed is shown in Table F- 4. The calcine factor is the ratio of wt % calcine solids to wt % total solids. Adjust the values in Table F-4 based upon the measured calcine factor.

Table F- 4 Glass Formers required for One Liter of HLW Precipitated Hydroxide Pretreated Feed Simulant to produce the HLW Precipitated Hydroxide Melter Feed Simulant

Blend together the following glass formers	grams
10 Mole Borax,	172.14
Lithium Carbonate	56.37
Sodium Carbonate	39.17
Silica, SiO_2 (Sil-co-Sil 75)	260.38
Zinc Oxide, ZnO (K-920)	11.97

3.3. PRECAUTIONS

- Material Safety Data Sheets (MSDS) should be reviewed for all of the compounds in the simulant formulation.
- Appropriate safety apparel (acid-resistant gloves, etc) should be worn when working with chemicals as specified in the MSDS. Many of the compounds in the HLW Precipitated Hydroxide simulant are hazardous.
- Addition of the transition metal nitrates to the initial solutions will produce a very acidic solution.
- Addition of the NaOH solution results in significant heat generation. The NaOH can be added slowly allowing heat to dissipate, or the mixing container can be cooled by use of an external or internal cooling system (ice bath, cooling coils, etc). The cooling system is only necessary if the batch temperature exceeds 65 ° C.
- The carbonate salts are added after the NaOH to avoid carbonate decomposition.
- Addition of sodium nitrite must be made after the addition of sodium hydroxide to avoid generation of NO_x vapors.
- Good mixing is necessary when adding the Cesium Ion Exchange Concentrate simulant to prevent creating local regions of the slurry with excessively acidic conditions. If mixing is not adequate, the potential exists for generation of CO_2 and NO_x gases.
- The addition of the glass formers will also produce heat as a result of the reaction between hydroxide ion and the boric acid. For a one liter batch of the HLW Precipitated Hydroxide pretreated feed simulant, a temperature increase of one degree C has been measured using a glass former addition period of 15 minutes.

3.4. OTHER CONSIDERATIONS

- The stability of the HLW Precipitated Hydroxide pretreated feed simulant is good within the normal process time period for the HLW vitrification facility.
- Preliminary tests combined with other HLW melter feed studies suggest that the HLW Precipitated Hydroxide melter feed simulant does not have stability problems within the normal process time period for the HLW vitrification facility.
- The HLW Precipitated Hydroxide pretreated feed simulant should not be stored in glass or glass-lined containers since etching of the glass could occur which could impact the composition and the rheological properties of the simulant.

4. Key Characteristics and Limitations of the HLW Precipitated Hydroxide Pretreated Waste Feed and HLW Precipitated Hydroxide Melter Feed Simulants

4.1. KEY CHARACTERISTICS

The HLW Precipitated Hydroxide simulant composition is designed to match the composition of actual AZ-101 sludge. Of specific concern are the constituents that can interact with the glass formers to modify the physical properties of the simulant. These constituents include the Fe, Si, Zr, Na, Al, OH^-, and CO_3^{-2} concentrations. Solution density and viscosity are process-affecting and result from the concentration of the previously mentioned species.

4.2. LIMITATIONS

The simulants described in this document are limited in their ability to exactly duplicate the actual waste due to a lack of complete information on all compounds present in the sludge. Also impacting the simulant properties is the lack of extended thermal and radiation history on the waste simulant.

5. Validation of the Simulant

Validation of a simulant is normally based upon comparison of the simulant with actual waste measurements for the waste that the simulant is designed to duplicate. Upon completion of the HLW Precipitated Hydroxide simulant development program a comparison with actual AZ-101 waste will be made. Properties to compare include:

- Chemical composition.
- The rheological properties of the simulants (yield stress and consistency).
- Density.

5.1. CHEMICAL COMPOSITION

Chemical composition is a required feature for the HLW Precipitated Hydroxide simulant. The composition of the pretreated HLW Precipitated Hydroxide simulant is shown in Table F- 5.

Table F- 5 Chemical Analysis of Pretreated HLW Precipitated Hydroxide Compared to Radioactive Washed, Leached AZ-101 Sludge Solids

Species	Pretreated HLW Precipitated Hydroxide Simulant µg/gram solids	Radioactive AZ-101 Washed, Leached µg /gram solids	% of Target
Ag	<280	902	<31
Al	86659	99872	87
B	3573	91	3927
Ba	1657	1510	110
C_2O_4	186	518	36
Ca	8158	7505	109
Cd	11265	14500	78
Ce	3444	5240	66
Cl	443	703	63
Co	150	128	117
Cr	2344	2284	103
Cu	609	584	104
F	172	390	44
Fe	202384	202384	100
K	3172	2000	159
K	2508	2000	125
La	3755	5808	65
Mg	1554	1540	101
Mn	5438	5364	101
Mo	<90	66	<139
Na	42212	54545	77
Nd	3108	4290	72
Ni	9970	9992	100
NO_2	4623	7268	64
NO_3	48686	2178	2235
P	2564	4505	57
PO_4	627	<340	NA
Rh	546	512	107
Ru	947	1600	59
Si	15794	13055	121
Sn	1554	3600	43

Species	Pretreated HLW Precipitated Hydroxide Simulant µg/gram solids	Radioactive AZ-101 Washed, Leached µg /gram solids	% of Target
SO_4	1997	2410	83
Ti	341	178	191
Zn	337	278	121
Zr	61505	65050	95

The values given for the pretreated HLW Precipitated Hydroxide solids were normalized based upon the value for Fe to put the results on the same basis as the radioactive AZ-101 results. An alternative comparison was also made without the normalization by converting the measured HLW Precipitated Hydroxide simulant concentration and the radioactive AZ-101 values to a wt % oxides basis and comparing those values. The results were essentially the same as the percent of target values shown above.

5.2. CHARGE BALANCING

The only portion of the HLW Precipitated Hydroxide simulant that required charge balancing was the supernate and the Cesium Ion Exchange Concentrate simulant. The OLI software used to model the Cesium Ion Exchange Eluant evaporator automatically performs a charge balance.

6. Simulant Properties Compared to Bounding Waste Properties

The rheograms of the Pretreated HLW Precipitated Hydroxide simulant and HLW Precipitated Hydroxide Melter Feed simulants indicate that the fluids are non-Newtonian in behavior since they are not a linear function of the shear. Figure F- 1 shows the comparison of simulant to actual at 25 ° C.

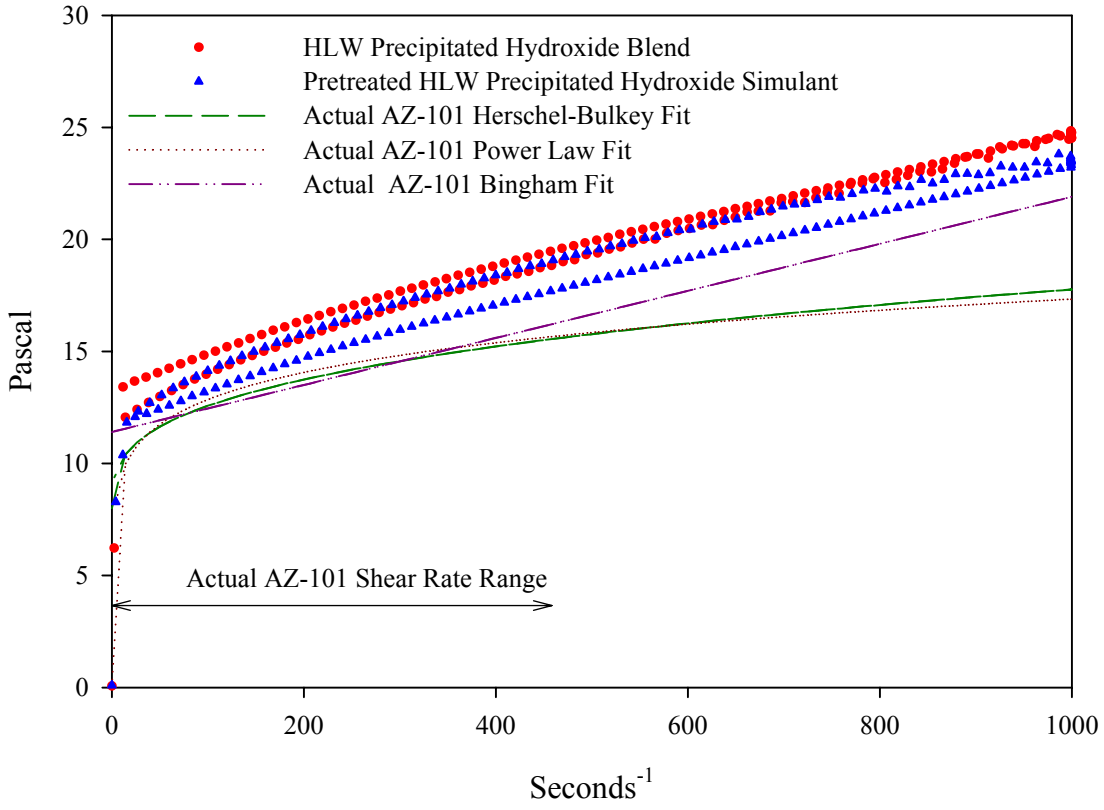

Figure F- 1 Rheology of Pretreated HLW Precipitated Hydroxide Simulant at 22.3 wt % Total Solids Compared to Radioactive AZ-101 Rheology Model Results

The yield stress of the pretreated HLW Precipitated Hydroxide simulant was 12.5 Pascals at 25 ° C and 13.7 Pascals at 40 ° C based upon a Bingham Plastic model fit for the up flow curve from 50 to 1000 sec^{-1}. The radioactive AZ-101 yield stress for 22 wt % undissolved solids is 11.4 Pascals at 25 ° C and 10.3 Pascals at 40 ° C. The comparison at 25 ° C is excellent. The consistency of the pretreated HLW Precipitated Hydroxide simulant was 11 mPa·s at 25 ° C (within 5% of the actual) and 10.4 mPa·s at 40 ° C (within 40% of the actual) also based upon the Bingham Plastic model fit.

The yield stress of the HLW Precipitated Hydroxide melter feed simulant was 18.9 Pascals (compared to 14.7 Pa) at 25 ° C and 15.7 Pascals at 40 ° C (compared to 18.1 Pa) based upon a Bingham Plastic model fit for the up flow curve from 50 to 1000 sec^{-1}. The consistency of the HLW Precipitated Hydroxide melter feed simulant was 28.5 mPa·s at 25 ° C (within 40% of the actual) and 20.2 mPa·s at 40 ° C (within 5% of the actual) also based upon the Bingham Plastic model fit. In both cases a better model fit was obtained using power law with intercept (Herschel-Bulkey) model.

7. Simulant Development Organization

The pretreated HLW Precipitated Hydroxide simulant and HLW Precipitated Hydroxide melter feed simulant were developed at Westinghouse Savannah River Company, Savannah River Technology Center. The primary contact for the simulant development work is:

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8. References

Kerry Prindiville. **Test Specification: Development of Simulants to Support Mixing Tests for High Level Waste and Low Activity Waste**. 24590-WTP-TSP-RT-01-004, Rev. 1, River Protection Project, Waste Treatment Plant, Richland, WA, 99352, November 2002.

G. H. Beeman. **Composition of AZ-101 Envelope D and Associated Wastes**. RPP-WTP-02-168, RPP-WTP-02-184, RPP-WTP-02-199, Battelle – Pacific Northwest Division, Richland, WA 99352 (June 21, 2002),(July 31, 2002), (September 5, 2002).

APPENDIX G

APPENDIX G: OLI/ESP MODELING OF TANK AP-101 CESIUM ELUATE EVAPORATION

SRT-PDH-2003-00002

January 20, 2003

CC: D. A. Crowley, 999-W

T. B. Calloway, 999-W

K. A. Howard, 773-42A

To: R. E. Eibling

From: A. S. Choi

OLI/ESP MODELING OF TANK AP-101 CESIUM ELUATE EVAPORATION

Included in this memo are the results of semi-batch evaporation modeling of tank AP-101 cesium eluate using the environmental simulation program (ESP), licensed by OLI systems, inc.[1] The goal was to determine the chemical compositions of cesium eluate solutions concentrated to 80% and 100% bulk saturation. The bulk saturation limit of a multicomponent system is defined here as the point where the solution would become just saturated with one or more of the major salt species present or supersaturated with other minor salt species to the extent that the total insoluble solids formed exclusively out of the minor salt constituents would just exceed 0.5 wt% of the solution, whichever occurs first. These saturation criteria were applied to the assumed storage conditions of 25 °C and 1 atm.

[1] ESP Software, http://www.olisystems.com/, OLI Systems, Inc., Morris Plains, NJ (2002).

The key process features captured by the model include the following: The reboiler pot was initially charged with 7.24 M nitric acid solution and kept under vacuum so that boilup would occur at 50 ^{o}C, while maintaining a constant liquid level in the pot. The feeding was continued with no bottom product withdrawal, until the liquid in the pot reached the bulk saturation limit defined above. Throughout the feeding and boilup period, the acid concentration in the pot will continuously decrease but the salt content will increase. As a result, the vapor-liquid equilibrium of nitric acid solution in the pot will change continuously, which was the essence of this electrolyte chemistry modeling. Once the bulk saturation limit was determined, the operational target endpoint of 80% saturation was determined by backing off to the point where the ionic product of the target salt constituents equaled 80% of its solubility product.

The composition of Tank AP-101 cesium eluate provided by you is given in Table 1. As expected, nitric acid is the most dominant species on a molar basis, followed by sodium. Besides these two major species, silica and boron stand out among the remaining minor species; however, based on earlier analytical results,[2] it is suspected that their presence could very well have been due to the leaching of glassware during the storage of strongly acidic samples.

TABLE 1. Composition of Tank AP-101 Cesium Eluate.

Compounds	Moles/Liter
Aluminum Nitrate	7.41E-04
Barium Nitrate	2.18E-05
Boric Acid	8.33E-03
Cadmium Nitrate	4.45E-05
Calcium Nitrate	1.97E-03
Cesium Nitrate	2.78E-04
Sodium Chromate	1.04E-03
Copper Nitrate	7.87E-05
Ferric Nitrate	2.86E-04
Lead nitrate	4.83E-05
Nickel Nitrate	5.11E-05
Potassium Nitrate	4.68E-03
Sodium meta-silicate	5.95E-03
Sodium Chloride	4.80E-03
Sodium Sulfate	2.95E-03
Sodium Nitrate	6.95E-02
Nitric acid	3.90E-01
Oxalic Acid	1.82E-03

Density (g/ml) =	1.011

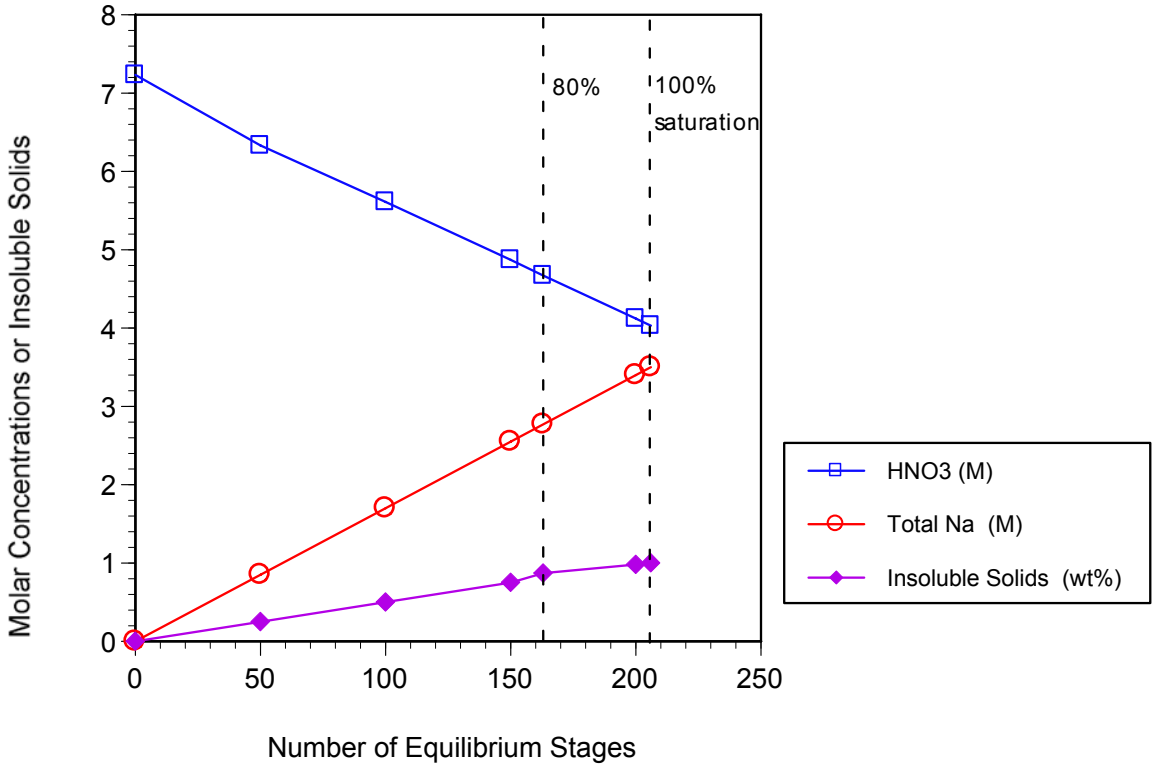
[2] Pierce, R. A., "Cesium Eluate Analytical Data Evaluation," **WSRC-TR-2001-00594, SRT-RPP-2001-00228**, Westinghouse Savannah River Co., Aiken, SC, December 2001.

The actual input to the model were the full-scale molar flow rates derived from the composition given in Table 1. The solubility is an intensive property and, therefore, independent of the absolute flow rates chosen. Nevertheless, the full-scale flow rates were used in this task so that the resulting mass balance would reflect instantaneous flows required to satisfy the design basis Envelope B glass production rate of 60 metric tons per day at a sodium loading of 10 wt% Na_2O. The corresponding instantaneous flow rate of cesium required to satisfy the 100% Envelope B glass attainment was calculated to be 119.14 g/hr, which is reflected on the feed rate of cesium to the evaporator in the model.

The calculated compositions of the AP-101 cesium eluate feed and its concentrated products at 80% and 100% saturation are given in Appendix A and B in the true and apparent species forms, respectively. The compositions presented in the true species form are the equilibrium ionic speciation actually predicted by the model and, therefore, should represent the reality more closely. On the other hand, the compositions presented in the apparent species form were derived by letting the software determine the molecular forms that satisfy the mass balance of given ionic distributions; as a result, some unrealistic molecular species could be chosen by the software from its database. This is indeed what we find in the apparent species output given in Appendix B. For example, the software predicted that sodium aluminate and hydroxides of copper, iron and nickel would form under such strongly acidic conditions as pH $\approx$ 0.

The model results showed that Tank AP-101 cesium eluate would become saturated with $NaNO_3$ when the pot acidity drops to 4 M HNO_3. At this point, the insoluble solids level in the pot was 1 wt%, which is twice as high as the supersaturation criterion of 0.5 wt% defined earlier. Nearly all the insoluble solids predicted to form was due to SiO_2 and, in fact, even the unevaporated feed was already predicted to contain SiO_2 solids. However, the formation of SiO_2 solids was overridden in this study based on its suspected origin discussed earlier. The pot acidity at 80% saturation with respect to $NaNO_3$ was predicted to be 4.7 M HNO_3. The full compositions of 100% and 80% saturated AP-101 cesium eluate solutions are given in Appendix A. In case you need to target the endpoints other than 80% saturation, I have also included the entire operating curve shown in Figure 2.

FIGURE 1. Profiles of Concentrations and Insoluble Solids in the Pot during Semi-Batch Evaporation of Tank AP-101 Cesium Eluate.



APPENDIX A

True Species Output

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================================================================================

              O   O   O          L                   I I I I
            O           O        L                     I
          O               O      L                     I
         O                 O     L                     I
         O                 O     L                     I
         O                 O     L                     I
          O               O      L                     I
            O           O        L                     I
              O   O   O          L L L L L L L L     I I I I


        E N V I R O N M E N T A L   S I M U L A T I O N   P R O G R A M

                        V - 6.6   September 1, 2002

                             PROCESS: DSTIL_5

                       CHEMISTRY MODEL: AP101CS

                        THIS FILE NAME: DSTIL_5.LIS

                                 DATE: 01/18/2003

================================================================================
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STREAM: **AP-101 Cs Eluate Feed**

Phases---------->	Aqueous	Solid	Vapor	Organic
Temperature, C	20.	20.	20.	20.
Pressure, atm	1.	1.	1.	1.
pH	0.410175			
Total mol/hr	175553.	13.5452	0.0	0.0
----------	mol/hr--------	mol/hr--------	mol/hr--------	mol/hr--------
H2O	172523.	0.0	0.0	0.0
H2SO4	1.01893E-10	0.0	0.0	0.0
HCL	1.96806E-06	0.0	0.0	0.0
HNO3	21.2976	0.0	0.0	0.0
SO3	1.26799E-14	0.0	0.0	0.0
CAC2O4	2.42711E-05	0.0	0.0	0.0
CACL2	1.93130E-24	0.0	0.0	0.0
CAH2SIO4	4.62428E-21	0.0	0.0	0.0
CAHC2O42	7.37002E-06	0.0	0.0	0.0
CASO4	0.00210184	0.0	0.0	0.0
CDC2O4	1.67661E-07	0.1354106	0.0	0.0
CDCL2	2.25449E-05	0.0	0.0	0.0
CDOH2	1.69824E-23	0.0	0.0	0.0
CDSO4	1.90651E-05	0.0	0.0	0.0
CSCL	5.95956E-04	0.0	0.0	0.0
CSNO3	0.246837	0.0	0.0	0.0
CUC2O4	0.00203326	0.0	0.0	0.0
CUCL2	1.09361E-06	0.0	0.0	0.0
CUNO32	0.00325141	0.0	0.0	0.0
CUOH2	1.05151E-15	0.0	0.0	0.0
FECL3	7.98122E-14	0.0	0.0	0.0
FEIIIOH3	1.54035E-16	0.0	0.0	0.0
ALO2H2CL	1.65101E-29	0.0	0.0	0.0
ALOH3	1.73004E-16	0.0	0.0	0.0
BAOX	1.88526E-08	0.0	0.0	0.0
KCL	1.73185E-04	0.0	0.0	0.0
KHSO4	2.28262E-04	0.0	0.0	0.0
KNO3	3.0782	0.0	0.0	0.0
NABOH4	1.16584E-09	0.0	0.0	0.0
NAHSIO3	1.30624E-08	0.0	0.0	0.0
NANO3	28.0538	0.0	0.0	0.0
NIC2O4	0.0141296	0.0	0.0	0.0
NIOH2	7.36230E-21	0.0	0.0	0.0
NISO4	2.37146E-04	0.0	0.0	0.0
OXALAC	3.9128	0.0	0.0	0.0
PBC2O4	0.00715212	0.0	0.0	0.0
PBCL2	8.71371E-06	0.0	0.0	0.0
PBNO32	0.0210036	0.0	0.0	0.0
PBO	2.26328E-19	0.0	0.0	0.0
BASO4	6.62163E-07	0.04142868	0.0	0.0
SIO2	5.54795	13.36836	0.0	0.0
BOH3	26.486	0.0	0.0	0.0
OHION	8.40693E-11	0.0	0.0	0.0
ALOH2ION	2.47312E-11	0.0	0.0	0.0
ALOH4ION	1.33098E-22	0.0	0.0	0.0
ALOHCLION	4.11644E-08	0.0	0.0	0.0
ALOHION	7.17438E-06	0.0	0.0	0.0
ALSO42ION	5.03885E-05	0.0	0.0	0.0
ALSO4ION	0.0112989	0.0	0.0	0.0
B2OOH5ION	5.50840E-10	0.0	0.0	0.0
B3O3OH4ION	6.92393E-10	0.0	0.0	0.0
B4O5OH4ION	5.77981E-19	0.0	0.0	0.0
BAION	0.028068	0.0	0.0	0.0
BAOHION	5.53923E-17	0.0	0.0	0.0
BOH4ION	4.83568E-08	0.0	0.0	0.0

CACLION	6.72632E-08	0.0	0.0	0.0
CAH2BO3ION	8.92248E-10	0.0	0.0	0.0
CAHC2O4ION	0.0146346	0.0	0.0	0.0
CAHSIO3ION	1.41227E-11	0.0	0.0	0.0
CAION	4.80225	0.0	0.0	0.0
CANO3ION	1.45135	0.0	0.0	0.0
CAOHION	3.56502E-13	0.0	0.0	0.0
CDC2O42ION	4.76181E-12	0.0	0.0	0.0
CDC2O43ION	1.13910E-17	0.0	0.0	0.0
CDCL3ION	5.43751E-09	0.0	0.0	0.0
CDCL4ION	7.07242E-11	0.0	0.0	0.0
CDCLION	4.40926E-04	0.0	0.0	0.0
CDION	0.00418545	0.0	0.0	0.0
CDNO3ION	0.00141594	0.0	0.0	0.0
CDOHION	1.66548E-13	0.0	0.0	0.0
CLION	15.2512	0.0	0.0	0.0
CR2O7ION	0.167147	0.0	0.0	0.0
CRO4ION	7.70198E-06	0.0	0.0	0.0
CSION	0.638114	0.0	0.0	0.0
CSSO4ION	1.21552E-04	0.0	0.0	0.0
CUC2O42ION	6.39609E-06	0.0	0.0	0.0
CUCL3ION	1.24993E-11	0.0	0.0	0.0
CUCLION	9.37635E-04	0.0	0.0	0.0
CUION	0.161611	0.0	0.0	0.0
CUNO3ION	0.08245	0.0	0.0	0.0
CUOH3ION	1.55841E-27	0.0	0.0	0.0
CUOHION	3.97099E-09	0.0	0.0	0.0
FEIII2OH2ION	8.63013E-18	0.0	0.0	0.0
FEIIIC2O42ION	0.00603907	0.0	0.0	0.0
FEIIIC2O43ION	1.83800E-05	0.0	0.0	0.0
FEIIIC2O4ION	0.905066	0.0	0.0	0.0
FEIIICL2ION	4.27069E-10	0.0	0.0	0.0
FEIIICL4ION	6.03281E-18	0.0	0.0	0.0
FEIIICLION	5.84594E-08	0.0	0.0	0.0
FEIIIHC2O4ION	8.09670E-05	0.0	0.0	0.0
FEIIIION	2.58276E-04	0.0	0.0	0.0
FEIIINO3ION	2.95927E-06	0.0	0.0	0.0
FEIIIOH2ION	1.32649E-11	0.0	0.0	0.0
FEIIIOH4ION	8.42917E-26	0.0	0.0	0.0
FEIIIOHION	8.44468E-07	0.0	0.0	0.0
FEIIISO4ION	1.36092E-07	0.0	0.0	0.0
H2SIO4ION	1.68113E-21	0.0	0.0	0.0
H3SIO4ION	2.11996E-09	0.0	0.0	0.0
HCRO4ION	2.96958	0.0	0.0	0.0
HION	1172.78	0.0	0.0	0.0
HOXALATION	0.778862	0.0	0.0	0.0
HPBO2ION	6.75742E-30	0.0	0.0	0.0
HSO4ION	7.78569	0.0	0.0	0.0
KION	11.8066	0.0	0.0	0.0
KSO4ION	0.00425473	0.0	0.0	0.0
NAION	271.258	0.0	0.0	0.0
NASO4ION	0.130189	0.0	0.0	0.0
NIC2O42ION	5.00393E-09	0.0	0.0	0.0
NICLION	1.11204E-05	0.0	0.0	0.0
NIION	0.1099	0.0	0.0	0.0
NINO3ION	0.0383159	0.0	0.0	0.0
NIOH3ION	0.0	0.0	0.0	0.0
NIOHION	6.94975E-12	0.0	0.0	0.0
NO3ION	1446.35	0.0	0.0	0.0
ALION	2.34676	0.0	0.0	0.0
OXALATION	4.35331E-04	0.0	0.0	0.0
PBCL3ION	2.45588E-08	0.0	0.0	0.0
PBCL4ION	2.58846E-10	0.0	0.0	0.0

PBCLION	0.00103993	0.0	0.0	0.0
PBION	0.0449315	0.0	0.0	0.0
PBNO33ION	0.00266008	0.0	0.0	0.0
PBNO3ION	0.0766985	0.0	0.0	0.0
PBOHION	4.04189E-10	0.0	0.0	0.0
SO4ION	1.39669	0.0	0.0	0.0
Total g/hr	3.21463E+06	840.038	0.0	0.0
Volume, L/hr	3160.22	0.366714	0.0	0.0
Enthalpy, cal/hr	-1.19063E+10	-2.92524E+06	0.0	0.0
Density, g/L	1017.22	2290.72		
Vapor fraction	0.0	0.0	0.0	0.0
Solid fraction	0.0	1.	0.0	0.0
Organic fraction	0.0	0.0	0.0	0.0
Osmotic Pres, atm	24.4621			
Redox Pot, volts	0.0			
E-Con, 1/ohm-cm	0.131581			
E-Con, cm2/ohm-mol	265.489			
Abs Visc, cP	1.01492			
Rel Visc	1.01288			
Ionic Strength	0.479457			

STREAM: **80% Concentrated Cs Eluate**

Phases---------->	Aqueous	Solid	Vapor	Organic
Temperature, C	25.	25.	25.	25.
Pressure, atm	1.	1.	1.	1.
pH	-1.0608			
Total mol/hr	940702.	3072.51	0.0	0.0
----------	mol/hr--------	mol/hr--------	mol/hr--------	mol/hr--------
H2O	719408.	0.0	0.0	0.0
H2SO4	2.56721E-06	0.0	0.0	0.0
HCL	0.0162784	0.0	0.0	0.0
HNO3	28393.6	0.0	0.0	0.0
SO3	5.76024E-10	0.0	0.0	0.0
CAC2O4	2.96536E-05	0.0	0.0	0.0
CACL2	3.52543E-19	0.0	0.0	0.0
CAH2SIO4	5.57241E-23	0.0	0.0	0.0
CAHC2O42	2.36547E-04	0.0	0.0	0.0
CASO4	0.219027	0.0	0.0	0.0
CDC2O4	1.17966E-06	10.03049	0.0	0.0
CDCL2	4.50227	0.0	0.0	0.0
CDOH2	1.90634E-24	0.0	0.0	0.0
CDSO4	0.0130811	0.0	0.0	0.0
CSCL	0.142054	0.0	0.0	0.0
CSNO3	144.176	0.0	0.0	0.0
CUC2O4	2.64428E-04	0.0	0.0	0.0
CUCL2	0.00497093	0.0	0.0	0.0
CUNO32	23.0711	0.0	0.0	0.0
CUOH2	2.10401E-18	0.0	0.0	0.0
FECL3	1.78791E-05	0.0	0.0	0.0
FEIIIOH3	9.82719E-18	0.0	0.0	0.0
ALO2H2CL	5.11990E-29	0.0	0.0	0.0
ALOH3	3.74956E-19	0.0	0.0	0.0
BAOX	7.71170E-10	0.0	0.0	0.0
KCL	0.0427395	0.0	0.0	0.0
KHSO4	0.238168	0.0	0.0	0.0
KNO3	2153.37	0.0	0.0	0.0
NABOH4	3.30098E-08	0.0	0.0	0.0
NAHSIO3	1.13322E-08	0.0	0.0	0.0
NANO3	24063.5	0.0	0.0	0.0
NIC2O4	0.0138076	0.0	0.0	0.0
NIOH2	1.08563E-22	0.0	0.0	0.0
NISO4	0.0274709	0.0	0.0	0.0
OXALAC	780.822	0.0	0.0	0.0
PBC2O4	3.05135E-05	0.0	0.0	0.0
PBCL2	0.00123776	0.0	0.0	0.0
PBNO32	5.2431	0.0	0.0	0.0
PBO	2.66995E-23	0.0	0.0	0.0
BASO4	3.42694E-06	11.02129	0.0	0.0
SIO2	31.905	3051.458	0.0	0.0
BOH3	4317.22	0.0	0.0	0.0
OHION	9.15076E-12	0.0	0.0	0.0
ALOH2ION	1.06435E-12	0.0	0.0	0.0
ALOH4ION	4.11332E-27	0.0	0.0	0.0
ALOHCLION	5.06833E-06	0.0	0.0	0.0
ALOHION	2.41309E-06	0.0	0.0	0.0
ALSO42ION	0.0935757	0.0	0.0	0.0
ALSO4ION	6.85015	0.0	0.0	0.0
B2OOH5ION	8.05030E-08	0.0	0.0	0.0
B3O3OH4ION	7.23645E-06	0.0	0.0	0.0
B4O5OH4ION	4.81522E-14	0.0	0.0	0.0
BAION	0.306832	0.0	0.0	0.0
BAOHION	1.28584E-18	0.0	0.0	0.0
BOH4ION	9.76275E-08	0.0	0.0	0.0

CACLION	1.29538E-04	0.0	0.0	0.0
CAH2BO3ION	2.42561E-08	0.0	0.0	0.0
CAHC2O4ION	0.431344	0.0	0.0	0.0
CAHSIO3ION	8.27370E-12	0.0	0.0	0.0
CAION	219.153	0.0	0.0	0.0
CANO3ION	802.268	0.0	0.0	0.0
CAOHION	1.23060E-13	0.0	0.0	0.0
CDC2O42ION	5.05886E-12	0.0	0.0	0.0
CDC2O43ION	1.18100E-17	0.0	0.0	0.0
CDCL3ION	0.0317908	0.0	0.0	0.0
CDCL4ION	0.0581195	0.0	0.0	0.0
CDCLION	2.64046	0.0	0.0	0.0
CDION	0.690011	0.0	0.0	0.0
CDNO3ION	5.0975	0.0	0.0	0.0
CDOHION	3.66606E-13	0.0	0.0	0.0
CLION	820.442	0.0	0.0	0.0
CR2O7ION	143.609	0.0	0.0	0.0
CRO4ION	3.25875E-05	0.0	0.0	0.0
CSION	0.0431135	0.0	0.0	0.0
CSSO4ION	0.00260713	0.0	0.0	0.0
CUC2O42ION	1.36180E-07	0.0	0.0	0.0
CUCL3ION	1.52186E-06	0.0	0.0	0.0
CUCLION	0.136379	0.0	0.0	0.0
CUION	0.823746	0.0	0.0	0.0
CUNO3ION	16.7608	0.0	0.0	0.0
CUOH3ION	0.0	0.0	0.0	0.0
CUOHION	1.81524E-10	0.0	0.0	0.0
FEIII2OH2ION	6.42823E-15	0.0	0.0	0.0
FEIIIC2O42ION	0.0332071	0.0	0.0	0.0
FEIIIC2O43ION	3.30540E-05	0.0	0.0	0.0
FEIIIC2O4ION	146.785	0.0	0.0	0.0
FEIIICL2ION	0.00307899	0.0	0.0	0.0
FEIIICL4ION	3.18085E-08	0.0	0.0	0.0
FEIIICLION	0.0352727	0.0	0.0	0.0
FEIIIHC2O4ION	1.62157	0.0	0.0	0.0
FEIIIION	0.0287241	0.0	0.0	0.0
FEIIINO3ION	0.0582514	0.0	0.0	0.0
FEIIIOH2ION	1.99401E-11	0.0	0.0	0.0
FEIIIOH4ION	1.26480E-28	0.0	0.0	0.0
FEIIIOHION	1.10301E-05	0.0	0.0	0.0
FEIIISO4ION	0.00371495	0.0	0.0	0.0
H2SIO4ION	2.21665E-23	0.0	0.0	0.0
H3SIO4ION	1.03402E-10	0.0	0.0	0.0
HCRO4ION	251.315	0.0	0.0	0.0
HION	53778.8	0.0	0.0	0.0
HOXALATION	2.82268	0.0	0.0	0.0
HSO4ION	1247.88	0.0	0.0	0.0
KION	273.24	0.0	0.0	0.0
KSO4ION	0.084286	0.0	0.0	0.0
NAION	24731.7	0.0	0.0	0.0
NASO4ION	13.7054	0.0	0.0	0.0
NIC2O42ION	7.34764E-10	0.0	0.0	0.0
NICLION	0.0108556	0.0	0.0	0.0
NIION	5.92886	0.0	0.0	0.0
NINO3ION	20.5218	0.0	0.0	0.0
NIOHION	2.32602E-12	0.0	0.0	0.0
NO3ION	78237.	0.0	0.0	0.0
ALION	377.43	0.0	0.0	0.0
OXALATION	4.27302E-04	0.0	0.0	0.0
PBCL3ION	1.21173E-04	0.0	0.0	0.0
PBCL4ION	1.81807E-04	0.0	0.0	0.0
PBCLION	0.00427047	0.0	0.0	0.0
PBION	0.0344734	0.0	0.0	0.0

PBNO33ION	19.5343	0.0	0.0	0.0
PBNO3ION	0.201784	0.0	0.0	0.0
PBOHION	6.10077E-13	0.0	0.0	0.0
SO4ION	247.463	0.0	0.0	0.0
Total g/hr	2.32450E+07	187927.	0.0	0.0
Volume, L/hr	17598.	83.7875	0.0	0.0
Enthalpy, cal/hr	-6.04124E+10	-6.63498E+08	0.0	0.0
Density, g/L	1320.89	2242.91		
Vapor fraction	0.0	0.0	0.0	0.0
Solid fraction	0.0	1.	0.0	0.0
Organic fraction	0.0	0.0	0.0	0.0
Osmotic Pres, atm	719.53			
Redox Pot, volts	0.0			
E-Con, 1/ohm-cm	0.61181			
E-Con, cm2/ohm-mol	75.7504			
Abs Visc, cP	1.80731			
Rel Visc	2.02904			
Ionic Strength	6.41401			

STREAM: **100% Concentrated Cs Eluate**

Phases---------->	Aqueous	Solid	Vapor	Organic
Temperature, C	25.	25.	25.	25.
Pressure, atm	1.	1.	1.	1.
pH	-1.05852			
Total mol/hr	935404.	3903.42	0.0	0.0
----------	mol/hr--------	mol/hr--------	mol/hr--------	mol/hr--------
H2O	709570.	0.0	0.0	0.0
H2SO4	2.43687E-06	0.0	0.0	0.0
HCL	0.0148996	0.0	0.0	0.0
HNO3	26823.1	0.0	0.0	0.0
SO3	5.49481E-10	0.0	0.0	0.0
CAC2O4	4.79953E-05	0.0	0.0	0.0
CACL2	4.42385E-19	0.0	0.0	0.0
CAH2SIO4	6.17175E-23	0.0	0.0	0.0
CAHC2O42	5.54006E-04	0.0	0.0	0.0
CASO4	0.269105	0.0	0.0	0.0
CDC2O4	1.01941E-06	20.19473	0.0	0.0
CDCL2	3.01654	0.0	0.0	0.0
CDOH2	1.12729E-24	0.0	0.0	0.0
CDSO4	0.00858104	0.0	0.0	0.0
CSCL	0.164769	0.0	0.0	0.0
CSNO3	182.251	0.0	0.0	0.0
CUC2O4	4.45675E-04	0.0	0.0	0.0
CUCL2	0.00649553	0.0	0.0	0.0
CUNO32	27.6881	0.0	0.0	0.0
CUOH2	2.42663E-18	0.0	0.0	0.0
FECL3	1.62938E-05	0.0	0.0	0.0
FEIIIOH3	7.42629E-18	0.0	0.0	0.0
ALO2H2CL	4.09817E-29	0.0	0.0	0.0
ALOH3	2.81967E-19	0.0	0.0	0.0
BAOX	8.77888E-10	0.0	0.0	0.0
KCL	0.0488264	0.0	0.0	0.0
KHSO4	0.282174	0.0	0.0	0.0
KNO3	2693.92	0.0	0.0	0.0
NABOH4	5.11216E-08	0.0	0.0	0.0
NAHSIO3	1.20002E-08	0.0	0.0	0.0
NANO3	27469.	0.0	0.0	0.0
NIC2O4	0.0221499	0.0	0.0	0.0
NIOH2	1.19173E-22	0.0	0.0	0.0
NISO4	0.0334527	0.0	0.0	0.0
OXALAC	978.507	0.0	0.0	0.0
PBC2O4	4.42008E-05	0.0	0.0	0.0
PBCL2	0.00139008	0.0	0.0	0.0
PBNO32	5.40802	0.0	0.0	0.0
PBO	2.65965E-23	0.0	0.0	0.0
BASO4	2.96141E-06	14.03982	0.0	0.0
SIO2	27.5875	3869.185	0.0	0.0
BOH3	5456.12	0.0	0.0	0.0
OHION	7.42309E-12	0.0	0.0	0.0
ALOH2ION	9.03869E-13	0.0	0.0	0.0
ALOH4ION	3.67257E-27	0.0	0.0	0.0
ALOHCLION	4.64319E-06	0.0	0.0	0.0
ALOHION	1.97696E-06	0.0	0.0	0.0
ALSO42ION	0.107934	0.0	0.0	0.0
ALSO4ION	6.51191	0.0	0.0	0.0
B2OOH5ION	1.88670E-07	0.0	0.0	0.0
B3O3OH4ION	2.50487E-05	0.0	0.0	0.0
B4O5OH4ION	2.24049E-13	0.0	0.0	0.0
BAION	0.276665	0.0	0.0	0.0
BAOHION	1.13161E-18	0.0	0.0	0.0

BOH4ION	1.39878E-07	0.0	0.0	0.0
CACLION	2.06272E-04	0.0	0.0	0.0
CAH2BO3ION	4.51894E-08	0.0	0.0	0.0
CAHC2O4ION	0.7951	0.0	0.0	0.0
CAHSIO3ION	1.04879E-11	0.0	0.0	0.0
CAION	265.353	0.0	0.0	0.0
CANO3ION	1025.28	0.0	0.0	0.0
CAOHION	1.53979E-13	0.0	0.0	0.0
CDC2O42ION	7.32897E-12	0.0	0.0	0.0
CDC2O43ION	3.71696E-17	0.0	0.0	0.0
CDCL3ION	0.0286064	0.0	0.0	0.0
CDCL4ION	0.050611	0.0	0.0	0.0
CDCLION	1.89902	0.0	0.0	0.0
CDION	0.456628	0.0	0.0	0.0
CDNO3ION	3.49335	0.0	0.0	0.0
CDOHION	2.44814E-13	0.0	0.0	0.0
CLION	967.292	0.0	0.0	0.0
CR2O7ION	230.648	0.0	0.0	0.0
CRO4ION	3.66443E-05	0.0	0.0	0.0
CSION	0.0272994	0.0	0.0	0.0
CSSO4ION	0.00397667	0.0	0.0	0.0
CUC2O42ION	3.84783E-07	0.0	0.0	0.0
CUCL3ION	2.67080E-06	0.0	0.0	0.0
CUCLION	0.191301	0.0	0.0	0.0
CUION	1.07779	0.0	0.0	0.0
CUNO3ION	22.5957	0.0	0.0	0.0
CUOH3ION	0.0	0.0	0.0	0.0
CUOHION	2.37454E-10	0.0	0.0	0.0
FEIII2OH2ION	4.71829E-15	0.0	0.0	0.0
FEIIIC2O42ION	0.0675887	0.0	0.0	0.0
FEIIIC2O43ION	1.33022E-04	0.0	0.0	0.0
FEIIIC2O4ION	185.523	0.0	0.0	0.0
FEIIICL2ION	0.00301731	0.0	0.0	0.0
FEIIICL4ION	3.89327E-08	0.0	0.0	0.0
FEIIICLION	0.0325078	0.0	0.0	0.0
FEIIIHC2O4ION	2.05755	0.0	0.0	0.0
FEIIIION	0.0243175	0.0	0.0	0.0
FEIIINO3ION	0.0503286	0.0	0.0	0.0
FEIIIOH2ION	1.70906E-11	0.0	0.0	0.0
FEIIIOH4ION	1.20546E-28	0.0	0.0	0.0
FEIIIOHION	9.26910E-06	0.0	0.0	0.0
FEIIISO4ION	0.00356433	0.0	0.0	0.0
H2SIO4ION	2.21951E-23	0.0	0.0	0.0
H3SIO4ION	1.00913E-10	0.0	0.0	0.0
HCRO4ION	219.304	0.0	0.0	0.0
HION	44105.1	0.0	0.0	0.0
HOXALATION	4.01917	0.0	0.0	0.0
HSO4ION	1644.67	0.0	0.0	0.0
KION	372.851	0.0	0.0	0.0
KSO4ION	0.125081	0.0	0.0	0.0
NAION	34197.9	0.0	0.0	0.0
NASO4ION	17.9433	0.0	0.0	0.0
NIC2O42ION	1.97598E-09	0.0	0.0	0.0
NICLION	0.0144933	0.0	0.0	0.0
NIION	7.31696	0.0	0.0	0.0
NINO3ION	26.1073	0.0	0.0	0.0
NIOHION	2.89601E-12	0.0	0.0	0.0
NO3ION	78105.4	0.0	0.0	0.0
ALION	479.153	0.0	0.0	0.0
OXALATION	6.25321E-04	0.0	0.0	0.0
PBCL3ION	1.49577E-04	0.0	0.0	0.0
PBCL4ION	2.70454E-04	0.0	0.0	0.0
PBCLION	0.00514839	0.0	0.0	0.0

PBION	0.0390917	0.0	0.0	0.0
PBNO33ION	25.9339	0.0	0.0	0.0
PBNO3ION	0.231785	0.0	0.0	0.0
PBOHION	6.85843E-13	0.0	0.0	0.0
SO4ION	246.595	0.0	0.0	0.0
Total g/hr	2.37085E+07	239802.	0.0	0.0
Volume, L/hr	17614.8	106.244	0.0	0.0
Enthalpy, cal/hr	-6.12181E+10	-8.42972E+08	0.0	0.0
Density, g/L	1345.94	2257.08		
Vapor fraction	0.0	0.0	0.0	0.0
Solid fraction	0.0	1.	0.0	0.0
Organic fraction	0.0	0.0	0.0	0.0
Osmotic Pres, atm	721.199			
Redox Pot, volts	0.0			
E-Con, 1/ohm-cm	0.528506			
E-Con, cm2/ohm-mol	63.4375			
Abs Visc, cP	1.96166			
Rel Visc	2.20233			
Ionic Strength	6.58144			

STREAM: Cumulative Condensate @ 100% Saturation

Phases---------->	Aqueous	Solid	Vapor	Organic
Temperature, C	40.0002	40.0002	40.0002	40.0002
Pressure, atm	0.0729523	0.0729523	0.0729523	0.0729523
pH	0.343345			
Total mol/hr	3.61684E+07	0.0	0.0	0.0
----------	mol/hr	mol/hr	mol/hr	mol/hr
H2O	3.55741E+07	0.0	0.0	0.0
HCL	0.0011886	0.0	0.0	0.0
HNO3	8569.64	0.0	0.0	0.0
OHION	6.52650E-08	0.0	0.0	0.0
CLION	2166.41	0.0	0.0	0.0
HION	292871.	0.0	0.0	0.0
NO3ION	290704.	0.0	0.0	0.0
	==========	==========	==========	==========
Total g/hr	6.59816E+08	0.0	0.0	0.0
Volume, L/hr	655690.	0.0	0.0	0.0
Enthalpy, cal/hr	-2.43542E+12	0.0	0.0	0.0
Density, g/L	1006.29			
Vapor fraction	0.0	0.0	0.0	0.0
Solid fraction	0.0	0.0	0.0	0.0
Organic fraction	0.0	0.0	0.0	0.0
Osmotic Pres, atm	25.5319			
Redox Pot, volts	0.0			
E-Con, 1/ohm-cm	0.19425			
E-Con, cm2/ohm-mol	422.531			
Abs Visc, cP	0.670811			
Rel Visc	1.02632			
Ionic Strength	0.456987			

APPENDIX B

Apparent Species Output

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        O   O   O          L                   I I I I
      O           O        L                     I
    O               O      L                     I
   O                  O    L                     I
   O                  O    L                     I
   O                  O    L                     I
    O               O      L                     I
      O           O        L                     I
        O   O   O          L L L L L L L L     I I I I


        E N V I R O N M E N T A L   S I M U L A T I O N   P R O G R A M

                     V - 6.6   September 1, 2002

                          PROCESS: DSTIL_5

                    CHEMISTRY MODEL: AP101CS

                     THIS FILE NAME: DSTIL_5.LIS

                               DATE: 01/18/2003

================================================================================
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STREAM: **AP-101 Cs Eluate Feed**

Phases---------->	Aqueous	Solid	Vapor	Organic
Temperature, C	20.	20.	20.	20.
Pressure, atm	1.	1.	1.	1.
pH	0.410175			
Total mol/hr	174107.	13.5452	0.0	0.0
----------	mol/hr--------	mol/hr--------	mol/hr--------	mol/hr--------
H2O	172560.	0.0	0.0	0.0
HNO3	1214.39	0.0	0.0	0.0
SO3	9.33093	0.0	0.0	0.0
CAC2O4	5.61931	0.0	0.0	0.0
CDC2O4	0.0	0.1354106	0.0	0.0
CDOH2	0.0060841	0.0	0.0	0.0
CSNO3	0.885668	0.0	0.0	0.0
CUOH2	0.250291	0.0	0.0	0.0
FEIIIOH3	0.911467	0.0	0.0	0.0
BAOX	0.0280687	0.0	0.0	0.0
KCL	14.6034	0.0	0.0	0.0
KNO3	0.286075	0.0	0.0	0.0
NANO3	285.178	0.0	0.0	0.0
NIOH2	0.162594	0.0	0.0	0.0
PBO	0.153494	0.0	0.0	0.0
BASO4	0.0	0.04142868	0.0	0.0
SIO2	5.54795	13.36836	0.0	0.0
NA2CRO4	3.30388	0.0	0.0	0.0
CA2CL2O	0.325531	0.0	0.0	0.0
NAALO22	1.17906	0.0	0.0	0.0
NAB5O8	5.29721	0.0	0.0	0.0
	==========	==========	==========	==========
Total g/hr	3.21463E+06	840.038	0.0	0.0
Volume, L/hr	3160.22	0.366714	0.0	0.0
Enthalpy, cal/hr	-1.19063E+10	-2.92524E+06	0.0	0.0
Density, g/L	1017.22	2290.72		
Vapor fraction	0.0	0.0	0.0	0.0
Solid fraction	0.0	1.	0.0	0.0
Organic fraction	0.0	0.0	0.0	0.0
Osmotic Pres, atm	24.4621			
Redox Pot, volts	0.0			
E-Con, 1/ohm-cm	0.131581			
E-Con, cm2/ohm-mol	265.489			
Abs Visc, cP	1.01492			
Rel Visc	1.01288			
Ionic Strength	0.479457			

STREAM: **80% Concentrated Cs Eluate**

Phases---------->	Aqueous	Solid	Vapor	Organic
Temperature, C	25.	25.	25.	25.
Pressure, atm	1.	1.	1.	1.
pH	-1.0608			
Total mol/hr	864449.	3072.51	0.0	0.0
----------	mol/hr--------	mol/hr--------	mol/hr--------	mol/hr--------
H2O	725380.	0.0	0.0	0.0
HNO3	85639.4	0.0	0.0	0.0
SO3	1516.67	0.0	0.0	0.0
CAC2O4	932.258	0.0	0.0	0.0
CDC2O4	0.0	10.03049	0.0	0.0
CDOH2	13.0332	0.0	0.0	0.0
CSNO3	144.364	0.0	0.0	0.0
CUOH2	40.7973	0.0	0.0	0.0
FEIIIOH3	148.569	0.0	0.0	0.0
BAOX	0.306835	0.0	0.0	0.0
KCL	743.009	0.0	0.0	0.0
KNO3	1683.97	0.0	0.0	0.0
NANO3	46484.	0.0	0.0	0.0
NIOH2	26.5028	0.0	0.0	0.0
PBO	25.0195	0.0	0.0	0.0
BASO4	0.0	11.02129	0.0	0.0
SIO2	31.905	3051.458	0.0	0.0
NA2CRO4	538.533	0.0	0.0	0.0
CA2CL2O	44.9067	0.0	0.0	0.0
NAALO22	192.187	0.0	0.0	0.0
NAB5O8	863.444	0.0	0.0	0.0
	==========	==========	==========	==========
Total g/hr	2.32450E+07	187927.	0.0	0.0
Volume, L/hr	17598.	83.7875	0.0	0.0
Enthalpy, cal/hr	-6.04124E+10	-6.63498E+08	0.0	0.0
Density, g/L	1320.89	2242.91		
Vapor fraction	0.0	0.0	0.0	0.0
Solid fraction	0.0	1.	0.0	0.0
Organic fraction	0.0	0.0	0.0	0.0
Osmotic Pres, atm	719.53			
Redox Pot, volts	0.0			
E-Con, 1/ohm-cm	0.61181			
E-Con, cm2/ohm-mol	75.7504			
Abs Visc, cP	1.80731			
Rel Visc	2.02904			
Ionic Strength	6.41401			

STREAM: **100% Concentrated Cs Eluate**

Phases---------->	Aqueous	Solid	Vapor	Organic
Temperature, C	25.	25.	25.	25.
Pressure, atm	1.	1.	1.	1.
pH	-1.05852			
Total mol/hr	859934.	3903.42	0.0	0.0
----------	mol/hr--------	mol/hr--------	mol/hr--------	mol/hr--------
H2O	717080.	0.0	0.0	0.0
HNO3	75354.2	0.0	0.0	0.0
SO3	1916.67	0.0	0.0	0.0
CAC2O4	1170.79	0.0	0.0	0.0
CDC2O4	0.0	20.19473	0.0	0.0
CDOH2	8.95334	0.0	0.0	0.0
CSNO3	182.447	0.0	0.0	0.0
CUOH2	51.5599	0.0	0.0	0.0
FEIIIOH3	187.762	0.0	0.0	0.0
BAOX	0.276668	0.0	0.0	0.0
KCL	855.094	0.0	0.0	0.0
KNO3	2212.14	0.0	0.0	0.0
NANO3	58746.7	0.0	0.0	0.0
NIOH2	33.4944	0.0	0.0	0.0
PBO	31.6198	0.0	0.0	0.0
BASO4	0.0	14.03982	0.0	0.0
SIO2	27.5875	3869.185	0.0	0.0
NA2CRO4	680.6	0.0	0.0	0.0
CA2CL2O	60.4567	0.0	0.0	0.0
NAALO22	242.887	0.0	0.0	0.0
NAB5O8	1091.22	0.0	0.0	0.0
	==========	==========	==========	==========
Total g/hr	2.37085E+07	239802.	0.0	0.0
Volume, L/hr	17614.8	106.244	0.0	0.0
Enthalpy, cal/hr	-6.12181E+10	-8.42972E+08	0.0	0.0
Density, g/L	1345.94	2257.08		
Vapor fraction	0.0	0.0	0.0	0.0
Solid fraction	0.0	1.	0.0	0.0
Organic fraction	0.0	0.0	0.0	0.0
Osmotic Pres, atm	721.199			
Redox Pot, volts	0.0			
E-Con, 1/ohm-cm	0.528506			
E-Con, cm2/ohm-mol	63.4375			
Abs Visc, cP	1.96166			
Rel Visc	2.20233			
Ionic Strength	6.58144			

STREAM: **Cumulative Condensate @ 100% Saturation**

Phases---------->	Aqueous	Solid	Vapor	Organic
Temperature, C	40.0002	40.0002	40.0002	40.0002
Pressure, atm	0.0729523	0.0729523	0.0729523	0.0729523
pH	0.343345			
Total mol/hr	3.58755E+07	0.0	0.0	0.0
----------	mol/hr	mol/hr	mol/hr	mol/hr
H2O	3.55741E+07	0.0	0.0	0.0
HCL	2166.42	0.0	0.0	0.0
HNO3	299274.	0.0	0.0	0.0
	==========	==========	==========	==========
Total g/hr	6.59816E+08	0.0	0.0	0.0
Volume, L/hr	655690.	0.0	0.0	0.0
Enthalpy, cal/hr	-2.43542E+12	0.0	0.0	0.0
Density, g/L	1006.29			
Vapor fraction	0.0	0.0	0.0	0.0
Solid fraction	0.0	0.0	0.0	0.0
Organic fraction	0.0	0.0	0.0	0.0
Osmotic Pres, atm	25.5319			
Redox Pot, volts	0.0			
E-Con, 1/ohm-cm	0.19425			
E-Con, cm2/ohm-mol	422.531			
Abs Visc, cP	0.670811			
Rel Visc	1.02632			
Ionic Strength	0.456987			

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APPENDIX H

APPENDIX H: PARTICLE SIZE DATA FOR BOUNDING LAW AND HLW SIMULANTS AND FOR THE HLW PRECIPITATED HYDROXIDE SIMULANT

The following particle size distribution results were obtained from measurements of simulants prepared during this study. The following abbreviations and their meanings apply to these results:

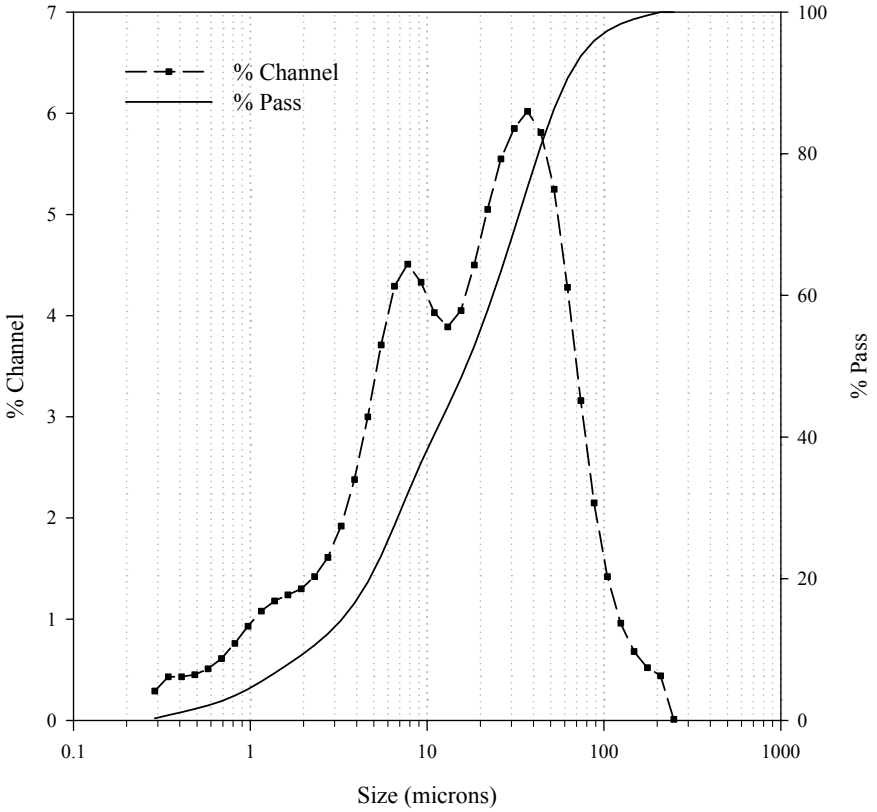
mv Mean diameter in microns based on the volume distribution. The value is strongly influenced (weighted) by the coarse (large) particles.

mn Mean diameter in microns based on the number distribution. The value is strongly influenced (weighted) by the small particles.

ma Mean diameter in microns based on the area distribution. The value is less influenced (weighted) by the coarse particles.

cs Calculated Specific Surface Area based on assumption of smooth, solid, spherical particles.

sd Standard deviation, in microns, of the measured particle size distribution.



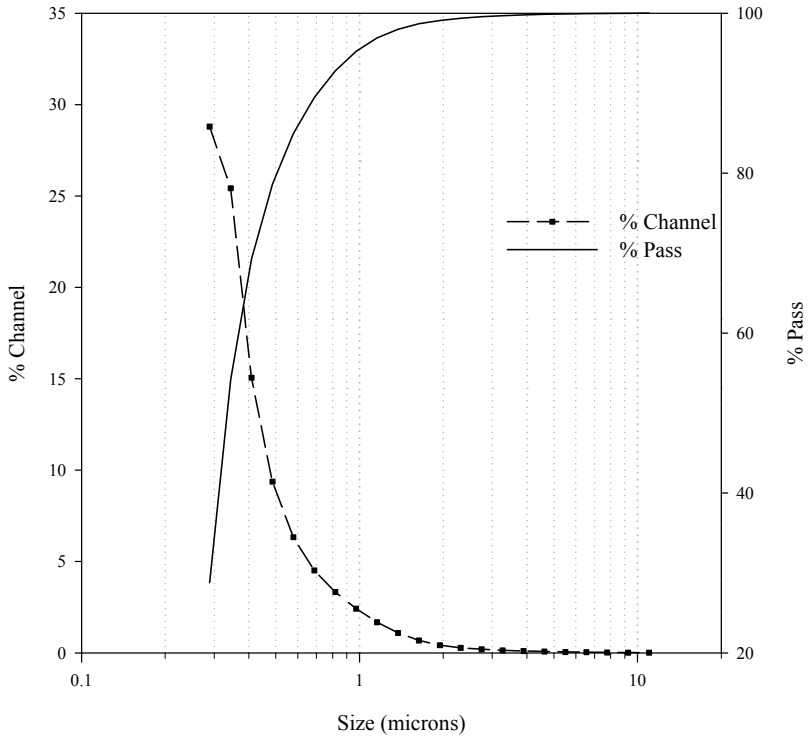
Microns	% Channel	% Pass	Microns	% Channel	% Pass
0.289	0.29	0.29	9.25	4.33	36.38
0.344	0.43	0.72	11	4.03	40.41
0.409	0.43	1.15	13.08	3.89	44.3
0.486	0.45	1.6	15.56	4.05	48.35
0.578	0.51	2.11	18.5	4.5	52.85
0.688	0.61	2.72	22	5.05	57.9
0.818	0.76	3.48	26.16	5.55	63.45
0.972	0.93	4.41	31.11	5.85	69.3
1.156	1.08	5.49	37	6.02	75.32
1.375	1.18	6.67	44	5.81	81.13
1.635	1.24	7.91	52.33	5.25	86.38
1.945	1.3	9.21	62.23	4.28	90.66
2.312	1.42	10.63	74	3.16	93.82
2.75	1.61	12.24	88	2.15	95.97
3.27	1.92	14.16	104.7	1.42	97.39
3.889	2.38	16.54	124.5	0.96	98.35
4.625	3	19.54	148	0.68	99.03
5.5	3.71	23.25	176	0.52	99.55
6.541	4.29	27.54	209.3	0.44	99.99
7.778	4.51	32.05	248.9	0.01	100

Summary	Amount	Units
mv	26.09	microns
mn	0.444	microns
ma	4.858	microns
cs	1.235	M^2/CC
sd	22.24	microns

Percentiles	Amount
10%	2.147
20%	4.734
25%	5.916
40%	10.8
50%	16.62
60%	23.53
70%	31.75
75%	36.67
90%	60.43
95%	80.67

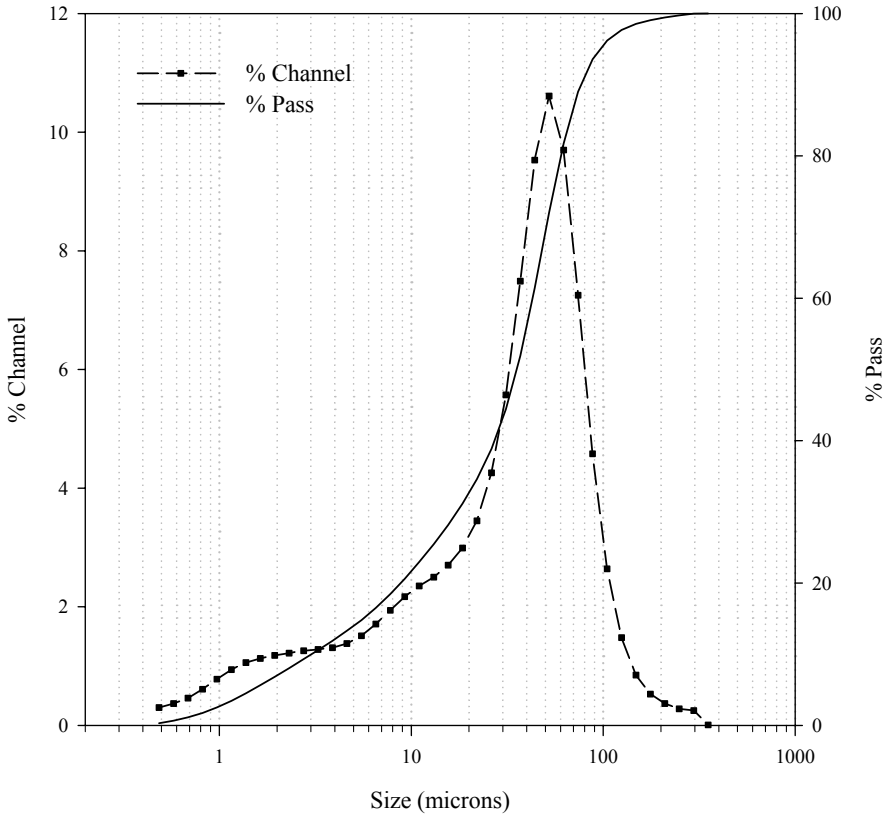
Diameter	Vol%	Width
31.94	60	45.12
4.783	40	7.046

Figure H- 1 Particle Size Distribution Based Upon Volume for the Low Bound LAW Melter Feed Physical Simulant



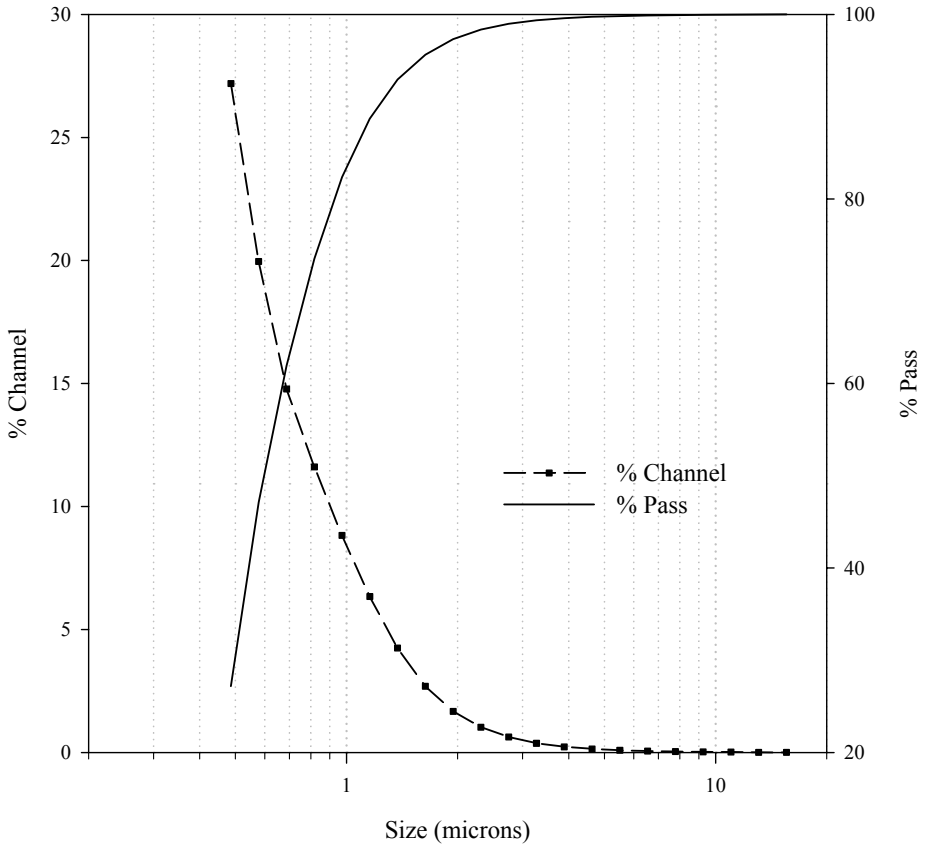
Microns	% Channel	% Pass	Summary	Amount	Units
0.289	28.8	28.8	mv	26.09	microns
0.344	25.42	54.22	mn	0.444	microns
0.409	15.06	69.28	ma	4.858	microns
0.486	9.37	78.65	cs	1.235	M^2/CC
0.578	6.33	84.98	sd	0.145	microns
0.688	4.51	89.49	**Percentiles**	**Amount**	
0.818	3.33	92.82	10%	0.261	
0.972	2.42	95.24	20%	0.276	
1.156	1.68	96.92	25%	0.283	
1.375	1.09	98.01	40%	0.31	
1.635	0.68	98.69	50%	0.332	
1.945	0.42	99.11	60%	0.364	
2.312	0.27	99.38	70%	0.414	
2.75	0.19	99.57	75%	0.451	
3.27	0.13	99.7	90%	0.705	
3.889	0.1	99.8	95%	0.954	
4.625	0.07	99.87	**Diameter**	**Vol%**	**Width**
5.5	0.05	99.92	0.332	100	0.291
6.541	0.04	99.96			
7.778	0.02	99.98			
9.25	0.01	99.99			
11	0.01	100			

Figure H- 2 Particle Size Distribution Based Upon Number for the Low Bound LAW Melter Feed Physical Simulant



Microns	% Channel	% Pass	Microns	% Channel	% Pass	Summary	Amount	Units
0.486	0.3	0.3	15.56	2.7	28.16	mv	39.4	microns
0.578	0.37	0.67	18.5	2.99	31.15	mn	0.764	microns
0.688	0.46	1.13	22	3.45	34.6	ma	7.909	microns
0.818	0.61	1.74	26.16	4.26	38.86	cs	0.759	M^2/CC
0.972	0.78	2.52	31.11	5.57	44.43	sd	29.51	microns
1.156	0.94	3.46	37	7.49	51.92	**Percentiles**	**Amount**	
1.375	1.06	4.52	44	9.53	61.45	10%	3.021	
1.635	1.13	5.65	52.33	10.61	72.06	20%	8.825	
1.945	1.18	6.83	62.23	9.7	81.76	25%	12.69	
2.312	1.22	8.05	74	7.25	89.01	40%	27.22	
2.75	1.26	9.31	88	4.58	93.59	50%	35.54	
3.27	1.28	10.59	104.7	2.64	96.23	60%	42.93	
3.889	1.31	11.9	124.5	1.48	97.71	70%	50.6	
4.625	1.38	13.28	148	0.85	98.56	75%	54.99	
5.5	1.51	14.79	176	0.53	99.09	90%	76.36	
6.541	1.71	16.5	209.3	0.37	99.46	95%	95.38	
7.778	1.94	18.44	248.9	0.28	99.74	**Diameter**	**Vol%**	**Width**
9.25	2.17	20.61	296	0.25	99.99	35.54	100	59.01
11	2.35	22.96	352	0.01	100			
13.08	2.5	25.46						

Figure H- 3 Particle Size Distribution Based Upon Volume for the High Bound LAW Melter Feed Physical Simulant



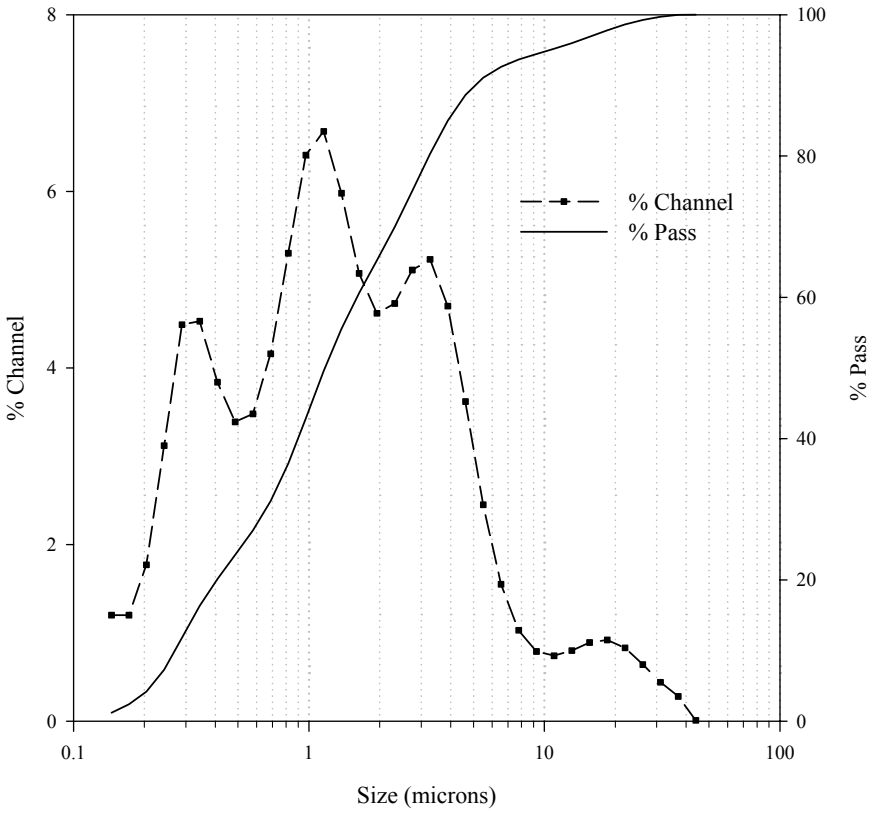
Microns	% Channel	% Pass
0.486	27.19	27.19
0.578	19.96	47.15
0.688	14.78	61.93
0.818	11.61	73.54
0.972	8.83	82.37
1.156	6.34	88.71
1.375	4.25	92.96
1.635	2.69	95.65
1.945	1.67	97.32
2.312	1.03	98.35
2.75	0.63	98.98
3.27	0.38	99.36
3.889	0.23	99.59
4.625	0.15	99.74
5.5	0.09	99.83
6.541	0.06	99.89
7.778	0.04	99.93
9.25	0.03	99.96
11	0.02	99.98
13.08	0.01	99.99
15.56	0.01	100

Summary	Amount	Units
mv	39.4	microns
mn	0.764	microns
ma	7.909	microns
cs	0.759	M^2/CC
sd	0.277	microns

Percentiles	Amount
10%	0.441
20%	0.467
25%	0.48
40%	0.539
50%	0.596
60%	0.671
70%	0.773
75%	0.84
90%	1.211
95%	1.559

Diameter	Vol%	Width
0.596	100	0.555

Figure H- 4 Particle Size Distribution Based Upon Number for the High Bound LAW Melter Feed Physical Simulant



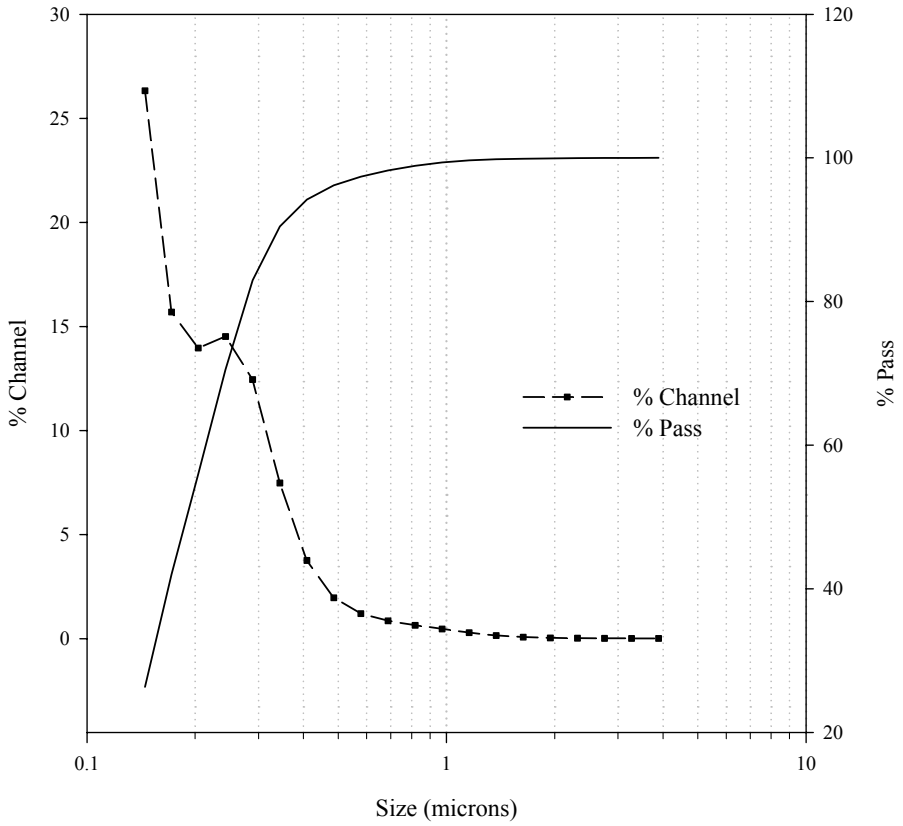
Microns	% Channel	% Pass	Microns	% Channel	% Pass
0.145	1.2	1.2	2.75	5.11	75.08
0.172	1.2	2.4	3.27	5.23	80.31
0.204	1.77	4.17	3.889	4.7	85.01
0.243	3.12	7.29	4.625	3.62	88.63
0.289	4.49	11.78	5.5	2.45	91.08
0.344	4.53	16.31	6.541	1.55	92.63
0.409	3.84	20.15	7.778	1.03	93.66
0.486	3.39	23.54	9.25	0.79	94.45
0.578	3.48	27.02	11	0.74	95.19
0.688	4.16	31.18	13.08	0.8	95.99
0.818	5.3	36.48	15.56	0.89	96.88
0.972	6.41	42.89	18.5	0.92	97.8
1.156	6.68	49.57	22	0.83	98.63
1.375	5.98	55.55	26.16	0.64	99.27
1.635	5.07	60.62	31.11	0.44	99.71
1.945	4.62	65.24	37	0.28	99.99
2.312	4.73	69.97	44	0.01	100

Summary	Amount	Units
mv	2.576	microns
mn	0.227	microns
ma	0.699	microns
cs	8.586	M2/CC
sd	1.698	microns

Percentiles	Amount
10%	0.271
20%	0.406
25%	0.524
40%	0.902
50%	1.17
60%	1.599
70%	2.314
75%	2.743
90%	5.049
95%	10.52

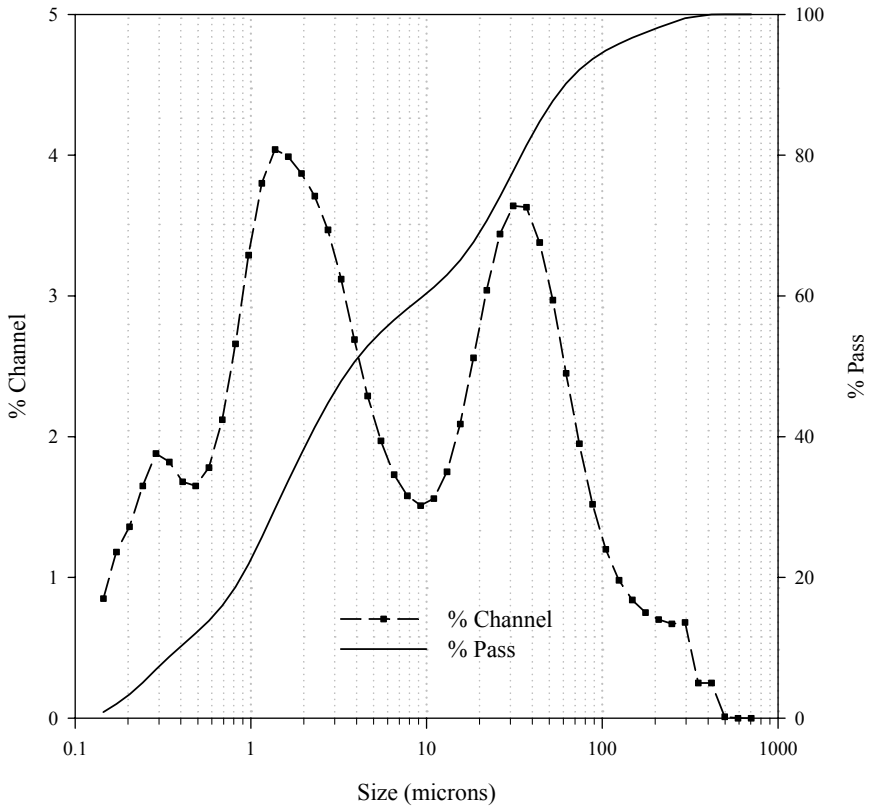
Diameter	Vol %	Width
16.6	6	13.55
2.981	34	2.738
0.911	40	0.75
0.273	20	0.162

Figure H- 5 Particle Size Distribution Based Upon Volume for the Low Bound Pretreated HLW Feed Physical Simulant



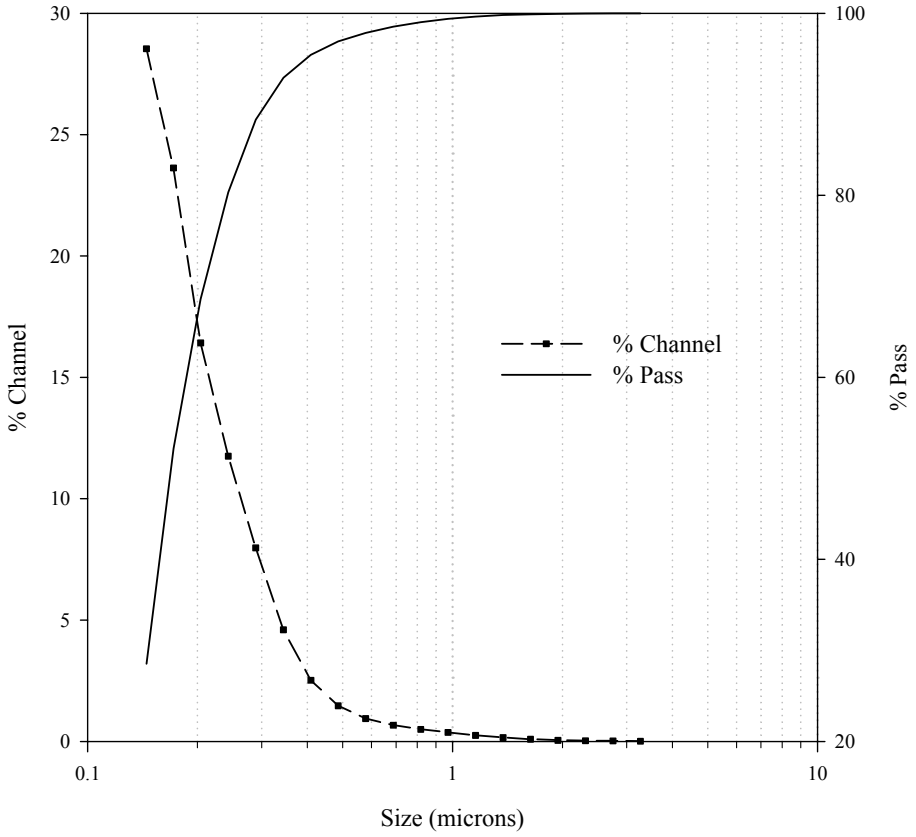
Microns	% Channel	% Pass	Summary	Amount	Units
0.145	26.33	26.33	mv	2.576	microns
0.172	15.7	42.03	mn	0.227	microns
0.204	13.97	56	ma	0.699	microns
0.243	14.52	70.52	cs	8.586	M^2/CC
0.289	12.45	82.97	sd	0.08	microns
0.344	7.48	90.45	**Percentiles**	**Amount**	
0.409	3.76	94.21	10%	0.131	
0.486	1.97	96.18	20%	0.138	
0.578	1.21	97.39	25%	0.144	
0.688	0.86	98.25	40%	0.168	
0.818	0.65	98.9	50%	0.19	
0.972	0.47	99.37	60%	0.214	
1.156	0.29	99.66	70%	0.242	
1.375	0.15	99.81	75%	0.257	
1.635	0.08	99.89	90%	0.339	
1.945	0.04	99.93	95%	0.433	
2.312	0.03	99.96	**Diameter**	**Vol%**	**Width**
2.75	0.02	99.98	0.245	58	0.154
3.27	0.01	99.99	0.142	42	0.028
3.889	0.01	100			

Figure H- 6 Particle Size Distribution Based Upon Number for the Low Bound Pretreated HLW Feed Physical Simulant



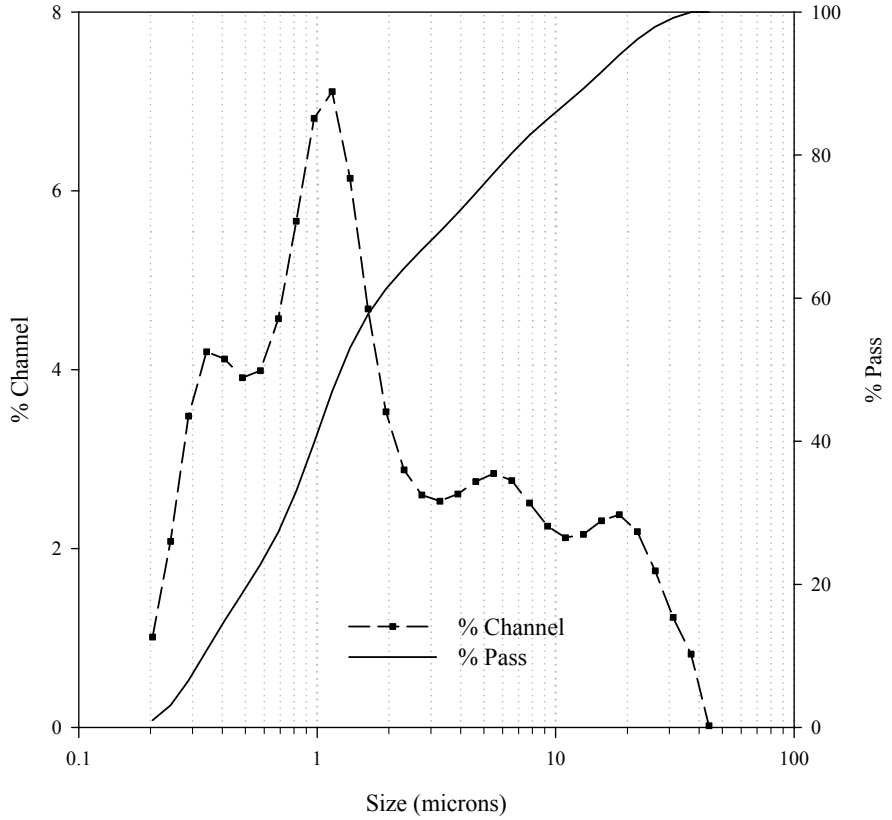
rons	% Channel	% Pass	Microns	% Channel	% Pass	Summary	Amount	Units
.45	0.85	0.85	9.25	1.51	59.69	mv	23.9	microns
.72	1.18	2.03	11	1.56	61.25	mn	0.209	microns
204	1.36	3.39	13.08	1.75	63	ma	1.204	microns
243	1.65	5.04	15.56	2.09	65.09	cs	4.985	M^2/CC
289	1.88	6.92	18.5	2.56	67.65	sd	20.76	microns
344	1.82	8.74	22	3.04	70.69	**Percentiles**	**Amount**	
409	1.68	10.42	26.16	3.44	74.13	10%	0.391	
486	1.65	12.07	31.11	3.64	77.77	20%	0.883	
578	1.78	13.85	37	3.63	81.4	25%	1.12	
588	2.12	15.97	44	3.38	84.78	40%	2.171	
318	2.66	18.63	52.33	2.97	87.75	50%	3.73	
972	3.29	21.92	62.23	2.45	90.2	60%	9.584	
.56	3.8	25.72	74	1.95	92.15	70%	21.2	
375	4.04	29.76	88	1.52	93.67	75%	27.28	
535	3.99	33.75	104.7	1.2	94.87	90%	61.29	
945	3.87	37.62	124.5	0.98	95.85	95%	107	
512	3.71	41.33	148	0.84	96.69	**Diameter**	**Vol%**	**Width**
75	3.47	44.8	176	0.75	97.44	264.5	2	114.6
27	3.12	47.92	209.3	0.7	98.14	31.7	40	56.19
389	2.69	50.61	248.9	0.67	98.81	1.676	48	3.08
525	2.29	52.9	296	0.68	99.49	0.249	10	0.179
.5	1.97	54.87	352	0.25	99.74			
541	1.73	56.6	418.6	0.25	99.99			
778	1.58	58.18	497.8	0.01	100			

Figure H- 7 Particle Size Distribution Based Upon Volume for the Low Bound HLW Melter Feed Physical Simulant



Microns	% Channel	% Pass	Summary	Amount	Units
0.145	28.54	28.54	mv	23.9	microns
0.172	23.63	52.17	mn	0.209	microns
0.204	16.42	68.59	ma	1.204	microns
0.243	11.75	80.34	cs	4.985	M^2/CC
0.289	7.98	88.32	sd	0.063	microns
0.344	4.6	92.92	**Percentiles**	**Amount**	
0.409	2.52	95.44	10%	0.13	
0.486	1.47	96.91	20%	0.137	
0.578	0.94	97.85	25%	0.142	
0.688	0.67	98.52	40%	0.157	
0.818	0.5	99.02	50%	0.169	
0.972	0.37	99.39	60%	0.185	
1.156	0.25	99.64	70%	0.208	
1.375	0.16	99.8	75%	0.223	
1.635	0.09	99.89	90%	0.305	
1.945	0.05	99.94	95%	0.394	
2.312	0.03	99.97	**Diameter**	**Vol%**	**Width**
2.75	0.02	99.99	0.169	100	0.126
3.27	0.01	100			

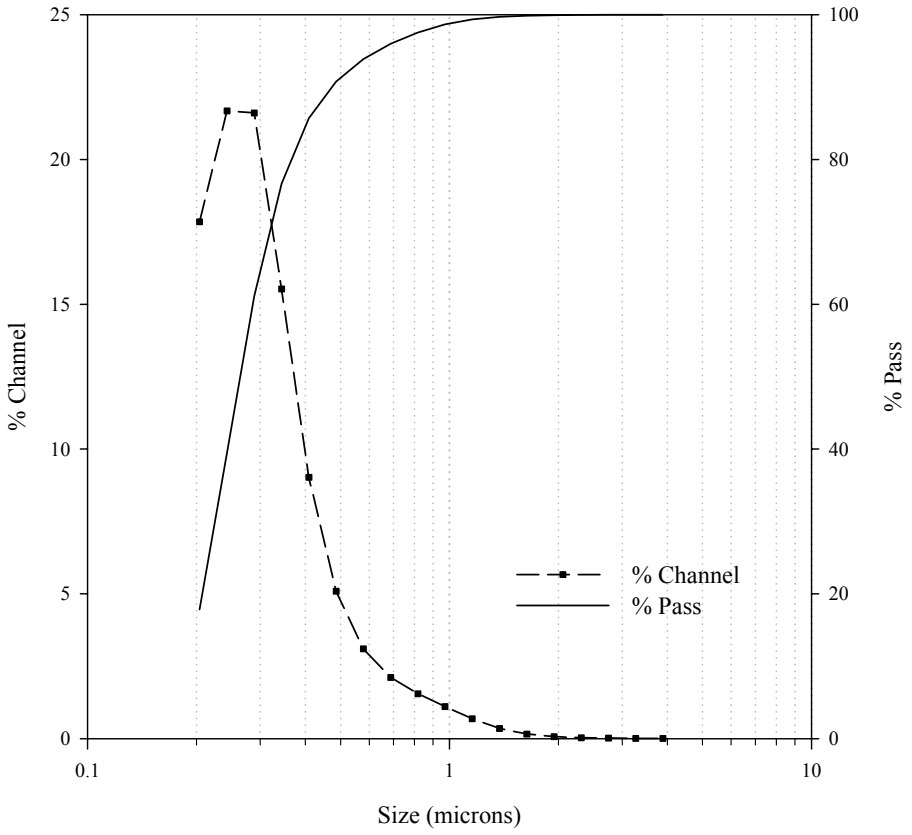
Figure H- 8 Particle Size Distribution Based Upon Number for the Low Bound HLW Melter Feed Physical Simulant



Microns	% Channel	% Pass	Microns	% Channel	% Pass	Summary	Amount	Units
0.204	1.01	1.01	3.27	2.53	69.3	mv	4.293	microns
0.243	2.08	3.09	3.889	2.61	71.91	mn	0.315	microns
0.289	3.48	6.57	4.625	2.75	74.66	ma	0.872	microns
0.344	4.2	10.77	5.5	2.84	77.5	cs	6.88	M2/CC
0.409	4.12	14.89	6.541	2.76	80.26	sd	4.053	microns
0.486	3.91	18.8	7.778	2.51	82.77	**Percentiles**	**Amount**	
0.578	3.99	22.79	9.25	2.25	85.02	10%	0.333	
0.688	4.57	27.36	11	2.12	87.14	20%	0.513	
0.818	5.66	33.02	13.08	2.16	89.3	25%	0.631	
0.972	6.81	39.83	15.56	2.31	91.61	40%	0.976	
1.156	7.11	46.94	18.5	2.38	93.99	50%	1.255	
1.375	6.14	53.08	22	2.19	96.18	60%	1.817	
1.635	4.68	57.76	26.16	1.75	97.93	70%	3.429	
1.945	3.53	61.29	31.11	1.23	99.16	75%	4.724	
2.312	2.88	64.17	37	0.82	99.98	90%	13.8	
2.75	2.6	66.77	44	0.02	100	95%	19.98	

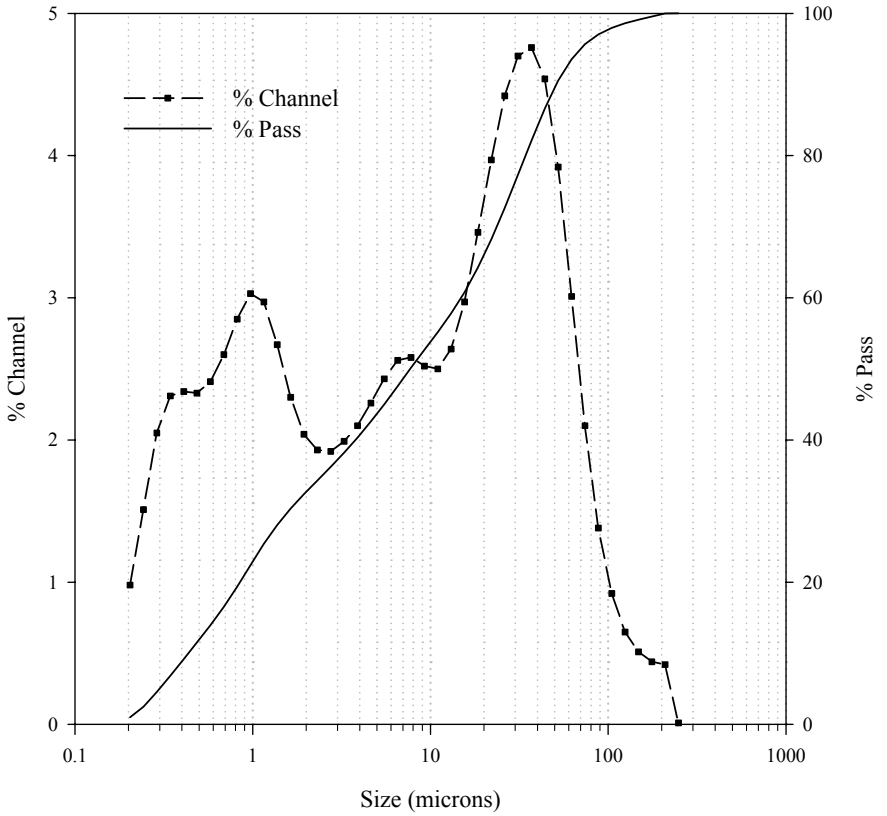
Diameter	Vol%	Width
16.61	15	13.97
4.989	18	4.055
0.996	52	1.101
0.3	15	0.138

Figure H- 9 Particle Size Distribution Based Upon Volume for the High Bound Pretreated HLW Feed Physical Simulant



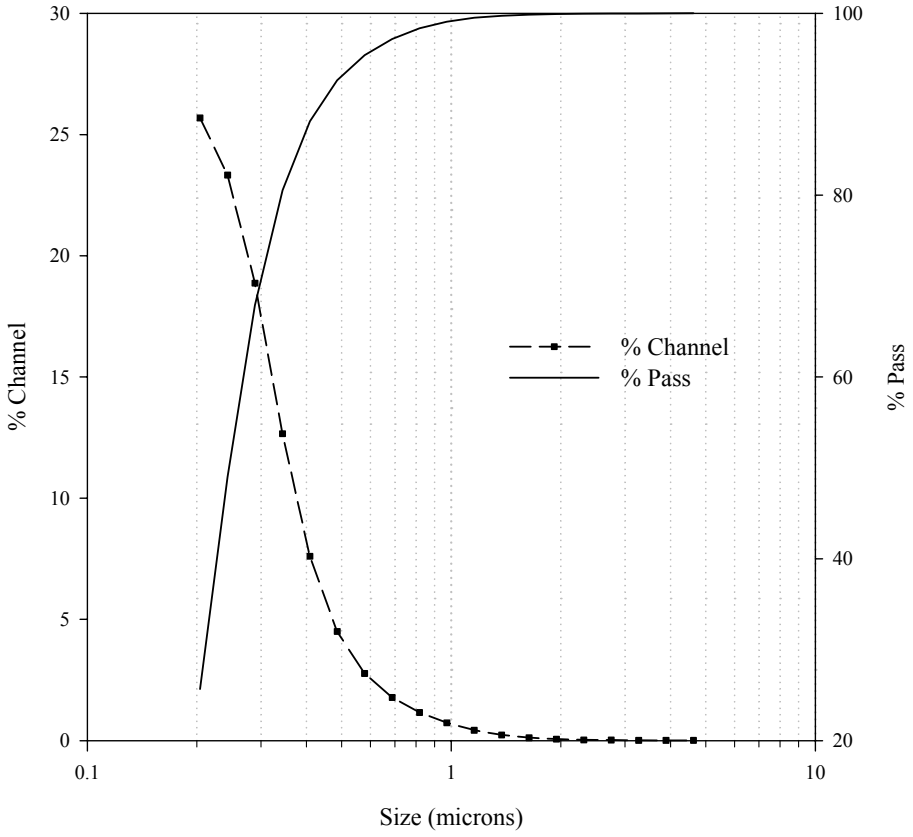
Microns	% Channel	% Pass	Summary	Amount	Units
0.204	17.85	17.85	mv	4.293	microns
0.243	21.68	39.53	mn	0.315	microns
0.289	21.61	61.14	ma	0.872	microns
0.344	15.53	76.67	cs	6.88	M2/CC
0.409	9.03	85.7	sd	0.095	microns
0.486	5.09	90.79	**Percentiles**	**Amount**	
0.578	3.1	93.89	10%	0.192	
0.688	2.11	96	20%	0.208	
0.818	1.55	97.55	25%	0.216	
0.972	1.11	98.66	40%	0.244	
1.156	0.69	99.35	50%	0.264	
1.375	0.35	99.7	60%	0.286	
1.635	0.16	99.86	70%	0.316	
1.945	0.07	99.93	75%	0.336	
2.312	0.03	99.96	90%	0.471	
2.75	0.02	99.98	95%	0.629	
3.27	0.01	99.99	**Diameter**	**Vol%**	**Width**
3.889	0.01	100	0.264	100	0.191

Figure H- 10 Particle Size Distribution Based Upon Number for the High Bound Pretreated HLW Feed Physical Simulant



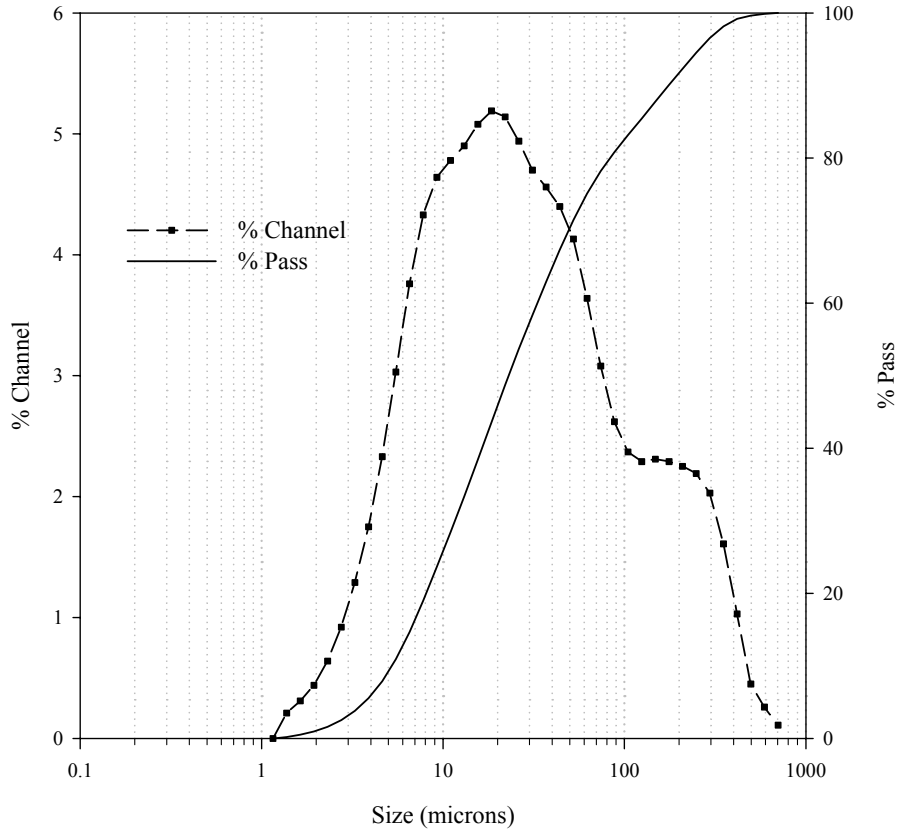
Microns	% Channel	% Pass	Microns	% Channel	% Pass	Summary	Amount	Units
0.204	0.98	0.98	7.778	2.58	50.16	mv	19.45	microns
0.243	1.51	2.49	9.25	2.52	52.68	mn	0.293	microns
0.289	2.05	4.54	11	2.5	55.18	ma	1.452	microns
0.344	2.31	6.85	13.08	2.64	57.82	cs	4.132	M^2/CC
0.409	2.34	9.19	15.56	2.97	60.79	sd	19.53	microns
0.486	2.33	11.52	18.5	3.46	64.25	**Percentiles**	**Amount**	
0.578	2.41	13.93	22	3.97	68.22	10%	0.434	
0.688	2.6	16.53	26.16	4.42	72.64	20%	0.848	
0.818	2.85	19.38	31.11	4.7	77.34	25%	1.13	
0.972	3.03	22.41	37	4.76	82.1	40%	3.788	
1.156	2.97	25.38	44	4.54	86.64	50%	7.696	
1.375	2.67	28.05	52.33	3.92	90.56	60%	14.89	
1.635	2.3	30.35	62.23	3.01	93.57	70%	23.63	
1.945	2.04	32.39	74	2.1	95.67	75%	28.56	
2.312	1.93	34.32	88	1.38	97.05	90%	50.95	
2.75	1.92	36.24	104.7	0.92	97.97	95%	69.53	
3.27	1.99	38.23	124.5	0.65	98.62	**Diameter**	**Vol%**	**Width**
3.889	2.1	40.33	148	0.51	99.13	30	47	42.81
4.625	2.26	42.59	176	0.44	99.57	4.943	18	4.555
5.5	2.43	45.02	209.3	0.42	99.99	0.937	25	1.079
6.541	2.56	47.58	248.9	0.01	100	0.29	10	0.149

Figure H- 11 Particle Size Distribution Based Upon Volume for the High Bound HLW Melter Feed Physical Simulant



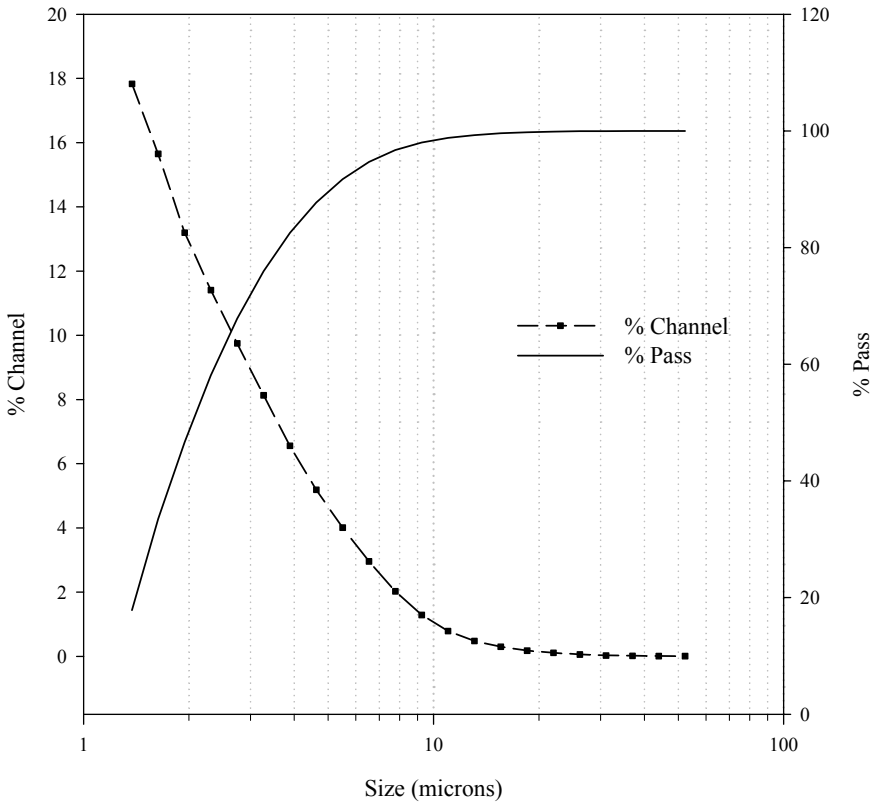
Microns	% Channel	% Pass	Summary	Amount	Units
0.204	25.68	25.68	mv	19.45	microns
0.243	23.33	49.01	mn	0.293	microns
0.289	18.87	67.88	ma	1.452	microns
0.344	12.66	80.54	cs	4.132	M^2/CC
0.409	7.6	88.14	sd	0.088	microns
0.486	4.5	92.64	**Percentiles**	**Amount**	
0.578	2.77	95.41	10%	0.186	
0.688	1.78	97.19	20%	0.198	
0.818	1.16	98.35	25%	0.203	
0.972	0.73	99.08	40%	0.227	
1.156	0.43	99.51	50%	0.245	
1.375	0.23	99.74	60%	0.267	
1.635	0.12	99.86	70%	0.296	
1.945	0.06	99.92	75%	0.315	
2.312	0.03	99.95	90%	0.435	
2.75	0.02	99.97	95%	0.561	
3.27	0.01	99.98	**Diameter**	**Vol%**	**Width**
3.889	0.01	99.99	0.245	100	0.175
4.625	0.01	100			

Figure H- 12 Particle Size Distribution Based Upon Number for the High Bound HLW Melter Feed Physical Simulant



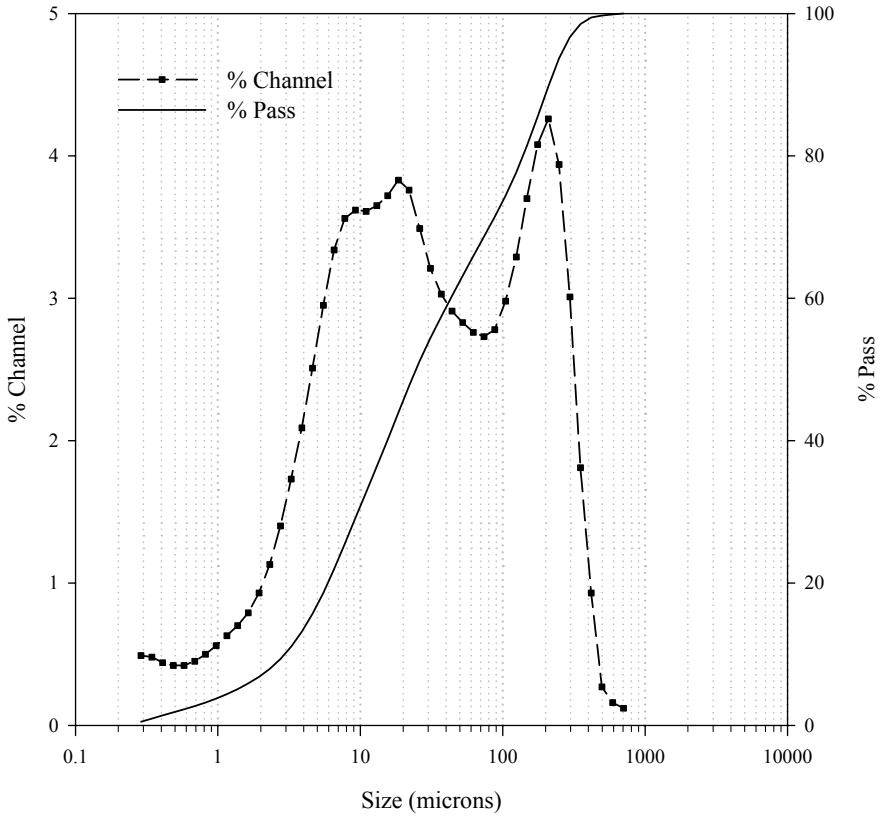
Microns	% Channel	% Pass	Microns	% Channel	% Pass	Summary	Amount	Units
1.156	0	0	31.11	4.7	58.38	mv	58.96	microns
1.375	0.21	0.21	37	4.56	62.94	mn	2.798	microns
1.635	0.31	0.52	44	4.4	67.34	ma	12.68	microns
1.945	0.44	0.96	52.33	4.13	71.47	cs	0.473	M^2/CC
2.312	0.64	1.6	62.23	3.64	75.11	sd	52.22	microns
2.75	0.92	2.52	74	3.08	78.19	**Percentiles**	**Amount**	
3.27	1.29	3.81	88	2.62	80.81	10%	5.24	
3.889	1.75	5.56	104.7	2.37	83.18	20%	8.078	
4.625	2.33	7.89	124.5	2.29	85.47	25%	9.719	
5.5	3.03	10.92	148	2.31	87.78	40%	16.41	
6.541	3.76	14.68	176	2.29	90.07	50%	22.97	
7.778	4.33	19.01	209.3	2.25	92.32	60%	33.08	
9.25	4.64	23.65	248.9	2.19	94.51	70%	49.12	
11	4.78	28.43	296	2.03	96.54	75%	61.89	
13.08	4.9	33.33	352	1.61	98.15	90%	175.1	
15.56	5.08	38.41	418.6	1.03	99.18	95%	259	
18.5	5.19	43.6	497.8	0.45	99.63	**Diameter**	**Vol%**	**Width**
22	5.14	48.74	592	0.26	99.89	197.8	17	191.2
26.16	4.94	53.68	704	0.11	100	17.3	83	42.69

Figure H- 13 Particle Size Distribution Based Upon Volume for the Initial HLW Precipitated Hydroxide Simulant Sludge



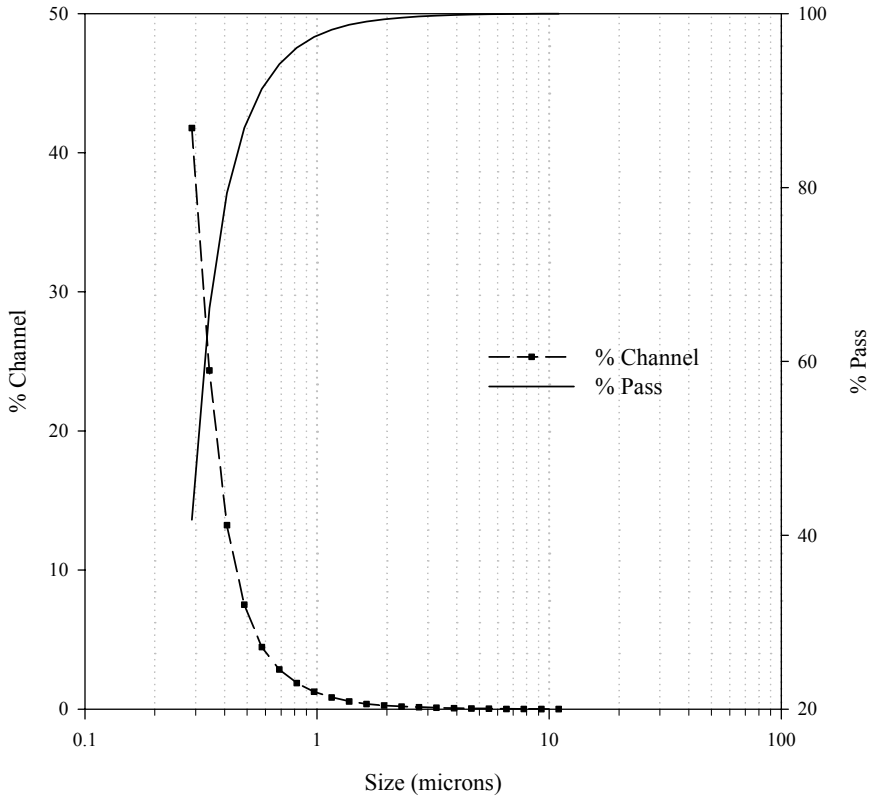
Microns	% Channel	% Pass	Summary	Amount	Units
1.375	17.83	17.83	mv	58.96	microns
1.635	15.65	33.48	mn	2.798	microns
1.945	13.2	46.68	ma	12.68	microns
2.312	11.41	58.09	cs	0.473	M^2/CC
2.75	9.75	67.84	sd	1.358	microns
3.27	8.13	75.97	**Percentiles**	**Amount**	
3.889	6.56	82.53	10%	1.287	
4.625	5.19	87.72	20%	1.406	
5.5	4.01	91.73	25%	1.482	
6.541	2.96	94.69	40%	1.776	
7.778	2.03	96.72	50%	2.041	
9.25	1.29	98.01	60%	2.389	
11	0.79	98.8	70%	2.872	
13.08	0.48	99.28	75%	3.201	
15.56	0.3	99.58	90%	5.079	
18.5	0.18	99.76	95%	6.698	
22	0.11	99.87	**Diameter**	**Vol%**	**Width**
26.16	0.06	99.93	2.041	100	2.716
31.11	0.03	99.96			
37	0.02	99.98			
44	0.01	99.99			
52.33	0.01	100			

Figure H- 14 Particle Size Distribution Based Upon Number for the Initial HLW Precipitated Hydroxide Simulant Sludge



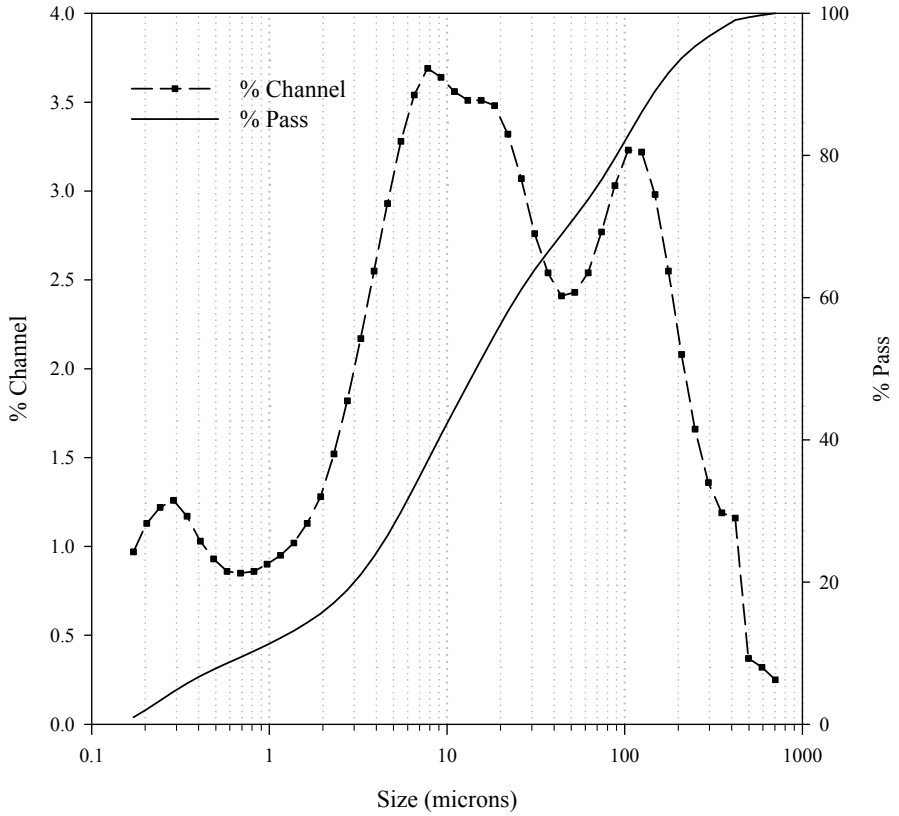
Microns	% Channel	% Pass	Microns	% Channel	% Pass	Summary	Amount	Units
0.289	0.49	0.49	22	3.76	47.71	mv	70.76	microns
0.344	0.48	0.97	26.16	3.49	51.2	mn	0.386	microns
0.409	0.44	1.41	31.11	3.21	54.41	ma	5.715	microns
0.486	0.42	1.83	37	3.03	57.44	cs	1.05	M^2/CC
0.578	0.42	2.25	44	2.91	60.35	sd	80.33	microns
0.688	0.45	2.7	52.33	2.83	63.18	**Percentiles**	**Amount**	
0.818	0.5	3.2	62.23	2.76	65.94	10%	2.95	
0.972	0.56	3.76	74	2.73	68.67	20%	5.921	
1.156	0.63	4.39	88	2.78	71.45	25%	7.588	
1.375	0.7	5.09	104.7	2.98	74.43	40%	15.45	
1.635	0.79	5.88	124.5	3.29	77.72	50%	24.62	
1.945	0.93	6.81	148	3.7	81.42	60%	43.09	
2.312	1.13	7.94	176	4.08	85.5	70%	80.48	
2.75	1.4	9.34	209.3	4.26	89.76	75%	108	
3.27	1.73	11.07	248.9	3.94	93.7	90%	211.4	
3.889	2.09	13.16	296	3.01	96.71	95%	266.4	
4.625	2.51	15.67	352	1.81	98.52	**Diameter**	**Vol%**	**Width**
5.5	2.95	18.62	418.6	0.93	99.45	158.4	34	172.1
6.541	3.34	21.96	497.8	0.27	99.72	21.83	37	30.96
7.778	3.56	25.52	592	0.16	99.88	4.509	28	5.855
9.25	3.62	29.14	704	0.12	100	0.311	1	0.107
11	3.61	32.75	418.6	1.03	101.03			
13.08	3.65	36.4	497.8	0.45	101.48			
15.56	3.72	40.12	592	0.26	101.74			
18.5	3.83	43.95	704	0.11	101.85			

Figure H- 15 Particle Size Distribution Based Upon Volume for HLW Precipitated Hydroxide Simulant after Evaporation



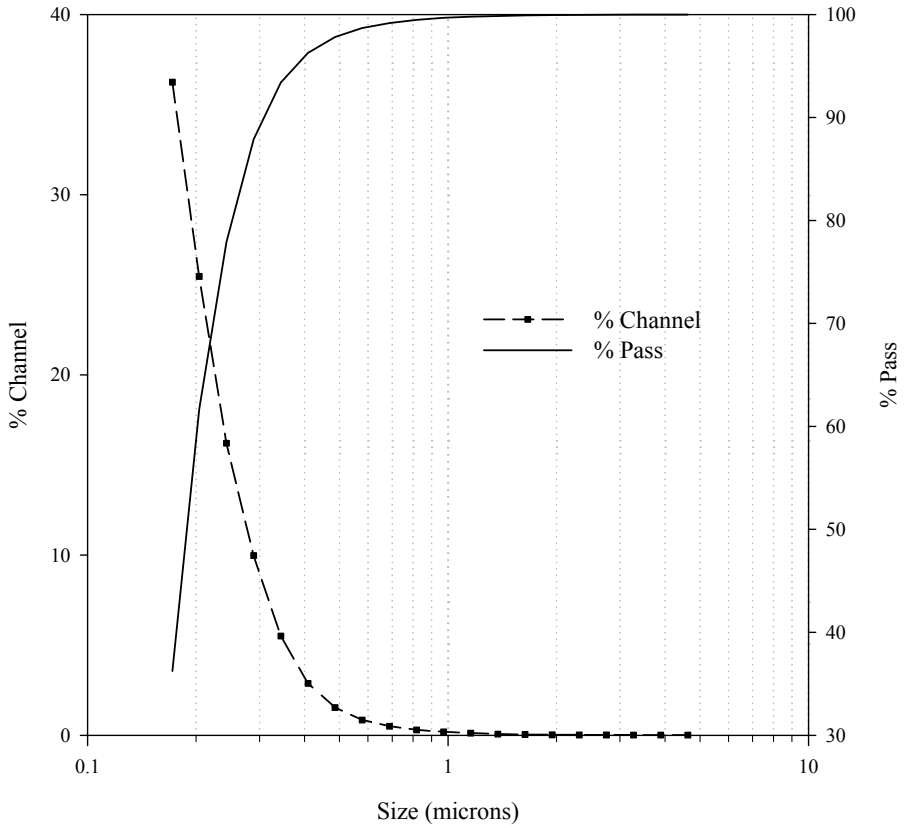
Microns	% Channel	% Pass	Summary	Amount	Units
0.289	41.78	41.78	mv	58.96	microns
0.344	24.36	66.14	mn	2.798	microns
0.409	13.23	79.37	ma	12.68	microns
0.486	7.51	86.88	cs	0.473	M^2/CC
0.578	4.47	91.35	sd	1.358	microns
0.688	2.85	94.2	**Percentiles**	**Amount**	
0.818	1.88	96.08	10%	1.287	
0.972	1.25	97.33	20%	1.406	
1.156	0.84	98.17	25%	1.482	
1.375	0.55	98.72	40%	1.776	
1.635	0.37	99.09	50%	2.041	
1.945	0.26	99.35	60%	2.389	
2.312	0.19	99.54	70%	2.872	
2.75	0.14	99.68	75%	3.201	
3.27	0.1	99.78	90%	5.079	
3.889	0.07	99.85	95%	6.698	
4.625	0.05	99.9	**Diameter**	**Vol%**	**Width**
5.5	0.04	99.94	2.041	100	2.716
6.541	0.02	99.96			
7.778	0.02	99.98			
9.25	0.01	99.99			
11	0.01	100			

Figure H- 16 Particle Size Distribution Based Upon Number for HLW Precipitated Hydroxide Simulant after Evaporation



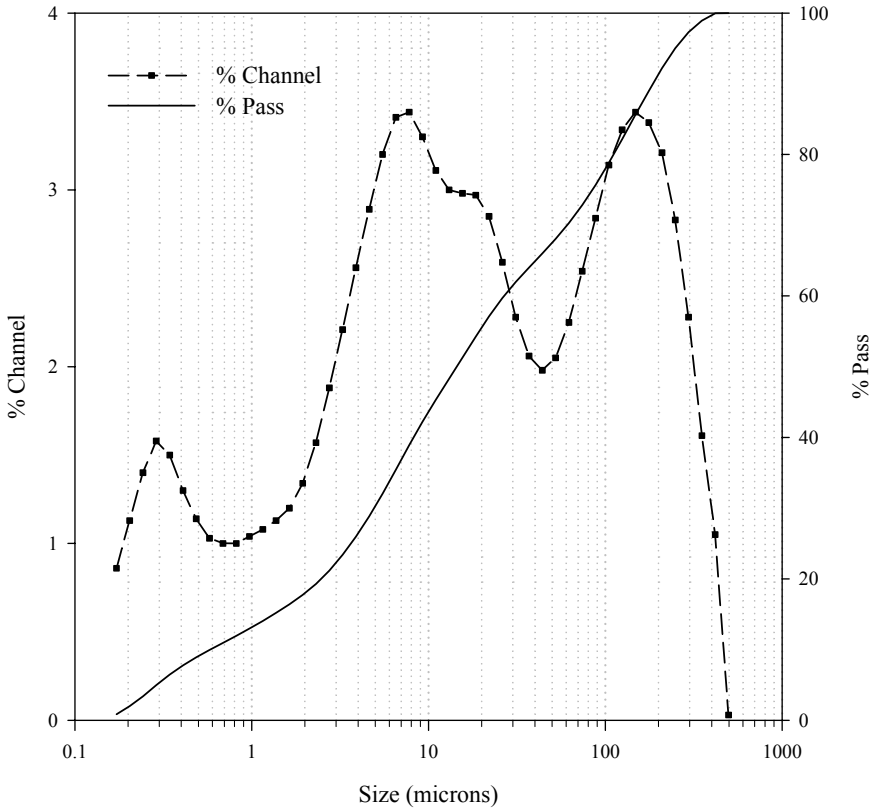
Microns	% Channel	% Pass	Microns	% Channel	% Pass	Summary	Amount	Units
0.172	0.97	0.97	13.08	3.51	47.77	mv	53.95	microns
0.204	1.13	2.1	15.56	3.51	51.28	mn	0.22	microns
0.243	1.22	3.32	18.5	3.48	54.76	ma	2.131	microns
0.289	1.26	4.58	22	3.32	58.08	cs	2.816	M^2/CC
0.344	1.17	5.75	26.16	3.07	61.15	sd	54.59	microns
0.409	1.03	6.78	31.11	2.76	63.91	**Percentiles**	**Amount**	
0.486	0.93	7.71	37	2.54	66.45	10%	0.773	
0.578	0.86	8.57	44	2.41	68.86	20%	3.014	
0.688	0.85	9.42	52.33	2.43	71.29	25%	4.231	
0.818	0.86	10.28	62.23	2.54	73.83	40%	8.946	
0.972	0.9	11.18	74	2.77	76.6	50%	14.61	
1.156	0.95	12.13	88	3.03	79.63	60%	24.48	
1.375	1.02	13.15	104.7	3.23	82.86	70%	47.76	
1.635	1.13	14.28	124.5	3.22	86.08	75%	67.09	
1.945	1.28	15.56	148	2.98	89.06	90%	157.3	
2.312	1.52	17.08	176	2.55	91.61	95%	239.2	
2.75	1.82	18.9	209.3	2.08	93.69	**Diameter**	**Vol%**	**Width**
3.27	2.17	21.07	248.9	1.66	95.35	106.8	34	175.6
3.889	2.55	23.62	296	1.36	96.71	7.947	58	18.49
4.625	2.93	26.55	352	1.19	97.9	0.278	8	0.259
5.5	3.28	29.83	418.6	1.16	99.06			
6.541	3.54	33.37	497.8	0.37	99.43			
7.778	3.69	37.06	592	0.32	99.75			
9.25	3.64	40.7	704	0.25	100			
11	3.56	44.26						

Figure H- 17 Particle Size Distribution Based Upon Volume for the HLW Precipitated Hydroxide Blend Simulant



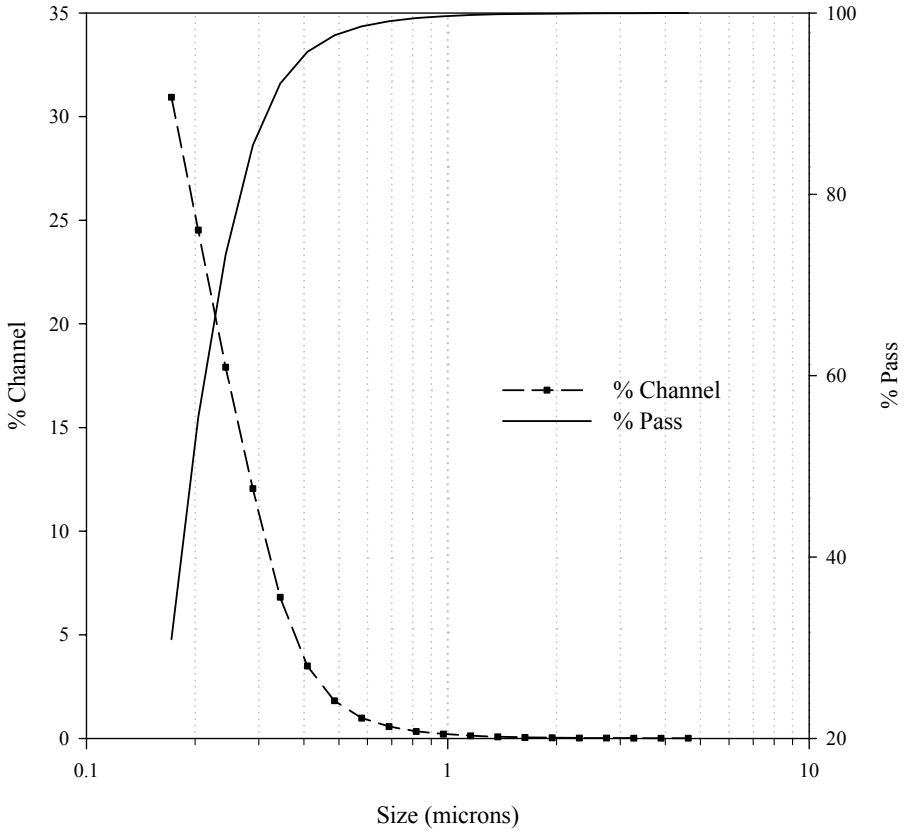
Microns	% Channel	% Pass	Summary	Amount	Units
0.172	36.24	36.24	mv	53.95	microns
0.204	25.46	61.7	mn	0.22	microns
0.243	16.21	77.91	ma	2.131	microns
0.289	9.98	87.89	cs	2.816	M^2/CC
0.344	5.51	93.4	sd	0.055	microns
0.409	2.88	96.28	**Percentiles**	**Amount**	
0.486	1.54	97.82	10%	0.153	
0.578	0.85	98.67	20%	0.161	
0.688	0.5	99.17	25%	0.164	
0.818	0.3	99.47	40%	0.175	
0.972	0.19	99.66	50%	0.186	
1.156	0.12	99.78	60%	0.201	
1.375	0.07	99.85	70%	0.221	
1.635	0.05	99.9	75%	0.234	
1.945	0.03	99.93	90%	0.306	
2.312	0.02	99.95	95%	0.374	
2.75	0.02	99.97	**Diameter**	**Vol%**	**Width**
3.27	0.01	99.98	0.186	100	0.109
3.889	0.01	99.99			
4.625	0.01	100			

Figure H- 18 Particle Size Distribution Based Upon Number for the HLW Precipitated Hydroxide Blend Simulant



Microns	% Channel	% Pass	Microns	% Channel	% Pass	Summary	Amount	Units
0.172	0.86	0.86	13.08	3	48.3	mv	57.68	microns
0.204	1.13	1.99	15.56	2.98	51.28	mn	0.229	microns
0.243	1.4	3.39	18.5	2.97	54.25	ma	1.947	microns
0.289	1.58	4.97	22	2.85	57.1	cs	3.082	M^2/CC
0.344	1.5	6.47	26.16	2.59	59.69	sd	67.47	microns
0.409	1.3	7.77	31.11	2.28	61.97	**Percentiles**	**Amount**	
0.486	1.14	8.91	37	2.06	64.03	10%	0.584	
0.578	1.03	9.94	44	1.98	66.01	20%	2.476	
0.688	1	10.94	52.33	2.05	68.06	25%	3.657	
0.818	1	11.94	62.23	2.25	70.31	40%	8.239	
0.972	1.04	12.98	74	2.54	72.85	50%	14.45	
1.156	1.08	14.06	88	2.84	75.69	60%	26.76	
1.375	1.13	15.19	104.7	3.14	78.83	70%	60.84	
1.635	1.2	16.39	124.5	3.34	82.17	75%	84.52	
1.945	1.34	17.73	148	3.44	85.61	90%	185.6	
2.312	1.57	19.3	176	3.38	88.99	95%	248.4	
2.75	1.88	21.18	209.3	3.21	92.2	**Diameter**	**Vol%**	**Width**
3.27	2.21	23.39	248.9	2.83	95.03	123.5	36	176.6
3.889	2.56	25.95	296	2.28	97.31	7.065	54	17.64
4.625	2.89	28.84	352	1.61	98.92	0.289	10	0.252
5.5	3.2	32.04	418.6	1.05	99.97			
6.541	3.41	35.45	497.8	0.03	100			
7.778	3.44	38.89	592	0	100			
9.25	3.3	42.19	704	0	100			
11	3.11	45.3						

Figure H- 19 Particle Size Distribution Based Upon Volume for the Pretreated HLW Precipitated Hydroxide Feed Simulant



Microns	% Channel	% Pass	Summary	Amount	Units
0.172	30.93	30.93	mv	57.68	microns
0.204	24.52	55.45	mn	0.229	microns
0.243	17.91	73.36	ma	1.947	microns
0.289	12.05	85.41	cs	3.082	M^2/CC
0.344	6.81	92.22	sd	0.061	microns
0.409	3.5	95.72	**Percentiles**	**Amount**	
0.486	1.82	97.54	10%	0.155	
0.578	0.98	98.52	20%	0.163	
0.688	0.57	99.09	25%	0.167	
0.818	0.34	99.43	40%	0.182	
0.972	0.21	99.64	50%	0.196	
1.156	0.13	99.77	60%	0.212	
1.375	0.08	99.85	70%	0.234	
1.635	0.05	99.9	75%	0.248	
1.945	0.03	99.93	90%	0.321	
2.312	0.02	99.95	95%	0.39	
2.75	0.02	99.97	**Diameter**	**Vol%**	**Width**
3.27	0.01	99.98	0.196	100	0.122
3.889	0.01	99.99			
4.625	0.01	100			

Figure H- 20 Particle Size Distribution Based Upon Number for the Pretreated HLW Precipitated Hydroxide Feed Simulant

APPENDIX I

APPENDIX I: SUMMARY DATA TABLES FOR BOUNDING LAW AND HLW SIMULANTS AND FOR THE HLW PRECIPITATED HYDROXIDE SIMULANT

The following summary data tables are based upon the guidelines for chemical, physical, and rheological measurements provide by RPP-WTP.

Table I- 1 Physical Property Data Summary for Low Bound LAW Pretreated Waste

Physical Property Data Summary for Sample	**Low Bound LAW Pretreated Waste**	
Physical Property	**Results**	
Sodium concentration of LAW waste or pretreated waste	3	Molar
pH	NM	
Solid phases present	no	yes/no
Particle size distribution - Mean Vol. Distribution	NA	μm
Particle size distribution - Mean No. Distribution	NA	μm
Density – Bulk slurry	1.158	g/mL
Density – settled solids	NA	g/mL
Density – centrifuged solids	NA	g/mL
Density - supernatant liquid	1.158	g/mL
Vol. % settled solids after 72 hours	NA	%
Vol. % centrifuged solids	NA	%
Wt % total dried solids	13.30	%
Wt % centrifuged solids	NA	%
Wt % oven dried solids	13.30	%
Wt % undissolved solids	0.00	%
Wt % dissolved solids	13.30	%

Table I- 2 Rheological Model Fits for Low Bound LAW Pretreated Waste at 25 and 40 ° C

Model/model Parameter	**Parameter Value**	**Parameter Value**	**Parameter Value**	**Parameter Value**
Newtonian	**3 M Simple LAW-25C-R1rev.rwd**	**3 M Simple LAW-25C-R2.rwd**	**3 M Simple LAW-40C-R1rev.rwd**	**3 M Simple LAW-40C-R2a.rwd**
Shear rate range data fitted (sec^{-1})	0-1000	0-1000	0-1000	0-1000
□ – viscosity (mPa-sec)	1.656	1.664	1.219	1.227
R^2 – correlation coefficient	1	1	0.9998	1
Ostwald (or Power Law):	**3 M Simple LAW-25C-R1rev.rwd**	**3 M Simple LAW-25C-R2.rwd**	**3 M Simple LAW-40C-R1rev.rwd**	**3 M Simple LAW-40C-R2a.rwd**
Shear rate range data fitted (sec^{-1})	0-1000	0-1000	0-1000	0-1000
m – the consistency coefficient ($Pa\text{-}sec^n$)	0.001527	0.001532	0.001211	0.001153
n – the power law exponent	1.012	1.012	1.001	1.009
R^2 – correlation coefficient	1	1	0.9998	1
Bingham Plastic:	**3 M Simple LAW-25C-R1rev.rwd**	**3 M Simple LAW-25C-R2.rwd**	**3 M Simple LAW-40C-R1rev.rwd**	**3 M Simple LAW-40C-R2a.rwd**
Shear rate range data fitted (sec^{-1})	0-1000	0-1000	0-1000	0-1000
□$_O^B$ - the Bingham yield stress (Pa)	-0.0071	-0.0072	-0.000185	-0.00395
□$_P$ - the plastic viscosity (cP)	1.67	1.67	1.22	1.232
R^2 – correlation coefficient	1	1	0.9998	1
Herschel-Bulkley:	**3 M Simple LAW-25C-R1rev.rwd**	**3 M Simple LAW-25C-R2.rwd**	**3 M Simple LAW-40C-R1rev.rwd**	**3 M Simple LAW-40C-R2a.rwd**
Shear rate range data fitted (sec^{-1})	0-1000	0-1000	0-1000	0-1000
□$_O^H$ - the Herschel-Bulkley yield stress (Pa)	-0.00032	0.0001	0.001086	0.000053
k - the Herschel-Bulkely consistency coefficient (cP)	1.531	1.531	1.194	1.153
b - the Hershel-Bulkely power law exponent	1.012	1.013	1.003	1.009
R^2 – correlation coefficient	1	1	0.9998	1

Table I- 3 Physical Property Data Summary for Low Bound LAW Melter Feed

Physical Property Data Summary for Sample	**Low Bound LAW Melter Feed**	
Physical Property	**Results**	
Sodium concentration of LAW waste or pretreated waste	3	Molar
pH - 24 hr	11.01	
Solid phases present	yes	yes/no
Particle size distribution - Mean Vol. Distribution	26.09	µm
Particle size distribution - Mean No. Distribution	0.44	µm
Particle size distribution - Mean Area Distribution	4.86	µm
Density – Bulk slurry	1.67	g/mL
Density – settled solids	NM	g/mL
Density – centrifuged solids	NM	g/mL
Density - supernatant liquid	NM	g/mL
Vol. % settled solids after 72 hours	30.80	%
Vol. % centrifuged solids	NM	%
Wt % total dried solids	NM	%
Wt % centrifuged solids	NM	%
Wt % oven dried solids	39.80	%
Wt % undissolved solids	32.50	%
Wt % dissolved solids	7.30	%

Table I- 4 Glass Former Chemicals Utilization for Low Bound LAW Melter Feed

Sample Identification:	**Low Bound LAW Melter Feed**	**Volume**	**500**	**mL**
Source Chemical	Manufacturer	Oxide	Target Mass (g)	Actual Mass Added (g)
Kyanite	Kyanite Mining Corp	Al_2O_3	17.83	17.832
Boric Acid Technical	U.S. Borax	B_2O_3	43.83	43.833
10M Borax	U.S. Borax	Na_2O/B_2O_3	NA	NA
Soda Ash	Solvay Minerals	Na_2CO_3	NA	NA
Wollastonite	NYCO	CaO	10.58	10.58
Fe_2O_3 5001	Prince Mfg. Co.	Fe_2O_3	13.60	13.6
Li_2CO_3	Chemettal-Foote	Li_2O	NA	NA
Olivine	Unimin Corp	MgO	7.75	7.75
SCS-75	U.S. Silica	SiO_2	91.81	91.812
Rutile (Air floated)	Chemalloy Co.	TiO_2	5.26	5.262
Kadox	Zinc Corp Amer.	ZnO	7.49	7.49
Zircon	Amer. Miner, Inc.	ZrO_2	11.33	11.333
Sucrose	Amalgamated Sugar	Sugar	NA	NA

Table I- 5 Description of Mixing for Low Bound LAW Melter Feed

Sample Identification:	**Low Bound LAW Melter Feed**
Melter Feed ID:	LAW Melter Feed at 3 M Na
Processing Scale (lab/bench, pilot or full)	Lab/Bench
Activity/Property	**Data or Explanation**
Order of Chemical Additions	Glass formers mixed together then addition to LAW Waste
Mixing Time	60 minutes
Impeller Speed	300-500 rpm
Impeller Diameter	50 mm
Type of Impeller	Rushton
Tank Diameter	85 mm
Number of Baffles	0
Size of Baffles	NA
Location of impeller	off-center
Comments	None

Table I- 6 Rheological Model Fits for Low Bound LAW Melter Feed at 25 and 40 ° C

Model/model Parameter	Parameter Value	Parameter Value	Parameter Value	Parameter Value
Newtonian	**AP-101 LMF 3M_25C_R1rev.rwd**	**AP-101 LMF 3M_25C_R2rev.rwd**	**LAWMF 3M_40C_R1.rwd**	**LAWMF 3M_40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-400	0-400	0-350	0-350
μ – viscosity (mPa-sec)	2.771	2.798	2.095	2.199
R^2 – correlation coefficient	0.9998	0.998	0.9892	0.991
Ostwald (or Power Law):	**AP-101 LMF 3M_25C_R1rev.rwd**	**AP-101 LMF 3M_25C_R2rev.rwd**	**LAWMF 3M_40C_R1.rwd**	**LAWMF 3M_40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-400	0-400	0-350	0-350
m – the consistency coefficient ($Pa\text{-}sec^n$)	0.00269	0.00272	0.00136	0.0014
n – the power law exponent	1.005	1.005	1.078	1.082
R^2 – correlation coefficient	0.9998	0.998	0.9916	0.9936
Bingham Plastic:	**AP-101 LMF 3M_25C_R1rev.rwd**	**AP-101 LMF 3M_25C_R2rev.rwd**	**LAWMF 3M_40C_R1.rwd**	**LAWMF 3M_40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-400	0-400	0-350	0-350
τ_O^B - the Bingham yield stress (Pa)	0.0022	0.0019	-0.0087	-0.011
η_P - the plastic viscosity (cP)	2.763	2.791	2.133	2.246
R^2 – correlation coefficient	0.9998	0.998	0.9896	0.9916
Herschel-Bulkley:	**AP-101 LMF 3M_25C_R1rev.rwd**	**AP-101 LMF 3M_25C_R2rev.rwd**	**LAWMF 3M_40C_R1.rwd**	**LAWMF 3M_40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-400	0-400	0-350	0-350
τ_O^H - the Herschel-Bulkley yield stress (Pa)	0.0153	0.015	0.0335	0.0318
k - the Herschel-Bulkely consistency coefficient (cP)	2.198	2.227	0.627	0.697
b - the Hershel-Bulkely power law exponent	1.037	1.037	1.205	1.196
R^2 – correlation coefficient	0.9982	0.9982	0.9934	0.995

Table I- 7 Physical Property Data Summary for High Bound LAW Pretreated Waste

Physical Property Data Summary for Sample	High Bound LAW Pretreated Waste	
Physical Property	**Results**	
Sodium concentration of LAW waste or pretreated waste	10.5	Molar
pH	NM	
Solid phases present	yes	yes/no
Particle size distribution - Mean Vol. Distribution	26.09	µm
Particle size distribution - Mean No. Distribution	0.444	µm
Particle size distribution - Mean Area Distribution	4.858	µm
Density – Bulk slurry	1.489	g/mL
Density – settled solids	NM	g/mL
Density – centrifuged solids	NM	g/mL
Density - supernatant liquid	NM	g/mL
Vol. % settled solids after 72 hours	41.00	%
Vol. % centrifuged solids	NM	%
Wt % total dried solids	13.30	%
Wt % centrifuged solids	NM	%
Wt % oven dried solids	52.07	%
Wt % undissolved solids	8.12	%
Wt % dissolved solids	43.95	%

Table I- 8 Rheological Model Fits for High Bound LAW Pretreated Waste at 25 and 40 ° C

Model/model Parameter	Parameter Value	Parameter Value	Parameter Value	Parameter Value
Newtonian	**AP-101SIM,10.5M Na_25C_R1rev.rwd**	**AP-101SIM,10.5M Na_25C_R2rev.rwd**	**AP-101SIM,10.5M Na_40C_R1rev.rwd**	**AP-101SIM,10.5M Na_40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-1000	0-1000	0-1000	0-1000
μ – viscosity (mPa-sec)	15.54	15.6	9.58	9.64
R^2 – correlation coefficient	0.9968	0.9978	0.996	0.9964
Ostwald (or Power Law):	**AP-101SIM,10.5M Na_25C_R1rev.rwd**	**AP-101SIM,10.5M Na_25C_R2rev.rwd**	**AP-101SIM,10.5M Na_40C_R1rev.rwd**	**AP-101SIM,10.5M Na_40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-1000	0-1000	0-1000	0-1000
m – the consistency coefficient ($Pa\text{-}sec^n$)	0.0214	0.0202	0.0149	0.0149
n – the power law exponent	0.9514	0.961	0.9336	0.9347
R^2 – correlation coefficient	0.9978	0.9984	0.9982	0.9986
Bingham Plastic:	**AP-101SIM,10.5M Na_25C_R1rev.rwd**	**AP-101SIM,10.5M Na_25C_R2rev.rwd**	**AP-101SIM,10.5M Na_40C_R1rev.rwd**	**AP-101SIM,10.5M Na_40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	50-1000, Up	50-1000, Up	50-1000, Up	50-1000, Up
τ_O^B - the Bingham yield stress (Pa)	0.53	0.47	0.43	0.41
η_P - the plastic viscosity (cP)	15.1	15.2	9.12	9.2
R^2 – correlation coefficient	0.9994	0.9996	0.9996	0.9996
Herschel-Bulkley:	**AP-101SIM,10.5M Na_25C_R1rev.rwd**	**AP-101SIM,10.5M Na_25C_R2rev.rwd**	**AP-101SIM,10.5M Na_40C_R1rev.rwd**	**AP-101SIM,10.5M Na_40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-1000	0-1000	0-1000	0-1000
τ_O^H - the Herschel-Bulkley yield stress (Pa)	0.0593	0.0836	0.151	0.144
k - the Herschel-Bulkely consistency coefficient (cP)	20.23	18.61	11.69	11.85
b - the Hershel-Bulkely power law exponent	0.9593	0.9722	0.9665	0.9657
R^2 – correlation coefficient	0.9978	0.9984	0.9982	0.9986

Table I- 9 Physical Property Data Summary for High Bound LAW Melter Feed

Physical Property Data Summary for Sample	High Bound LAW Melter Feed	
Physical Property	**Results**	
Sodium concentration of LAW waste or pretreated waste	8	Molar
pH - 24 hr	4.4	
Solid phases present	yes	yes/no
Particle size distribution - Mean Vol. Distribution	39.4	µm
Particle size distribution - Mean No. Distribution	0.764	µm
Particle size distribution - Mean Area Distribution	7.909	µm
Density – Bulk slurry	1.71	g/mL
Density – settled solids	NM	g/mL
Density – centrifuged solids	NM	g/mL
Density - supernatant liquid	NM	g/mL
Vol. % settled solids after 72 hours	100.00	%
Vol. % centrifuged solids	NM	%
Wt % total dried solids	NM	%
Wt % centrifuged solids	NM	%
Wt % oven dried solids	67.43	%
Wt % undissolved solids	NM	%
Wt % dissolved solids	NM	%

Table I- 10 Glass Former Chemicals Utilization for High Bound LAW Melter Feed

Sample Identification:	**High Bound LAW Melter Feed**	**Volume**	**500**	**mL**
Source Chemical	Manufacturer	Oxide	Target Mass (g)	Actual Mass Added (g)
Kyanite	Kyanite Mining Corp	Al_2O_3	47.56	47.559
Boric Acid Technical	U.S. Borax	B_2O_3	116.87	116.871
10M Borax	U.S. Borax	Na_2O/B_2O_3	NA	NA
Soda Ash	Solvay Minerals	Na_2CO_3	NA	NA
Wollastonite	NYCO	CaO	28.21	28.209
Fe_2O_3 5001	Prince Mfg. Co.	Fe_2O_3	36.28	36.282
Li_2CO_3	Chemettal-Foote	Li_2O	NA	NA
Olivine	Unimin Corp	MgO	20.66	20.658
SCS-75	U.S. Silica	SiO_2	244.84	244.841
Rutile (Air floated)	Chemalloy Co.	TiO_2	14.03	14.031
Kadox	Zinc Corp Amer.	ZnO	19.98	19.983
Zircon	Amer. Miner, Inc.	ZrO_2	30.23	30.232
Sucrose	Amalgamated Sugar	Sugar	NA	NA
Xanthan Gum	Kraft Chemical	Gum	1.88	1.879

Table I- 11 Mixing Information for High Bound LAW Melter Feed

Sample Identification:	**High Bound LAW Melter Feed**
Melter Feed ID:	NO3-8M-0.15-Lot2502799
Processing Scale (lab/bench, pilot or full)	Lab/Bench
Activity/Property	**Data or Explanation**
Order of Chemical Additions	Glass formers mixed with Xanthan Gum together then addition to LAW Waste
Mixing Time	60 minutes
Impeller Speed	300-500 rpm
Impeller Diameter	50
Type of Impeller	Rushton
Tank Diameter	85
Number of Baffles	0
Size of Baffles	NA
Location of impeller	off-center
Comments	None

Table I- 12 Rheological Model Fits for High Bound LAW Melter Feed at 25 and 40 ° C

Model/model Parameter	Parameter Value	Parameter Value	Parameter Value	Parameter Value
Newtonian	**NO3-8M-0.15-LOT-2502799_@25C_R1 rev.rwd**	**NO3-8M-0.15-LOT-2502799_@25C_R2.rwd**	**NO3-8M-0.15-LOT-2502799_@40C_R1 rev.rwd**	**NO3-8M-0.15-LOT-2502799_@40C_R2 rev.rwd**
Shear rate range data fitted (sec^{-1})	NA	NA	NA	NA
μ – viscosity (mPa-sec)	NA	NA	NA	NA
R^2 – correlation coefficient	NA	NA	NA	NA
Ostwald (or Power Law):	**NO3-8M-0.15-LOT-2502799_@25C_R1 rev.rwd**	**NO3-8M-0.15-LOT-2502799_@25C_R2.rwd**	**NO3-8M-0.15-LOT-2502799_@40C_R1 rev.rwd**	**NO3-8M-0.15-LOT-2502799_@40C_R2 rev.rwd**
Shear rate range data fitted (sec^{-1})	0-1000, Up Curve	0-1000, Up Curve	0-1000, Up Curve	0-1000, Up Curve
m – the consistency coefficient ($Pa\text{-}sec^n$)	1.045	1.041	0.8937	0.9036
n – the power law exponent	0.608	0.6031	0.5765	0.573
R^2 – correlation coefficient	0.9988	0.9998	0.999	0.9994
Bingham Plastic:	**NO3-8M-0.15-LOT-2502799_@25C_R1 rev.rwd**	**NO3-8M-0.15-LOT-2502799_@25C_R2.rwd**	**NO3-8M-0.15-LOT-2502799_@40C_R1 rev.rwd**	**NO3-8M-0.15-LOT-2502799_@40C_R2 rev.rwd**
Shear rate range data fitted (sec^{-1})	50-1000, Up Curve	50-1000, Up Curve	50-1000, Up Curve	50-1000, Up Curve
τ_O^B - the Bingham yield stress (Pa)	14.68	14.44	11.24	11.23
η_P - the plastic viscosity (cP)	58.14	55.73	38.97	38.36
R^2 – correlation coefficient	0.9898	0.9864	0.9862	0.9864
Herschel-Bulkley:	**NO3-8M-0.15-LOT-2502799_@25C_R1 rev.rwd**	**NO3-8M-0.15-LOT-2502799_@25C_R2.rwd**	**NO3-8M-0.15-LOT-2502799_@40C_R1 rev.rwd**	**NO3-8M-0.15-LOT-2502799_@40C_R2 rev.rwd**
Shear rate range data fitted (sec^{-1})	0-1000, Up Curve	0-1000, Up Curve	0-1000, Up Curve	0-1000, Up Curve
τ_O^H - the Herschel-Bulkley yield stress (Pa)	3.111	1.485	1.986	1.762
k - the Herschel-Bulkely consistency coefficient (cP)	680.5	855.3	618.2	651.8
b - the Hershel-Bulkely power law exponent	0.6645	0.6289	0.6246	0.6156
R^2 – correlation coefficient	0.9996	0.9998	0.9996	0.9998

Table I- 13 Physical Property Data Summary for Low Bound HLW Pretreated Waste

Physical Property Data Summary for Sample	Low Bound HLW Pretreated Waste	
Physical Property	**Results**	Units
Sodium concentration of LAW waste or pretreated waste	NM	Molar
Oxides Loading of HLW Sludge, grams oxide/Liter	NM	g/L
pH - 24 Hours	11.75	pH
Solid phases present	yes	yes/no
Particle size distribution - Mean Vol. Distribution	2.576	µm
Particle size distribution - Mean No. Distribution	0.227	µm
Particle size distribution - Mean Area Distribution	0.699	µm
Density – Bulk slurry	1.126	g/mL
Density – settled solids	NA	g/mL
Density – centrifuged solids	NA	g/mL
Density - supernatant liquid	NM	g/mL
Vol. % settled solids after 72 hours	25.90	%
Vol. % centrifuged solids	NM	%
Wt % total dried solids	13.30	%
Wt % centrifuged solids	NM	%
Wt % oven dried solids	15.59	%
Wt % undissolved solids	13.04	%
Wt % dissolved solids	2.56	%

Table I- 14 Mixing Information for Low Bound HLW Pretreated Waste

Sample Identification:	Low Bound HLW Pretreated Waste
HLW Feed ID:	20-L-CRV
Processing Scale (lab/bench, pilot or full)	Lab/Bench
Activity/Property	**Data or Explanation**
Order of Chemical Additions	Oxides added to already prepared supernate
Mixing Time	60 minutes
Impeller Speed	300-500 rpm
Impeller Diameter	50
Type of Impeller	Rushton
Tank Diameter	85
Number of Baffles	0
Size of Baffles	NA
Location of impeller	off-center
Comments	None

Table I- 15 Rheological Model Fits for Low Bound HLW Pretreated Waste at 25 and 40 ° C

Model/model Parameter	Parameter Value	Parameter Value	Parameter Value	Parameter Value
Newtonian	**20-L-MFPV_@25C_R1rev.rwd**	**20-L-MFPV_@25C_R2rev.rwd**	**20-L-MFPV_@40C_R1rev.rwd**	**20-L-MFPV_@40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-500, Up Curve	0-500, Up Curve	0-400, Up Curve	0-400, Up Curve
μ – viscosity (mPa-sec)	4.05	4.09	3.78	3.55
R^2 – correlation coefficient	0.9647	0.9647	0.957	0.9254
Ostwald (or Power Law):	**20-L-MFPV_@25C_R1rev.rwd**	**20-L-MFPV_@25C_R2rev.rwd**	**20-L-MFPV_@40C_R1rev.rwd**	**20-L-MFPV_@40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-500, Up Curve	0-500, Up Curve	0-400, Up Curve	0-400, Up Curve
m – the consistency coefficient ($Pa\text{-}sec^n$)	0.0132	0.0157	0.0128	0.0177
n – the power law exponent	0.7984	0.7706	0.7833	0.7155
R^2 – correlation coefficient	0.99	0.992	0.987	0.9852
Bingham Plastic:	**20-L-MFPV_@25C_R1rev.rwd**	**20-L-MFPV_@25C_R2rev.rwd**	**20-L-MFPV_@40C_R1rev.rwd**	**20-L-MFPV_@40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-500, Up Curve	0-500, Up Curve	0-400, Up Curve	0-400, Up Curve
τ_O^B - the Bingham yield stress (Pa)	0.18	0.2	0.148	0.176
η_P - the plastic viscosity (cP)	35.05	34.87	32.24	28.87
R^2 – correlation coefficient	0.9968	0.9974	0.9966	0.9954
Herschel-Bulkley:	**20-L-MFPV_@25C_R1rev.rwd**	**20-L-MFPV_@25C_R2rev.rwd**	**20-L-MFPV_@40C_R1rev.rwd**	**20-L-MFPV_@40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-500, Up Curve	0-500, Up Curve	0-400, Up Curve	0-400, Up Curve
τ_O^H - the Herschel-Bulkley yield stress (Pa)	0.1945	0.18	0.168	0.168
k - the Herschel-Bulkely consistency coefficient (cP)	3.04	4.42	2.38	3.3
b - the Hershel-Bulkely power law exponent	1.023	0.9628	1.05	0.9781
R^2 – correlation coefficient	0.9968	0.9976	0.9968	0.9954

Table I- 16 Physical Property Data Summary for Low Bound HLW Melter Feed

Physical Property Data Summary for Sample	**Low Bound HLW Melter Feed**	
Physical Property	**Results**	Units
Sodium concentration of LAW waste or pretreated waste	NA	Molar
Oxides Loading of HLW Melter Feed, grams oxide/Liter	NM	g/L
pH - 24 hr	9.88	pH
Solid phases present	yes	yes/no
Particle size distribution - Mean Vol. Distribution	23.9	µm
Particle size distribution - Mean No. Distribution	0.209	µm
Particle size distribution - Mean Area Distribution	1.204	µm
Density – Bulk slurry	1.324	g/mL
Density – settled solids	NM	g/mL
Density – centrifuged solids	NM	g/mL
Density - supernatant liquid	NM	g/mL
Vol. % settled solids after 72 hours	44.10	%
Vol. % centrifuged solids	NM	%
Wt % total dried solids	NM	%
Wt % centrifuged solids	NM	%
Wt % oven dried solids	37.39	%
Wt % undissolved solids	30.76	%
Wt % dissolved solids	6.63	%
Wt % Calcined solids	NM	%

Table I- 17 Glass Former Chemicals Used in Low Bound HLW Melter Feed

Sample Identification:	Low Bound HLW Melter Feed	Volume	250	mL
Source Chemical	Manufacturer	Oxide	Target Mass (g)	Actual Mass Added (g)
Kyanite	Kyanite Mining Corp	Al_2O_3	NA	NA
Boric Acid Technical	U.S. Borax	B_2O_3	NA	NA
10M Borax	U.S. Borax	Na_2O/B_2O_3	34.246	34.246
Soda Ash	Solvay Minerals	Na_2CO_3	7.791	7.792
Wollastonite	NYCO	CaO	NA	NA
Fe_2O_3 5001	Prince Mfg. Co.	Fe_2O_3	NA	NA
Li_2CO_3	Chemettal-Foote	Li_2O	11.214	11.214
Olivine	Unimin Corp	MgO	NA	NA
SCS-75	U.S. Silica	SiO_2	51.800	51.801
Rutile (Air floated)	Chemalloy Co.	TiO_2	NA	NA
Kadox	Zinc Corp Amer.	ZnO	2.381	2.381
Zircon	Amer. Miner, Inc.	ZrO_2	NA	NA
Sucrose	Amalgamated Sugar	Sugar	NA	NA

Table I- 18 Mixing Information for Low Bound HLW Melter Feed

Sample Identification:	Low Bound HLW Melter Feed
Melter Feed ID:	20-L-MFPV
Processing Scale (lab/bench, pilot or full)	Lab/Bench
Activity/Property	**Data or Explanation**
Order of Chemical Additions	Glass formers mixed dry then added to HLW Waste
Mixing Time	60 minutes
Impeller Speed	300-500 rpm
Impeller Diameter	50 mm
Type of Impeller	Rushton
Tank Diameter	85 mm
Number of Baffles	0
Size of Baffles	NA
Location of impeller	off-center
Comments	None

Table I- 19 Rheological Model Fits for Low Bound HLW Melter Feed at 25 and 40 ° C

Model/model Parameter	**Parameter Value**	**Parameter Value**	**Parameter Value**	**Parameter Value**
Newtonian	**20-L-MFPV_@25C_R1rev.rwd**	**20-L-MFPV_@25C_R2rev.rwd**	**20-L-MFPV_@40C_R1rev.rwd**	**20-L-MFPV_@40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-500, Up Curve	0-500, Up Curve	0-400, Up Curve	0-400, Up Curve
μ – viscosity (mPa-sec)	4.05	4.09	3.78	3.55
R^2 – correlation coefficient	0.9647	0.9647	0.957	0.9254
Ostwald (or Power Law):	**20-L-MFPV_@25C_R1rev.rwd**	**20-L-MFPV_@25C_R2rev.rwd**	**20-L-MFPV_@40C_R1rev.rwd**	**20-L-MFPV_@40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-500, Up Curve	0-500, Up Curve	0-400, Up Curve	0-400, Up Curve
m – the consistency coefficient ($Pa\text{-}sec^n$)	0.0132	0.0157	0.0128	0.0177
n – the power law exponent	0.7984	0.7706	0.7833	0.7155
R^2 – correlation coefficient	0.99	0.992	0.987	0.9852
Bingham Plastic:	**20-L-MFPV_@25C_R1rev.rwd**	**20-L-MFPV_@25C_R2rev.rwd**	**20-L-MFPV_@40C_R1rev.rwd**	**20-L-MFPV_@40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-500, Up Curve	0-500, Up Curve	0-400, Up Curve	0-400, Up Curve
τ_O^B - the Bingham yield stress (Pa)	0.18	0.2	0.148	0.176
η_P - the plastic viscosity (cP)	35.05	34.87	32.24	28.87
R^2 – correlation coefficient	0.9968	0.9974	0.9966	0.9954
Herschel-Bulkley:	**20-L-MFPV_@25C_R1rev.rwd**	**20-L-MFPV_@25C_R2rev.rwd**	**20-L-MFPV_@40C_R1rev.rwd**	**20-L-MFPV_@40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-500, Up Curve	0-500, Up Curve	0-400, Up Curve	0-400, Up Curve
τ_O^H - the Herschel-Bulkley yield stress (Pa)	0.1945	0.18	0.168	0.168
k - the Herschel-Bulkely consistency coefficient (cP)	3.04	4.42	2.38	3.3
b - the Hershel-Bulkely power law exponent	1.023	0.9628	1.05	0.9781
R^2 – correlation coefficient	0.9968	0.9976	0.9968	0.9954

Table I- 20 Physical Property Data Summary for High Bound HLW Pretreated Waste

Physical Property Data Summary for Sample	High Bound HLW Pretreated Waste	
Physical Property	**Results**	Units
Sodium concentration of LAW waste or pretreated waste	NM	Molar
Oxides Loading of HLW Sludge, grams oxide/Liter	NM	g/L
pH	6.82	pH
Solid phases present	yes	yes/no
Particle size distribution - Mean Vol. Distribution	4.293	µm
Particle size distribution - Mean No. Distribution	0.315	µm
Particle size distribution - Mean Area Distribution	0.872	µm
Density – Bulk slurry	1.310	g/mL
Density – settled solids	NM	g/mL
Density – centrifuged solids	NM	g/mL
Density - supernatant liquid	NM	g/mL
Vol. % settled solids after 72 hours	88.10	%
Vol. % centrifuged solids	NM	%
Wt % total dried solids	36.03	%
Wt % centrifuged solids	NM	%
Wt % oven dried solids	36.03	%
Wt % undissolved solids	33.28	%
Wt % dissolved solids	2.75	%

Table I- 21 Mixing Information for High Bound HLW Pretreated Waste

Sample Identification:	High Bound HLW Pretreated Waste
HLW Feed ID:	HLW-41-CRV
Processing Scale (lab/bench, pilot or full)	Lab/Bench
Activity/Property	**Data or Explanation**
Order of Chemical Additions	Oxides added to already prepared supernate
Mixing Time	60 minutes
Impeller Speed	300-500 rpm
Impeller Diameter	50 mm
Type of Impeller	Rushton
Tank Diameter	85 mm
Number of Baffles	0
Size of Baffles	NA
Location of impeller	off-center
Comments	None

Table I- 22 Rheological Model Fits for High Bound HLW Pretreated Waste at 25 and 40 ° C

Model/model Parameter	Parameter Value	Parameter Value	Parameter Value	Parameter Value
Newtonian	**HLW-CRV-41_25C_R1rev.rwd**	**HLW-CRV-41_25C_R2rev.rwd**	**HLW-CRV-41_@40C_R1rev.rwd**	**HLW-CRV-41_@40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	NA	NA	NA	NA
μ – viscosity (mPa-sec)	NA	NA	NA	NA
R^2 – correlation coefficient	NA	NA	NA	NA
Ostwald (or Power Law):	**HLW-CRV-41_25C_R1rev.rwd**	**HLW-CRV-41_25C_R2rev.rwd**	**HLW-CRV-41_@40C_R1rev.rwd**	**HLW-CRV-41_@40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-1000, Up Curve	0-1000, Up Curve	0-1000, Up Curve	0-1000, Up Curve
m – the consistency coefficient (Pa-sec^n)	7.441	7.678	5.97	6.321
n – the power law exponent	0.1805	0.1801	0.2012	0.1922
R^2 – correlation coefficient	0.995	0.9946	0.992	0.997
Bingham Plastic:	**HLW-CRV-41_25C_R1rev.rwd**	**HLW-CRV-41_25C_R2rev.rwd**	**HLW-CRV-41_@40C_R1rev.rwd**	**HLW-CRV-41_@40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	50-1000, Up Curve	50-1000, Up Curve	50-1000, Up Curve	50-1000, Up Curve
τ_O^B - the Bingham yield stress (Pa)	17.24	17.84	15.11	15.46
η_P - the plastic viscosity (cP)	9.84	9.95	10.09	9.5
R^2 – correlation coefficient	0.9543	0.9487	0.9637	0.9536
Herschel-Bulkley:	**HLW-CRV-41_25C_R1rev.rwd**	**HLW-CRV-41_25C_R2rev.rwd**	**HLW-CRV-41_@40C_R1rev.rwd**	**HLW-CRV-41_@40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-1000, Up Curve	0-1000, Up Curve	0-1000, Up Curve	0-1000, Up Curve
τ_O^H - the Herschel-Bulkley yield stress (Pa)	2.3	2.659	2.737	0.566
k - the Herschel-Bulkely consistency coefficient (cP)	5728	5726	4084	5904
b - the Hershel-Bulkely power law exponent	0.2054	0.2078	0.2394	0.1988
R^2 – correlation coefficient	0.9964	0.997	0.9934	0.997

Table I- 23 Physical Property Data Summary for High Bound HLW Melter Feed

Physical Property Data Summary for Sample	**High Bound HLW Melter Feed**	
Physical Property	**Results**	Units
Sodium concentration of LAW waste or pretreated waste	NA	Molar
Oxides Loading of HLW Melter Feed, grams oxide/Liter	NM	g/L
pH - 24 hr	9.87	pH
Solid phases present	yes	yes/no
Particle size distribution - Mean Vol. Distribution	19.45	µm
Particle size distribution - Mean No. Distribution	0.293	µm
Particle size distribution - Mean Area Distribution	1.452	µm
Density – Bulk slurry	1.642	g/mL
Density – settled solids	NM	g/mL
Density – centrifuged solids	NM	g/mL
Density - supernatant liquid	NM	g/mL
Vol. % settled solids after 72 hours	94.40	%
Vol. % centrifuged solids	NM	%
Wt % total dried solids	NM	%
Wt % centrifuged solids	NM	%
Wt % oven dried solids	60.89	%
Wt % undissolved solids	53.63	%
Wt % dissolved solids	7.26	%

Table I- 24 Glass Former Chemicals Used in High Bound HLW Melter Feed

Sample Identification:	High Bound HLW Melter Feed	Volume	250	mL
Source Chemical	Manufacturer	Oxide	Target Mass (g)	Actual Mass Added (g)
Kyanite	Kyanite Mining Corp	Al_2O_3	NA	NA
Boric Acid Technical	U.S. Borax	B_2O_3	NA	NA
10M Borax	U.S. Borax	Na_2O/B_2O_3	95.846	95.846
Soda Ash	Solvay Minerals	Na_2CO_3	21.806	21.806
Wollastonite	NYCO	CaO	NA	NA
Fe_2O_3 5001	Prince Mfg. Co.	Fe_2O_3	NA	NA
Li_2CO_3	Chemettal-Foote	Li_2O	31.384	31.384
Olivine	Unimin Corp	MgO	NA	NA
SCS-75	U.S. Silica	SiO_2	144.974	144.974
Rutile (Air floated)	Chemalloy Co.	TiO_2	NA	NA
Kadox	Zinc Corp Amer.	ZnO	6.665	6.665
Zircon	Amer. Miner, Inc.	ZrO_2	NA	NA
Sucrose	Amalgamated Sugar	Sugar	NA	NA

Table I- 25 Mixing Information for High Bound HLW Melter Feed

Sample Identification:	High Bound HLW Melter Feed
Melter Feed ID:	HLW-MFPV-41
Processing Scale (lab/bench, pilot or full)	Lab/Bench
Activity/Property	**Data or Explanation**
Order of Chemical Additions	Glass formers mixed dry then added to HLW Waste
Mixing Time	60 minutes
Impeller Speed	300-500 rpm
Impeller Diameter	50 mm
Type of Impeller	Rushton
Tank Diameter	85 mm
Number of Baffles	0
Size of Baffles	NA
Location of impeller	off-center
Comments	None

Table I- 26 Rheological Model Fits for High Bound HLW Melter Feed at 25 and 40 ° C

Model/model Parameter	Parameter Value	Parameter Value	Parameter Value	Parameter Value
Newtonian	**HLW-MFPV-41_25C_R1rev.rwd**	**HLW-MFPV-41_25C_R2rev.rwd**	**HLW-MFPV-41_40C_R1rev.rwd**	**HLW-MFPV-41_40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	NA	NA	NA	NA
μ – viscosity (mPa-sec)	NA	NA	NA	NA
R^2 – correlation coefficient	NA	NA	NA	NA
Ostwald (or Power Law):	**HLW-MFPV-41_25C_R1rev.rwd**	**HLW-MFPV-41_25C_R2rev.rwd**	**HLW-MFPV-41_40C_R1rev.rwd**	**HLW-MFPV-41_40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-1000, Up Curve	0-1000, Up Curve	0-1000, Up Curve	0-1000, Up Curve
m – the consistency coefficient (Pa-sec^n)	7.729	5.53	7.764	8.27
n – the power law exponent	0.3106	0.3564	0.2776	0.2931
R^2 – correlation coefficient	0.9892	0.9853	0.9874	0.9866
Bingham Plastic:	**HLW-MFPV-41_25C_R1rev.rwd**	**HLW-MFPV-41_25C_R2rev.rwd**	**HLW-MFPV-41_40C_R1rev.rwd**	**HLW-MFPV-41_40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	50-1000, Up Curve	50-1000, Up Curve	50-1000, Up Curve	50-1000, Up Curve
τ_O^B - the Bingham yield stress (Pa)	32.03	27.59	27.48	31.29
η_P - the plastic viscosity (cP)	37.94	41.4	28.56	35.25
R^2 – correlation coefficient	0.9797	0.9874	0.9767	0.9803
Herschel-Bulkley:	**HLW-MFPV-41_25C_R1rev.rwd**	**HLW-MFPV-41_25C_R2rev.rwd**	**HLW-MFPV-41_40C_R1rev.rwd**	**HLW-MFPV-41_40C_R2rev.rwd**
Shear rate range data fitted (sec^{-1})	0-1000, Up Curve	0-1000, Up Curve	0-1000, Up Curve	0-1000, Up Curve
τ_O^H - the Herschel-Bulkley yield stress (Pa)	8.688	12.82	8.236	10.74
k - the Herschel-Bulkely consistency coefficient (cP)	3920	1436	3680	3388
b - the Hershel-Bulkely power law exponent	0.3901	0.5235	0.363	0.3973
R^2 – correlation coefficient	0.9922	0.9948	0.9912	0.9916

Table I- 27 Physical Property Data Summary for Pretreated HLW Precipitated Hydroxide Simulant

Physical Property Data Summary for Sample	**Pretreated HLW Precipitated Hydroxide Waste at 22.26 wt % Total Solids**	
Physical Property	**Results**	Units
Sodium concentration of LAW waste or pretreated waste	NA	Molar
pH	12.48	pH
Solid phases present	yes	yes/no
Particle size distribution - Mean Vol. Distribution	57.68	µm
Particle size distribution - Mean No. Distribution	0.229	µm
Particle size distribution - Mean Area Distribution	1.947	µm
Density – Bulk slurry	1.20	g/mL
Density – settled solids	NA	g/mL
Density – centrifuged solids	NA	g/mL
Density - supernatant liquid	NM	g/mL
Vol. % settled solids after 72 hours	96.70	%
Vol. % centrifuged solids	NA	%
Wt % total dried solids	NA	%
Wt % centrifuged solids	NA	%
Wt % oven dried solids	22.26	%
Wt % undissolved solids	19.05	%
Wt % dissolved solids	3.21	%
Wt % Calcined solids	19.75	%

Table I- 28 Mixing Information for Pretreated HLW Precipitated Hydroxide Simulant

Sample Identification:	**Pretreated HLW Precipitated Hydroxide Waste at 22.26 wt % Total Solids**
Melter Feed ID:	Pretreated HLW Precipitated Hydroxide Waste at 22.26 wt % Total Solids
Processing Scale (lab/bench, pilot or full)	Lab/Bench
Activity/Property	**Data or Explanation**
Order of Chemical Additions	Prepared by precipitation/washing/evaporation/additions
Mixing Time	Many Hours
Impeller Speed	300-500 rpm
Impeller Diameter	Varies
Type of Impeller	Propeller
Tank Diameter	Used Standard 55 gallon drum
Number of Baffles	None
Size of Baffles	None
Location of impeller	off-center
Comments	None

Table I- 29 Rheological Model Fits for Pretreated HLW Precipitated Hydroxide at 22.26 Wt % Total Solids at 25 and 40 ° C

Model/model Parameter	Parameter Value	Parameter Value	Parameter Value	Parameter Value
Ostwald (or Power Law):	**PRE-TREATED QARD_25C_R1.rwd**	**PRE-TREATED QARD_25C_R2.rwd**	**PRE-TREATED QARD_40C_R1rev.rwd**	**PRE-TREATED QARD_40C_R2.rwd**
Shear rate range data fitted (sec^{-1})	0-1000	0-1000	0-1000	0-1000
m – the consistency coefficient (Pa-sec^n)	4.471	4.577	5.441	5.491
n – the power law exponent	0.2305	0.2267	0.2058	0.2061
R^2 – correlation coefficient	0.9524	0.9339	0.931	0.9254
Fitted Region	Up Flow Curve	Up Flow Curve	Up Flow Curve	Up Flow Curve
Bingham Plastic:	**PRE-TREATED QARD_25C_R1.rwd**	**PRE-TREATED QARD_25C_R2.rwd**	**PRE-TREATED QARD_40C_R1rev.rwd**	**PRE-TREATED QARD_40C_R2.rwd**
Shear rate range data fitted (sec^{-1})	50-1000	50-1000	50-1000	50-1000
τ_O^B - the Bingham yield stress (Pa)	12.02	12.03	13.78	13.65
η_P - the plastic viscosity (cP)	11.67	11.66	10.13	10.73
R^2 – correlation coefficient	0.9359	0.9508	0.9976	0.9966
Fitted Region	Up Flow Curve	Up Flow Curve	Up Flow Curve	Up Flow Curve
Herschel-Bulkley:	**PRE-TREATED QARD_25C_R1.rwd**	**PRE-TREATED QARD_25C_R2.rwd**	**PRE-TREATED QARD_40C_R1rev.rwd**	**PRE-TREATED QARD_40C_R2.rwd**
Shear rate range data fitted (sec^{-1})	0-1000	0-1000	0-1000	0-1000
τ_O^H - the Herschel-Bulkley yield stress (Pa)	7.597	9.396	4.328	9.051
k - the Herschel-Bulkely consistency coefficient (cP)	0.6271	0.2291	2.627	0.5705
b - the Hershel-Bulkely power law exponent	0.4595	0.5897	0.2819	0.468
R^2 – correlation coefficient	0.9663	0.9681	0.9332	0.9399
Fitted Region	Up Flow Curve	Up Flow Curve	Up Flow Curve	Up Flow Curve

Table I- 30 Physical Property Data Summary for HLW Precipitated Hydroxide Melter Feed

Physical Property Data Summary for Sample	**HLW Precipitated Hydroxide Melter Feed**	
Physical Property	**Results**	Units
Sodium concentration of LAW waste or pretreated waste	NA	Molar
Oxides Loading of HLW Melter Feed, grams oxide/Liter	NM	g/L
pH - 24 hr	9.34	pH
Solid phases present	yes	yes/no
Particle size distribution - Mean Vol. Distribution	NM	µm
Particle size distribution - Mean No. Distribution	NM	µm
Particle size distribution - Mean Area Distribution	NM	µm
Density – Bulk slurry	1.400	g/mL
Density – settled solids	NM	g/mL
Density – centrifuged solids	NM	g/mL
Density - supernatant liquid	NM	g/mL
Vol. % settled solids after 72 hours	96.20	%
Vol. % centrifuged solids	NM	%
Wt % total dried solids	NM	%
Wt % centrifuged solids	NM	%
Wt % oven dried solids	45.42	%
Wt % undissolved solids	37.75	%
Wt % dissolved solids	7.67	%

Table I- 31 Glass Former Chemicals Utilized in HLW Precipitated Hydroxide Melter Feed

Sample Identification:	**HLW Precipitated Hydroxide HLW Melter Feed**	**Volume**	**500**	**mL**
Source Chemical	Manufacturer	Oxide	Target Mass (g)	Actual Mass Added (g)
Kyanite	Kyanite Mining Corp	Al_2O_3	NA	NA
Boric Acid Technical	U.S. Borax	B_2O_3	NA	NA
10M Borax	U.S. Borax	Na_2O/B_2O_3	104.426	104.4
Soda Ash	Solvay Minerals	Na_2CO_3	23.758	23.8
Wollastonite	NYCO	CaO	NA	NA
Fe_2O_3 5001	Prince Mfg. Co.	Fe_2O_3	NA	NA
Li_2CO_3	Chemettal-Foote	Li_2O	34.194	34.2
Olivine	Unimin Corp	MgO	NA	NA
SCS-75	U.S. Silica	SiO_2	157.953	158
Rutile (Air floated)	Chemalloy Co.	TiO_2	NA	NA
Kadox	Zinc Corp Amer.	ZnO	7.262	7.3
Zircon	Amer. Miner, Inc.	ZrO_2	NA	NA
Sucrose	Amalgamated Sugar	Sugar	NA	NA

Table I- 32 Mixing Information for HLW Precipitated Hydroxide Melter Feed

Sample Identification:	**HLW Precipitated Hydroxide HLW Melter Feed**
Melter Feed ID:	QARD-MF-22
Processing Scale (lab/bench, pilot or full)	Lab/Bench
Activity/Property	**Data or Explanation**
Order of Chemical Additions	Glass formers mixed dry then added to Pretreated HLW Precipitated Hydroxide Waste
Mixing Time	60 minutes
Impeller Speed	300-500 rpm
Impeller Diameter	50 mm
Type of Impeller	Rushton
Tank Diameter	85 mm
Number of Baffles	0
Size of Baffles	NA
Location of impeller	off-center
Comments	None

Table I- 33 Rheological Model Fits for HLW Precipitated Hydroxide Melter Feed with 22.26 Wt % Total HLW Solids at 25 and 40 ° C

Model/model Parameter	Parameter Value	Parameter Value	Parameter Value	Parameter Value
Newtonian	**QARDMF-22_25C_R1rev.rwd**	**QARDMF-22_25C_R2rev.rwd**	**QARDMF-22_40C_R1rev.rwd**	**QARDMF-22_40C_R2.rwd**
Shear rate range data fitted (sec^{-1})	NA	NA	NA	NA
μ – viscosity (mPa-sec)	NA	NA	NA	NA
R^2 – correlation coefficient	NA	NA	NA	NA
Ostwald (or Power Law):	**QARDMF-22_25C_R1rev.rwd**	**QARDMF-22_25C_R2rev.rwd**	**QARDMF-22_40C_R1rev.rwd**	**QARDMF-22_40C_R2.rwd**
Shear rate range data fitted (sec^{-1})	0-1000, Up Curve	0-1000, Up Curve	0-1000, Up Curve	0-1000, Up Curve
m – the consistency coefficient (Pa-sec^n)	3.987	3.987	4.951	3.755
n – the power law exponent	0.3486	0.3487	0.2729	0.3188
R^2 – correlation coefficient	0.9686	0.9718	0.918	0.9113
Bingham Plastic:	**QARDMF-22_25C_R1rev.rwd**	**QARDMF-22_25C_R2rev.rwd**	**QARDMF-22_40C_R1rev.rwd**	**QARDMF-22_40C_R2.rwd**
Shear rate range data fitted (sec^{-1})	50-1000, Up Curve	50-1000, Up Curve	50-1000, Up Curve	50-1000, Up Curve
τ_O^B - the Bingham yield stress (Pa)	18.88	18.9	16.28	15.13
η_P - the plastic viscosity (cP)	28.47	28.48	18.9	21.52
R^2 – correlation coefficient	0.993	0.992	0.994	0.9956
Herschel-Bulkley:	**QARDMF-22_25C_R1rev.rwd**	**QARDMF-22_25C_R2rev.rwd**	**QARDMF-22_40C_R1rev.rwd**	**QARDMF-22_40C_R2.rwd**
Shear rate range data fitted (sec^{-1})	0-1000, Up Curve	0-1000, Up Curve	0-1000, Up Curve	0-1000, Up Curve
τ_O^H - the Herschel-Bulkley yield stress (Pa)	12.18	11.78	14.34	14.53
k - the Herschel-Bulkely consistency coefficient (cP)	452.2	507	79.65	28.06
b - the Hershel-Bulkely power law exponent	0.624	0.609	0.8027	0.9658
R^2 – correlation coefficient	0.9904	0.9904	0.9696	0.9708