This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U.S. Department of Energy.

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Mixing Envelope D Sludge with LAW Intermediate Products with and without Glass Formers

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Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

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WSRC-TR-2001-00203, Rev. 0
SRT-RPP-2001-00051, Rev. 0
TRPT-24590-01-00001

KEYWORDS:
Rheology
Hanford River Protection Project
Simulants
Hanford Waste Tanks
RETENTION - Permanent

Mixing Envelope D Sludge with LAW Intermediate Products with and without Glass Formers

SAVANNAH RIVER TECHNOLOGY CENTER

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Publication Date: September 2001

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Prepared for the U.S. Department of Energy under Contract No. DE-AC09-96SR18500

DOCUMENT: **WSRC-TR-2001-00203, Rev. 0 (SRT-RPP-2001-00051, Rev. 0) TRPT-24590-01-00001**

TITLE: Mixing Envelope D Sludge with LAW Intermediate Products with and without Glass Formers

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Executive Summary

The Department of Energy (DOE) Office of River Protection is in the process of designing a waste treatment system to process the Hanford Reservation High Level Waste (HLW). Envelope D sludge slurries will be blended with the concentrated Cs/Tc eluates, and the Sr/TRU intermediates separated from Envelope A, B, and C feeds. The resulting blend (Envelope D + Eluates + Sr/TRU precipitates) will be transferred to the HLW vitrification facility where glass formers will be added. This report documents the testing using waste simulants to obtain physical property and chemical composition data (e.g. rheology, elemental) on the expected HLW slurries that are generated during the blending of simulated sludges, eluates and Sr/TRU precipitates. Additionally, the resulting simulated HLW Melter slurries were also characterized for chemical and physical properties.

This study produced two washed simulated sludges (representing tanks 241-AZ-101 and 241-AZ-102 sludge), a Sr/TRU washed precipitate produced from tank 241-AN-107 simulant, and a concentrated blended eluate simulant based upon eluates from processing 241-AZ-102 supernate. The physical properties and rheological properties of these individual products and their planned blends with and without glass formers were measured. Based upon these results the following conclusions were found.

- A comparison of the apparent viscosities of the simulated AZ-102 sludge to the actual AZ-102 waste at a shear rate of 200 seconds^{-1} indicates that the simulant's rheology behaves similarly to the real waste.
- Shearing reduces the particle size and modifies the particle size distribution for the simulated sludges and the Sr/TRU precipitate.
- Shearing the Sr/TRU precipitate reduced the yield stress of the precipitate.
- The rheological properties of the AZ-101 and AZ-102 simulated sludges and the Sr/TRU precipitate are distinctly nonnewtonian and can be represented by a Bingham flow model.
- As expected, the blended eluate simulant is a Newtonian fluid.
- The yield stress as determined by the vane method appears to agree well with the maximum observed using the concentric cylinder and cone and plate methods.
- The yield stress determined by using the Bingham model is a strong function of the insoluble solids loading for the AZ-101, AZ-102 simulated sludges and for the simulated AN-107 Sr/TRU precipitate which is consistent with results from other HLW slurries.
- The plastic viscosity or consistency of the simulated sludges based upon a Bingham flow model was relatively insensitive to the change in insoluble solids until the insoluble solids loading was above 18 to 19 weight percent.

Blending tests using actual fresh Hanford Envelope D waste should be conducted to determine if the yield stresses observed in this study are typical or bounding on the process. The use of caustic glass formers such as LiOH and NaOH can benefit the rheology of melter feed by reducing the yield stress of the feed. This study did not evaluate the effect of glass former particle size on rheology. Glass former particle size is known to have strong impact on rheology. Future melter feed rheology tests that vary the particle size of the glass formers should be conducted.

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Introduction

The Department of Energy (DOE) Office of River Protection is in the process of designing a waste treatment system to process the Hanford Site High Level Waste (HLW). Westinghouse Savannah River Company - Savannah River Technology Center (WSRC-SRTC) is assisting in performing process testing and demonstrations for this effort. The design of the River Protection Project Waste Treatment Plant (RPP-WTP) Pretreatment facilities includes storage capacity for the Envelope D washed solids and the concentrated Cs/Tc eluates from LAW pretreatment. Envelope D sludge slurries will be blended with the concentrated Cs/Tc eluates from processing Envelope A, B and C feeds and the Sr/TRU intermediates separated from C feeds. The resulting blend (Envelope D + Eluates + Sr/TRU precipitates) will be transferred to the HLW vitrification facility where glass formers will be added. The resulting HLW melter feed will be transferred to a joule-heated melter and vitrified into an acceptable waste form[1]. During initial startup of the RPP pretreatment and HLW vitrification facilities, the RPP-WTP pretreatment facilities will only produce washed Envelope D sludge slurries and Cs/Tc eluate; therefore it is anticipated that the feed to the HLW vitrification facilities will be comprised of Envelope D sludge and concentrated Cs/Tc eluate[2].

RPP R&T subcontractors (WSRC-SRTC and Battelle PNNL) have conducted R&T testing activities that have characterized the expected concentration of simulated and actual washed Envelope D sludge slurries and the Sr/TRU precipitates[3,4,5]. WSRC-SRTC has also conducted modeling of the Cs and Tc eluate evaporators and the resulting blend of concentrated Cs and Tc eluates. Battelle PNNL and WSRC-SRTC are in the process of conducting tests with actual Envelope D (AZ-102) + Sr/TRU precipitates (AN-107) and eluate samples.

WSRC-SRTC has been requested by the RPP-WTP R&T group to conduct laboratory scale testing of the expected blends of simulated Envelope D sludges (AZ-101 and AZ-102) + Cs/Tc Eluates (AZ-102) + Sr/TRU precipitates (AN-107) and Envelope D sludge (AZ-101 and AZ-102) + Cs/Tc Eluates (AZ-102)[6] as shown in Figure 1. Additionally, RPP R&T has requested WSRC-SRTC to characterize the resulting Melter Feeds (Envelope D sludges + LAW Intermediates + Eluates + Glass Formers). This report documents the testing using waste simulants to obtain physical property and chemical composition data (e.g. rheology, elementals) on the expected HLW slurries that are generated during the blending of simulated sludges,

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1 Page, M. et. al., Basis of Design, DB-W375-EG00001, Rev. 1, BNFL, Inc. River Protection Project Richland, WA, June 18, 1999.

2 Johnson, M. E. to Page, M., Interim Storage of Pretreated LAW Solution in the LAW Feed Receipt Vessels (System PT-110), CCN#: 011389, BNFL Inc. River Protection Project, Richland WA, February 17, 2000.

3 Hallen, R. T. et. al., Combined Entrained Solids and Sr/TRU Removal from Diluted AN107 Diluted Feed, BNFL-RPT-027 Rev. 0 Draft, Battelle Memorial Laboratories Richland WA, February 2000

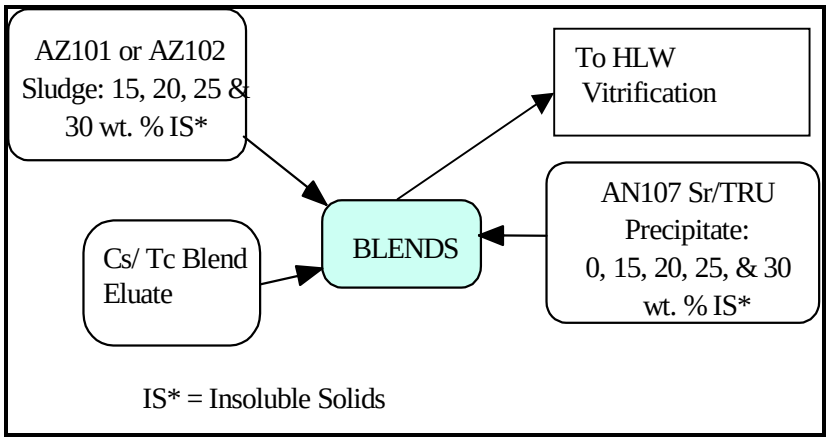
4 Duignan, M. R., Final Report: Pilot-scale Cross-flow Ultrafiltration Test Using Hanford Site Tank 241-An107 Waste Simulant – Envelope C + Entrained Solids + Strontium-Transuranic Precipitation, BNF-003-98-0226, Westinghouse Savannah River Company, Savannah River Site, Aiken SC, March 24, 2000.

5 Morrey, E. V. et. al., Comparison of Simulants to Actual Neutralized Current Acid Waste: Process and Product Testing of Three NCAW Core Samples from Tanks 101-AZ and 102-AZ, Pacific Northwest National Laboratory, Richland WA October 1996.

6 Work For Others Agreement No. WFO-98-003 Between Westinghouse Savannah River Company, Inc. Operating under Prime Contract No. DE-AC09-96SR18500 for the U. S. Department of Energy and BNFL, Inc.

eluates and precipitates as shown in Figure 1. Additionally, the simulated HLW slurries were also characterized after glass formers had been added.

Figure 1 Flow Chart of Sludge, Eluate and Sr/TRU precipitate Blends



The objectives of this task are to provide information on the behavior (physical and chemical composition) of HLW slurries, following blending of the washed Envelope D slurries with Cs/Tc eluates and Sr/TRU precipitates and on the expected Melter Feeds derived from these blends. The research described in this report was conducted under task plan WSRC-RP-2000-00731.[7] The RPP flow sheet for filtration of Envelope D and the Sr/TRU precipitates assumes these slurries can be concentrated to approximately 20 weight % insoluble solids. However, to properly bound the design and operation of the filters, downstream piping systems, storage vessels and vitrification mixing systems, testing with insoluble solids contents ranging from 15 to 30 weight % was to be performed by WSRC-SRTC[8]. The composition of the blended slurries used in this study was based upon glass formulations provided by VSL[9].

Initial modeling results from WSRC-SRTC have indicated that the blended Cs/Tc eluate is slightly alkaline[10]. Washed Envelope D sludge and Sr/TRU precipitate slurries are also alkaline. Since HLW melter feed slurries processed by other DOE vitrification facilities have traditionally been slightly acidic in nature, WSRC-SRTC will test various Envelope D/Eluate/Sr/TRU slurries with nitric acid and determine the effects of pH on the physical and chemical composition. Past research conducted by DOE subcontractors indicates that HLW slurries that have been acidified are less viscous and have lower yield stresses[11,12].

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[7] Hansen, E. K., et. al., Task Technical and Quality Assurance Plan for Mixing Envelope D Sludge with LAW Intermediate Products (Sr/TRU Precipitate and Cs/TC Eluate) with and without Glass Formers, WSRC-RP-2000-00731, SRT-RPP-2000-00002, Westinghouse Savannah River Company, Aiken SC, October 3, 2000.

[8] Johnson, M. E. to Calloway, T. B., Re: Sludge/Sr-TRU/Eluate Mixing, Email, BNFL, Inc. River Protection Project, Richland WA, 4/13/00

[9] VSL glass formulations are listed in Appendix B, Tables B – 41 and B – 42.

[10] Choi, A. S. to Johnson, Estimation of Physical Properties of Tank 241-AN107 Cesium and Technetium Eluate Concentrate Blend, Email, Westinghouse Savannah River Company, Aiken, SC, 2/22/00

[11] Fowler, J. R., Rheology of Synthetic Feed for the Slurry-Fed Melter, DPST-91-491, E. I. DuPont de Nemours & Co., Savannah River Laboratory, Aiken SC, June 29, 1981

[12] Smith, P. A., The Effects of Formic Acid and Nitric Acid on Simulated Hanford Neutralized Current Acid Waste Rheology, PNNL-12052, Pacific Northwest Laboratory, Richland WA 99352, Unpublished copy Forwarded to WSRC from BNFL, 2/22/98

The RPP vitrification flow sheet does not currently acidify the Melter Feed (waste + glass formers) slurries. Therefore, this task will only test Melter Feeds that have not been acidified. If significant process/costs benefits can be achieved by acidifying the slurry during Pretreatment, RPP may choose to test Melter Feed slurries that have been acidified.

Experimental

The original task[7] specified testing the AZ101 and AZ102 sludge simulants from a insoluble solids content of 10 to 30 weight percent (wt. %), in 5 wt. % increments. The sludge simulants were blended with the blended AZ-102 Cs/Tc eluate simulant and an AN-107 Sr/TRU precipitate simulant followed by tests with and without glass formers as shown in Table 1 and Table 2 respectively. Table 1 also provides waste streams that were to be acidified with nitric acid. Table 2 also includes 30 day extended mixing tests to determine if the glass formers will impact the rheological properties of the slurry over time. The blended combination of sludge with eluate and Sr/TRU precipitate and extended mixing tests were agreed upon in the Task Plan[7]. These blending ratios may not necessarily be the actual ratios of real sludge to that of LAW waste streams in the pretreatment plant. Additionally, the glass former chemicals used in these experiments were based on these pre-blending ratios, hence the ratio and type of glass formers may not necessarily be the same used in the vitrification plant.

The targeted wt. % insoluble solids were obtained by centrifuging (at 4333 g's) the base sludges and then decanting a calculated amount of supernate. During the processing of the AZ101 and AZ102 sludge simulants to their targeted wt. % insoluble concentrations, it was determined that the AZ101 sludge simulant could only be concentrated to 21 wt. % insoluble solids and the AZ102 sludge simulant to 27 wt. % insoluble solids, via centrifuging. These limiting sludges were based on completely decanting all the supernate upon centrifuging a sample of the base sludge, hence no standing liquid was remaining. The limiting sludges were then blended at a very high shear rate and allowed to sit to determine if any residual liquid would form, none did. The only other method to increase the wt. % insoluble solids is via drying, but this was not attempted, since this would only make the sludge thicker. The 25 wt. % insoluble solids AZ102 sludge simulant was also determined to be unrealistic for processing, when visually comparing it to the AZ101 sludge simulant at 20 wt. % insoluble solids. Hence, the original scope was drastically reduced, by eliminating all blended combinations above 20 wt. % insoluble solids for both AZ101 and AZ102 sludge simulant. Two lower wt. % insoluble solids concentrations were added and are shown in the Test Number column as ADD items. These ADD items were not part of the original task plan, but were added at the discretion of the researchers. Table 1 and Table 2 have been high-lighted to reflect these changes by yellow boxing items removed from the scope of work and green boxing items that were added to the scope of work. All items completed in Table 1 and Table 2 are bolded.

Table 1 Blend Matrix for Sludge and LAW Intermediate Products without Glass Formers

Test No.	Envelope D Simulant		Sr/TRU Precipitate Slurry Addition AN107 Insoluble Solids Concentration (%)*	pH Adjustment (After Initial Mixture Characterization- with HNO_3)
	Simulant	Insoluble Solids Concentration (%)		
1.1	AZ101	30	30	Yes
1.2	AZ101	25	25	Yes
1.3	**AZ101**	**20**	**20**	Yes
1.4	**AZ101**	**15**	**15**	**Yes**
1.5	**AZ101**	**15**	**25**	**Yes**
1.6	AZ101	25	15	Yes
1.7	AZ101	30	0	Yes
1.8	AZ101	25	0	Yes
1.9	AZ101	20	0	Yes
1.10	AZ101	15	0	No
ADD-1	**AZ101**	**7.5**	**15**	**No**
ADD-2	**AZ101**	**10**	**15**	**No**
2.1	AZ102	30	30	Yes
2.2	AZ102	25	25	Yes
2.3	**AZ102**	**20**	**20**	**Yes**
2.4	**AZ102**	**15**	**15**	**No**
2.5	**AZ102**	**15**	**25**	**Yes**
2.6	AZ102	25	15	Yes
2.7	AZ102	30	0	Yes
2.8	AZ102	25	0	Yes
2.9	**AZ102**	**20**	**0**	Yes
2.10	AZ102	15	0	No
ADD-3	**AZ102**	**10**	**15**	**No**
ADD-4	**AZ102**	**12.5**	**15**	**No**

***Eluate is added to All Blends**

Items highlighted in Yellow were not tested

Items highlighted in Green were added for additional data, without titration

Table 2 Blend Matrix for Sludge with LAW Intermediate Products and Glass Formers

Test No.	Envelope D Simulant		Sr/TRU Precipitate Slurry Addition AN107 Insoluble Solids Concentration (%)*	30 Day Melter Feed Stability Test
	Simulant	Insoluble Solids Concentration (%)		
1.1	AZ101	30	30	Yes
1.2	AZ101	25	25	No
1.3	**AZ101**	**20**	**20**	**No**
1.4	**AZ101**	**15**	**15**	**Yes**
1.5	**AZ101**	**15**	**25**	**No**
1.6	AZ101	25	15	No
1.7	AZ101	30	0	No
1.8	AZ101	25	0	No
1.9	AZ101	20	0	No
1.10	AZ101	15	0	No
ADD-1	**AZ101**	**15**	**0**	**No**
ADD-2	**AZ101**	**15**	**0**	**No**
2.1	AZ102	30	30	No
2.2	AZ102	25	25	No
2.3	AZ102	20	20	No
2.4	**AZ102**	**15**	**15**	**No**
2.5	**AZ102**	**15**	**25**	**No**
2.6	AZ102	25	15	No
2.7	AZ102	30	0	No
2.8	AZ102	25	0	No
2.9	**AZ102**	**20**	**0**	**No**
2.10	AZ102	15	0	No
ADD-3	**AZ102**	**10**	**15**	**No**
ADD-4	**AZ102**	**12.5**	**15**	**No**

*** Eluate is Added to all Blend**
Items highlighted in Yellow were not tested
Items highlighted in Green were added for additional data, without titration

The basis, formulation and production of the AZ-101 and AZ-102 simulated sludges, the Sr/TRU precipitate simulant, and the blended AZ-102 Cs/TC eluate simulant are described in Appendix B. The basis for waste stream blending and for the glass former additions is also described in Appendix B.

Physical and Rheological Measurement Methods

Solids, density, pH, particle size & Titration

The weight percent solids were determined by oven drying the samples between 105-115°C overnight or using a CEM microwave moisture/solids analyzer. The homogenous sample (slurry or liquid) is then placed on a microwave pad or in an oven crucible and weighed, the mass of the sample used is considered as the total mass (m_{tt}). The sample is then placed into the

oven/microwave to drive off all the water and the resulting remaining mass is the total solids (m_{ts}) in the sample. The wt. % total solids (TS) was determined using equation [1].

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

A sample of the slurry is centrifuged (at 42500 m/s^2) 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 microwave pad or in an oven crucible and weighed, the mass of sample used is considered as the total mass of the supernate (m_{st}). The sample is then placed into the oven/microwave 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.

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

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.

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

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

Weight percent calcine solids is obtained by calcining a known mass of sample at 1223 K for two hours, cooling in a dessicator, and obtaining the calcined weight. The calcine factor is calculated by dividing the calcine weight percent solids by the weight percent total solids.

Density measurements were made using a specific gravity cup and cap unit (pycnometer). The cup/cap was first tared using a calibrated weigh scale. The sample was placed into the cup and then the cap was used to press out excess sample and the excess sample removed. The mass of the cup/sample/cap was then measured on the calibrated weigh scale. The density of the slurry or eluate was then determined by dividing this mass by the known volume of the cup/cap unit (8.321 cm^3). The volume of the cup was verified using deionized water. All density measurements were made at normal laboratory temperatures, 293-295 K, unless otherwise specified.

Measurements of pH were made using a Fisher Scientific Accumet® model 15 pH meter. The instrument was calibrated using pH 4 and pH 10 buffer solutions, and then checked against a pH 7 buffer. Indicated instrument results were within 0.1 pH unit for the pH 7 buffer.

Particle size distributions were measured using a MicroTrac-SRA150 particle analyzer. Light from a laser passes through a sample cell and produces a diffraction pattern, in which the intensity is measured. A proprietary algorithm in the MicroTrac software analyzes the measured intensity profile. The reported results assume that the particles are spherical in nature. The analyzer is calibrated every 6 months by the vendor.

Rheology

Slurry rheology was characterized using both Haake RV20 (with an M5 measuring head) and Haake RS150 rheometers. Both rheometers are Searle type measuring systems, where both the speed and torque are measured at the rotating shaft.

The RV20 rheometer is a controlled rate (where the shear rate is applied and the resulting shear stress is measured) rheometer. A concentric cylindrical geometry was used to measure the flow properties using the RV20. The MV1 stainless steel cylindrical rotor (40.08-mm outside diameter, 60-mm length), with a recessed bottom to reduce end effects, was the inner cylinder. The MV1 rotor was then attached to the M5 measuring head driver motor. A slurry sample was placed into a cylindrical stainless cup (42-mm inside diameter) and loaded into the heating jacket. The heating jacket controlled the temperature of the rotor, sample and cup. A heating/cooling temperature bath was attached to the heating jacket to provide the heat sink. All measurements were taken at 298 K. All rheology measurements were taken using a linear shear rate ramp from 0 to 350 sec^{-1} in five minutes, holding the shear rate at 350 sec^{-1} for two minutes, and then linearly decreasing the shear rate from 350 to 0 sec^{-1} in five minutes.

The RS150 rheometer can be controlled using either the controlled rate or controlled stress modes. In this study, only the controlled rate mode was used. Cone and plate geometry, listed in Table 3 was used to obtain all the flow curves. Flow curves were obtained using a 60-mm stainless steel measuring plate that was initially attached to the plate-heating jacket. The 60-mm cone with a vapor trap was attached to the RS150. The RS150, controlled via software, initially finds the zero point (distance between the cone and measuring plate is zero) and then the sample is loaded onto the measuring plate. A gap setting (distance between the cone and measuring plate) as determined by the vendor and listed in Table 3, was obtained using the RS150 software, given the specified cone geometry. Excess sample was trimmed from the exposed edge to minimize end effects. Water (3 to 5 degrees Kelvin above the measured temperature) was added to the vapor trap reservoir to try to maintain vapor space humidity, since these slurries had a tendency to evaporate during the measurement around the exposed edge. A heating/cooling temperature bath was attached to the plate-heating jacket to provide the heat sink. All measurements were taken at 298 K and 323 K for the sludge/slurry and from 293 K to 353 K in 10 degree increments for the eluate.

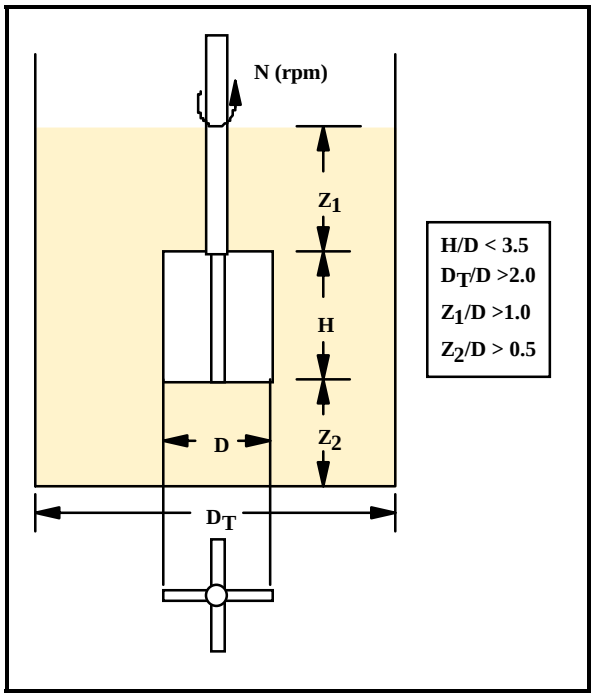
Table 3 - RS150 Measurement Job Programs

Material	Geometry	Linear shear rate ramp (up)	Holding shear rate	Linear shear rate ramp (down)
		range & time	range & time	range & time
Sludge – Slurry	Cone-Plate 2^o 60-mm cone Gap = 0.107-mm	$0 \leq \dot{\gamma} \leq 1000$ sec^{-1} 5 min	$\dot{\gamma} = 1000$ sec^{-1} 2 min	$1000 \geq \dot{\gamma} \geq 0$ sec^{-1} 5 min
Sludge – Slurry	Cone-Plate 2^o 60-mm cone Gap = 0.107-mm	$0 \leq \dot{\gamma} \leq 2000$ sec^{-1} 5 min	$\dot{\gamma} = 2000$ sec^{-1} 2 min	$2000 \geq \dot{\gamma} \geq 0$ sec^{-1} 5 min
Sludge	Vane FL-22, D = 22-mm, H = 16-mm	Varied rotational speed from 0.001 to 0.04 radian/sec. Time was varied to obtain the maximum stress.		
Eluate	Cone-Pate 0.5^o 60-mm cone, gap = 0.029-mm	$0 \leq \dot{\gamma} \leq 2000$ sec^{-1} 20 S/S readings	$\dot{\gamma} = 2000$ sec^{-1} 10 sec	$2000 \geq \dot{\gamma} \geq 0$ sec^{-1} 20 S/S readings

The yield stress of one of the sludge samples was analyzed using vane FL-22 geometry. The dimensions of the vane are provided in Table 3. The vane was placed into a cup with an inside diameter of 43.4-mm and the temperature of the sample was maintained at 298 K using the heating/cooling temperature bath. The location of the vane and the amount of sample used was based on work performed by Dzuy and Boger[13]. The location of the vane and minimal physical dimensions as recommended by Dzuy and Boger are shown in Figure 2. All the dimensions were met other than D_T/D, which in this case was 1.97.

[13] N. Q. Dzuy and D. V. Boger, **Direct Yield Stress Measurement with the Vane Method**, Journal of Rheology, Volume 29, 335-347, 1985

Figure 2 Vane Geometry Measurement Dimensions



Both the RV20 and RS150 rheometers were functionally checked using a 102.5 mPa-sec silicone oil standard at 298 K on each day that the instruments were used for measurement. Results for the standards were always within ±5%. The RS150 measuring plate was checked on a weekly basis to verify the measuring surface was level.

The resulting uncorrected flow curves obtained from both the cylindrical and cone/plate geometry's have not been corrected for slip, viscous/thermal effects, or end effects. No secondary flow problems, such as Taylor vortices were noted in any of these measurements. Since no corrections were performed, the flow curves from the cylindrical and cone/plate geometry's may not necessarily produce the same results. A standard method of correcting cone/plate results for slip was not available.

The uncorrected flow curves for the sludges and slurries were modeled using the Bingham Plastic rheological model, equation [5]. The eluate was modeled using Newton's equation [6].

$$\tau = \tau_o + \eta\dot{\gamma} \quad [5]$$

$$\tau = \mu\dot{\gamma} \quad [6]$$

Where: τ_o = Bingham plastic yield stress (Pa)

τ = Shear stress (Pa)

$\dot{\gamma}$ = Shear rate (sec^{-1})

η = Bingham Plastic consistency or Bingham plastic viscosity (mPa-sec)

μ = Newtonian viscosity (mPa-sec)

The flow curves obtained from the RV20 were fitted between 100 to 1000 sec^{-1} using equation [5]. For the RS150, the flow curves for the sludges and slurries were fitted between 100 to 1000 sec^{-1}, unless otherwise noted and specified using equation [5]. For the eluate, the flow curves were fitted between 0 to 2000 sec^{-1} using equation [5].

Marek[14] modeled the two Bingham fluid parameters, as a function of wt. % insoluble solids (IS) and wt % total solids (TS) content of the slurry. The original theoretical model described the "apparent viscosity" of a Newtonian slurry[15] as a function of the volume fraction of insoluble solids. This equation[15] has been modified and used by Marek to model both the Bingham Plastic yield stress and consistency as a function of wt. % IS concentration of the slurry and are shown as equations [6] and [7]. In this report, the dependence of yield stress and consistency on wt. % TS concentration will also be determined using equations [6] and [7]. The unknown parameters in equations [6] and [7] were obtained using Table Curve 2D software 4.01.

$$\tau_o = A_1 \frac{\exp^{b_1 * C}}{(1 - C / C_{\max,1})} \qquad [6]$$

$$\eta = A_2 \frac{\exp^{b_2 * C}}{(1 - C / C_{\max,2})} \qquad [7]$$

Where: τ_o = yield stress from the Bingham Plastic model (Pa)
η = consistency (plastic viscosity) from the Bingham Plastic model (mPa-sec)
C = insoluble solids concentration (wt. %)
A_i = modeled parameter (dynes/cm^2or mPa-sec)
$C_{\max,i}$ = modeled parameters corresponding to maximum wt. % insoluble solids
b_i = modeled parameters (wt. %)$^{-1}$

The yield stress, using the vane method was determined using equation [8]. Equation [8] assumes that the stress is uniformly distributed over both surface ends and at the cylindrical wall of the vane[13, 16, 17]. The Haake RS150 software uses this equation and the results are plotted with stress versus time. The maximum measured stress is considered as the yield stress (called the dynamic yield stress[16]).

$$\tau_o = \frac{T_m}{K}, \quad K = \frac{\pi D^3}{2}\left(\frac{H}{D} + \frac{1}{3}\right) \qquad [8]$$

Where: τ_o = yield stress (Pa)
D = diameter of the vane (m)
H = height of the vane (m)
T_m = Torque (N-m).

[14] J. C. Marek, **Rheology Measurements of Simulated Slurry Mix Evaporator Material (U)**, WSRC-TR-97-00343, Rev. 0, October 17, 1997
[15] C. A. Shook and M. C. Roco, **Slurry Flow – Principles and Practice**, Butterworth-Heinemann, pp. 61-64, 1991
[16] P. V. Liddell and D. V. Boger, **Yield Stress Measurements with the vane**, Journal of Non-Newtonian Fluid Mechanics, Vol. 63, pp. 235 – 261, 1996
[17] N. J. Alderman, G. H. and J. D. Sherwood, **Vane rheometry of bentonite gels**, Journal of Non-Newtonian Fluid Mechanics, pp. 291-310, 1991

During the yield stress measurements using the vane, the measured rotational speed of the rotor behaves as described by Liddell[16].

> "It should be pointed out that, although the vane is considered to be in a rate controlled mode, the actual relative motion between the vane and the material varies throughout the measurement. During the elastic deformation the vane is essentially stationary relative to the suspension, so that the rate of stress development can be directly calculated as the product of the applied rotation speed (rad/sec), the measuring system stiffness (Nm/rad) and the inverse of the vane constant (m^3). During viscoelastic flow, the vane rotates slightly relative to the suspension, causing a reduction in the rate of stress development. The rate of stress development during viscoelastic flow is dependent on the material properties as well as the applied rotational speed. When the yield stress is reached the rate of stress development is zero, which corresponds to relative motion between the vane and the material at a rate equal to the applied rotational speed."

The effect of temperature on viscosity was modeled using Arrhenius[18] equation shown as equation [9].

$$\mu = A_{Arr} \cdot e^{(B_{Arr}/T)} \qquad [9]$$

Where: μ = Newtonian viscosity (mPa-sec)
A_{Arr} = Arrhenius Fitting Parameter (mPa-sec)
B_{Arr} = Arrhenius Fitting Parameter (Kelvin)
T = Temperature (Kelvin)

[18] R. Darby, **Chemical Engineering Fluid Mechanics**, Marcel Dekker, Inc., pg. 63, 1996

RESULTS

AZ-101 Simulant

Table 4 contains the density, pH and weight percent solids analyses. Changing the weight % insoluble solids (IS) concentration did not impact the pH of the slurry, since the composition of the supernate did not change. The density versus weight % IS and TS (via the oven results) were fitted to a 2nd order polynomial and shown as equations [10] and [11] respectively. The maximum weight % IS concentration obtained using the centrifuge was 20.84 weight %, as measured using the microwave. The low weight % IS concentration from centrifuging could be due to the repulsive forces of the flocculated particles being very high, thus trapping the supernate in the solids structure. The solids analyses performed using the microwave method yielded higher total and insoluble results as compared to the oven method. The difference between the methods is assumed to be due to the waters of hydration and the apparent inability of the microwave to remove waters of hydration. Both results are presented so that comparisons can be made between the same method results.

$$\rho_{AZ101}(wt\%_{IS}) = 0.2339\cdot(wt\%_{IS})^2 + 3.5654\cdot(wt\%_{IS}) + 1029.9, \quad \left\{\frac{kg}{m^3}\right\}$$
$$6.62\% \le \cdot wt\%_{IS} \le 18.55\%, \quad R^2 = 0.9985 \qquad [10]$$

$$\rho_{AZ101}(wt\%_{TS}) = 0.2494\cdot(wt\%_{TS})^2 + 2.661\cdot(wt\%_{TS}) + 1023.5, \quad \left\{\frac{kg}{m^3}\right\}$$
$$8.47\% \le \cdot wt\%_{TS} \le 20.00\%, \quad R^2 = 0.9989 \qquad [11]$$

Table 4 Physical and Chemical Data for AZ-101 Simulant

Target wt % I.S.	Density (kg/m^3)	pH	Wt. % Solids Analysis Oven / Microwave		
			Total	Soluble	Insoluble
7.5	1065	9.93	8.47 / 8.97	1.85 / 1.50	6.62 / 7.47
10.0	1080	10.06	10.91 / 11.56	1.71 / 1.46	9.18 / 10.10
12.5	--	--	13.81 / --	1.66 / --	12.15 / --
15.0	1125	10.11	15.39 / 16.26	1.63 / 1.38	13.78 / 14.88
15.0 2nd batch	--	--	15.32 / --	1.51 / --	13.81 / --
16.0	--	--	17.03 / --	1.57 / --	15.46 / --
17	--	--	18.07 / --	1.59 / --	16.48 / --
18	--	--	19.22 / --	1.55 / --	17.66 / --
19	--	--	20.25 / --	1.58 / --	18.67 / --
20.0	1176	10.10	20.00 /20.77	1.45 / 1.31	18.55 / 19.47
Maximum value via centrifuging			-- / 22.16	-- / 1.31	-- / 20.84

All of the flow curves, unless other wise specified, were obtained using the cone and plate geometry on the Haake RS150 rheometer. Inspection of these curves typically show that as the weight % IS increases, the slurry becomes more thixotropic. Flow curve measurements could not be obtained for the 323 K temperature runs for weight % IS above 15 weight % target, using the cone to plate geometry due to sample drying. A large peak in the measured stress was observed for all the flow curves at the beginning of the initial up curve measurement. The peak may show that these slurries have a well-defined structure that breaks down after shearing. An alternative explanation for the peak is that the peak is due to slip occurring between the sensor and the sample. Measurements were not made during this study to allow for correction of the data for slip. If the peak value is due to a well-defined structure, then it could potentially be used for engineering purposes, such as startup torque, slope for natural draining, etc.

Table 5 contains the Bingham Plastic parameters fitted to the rheological data on the return or down flow curves shown in FIGURE A - 1, FIGURE A - 2 and FIGURE A - 3 in Appendix A. Only the return curves (down flow curves) were fitted, due to the reasons described in the previous paragraph. Also the up flow curves, especially for the higher insoluble solids content, did not provide a realistic fit to any rheological model. The results in Table 5 show that the yield stress is most impacted by the change in weight % IS. For a given weight % IS, the yield stress is greater and the consistency is smaller when comparing the 298 K data to the 323 K data. The yield stress as a function of weight % insoluble solids are shown in Figure 3 and Figure 4 for the 298 K and 323 K measurements respectively.

Figure 3 Simulated AZ-101, Yield Stress versus Wt. % Insoluble Solids, 298 K

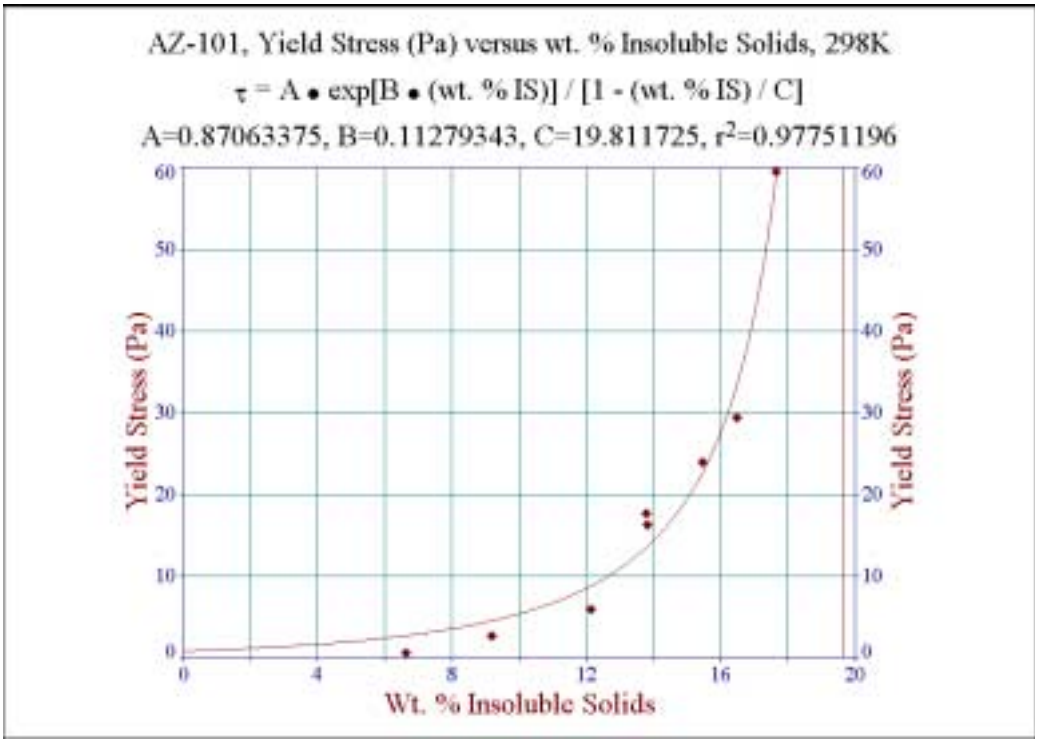
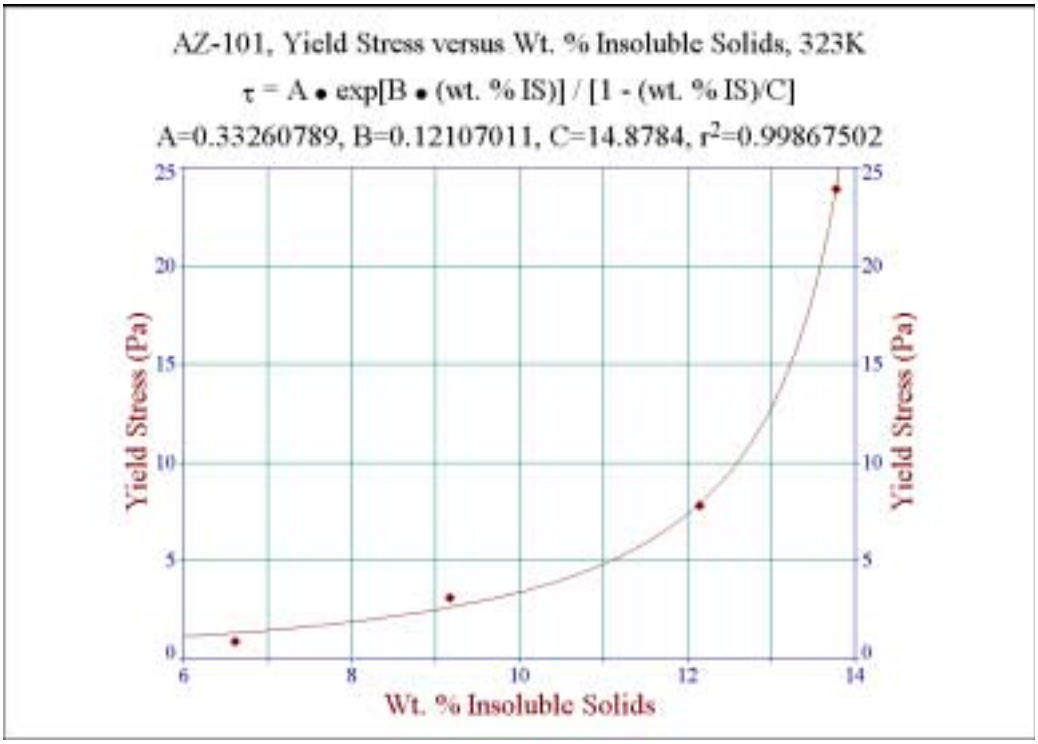


Figure 4 Simulated AZ-101, Yield Stress versus Wt. % Insoluble Solids, 323 K



The curves in Figure 3 and Figure 4 were fitted using equation [6] and are shown as equations [12] and [13]. Comparing the maximum weight % IS parameter (C_{max}), the 323 K value is smaller, which is most likely due to the limited number of available data points to which the curve was fitted. The C_{max} for the 298 K data is of the same magnitude as the maximum weight % IS obtained using the centrifuge shown in Table 4, after adjusting the measured microwave result to an oven-based value. The consistency versus wt. % I.S. curves were not generated, because the consistency seemed to be fairly insensitive to the change in wt. % I.S., until it reached a much higher wt % I.S. concentration, where the yield stress had already become large.

$$\tau_{o,AZ101}(298K) = \frac{0.871 \cdot e^{0.1128 \cdot (wt\%_{IS})}}{1 - \frac{wt\%_{IS}}{19.81}} \{Pa\}, \quad 6.62\% \le \cdot wt\%_{IS} \le 18.55\%, \quad R^2 = 0.9775 \qquad [12]$$

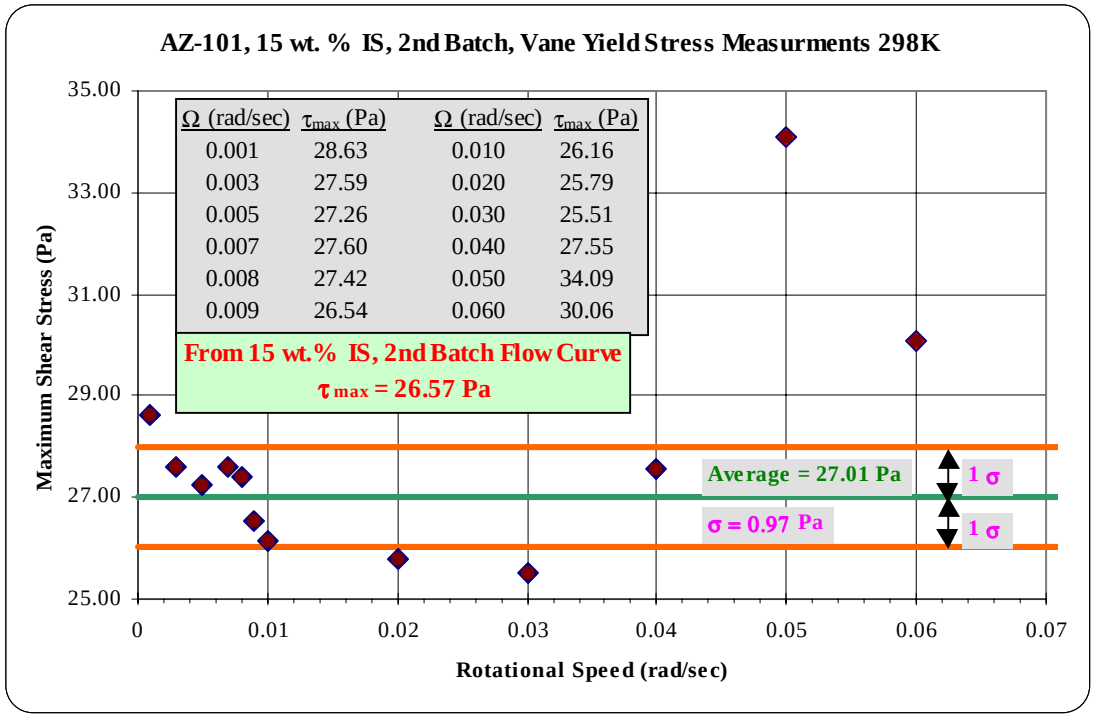
$$\tau_{o,AZ101}(323K) = \frac{0.333 \cdot e^{0.1211 \cdot (wt\%_{IS})}}{1 - \frac{wt\%_{IS}}{14.88}} \{Pa\}, \quad 6.62\% \le \cdot wt\%_{IS} \le 13.78\%, \quad R^2 = 0.9987 \qquad [13]$$

Table 5 Rheological Properties for AZ-101 Simulant

Wt. %Insoluble Solids		298 K			323 K			Fitted Shear rate range (sec^{-1})
Target	Measured	Yield Stress (Pa)	Consistency (mPa-sec)	R^2	Yield Stress (Pa)	Consistency (mPa-sec)	R^2	
7.5	6.62	0.68	3.1	0.9974	0.88	1.67	0.9974	50 – 700
10.0	9.18	2.75	4.3	0.9990	3.99	3.10	0.9982	100-1000
12.5	12.15	5.97	5.1	0.9990	7.8	2.87	0.9974	100-1000 200 - 1000
15.0	13.78	17.7	9.4	0.9998	23.9	5.32	0.9872	200 – 1000 400 – 2000
15.0 2nd batch	13.81	16.3	7.7	0.9996	--	--	--	200 - 1000
16.0	15.46	24.0	8.0	0.9996	--	--	--	200 – 1000
17	16.48	29.4	7.4	0.9990	--	--	--	200 – 1000
18	17.66	59.5	10.0	0.9960	--	--	--	200 - 1000
20.0	18.55	193.2	67.2	0.9864	--	--	--	1000 - 2000

The yield stresses in Table 5 represent the return or down flow curves fitted to the Bingham Plastic model. These calculated values were smaller than the peak stress in the up curve, taken during the initial measurement of the up curve. To investigate this peak, a vane was used to measure the yield stress of the 2nd batch of targeted 15 wt. % I.S. AZ-101 slurry at various rotor speeds. The flow curve for this slurry is shown in FIGURE A - 4 in the Appendix. The vane measurements are shown in FIGURE A - 5 and the maximum measured stress for each curve is shown in Figure 5. The average yield stress of the vane was calculated and a comparison to the measured peak yield stress from the up flow curve shows they are approximately the same. Note this may only be a coincidence that the peak stress from the up curve is approximately the same as that of the vane. The yields stress from the down flow curve in FIGURE A - 4 is 16.25 Pa and differs greatly from that of the average vane measurement. The fitted flow curve would represent a steady state condition, which would be used for normal operations. It can be concluded that the fitted data in Table 5, as well as all the analyses concerning all the slurries in this study, need to be analyzed using a method in which the flow curve can be corrected, if necessary. This analysis may show that these slurries indeed do have a high yield stress that quickly dissipates under applied shear, in which the vane measured yield stress could be used for startup torque, re-starting flow in a filled pipeline, flushing, or any other engineering application where this yield stress may be of importance. The higher yield stress from the vane measurement could replace the lower curve fitted yield stress. This would be conservative, but it needs further investigation.

Figure 5 AZ-101, 15 wt. % IS, 2nd Batch, Yield Stress Using Vane Geometry 298 K



During the yield stress measurements using the vane, the measured rotational speed of the rotor behaved as described by Liddell[16].

AZ-102 Sludge Simulant

Table 6 contains the density, pH and weight percent solids analyses. Changing the weight % IS concentration did not impact the pH of the slurry. This was expected, since the composition of the supernate did not change when targeting the different weight % IS concentrations. The density versus weight % IS and TS (via the oven results) were fitted to a 2nd order polynomial and shown as equations [14] and [15] respectively. The maximum weight % IS concentration obtained using the centrifuge was 26.99 wt. %, as measured using the microwave. This weight % IS concentration from centrifuging could be due to the repulsive forces of the flocculated particles being very high, thus trapping the supernate in the solids structure. The solids analyses performed using the microwave yielded higher total and insoluble solids as compared to the oven. The AZ-102 simulant was concentrated to a higher I.S. concentration than the AZ-101 simulant.

$$\rho_{AZ102}(wt\%_{IS}) = 0.2876\cdot(wt\%_{IS})^2 + 1.4816\cdot(wt\%_{IS}) + 1029.4, \quad \left\{\frac{kg}{m^3}\right\}$$
$$9.56\% \le \cdot wt\%_{IS} \le 19.63\%, \quad R^2 = 0.9978 \qquad [14]$$

$$\rho_{AZ102}(wt\%_{TS}) = 0.3005 \cdot (wt\%_{TS})^2 + 0.8506 \cdot (wt\%_{TS}) + 1030.7, \quad \left\{\frac{kg}{m^3}\right\} \qquad [15]$$

$$10.10\% \le \cdot wt\%_{TS} \le 20.11\%, \quad R^2 = 0.998$$

Table 6 Physical and Chemical Data for AZ-102 Simulant

Target wt % I.S.	Density (kg/m^3)	pH	Wt. % Solids Analysis Oven / Microwave		
			Total	Soluble	Insoluble
10.0	1071	11.52	10.10 / 10.59	0.54 / 0.52	9.56 / 10.007
12.5	1085	11.50	12.42 / 12.82	0.53 / 0.51	11.89 / 12.31
13.75	--	--	13.89 / --	0.53 / --	13.36 / --
15.0	1114	11.57	15.11 / 15.57	0.54 / 0.49	14.57 / 15.07
17.0	--	--	16.61 / --	0.52 / --	16.09 / --
18.0	--	--	17.74 / --	0.51 / --	17.23 / --
19.0	--	--	18.59 / --	0.56 / --	18.03 / --
20.0	1169	11.55	20.11 / 20.53	0.48 / 0.49	19.63 / 20.06
25	--	--	25.12 / --	0.42 / --	24.70 / --
Maximum value via centrifuging			-- /27.44	-- / 0.45	-- / 26.99

Table 7 contains the Bingham Plastic parameters fitted to the rheological data of the return curves shown in FIGURE A - 6, FIGURE A - 7 and FIGURE A - 8 in Appendix A. Inspection of these curves typically shows that as the weight % IS increases, the slurry became more thixotropic. Flow curve measurements could not be obtained for the 323 K temperature runs for weight % IS. above 18 wt. % target, using the cone to plate geometry due to the sample drying. For all the flow curves, other than the lowest weight % IS measurement, at the beginning of the initial up curve measurement, a large peak in the measured stress was observed. The peak may show that these slurries have a well-defined structure that breaks down after shearing. An alternative explanation for the peak is that the peak is due to slip occurring between the sensor and the sample. Measurements were not made during this study to allow for correction of the data for slip. The results in Table 7 show that of the two Bingham Plastic Parameters, the yield stress was most impacted by the change in weight % IS, which was consistent with how the AZ-101 simulant behaved. For a given weight % IS, the yield stress was greater at 323 K and the consistency was smaller at 323 K when comparing to the 298 K data. The yield stress as a function of weight % insoluble solids is shown in Figure 6 and Figure 7 for the 298 K and 323 K measurements respectively.

Figure 6 Simulated AZ-102, Yield Stress versus Wt. % Insoluble Solids, 298 K

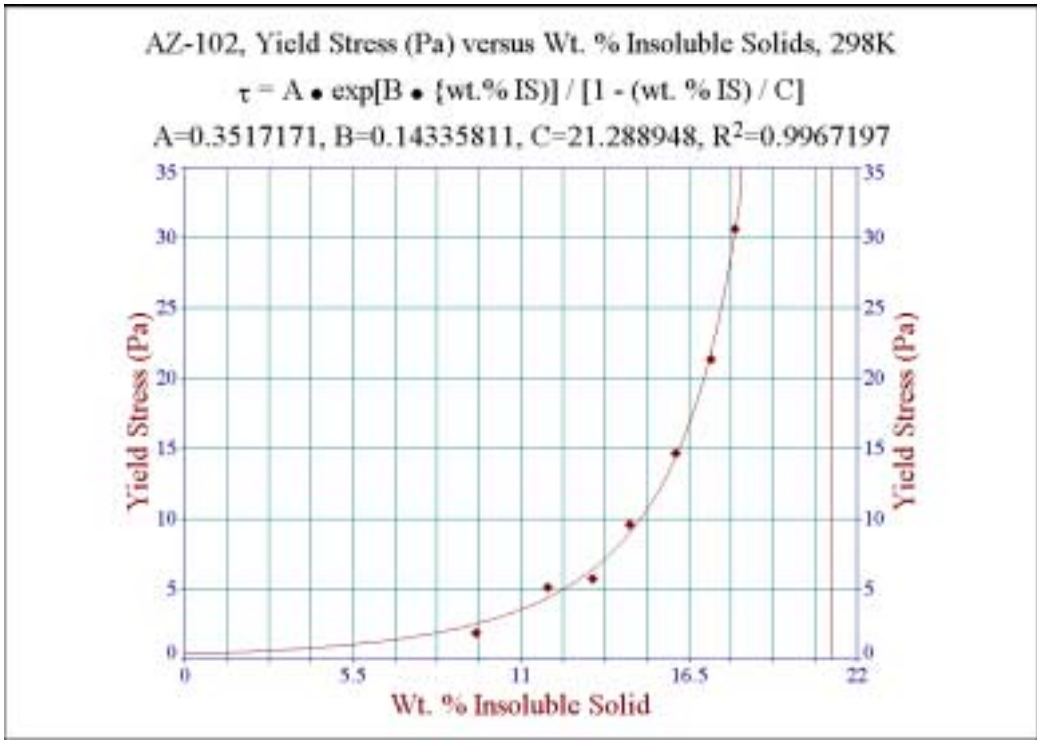
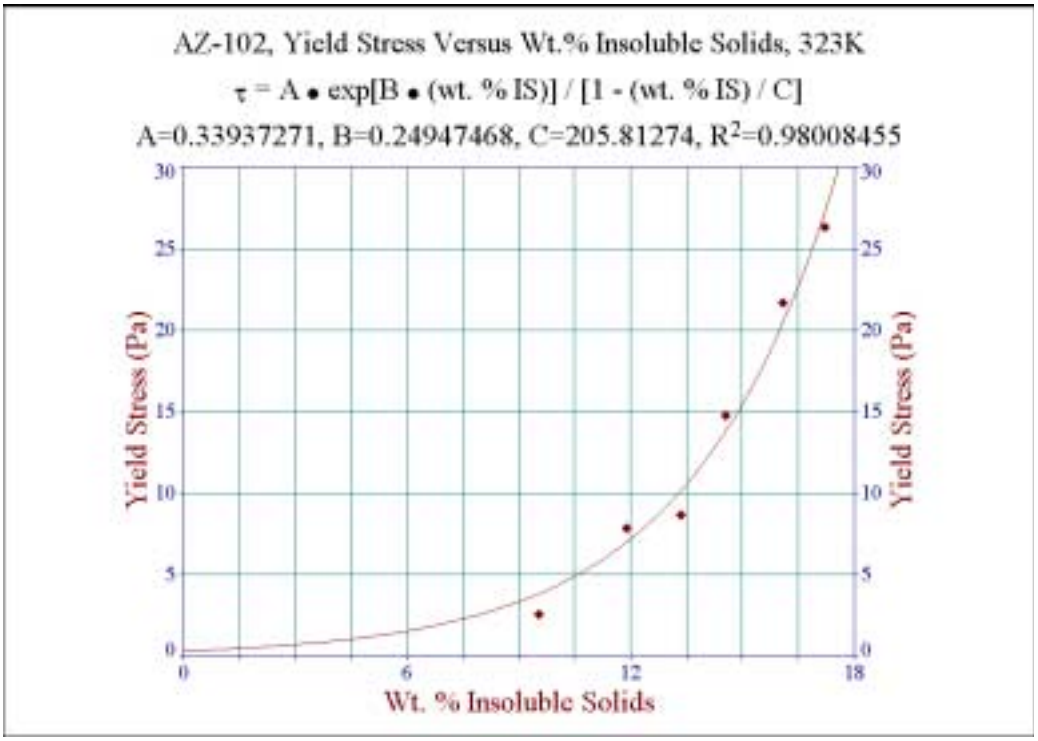


Figure 7 Simulated AZ-102, Yield Stress versus Wt. % Insoluble Solids, 323 K



The curves in Figure 6 and Figure 7 were fitted using equation [6] and are shown as equations [16] and [17]. The maximum weight % IS parameter (C_{max}) for the 323 K fit was unrealistic, since the maximum total solids can not exceed 100%. The flow curve for the 18 weight % IS seems to be impacted by drying, as shown in FIGURE A - 7, which could have impacted the calculated yield stress, thus impacting C_{max}. The C_{max} for the 298 K data was smaller than the maximum weight % IS shown in Table 6, which was 26.99 weight % IS (note that this was based on the microwave). The C_{max} was very dependent on the 20 weight % IS yield stress determination, which if over estimated, would cause this calculated value to be smaller. The consistency versus weight % IS curves were not generated, due to the same reason as specified for the AZ-101 simulant.

$$\tau_{o,AZ102}(298K) = \frac{0.352 \cdot e^{0.1434 \cdot (wt\%_{IS})}}{1 - \frac{wt\%_{IS}}{21.29}} \{Pa\}, \quad 9.56\% \le \cdot wt\%_{IS} \le 19.63\%, \quad R^2 = 0.9967 \qquad [16]$$

$$\tau_{o,AZ102}(323K) = \frac{0.339 \cdot e^{0.2495 \cdot (wt\%_{IS})}}{1 - \frac{wt\%_{IS}}{205.81}} \{Pa\}, \quad 9.56\% \le \cdot wt\%_{IS} \le 17.23\%, \quad R^2 = 0.9801 \qquad [17]$$

Table 7 Rheological Properties for AZ-102 Simulant

Wt. %Insoluble Solids		298 K			323 K			Fitted Shear rate range (sec^{-1})
Target	Measured	Yield Stress (Pa)	Consistency (mPa-sec)	R^2	Yield Stress (Pa)	Consistency (mPa-sec)	R^2	
10.0	9.56	1.85	3.6	0.9988	2.57	3.0	0.9984	200 – 1000
12.5	11.89	5.09	4.5	0.9992	7.86	3.6	0.9992	200 – 1000
13.75	13.36	5.71	4.9	0.9994	8.66	3.4	0.9984	200 – 1000
15.0	14.57	9.61	6.1	0.9992	14.78	4.3	0.9912	200 – 1000
17.0	16.09	14.64	6.0	0.9990	21.68	4.0	0.8887	200 – 1000 250 – 1000
18.0	17.23	21.35	6.1	0.9950	26.33	25.8	0.9930	200 – 1000 350 – 1000
19.0	18.03	30.63	6.2	0.9976	--	--	--	400 – 1000
20.0	19.63	41.00	21.5	0.9982	--	--	--	200 – 2000

Rheology measurements on actual AZ-102 sludge have been collected by researchers at the Pacific Northwest National Laboratory.[19] A comparison of the apparent viscosity at a shear rate of 200 sec^{-1} indicates that the simulant rheology performance is similar to that of the real waste. The comparison of apparent viscosity is shown in Table 8. Both sets of data show that the viscosity is a strong function of the solids content of the slurries. The relative magnitude of the values is similar considering that the simulant has not experienced either the radiation or thermal aging that is characteristic of actual waste storage.

[19] P. R. Bredt, L. K. Jagoda, D. E. Rinehart, **Rheological Studies on Pretreated Feed and Melter Feed from C-104 and AZ-102**, PNNL-13359, WTP-RPT-004, Rev. 0, Pacific Northwest National Laboratory, Richland, WA 99352, January 2001.

Table 8: Apparent Viscosity Comparison of Simulated and Actual AZ-102 Sludge

Weight % Total Solids	Apparent Viscosity @ 200 s^{-1} (milliPascal-seconds)	
	AZ-102 Simulated Sludge	Actual AZ-102 Sludge
25	-	1125
20	232	163 and 185
15	54	110

AN-107 Sr/TRU Precipitate Simulant

Table 9 contains the density, pH, and weight percent solids analyses. Changing the weight % IS concentration of the washed simulant did not impact the pH of the slurry since the composition of the supernate did not change when targeting the different weight % IS concentrations. The density versus weight % IS and T.S. (via the oven results) were fitted to a 3rd order polynomial and shown as equations [18] and [19] respectively. The weight % IS of the washed simulant using the centrifuge was not measured. The density of the unwashed simulant is approximately 30% greater than the final washed simulant when measured at 15 weight % IS since the total solids in the unwashed simulant was 40.92 weight % as compared to 17.65 weight % of the washed simulant.

$$\rho_{washedSr/TRU}(wt\%_{IS}) = 0.0389\cdot(wt\%_{IS})^3 - 1.168\cdot(wt\%_{IS})^2 + 12.735\cdot(wt\%_{IS}) + 10255, \left\{\frac{kg}{m^3}\right\} \quad [18]$$

$$10.03\% \le \cdot wt\%_{IS} \le 24.69\%, \quad R^2 = 1.0$$

$$\rho_{washedSr/TRU}(wt\%_{TS}) = 0.0402\cdot(wt\%_{TS})^3 - 1.4767\cdot(wt\%_{TS})^2 + 19.062\cdot(wt\%_{TS}) + 999.2, \left\{\frac{kg}{m^3}\right\} \quad [19]$$

$$12.32\% \le \cdot wt\%_{TS} \le 26.86\%, \quad R^2 = 1.0$$

Table 9 Physical and Chemical Data for AN-107, Sr/TRU Precipitated Simulated Sludge

Target wt % I.S.	Density (kg/m^3)	pH	Wt. % Solids Analysis Oven / Microwave		
			Total	Soluble	Insoluble
10.0	1085	10.05	12.32 / 12.65	2.28 / 2.43	10.03 / 10.23
15.0	1093	9.91	16.78 / 17.65	2.36 / 2.29	14.42 / 15.37
15.0 unwashed	1452	--	-- / 40.92	-- / 25.14	-- / 15.77
Initial Washed/sheared	1117	--	-- / 20.72	-- / 2.20	-- / 18.53
18.33	--	--	18.77 / --	2.15 / --	16.62 / --
20.0	1129	9.80	21.80 / 22.52	2.25 / 2.15	19.55 / 20.37
23.33	--	--	23.2 / --	2.05 / --	21.15 / --
25.0	1224	9.80	26.86 / 27.32	2.17 / 2.02	24.69 / 25.30

Figure 8 shows the flow curves for the 15 weight % unwashed AN-107 Sr/TRU measured at 298 K and 323 K using the M5/RV20 rheometer with the MV1 concentric cylinder sensor. The measurement were taken with a linear ramp time up of 7 minutes, 2 minutes hold at 1000 s^{-1}, and a linear ramp down time of 7 minutes. There seems to be little difference in the calculated yields stress, using equation [5]. The 298 K consistency is thicker than the 323 K consistency, as expected due to the increase in temperature.

Figure 8 Fifteen wt. % I.S. Unwashed AN-107 Sr/TRU Flow Curves

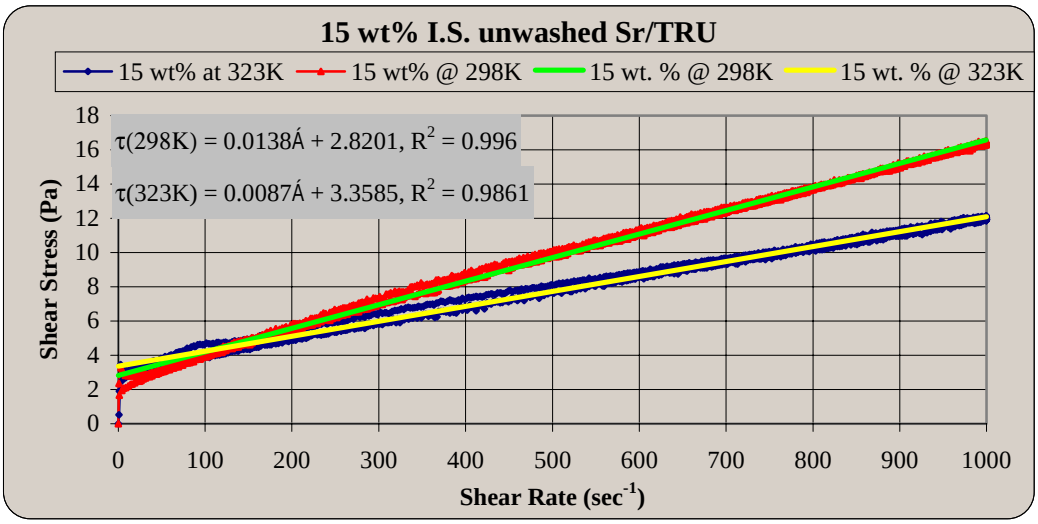


Table 10 contains the Bingham Plastic parameters fitted to the rheological data of the return curves of the washed Sr/TRU precipitate shown in FIGURE A - 9 and FIGURE A - 10 in Appendix A. All of the flow curves for the washed Sr/TRU precipitate were taken using the RS150 rheometer using cone and plate geometry. Inspection of FIGURE A - 9 shows that the flow curves exhibit little thixotropic behavior until the insoluble solids loading was 25 weight %. Flow curve measurements could not be obtained for the 323 K temperature runs for weight % IS above 20 weight % IS, using the cone to plate geometry due to the sample drying. A large peak in the measured stress was observed at the beginning of the initial up curve measurement for all the flow curves, other than the two lowest weight % IS measurements. The peak could show that these slurries have a well-defined structure that breaks down after shearing or that slip was occurring between the cone and the fluid. The results in Table 10 show that the yield stress is most impacted by the change in weight % IS, which was consistent with how the AZ-101 and AZ-102 sludge simulants behaved. For a given weight % IS, the yield stress was greater and the consistency was smaller when comparing the 298 K data to the 323 K data, exhibiting the same trends observed with the AZ-101 and AZ-102 slurries. The yield stress as a function of wt. % insoluble solids are shown in Figure 9 and Figure 10 for the 298 K and 323 K measurements respectively.

Figure 9 Simulated AN-107 Sr/TRU Prec/washed, Yield Stress vs. Wt. % IS, 298 K

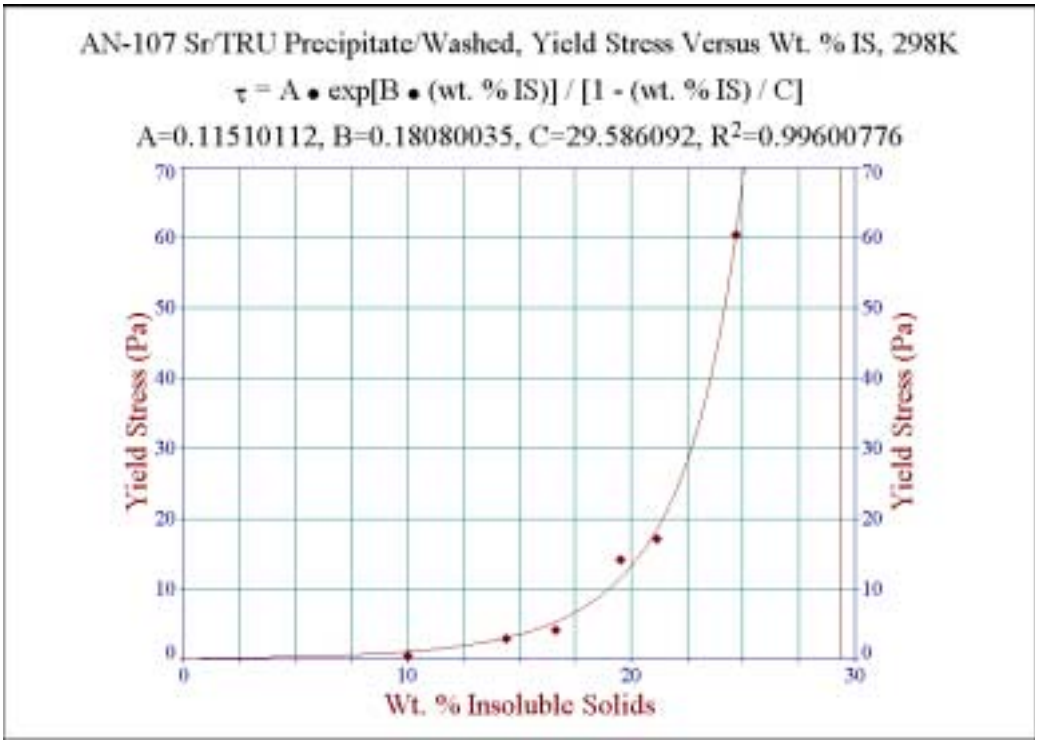
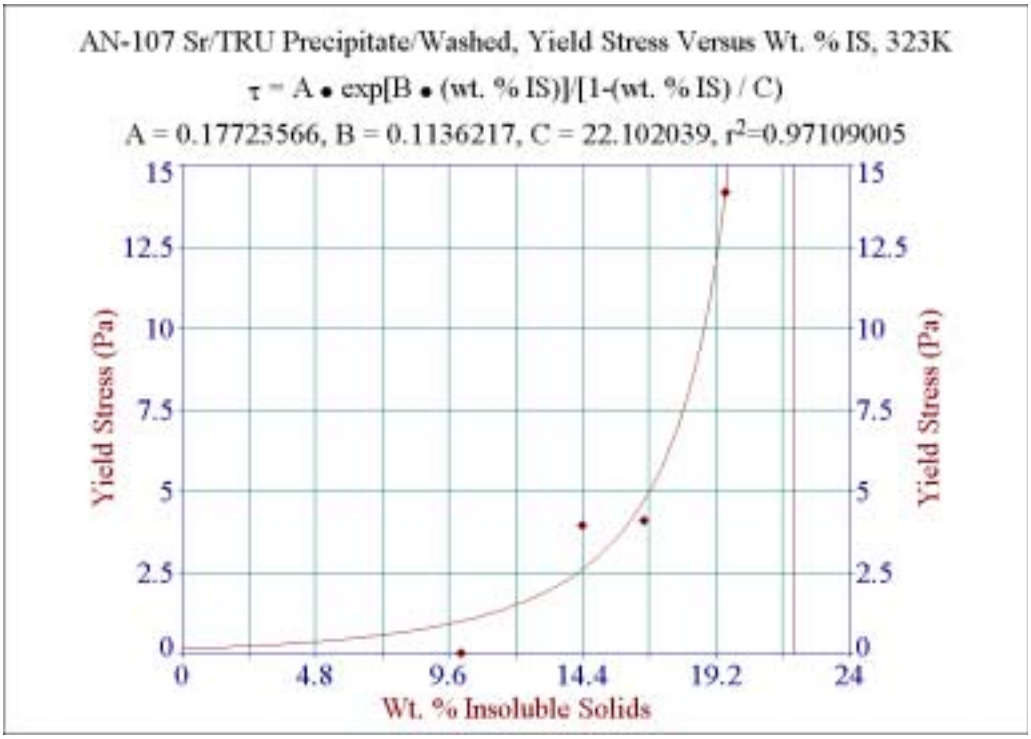


Figure 10 Simulated AN-107 Sr/TRU Prec/washed, Yield Stress vs. Wt. % IS, 323 K



The curves in Figure 9 and Figure 10 were fitted using equation [6] and are shown as equations [20] and [21]. The C_{max} for the 298 K data is larger than the C_{max} for the 323 K data. This was

consistent with the AZ-101 and AZ-102 results when comparing the 323 K to the 298 K C_{max} values. The C_{max} at 298 K can not be compared to any physical measurement, but seems to be reasonable in determining the maximum concentration. The consistency versus weight % IS curves were not generated, due to the same reason as specified for the AZ-101 simulant.

Because different measuring heads (due to different instruments) were used to measure the rheological properties of the 15 weight % unwashed and washed Sr/TRU slurries, they technically cannot be compared, until they have been corrected for non-Newtonian behavior and slip. However, the following comparison is based on the assumption that the flow curves are comparable. The 15 weight % IS unwashed Sr/TRU shown in Figure 8, when compared to the washed 15 weight % IS results in Table 10, show that the yield stresses are about the same. The consistency of the unwashed Sr/TRU is approximately 3 times thicker than the washed 15 weight % IS since the total solids of the unwashed is much greater than the washed.

$$\tau_{o,washedSr/TRU}(298K) = \frac{0.115 \cdot e^{0.1808 \cdot (wt\%_{IS})}}{1 - \frac{wt\%_{IS}}{29.59}} \{Pa\}, \quad 10.03\% \le \cdot wt\%_{IS} \le 24.69\%, \quad R^2 = 0.9960 \quad [20]$$

$$\tau_{o,washedSr/TRU}(323K) = \frac{0.177 \cdot e^{0.1136 \cdot (wt\%_{IS})}}{1 - \frac{wt\%_{IS}}{22.10}} \{Pa\}, \quad 10.03\% \le \cdot wt\%_{IS} \le 19.55\%, \quad R^2 = 0.9711 \quad [21]$$

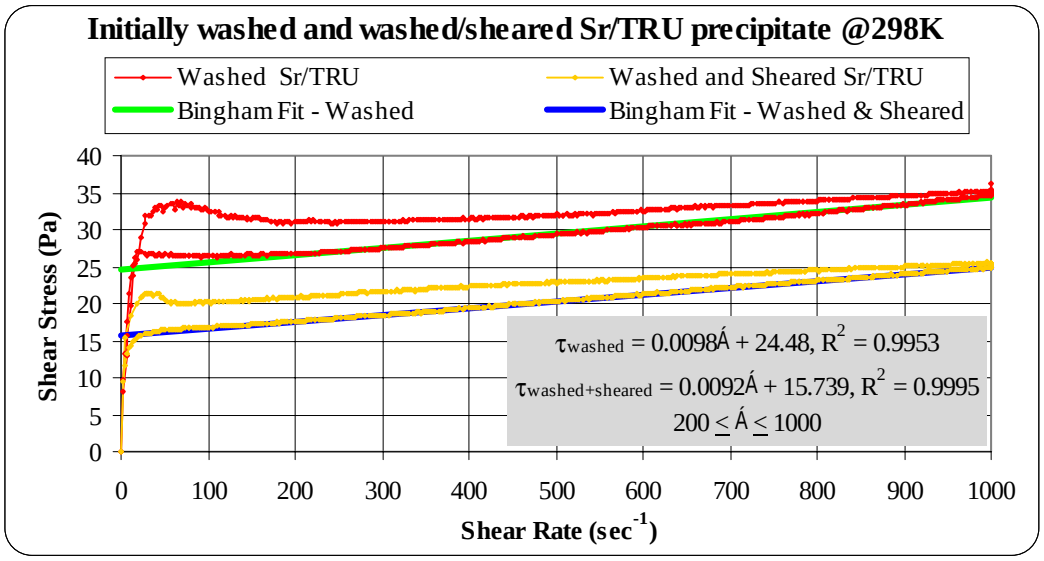
Table 10 Rheological Properties of washed AN-107, Sr/TRU Precipitate

Wt. %Insoluble Solids		298 K			323 K			Fitted Shear rate range (sec^{-1})
Target	Measured	Yield Stress (Pa)	Consistency (mPa-sec)	R^2	Yield Stress (Pa)	Consistency (mPa-sec)	R^2	
10.0	10.03	0.52	2.9	0.9970	0.03	1.8	0.9401	100 – 700 100 – 1000
15.0	14.42	2.94	4.8	0.9972	3.97	3.3	0.9843	100 – 1000
18.33	16.62	4.10	4.8	0.9986	5.63	3.5	0.9988	200 – 1000
20.0	19.55	14.18	7.5	0.9998	20.93	5.5	0.9876	200 – 1000 900 – 2000
23.33	21.15	17.21	7.9	0.9990	--	--	--	200 – 1000
25.0	24.69	60.44	13.7	0.9996	--	--	--	200 – 1000

Figure 11 shows the rheological effect shearing has on the washed Sr/TRU precipitate as measured using the M5/RV20 rheometer. The measurements were taken with a linear ramp time up of 7 minutes, 2 minutes hold at 1000 s^{-1}, and a linear ramp down time of 7 minutes. The equipment used to shear this slurry is described in the Simulant Preparation, AZ-101 sludge simulant section in Appendix B and the time of shearing is the Sr/TRU section of Appendix B. The particle size distributions of the washed and washed & sheared slurries are shown in FIGURE A - 23 and FIGURE A - 24 respectively. These figures show that the particle size distribution becomes narrower in the direction of smaller particle size and the volume average particle size decreases after shearing was completed as reported in Table B- 22 in Appendix B. This is consistent with the results shown in Figure 11. The washed slurry is rheologically thicker (specifically a higher yield stress) than the washed & sheared slurry. This could be due to the

larger flocculated (and most likely non-spherical in shape) particles, which when placed under a shear, require more energy to orient the particles in the direction of flow. The shearing, which reduced the particle size, could have also made the particles more consistent in shape, thus reducing the yield stress. Shearing did not seem to affect the consistency of the slurry. Both slurries have thixotropic characteristics, with the washed slurry being more thixotropic.

Figure 11 Rheological Shear Effects Of Washed Sr/TRU Precipitate



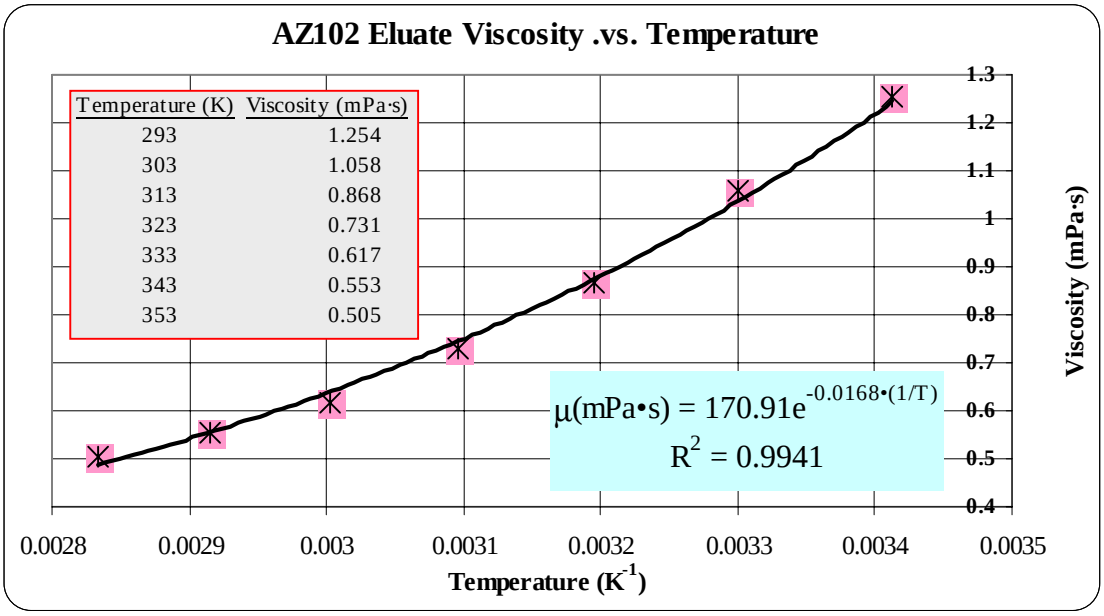
AZ-102 Cs/Tc Eluate Simulant

The density, pH and solids analyses are shown in Table 11 for the concentrated blended eluate. There was a slight amount of insoluble solids in the simulant. FIGURE A - 11 in Appendix A contains the individual flow curves ranging between 293 K to 353 K obtained using the RS150 rheometer. All the flow curves in FIGURE A - 11 are Newtonian. The 353 K flow curve, the highest measured temperature, seems to be affected by drying and is questionable, but is still presented and used. The viscosity data from FIGURE A - 11 is shown in Figure 12 and fitted to Arrhenius equation, equation [9], which is located on the figure itself. The data seem to fit well to the Arrhenius equation.

Table 11 Physical and Chemical Data for AZ-102 Cs/Tc Eluate

		wt % Solids Analysis – Oven	
Density (kg/m^3)	pH	Total	Insoluble
1110	8.72	19.45	0.61

Figure 12 AZ102 Eluate Viscosity Versus Temperature Data – Curve



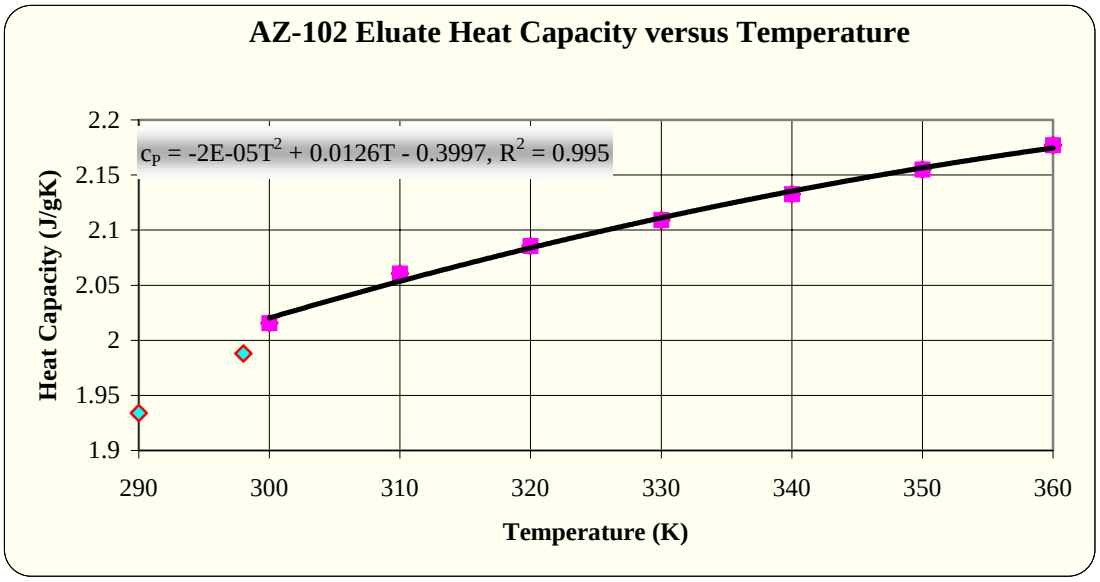
The heat capacity of the eluate was measured between 290 K to 360 K and is shown in Figure 13 and the data is shown in Table 12. A 2nd order polynomial was fitted to all the data, except for the first two data points. [20] These two points are near the instrument start up temperature and are highly uncertain. The 2nd order polynomial curve described above and is shown in Figure 13 is recommended for calculating the heat capacity of the first two data points.

Table 12 Heat Capacity Data for AZ-102 Eluate Simulant

Temp(K)	cP(J/gK)	Temp(K)	cP(J/gK)
290	1.934	330	2.109
298	1.988	340	2.133
300	2.016	350	2.155
310	2.061	360	2.177
320	2.086		

[20] F. Fondeur, email, "Heat Capacity Measurement", 12/13/00

Figure 13 AZ-102 Eluate Heat Capacity Versus Temperature



AZ-101 + Blended Compositions

The pH, solids analyses, and rheological results are shown in Table 13 for the various AZ-101 test mixtures. Particle size distribution was measured for the AZ-101 blends and are shown in Appendix A. The blended compositions have little effect on the pH, which is consistent with blending three nonreactive mixtures whose initial pH is similar. Comparing these values to the baseline data in Table 5 shows that the yield stress and consistency decreased when the added Cs/Tc eluate and Sr/TRU precipitate diluted the base slurry as shown in test mixtures 1.4, 1.5, ADD-1, and ADD-2. The opposite was true, when the thicker Sr/TRU precipitate was added to text mixture 1.3.

Table 13 Physical, Chemical and Rheological Data for AZ-101, Eluate, and Sr/TRU blends

Test Mixture	pH	Wt. % Solids Analysis Oven Method		Density (kg/m^3)	Yield Stress (Pa)	Consistency (mPa-sec)	R^2	Fitted Shear rate range (sec^{-1})
		Total	Insoluble					
1.3	9.92	20.21	18.64	1173.4	61.99	12.7	0.9984	200 - 1000
1.4	10.14	15.72	14.12	1107.1	11.98	7.5	0.9990	200 – 1000
1.5	10.17	16.49	14.95	1130.1	18.64	9.1	0.9984	200 – 1000
ADD-1	9.92	9.01	7.21	1064.8	0.52	3.0	0.9974	100 – 800
ADD-2	9.98	11.35	9.54	1087.2	2.07	4.2	0.9960	200 – 800

AZ-102 + Blended Compositions

The pH, solids analyses, and rheological results are shown in Table 14 for the various AZ-102 test mixtures. Particle size distributions were measured for the AZ-102 blends and shown in Appendix A. The blended compositions had little effect on pH, which is consistent with

blending three nonreactive mixtures whose initial pH was similar. Comparing these values to the baseline data in Table 7 shows that the yield stress and consistency increased when the added Cs/Tc eluate and Sr/TRU precipitate thickened the base slurry as shown in test mixtures 2.4, 2.5, ADD-3, and ADD-4. Comparing test mixtures 2.3 and 2.9 to the baseline data in Table 7 shows that the results are different in behavior. This could be due to the applied shear rate range for the base case was 0-2000 sec^{-1} as compared to 0-1000 sec^{-1} for test mixtures 2.3 and 2.9. Comparing test mixtures 2.3 to 2.9 show that it's behaves as expected, where 2.9 is thinner than 2.3.

Table 14 Physical, Chemical and Rheological Data for AZ-102, Eluate, and Sr/TRU blends

Test Mixture	pH	Wt. % Solids Analysis Oven Method		Density (kg/m^3)	Yield Stress (Pa)	Consistency (mPa-sec)	R^2	Fitted Shear rate range (sec^{-1})
		Total	Insoluble					
2.3	11.24	20.15	19.12	1171.6	59.46	9.4	0.9946	200 - 1000
2.4	11.16	15.19	14.22	1111.7	11.29	6.2	0.9984	100 - 1000
2.5	11.14	15.66	14.74	1109.4	13.16	7.2	0.9972	200 - 1000
2.9	11.41	19.93	19.05	1172.2	54.22	8.1	0.9898	300 - 1000
ADD-3	11.18	10.54	9.69	1078.8	2.78	3.6	0.9988	100 - 1000
ADD-4	11.10	12.75	11.88	1052.3	6.58	4.1	0.9984	100 - 1000

Effect of pH Adjustment

The goal of the pH adjustment experiment was to determine if adjusting the pH with a suitable acid would allow the blend to be produced at higher total solids loading by modifying the blend rheological properties. Test mixtures 1.4, 1.5, 2.3 and 2.5 were adjusted with nitric acid to produce blends with pH values of nominally 9, 7 and 5. Nitric acid was chosen for the pH adjustment as having potentially the least impact on glass properties compared to the other mineral acids, which have either undesirable glass properties or poor corrosion characteristics. A reducing acid (organic acid) could also have been used but other potential problems can occur. The data from the pH adjustment is shown in Table 15. Results for the pH 9 and 7 samples for weight percent solids and density were not obtained because of the small amount of sample available and the need to preserve as much sample as possible for the rheology measurements. The yield stress values were based on fitting a Bingham model to the up flow curve since the curves generally fit well from 100 to 1000 sec^{-1}.

During the pH adjustment process, it was noted that gas evolution occurred and that the blend flow properties were visibly changing. The gas evolution was presumed to be due to the conversion of carbonate to CO_2 by the nitric acid. Due to this reaction, a replacement of each carbonate anion is made with two nitrate anions and a water molecule. The net result would be an increase in total solids due to the mass of two nitrate anions for each carbonate anion converted to CO_2. The increase in total solids was observed for all four of the test mixtures when comparing the initial pH total solids to the pH 5 total solids as shown in Table 15. Since many of the metal carbonates are insoluble or have limited solubility and all of the metal nitrates are soluble, an increase in the soluble solids and a decrease in the insoluble solids would also be expected. The results in Table 15 also demonstrate this change in slurry physical properties.

The observation during mixing of the pH adjusted test blends that the flow properties of the test blends appeared to be changing was confirmed by the rheology measurements as shown in Table 15.

Table 15 Physical and Rheological Data for pH-Adjusted AZ-101 and AZ-102 Blends at 298 K

Test Mixture	pH	Wt. % Solids Analysis Oven Method		Density (kg/m^3)	Yield Stress (Pa)	Consistency (mPa-sec)	R^2	Fitted Shear rate range (sec^{-1})
		Total	Insoluble					
1.4	10.14	15.72	14.12	1107.1	11.49	7.6	0.9986	200 – 1000
1.4	8.16				20.04	6.8	0.9952	100 - 1000
1.4	7.01				36.11	10.0	0.9908	200 – 1000
1.4	5.09	16.64	11.68	1134.6	27.44	8.9	0.9946	200 – 1000
1.5	10.17	16.49	14.95	1130.1	18.64	9.1	0.9984	200 - 1000
1.5	8.43				31.64	9.2	0.9874	200 – 1000
1.5	7.03				50.88	10.1	0.9894	200 – 1000
1.5	5.12	17.36	12.4	1139.6	40.29	9.3	0.9944	200 – 1000
2.3	11.24	20.15	19.12	1171.6	59.46	9.4	0.9946	200 - 1000
2.3	8.61				85.43	14.3	0.9811	100 – 1000
2.3	6.75				88.58	10.1	0.9586	200 - 1000
2.3	4.77	20.84	16.44	1181.4	36.21	11.6	0.9958	200 – 1000
2.5	11.14	15.66	14.74	1109.4	13.16	7.2	0.9972	200 – 1000
2.5	8.75				18.95	8.1	0.9992	100 – 1000
2.5	6.68				19.18	9.1	0.9966	100 - 1000
2.5	4.72	16.59	12.85	1131.5	10.9	6.9	0.9964	200 - 1000

The impact of shifting the pH was most noticeable with respect to the yield stress of the slurry. As the pH declined from about 11 to near 7, the yield stress increased in all test cases. The second addition also increased the yield stress. The final acid additions then began to reduce the yield stress. A plot of yield stress as a function of pH based upon the data in Table 15 is shown in Figure 14. The process of pH adjustment would be a movement from the right side of the plot to the left side of the plot. A maximum in yield stress occurs near pH 7 based upon all four curves. The existence of the maximum is consistent with prior studies on the effect of pH on metal hydroxide slurries.[21,22,23] Based upon the four tests in this study, the pH would probably have to be changed to a value less than 5 to achieve any significant reduction in yield stress.

An analysis of the data for consistency does not show any definite trends in the data. Figure 15 does not show any reproducible pattern to the measured values of consistency as a function of pH.

[21] Y.K. Leong, P.J.Scales, T. W. Healy, D. V. Bolger, "Interparticle forces arising from adsorbed polyelectrolytes in colloidal suspensions". **Colloids and Surfaces A: Physicochemical and Engineering Aspects** Vol. 95 p 43-52 (1995).

[22] M. Subanna, P. Malghan, and S. G. Malghan, "Shear yield stress of flocculated alumina-zirconia mixed suspensions: effect of solid loading, composition and particle size distribution". **Chemical Engineering Science**, Vol. 53, p 3073-3079 (1998).

[23] J. P. LaFemina (Task Leader), **Tank Waste Treatment Science Task Quarterly Report for January to March 1995**, PNL-10763/UC-721, April 1, 1995.

Figure 14 Yield Stress as a Function of pH at 298 K

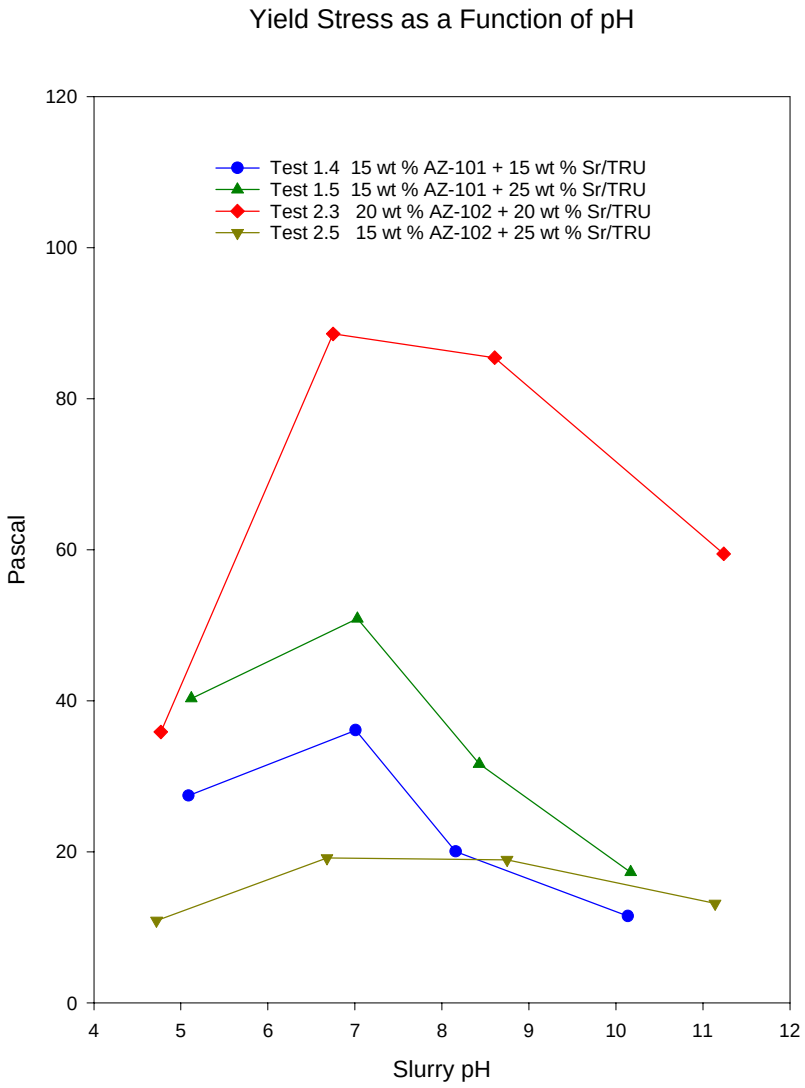
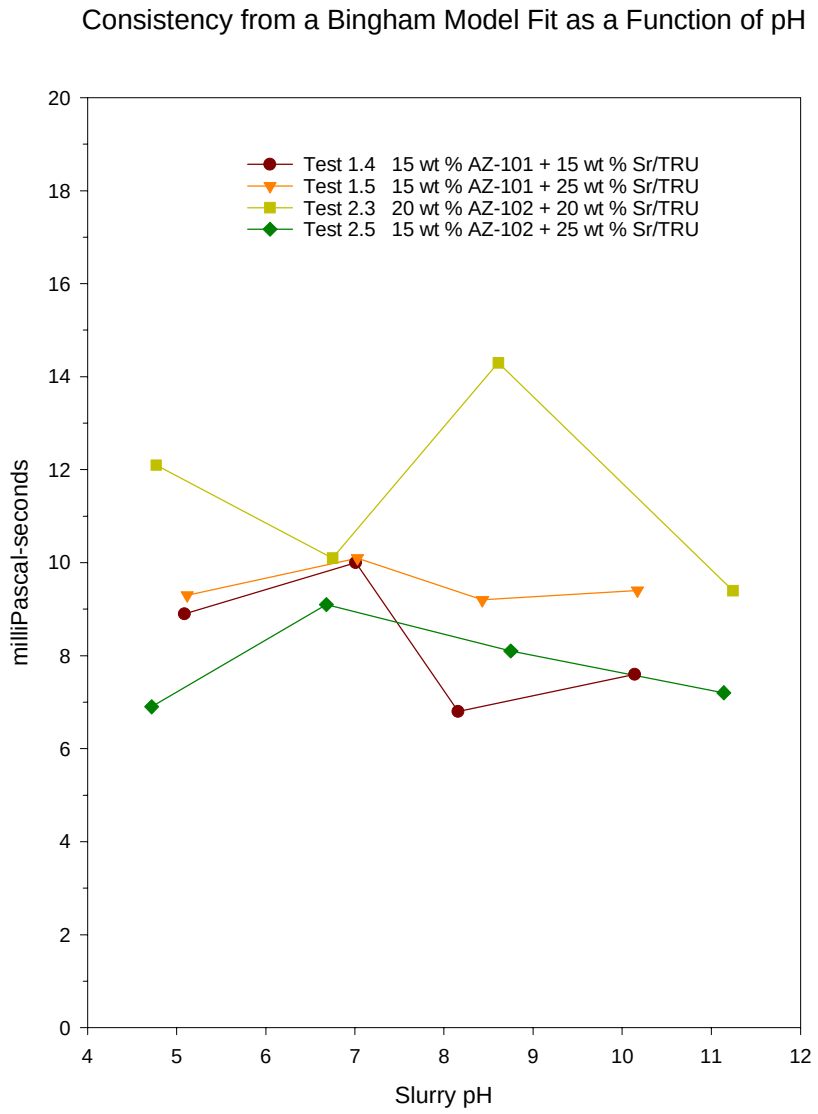


Figure 15 Consistency as a Function of pH at 298 K



Samples of the supernate from the pH 5 adjusted tests were analyzed for soluble species concentrations to determine the changes in the solids due to pH. Table 16 lists the composition for the supernate at the starting pH and at the final pH for all four tests.

Table 16 Effect of pH Change on Soluble Blend Components

	Test 1.4	Test 1.4	Test 1.5	Test 1.5	Test 2.3	Test 2.3	Test 2.5	Test 2.5
	pH 10.14	pH 5.09	pH 10.17	pH 5.12	pH 11.24	pH 4.77	pH 11.14	pH 4.72
Component	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
B	41	41	40	42	32	13	30	16
Ba	0.05	54	0.04	52	<0.06	53	0.02	39
Ca	2.7	696	2.8	715	3	454	3.1	343
Cd	4.1	871	2.2	736	2.5	2950	1.8	2350
Co	<0.04	70	<0.04	55	<0.2	2.3	<0.04	2.7
Cr	6.2	<0.5	5.8	<0.5	22	<0.5	17	<0.5
Fe	<0.04	<0.4	<0.04	<0.4	<0.2	<0.4	<0.04	<0.4
Mg	0.6	61	0.6	63	0.9	255	0.6	192
Mn	0.2	935	0.1	830	<0.05	459	<0.01	471
Na	5680	8840	5320	8890	4410	6110	3750	5060
K	409	624	409	655	38	58	28	30
Ni	2.6	453	1.5	365	2.1	1120	1.3	910
Sr	0.14	5690	0.15	6200	0.29	5670	0.16	4460
Nitrate	4380	39110	4750	39100	3020	35500	2190	26950
Nitrite	3780	1860	3980	1990	1085	260	1010	272
Chloride	93	57	98	59	341	205	313	208
Fluoride	71	<20	75	<20	40	<20	42	<20
Sulfate	749	37	764	44	453	17	369	17

The replacement of carbonate with nitrate can be seen in the increase in solubility of the following metals, which form sparingly soluble carbonates: Ba, Ca, Mg, Mn, and Sr. Since most of these also form sparingly soluble fluorides and sulfates, the drop in fluoride and in sulfate is consistent with an increase in the metal ion in solution. Barium also forms an insoluble chromate, which would explain the drop in chromium assuming that it is present in the supernate as chromate. The increase in soluble manganese indicates that Mn(II) is present in the blend since Mn(IV) forms an insoluble oxide (MnO_2). Since both the AZ-102 and AZ-101 sludges were produced with MnO_2, the soluble Mn(II) must come from the Sr/TRU precipitate. The decrease in soluble nitrite is probably due to acid decomposition of the nitrite during pH adjustment. The increase in solubility of Cd, Co and Ni is consistent with the solubility curves of their hydroxide species. The lack of dissolution of iron is also consistent with the pH achieved and the solubility curve for Fe(III) hydroxides.

AZ-101 + Blended Compositions + Glass Formers

The pH, solids analyses, and rheological results are shown in Table 17 for the various AZ-101 test mixtures combined with glass formers. The particle size data for the AZ-101 test mixtures with glass formers is shown in Appendix A. The blended combinations seem to have little effect on pH, even after the glass formers have been added. Insoluble solids analysis could not be performed for test mixtures 1.3, 1.4, and 1.5, since the available amount of slurry made did not lead to enough supernate to be separated from the structure. The flow curves are shown in FIGURE A - 12 in the appendix. The flow curves in this figure are such that 3 of the 5 curves (tests 1.4, 1.5, ADD-2) had return curves that were above the up curves. This could mean that these slurries are rheopectic, and would have to be verified by measuring the flow curve using other geometry's. These flow curves could also be due to edge effects, where drying would be the issue. Comparing the baseline data in Table 7 to Table 17, the yield stress and consistency have both increased drastically due to the addition of glass formers. These large differences will impact both mixing and transport issues, given that this process will be performed in one vessel.

Table 17 Physical and Rheological Data for AZ-101 Blended Compositions + Glass Formers

Test Mixture	pH	wt. % Solids Analysis Oven Method		Density (kg/m^3)	Yield Stress (Pa)	Consistency (mPa-sec)	R^2	Fitted Shear rate range (sec^{-1})
		Total	Insoluble					
1.3	10.2	39.05	*	1387	340.3	123.9	0.9966	d: 100 – 1000
1.4	10.3	32.47	*	1321	48.52	37.3	0.9990	u: 100 – 1000
1.5	10.3	33.66	*	1308	76.83	56.6	0.9990	u: 100 – 1000
ADD-1	10.2	24.71	20.37	1218	2.55	6.8	0.9892	d: 200 – 1000
ADD-2	10.2	30.02	24.08	1248	11.54	12.4	0.9990	u: 100 – 1000

***** Centrifuging could not separate enough supernate for measurement

Test mixture 1.4 was selected as the blend that would be mixed for 30 days to see if there were any dynamic effects on rheology. Samples of this blend were taken at specified time intervals to look at the pH, total solids, and rheology. The results are shown in Table 18. The flow curves are shown in FIGURE A - 13. All the flow curves, except for the 2 hr measurement, were such that the down curve was slightly below the up, indicating slight thixotropic characteristics. The 2 hr flow curve shows rheopectic behavior, but this would have to be confirmed. The 30-day test only lasted 23 days, before the test was stopped, due to the limited change in yield stress between the 19 and 23-day measurements. In Table 18, both the yield stress and

consistency decrease over time, which indicates this slurry is not stable with respect to rheological properties. The pH and weight % TS also changed, but not drastically. The proposed reason for this behavior is that the glass formers used in this test, specifically LiOH and NaOH, reacted with the aluminum to form a soluble salt over time. The result would be a decrease in insoluble solids and an increase in soluble solids. Considering the large reduction in yield stress, the use of hydroxide forms of the alkali metals could help in improving the flow characteristics of the HLW melter feed.

Table 18 Total Solids and Rheological Data for AZ-101 Test 1.4 – 30 Day Test

Time	pH	wt. % Total Solids Oven Method	Yield Stress (Pa)	Consistency (mPa-sec)	R^2	Fitted Shear rate range (sec^{-1})
2 hours	9.97	32.25	39.95	31.94	0.9998	100 – 1000
1 day	9.99	32.11	32.81	19.16	0.9992	100 – 1000
3 days	10.02	32.05	29.03	15.35	0.9997	100 – 1000
19 days	9.82	31.94	13.23	11.42	0.9991	100 – 1000
23 days	9.73	31.80	11.37	9.90	0.9871	100 – 1000

AZ-102 + Blended Compositions + Glass Formers

The pH, solids analyses, and rheological results are shown in Table 19 for the various AZ-102 test mixtures. The particle size data for the AZ-102 test mixtures with glass formers is shown in Appendix A. The addition of glass formers causes the pH of the blended mixture to decrease. The flow curves are shown in FIGURE A - 14 in Appendix A. These flow curves show very few thixotropic characteristics, unlike the AZ-101 blends + glass formers. Comparing the base line data in Table 7 to Table 19, the yield stress and consistency have both increased slightly due to the addition of glass formers. The largest change is in the consistency. These changes will impact mixing and pumping issues, but the degree of impact will need to be quantified based on the process equipment being used.

Table 19 Physical and Rheological Data for AZ-102 Blended Compositions + Glass Formers

Test Mixture	pH	wt. % Solids Analysis Oven Method		Density (kg/m^3)	Yield Stress (Pa)	Consistency (mPa-sec)	R^2	Fitted Shear rate range (sec^{-1})
		Total	Insoluble					
2.3	10.5	39.82	5.68**	1418	*	*		
2.4	9.69	32.96	7.34**	1305	14.97	15.12	0.9952	200 – 1000
2.5	10.03	33.65	7.84**	1341	15.97	15.76	0.9946	200 – 1000
2.9	9.68	41.39	*	1438	*	*		
ADD-3	10.35	24.93	*	1227	3.28	6.46	0.9982	200 – 1000
ADD-4	10.24	28.77	*	1268	7.19	9.40	0.9964	200 – 1000

***** Data was not obtained.
*** Questionable numbers from analysis.

Conclusions and Recommendations

The HLW mixing study produced two washed simulated sludges (representing tanks 241-AZ-101 and 241-AZ-102 sludge), a Sr/TRU washed precipitate produced from tank 241-AZ-107 simulant, and a concentrated blended eluate simulant based upon eluates from processing 241-AZ-102 supernate. The physical properties and rheological properties of these individual products and their planned blends with and without glass formers were measured. Based upon these results the following conclusions were found.

- Shearing reduces the particle size and modifies the particle size distribution for the simulated sludges and the Sr/TRU precipitate, which could impact filtration.
- Shearing the Sr/TRU precipitate reduced the yield stress of the precipitate.
- The rheological properties of the AZ-101 and AZ-102 simulated sludges and the Sr/TRU precipitate are distinctly nonnewtonian and can be represented by a Bingham flow model.
- The blended eluate simulant is a Newtonian fluid.
- The yield stress as determined by the vane method appears to agree well with the maximum observed in the initial portion of the up flow. This could be an indication that slip is occurring in the flow curve measurement.
- The yield stress (Bingham model) is a strong function of the insoluble solids loading for the AZ-101, AZ-102 simulated sludges and for the simulated AN-107 Sr/TRU precipitate.
- The consistency of the simulated sludges is not significantly impacted by the change in insoluble solids until very high solids loading are reached.
- A comparison of the simulated AZ-102 sludge to the actual AZ-102 waste indicates that the simulant's rheology behaves similarly to the real waste.
- Physical property relationships were determined for the slurries including weight percent total solids, weight percent insoluble solids, and density.
- Yield stress relationships were determined for both sludges and precipitate as functions of either total solids or insoluble solids.
- The viscosity and heat capacity of the blended eluate simulant were determined.
- The yield stress of the blended wastes was strongly effected by pH with a maximum probably near pH 7.
- The variation in consistency of the simulated sludges was poorly correlated to the change in pH.
- Addition of acid to improve rheology (reduce yield stress) would require reducing the pH to below pH 5 to achieve significant improvement.
- The addition of an equal-solids-loaded Sr/TRU precipitate to an Envelope D waste of similar solids loading will act to slightly reduce the yield stress by diluting the sludge solids.
- The rheological behavior of the blended compositions of LAW waste streams (Sr/TRU precipitate & Eluate) with the base HLW sludge did not greatly impact the rheological behavior of the base HLW sludge.
- The addition of small amounts of the blended eluate will not impact the pH of the simulated sludge.
- Time dependent effects on rheology were observed upon addition of glass formers containing LiOH and NaOH. Rheology of sludge became thinner over time.
- Drying of the slurries at elevated temperatures interfered with obtaining the rheology measurements using the cone and plate on the Haake RS150.
- Since there is no present design basis of the HLW vitrification plant, specifically mixing and transport, the impact of the physical characteristics of the slurries quantified in this study on the HLW vitrification process are unknown.

- Since there is no present design basis of the effected pre-treatment plant, specifically mixing and transport, the impact of the physical characteristics of the Sr/TRU precipitate slurries and Cs/Tc eluate quantified in this study are unknown.

Based upon these conclusions and the other observations that occurred during the study, the following recommendations should be considered when planning additional HLW mixing studies.

- If slippage is evident in the flow curve measurement, then yield stress measurement using the vane rotor and flow curve using a different concentric rotor or parallel plate gaps is recommended to characterize the yield stress and to correct the flow curve. Such tests should include both simulant and actual waste studies.
- Any HLW blending or processing studies must include the expected shearing, since shearing impacts particle size and the flow properties of the waste simulants.
- If acid adjustment of waste pH is considered, then the adjustment must target a pH less than 5 to avoid the peak in yield stress observed near pH 7.
- Acid neutralization studies of HLW should include variations of HLW waste streams blends, such as sludge + Cs, sludge + Tc, sludge + Sr/TRU precipitate, sludge + Sr/TRU precipitate + Tc, etc.
- If acidification of the HLW is added to the WTP process, then additional studies are necessary to determine the limiting pH based upon the settling properties of the slurry, to determine the heat of neutralization, to determine the generation rate and composition of offgas, and to determine the impact of acidification on melter feed properties and glass formulation.
- The use of caustic glass formers such as LiOH and NaOH can benefit the rheology of melter feed by reducing the yield stress of the feed.
- Additional work on modifying the production of sludge simulants through precipitation is recommended. Such studies should aim to decrease the gelatinous nature of the primary metal hydroxide precipitates.

APPENDIX A: Rheograms and Particle Size Results

Table of Appendix A Figures

FIGURE A - 1 Simulated AZ-101 Flow Curves @ 298 K {7.5, 10, 12.5, 15, 16, 17, & 18 wt. % IS}

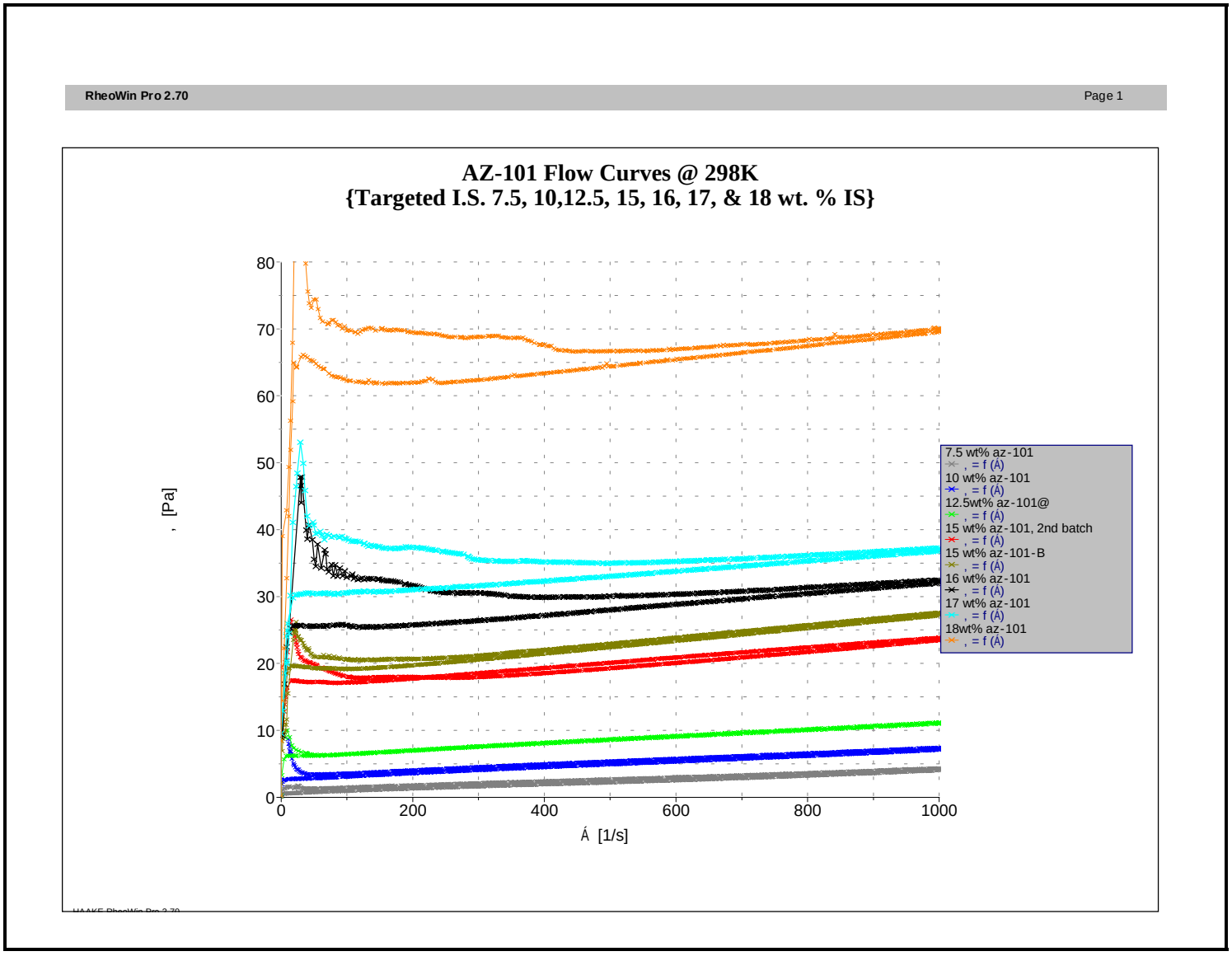


FIGURE A - 2 Simulated AZ-101 Flow Curve @ 293 K, 20 wt. % IS

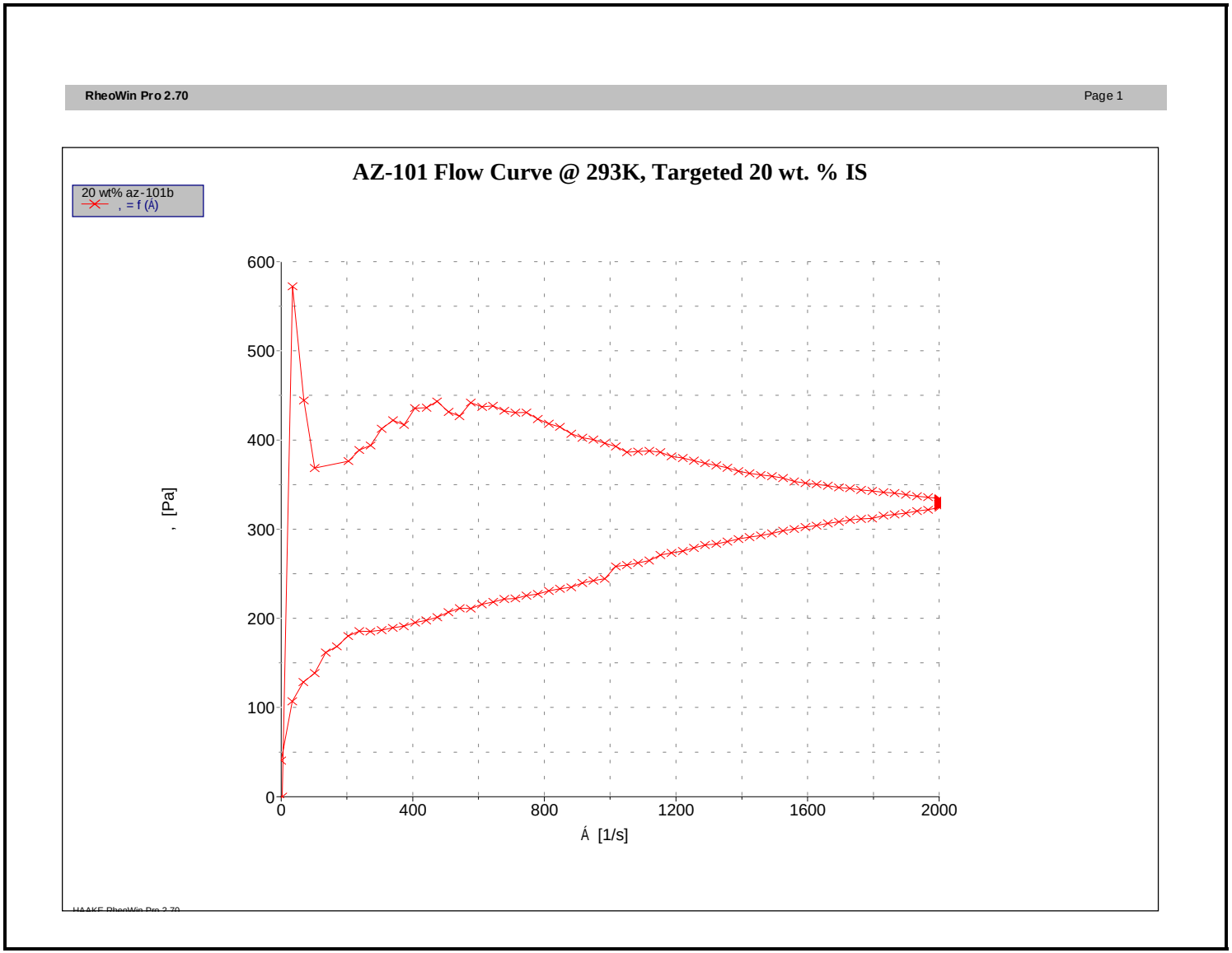


FIGURE A - 3 Simulated AZ-101 Flow Curves @ 323 K

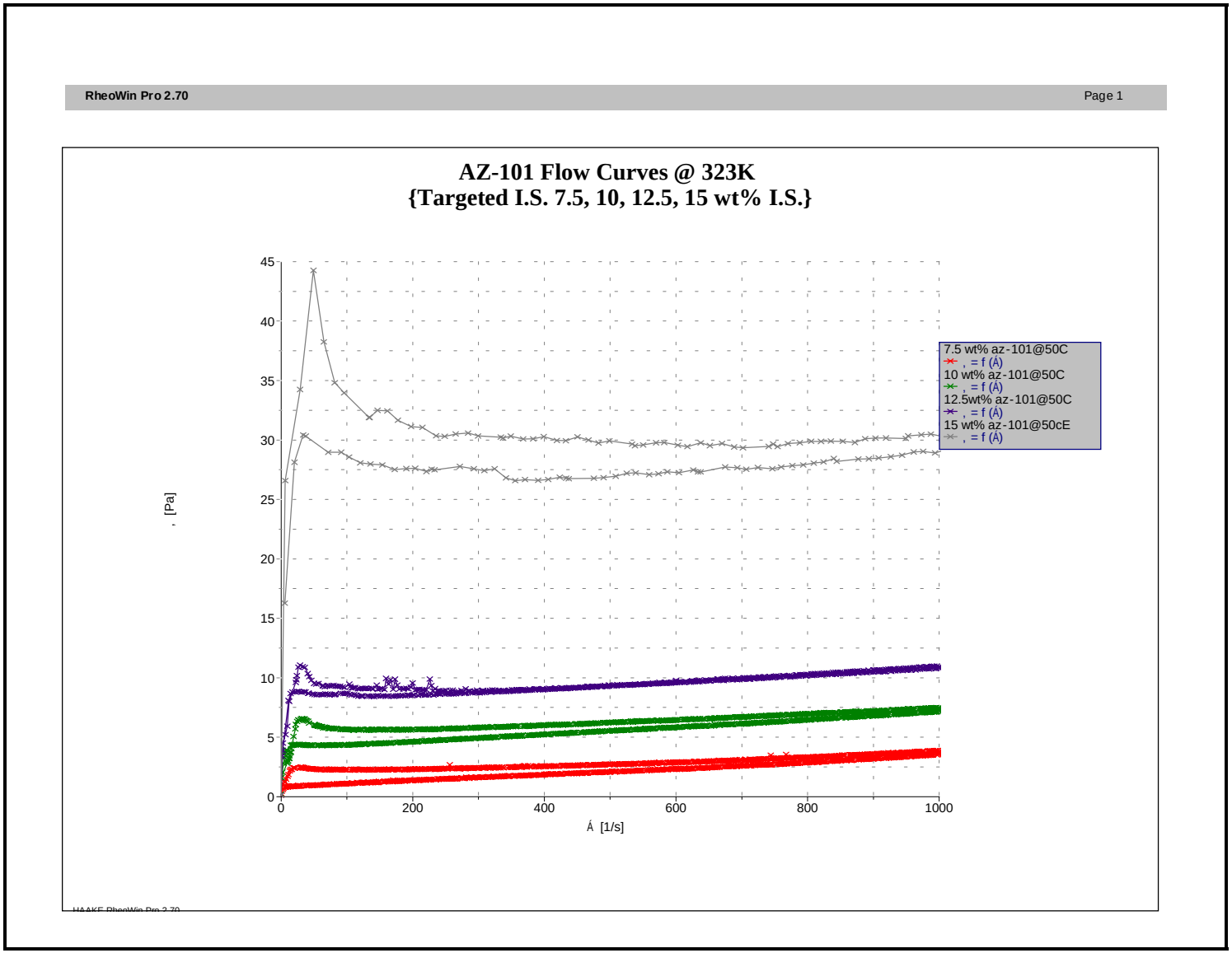


FIGURE A - 4 Simulated AZ-101. 15 wt. %, 2nd Batch, Flow Curve @ 298 K

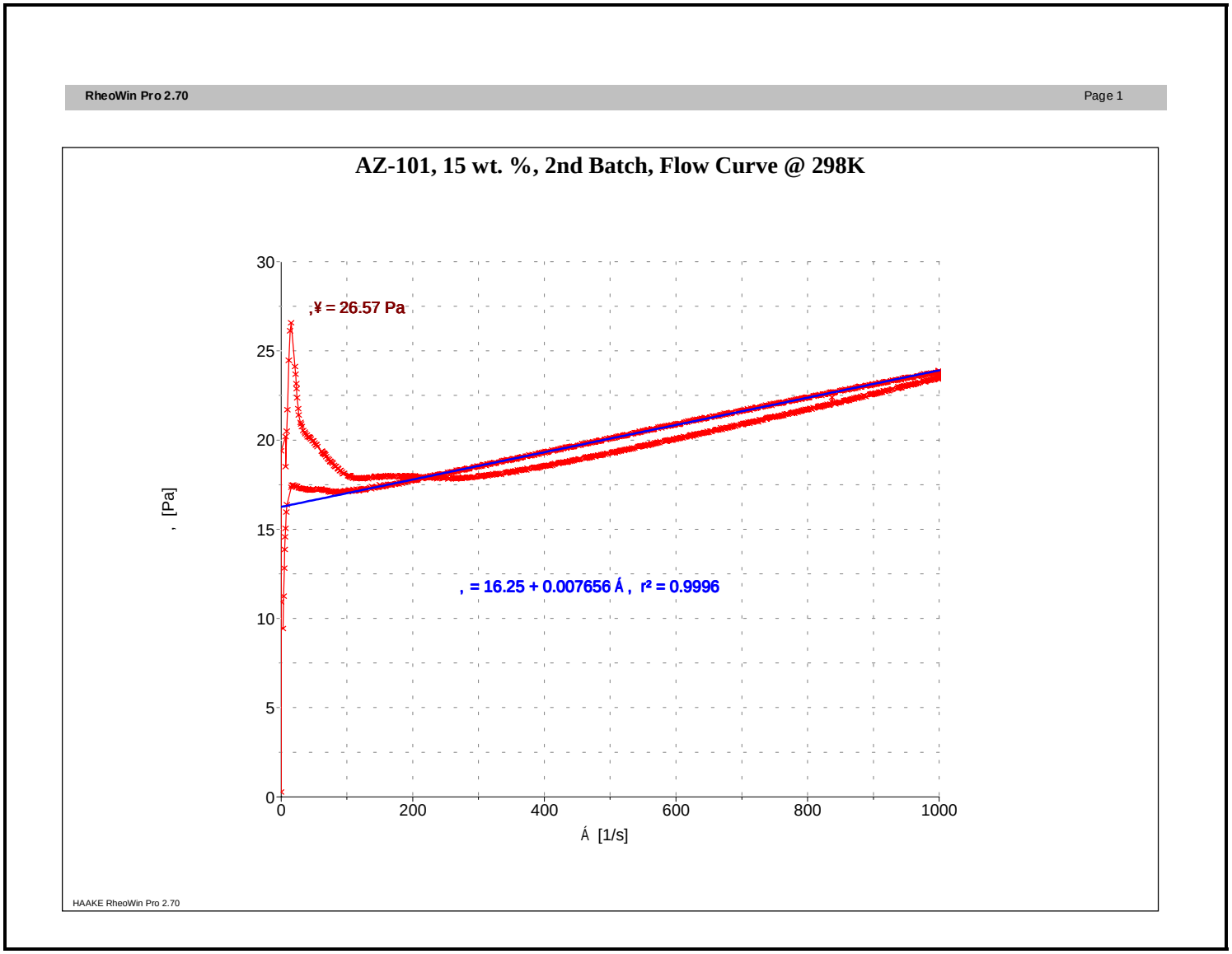


FIGURE A - 5 Simulated AZ-101, 15 wt. % IS Yield Stress Using FL-22 Vane for Various Rotational Speeds @ 298 K

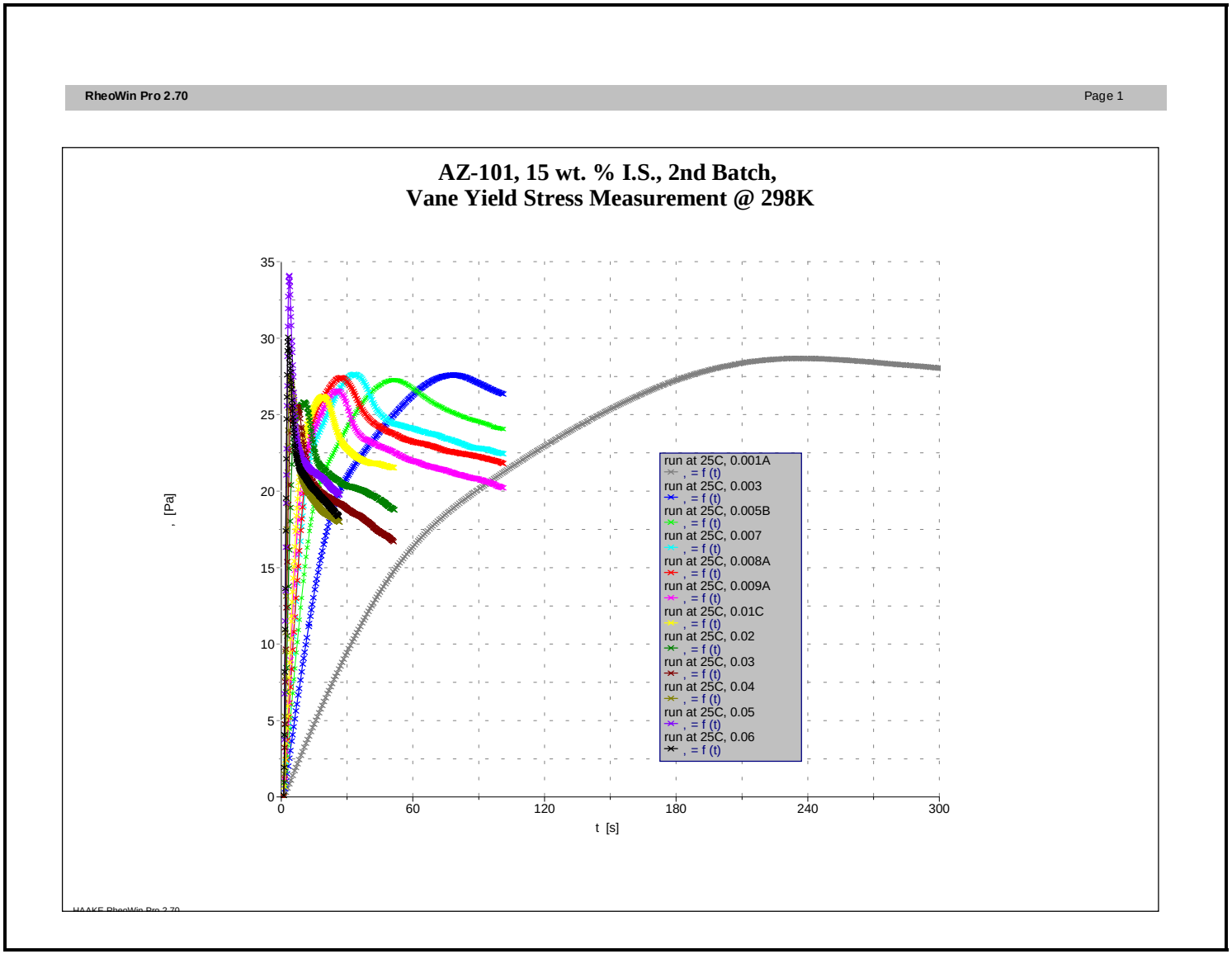


FIGURE A - 6 Simulated AZ-102 Flow Curves @ 298 K {10, 12.5, 13.75, 15, 17, 18, & 19 wt. % IS}

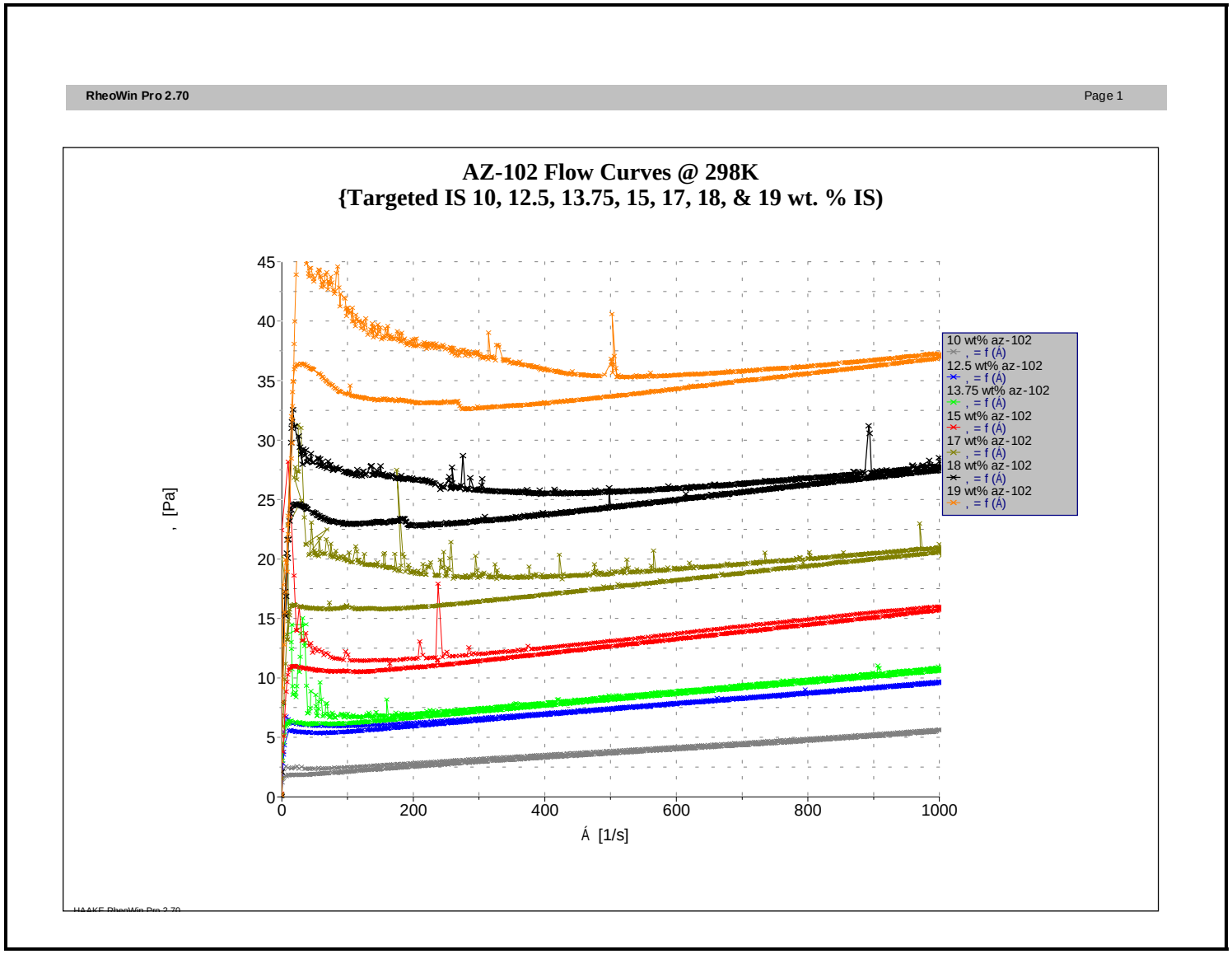


FIGURE A - 7 Simulated AZ-102 Flow Curves @ 298 K for 20 wt. % IS

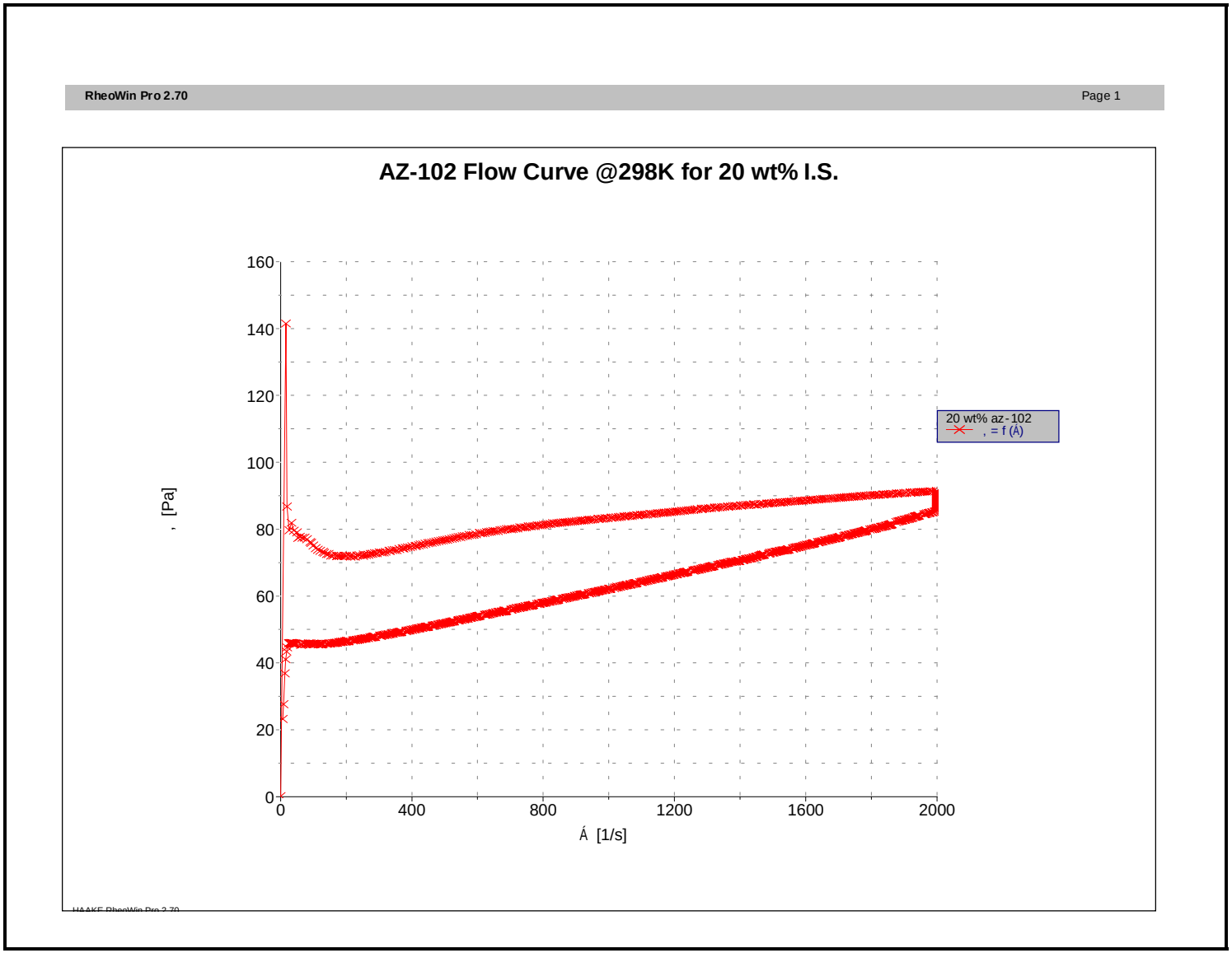


FIGURE A - 8 Simulated AZ-102 Flow Curves @ 323 K

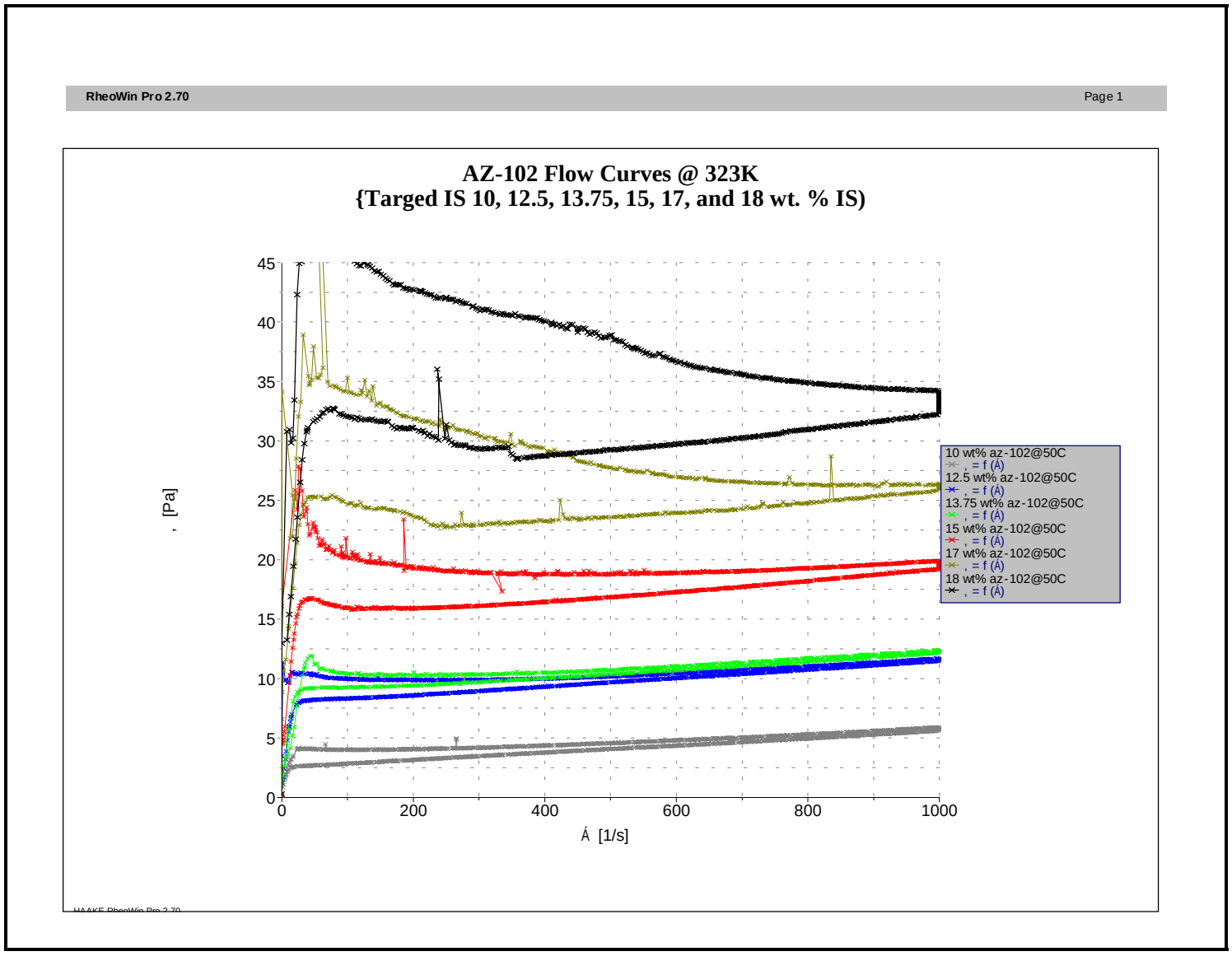


FIGURE A - 9 Simulated AN-107, Sr/TRU Precipitated/Washed Sludge Flow Curves @ 298 K

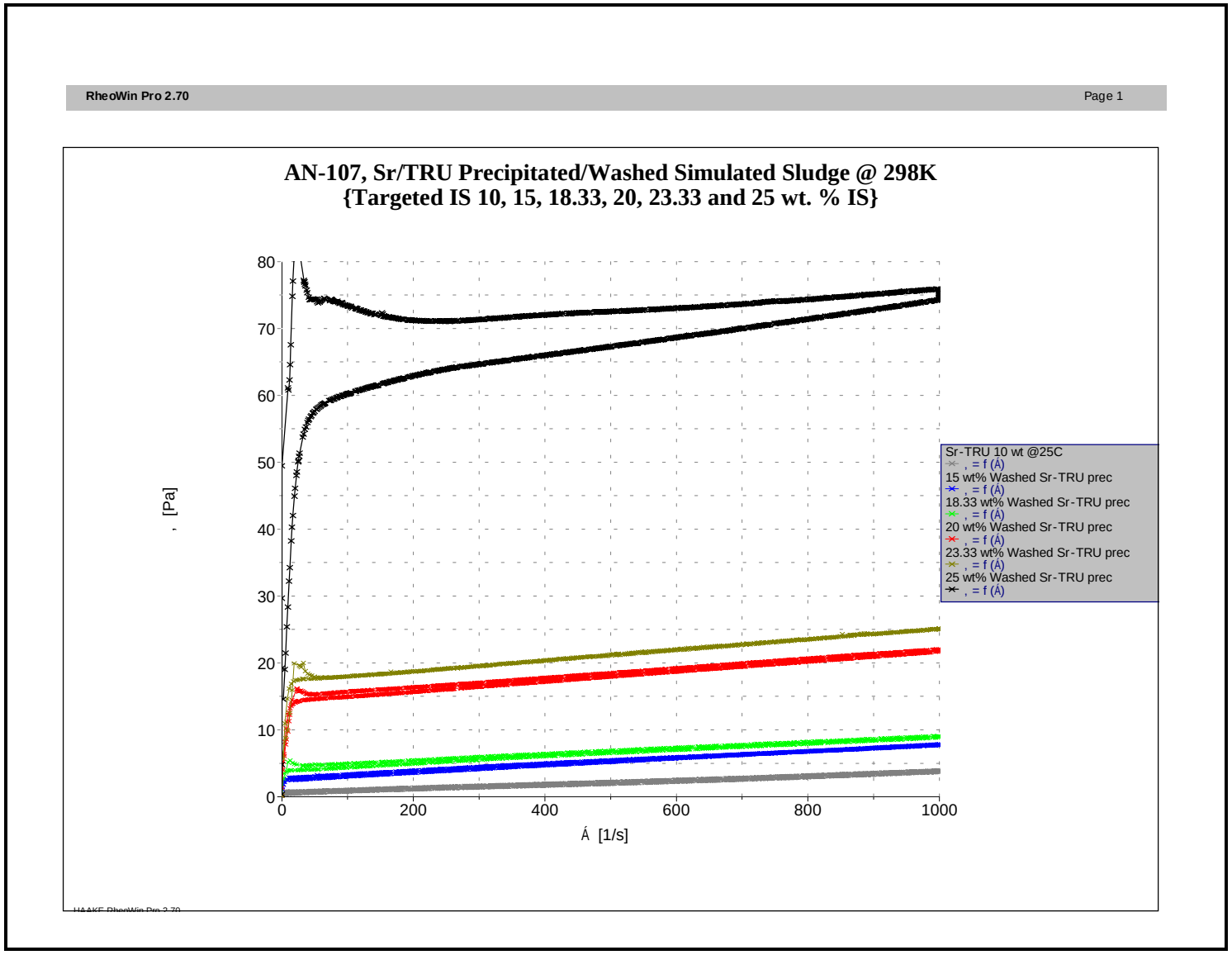


FIGURE A - 10 Simulated AN-107, Sr/TRU Precipitated/Washed Sludge Flow Curves @ 323 K

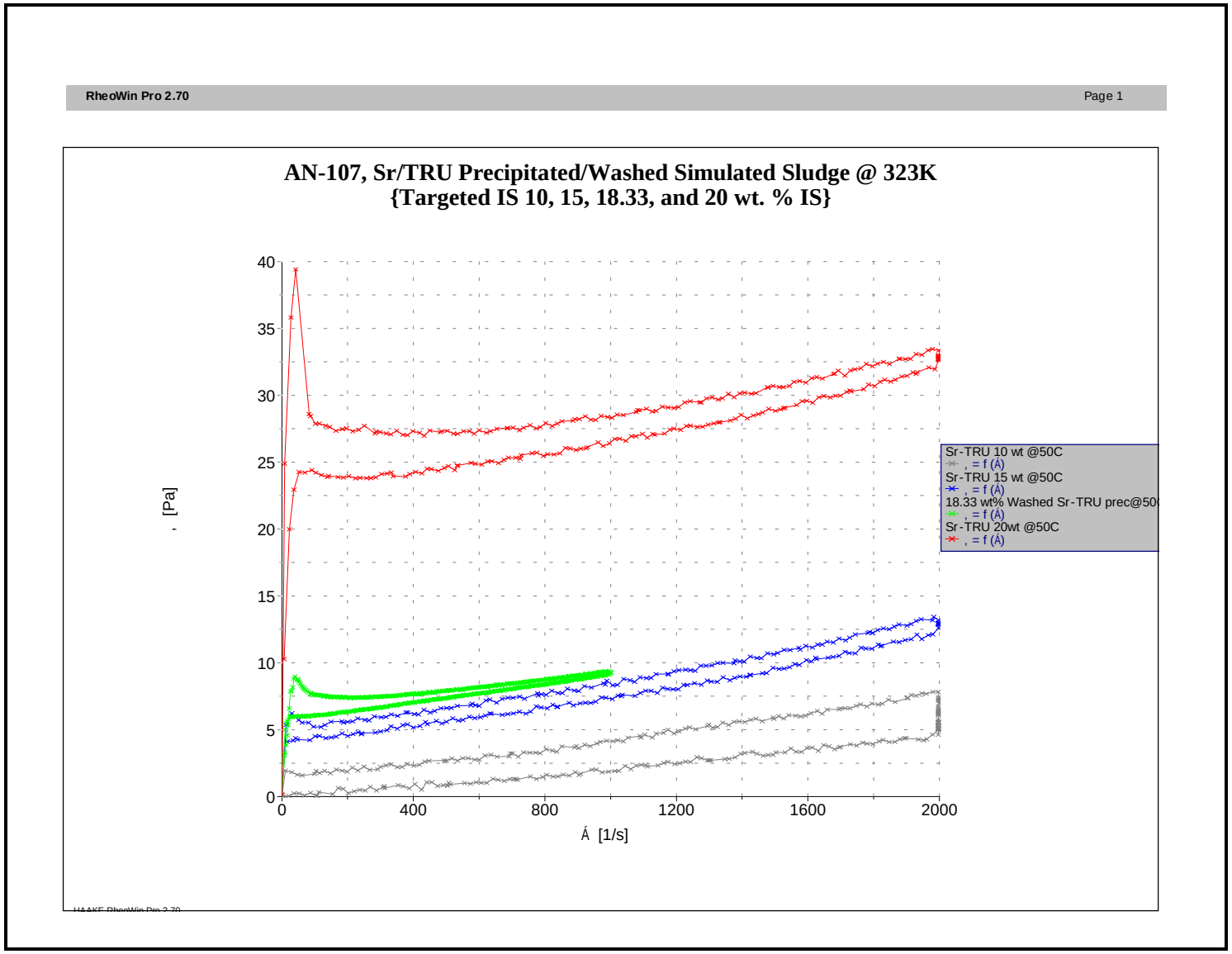


FIGURE A - 11 AN-102 Cs/Tc Eluate Flow Curves From 293 K to 353 K

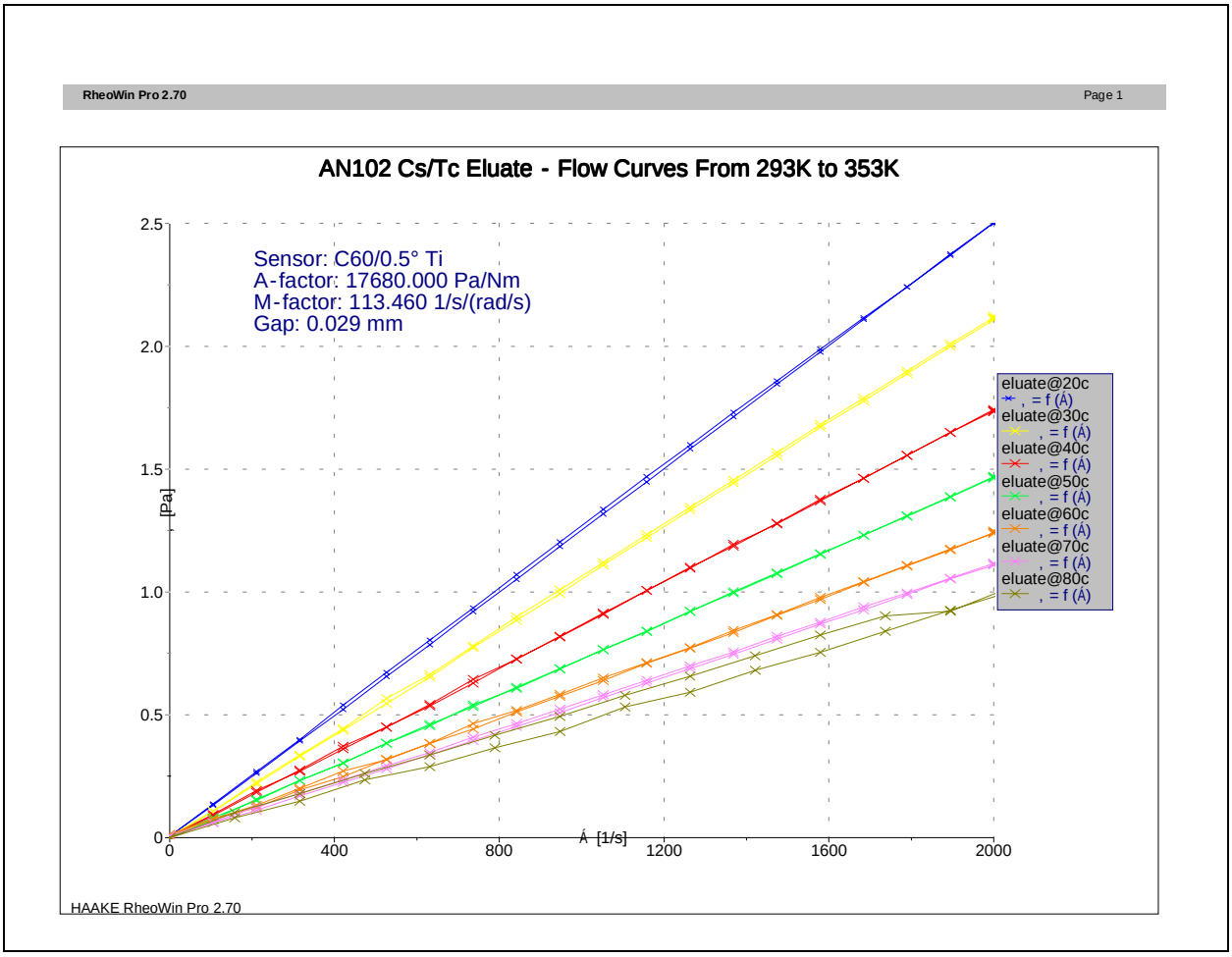


FIGURE A - 12 Flow Curves For Test 1.3, 1.4, 1.5, ADD-1, & ADD-2 with Glass Formers @ 298 K

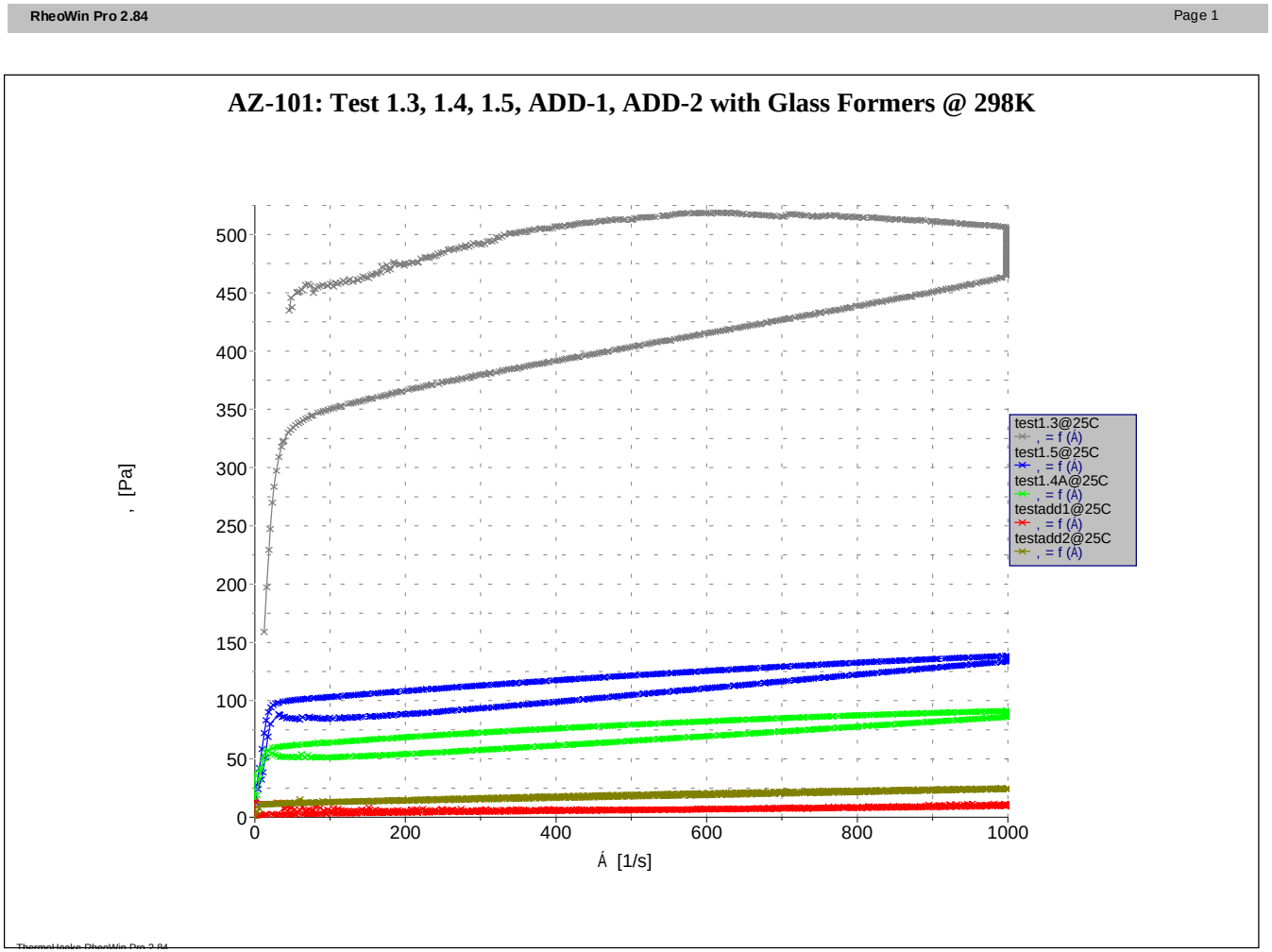


FIGURE A - 13 AZ-101 15 wt.% I.S. 30-Day Mixing Test

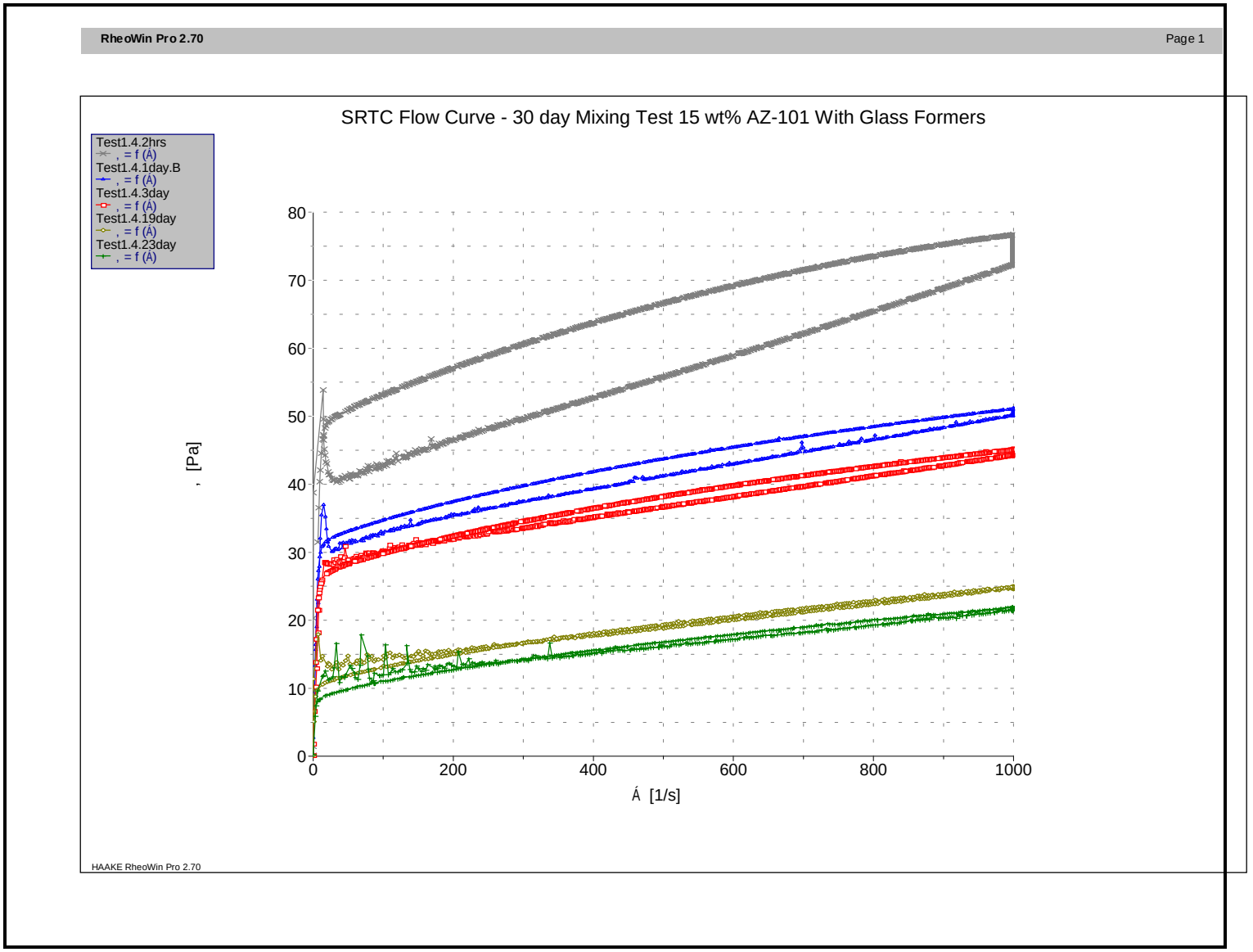


FIGURE A - 14 Flow Curves For Test 2.3, 2.4, 3.5, 2.9, ADD-3, & ADD-4 @ 298 K

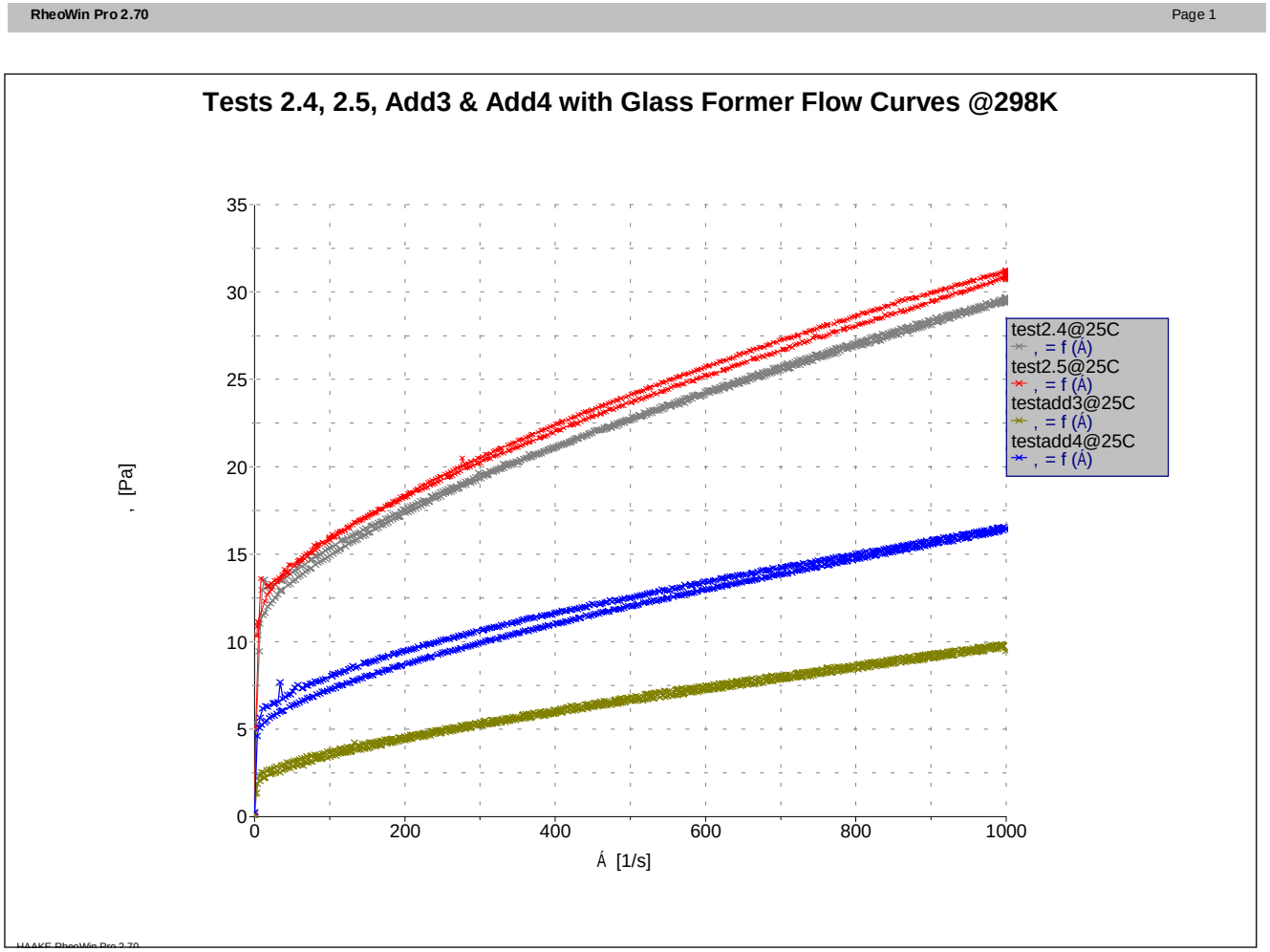


FIGURE A - 15 Flow Curves for pH-Adjusted Test 1.4 at 298 K

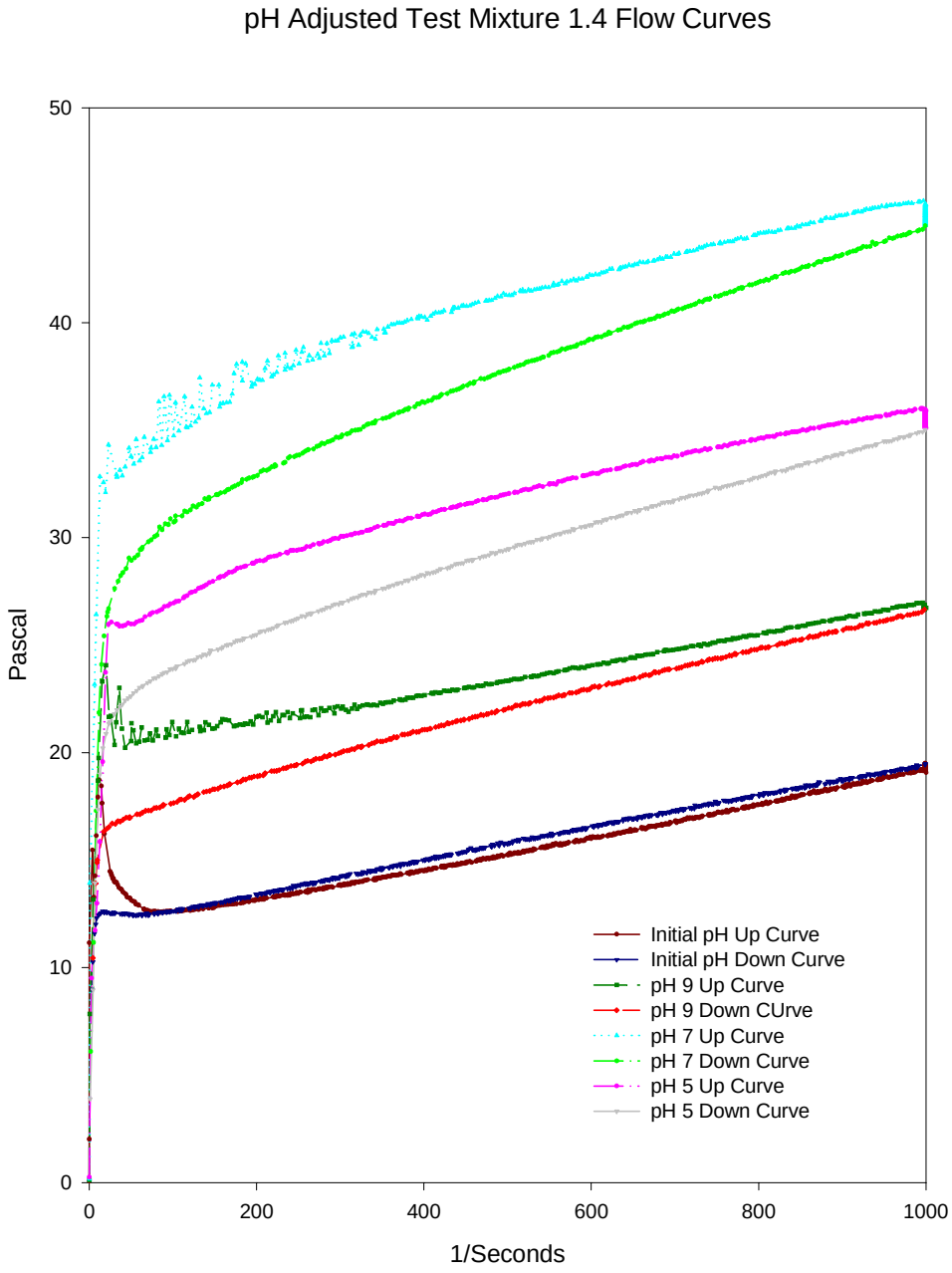


FIGURE A - 16 Flow Curves for pH-adjusted Test 1.5 at 298 K

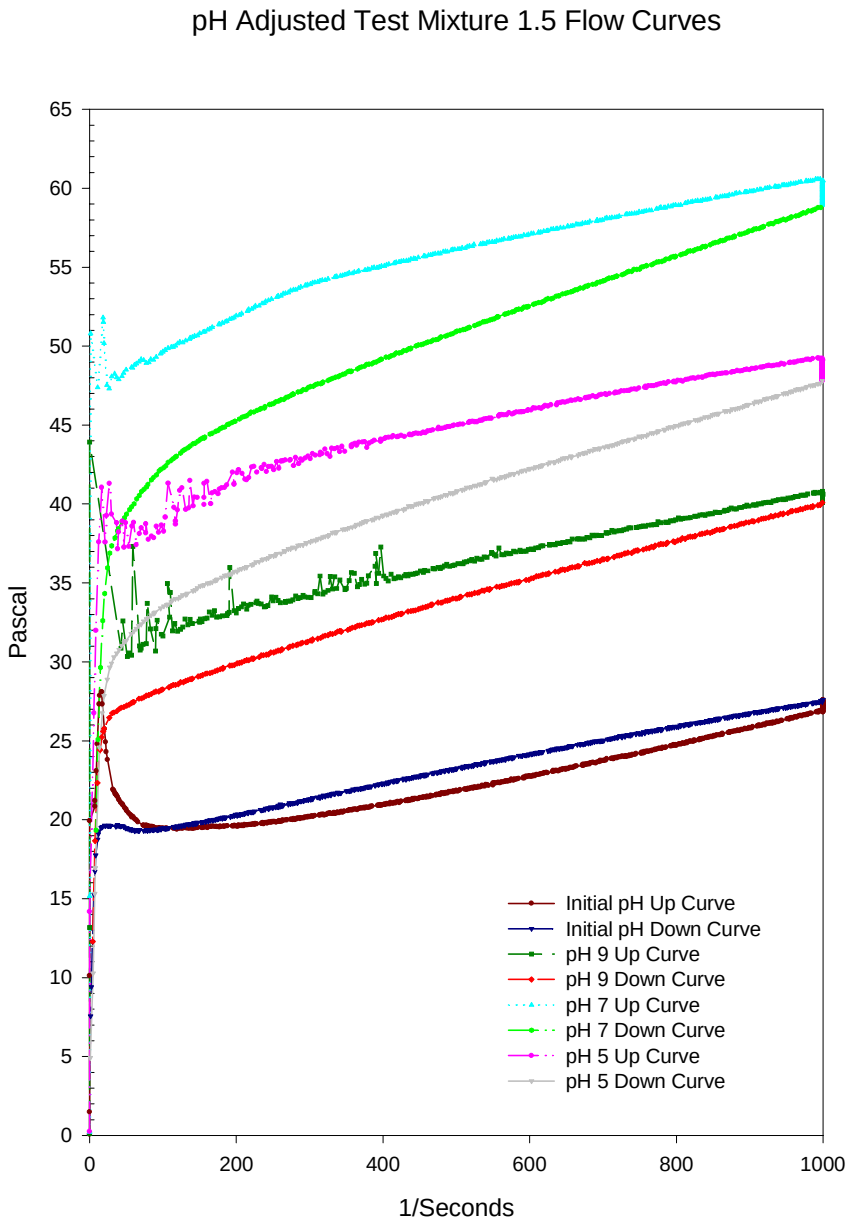


FIGURE A - 17 Flow Curve for pH adjusted Test 2.3 at 298 K

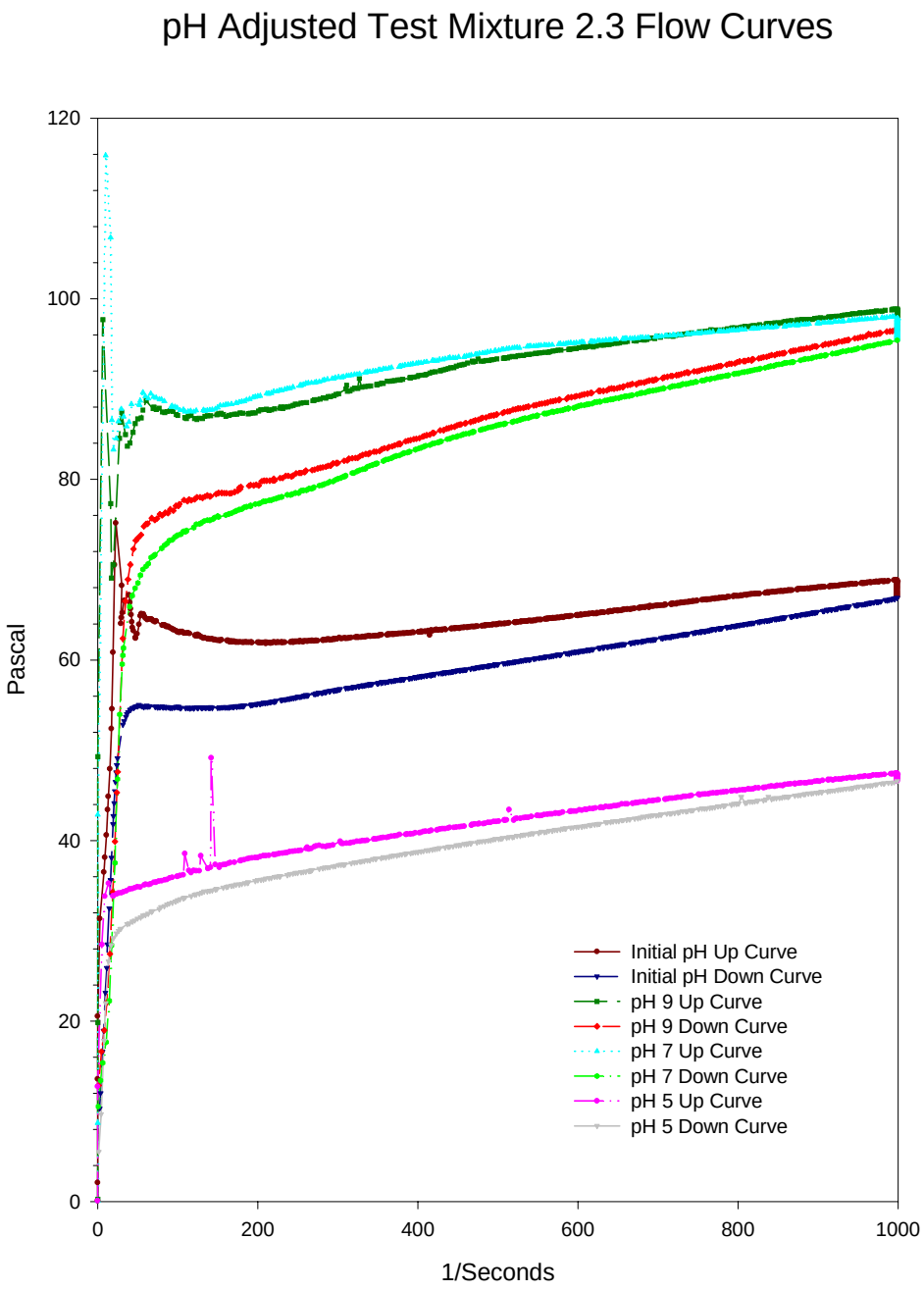


FIGURE A - 18 Flow Curves for pH-adjusted Test 2.5 at 298 K

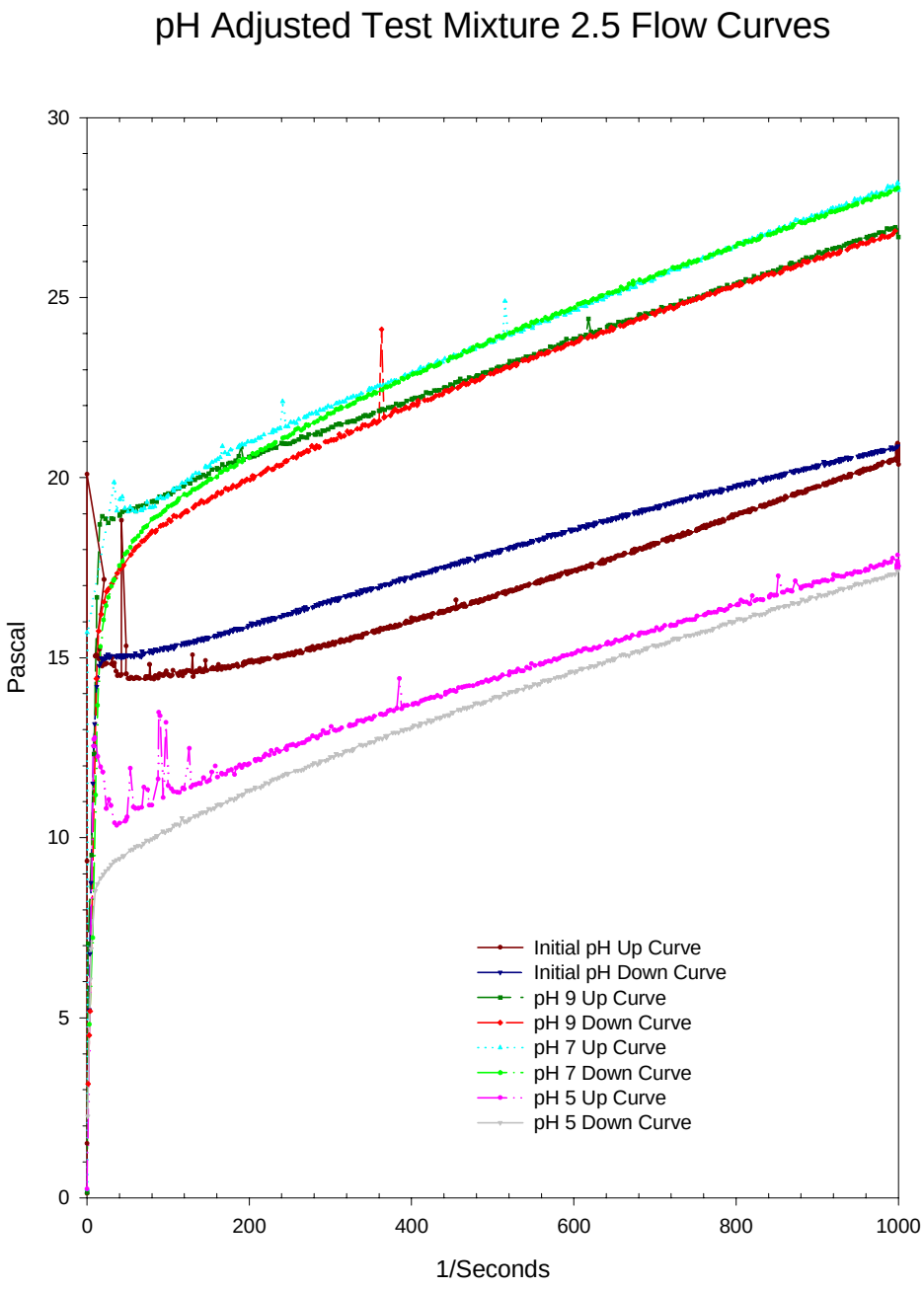


FIGURE A - 19 AZ-101 Sludge Simulant Particle Size Before Shearing

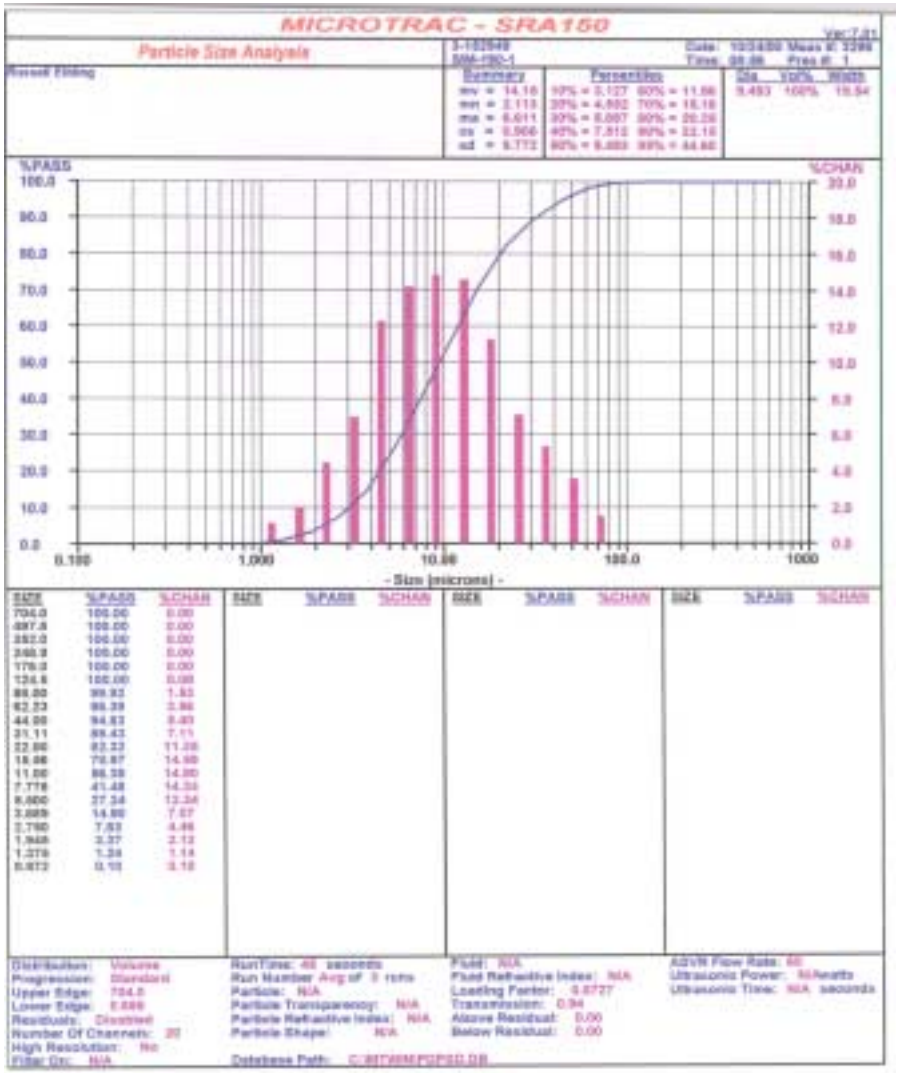


FIGURE A - 20 AZ-101 Sludge Simulant Particle Size After Shearing

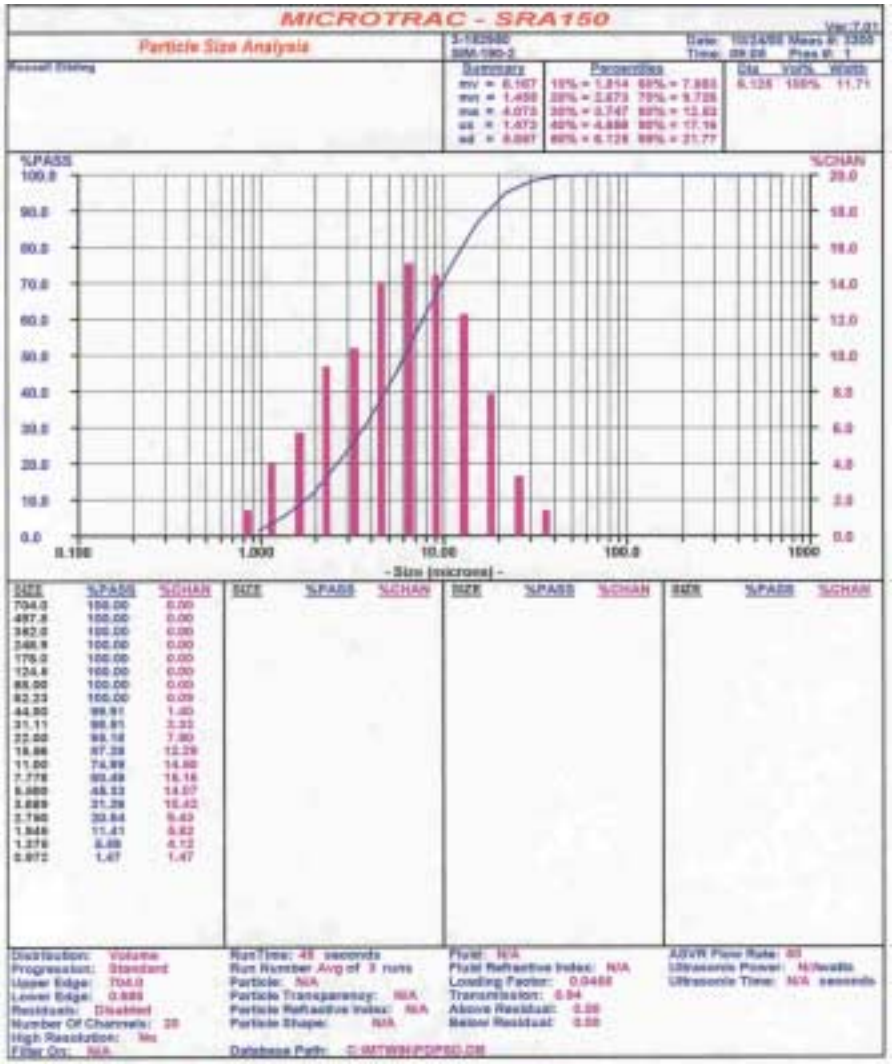


FIGURE A - 21 AZ-102 Sludge Simulant Particle Size Before Shearing

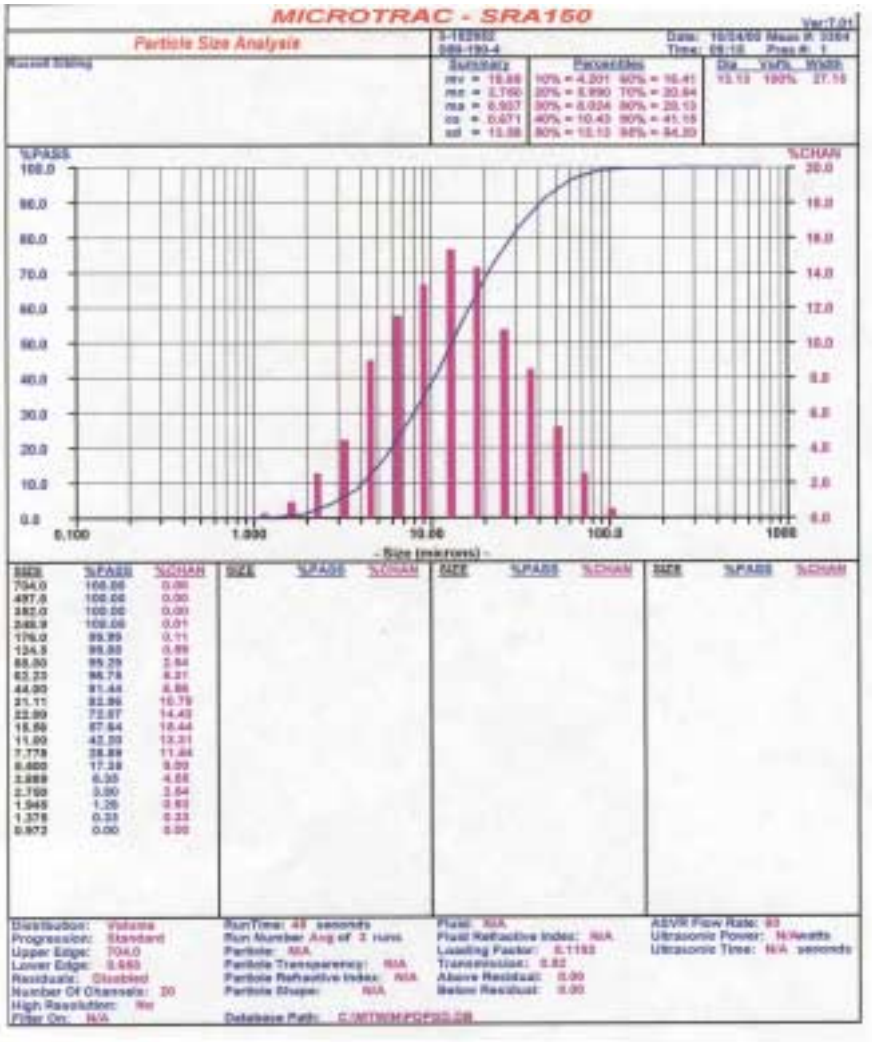


FIGURE A - 22 AZ-102 Sludge Simulant Particle Size After Shearing

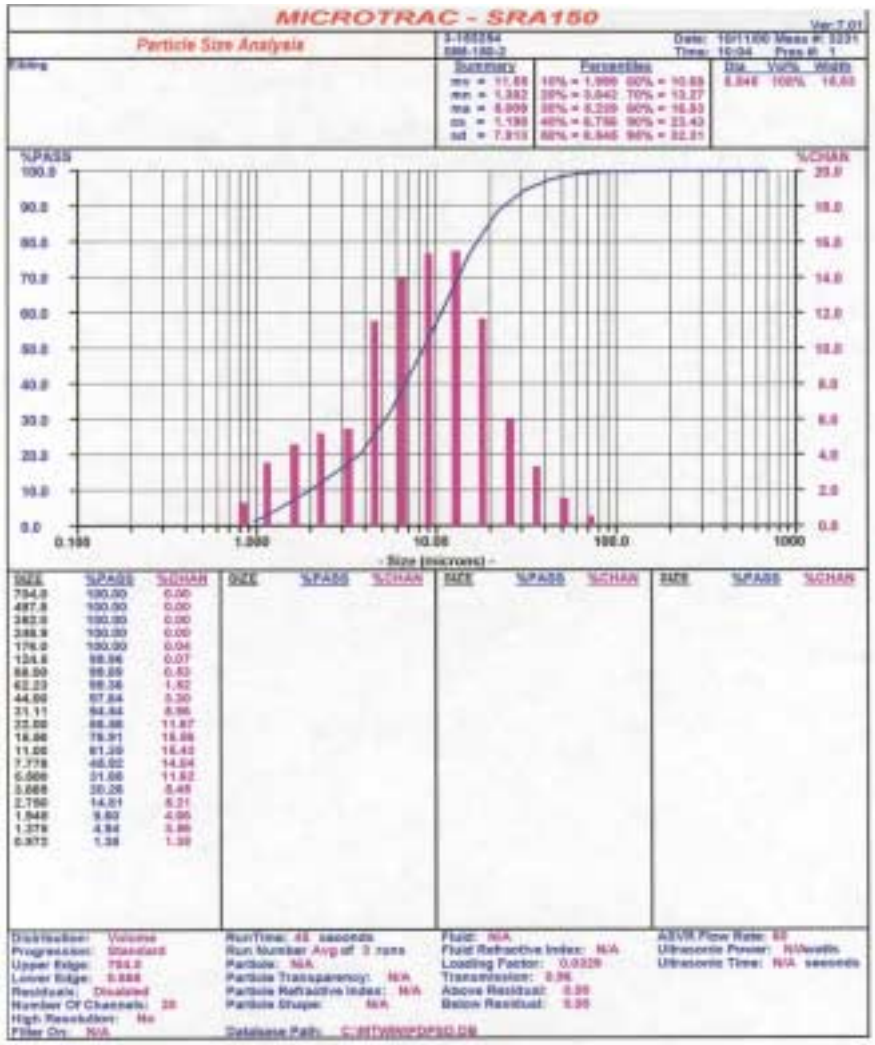


FIGURE A - 23 AN-107 Sr/TRU Prep/Washed Particle Size Before Shearing

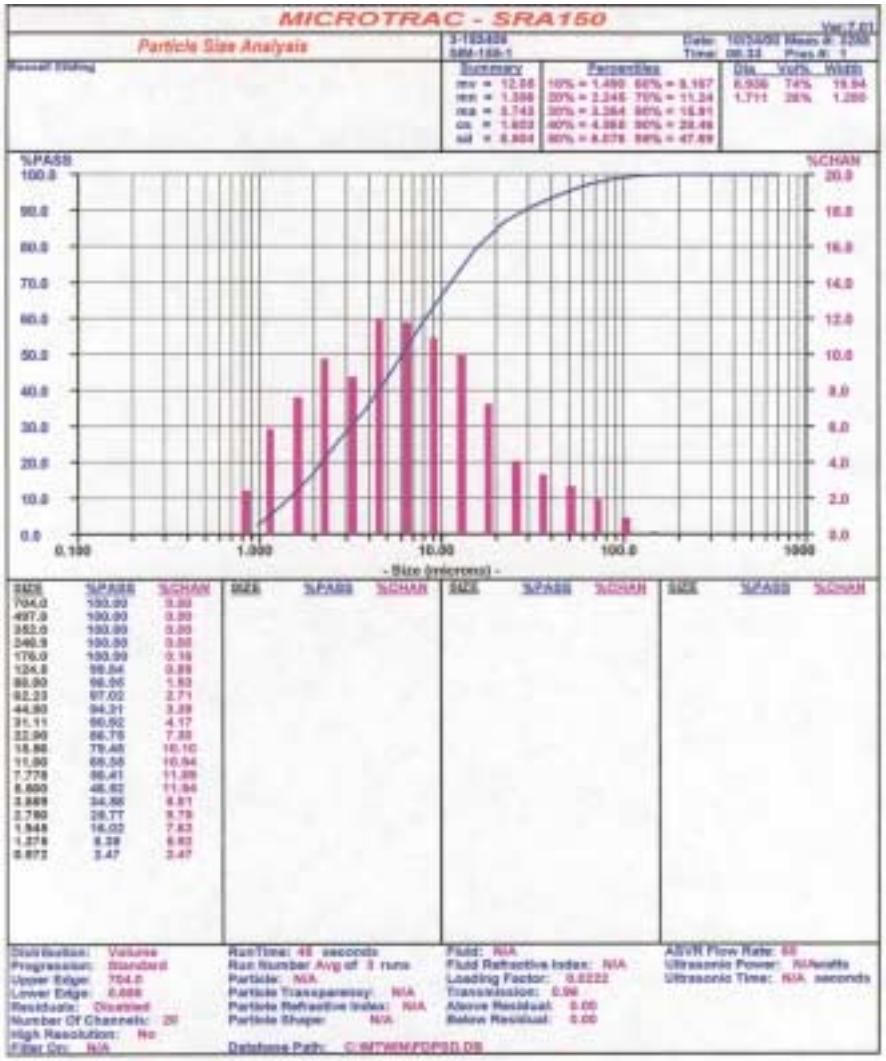


FIGURE A - 24 AN-107 Sr/TRU Prep/Washed Particle Size After Shearing

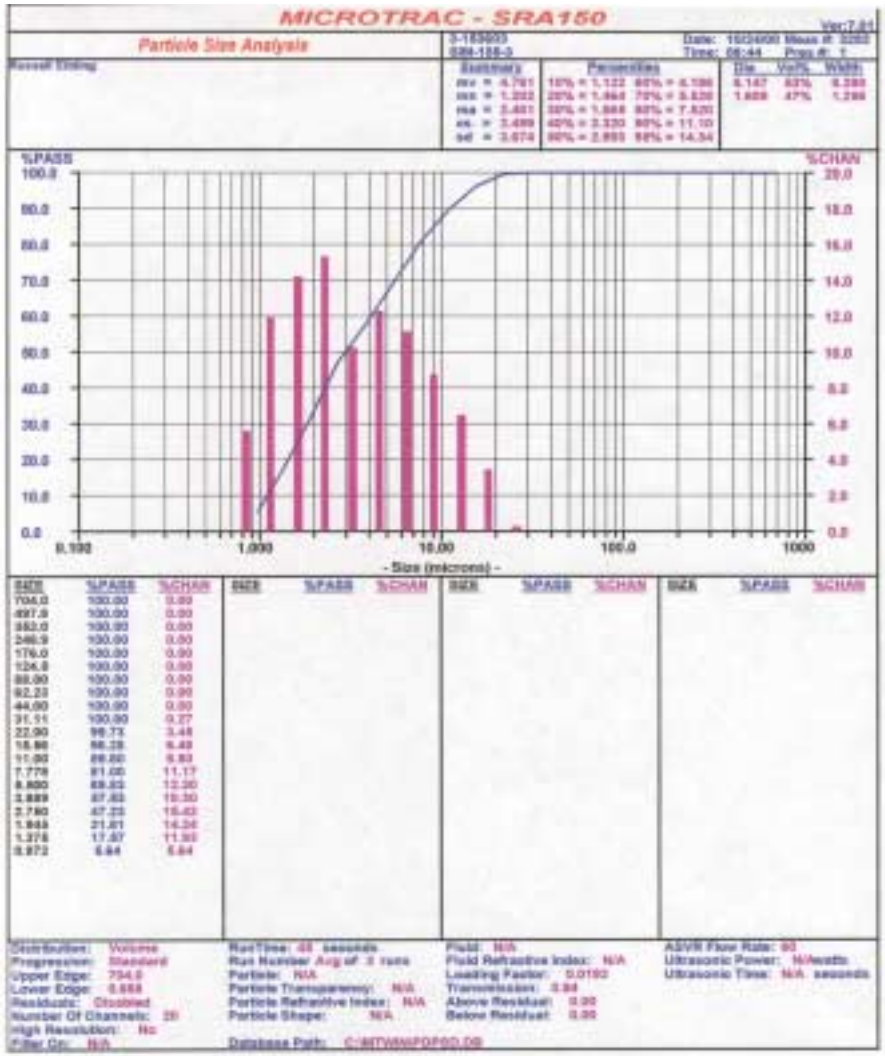


FIGURE A - 25 Particle Size Test No. 1.3, without Glass Formers

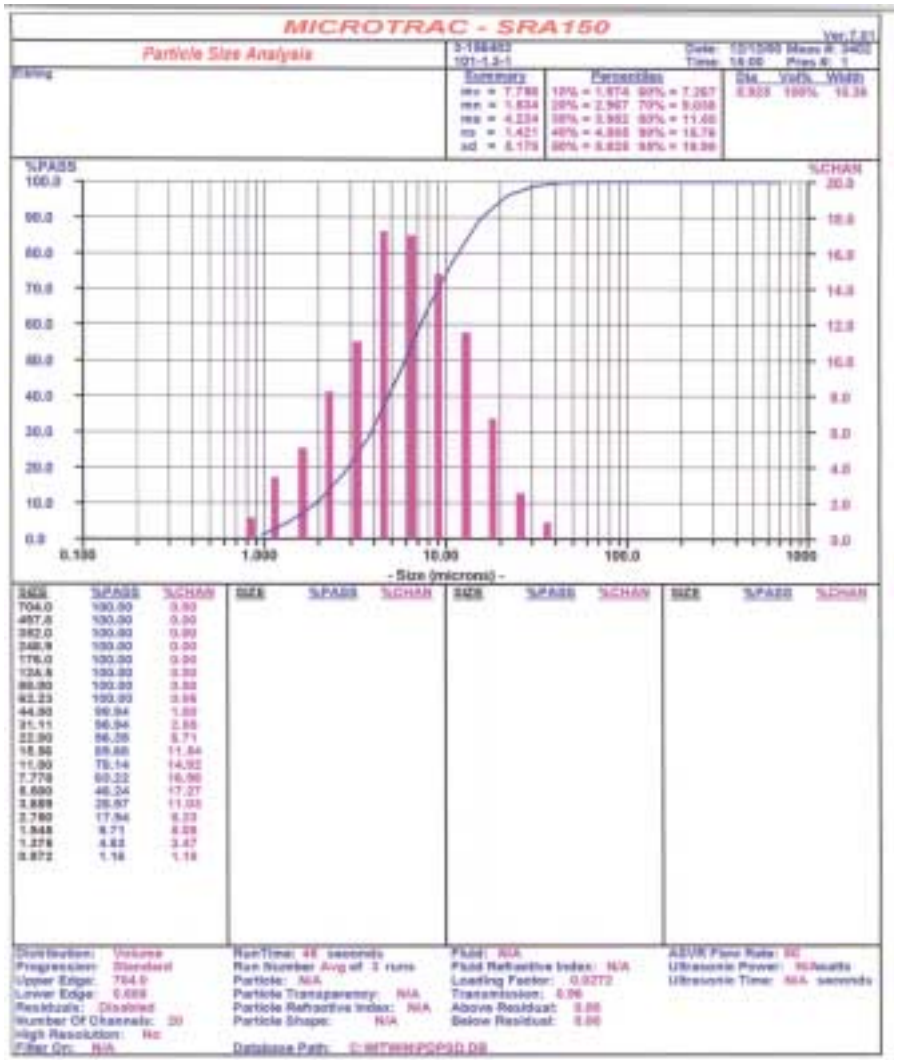


FIGURE A - 26 Particle Size Test No. 1.3, with Glass Formers

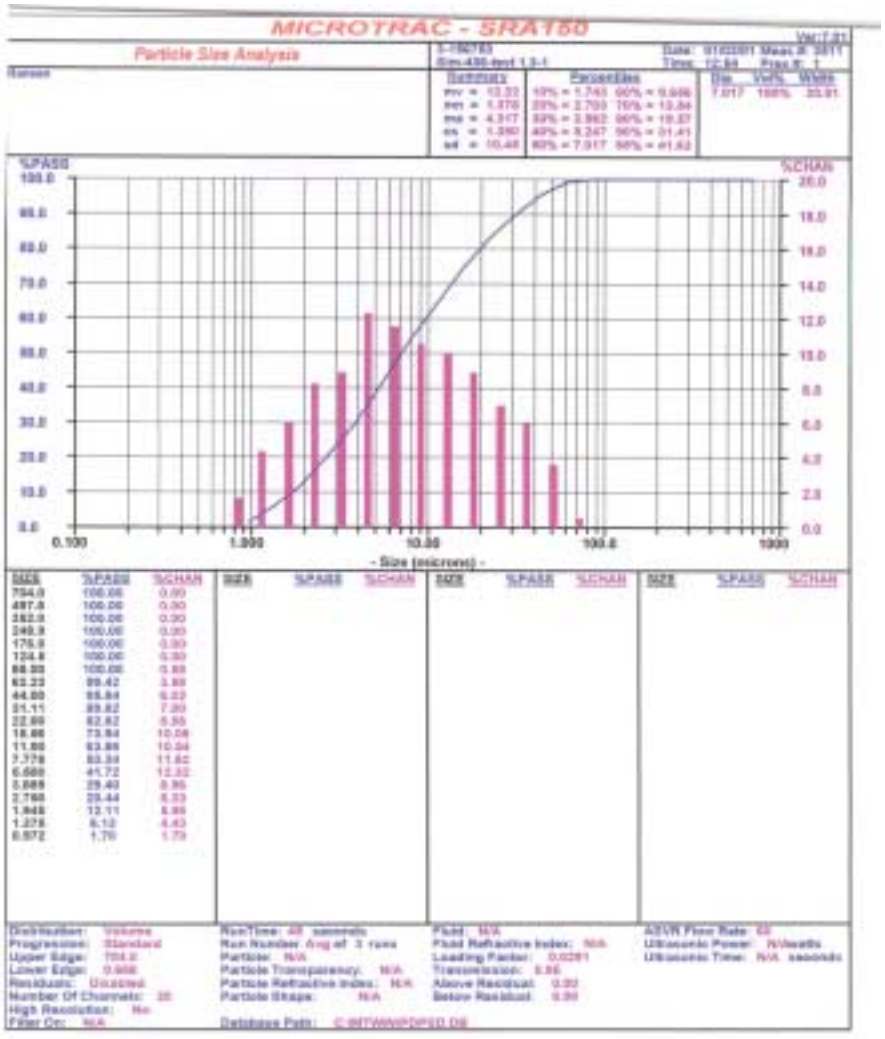


FIGURE A - 27 Particle Size Test No. 1.4, without Glass Formers

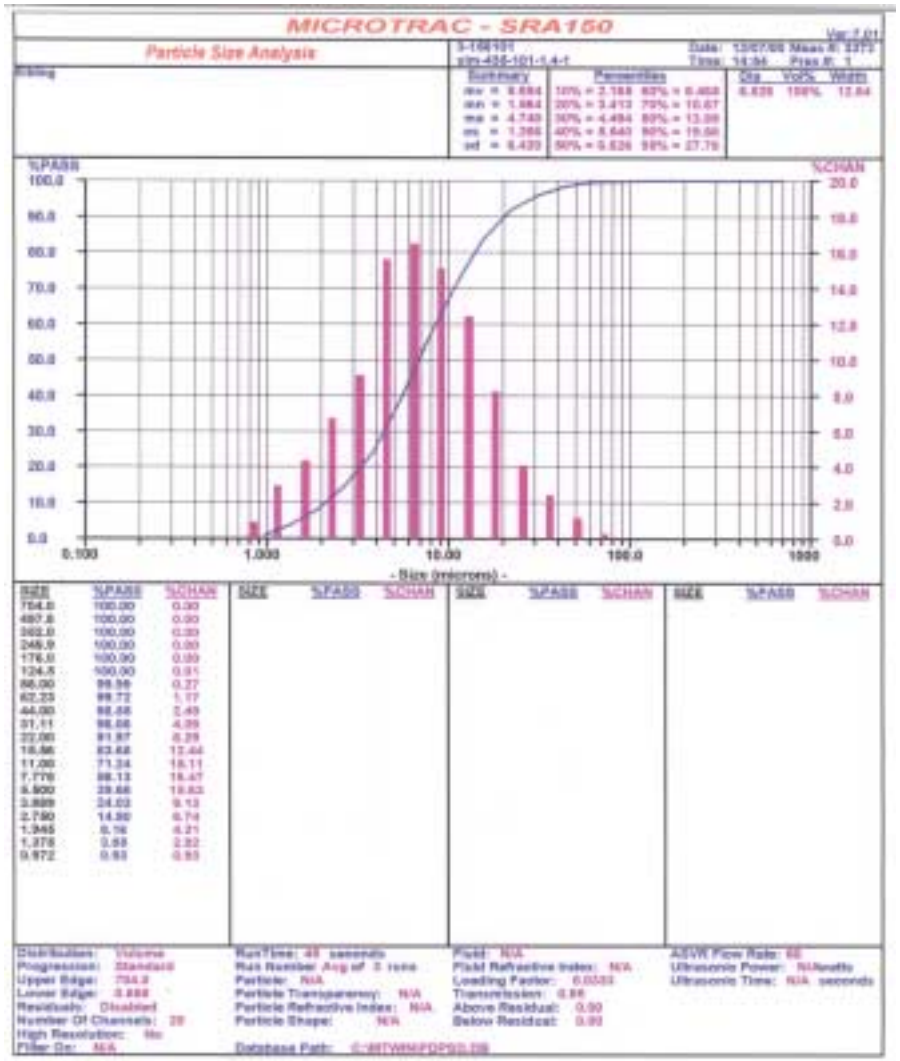


FIGURE A - 28 Particle Size Test No. 1.4, with Glass Formers

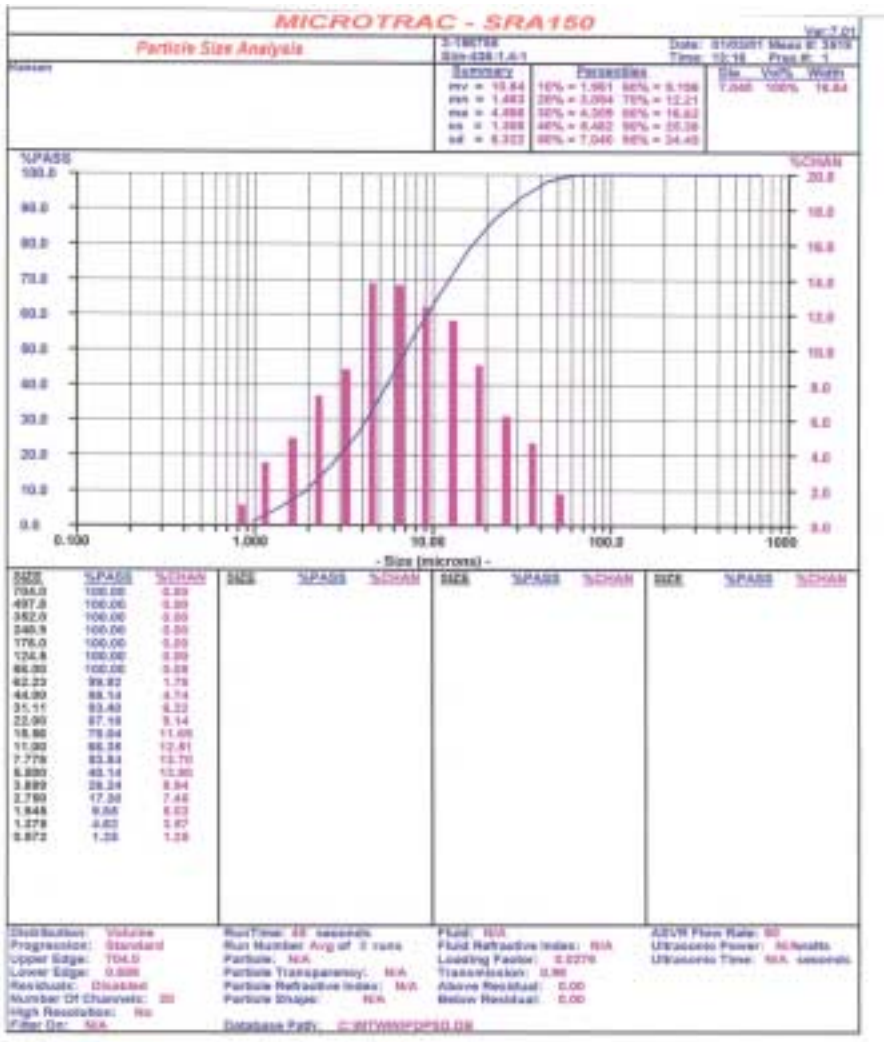


FIGURE A - 29 Particle Size Test No. 1.5, without Glass Formers

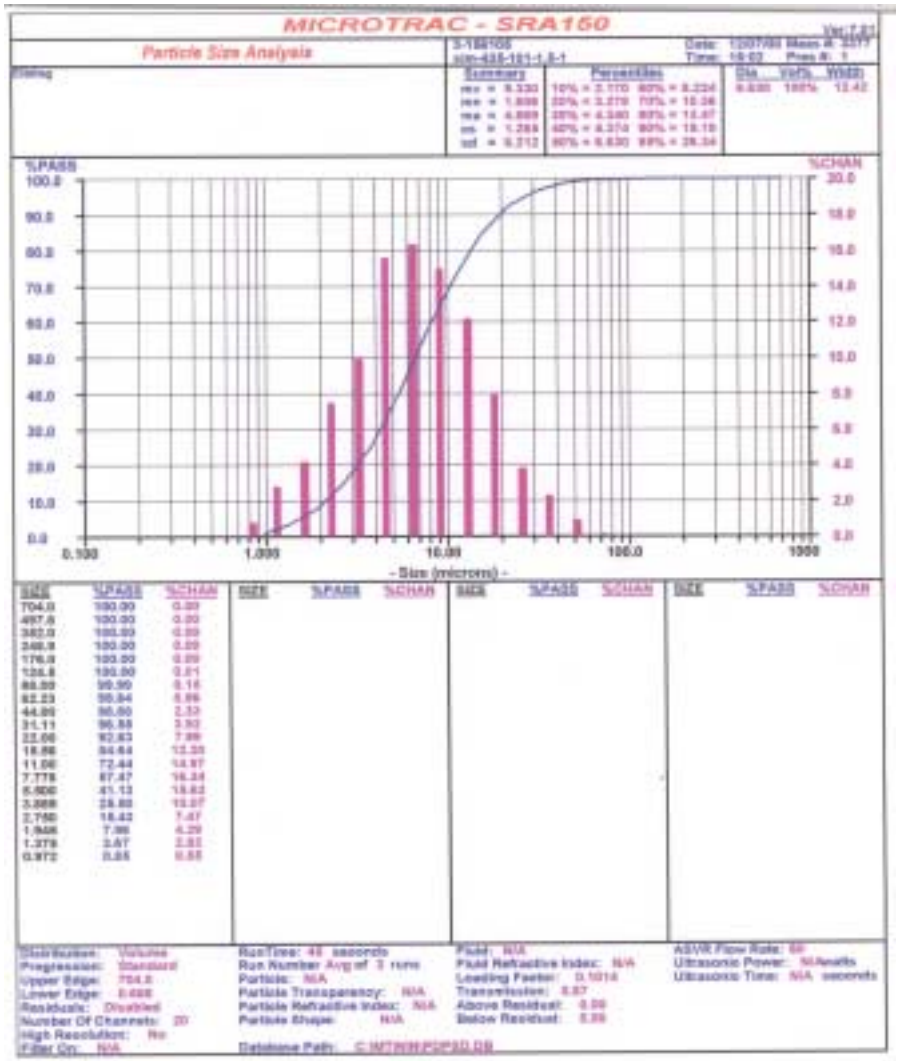


FIGURE A - 30 Particle Size Test No. 1.5, with Glass Formers

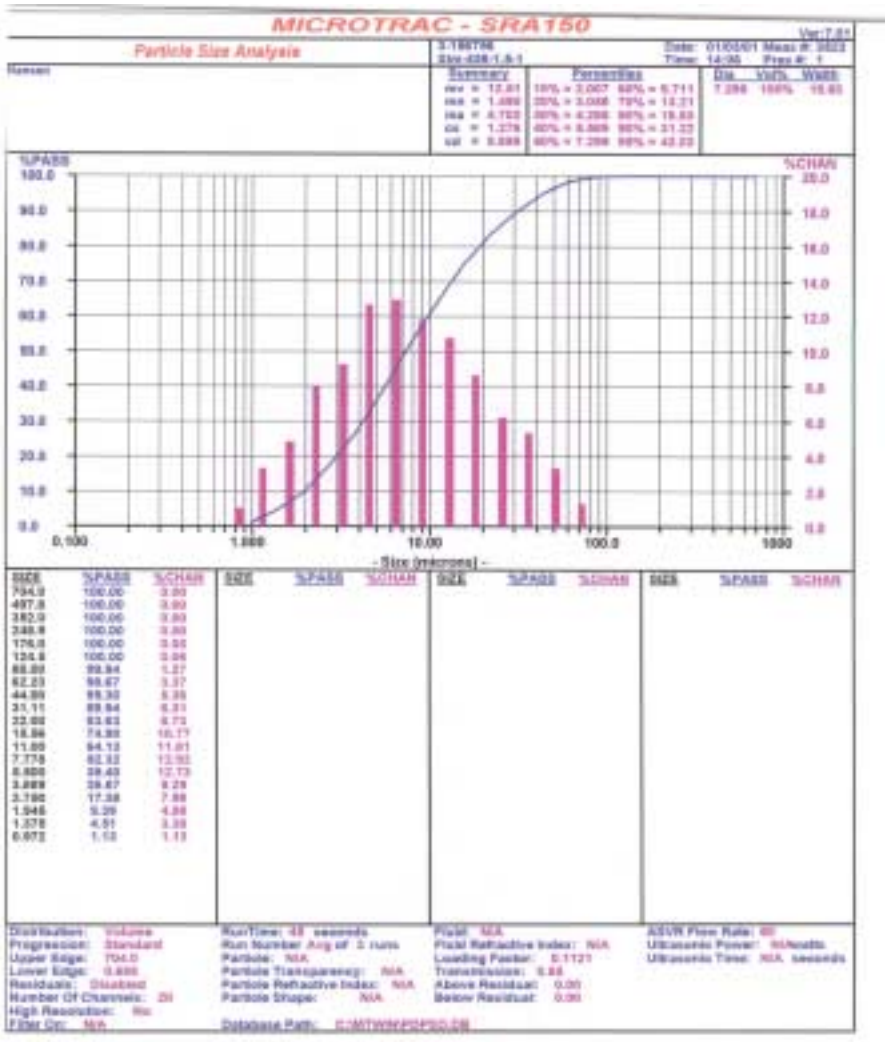


FIGURE A - 31 Particle Size Test No. ADD-1, without Glass Formers

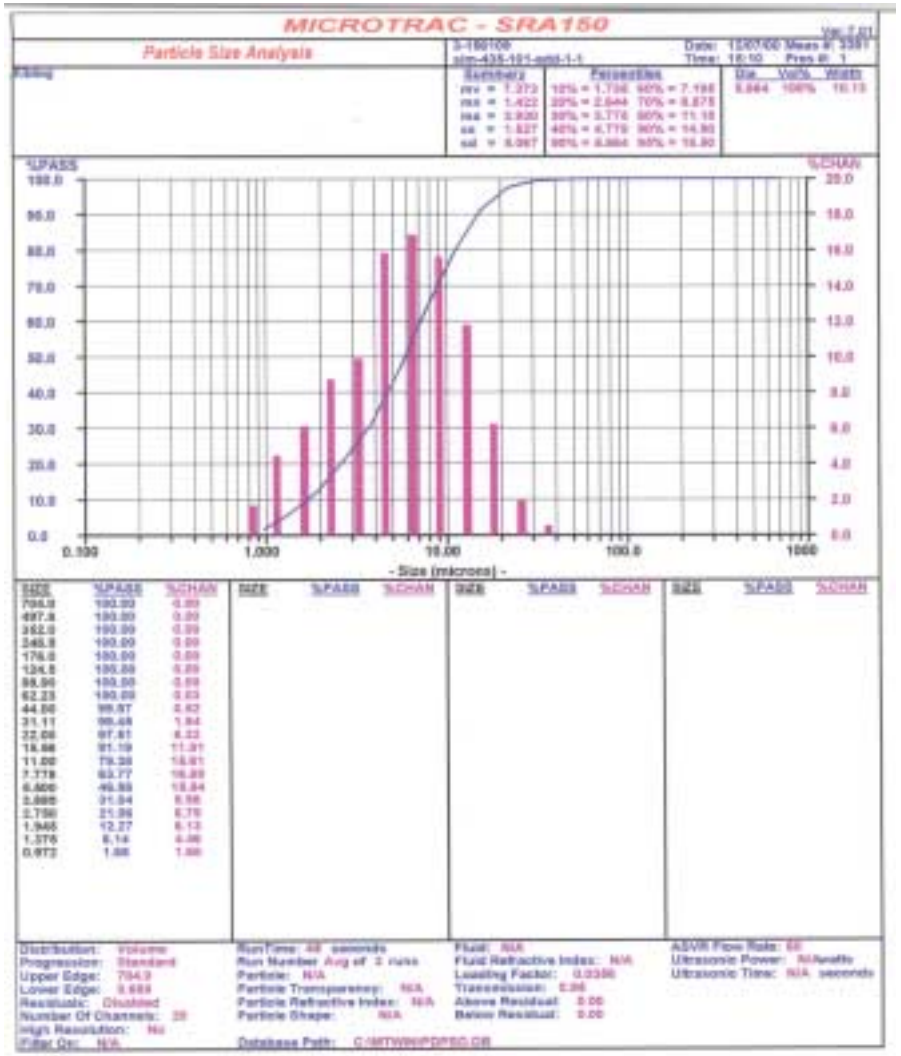


FIGURE A - 32 Particle Size Test No. ADD-1, with Glass Formers

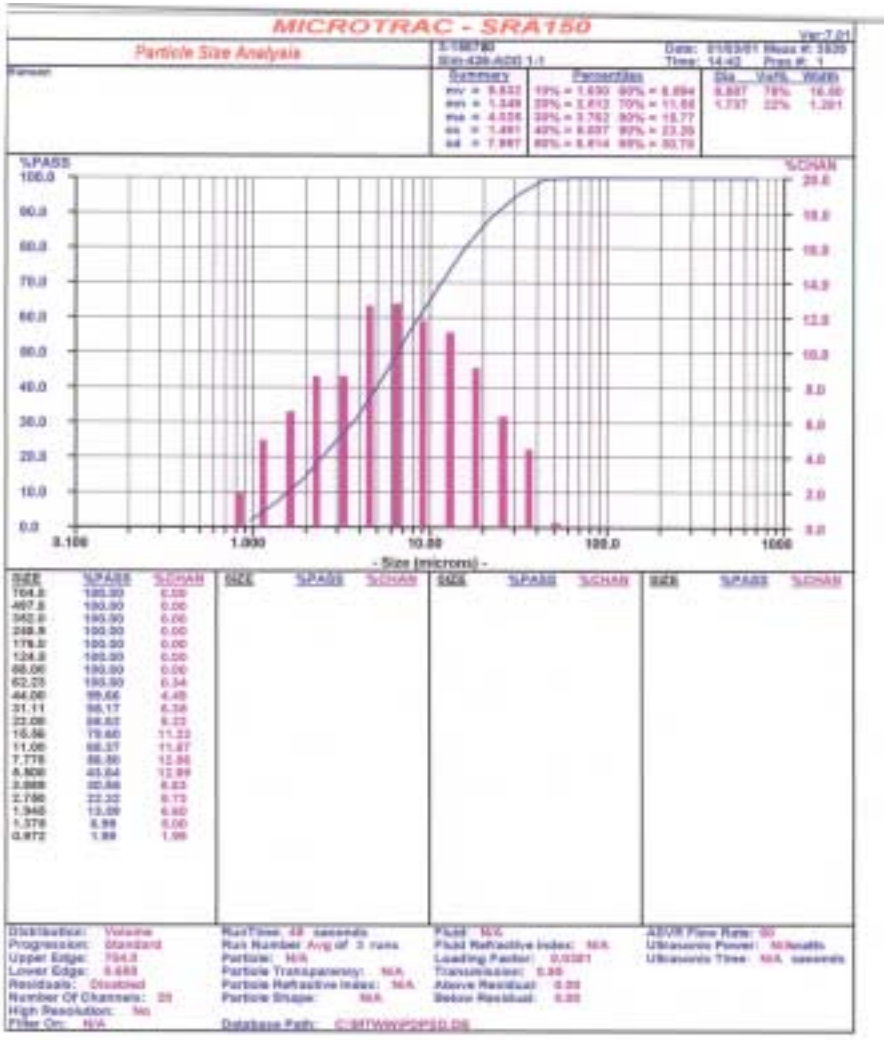


FIGURE A - 33 Particle Size Test No. ADD-2, without Glass Formers

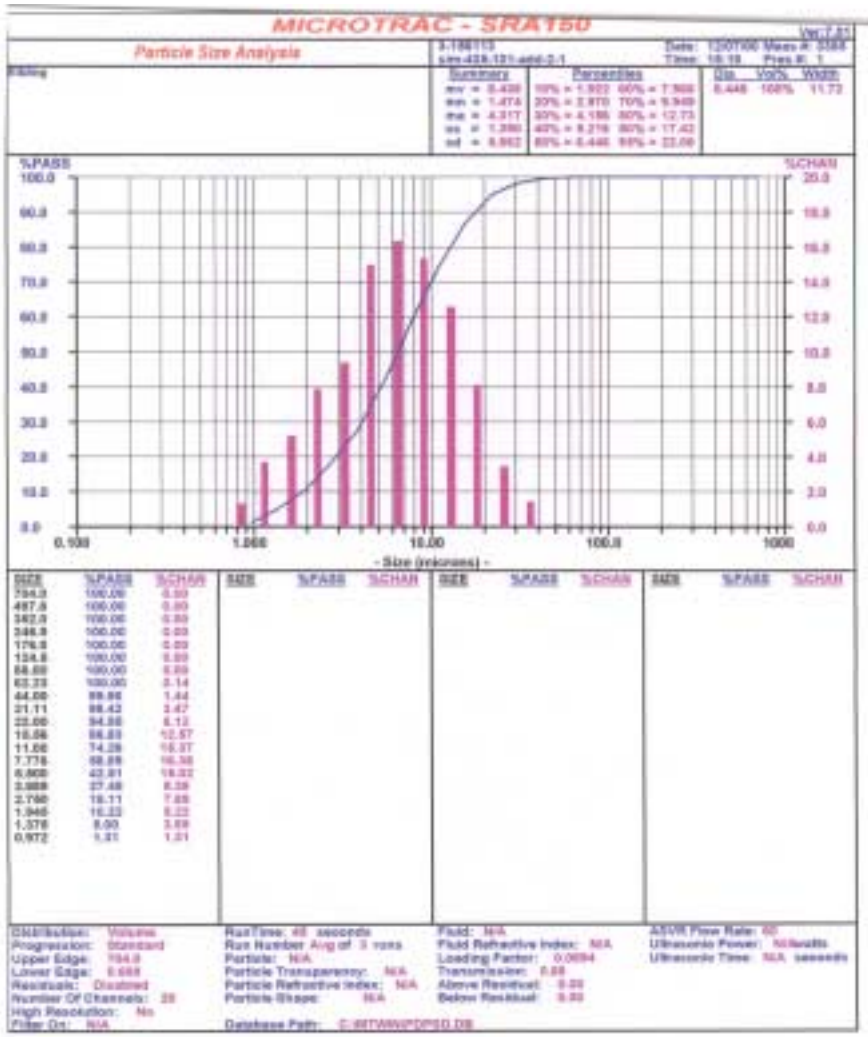


FIGURE A - 34 Particle Size Test No. ADD-2, with Glass Formers

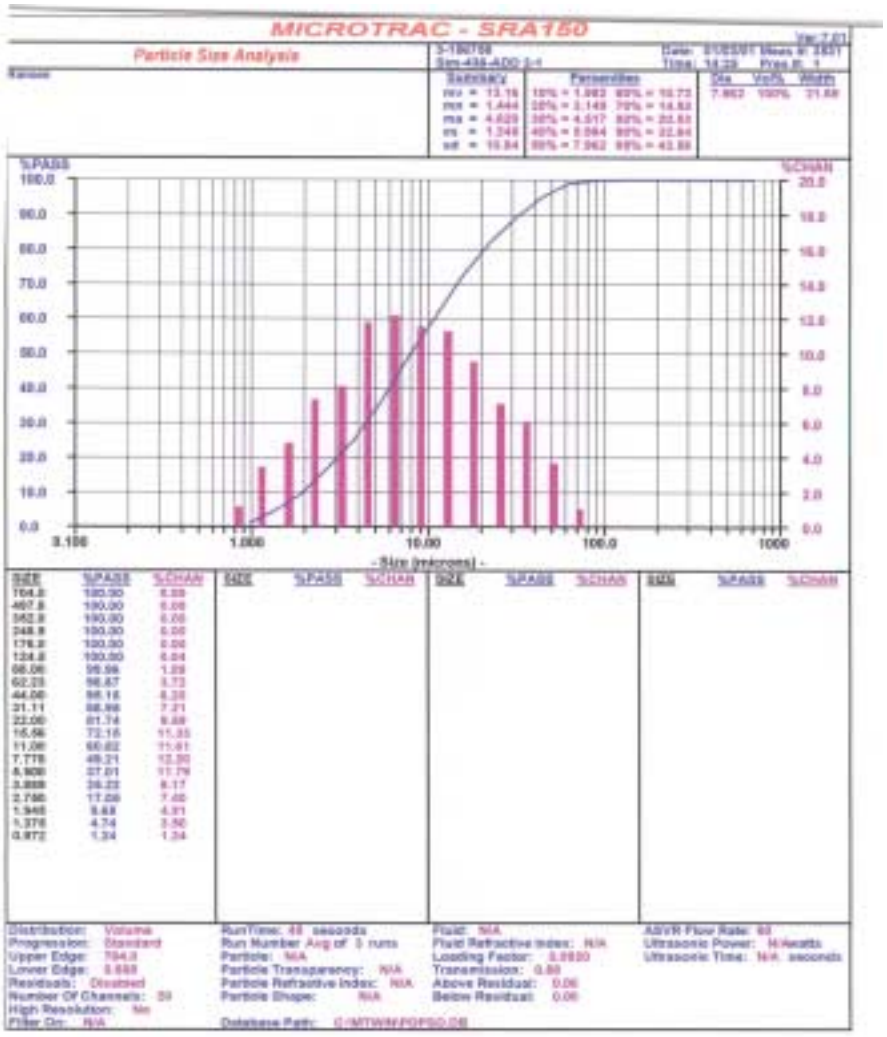


FIGURE A - 35 Particle Size Test No. 2.3, without Glass Formers

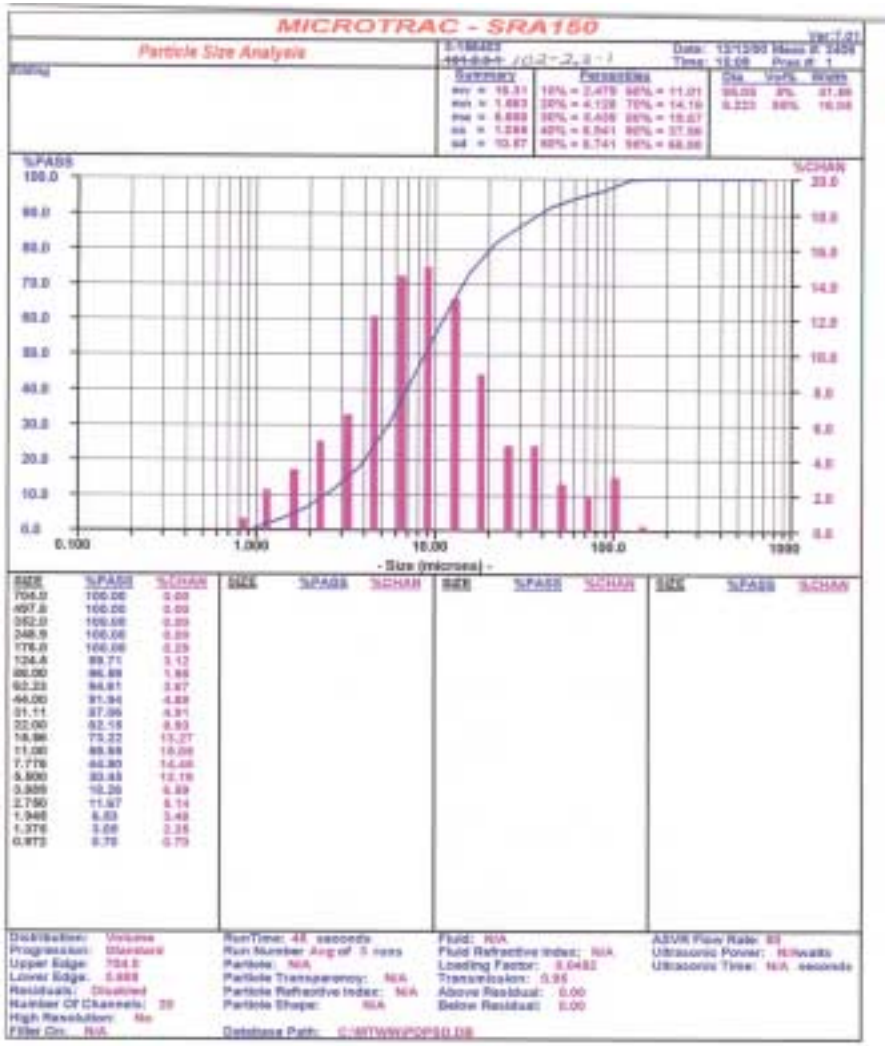


FIGURE A - 36 Particle Size Test No. 2.3, with Glass Formers

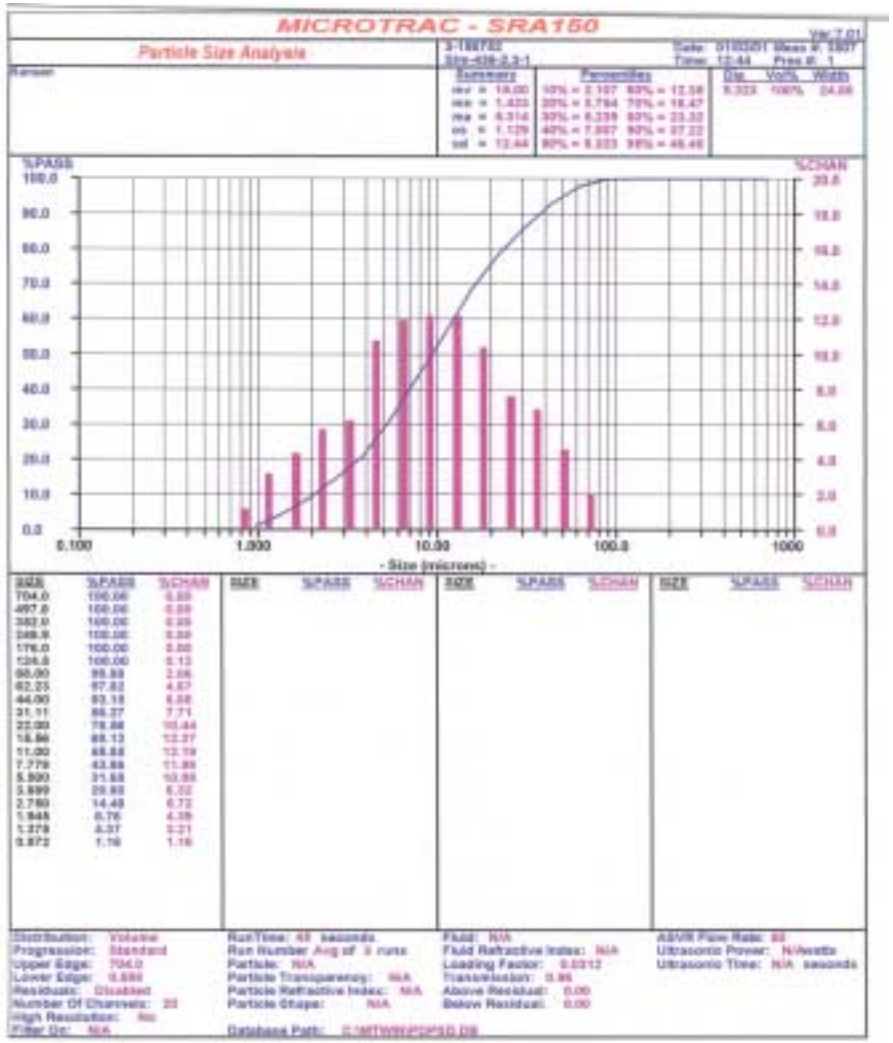


FIGURE A - 37 Particle Size Test No. 2.4, without Glass Formers

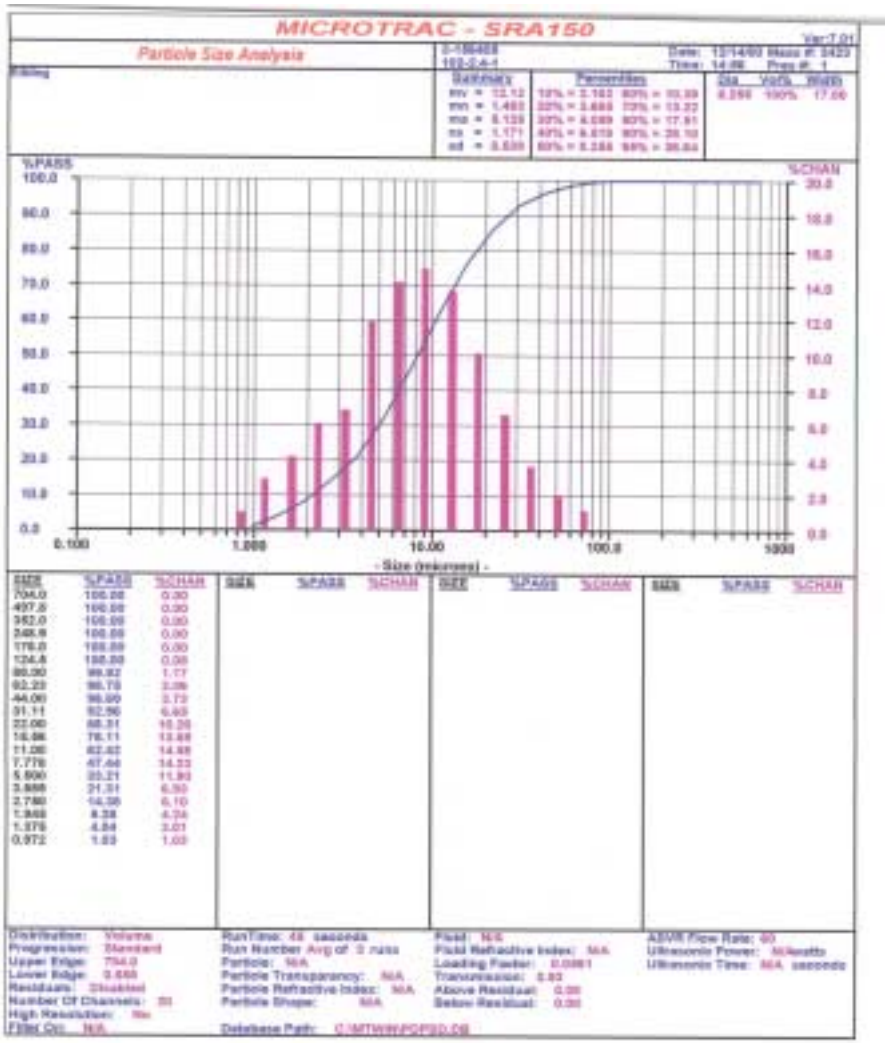


FIGURE A - 38 Particle Size Test No. 2.4, with Glass Formers

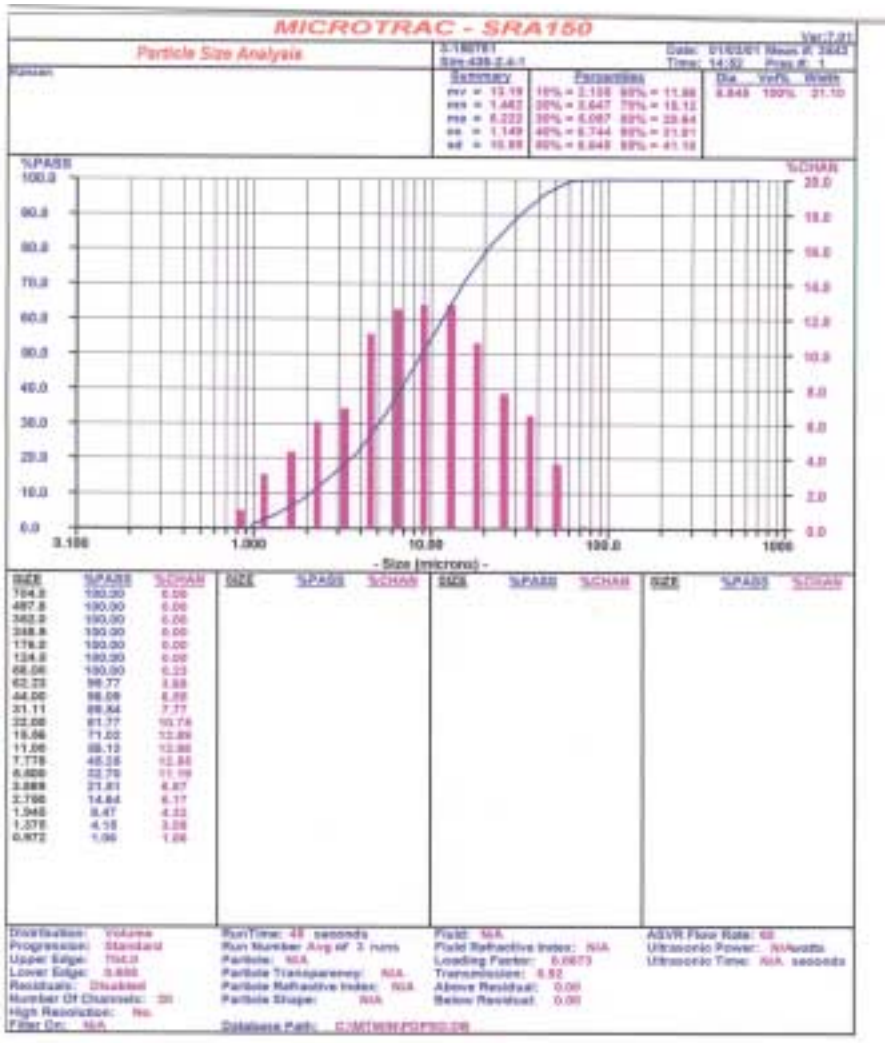


FIGURE A - 39 Particle Size Test No. 2.5, without Glass Formers

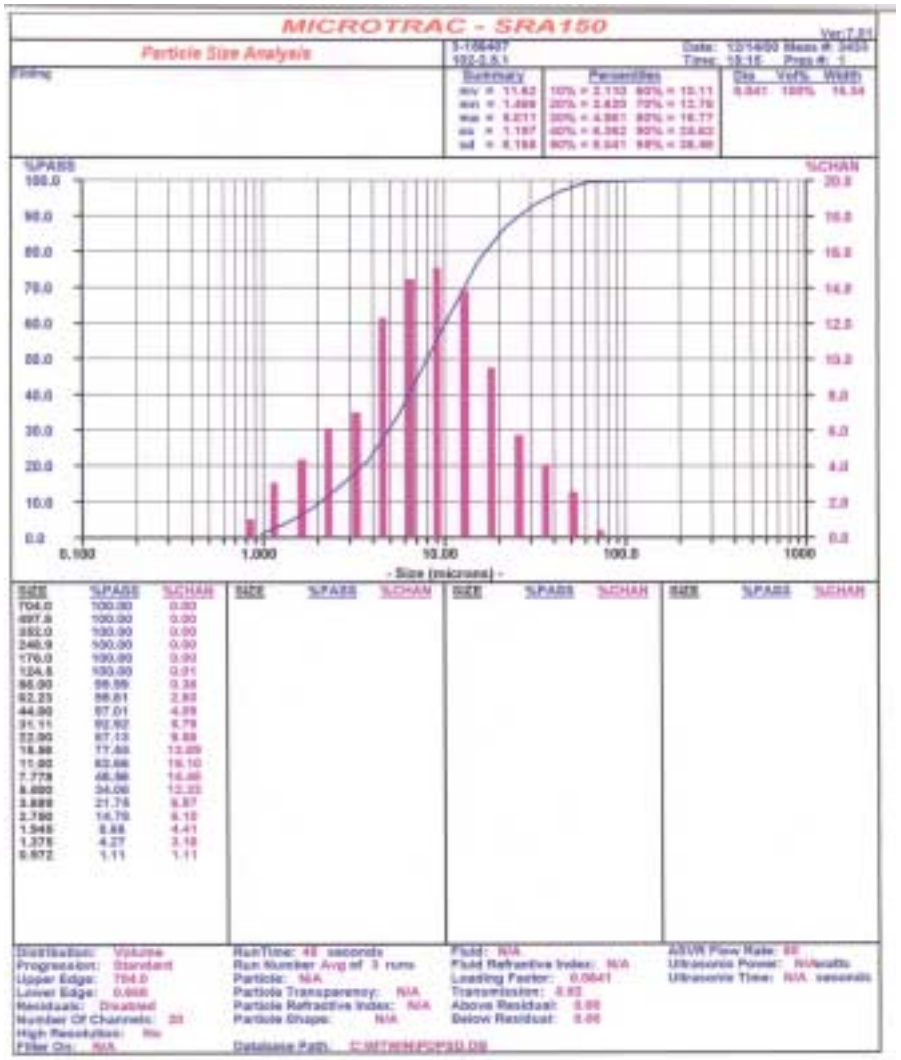


FIGURE A - 40 Particle Size Test No. 2.5, with Glass Formers

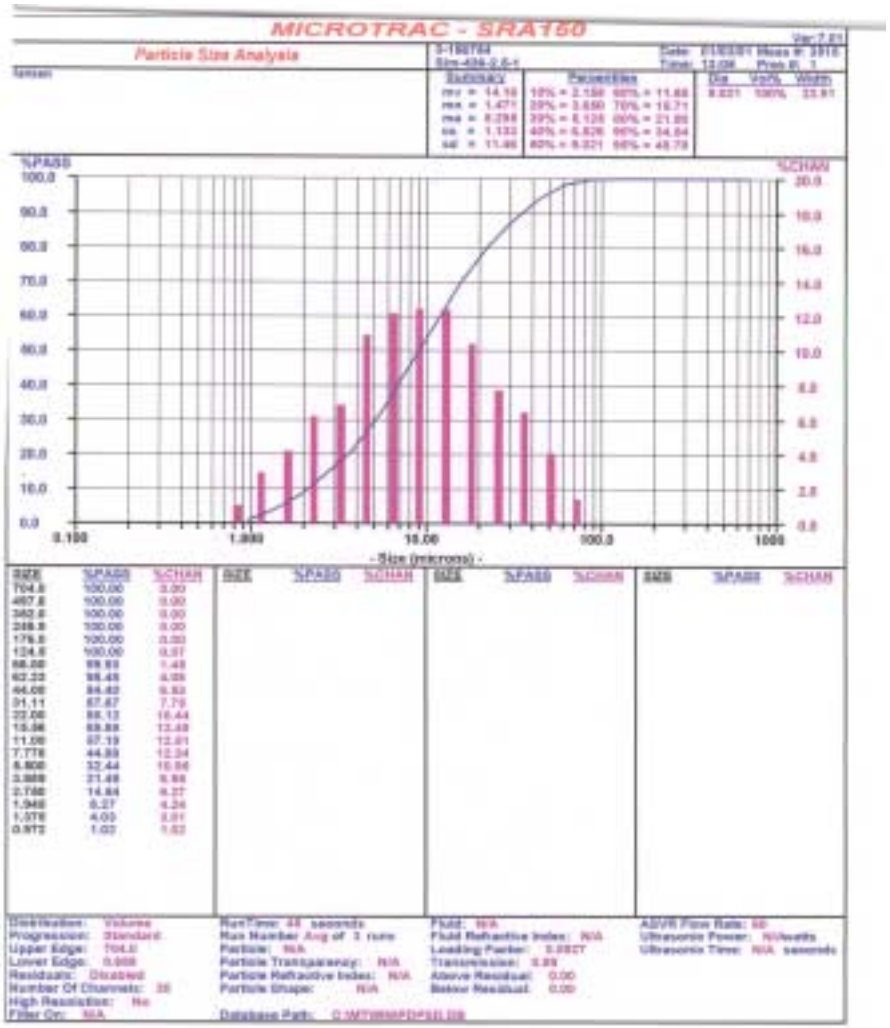


FIGURE A - 41 Particle Size Test No. ADD-3, without Glass Formers

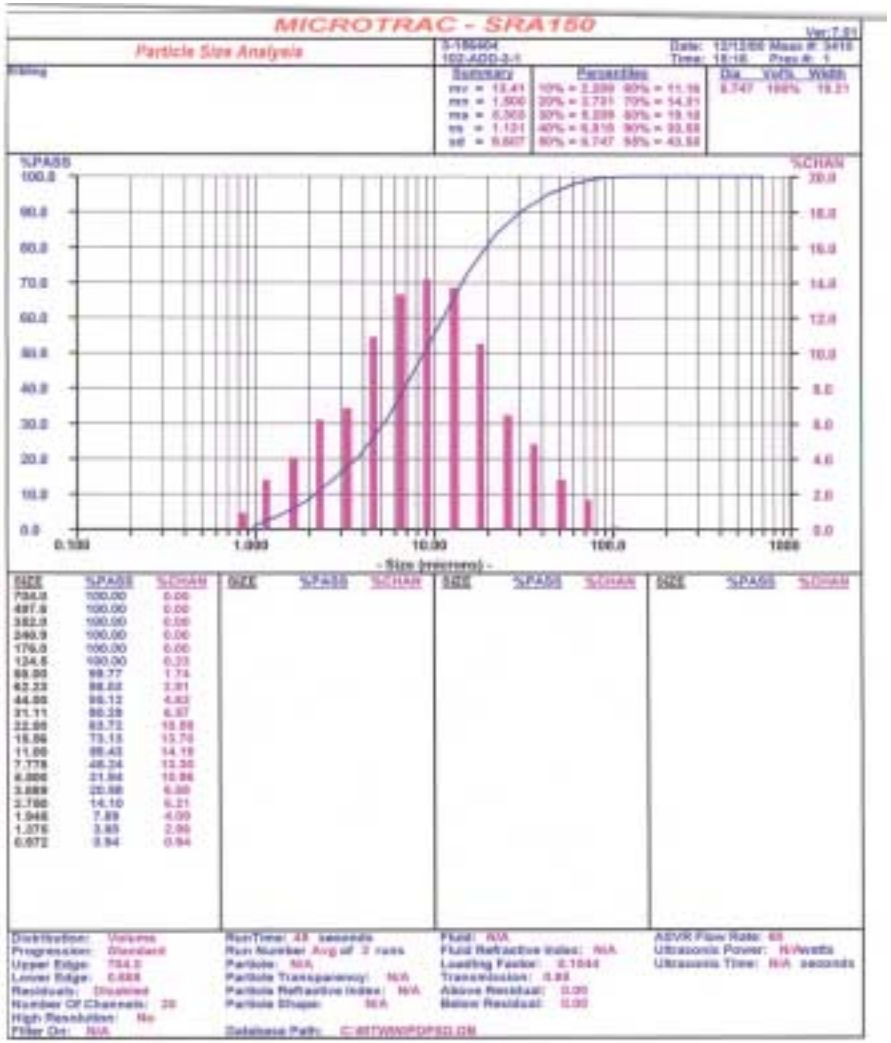


FIGURE A - 42 Particle Size Test No. ADD-3 with Glass Formers

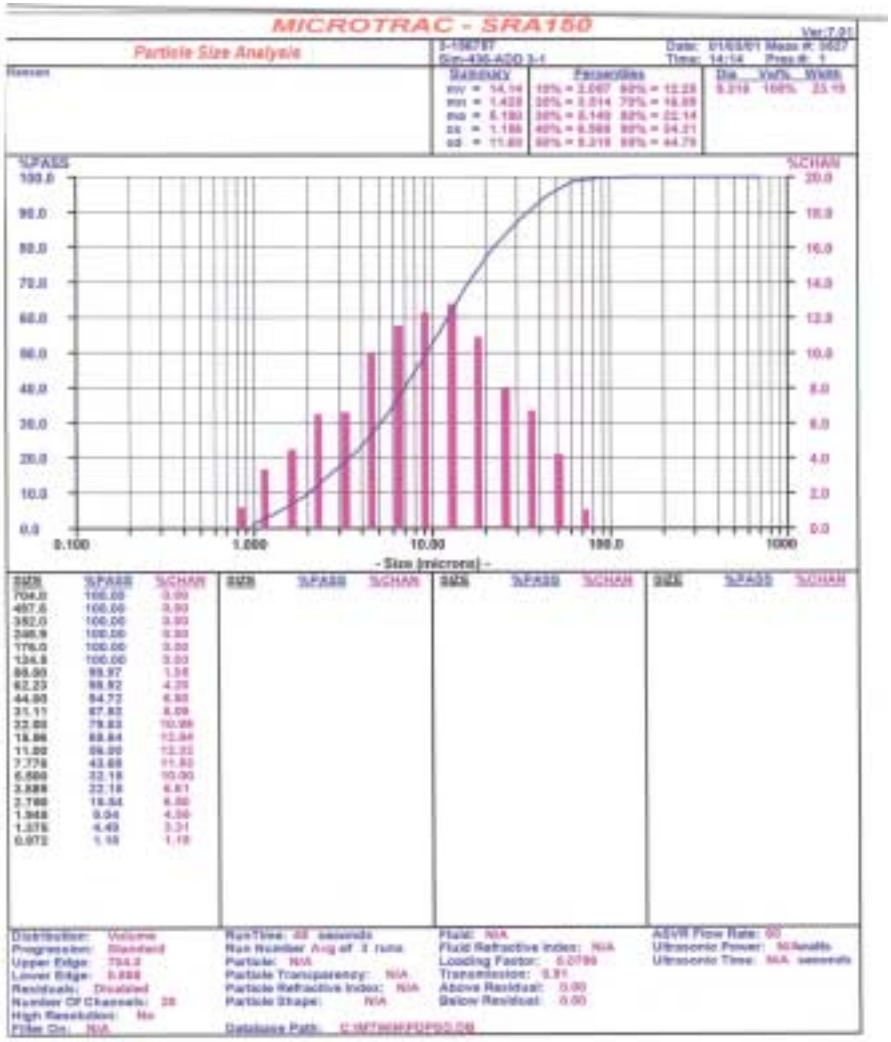


FIGURE A - 43 Particle Size Test No. ADD-4, without Glass Formers

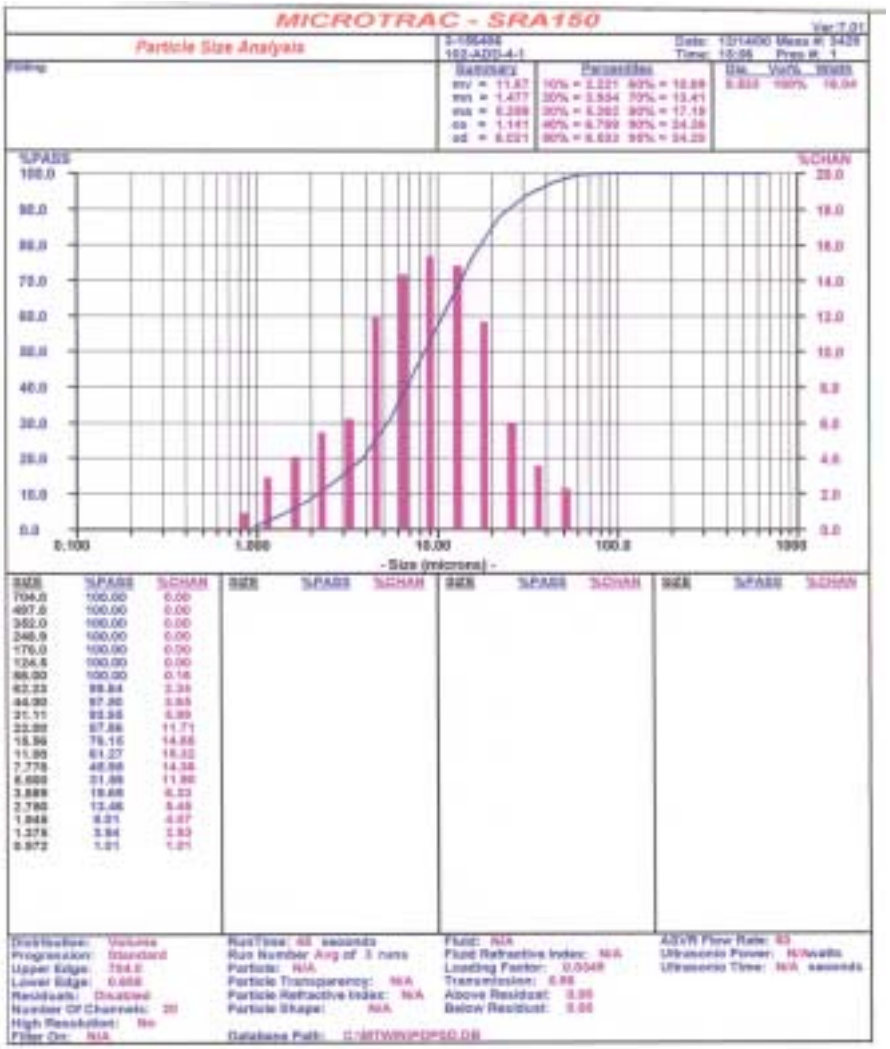
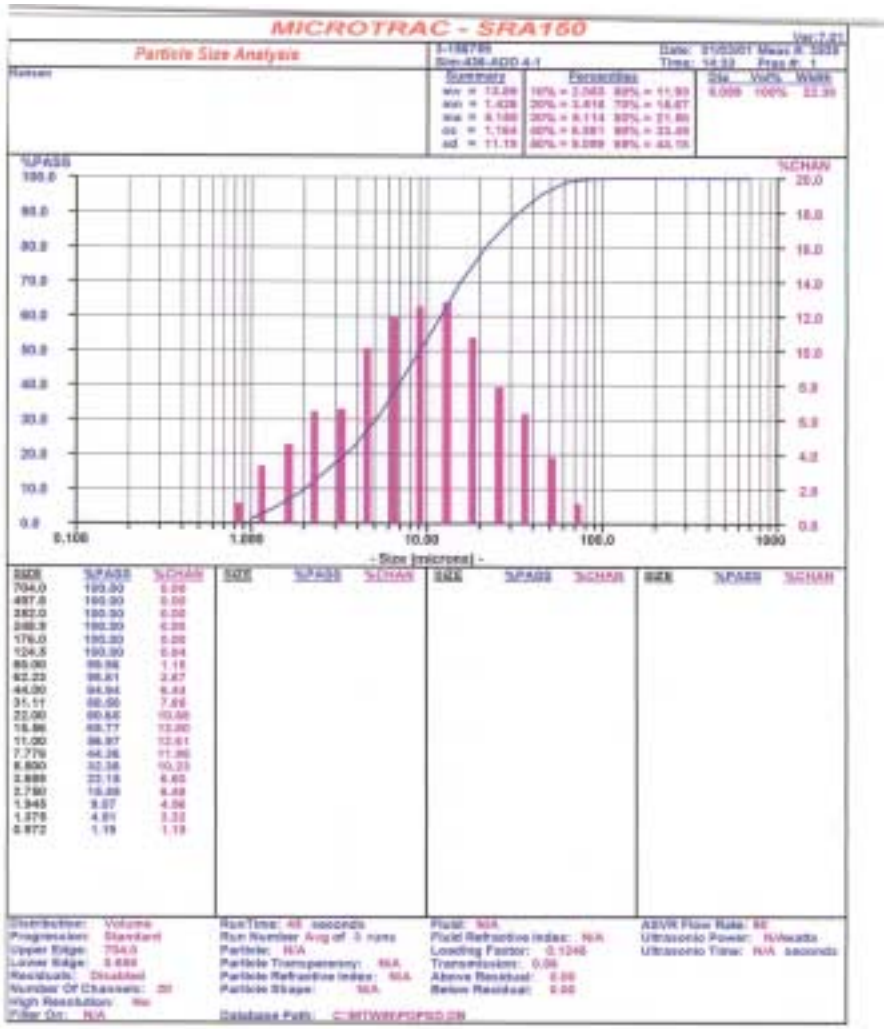


FIGURE A - 44 Particle Size Test No. ADD-4, with Glass Formers



APPENDIX B: Simulant Preparation and Blending

Table of Appendix B Tables

Table of Appendix B Figures

AZ-101 Sludge Simulant

The sludge simulants used in this study were created by caustic precipitation of metal nitrate solutions. The precipitation procedure is designed to mimic the waste generation process, which has occurred within the Hanford waste tanks. The aspects of waste storage that cannot be duplicated are radiation exposure and thermal aging. The basis for the composition of the AZ-101 sludge simulant was derived from the composition of two core samples from tank 241-AZ-101[24, 25]. The AZ-101 simulant composition represents AZ-101 sludge that has been washed, but not caustic leached to reduce the aluminum content. Table B- 1 is the AZ-101 sludge composition.

Table B- 1: Blended AZ-101 Solids Composition

Component	g/L	µg/g of solids	Component	g/L	µg/g of solids
Aluminum	8.970	57907	Nickel	2.719	17552
Barium	0.328	2114	Potassium	0.986	6365
Boron	0.124	803	Silver	0.346	2235
Cadmium	3.454	22295	Sodium	12.853	82976
Calcium	1.400	9036	Silicon	2.182	14084
Cerium	0.436	2817	Strontium	0.234	1508
Chromium	0.347	2238	Titanium	0.042	274
Cobalt	0.443	2860	Zinc	0.134	865
Copper	0.152	979	Zirconium	14.772	95366
Iron	44.150	285023	TIC	1.109	7161
Lanthanum	1.784	11520	Chloride	0.039	255
Lead	0.505	3258	Fluoride	0.215	1390
Magnesium	0.249	1610	Nitrate	3.909	25238
Manganese	1.027	6630	Nitrite	5.567	35942
Molybdenum	0.022	144	Phosphate	0.260	1678
Neodymium	1.192	7696	Sulfate	1.406	9078

Table B- 1 does not include any uranium since a non-radioactive simulant was required for this study. The required concentration for uranium would be 24810 micrograms/gram solids.

The AZ-101 sludge simulant was calculated to produce thirty liters of simulant or about 4600 grams of sludge solids. The AZ-101 simulated sludge was produced by the following sequence of reactions and mixing steps shown in Table B- 2 based upon the sludge simulation method that has been previously described.[26]

---

[24] K. M. Hodgson, **Tank Characterization Report for Double-Shell Tank 241-AZ-101**, WHC-SD-WM-ER-410, Rev 0, Westinghouse Hanford Company, Richland, WA 99352 (July 26. 1995).

[25] E. V. Morrey, J. M. Tingey, M. L. Elliott, **Comparison of Simulants to Actual Neutralized Current Acid Waste: Process and Product Testing of Three NCAW Core Samples From Tanks 101-AZ and 102-AZ**, PNNL-11025, UC-2030, Pacific Northwest National Laboratory, Richland, WA 99352 (October 1996).

[26] R. E. Eibling and C. Nash, **Hanford Waste Simulants Created to Support the Research and Development on the River Protection Project – Waste Treatment Plant**, WSRC-TR-2000-00338, SRT-RPP-2000-00017, Westinghouse Savannah River Company, Aiken, SC 29808 (September 2000).

Table B- 2: Sequence of Making AZ-101 Simulated Sludge

Sequence	Reaction
A	The generation of hydrated manganese dioxide by reacting permanganate ion and manganese (II) ion.
B	Addition of transition metals and alkaline earth metals as metal nitrates or chlorides.
C	Precipitation of the metal ions by addition of 8 molar sodium hydroxide solution until the pH is greater than 10.
D	Addition of 12 liters of 0.6 molar sodium carbonate solution to enable the conversion of some of the hydroxides to the less-soluble carbonates, such as the conversion of strontium hydroxide to strontium carbonate.
E	Wash the sludge with inhibited water (0.01 molar NaOH and 0.01 molar $NaNO_2$) to reduce the nitrate concentration to less than 1000 mg/L.
F	Add hydroxide-reactive insoluble species of known particle size.
G	Add soluble salts to the desired final concentrations.

The precipitation and washing was started in a 50 liter polypropylene carboy with its top removed to allow the positioning of an agitator for mixing the sludge. The precipitation was conducted at ambient lab temperatures, 293-298 K, with no provision for controlling the solution temperature. Two impellers on one shaft were used to provide the mixing. The lower impeller, located near the bottom of the vessel, was a 3-inch diameter, ½ inch wide 6-blade Rushton impeller. The top impeller, located approximately 10 inches above the bottom impeller was as 3-inch diameter, ½ inch wide, 4-blade 45^o pitched impeller. The speed of the shaft ranged between 500 to 1500 rpm to provide adequate mixing in preparing the sludge. Table B- 3 lists the reagents used to complete sequence steps A and B of the sludge preparation procedure.

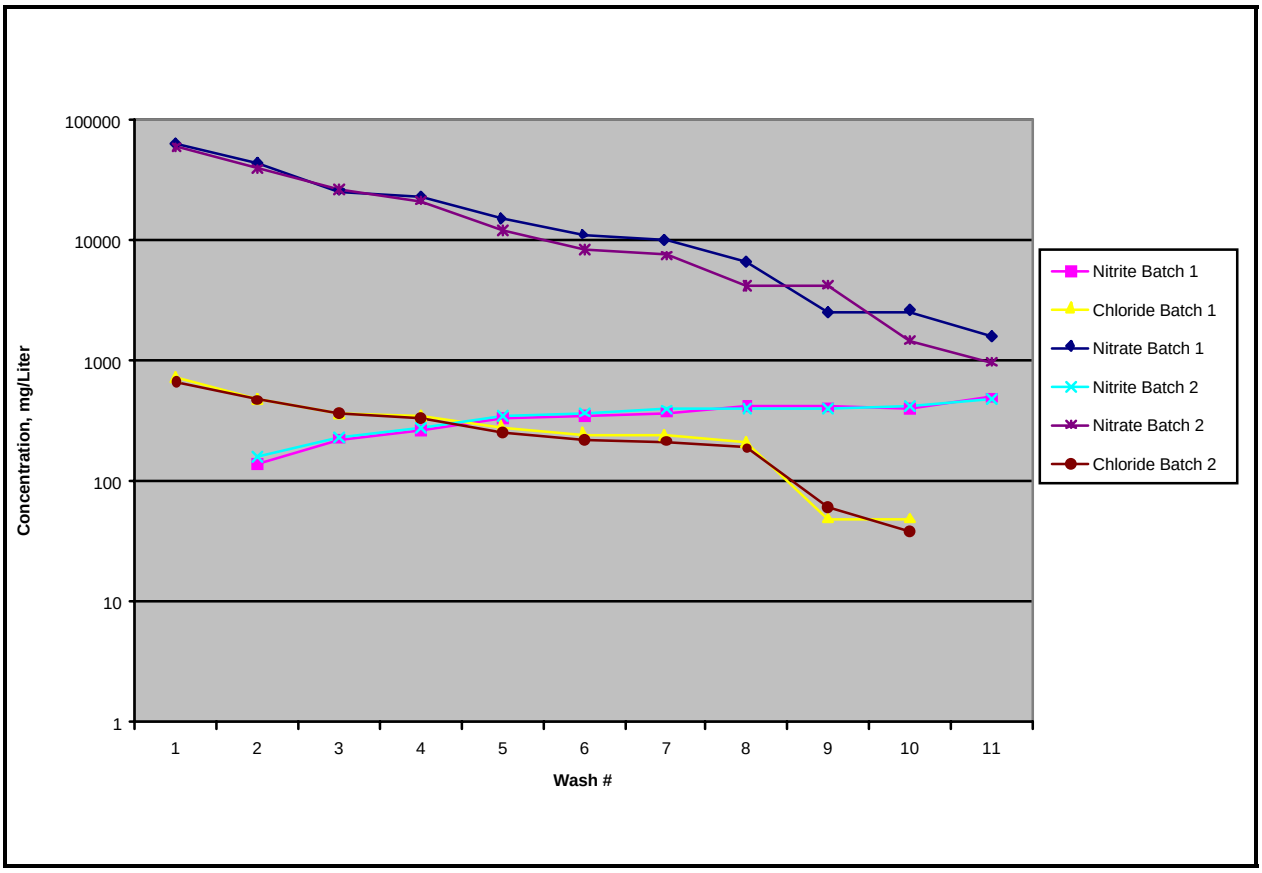
Table B- 3: Thirty Liter AZ-101 Sludge Simulant Recipe Part A

Sequence	Compound	Formula	Mass, grams
A	Water	H_2O	15000.04
A	Potassium Permanganate	$KMnO_4$	35.45
A	Managanous Nitrate Solution	50 Wt %	120.43
B	Ferric Nitrate	$Fe(NO_3)_3 \bullet 9H_2O$	9581.5
B	Nickel Nitrate	$Ni(NO_3)_2 \bullet 6H_2O$	263.91
B	Nickelous Chloride	$NiCl_2 \bullet 6H_2O$	114.66
B	Zirconyl Nitrate	$ZrO(NO_3)_2 \bullet xH_2O$ x~6	1648.5
B	Cerium Nitrate	$Ce(NO_3)_3 \bullet 6H_2O$	40.57
B	Lanthanum Nitrate	$La(NO_3)_3 \bullet 6H_2O$	166.87
B	Neodymium Nitrate	$Nd(NO_3)_3 \bullet 6H_2O$	108.68
B	Barium Nitrate	$Ba(NO_3)_2$	18.70
B	Calcium Nitrate	$Ca(NO_3)_2 \bullet 4H_2O$	247.42
B	Cadmium Nitrate	$Cd(NO_3)_2 \bullet 4H_2O$	284.31
B	Chromium Nitrate	$Cr(NO_3)_3 \bullet 9H_2O$	80.04
B	Cobalt Nitrate	$Co(NO_3)_2 \bullet 6H_2O$	65.62
B	Copper Nitrate	$Cu(NO_3)_2 \bullet 6H_2O$	17.30
B	Dysprosium Nitrate	$Dy(NO_3)_3 \bullet 5H_2O$	1.925
B	Magnesium Nitrate	$Mg(NO_3)_2 \bullet 6H_2O$	78.94
B	Lead Nitrate	$Pb(NO_3)_2$	24.20
B	Rhodium Nitrate Solution	$Rh(NO_3)_3$, 4.933 wt % Rh	93.59
B	Ruthenium Trichloride	$RuCl_3$, 41.74 wt % Ru	18.47
B	Strontium Nitrate	$Sr(NO_3)_2$	16.926
B	Zinc Nitrate	$Zn(NO_3)_2 \bullet 6H_2O$	18.31
B	Silver Nitrate	$AgNO_3$	16.357

The pH of the simulant was 0.28 after the metal addition listed as sequence B in Table B- 2 was completed. The metals were precipitated with 8 molar sodium hydroxide by adding the sodium hydroxide solution at 5-10 mL/min while agitating at 500-800 rpm until the slurry pH was greater than ten (Table B- 2, sequence C). The pH of the solution was monitored during the addition of sodium hydroxide solution. Mixing was difficult after the pH had risen above four and fouling of the pH probe required frequent cleaning to support the pH measurement. After reaching a pH of 10, twelve liters of 0.6 molar sodium carbonate solution was added (Table B- 2, sequence D) and the sludge slurry mixed for several hours. The slurry was then allowed to settle for 48 hours. The settled volume of the AZ-101 sludge simulant was about forty liters.

Since batch washing with gravity settling was planned for reducing the nitrate concentration, the settled sludge was blended and then split into two batches. The first wash for each batch was with deionized water. Subsequent washes were with inhibited water, 0.01 molar in NaOH and 0.01 molar in $NaNO_2$. Samples of the decanted supernate were analyzed for anions to determine when the washing endpoint was reached. Figure B – 1 shows the nitrate, chloride and nitrite concentrations during each stage of washing.

Figure B – 1 Washing of Precipitated AZ-101 Simulated Sludge Solids



The decanted washes had virtually no color indicating that the transition metals were remaining insoluble during the series of washes. The large number of washes was dictated by the limited wash volume that could be obtained at each step, due to the limited free supernate that could be decanted. The settling time for each wash step was generally 18-48 hours. The washed solids from each batch were blended together after the final wash to allow the remaining sequence of additions to occur on a single batch.

The final addition of chemicals to the simulated sludge consisted of insoluble solids, which could react with the hydroxide used to precipitate the transition metals, and the soluble salts. Table B-4 lists the sequence and final chemical additions necessary to produce thirty liters of simulated AZ-101 sludge.

Table B- 4: Final Chemical Additions to AZ-101 Simulated Sludge

Sequence	Compound	Formula	Mass, grams
F	Titanium Dioxide	TiO_2, < 5 micron	2.127
F	Silica	SiO_2, <5 microns	140.02
F	Aluminum Oxide	Al_2O_3, <10 microns	508.43
G	Sodium Perrhenate	$NaReO_4$	1.080
G	Potassium Nitrate	KNO_3	75.08
G	Potassium Molybdate	K_2MoO_4	1.67
G	Boric Acid	H_3BO_3	21.35
G	Sodium Chloride	NaCl	1.95
G	Sodium Fluoride	NaF	14.28
G	Sodium Sulfate	Na_2SO_4	62.38
G	Sodium Phosphate	$Na_3PO_4 \bullet 12H_2O$	595.92
G	Sodium Nitrate	$NaNO_3$	119.64
G	Sodium Nitrite	$NaNO_2$	250.50

After the final chemical addition, the sludge was mixed and sampled for chemical analysis, particle size and solids loading. The final pH of the slurry was 10.39, which is reasonable for a slurry that initially was 0.01 molar in NaOH and has not been protected from absorption of carbon dioxide from the air. Absorption of carbon dioxide leads to a reduction in the free hydroxide concentration and the production of carbonate ion by the following reaction (9).

$$CO_2 + 2OH^- \longrightarrow CO_3^{-2} + H_2O \qquad [9]$$

Table B- 5lists the measured slurry physical properties.

Table B- 5: AZ-101 Simulated Sludge Initial Physical Properties

Weight % Total Solids	11.77
Weight % Soluble Solids	1.45
Weight % Insoluble Solids	10.31
Density at 295 K in kg/m^3	1077

The measured composition of the AZ-101 simulated sludge expressed in terms of weight % waste oxides is shown in Table B- 6 compared to the target composition. The only species which are significantly below the target concentration are the alkaline earth elements (Mg, Ca, and Sr) which were probably removed by the washing steps due to the limited solubility of the carbonate species expected in the sludge.

Table B- 6: Measured Compared to Target AZ-101 Sludge Composition Wt. % Oxides

Waste Oxide	Wt. % waste oxide Composition		Waste Oxide	Wt. % waste oxide Composition	
	Measured	Target		Measured	Target
Ag_2O	0.18	0.26	MnO	0.96	0.91
Al_2O_3	13.60	11.63	MoO_3	0.02	0.02
BaO	0.22	0.25	Na_2O	11.06	11.89
CaO	0.71	1.34	Nd_2O_3	0.92	0.95
CdO	2.64	2.71	NiO	2.42	2.37
CeO_2	0.26	0.37	P_2O_5	2.86	2.54
CoO	0.40	0.39	PbO	0.37	0.37
Cr_2O_3	0.36	0.35	SiO_2	3.37	3.20
CuO	0.13	0.13	SrO	0.10	0.19
Fe_2O_3	44.03	43.31	TiO_2	<0.06	0.05
K_2O	0.99	1.23	ZnO	0.13	0.11
La_2O_3	1.39	1.44	ZrO_2	12.77	13.69
MgO	0.09	0.28			

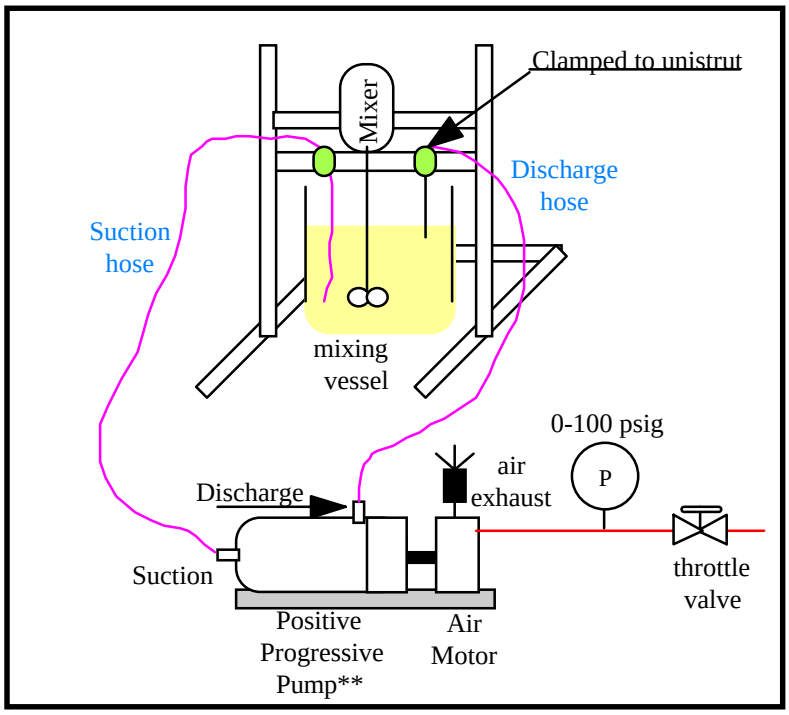
The processing of the actual Envelope D waste by the WTP will involve the transfer of the sludge by pumps from the tank farm to feed tanks. The sludge will then be washed with dilute caustic to remove soluble salts and reduce the sodium concentration. The separation of the wash liquid and control of solids loading in the product slurry will be accomplished by crossflow filtration. Since the actual Envelope D waste will experience substantial shearing during the crossflow filtration, the washed, simulated AZ-101 sludge was sheared by pumping the simulant through a pump typically used for a small crossflow filter. The amount of applied shearing used in this task was based on the Cells Filter Unit (CUF) operations performed at SRTC[27], specifically the shearing applied by the CUF pump. Based on the CUF operations[27], it took approximately 20 minutes to process 1L of Envelope C (with precipitated Sr/TRU). The CUF pump is a modified progressive cavity pump (high shear – due to the tight tolerances between the rotor and sleeve), which was operated at 30 psig to provide a recirculation flowrate of approximately 5 gpm. Thus, for the 40L AZ-101 batch, 13.3 hours of recirculation using the CUF pump was used to apply the appropriate amount of shearing. The slurry was removed from the bottom of the mixing vessel and returned just below the surface of the slurry. An agitator, with a single 3-inch diameter, ½ inch wide 6-blade Rushton impeller, located near the bottom, was used to assist the mixing in the vessel. The agitator applies much less shear than the CUF pump and its contribution was neglected in the shearing process. The agitator was operated at 550 rpm. A typical layout is shown in Figure B - 2. Samples of the simulated sludge before and after shearing were analyzed for particle size and the results are shown in Table B- 7.

Table B- 7: Particle Size Shearing Results for Simulated AZ-101 Sludge

	Before Shearing	After Shearing
Mean Particle Size by Volume	**14.15 microns**	**8.17 microns**
Mean Particle Size by Number	**2.11 microns**	**1.46 microns**
Largest Particles	**125 micron**	**62 micron**

[27] Charles Nash, "Simulant Shearing Basis", email, 6/21/00

Figure B - 2 Sludge Shearing Setup



Different solids concentrations of AZ-101 simulated sludge were obtained by centrifuging at 42500 m/s^2 and adding back the amount of supernate to achieve the desired solids loading. The residual supernate was retained for use in diluting to lower solids loadings. The slurries prepared are listed in Table 4.

AZ-102 Sludge Simulant

The AZ-102 sludge simulant was prepared in the same manner as the AZ-101 sludge simulant already described. The sludge composition listed in Table B- 8 represents pretreated (washed but not caustic leached) sludge.[28] The sequence of steps in preparing the simulated sludge was the same as listed in Table B- 2. The precipitation and washing was started in a 50 liter polypropylene carboy with its top removed to allow the positioning of an agitator for mixing the sludge. The precipitation was conducted at ambient lab temperatures, 293-298 K, with no provision for controlling the solution temperature. Two impellers on one shaft were used to provide the mixing. The lower impeller, located near the bottom of the vessel, was a 3-inch diameter, ½ inch wide 6-blade Rushton impeller. The top impeller, located approximately 10 inches above the bottom impeller was as 3-inch diameter, ½ inch wide, 4-blade 45^o pitched impeller. The speed of the shaft ranged between 500 to 1500 rpm to provide adequate mixing in preparing the sludge. The simulated sludge was prepared in a thirty liter batch, and the amounts used for steps A and B are shown in Table B- 9.

[28] K. P. Brooks, P. R. Bredt, S. K. Cooley, G. R. Golcar, L. K. Jagoda, K. G. Rappe, M. W. Urie**, Characterization, Washing, Leaching and Filtration of AZ-102 Solids**, PNWD-3045, BNFL-RPT-038 Rev. 0, Pacific Northwest National Laboratory, Richland, WA 99352 (August 2000).

Table B- 8: Blended AZ-102 Solids Composition

Component	g/L	µg/g of solids	Component t	g/L	µg/g of solids
Aluminum	11.43	107000	Nickel	1.729	16190
Barium	0.101	944	Silver	0.050	464
Boron	0.024	228	Sodium	8.022	75100
Cadmium	3.431	32120	Silicon	0.758	7100
Calcium	0.108	1007	Strontium	0.000	4
Cerium	0.166	1550	Titanium	0.015	145
Chromium	0.169	1582	Zinc	0.098	921
Cobalt	0.013	118	Zirconium	3.488	32650
Copper	0.001	5	TIC	0.174	1625
Iron	23.560	220560	Chloride	0.139	1300
Lanthanum	0.758	7094	Fluoride	0.032	300
Lead	0.007	62	Nitrate	0.892	8350
Magnesium	0.208	1950	Nitrite	0.187	1750
Manganese	0.574	5369	Phosphate	0.096	897
Neodymium	0.025	233	Sulfate	0.128	1200

Table B- 9: Thirty Liter AZ-102 Sludge Simulant Recipe Part A

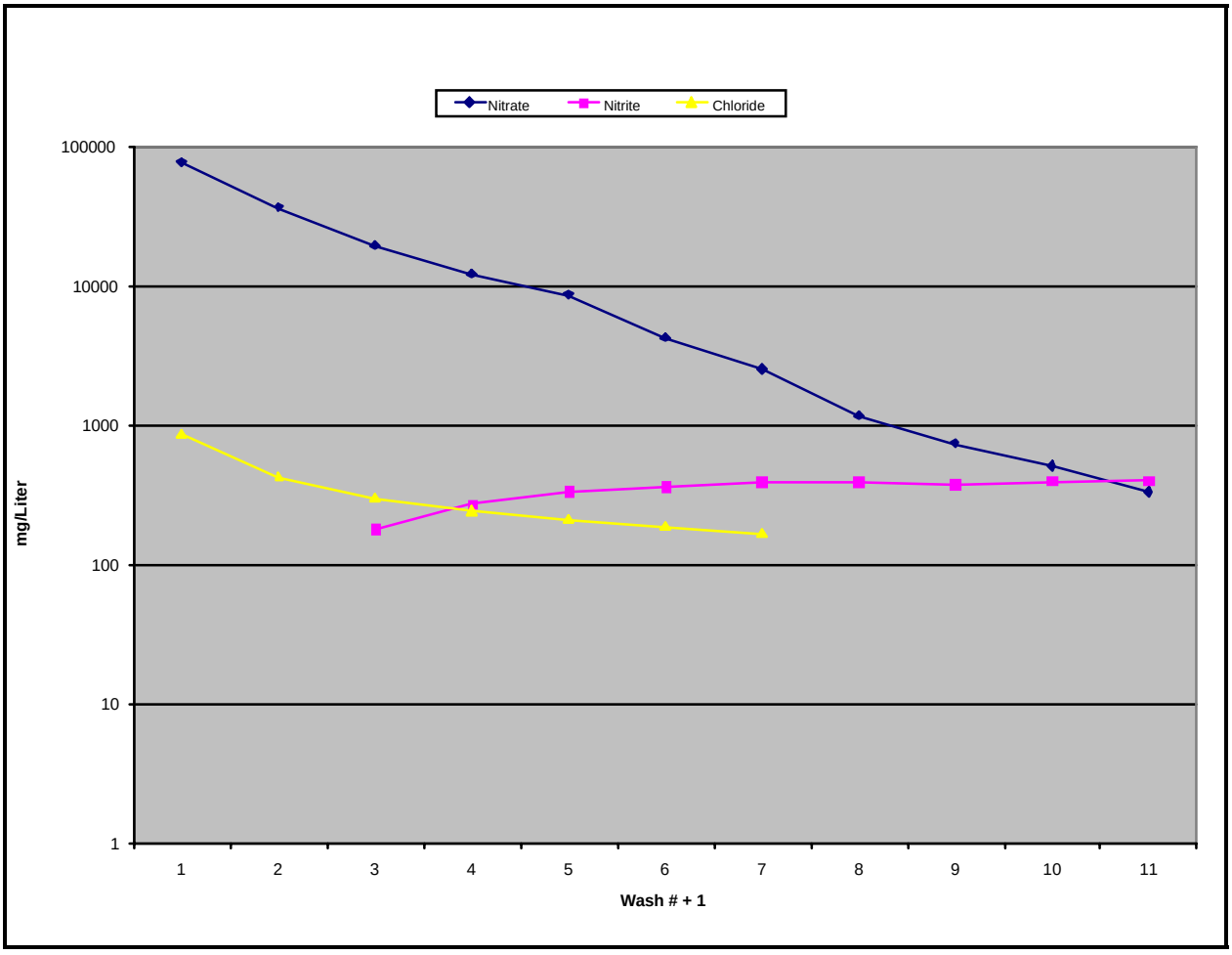
Sequence	Compound	Formula	Mass, grams
A	Water	H_2O	15000.2
A	Potassium Permanganate	$KMnO_4$	19.802
A	Managanous Nitrate Solution	50 Wt %	67.273
B	Ferric Nitrate	$Fe(NO_3)_3 \bullet 9H_2O$	5113.1
B	Nickel Nitrate	$Ni(NO_3)_2 \bullet 6H_2O$	257.07
B	Zirconyl Nitrate	$ZrO(NO_3)_2 \bullet xH_2O$ x~6	389.2
B	Cerium Nitrate	$Ce(NO_3)_3 \bullet 6H_2O$	15.39
B	Lanthanum Nitrate	$La(NO_3)_3 \bullet 6H_2O$	70.87
B	Neodymium Nitrate	$Nd(NO_3)_3 \bullet 6H_2O$	2.28
B	Barium Nitrate	$Ba(NO_3)_2$	5.761
B	Calcium Nitrate	$Ca(NO_3)_2 \bullet 4H_2O$	19.01
B	Cadmium Nitrate	$Cd(NO_3)_2 \bullet 4H_2O$	282.48
B	Chromium Nitrate	$Cr(NO_3)_3 \bullet 9H_2O$	39.03
B	Cobalt Nitrate	$Co(NO_3)_2 \bullet 6H_2O$	1.87
B	Copper Nitrate	$Cu(NO_3)_2 \bullet 6H_2O$	0.066
B	Magnesium Nitrate	$Mg(NO_3)_2 \bullet 6H_2O$	65.93
B	Lead Nitrate	$Pb(NO_3)_2$	0.32
B	Strontium Nitrate	$Sr(NO_3)_2$	0.0377
B	Zinc Nitrate	$Zn(NO_3)_2 \bullet 6H_2O$	13.432
B	Silver Nitrate	$AgNO_3$	2.344

The pH of the simulant was 0.63 after all the metals listed in step B of Table B- 9 were added. The metals were precipitated with 8 molar sodium hydroxide by adding the sodium hydroxide solution at 5-10 mL/min while agitating at 500-800 rpm. Sodium hydroxide addition was continued until the slurry pH was greater than ten (Table B- 2, sequence C). The pH of the solution was monitored continuously during the addition of sodium hydroxide solution. Mixing

was difficult after the pH had risen above four and fouling of the pH probe required frequent cleaning to support the pH measurement. Sodium hydroxide addition was stopped after the pH was greater than 10. The measured pH at this point after cleaning the pH probe was about 11.8. Next twelve liters of 0.6 molar sodium carbonate solution was added (Table B- 2, sequence D) and the sludge slurry mixed for several hours. The slurry was then allowed to settle for 48 hours. The settled volume was about 25 liters.

As in the AZ-101 sludge preparation, batch washing with gravity settling was planned for reducing the soluble species concentration, primarily nitrate. The AZ-102 sludge batch settled well and did not require splitting to achieve a reasonable wash ratio. The first wash for the AZ-102 sludge was with deionized water. Subsequent washes were with inhibited water, 0.01 molar in NaOH and 0.01 molar in $NaNO_2$. Samples of the decanted supernate were analyzed for anions to determine when the washing endpoint was reached. Figure B - 3 shows the nitrate, chloride and nitrite concentrations during each stage of washing.

Figure B - 3 Washing of Precipitated AZ-102 Sludge Simulant Solids



The decanted washes had virtually no color indicating that the transition metals were remaining insoluble during the series of washes. The large number of washes was dictated by the limited

wash volume that could be obtained at each step, due to the limited free supernate that could be decanted. The settling time for each wash step was generally 18-48 hours.

The final addition of chemicals to the AZ-102 simulated sludge consisted of insoluble solids, which could react with the hydroxide used to precipitate the transition metals, and the soluble salts. Table B- 10 lists the sequence and final chemical additions necessary to produce thirty liters of simulated AZ-102 sludge.

Table B- 10: Thirty Liter AZ-102 Simulated Sludge Recipe Part B
Final Chemical Additions to AZ-102 Simulated Sludge

Sequence	Compound	Formula	Mass, grams
F	Titanium Dioxide	TiO_2, < 5 micron	0.775
F	Silica	SiO_2, <5 microns	48.68
F	Aluminum Oxide	Al_2O_3, <10 microns	647.8
G	Boric Acid	H_3BO_3	4.180
G	Sodium Chloride	NaCl	6.87
G	Sodium Fluoride	NaF	2.125
G	Sodium Sulfate	Na_2SO_4	5.687
G	Sodium Phosphate	$Na_3PO_4 \bullet 12H_2O$	110.119
G	Sodium Nitrite	$NaNO_2$	8.412

After the final chemical additions, the sludge was sampled for physical properties and composition. Table B- 11 lists the physical properties. The comparison between the target sludge composition and the measured sludge composition on a waste oxide basis is shown in Table B- 12.

Table B- 11: AZ-102 Simulated Sludge Initial Physical Properties

Weight % Total Solids	13.6
Weight % Soluble Solids	0.43
Weight % Insoluble Solids	13.17
Density at 295 K (kg/m^3)	1072
pH of the slurry	12.03

Table B- 12: Measured Compared to Target AZ-102 Sludge Composition Wt. % Waste Oxides

Waste Oxide	Wt. % waste oxide Composition		Waste Oxide	Wt. % waste oxide Composition	
	Measured	Target		Measured	Target
Ag_2O	0.05	0.06	MnO	1.06	0.90
Al_2O_3	27.97	26.28	Na_2O	3.76	13.16
BaO	0.16	0.14	Nd_2O_3	0.05	0.04
CaO	0.22	0.18	NiO	3.08	2.68
CdO	5.25	4.77	P_2O_5	1.02	0.83
CeO_2	0.20	0.25	PbO	<0.05	0.01
CoO	0.03	0.02	SiO_2	2.44	1.97
Cr_2O_3	0.32	0.30	SrO	<0.0006	0.0006
CuO	<0.01	0.001	TiO_2	<0.50	0.03
Fe_2O_3	45.87	40.99	ZnO	0.18	0.15
La_2O_3	1.20	1.08	ZrO_2	6.08	5.73
MgO	0.48	0.42			

Since the actual Envelope D waste will experience substantial shearing during the crossflow filtration, the washed, simulated AZ-102 sludge was sheared by pumping the simulant through a pump typically used for a small crossflow filter. The same process of shearing was used that was described for the simulated AZ-101 sludge. Thus, for the 30 liter AZ-102 batch, 10 hours of recirculation using the CUF pump was used to apply the appropriate amount of shearing. Samples of the simulated sludge before and after shearing were analyzed for particle size, and the results are shown in Table B- 13.

Table B- 13: Particle Size Shearing Results for AZ-102 Simulated Sludge

	Before Shearing	After Shearing
Mean Particle Size by Volume	**18.69 microns**	**11.55 microns**
Mean Particle Size by Number	**2.75 microns**	**1.38 microns**
Largest Particles	**249 micron**	**176 micron**

Different solids concentrations of AZ-102 simulated sludge were obtained by centrifuging at 42500 m/s^2 and adding back the amount of supernate to achieve the desired solids loading. The residual supernate was retained for use in diluting to lower solids loadings. The slurries prepared are listed in Table 6.

AN-107 Sr/TRU Precipitate Simulant

The AN-107 Sr/TRU precipitate simulant was produced by applying the Sr/TRU process to an AN-107 supernate simulant containing entrained solids. The AN-107 supernate simulant has been previously described, and is based on recent samples from tank 241-AN-107.[26, 29, 30] The

[29] R. A. Esch, **Tank Waste Remediation System (TWRS) Privatization Private Contractor samples Waste Envelope C Material Tank 241-AN-107**, HNF-SD-WM-DP-205, Rev. 1, Rust Federal Services of Hanford, Inc., Richland, WA 99352 (April 8, 1997).

AN-107 entrained solids simulant was produced by the following sequence of reactions and mixing steps shown in Table B- 14 based upon the sludge simulation method that has also been previously described.[26]

Table B- 14: Sequence of Making AN-107 Entrained Solids Simulant

Sequence	Reaction
A	The transition metal nitrates, complexing chemicals and nonreactive salts are dissolved with sufficient water to create a solution.
B	A second solution is prepared by reacting sodium hydroxide with aluminum nitrate and adding additional salts
C	The solutions prepared in steps A and B are combined.
D	Addition of the three remaining salts, sodium carbonate, sodium nitrate and sodium nitrite, are made along with the remaining water necessary to achieve the required concentrations based upon solution density.
E	The solution is mixed overnight to dissolve the final salts.
F	The entrained solids compounds are added to the simulant and the slurry is mixed for several hours to thoroughly disperse the entrained solids Add hydroxide-reactive insoluble species of known particle size.

A forty-liter batch of the AN-107 simulant was produced at 5.5 molar sodium concentration by the recipe given in Table B- 15. After mixing the supernate simulant overnight, the entrained solids listed in Table B- 16 were added to the solution. The entrained solids represent unwashed solids, which are 0.5 wt. % of the total mass of the final solution. Based upon a planned solution density of 1.243 g/mL and 40 liters of solution, 248.6 grams of solids were added. Additional alumina and silica were added to represent the sodium aluminosilicate, since none of the latter reagent was available, and these quantities are listed in Table B- 16.

[30] J. A. Campbell, S. A. Clauss, K. E. Grant, V. Hoopes, G. M. Mong, R. Steele, D. Bellofatto, A. Sharma**, Organic Tanks Safety Program Organic Analysis Progress Report FY 1997**, PNNL-11738, UC-601, Pacific Northwest National Laboratory, Richland, WA 99352 (April 1998).

Table B- 15: Forty Liter AN-107 Supernate Simulant Recipe

Sequence	Compound	Formula	Mass, grams
A	Water	H_2O	8002.0
A	Calcium Nitrate	$Ca(NO_3)_2 \bullet 4H_2O$	87.34
A	Cerium Nitrate	$Ce(NO_3)_3 \bullet 6H_2O$	4.13
A	Cesium Nitrate	$CsNO_3$	0.68
A	Copper Nitrate	$Cu(NO_3)_2 \bullet 6H_2O$	2.88
A	Ferric Nitrate	$Fe(NO_3)_3 \bullet 9H_2O$	306.80
A	Lanthanum Nitrate	$La(NO_3)_3 \bullet 6H_2O$	3.67
A	Lead Nitrate	$Pb(NO_3)_2$	15.56
A	Magnesium Nitrate	$Mg(NO_3)_2 \bullet 6H_2O$	6.63
A	Manganous Chloride	$MnCl_2 \bullet 4H_2O$	50.88
A	Neodymium Nitrate	$Nd(NO_3)_3 \bullet 6H_2O$	7.31
A	Nickel Chloride	$NiCl_2 \bullet 6H_2O$	53.85
A	Potassium Nitrate	KNO_3	115.51
A	Strontium Nitrate	$Sr(NO_3)_2$	0.47
A	Zinc Nitrate	$Zn(NO_3)_2 \bullet 6H_2O$	5.37
A	Zirconyl Nitrate	$ZrO(NO_3)_2 \bullet xH_2O$ x~1	4.87
A	Disodium ethylenediaminetetraacetate	$Na_2C_{10}H_{14}N_2O_8 \bullet 2H_2O$	182.18
A	N-(2-Hydroxyethyl) ethylenediaminetriacetic acid	$C_{10}H_{18}N_2O_7$	54.27
A	Sodium Gluconate	$HOCH_2[CH(OH)]_4CO_2Na$	98.64
A	Glycolic Acid	$HOCH_2CO_2H$, 70 wt %	675.51
A	Citric Acid	$HOC(CO_2H)(CH_2CO_2H)_2 \bullet H_2O$	236.79
A	Nitrilotriacetic Acid	$N(CH_2CO_2H)_3$	14.29
A	Iminodiacetic Acid	$HN(CH_2CO_2H)_2$	151.50
A	Boric Acid	H_3BO_3	5.04
A	Sodium Chloride	NaCl	19.11
A	Sodium Fluoride	NaF	7.36
A	Sodium Chromate	Na_2CrO_4	13.90
A	Sodium Sulfate	Na_2SO_4	306.16
A	Potassium Molybdate	K_2MoO_4	2.20
B	Water	H_2O	8002.6
B	Sodium Hydroxide	NaOH	633.76
B	Aluminum Nitrate	$Al(NO_3)_3 \bullet 9H_2O$	134.63
B	Sodium Phosphate	$Na_3PO_4 \bullet 12H_2O$	111.46
B	Sodium Formate	NaHCOO	394.17
B	Sodium Acetate	$NaCH_3CO_2 \bullet 12H_2O$	59.43
B	Sodium Oxalate	$Na_2C_2O_4$	31.54
D	Sodium Carbonate	Na_2CO_3	3720.0
D	Sodium Nitrate	$NaNO_3$	7517.2
D	Sodium Nitrite	$NaNO_2$	2295.3
D	Water	H_2O	16444.0

Table B- 16: Forty Liter AN-107 Entrained Solids Simulant

Sequence	Compound	Formula	Mass, grams
F	Aluminum Oxide	Al_2O_3, <10 microns	12.93
F	Calcium Phosphate, tribasic	Ca_3PO_4	0.181
F	Chromic Oxide	Cr_2O_3, <10 microns	0.965
F	Ferric Oxide	Fe_2O_3	12.0
F	Manganese Dioxide	MnO_2	7.77
F	Silica	SiO_2, <5 microns	1.308
F	Sodium Oxalate	$Na_2C_2O_4$	85.98
F	Sodium Carbonate Monohydrate	$Na_2CO_3 \bullet H2O$	81.29
F	Sodium Fluoride	NaF	12.59
F	Sodium Sulfate	$Na_2SO_4 \bullet 10H_2O$	10.41
F	Sodium Phosphate	$Na_3PO_4 \bullet 12H_2O$	23.29

Sr/TRU Precipitation

The Sr/TRU precipitation consisted of raising the hydroxide level of the solution to one molar. The next step was adding strontium nitrate to precipitate strontium carbonate followed by sodium permanganate to react with the complexing agents. The slurry is digested at 323 K for 4 hours to complete the reactions due to permanganate anion and the complexing agents. The sequence of steps is listed in Table B- 17.

Table B- 17: Sr/TRU Precipitation Process

Sequence	Reaction
A	Add sufficient sodium hydroxide to increase free hydroxide concentration to 1.0±0.2 molar. Mix thoroughly.
B	Add the amount of 2 molar strontium nitrate solution needed to increase the strontium concentration to 0.075 molar. The addition was made over a 5 to 10 minute period while mixing the solution.
C	Add the amount of 1 molar sodium permanganate solution needed to increase the permanganate concentration to 0.05 molar. The addition was made over a 5 to 10 minute period while mixing the solution.
D	The Sr/TRU precipitated slurry is heated to 323±5 K for four hours while being continuously stirred.
E	The slurry was allowed to cool to ambient lab temperatures (295 K) overnight while stirring continued.
F	Separate precipitate from decontaminated supernate and wash the solids four times with equal volumes of inhibited (0.01 molar hydroxide) wash water

The free hydroxide concentration in AN-107 supernate is less than 0.02 molar. Therefore, the amount of sodium hydroxide required for a forty liter batch was 40 moles. Assuming the solution volumes were additive, the amounts of strontium nitrate solution and sodium permanganate solution required were 1.644 liters and 2.192 liters, respectively. The actual amounts used are listed in Table B- 18.

Table B- 18: Sr/TRU Precipitate Batching for Forty Liter AN-107 Batch

Reactant	Concentration	Density, kg/m^3	Mass Used, kg
Sodium Hydroxide	Solid	--	1.6000
Strontium Nitrate	2 Molar	1285	2.1129
Sodium Permanganate	1 Molar	1096	2.4023

In the WTP, the decontaminated Envelope C supernate is separated from the Sr/TRU precipitate by crossflow filtration. Since a crossflow system was not available for this study, the precipitate was initially allowed to separate from the supernate by gravity settling. After decanting the supernate, the remaining slurry was concentrated by centrifuging the slurry at 42500 m/s^2 to yield a slurry with nominally 15 wt % insoluble solids. The measured properties of the initial unwashed Sr/TRU precipitate slurry are listed in Table B- 19.

Table B- 19: Initial Sr/TRU Unwashed Precipitate Physical Properties

Weight % Total Solids	40.92
Weight % Soluble Solids	25.14
Weight % Insoluble Solids	15.77
Density at 295 K in g/mL	1.452

The rheology of the unwashed Sr/TRU precipitate was analyzed on the Haake M5 rheometer using the MV1 sensor. The results will be discussed in the results section. The precipitate was washed four times to reduce the soluble solids loading. The Sr/TRU precipitate in the WTP would be sheared by the pumps used for the crossflow filtration of the precipitate similar to the Envelope D preparations. The same process of shearing as described in processing the simulated AZ0-101 sludge was used. A period of 3.3 hours of recirculation using the CUF pump was used to apply the appropriate amount of shearing for the approximate 10 L of Sr/TRU precipitate.

During the shearing process, more than 55 % of the batch was inadvertently lost. Since insufficient Sr/TRU precipitate remained for the study, an additional thirty liter batch of AN-107 simulant was prepared and processed through the SR/TRU process. The recipe for the second batch of AN-107 simulant is listed in Table B- 20 and Table B- 21.

Table B- 20: Thirty Liter AN-107 Supernate Simulant Recipe (Batch 2)

Sequence	Compound	Formula	Mass, grams
A	Water	H_2O	5999.9
A	Calcium Nitrate	$Ca(NO_3)_2 \bullet 4H_2O$	65.5
A	Cerium Nitrate	$Ce(NO_3)_3 \bullet 6H_2O$	3.09
A	Cesium Nitrate	$CsNO_3$	0.5133
A	Copper Nitrate	$Cu(NO_3)_2 \bullet 6H_2O$	2.15
A	Ferric Nitrate	$Fe(NO_3)_3 \bullet 9H_2O$	230.00
A	Lanthanum Nitrate	$La(NO_3)_3 \bullet 6H_2O$	2.68
A	Lead Nitrate	$Pb(NO_3)_2$	11.68
A	Magnesium Nitrate	$Mg(NO_3)_2 \bullet 6H_2O$	4.97
A	Manganous Chloride	$MnCl_2 \bullet 4H_2O$	38.17
A	Neodymium Nitrate	$Nd(NO_3)_3 \bullet 6H_2O$	5.48
A	Nickel Chloride	$NiCl_2 \bullet 6H_2O$	49.41
A	Potassium Nitrate	KNO_3	86.64
A	Strontium Nitrate	$Sr(NO_3)_2$	0.300
A	Zinc Nitrate	$Zn(NO_3)_2 \bullet 6H_2O$	3.89
A	Zirconyl Nitrate	$ZrO(NO_3)_2 \bullet xH_2O$ x~1	3.60
A	Disodium ethylenediaminetetraacetate	$Na_2C_{10}H_{14}N_2O_8 \bullet 2H_2O$	136.6
A	N-(2-Hydroxyethyl) ethylenediaminetriacetic acid	$C_{10}H_{18}N_2O_7$	40.70
A	Sodium Gluconate	$HOCH_2[CH(OH)]_4CO_2Na$	73.88
A	Glycolic Acid	$HOCH_2CO_2H$, 70 wt %	506.6
A	Citric Acid	$HOC(CO_2H)(CH_2CO_2H)_2 \bullet H_2O$	177.6
A	Nitrilotriacetic Acid	$N(CH_2CO_2H)_3$	10.72
A	Iminodiacetic Acid	$HN(CH_2CO_2H)_2$	113.6
A	Boric Acid	H_3BO_3	3.77
A	Sodium Chloride	NaCl	34.23
A	Sodium Fluoride	NaF	5.53
A	Sodium Chromate	Na_2CrO_4	10.31
A	Sodium Sulfate	Na_2SO_4	229.5
A	Potassium Molybdate	K_2MoO_4	1.67
B	Water	H_2O	6000.0
B	Sodium Hydroxide	NaOH	475.3
B	Aluminum Nitrate	$Al(NO_3)_3 \bullet 9H_2O$	100.9
B	Sodium Phosphate	$Na_3PO_4 \bullet 12H_2O$	83.59
B	Sodium Formate	NaHCOO	295.6
B	Sodium Acetate	$NaCH_3CO_2 \bullet 12H_2O$	44.57
B	Sodium Oxalate	$Na_2C_2O_4$	23.67
D	Sodium Carbonate	Na_2CO_3	2789.2
D	Sodium Nitrate	$NaNO_3$	5593.3
D	Sodium Nitrite	$NaNO_2$	1721.6
D	Water	H_2O	12330.9

Table B- 21: Thirty Liter AN-107 Entrained Solids Simulant (Batch 2)

Sequence	Compound	Formula	Mass, grams
F	Aluminum Oxide	Al_2O_3, <10 microns	9.58
F	Calcium Phosphate, tribasic	Ca_3PO_4	0.144
F	Chromic Oxide	Cr_2O_3, <10 microns	0.711
F	Ferric Oxide	Fe_2O_3	8.90
F	Manganese Dioxide	MnO_2	5.76
F	Silica	SiO_2, <5 microns	3.032
F	Sodium Oxalate	$Na_2C_2O_4$	63.76
F	Sodium Carbonate Monohydrate	Na_2CO_3•H2O	60.29
F	Sodium Fluoride	NaF	9.33
F	Sodium Sulfate	Na_2SO_4•$10H_2O$	7.72
F	Sodium Phosphate	Na_3PO_4•$12H_2O$	17.26

The silica shown in Table B- 21 reflects an inadvertently high addition of silica to the entrained solids for the second batch of Sr/TRU precipitate. The higher level of silica was not expected to have any effect on the precipitate rheology since the insoluble portion of the entrained solids makes up a small fraction of the total insoluble solids in the precipitate. The second batch of AN-107 simulant was processed through the Sr/TRU precipitation steps as previously described, concentrated, washed and combined with the remaining precipitate from the first batch. The precipitate was sheared as previously described to represent the shearing from crossflow filtration. The particle size of the Sr/TRU precipitate was analyzed before and after shearing and is summarized in Table B- 22. More details on the particle size distribution can be found in the appendix.

Table B- 22: Particle Size of Washed Sr/TRU Product

	Before Shearing	After Shearing
Mean Particle Size by Volume	**12.05 microns**	**4.76 microns**
Mean Particle Size by Number	**1.31 microns**	**1.2 microns**
Largest Particles	**176 micron**	**31 micron**

The composition of the Sr/TRU product based upon analysis is listed in Table B- 23 on a weight percent oxide basis. As expected, the major components are Sr and Mn. Other important elements include in descending order: Na, Fe, Al and Ca.

Table B- 23: Composition of Sr/TRU Precipitate

Element	Analysis, µg/gm	Oxide	Oxide, µg/gm	Oxide wt %
Al	1960	Al_2O_3	3703	2.66
Ba	34	BaO	38	0.03
Ca	1950	CaO	2728	1.96
Cd	1.5	CdO	1.7	0.00
Ce	445	Ce_2O_3	521	0.37
Cr	221	Cr_2O_3	323	0.23
Cu	23	CuO	29	0.02
Fe	8034	Fe_2O_3	11487	8.26
K	59	K2O	71	0.05
La	182	La_2O_3	213	0.15
Mg	64	MgO	107	0.08
Mn	22200	MnO	28665	20.62
Na	12591	Na_2O	16972	12.21
Nd	350	Nd_2O_3	408	0.29
Ni	29	NiO	37	0.03
P	412	P_2O_5	944	0.68
Pb	1010	PbO	1088	0.78
Si	122	SiO_2	261	0.19
Sr	60300	SrO	71311	51.30
Zn	48	ZnO	59	0.04
Zr	34	ZrO_2	46	0.03

Different solids concentrations of Sr/TRU precipitate were obtained by centrifuging at 42500 m/s^2 and adding back sufficient supernate to achieve the desired solids loading. The residual supernate was retained for use in diluting to lower solids loadings. The slurries prepared are listed in Table 9.

Blended Eluate Simulant

The third process stream which is blended with the washed sludge and Sr/TRU precipitate streams is the blended eluate stream. The stream is a blend of the concentrated eluates from the cesium and technetium ion exchange columns. The Cs column is eluted with nitric acid and Tc column is eluted with water. Both eluates are concentrated by vacuum evaporation and then blended together. Currently, both ion exchange columns and both evaporators have only been independently tested. The combined processes have been modeled using the Environmental Simulation Program version 6.2 licensed by OLI Systems, Inc.[31] The model was applied to the results of ion exchange studies on AZ-102 supernate to obtain the output listed in Table B- 43 of Appendix B of this report. The basis for the simulant was derived from the composition of the blended eluate stream and is shown in Table B- 24.

[31] A. S. Choi, **Estimation of Physical Properties of AN-107 Cesium and Technetium Eluate Blend**, WSRC-TR-2000-00527, SRT-RPP-2000-00061, Westinghouse Savannah River Company, Aiken, SC 29808 (February 26, 2001).

Table B- 24: Derived Analytical Composition of Blended Eluate

Component	g/L	Molar	Component	g/L	Molar
Boron	0.171	1.58E-02	Nitrate	71.037	1.15
Calcium	0.001	1.32E-05	Nitrite	10.929	2.38E-01
Carbonate	1.06	1.77E-02	Oxalate	4.382	4.98E-02
Bicarbonate	7.845	1.29E-01	Hydrogen Phosphate	0.464	4.84E-03
Cesium	1.826	1.37E-02	Dihydrogen Phosphate	0.016	1.16E-04
Chloride	6.487	1.83E-01	Potassium	1.486	3.8E-02
Chromium	0.509	9.79E-03	Silicon	0.122	8.71E-03
EDTA	0.199	6.9E-04	Sodium	46.95	2.04
Glycolate	0.437	5.82E-03	Sulfate	10.99	2.29E-01
Hydroxide	0.005	3.23E-04	Citric Acid	0.219	1.14E-03
Iron	0.004	7.79E-05	Nitrilotriacetic Acid	0.013	6.92E-05
Lead	0.055	2.67E-04	Iminodiacetic acid	0.14	1.05E-03
Molybdenum	0.016	1.69E-04	Gluconate	0.082	4.17E-04
Nickel	0.02	3.37E-04	Hydrogen ion	0.047	4.66E-02

The blended eluate composition above was based on a model that did not reflect the planned WTP operation of the Tc eluate evaporator to achieve 80% of the solubility for the eluate concentrate. Several assumptions were necessary to convert the analytical values into compounds. Boron was assumed to be present as borate anion, chromium as chromate anion, molybdenum as molybdate anion, and silicon as silicate anion. The anions were added as the sodium or potassium salts. The complexants were added as the acid with sufficient sodium hydroxide to convert them to the salt. A test recipe gave a measured density of 1.107 grams/milliliter at 295 K, which agrees well with the OLI model prediction of 1.106 g/mL (see Appendix, Table A-1. The recipe used for producing two liters of the blended eluate is listed in Table B- 25.

Table B- 25: Blended Eluate Recipe for Two Liters of Feed

Compound	Formula	Mass, grams
Water	H_2O	800
Boric Acid	H_3BO_3	1.953
Calcium Nitrate	$Ca(NO_3)_2 \bullet 4H_2O$	0.006
Cesium Nitrate	$CsNO_3$	5.356
Sodium Chloride	NaCl	21.385
Sodium Chromate	Na_2CrO_4	3.17
Ferric Nitrate	$Fe(NO_3)_3 \bullet 9H_2O$	0.063
Lead Nitrate	$Pb(NO_3)_2$	0.177
Nickel Nitrate	$Ni(NO_3)_2 \bullet 6H_2O$	0.196
Sodium Nitrite	$NaNO_2$	32.783
Potassium Molybdate	K_2MoO_4	0.08
Potassium Nitrate	KNO_3	7.616
Disodium ethylenediaminetetraacetate	$Na_2C_{10}H_{14}N_2O_8 \bullet 2H_2O$	0.514
Sodium Oxalate	$Na_2C_2O_4$	13.343
Sodium Gluconate	$HOCH_2[CH(OH)]_4CO_2Na$	0.182
Glycolic Acid	$HOCH_2CO_2H$, 70 wt %	1.267
Citric Acid	$HOC(CO_2H)(CH_2CO_2H)_2$	0.479
Nitrilotriacetic Acid	$N(CH_2CO_2H)_3$	0.026
Iminodiacetic Acid	$HN(CH_2CO_2H)_2$	0.28
Sodium Metasilicate	$Na_2SiO_3 \bullet 9H_2O$	2.477
Sodium Sulfate	Na_2SO_4	32.511
Sodium Hydrogen Phosphate	$Na_2HPO_4 \bullet 12H_2O$	2.593
Sodium Dihydrogen Phosphate	$NaH_2PO_4 \bullet H_2O$	0.044
Sodium Hydroxide	NaOH	0.026
Sodium Carbonate	Na_2CO_3	3.744
Sodium Bicarbonate	$NaHCO_3$	21.603
Sodium Nitrate	$NaNO_3$	185.75
Sodium Hydroxide	NaOH	4.06
Water	H_2O	1073.0

The measured density of the two-liter batch was also 1.107 g/mL at 295 K. The pH of the two liter batch was 8.9. The eluate basis for blending with the sludge and the Sr/TRU precipitate is listed in Table B- 26 expressed as waste oxides.

Table B- 26: Blended Eluate Basis for Blending Streams

Component	Molar	Oxide	Oxide, g/L
Aluminum	7.13E-10	Al_2O_3	0.00
Barium	5.48E-07	BaO	0.00
Boron	1.58E-02	B_2O_3	0.55
Cadmium	0	CdO	0.00
Calcium	1.32E-05	CaO	0.00
Cerium	0	CeO_2	0.00
Cesium	1.37E-02	Cs_2O	1.94
Chromium	9.79E-03	Cr_2O_3	0.74
Cobalt	0	CoO	0.00
Copper	0	CuO	0.00
Iron	7.79E-05	Fe_2O_3	0.01
Lanthanum	0	La_2O_3	0.00
Lead	2.67E-04	PbO	0.06
Magnesium	0	MgO	0.00
Manganese	0	MnO_2	0.00
Molybdenum	1.69E-04	MoO_3	0.01
Neodymium	0	Nd_2O_3	0.00
Nickel	3.37E-04	NiO	0.03
Potassium	3.80E-02	K_2O	1.79
Phosphorus	5.00E-03	P_2O_5	0.35
Selenium	0	SeO_2	0.00
Silicon	4.36E-03	SiO_2	0.26
Silver	0	Ag_2O	0.00
Sodium	2.04E-00	Na_2O	63.29
Tin	0	SnO_2	0.00
Uranium	0.0072106	UO_2	1.95
Zinc	0	ZnO	0.00
Zirconium	0	ZrO_2	0.00
Total			70.97

The simulant does not contain the uranium shown in Table B- 26.

Blending Basis for the AZ-101 Test Mixtures

The Waste Treatment Plant of the River Protection Project will blend Envelope D sludges with Sr/TRU precipitate and the concentrated, blended ion exchange eluates to produce a glass waste form with a specified composition. The waste loading in the glass is therefore based on sludge, strontium and cesium loadings. The composition for the AZ-101 simulated sludge, the Sr/TRU precipitate and the blended eluate basis was provided to the Vitreous State Laboratory (VSL) at Catholic University, Washington, D.C. for computation of the necessary blending ratio. The essential factors in developing the blending ratio are the Al, Fe and Zr in the sludge, the strontium in the Sr/TRU precipitate and the total cesium in the blended eluate. The blending ratio is derived from the information in Table B- 27 provided by VSL. The cesium blend basis is based on assuming that ^{137}Cs is 25 % of the total cesium while the current design basis for AZ-101 and AZ-102 is 30 %.

Table B- 27: Vitreous State Laboratory (VSL) Blending Basis for AZ-101

		SRTC AZ-101 Simulant		AN107 TRU/Sr		SRTC AZ-102 Eluate		Oxide Contribution to 3250 kg of Glass		
		Oxide	Oxide	Oxide	Oxide	Oxide	Oxide	AZ101 Simulant	TRU/SR	AZ102 Eluate
		(g/g solid)	(wt%)	(mg/L)	(wt%)	g/L	(wt%)	(kg)	(kg)	(kg)
	Ag2O	2.40E-03	0.26%			0.00000	0.00%	2.54		0.000
	Al2O3	1.09E-01	11.77%	445.85	0.37%	0.00000	0.00%	115.64	0.504	0.000
	B2O3	2.59E-03	0.28%	67.61	0.06%	0.54972	0.77%	2.73	0.076	0.006
	BaO	2.36E-03	0.25%	11.16	0.01%	0.00008	0.00%	2.50	0.013	0.000
	CaO	1.26E-02	1.36%	2182.52	1.79%	0.00074	0.00%	13.36	2.468	0.000
	CdO	2.55E-02	2.74%			0.00000	0.00%	26.92	0.000	0.000
	CeO2	3.30E-03	0.35%			0.00000	0.00%	3.49	0.000	0.000
	CoO	3.64E-03	0.39%	6.36	0.01%	0.00000	0.00%	3.84	0.007	0.000
	Cr2O3	3.27E-03	0.35%	128.60	0.11%	0.74376	1.05%	3.46	0.145	0.008
	Cs2O					1.93574	2.73%		0.000	0.021
	CuO	1.23E-03	0.13%	37.55	0.03%	0.00000	0.00%	1.29	0.042	0.000
	Dy2O3	1.76E-04	0.02%					0.19	0.000	0.000
	Fe2O3	4.07E-01	43.83%	11222.23	9.21%	0.00622	0.01%	430.71	12.690	0.000
	K2O	7.67E-03	0.82%			1.78992	2.52%	8.10	0.000	0.019
	La2O3	1.35E-02	1.45%	248.62	0.20%	0.00000	0.00%	14.28	0.281	0.000
	MgO	2.67E-03	0.29%	190.68	0.16%	0.00000	0.00%	2.82	0.216	0.000
	MnO	8.56E-03	0.92%	28536.11	23.42%	0.00000	0.00%	9.05	32.269	0.000
	MoO3	2.17E-04	0.02%	15.00	0.01%	0.02429	0.03%	0.23	0.017	0.000
	Na2O	1.12E-01	12.03%	13040.56	10.70%	63.28656	89.15%	118.22	14.747	0.673
	Nd2O3	8.98E-03	0.97%			0.00000	0.00%	9.49	0.000	0.000
	NiO	2.23E-02	2.40%	50.90	0.04%	0.02519	0.04%	23.61	0.058	0.000
	P2O5					0.35478	0.50%		0.000	0.004
	PbO	3.51E-03	0.38%	64.63	0.05%	0.05953	0.08%	3.71	0.073	0.001
	Re2O7	2.06E-04	0.02%					0.22	0.000	0.000
	Rh2O3	1.23E-03	0.13%					1.30	0.000	0.000
	RuO2	2.19E-03	0.24%					2.31	0.000	0.000
	SiO2	3.01E-02	3.24%	254.53	0.21%	0.26168	0.37%	31.84	0.288	0.003
	SnO			29.50	0.02%	0.00000	0.00%		0.033	0.000
	SrO	1.78E-03	0.19%	64534.65	52.96%			1.88	72.977	0.000
	TiO2	4.56E-04	0.05%	23.31	0.02%			0.48	0.026	0.000
	UO2					1.94708	2.74%		0.000	0.021
	V2O5			23.21	0.02%				0.026	0.000
	ZnO	1.08E-03	0.12%	110.77	0.09%	0.00000	0.00%	1.14	0.125	0.000
	ZrO2	1.29E-01	13.86%	272.84	0.22%	0.00000	0.00%	136.16	0.309	0.000
	F	1.39E-03	0.15%	7.70	0.01%			1.47	0.009	0.000
	Cl	2.55E-04	0.03%	61.00	0.05%			0.27	0.069	0.000
	SO3	7.57E-03	0.81%	178.33	0.15%			8.00	0.202	0.000
	P2O5	1.25E-03	0.13%	105.33	0.09%			1.32	0.119	0.000
	TOTAL	0.9295	100.00%	121849.6	100.00%	70.9853	100.00%	982.56	137.79	0.76
				6010 kg of Sr to be added to		Cs137 is 25% of all Cs as in				
	Al+Fe+Zr		69.46%	a projected 316509 kg of AZ101		earlier simulant, total Cs2O to				
	Glass/Waste		3.30766955	Glass (Ref: E. Slaathaug)		be blended is still 0.0206 kg				
	Calculated Loading		0.30232766							
To make	3250	Oxide	982.56	SrO	72.98 kg	Cs2O	0.0206 kg			
kg of glass, need (kg)		Waste	1057.04	Sr/TRU product	1130.82 L	Eluate	10.64 L			
						Wt Eluate	11.77 kg			

The VSL blending ratio is based upon producing 3250 kilograms of glass. The mass of AZ-101 waste to use is based upon the sum of the mass of aluminum oxide, iron oxide and zirconium oxide making up 21 percent of the glass. For the composition listed in Table B- 27, the amount

of Al + Fe + Zr should be 682.5 kg and the amount of waste oxides should be 682.5/0.6946 or 982.6 kg. After converting from waste oxides to total solids, the amount required for 3250 kg of glass from Table B- 27 is 1057.04 kg of AZ-101 simulated sludge. Applying the same logic to the actually produced and measured AZ-101 simulated sludge gave the following:

Al + Fe + Zr Oxides	70.77 % (based on early analytical results)
AZ-101 Sludge Oxide Required	(3250*0.21)/0.7077 = 964.4 kg
AZ-101 Sludge Oxide Calcine factor	0.805
AZ-101 Sludge Solids Required	964.4/0.805 = 1198 kg.

The amount of Sr/TRU precipitate to add to the VSL formulated AZ-101 glass was based upon placing 6010 kg of strontium in 316509 kg of glass. For the AZ-101 glass, this requires that 72.98 kg of SrO be used for 3250 kg of glass. Applying the 72.98 kg of SrO to the information in Table B- 23 required that 72.98/0.513 = 142.26 kg of Sr/TRU waste oxides were required for 3250 kg of glass. Applying the measured calcine factor of 0.747 for the Sr/TRU precipitate, produced for this study, yielded 190.52 kg of precipitate solids for 3250 kg of glass.

The final essential blending ratio was for the amount of blended eluate to add to produce 3250 kg of glass. The amount of blended eluate was based upon 10.64 liters of the blended eluate for 3250 kg of glass. Applying the measured density of 1.107 g/mL to the volume yielded 11.78 kg of blended eluate for 3250 kg of glass. Table B- 28 summarizes the values used to create the waste blends for AZ-101 glass for rheology testing.

Table B- 28: AZ-101 Blending Ratios

Waste Stream	Weight, kg
AZ-101 Simulated Sludge Solids	1198
AN-107 Sr/TRU Precipitate Solids	190.52
AZ-102 Blended Eluate Simulant	11.78

Test 1.3

The goal of Test 1.3 was to mix 20 wt % insoluble solids AZ-101 sludge with 20 wt % insoluble solids Sr/TRU precipitate and blended eluate and determine the rheology of the mixture. The volume of the mixture needed was at least 750 mL. The following steps were used to make the test mixture:

1. Mass of 20 wt % insoluble solids AZ-101 Sludge simulant to use: 750*density (1.176 g/mL) = 882 grams. Actually used: 882.09 grams.
2. Mass of Sludge Solids is: 882 g * Wt % Total Solids (20.77 %) = 183.19 grams.
3. The amount of Sr/TRU solids required for 183.19 grams of sludge solids is: 183.19 g * Sr/TRU Basis (190.52)/AZ-101 Sludge Basis (1198) = 29.13 grams.
4. The amount of 20 wt % insoluble solids Sr/TRU precipitate to add is: 29.13/wt % total Solids Sr/TRU (22.52 %) = 129.37 grams. Actually used: 129.39 grams.

5. The amount of blended eluate to add:
   183.19 g * Basis for Eluate (11.78)/Basis for AZ-101 (1198) = 1.80 grams of eluate.
   Actually used: 1.8 grams.

The physical properties for the Test 1.3 blend are listed in Table 13. Mixing a ~20 weight % solids slurry with another ~20 weight % solids did not result in diluting the measured solids for the mixture. A sample of the test mixture was submitted for chemical analysis. The results expressed on a weight % oxide basis are shown in Table B- 29. The agreement between the found and the target is reasonable, since the target is based upon the originally planned compositions for the waste streams.

Table B- 29: Composition of Test 1.3 Compared to Target

Oxide	Wt %	Target Wt %	Oxide	Wt %	Target Wt %
Al_2O_3	11.87	10.36	P_2O_5	2.75	0.13
BaO	0.21	0.22	PbO	0.48	0.34
CaO	1.17	1.41	SiO_2	3.37	2.87
CdO	2.61	2.4	SrO	6.17	6.68
CoO	0.38	0.34	TiO_2	0.05	0.05
Cr_2O_3	0.38	0.32	ZnO	0.14	0.11
CuO	0.23	0.12	ZrO	11.7	12.17
Fe_2O_3	44.01	39.55	La_2O_3	1.37	1.3
MgO	0.1	0.27	K_2O	0.71	0.72
MnO	3.49	3.69	Ag_2O	0.23	0.23
MoO_3	0.03	0.02	CeO_2	0.36	0.31
Na_2O	7.19	11.92	Nd_2O_3	1.01	0.85

Test 1.4

The goal of Test 1.4 was to mix 15 wt % insoluble solids AZ-101 sludge with 15 wt % insoluble solids Sr/TRU precipitate and blended eluate and determine the rheology of the mixture. The volume of the mixture needed was at least 500 mL. The following steps were used to make the test mixture:

1. Mass of 15 wt % insoluble solids AZ-101 Sludge simulant to use: 500*density (1.125 g/mL) = 562.5 grams. Actually used: 562.53 grams.
2. Mass of Sludge Solids is: 562.5*Wt % Total Solids (16.26 %) = 91.46 grams.
3. The amount of Sr/TRU solids required for 91.46 grams of sludge solids is:
   91.46 g * Sr/TRU Basis (190.52)/AZ-101 Sludge Basis (1198) = 14.55 grams.
4. The amount of 15 wt % insoluble solids Sr/TRU precipitate to add is:
   14.55 g/wt % total Solids Sr/TRU (17.65 %) = 82.44 grams. Actually used: 82.47 grams.
5. The amount of blended eluate to add:
   91.46 g * Basis for Eluate (11.78)/Basis for AZ-101 (1198) = 0.9 grams of eluate. Actually used: 0.9 grams.

The physical properties for the Test 1.4 blend are listed in Table 13. Mixing a ~15 wt % solids slurry with another ~15 wt % solids did not result in diluting the measured solids for the mixture.

A sample of the test mixture was submitted for chemical analysis. The results expressed on a wt percent oxide basis are shown in Table B- 30. The agreement between the found and the target is reasonable, since the target is based upon the originally planned compositions for the waste streams.

Table B- 30: Composition of Test 1.4 Compared to Target

Oxide	Wt %	Target Wt %	Oxide	Wt %	Target Wt %
Al_2O_3	11.16	10.36	P_2O_5	2.56	0.13
B_2O_3	0.24	0.25	PbO	0.47	0.34
BaO	0.21	0.22	SiO_2	3.20	2.87
CaO	1.23	1.41	SrO	6.20	6.68
CdO	2.53	2.4	TiO_2	0.05	0.05
CoO	0.37	0.34	ZnO	0.13	0.11
Cr_2O_3	0.37	0.32	ZrO	9.45	12.17
CuO	0.17	0.12	La_2O_3	1.36	1.3
Fe_2O_3	42.56	39.55	K_2O	0.83	0.72
MgO	0.1	0.27	Re_2O_7	0.05	0.02
MnO	3.30	3.69	SO_3	0.54	0.73
MoO_3	0.02	0.02	Ag_2O	0.28	0.23
Na_2O	9.03	11.92	CeO_2	0.37	0.31
NiO	2.27	2.11	Nd_2O_3	0.95	0.85

Additional tests planned for Test 1.4 required determining the amount of acid needed to shift the test mixture's pH from 10.14 to values near 9, 7 and 5. A 2.23 gram sample of the mixture was added to 60 mL of deionized water and titrated with 0.1013 molar hydrochloric acid until the pH was 5. Figure B - 4 shows the resulting titration curve as a function of the moles of acid added/kilogram of sludge. The shape of the titration curve is controlled by the basic species being titrated. For the blended mixture in Test 1.4, the basic species include hydroxide, phosphate and carbonate with the major species being carbonate. The fitted equation shown in Figure B - 4 was empirically obtained using TableCurve™ 2D software and should not be used to extrapolate beyond the fitted region (pH 11 to pH 5). Based upon the titration curve, the amount of a monoprotic acid to reach pH 9 was 0.0695 moles per kilogram of the blended mixture. To reach pH 7 the amount of acid would be 0.156 moles per kilogram of slurry and for pH 5 the amount is 0.459 moles per kilogram of slurry. The adjustment of the pH of a portion of Test 1.4 with 10.34 molar nitric acid (50 wt %) consisted of the following steps:

1. Add 230 grams of Test 1.4 mixture to a tared, 250 mL bottle and record the weight. Actually used net weight was 229.54 grams. Tare weight was 28.35 grams.
2. Using a calibrated digital pipette add 1.54 mL of 10.34 molar nitric acid. Actually added 1.54 mL.
3. Mix thoroughly, measure, and record pH. Measured pH was 8.16.
4. Transfer about 30 grams of the pH-adjusted mixture to 30 mL container labeled as **Test 1.4 pH 9 Adjusted,** weigh and record the weight. Amount of slurry removed was 20.01 grams due to the thick, sticky properties of the slurry. This sample was used for rheology measurements.
5. Obtain mass of pH adjusted 250 mL bottle and calculate the amount of acid necessary to reduce pH to 7. Actual gross mass was 259.72 grams. Tare weight was 28.35 grams.

6. Using a calibrated digital pipette add 1.76 mL of 10.34 molar nitric acid. Actually added 1.76 mL.
7. Mix thoroughly, measure, and record pH. Measured pH was 7.01.
8. Transfer about 30 grams of the pH-adjusted mixture to 30 mL container labeled as **Test 1.4 pH 7 Adjusted,** weigh and record the weight. Amount of slurry removed was 17.83 grams due to the thick, sticky properties of the slurry. This sample was used for rheology measurements.
9. Obtain mass of pH adjusted 250 mL bottle and calculate the amount of acid necessary to reduce pH to 5. Actual gross mass was 213.52 grams. Tare Weight was 28.35 grams.
10. Using a calibrated digital pipette add 5.42 mL of 10.34 molar nitric acid. Actually added 5.42 mL.
11. Mix thoroughly, measure, and record pH. Measured pH was 5.09.
12. Labeled 250 mL bottle as **Test 1.4 pH 5 Adjusted** and used the sample for rheology and chemical analysis.

During the pH adjustment, gas evolution was observed during the acid addition. The gas produced was probably carbon dioxide due to the conversion of carbonate to bicarbonate and then to carbonic acid ($H_2O + CO_2$). The stability of the adjusted pH as a function of time was not studied as part of this program. The actual rheology results for the starting and pH-adjusted Test 1.4 mixtures are discussed in the main section of this report.

Figure B - 4: Test Mix 1.4 Titration Curve

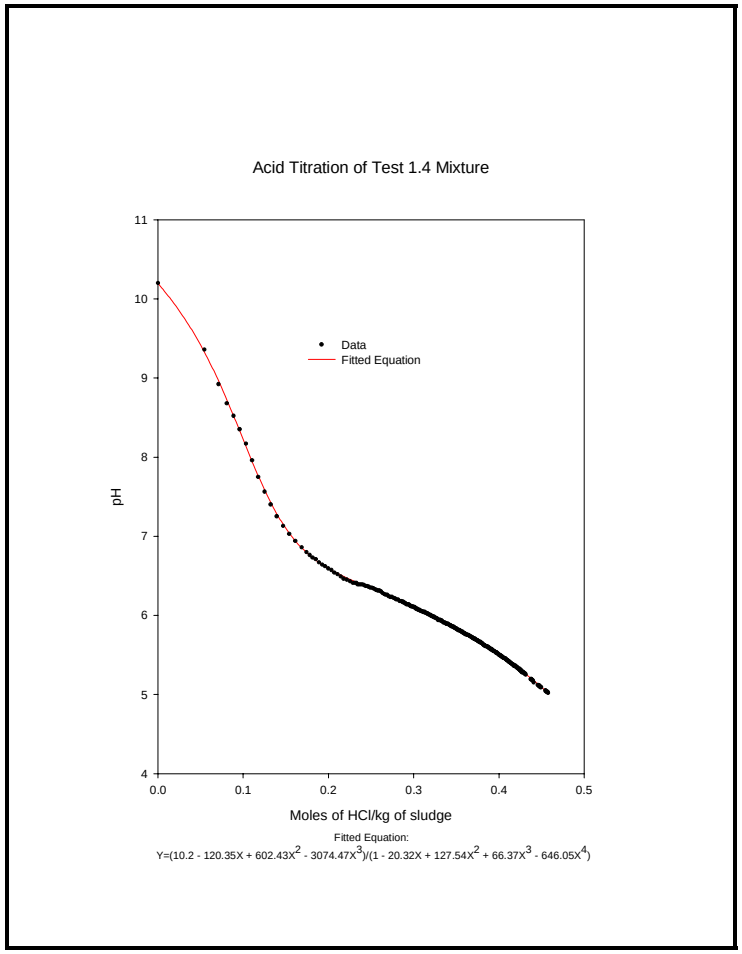
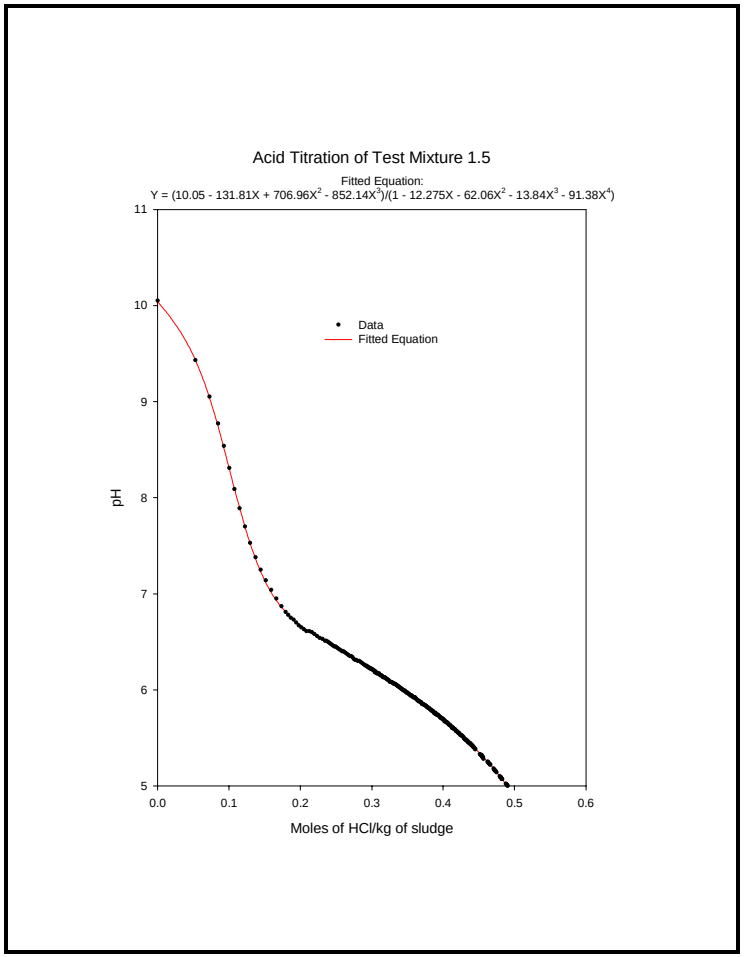


Figure B - 5: Test Mix 1.5 Titration Curve



Test 1.5

The goal of Test 1.5 was to mix 15 wt % insoluble solids AZ-101 sludge with 25 wt % insoluble solids Sr/TRU precipitate and blended eluate and determine the rheology of the mixture. The volume of the mixture needed was at least 500 mL. The following steps were used to make the test mixture:

1. Mass of 15 wt % insoluble solids AZ-101 Sludge simulant to use: 500 mL*density (1.125 g/mL) = 562.5 grams. Actually used: 562.52 grams.
2. Mass of Sludge Solids is: 562.5 g * Wt % Total Solids (16.26 %) = 91.46 grams.
3. The amount of Sr/TRU solids required for 91.46 grams of sludge solids is: 91.46 g * Sr/TRU Basis (190.52 g)/AZ-101 Sludge Basis (1198 g) = 14.55 grams.
4. The amount of 25 wt % insoluble solids Sr/TRU precipitate to add is: 14.55 g / wt % total Solids Sr/TRU (27.32 %) = 53.24 grams. Actually used: 53.26 grams.
5. The amount of blended eluate to add: 91.46 g * Basis for Eluate (11.78)/Basis for AZ-101 (1198) = 0.9 grams of eluate. Actually used: 0.9 grams.

The physical properties for the Test 1.5 blend are listed in Table 13. Mixing the ~15 wt % solids slurry with another smaller amount of ~25 wt % produced a mixture with a higher total about 16 wt %.. A sample of the test mixture was submitted for chemical analysis. The results expressed on a wt % oxide basis are shown in Table B- 31. The agreement between the found and the target composition was reasonable since the target is based upon the originally planned compositions for the waste streams.

Table B- 31: Composition of Test 1.5 Compared to Target

Oxide	Wt %	Target Wt %	Oxide	Wt %	Target Wt %
Al_2O_3	10.84	10.36	P_2O_5	2.38	0.13
B_2O_3	0.23	0.25	PbO	0.46	0.34
BaO	0.20	0.22	SiO_2	3.11	2.87
CaO	1.23	1.41	SrO	6.65	6.68
CdO	2.48	2.4	TiO_2	0.06	0.05
CoO	0.36	0.34	ZnO	0.13	0.11
Cr_2O_3	0.36	0.32	ZrO	11.72	12.17
CuO	0.14	0.12	La_2O_3	1.33	1.3
Fe_2O_3	41.34	39.55	K_2O	0.90	0.72
MgO	0.1	0.27	Re_2O_7	0.04	0.02
MnO	3.45	3.69	SO_3	0.53	0.73
MoO_3	0.01	0.02	Ag_2O	0.20	0.23
Na_2O	8.24	11.92	CeO_2	0.36	0.31
NiO	2.21	2.11	Nd_2O_3	0.94	0.85

Additional tests planned for Test 1.5 required determining the amount of acid needed to shift the test mixture's pH from 10.17 to values near 9, 7 and 5. A 2.21 gram sample of the mixture was added to 60 mL of deionized water and titrated with 0.1013 molar hydrochloric acid until the pH was 5. Figure B - 5 shows the resulting titration curve as a function of the moles of acid added/kilogram of sludge. The shape of the titration curve is controlled by the basic species

being titrated. For the blended mixture in Test 1.5, the basic species included hydroxide, phosphate and carbonate. The fitted equation shown in Figure B - 5 was empirically obtained using TableCurve™ 2D software and should not be used to extrapolate beyond the fitted region (pH 11 to pH 5). Based upon the titration curve, the amount of a monoprotic acid to reach pH 9 was 0.0747 moles per kilogram of the blended mixture. To reach pH 7 the amount of acid was 0.161 moles per kilogram of slurry and for pH 5 the amount was 0.49 moles per kilogram of slurry. The adjustment of the pH of a portion of Test 1.5 with 10.34 molar nitric acid (50 wt %) consisted of the following steps:

1. Add 230 grams of Test 1.5 mixture to a tared, 250 mL bottle and record the weight. Actually used net weight was 229.64 grams. Tare Weight was 28.5 grams.
2. Using a calibrated digital pipette add 1.66 mL of 10.34 molar nitric acid. Actually added 1.66 mL.
3. Mix thoroughly, measure, and record pH. The measured pH was 8.43.
4. Transfer about 30 grams of the pH-adjusted mixture to 30 mL container labeled as **Test 1.5 pH 9 Adjusted,** weigh and record the weight. Amount of slurry removed was 21.28 grams due to the thick, clinging properties of the slurry. This sample was used for rheology measurements.
5. Obtain mass of pH adjusted 250 mL bottle and calculate the amount of acid necessary to reduce pH to 7. Actual gross mass was 235.69 grams. Tare weight was 28.5 grams.
6. Using a calibrated digital pipette add 1.73 mL of 10.34 molar nitric acid. Actually added 1.73 mL.
7. Mix thoroughly, measure, and record pH. The measured pH was 7.03.
8. Transfer about 30 grams of the pH-adjusted mixture to 30 mL container labeled as **Test 1.5 pH 7 Adjusted,** weigh and record the weight. Amount of slurry removed was 20.09 grams due to the thick, clinging properties of the slurry. This sample was used for rheology measurements.
9. Obtain mass of pH adjusted 250 mL bottle and calculate the amount of acid necessary to reduce pH to 5. Actual gross mass was 208.59 grams. Tare weight was 28.5 grams.
10. Using a calibrated digital pipette add 5.73 mL of 10.34 molar nitric acid. Actually added 5.26 mL.
11. Mix thoroughly, measure, and record pH. The measured pH was 5.12.
12. Labeled 250 mL bottle as **Test 1.5 pH 5 Adjusted** and used the sample for rheology and chemical analysis.

During the pH adjustment, gas evolution was observed during the acid addition. The gas produced was probably carbon dioxide due to the conversion of carbonate to bicarbonate and then to carbonic acid ($H_2O + CO_2$). The actual pH and rheology results for the adjusted Test 1.5 mixtures is discussed in the main section of this report.

Test ADD-1

Tests ADD-1 and ADD-2 were added to the scope to increase the range of solids being studied, since insoluble solid levels above 20 wt % were not achievable for the AZ-101 simulated sludge. The goal of Test ADD-1 was to mix 7.5 wt % insoluble solids AZ-101 sludge with 15 wt % insoluble solids Sr/TRU precipitate and blended eluate and determine the rheology of the

mixture. The volume of the mixture needed was at least 500 mL. The following steps were used to make the test mixture:

1. Mass of 7.5 wt % insoluble solids AZ-101 sludge simulant to use:
   500 mL * density (1.065 g/mL) = 532.5 grams. Actually used: 532.51 grams.
2. Mass of Sludge Solids is: 532.5 g * Wt % Total Solids (8.97 %) = 47.77 grams.
3. The amount of Sr/TRU solids required for 47.77 grams of sludge solids is:
   47.77 g * Sr/TRU Basis (190.52)/AZ-101 Sludge Basis (1198) = 7.60 grams.
4. The amount of 15 wt % insoluble solids Sr/TRU precipitate to add is:
   7.60 g / wt % total Solids Sr/TRU (17.65 %) = 43.05 grams. Actually used: 43.05 grams.
5. The amount of blended eluate to add:
   47.77 g * Basis for Eluate (11.78)/Basis for AZ-101 (1198) = 0.47 grams of eluate. Actually used: 0.61 grams.

The physical properties for the Test ADD-1 blend are listed in Table 13. Mixing a ~7.5 wt % solids slurry with a ~15 wt % solids slurry raises the solids loading from that of the starting base slurry but only by a small amount due to the small amount of Sr/TRU used. A sample of the test mixture was submitted for chemical analysis. The results expressed on a weight percent oxide basis are shown in Table B- 32. The agreement between the found and the target wt % was reasonable, since the target is based upon the originally planned compositions for the waste streams.

Table B- 32: Composition of Test ADD-1 Compared to Target

Oxide	Wt %	Target Wt %	Oxide	Wt %	Target Wt %
Al_2O_3	10.44	10.36	P_2O_5	2.05	0.13
B_2O_3	0.30	0.25	PbO	0.43	0.34
BaO	0.18	0.22	SiO_2	2.93	2.87
CaO	1.49	1.41	SrO	6.07	6.68
CdO	2.38	2.4	TiO_2	0.05	0.05
CoO	0.33	0.34	ZnO	0.12	0.11
Cr_2O_3	0.34	0.32	ZrO	10.75	12.17
CuO	0.13	0.12	La_2O_3	1.25	1.3
Fe_2O_3	38.03	39.55	K_2O	1.46	0.72
MgO	0.1	0.27	Re_2O_7	0.04	0.02
MnO	3.33	3.69	SO_3	1.05	0.73
MoO_3	0.03	0.02	Ag_2O	0.25	0.23
Na_2O	13.3	11.92	CeO_2	0.34	0.31
NiO	2.05	2.11	Nd_2O_3	0.89	0.85

Test ADD-2

The goal of Test ADD-2 was to mix 10 wt % insoluble solids AZ-101 sludge with 15 wt % insoluble solids Sr/TRU precipitate and blended eluate and determine the rheology of the mixture. The volume of the mixture needed was at least 500 mL. The following steps were used to make the test mixture:

1. Mass of 10 wt % insoluble solids AZ-101 sludge simulant to use:
   500 mL * density (1.076 g/mL) = 538 grams. Actually used: 538 grams.
2. Mass of Sludge Solids is: 538 g * Wt % Total Solids (11.56 %) = 62.19 grams.
3. The amount of Sr/TRU solids required for 62.19 grams of sludge solids is:
   62.19 g * Sr/TRU Basis (190.52)/AZ-101 Sludge Basis (1198) = 9.89 grams.
4. The amount of 15 wt % insoluble solids Sr/TRU precipitate to add is:
   9.89 g / wt % total Solids Sr/TRU (17.65 %) = 56.04 grams. Actually used: 56.04 grams.
5. The amount of blended eluate to add:
   62.19 g * Basis for Eluate (11.78)/Basis for AZ-101 (1198) = 0.61 grams of eluate. Actually used: 0.64 grams.

The physical properties for the Test ADD-2 blend are listed in Table 13. Mixing a ~10 wt % solids slurry with a ~15 wt % solids slurry raises the solids loading from that of the starting base slurry but only by a small amount due to the small amount of Sr/TRU used. A sample of the test mixture was submitted for chemical analysis. The results expressed on a weight % oxide basis are shown in Table B- 33. The agreement between the found and the target weight % was reasonable, since the target was based upon the originally planned compositions for the waste streams.

Table B- 33: Composition of Test ADD-2 Compared to Target

Oxide	Wt %	Target Wt %	Oxide	Wt %	Target Wt %
Al_2O_3	10.79	10.36	P_2O_5	2.28	0.13
B_2O_3	0.25	0.25	PbO	0.44	0.34
BaO	0.19	0.22	SiO_2	2.99	2.87
CaO	1.39	1.41	SrO	6.06	6.68
CdO	2.37	2.4	TiO_2	0.07	0.05
CoO	0.34	0.34	ZnO	0.16	0.11
Cr_2O_3	0.35	0.32	ZrO	11.31	12.17
CuO	0.13	0.12	La_2O_3	1.29	1.3
Fe_2O_3	39.44	39.55	K_2O	1.23	0.72
MgO	0.1	0.27	Re_2O_7	0.03	0.02
MnO	3.27	3.69	SO_3	0.82	0.73
MoO_3	0.03	0.02	Ag_2O	0.25	0.23
Na_2O	11.06	11.92	CeO_2	0.37	0.31
NiO	2.12	2.11	Nd_2O_3	0.88	0.85

Blending Basis for the AZ-102 Test Mixtures

The Waste Treatment Plant of the River Protection Project will blend Envelope D sludge with Sr/TRU precipitate and the concentrated, blended ion exchange eluates to produce a glass waste form with a specified composition. The waste loading in the glass is therefore based on sludge, strontium and cesium loadings. The composition for the AZ-102 simulated sludge, the Sr/TRU precipitate and the blended eluate basis was provided to the Vitreous State Laboratory (VSL) at Catholic University for computation of the necessary blending ratio. The essential factors in developing the blending ratio are the Al, Fe and Zr in the sludge, the strontium in the Sr/TRU precipitate and the total cesium in the blended eluate. The blending ratio was derived from the information in Table B- 34 provided by VSL.

Table B- 34: VSL Blending Ratio for AZ-102 Waste Glass

Waste Oxide	AZ102 Solid (wt % ox.)	PNNL's Composition of SR/TRU ppt (wt % ox.)	SRS's OLI AZ-102 Eluate (wt % ox.)	Waste Oxide	AZ102 Solid (wt % ox.)	PNNL's Composition of SR/TRU ppt (wt % ox.)	SRS's OLI AZ-102 Eluate (wt % ox.)
Ag_2O	0.06%	0.00%	0.00%	MoO_3	0.00%	0.00%	0.03%
Al_2O_3	25.09%	0.00%	0.00%	Na_2O	8.40%	6.77%	89.15%
B_2O_3	0.03%	0.00%	0.77%	Nd_2O_3	0.68%	0.04%	0.00%
BaO	0.12%	0.03%	0.00%	NiO	2.50%	0.02%	0.04%
BeO	0.01%	0.00%		P_2O_5	1.49%	0.21%	0.50%
CaO	1.51%	0.61%	0.00%	PbO	0.29%	0.16%	0.08%
CdO	4.57%	0.00%	0.00%	SO_3	0.06%	0.00%	
CeO_2	0.19%	0.03%	0.00%	SiO_2	2.06%	0.00%	0.37%
Cl	0.11%			SnO_2	0.54%	0.00%	0.00%
CoO	0.02%	0.00%	0.00%	SrO	0.07%	60.00%	
Cr_2O_3	0.29%	0.11%	1.05%	TiO_2	0.03%	0.00%	
Cs_2O			2.73%	UO_2	5.27%	0.00%	2.74%
CuO	0.08%	0.01%	0.00%	V_2O_5	0.01%	0.00%	
F	0.03%	0.00%		Y_2O_3	0.05%	0.00%	
Fe_2O_3	39.29%	4.94%	0.01%	ZnO	0.13%	0.04%	0.00%
K_2O	0.00%	0.00%	2.52%	ZrO_2	4.80%	0.00%	0.00%
La_2O_3	0.97%	0.01%	0.00%	TOTAL	100.00%	100.00%	100.00%
MgO	0.39%	0.00%	0.00%	Blending	250.00	20.00	2.479
MnO	0.85%	27.02%	0.00%	Ratio (wt of oxides)			**272.48**

The blending ratio was based upon waste oxides for each of the three streams. The waste oxide values were converted to total solids values for the AZ-102 simulated sludge and for the Sr/TRU precipitate by dividing by the appropriate calcine factor. The calcine factor for the AZ-102 sludge was 0.868, which makes the total solids of AZ-102 sludge 287.91 grams. The calcine factor for the Sr/TRU precipitate was 0.747. Therefore, the Sr/TRU basis was 26.77 grams of Sr/TRU solids per 287.91 grams of AZ-102 sludge solids. The basis for the blended eluate was converted to grams of liquid basis by dividing the 2.479 grams of waste oxides by the total waste oxides/liter (69.03 grams) and multiplying by the solution density. The result was 39.75 grams of blended eluate liquid to be added for 287.91 grams of AZ-102 sludge solids. Comparison

with the blending ratio for the AZ-101 waste glass revealed that nearly ten times more eluate was added to the AZ-102 mixtures than to the AZ-101 mixtures. The application of these ratios is discussed with each test mixture.

Test 2.3

The goal of Test 2.3 was to mix 20 wt % insoluble solids AZ-102 sludge with 20 wt % insoluble solids Sr/TRU precipitate and blended eluate and determine the rheology of the mixture. The volume of the mixture needed was at least 600 mL. The following steps were used to make the test mixture:

1. Mass of 20 wt % insoluble solids AZ-102 sludge simulant to use:
   600 mL * density (1.169 g/mL) = 701.4 grams. Actually used: 699.2 grams.
2. Mass of Sludge Solids is: 701.4 g * Wt % Total Solids (20.53 %) = 144.0 grams.
3. The amount of Sr/TRU solids required for 144.0 grams of sludge solids is:
   144.0 g * Sr/TRU Basis (26.77)/AZ-102 Sludge Basis (287.91) = 13.39 grams.
4. The amount of 20 wt % insoluble solids Sr/TRU precipitate to add is:
   13.39 g / wt % total Solids Sr/TRU (22.52 %) = 59.46 grams.
   Actually used: 59.60 grams.
5. The amount of blended eluate to add:
   144.0 g * Basis for Eluate (39.75)/Basis for AZ-102 (287.91) = 19.88 grams of eluate.
   Actually used: 19.90 grams.

The physical properties for the Test 2.3 blend are listed in Table 14. Mixing a ~20 wt % solids slurry with another ~20 wt % solids did not result in diluting the measured solids for the mixture. A sample of the test mixture was submitted for chemical analysis. The results expressed on a weight % oxide basis are shown in Table B- 35. The agreement between the found and the target weight % was reasonable, since the target was based upon the originally planned compositions for the waste streams.

Table B- 35: Composition of Test 2.3 Compared to Target

Oxide	Wt %	Target Wt %	Oxide	Wt %	Target Wt %
Al_2O_3	25.66	23.01	P_2O_5	0.43	1.39
BaO	0.16	0.11	PbO	0.07	0.28
CaO	0.66	1.43	SiO_2	2.38	1.9
CdO	5.4	4.19	SrO	3.57	4.47
CoO	0.03	0.02	TiO_2	0.02	0.03
Cr_2O_3	0.36	0.28	ZnO	0.19	0.12
CuO	0.06	0.08	ZrO	5.57	4.4
Fe_2O_3	46.53	36.39	La_2O_3	1.15	0.89
MgO	0.46	0.36	K_2O	0.12	0.02
MnO	2.53	2.76	Ag_2O	0.09	0.06
MoO_3	0	0	CeO_2	0.26	0.17
Na_2O	4.25	9.04	Nd_2O_3	0.06	0.63

Additional tests planned for Test 2.3 required determining the amount of acid needed to shift the test mixture's pH from 11.24 to values near 9, 7 and 5. A 2.22 gram sample of the mixture was added to 60 mL of deionized water and titrated with 0.1013 molar hydrochloric acid until the pH

was 5. Figure B - 6 shows the resulting titration curve as a function of the moles of acid added/kilogram of sludge. The shape of the titration curve is controlled by the basic species being titrated. For the blended mixture in Test 2.3, the basic species included hydroxide, phosphate and carbonate. The fitted equation shown in Figure B - 6 was empirically obtained using TableCurve™ 2D software and should not be used to extrapolate beyond the fitted region (pH 11 to pH 4.75). Based upon the titration curve, the amount of a monoprotic acid to reach pH 9 was 0.1045 moles per kilogram of the blended mixture. To reach pH 7 the amount of acid was 0.201 moles per kilogram of slurry and for pH 5 the amount was 0.431 moles per kilogram of slurry. The adjustment of the pH of a portion of Test 2.3 with 10.34 molar nitric acid (50 wt %) consisted of the following steps:

1. Add 230 grams of Test 2.3 mixture to a tared, 250 mL bottle and record the weight. Actually used net weight was 249.48 grams. Tare Weight was 29.52 grams.
2. Using a calibrated digital pipette add 2.52 mL of 10.34 molar nitric acid. Actually added 2.52 mL.
3. Mix thoroughly, measure, and record pH. The measured pH was 8.61.
4. Transfer about 30 grams of the pH-adjusted mixture to 30 mL container labeled as **Test 2.3 pH 9 Adjusted,** weigh and record the weight. Amount of slurry removed was 19.48 grams due to the sticky nature of the slurry. This sample was used for rheology measurements.
5. Obtain mass of pH adjusted 250 mL bottle and calculate the amount of acid necessary to reduce pH to 7. Actual gross mass was 258.74 grams. Tare weight was 29.52 grams.
6. Using a calibrated digital pipette add 2.14 mL of 10.34 molar nitric acid. Actually added 2.14 mL.
7. Mix thoroughly, measure, and record pH. The measured pH was 6.75.
8. Transfer about 30 grams of the pH-adjusted mixture to 30 mL container labeled as **Test 2.3 pH 7 Adjusted,** weigh and record the weight. Amount of slurry removed was 18.60 grams due to the sticky nature of the slurry. This sample was used for rheology measurements.
9. Obtain mass of pH adjusted 250 mL bottle and calculate the amount of acid necessary to reduce pH to 5. Actual gross mass was 233.42 grams. Tare weight was 29.52 grams.
10. Using a calibrated digital pipette add 4.53 mL of 10.34 molar nitric acid. Actually added 4.53 mL.
11. Mix thoroughly, measure, and record pH. The measured pH was 4.77.
12. Labeled the 250 mL bottle as **Test 2.3 pH 5 Adjusted** and used the sample for rheology and chemical analysis.

During the pH adjustment, gas evolution was observed during the acid addition. The gas produced was probably carbon dioxide due to the conversion of carbonate to bicarbonate and then to carbonic acid ($H_2O + CO_2$). The actual pH and rheology results for the adjusted Test 2.3 mixtures is discussed in the main section of this report.

Figure B - 6: Test Mix 2.3 Titration Curve

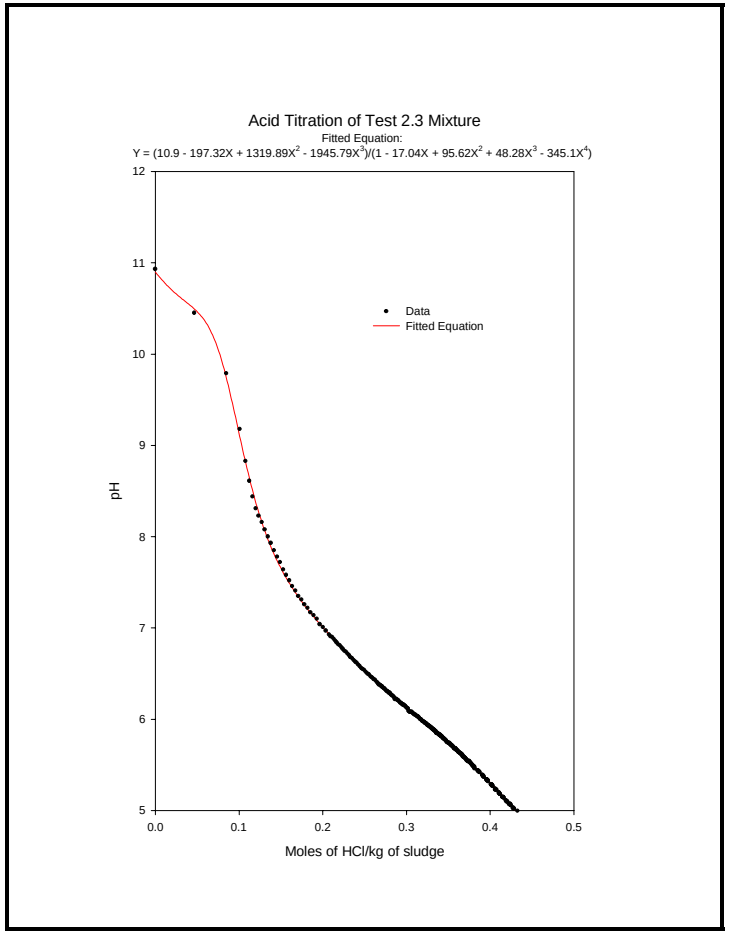
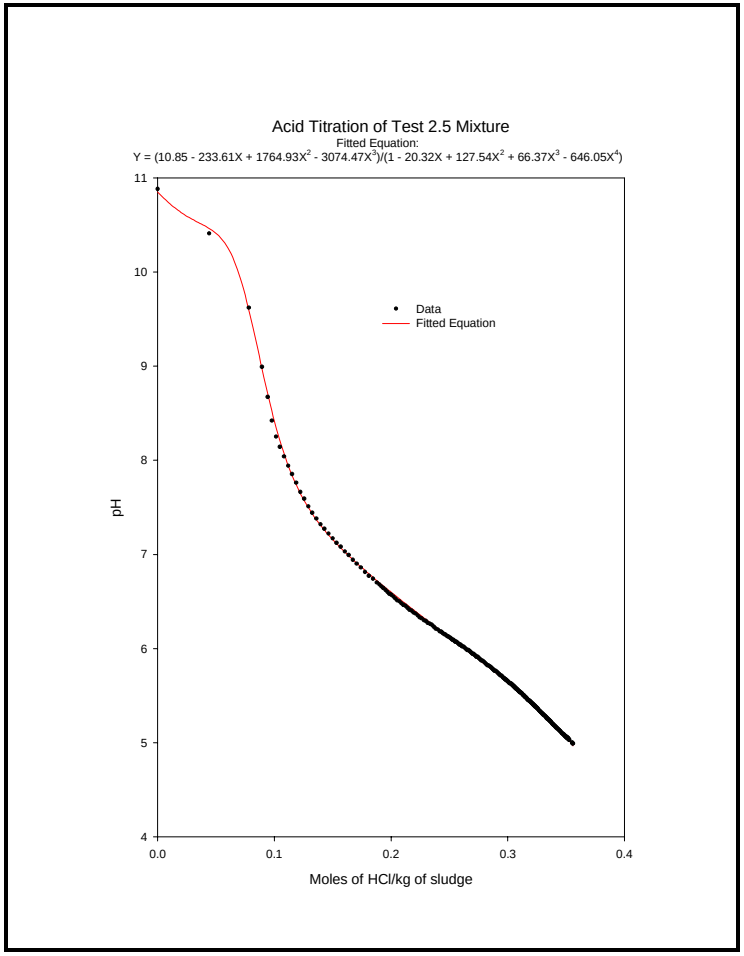


Figure B - 7: Test Mixture 2.5 Titration Curve



Test 2.4

The goal of Test 2.4 was to mix 15 wt % insoluble solids AZ-102 sludge with 15 wt % insoluble solids Sr/TRU precipitate and blended eluate and determine the rheology of the mixture. The volume of the mixture needed was at least 500 mL. The following steps were used to make the test mixture:

1. Mass of 15 wt % insoluble solids AZ-102 sludge simulant to use:
   500 mL * density (1.114 g/mL) = 557 grams. Actually used: 557.03 grams.
2. Mass of Sludge Solids is: 557 g * Wt % Total Solids (15.57 %) = 86.72 grams.
3. The amount of Sr/TRU solids required for 86.72 grams of sludge solids is:
   86.72 g * Sr/TRU Basis (26.77)/AZ-102 Sludge Basis (287.91) = 8.06 grams.
4. The amount of 15 wt % insoluble solids Sr/TRU precipitate to add is:
   8.06 g / wt % total Solids Sr/TRU (17.65 %) = 45.67 grams.
   Actually used: 45.77 grams.
5. The amount of blended eluate to add:
   86.72 g * Basis for Eluate (39.75)/Basis for AZ-102 (287.91) = 11.97 grams of eluate.
   Actually used: 11.98 grams.

The physical properties for the Test 2.4 blend are listed in Table 14. Mixing a ~15 wt % solids slurry with another ~15 wt % solids did not result in diluting the measured solids for the mixture. A sample of the test mixture was submitted for chemical analysis. The results expressed on a wt % oxide basis are shown in Table B- 36. The agreement between the found and the target composition was reasonable, since the target wt % was based upon the originally planned compositions for the waste streams.

Table B- 36: Composition of Test 2.4 Compared to Target

Oxide	Wt %	Target Wt %	Oxide	Wt %	Target Wt %
Al_2O_3	26.89	23.01	P_2O_5	0.94	1.39
BaO	0.15	0.11	PbO	0.08	0.28
CaO	0.74	1.43	SiO_2	2.35	1.9
CdO	5.12	4.19	SrO	3.44	4.47
CoO	0.03	0.02	TiO_2	0.03	0.03
Cr_2O_3	0.34	0.28	ZnO	0.19	0.12
CuO	0.02	0.08	ZrO	5.53	4.4
Fe_2O_3	44.87	36.39	La_2O_3	1.14	0.89
MgO	0.45	0.36	K_2O	0.09	0.02
MnO	2.41	2.76	Ag_2O	0.08	0.06
MoO_3	0.05	0	CeO_2	0.25	0.17
Na_2O	4.71	9.04	Nd_2O_3	0.09	0.63

Test 2.5

The goal of Test 2.5 was to mix 15 wt % insoluble solids AZ-102 sludge with 25 wt % insoluble solids Sr/TRU precipitate and blended eluate and determine the rheology of the mixture. The volume of the mixture needed was at least 500 mL. The following steps were used to make the test mixture:

1. Mass of 15 wt % insoluble solids AZ-102 sludge simulant to use:
   500 mL * density (1.114 g/mL) = 557 grams. Actually used: 557.0 grams.
2. Mass of Sludge Solids is: 557 g * Wt % Total Solids (15.57 %) = 86.72 grams.
3. The amount of Sr/TRU solids required for 86.72 grams of sludge solids is:
   86.72 g * Sr/TRU Basis (26.77)/AZ-102 Sludge Basis (287.91) = 8.06 grams.
4. The amount of 25 wt % insoluble solids Sr/TRU precipitate to add is:
   8.06 g / wt % total Solids Sr/TRU (27.32 %) = 29.50 grams.
   Actually used: 29.53 grams.
5. The amount of blended eluate to add:
   8.06 g *Basis for Eluate (39.75)/Basis for AZ-102 (287.91) = 11.97 grams of eluate.
   Actually used: 12.0 grams.

The physical properties for the Test 2.5 blend are listed in Table 14. Mixing a ~15 wt % solids slurry with a ~25 wt % solids did not significantly increase the measured solids for the mixture due to the small amount of Sr/TRU added. A sample of the test mixture was submitted for chemical analysis. The results expressed on a wt % oxide basis are shown in Table B- 37. The agreement between the found and the target is reasonable since the target is based upon the originally planned compositions for the waste streams.

Table B- 37: Composition of Test 2.5 Compared to Target Blend

Oxide	Wt %	Target Wt %	Oxide	Wt %	Target Wt %
Al_2O_3	27.3	23.01	P_2O_5	0.89	1.39
BaO	0.15	0.11	PbO	0.08	0.28
CaO	0.73	1.43	SiO_2	2.28	1.9
CdO	5.06	4.19	SrO	3.65	4.47
CoO	0.02	0.02	TiO_2	0.03	0.03
Cr_2O_3	0.34	0.28	ZnO	0.18	0.12
CuO	0.02	0.08	ZrO	5.53	4.4
Fe_2O_3	44.57	36.39	La_2O_3	1.12	0.89
MgO	0.45	0.36	K_2O	0.14	0.02
MnO	2.52	2.76	Ag_2O	0.09	0.06
MoO_3	0.01	0	CeO_2	0.26	0.17
Na_2O	4.49	9.04	Nd_2O_3	0.1	0.63

Additional tests planned for Test 2.5 required determining the amount of acid needed to shift the test mixture's pH from 11.14 to values near 9, 7 and 5. A 2.34 gram sample of the mixture was added to 60 mL of deionized water and titrated with 0.1013 molar hydrochloric acid until the pH was 5.

Figure B - 7 shows the resulting titration curve as a function of the moles of acid added/kilogram of sludge. The shape of the titration curve is controlled by the basic species being titrated. For the blended mixture in Test 2.5, the basic species include hydroxide, phosphate and carbonate. The fitted equation shown in Figure B - 7 was empirically obtained using TableCurve™ 2D software and should not be used to extrapolate beyond the fitted region (pH 11 to pH 4.75). Based upon the titration curve, the amount of a monoprotic acid to reach pH 9 was 0.0892 moles per kilogram of the blended mixture. To reach pH 7 the amount of acid was 0.162 moles per

kilogram of slurry and for pH 5 the amount was 0.355 moles per kilogram of slurry. The adjustment of the pH of a portion of Test 2.5 with 10.34 molar nitric acid (50 wt %) consisted of the following steps:

1. Add 230 grams of Test 2.5 mixture to a tared, 250 mL bottle and record the weight. Actually used net weight was 249.69 grams. Tare Weight was 29.27 grams.
2. Using a calibrated digital pipette add 2.15 mL of 10.34 molar nitric acid. Actually added 2.15 mL.
3. Mix thoroughly, measure, and record pH. The measured pH was 8.75.
4. Transfer about 30 grams of the pH-adjusted mixture to 30 mL container labeled as **Test 2.5 pH 9 Adjusted,** weigh and record the weight. Amount of slurry removed was 20.18 grams due to the thick, sticky properties of the slurry. This sample was used for rheology measurements.
5. Obtain mass of pH adjusted 250 mL bottle and calculate the amount of acid necessary to reduce pH to 7. Actual gross mass was 259.02 grams. Tare weight was 29.27 grams.
6. Using a calibrated digital pipette add 1.61 mL of 10.34 molar nitric acid. Actually added 1.61 mL.
7. Mix thoroughly, measure, and record pH. The measured pH was 6.68.
8. Transfer about 30 grams of the pH-adjusted mixture to 30 mL container labeled as **Test 2.5 pH 7 Adjusted,** weigh and record the weight. Amount of slurry removed was 16.94 grams due to the thick, sticky properties of the slurry. This sample was used for rheology measurements.
9. Obtain mass of pH adjusted 250 mL bottle and calculate the amount of acid necessary to reduce pH to 5. Actual gross mass was 241.59 grams. Tare weight was 29.27 grams.
10. Using a calibrated digital pipette add 3.97 mL of 10.34 molar nitric acid. Actually added 3.97 mL.
11. Mix thoroughly, measure, and record pH. The measured pH was 4.72.
12. Labeled the 250 mL bottle as **Test 2.5 pH 5 Adjusted** and used the sample for rheology and chemical analysis.

During the pH adjustment, gas evolution was observed during the acid addition. The gas produced was probably carbon dioxide due to the conversion of carbonate to bicarbonate and then to carbonic acid ($H_2O + CO_2$). The actual pH and rheology results for the adjusted Test 2.5 mixtures is discussed in the results section of this report.

Test 2.9

The goal of Test 2.9 was to mix 20 wt % insoluble solids AZ-102 sludge with blended eluate and determine the rheology of the mixture. The volume of the mixture needed was at least 600 mL. The following steps were used to make the test mixture:

1. Mass of 20 wt % insoluble solids AZ-102 sludge simulant to use:
   600 mL * density (1.169 g/mL) = 701.4 grams. Actually used: 700.26 grams.
2. Mass of Sludge Solids is: 701.4 g * Wt % Total Solids (20.53 %) = 144 grams.
3. The amount of blended eluate to add:
   144 g * Basis for Eluate (39.75)/Basis for AZ-102 (287.91) = 19.88 grams of eluate.
   Actually used: 19.89 grams.

The physical properties for the Test 2.9 blend are listed in Table 14. The mixture was essentially the same as the 20 wt % insoluble solids AZ-102 sludge, just diluted a little bit by the eluate. A sample of the test mixture was submitted for chemical analysis. The results expressed on a wt % oxide basis are shown in Table B- 38. The agreement between the found and the target composition was reasonable, since the target was based upon the originally planned compositions for the waste streams.

Table B- 38: Composition of Test 2.9 Compared to Target Blend

Oxide	Wt %	Target Wt %	Oxide	Wt %	Target Wt %
Al_2O_3	28.86	24.83	P_2O_5	0.84	1.48
BaO	0.16	0.12	PbO	0.04	0.28
CaO	0.49	1.49	SiO_2	2.67	2.05
CdO	5.49	4.52	SrO	0	0.07
CoO	0.03	0.02	TiO_2	0.04	0.03
Cr_2O_3	0.35	0.3	ZnO	0.19	0.13
CuO	0.01	0.08	ZrO	6.24	4.75
Fe_2O_3	47.8	38.88	La_2O_3	1.21	0.96
MgO	0.48	0.39	K_2O	0.08	0.03
MnO	1.07	0.84	Ag_2O	0.08	0.06
MoO_3	0.01	0	CeO_2	0.28	0.19
Na_2O	3.54	9.22	Nd_2O_3	0.03	0.68

Test ADD-3

The goal of Test ADD-3 was to mix 10 wt % insoluble solids AZ-102 sludge with 15 wt % insoluble solids Sr/TRU precipitate and blended eluate and determine the rheology of the mixture. The volume of the mixture needed was at least 500 mL. The following steps were used to make the test mixture:

1. Mass of 10 wt % insoluble solids AZ-102 sludge simulant to use:
   500 mL * density (1.0709 g/mL) = 535.45 grams. Actually used: 535.45 grams.
2. Mass of Sludge Solids is: 535.45 g * Wt % Total Solids (10.59 %) = 56.7 grams.
3. The amount of Sr/TRU solids required for 56.7 grams of sludge solids is:
   56.7 g * Sr/TRU Basis (26.77)/AZ-102 Sludge Basis (287.91) = 5.27 grams.
4. The amount of 15 wt % insoluble solids Sr/TRU precipitate to add is:
   5.27 g / wt % total Solids Sr/TRU (17.65 %) = 29.86 grams.
   Actually used: 29.88 grams.
5. The amount of blended eluate to add:
   56.7 g * Basis for Eluate (39.75)/Basis for AZ-102 (287.91) = 7.83 grams of eluate.
   Actually used: 7.83 grams.

The physical properties for the Test ADD-3 blend are listed in Table 14. Mixing a ~10 wt % solids slurry with a smaller amount of a ~15 wt % solids did not significantly change the weight percent solids for the mixture. A sample of the test mixture was submitted for chemical analysis. The results expressed on a wt % oxide basis are shown in Table B- 39. The agreement between

the found and the target composition was reasonable, since the target wt % was based upon the originally planned compositions for the waste streams.

Table B- 39: Composition of Test ADD-3 Compared to Target Blend

Oxide	Wt %	Target Wt %	Oxide	Wt %	Target Wt %
Al_2O_3	27.46	23.01	P_2O_5	0.94	1.39
BaO	0.15	0.11	PbO	0.09	0.28
CaO	0.89	1.43	SiO_2	2.45	1.9
CdO	4.92	4.19	SrO	3.37	4.47
CoO	0.02	0.02	TiO_2	0.03	0.03
Cr_2O_3	0.33	0.28	ZnO	0.18	0.12
CuO	0.01	0.08	ZrO	5.11	4.4
Fe_2O_3	43.77	36.39	La_2O_3	1.08	0.89
MgO	0.44	0.36	K_2O	0.37	0.02
MnO	2.36	2.76	Ag_2O	0.07	0.06
MoO_3	0.02	0	CeO_2	0.2	0.17
Na_2O	5.06	9.04	Nd_2O_3	0.13	0.63

Test ADD-4

The goal of Test ADD-4 was to mix 12.5 wt % insoluble solids AZ-102 sludge with 15 wt % insoluble solids Sr/TRU precipitate and blended eluate and determine the rheology of the mixture. The volume of the mixture needed was at least 500 mL. The following steps were used to make the test mixture:

1. Mass of 12.5 wt % insoluble solids AZ-102 sludge simulant to use:
   500 mL * density (1.0845 g/mL) = 542.25 grams. Actually used: 542.25 grams.
2. Mass of Sludge Solids is: 542.25 g * Wt % Total Solids (12.82 %) = 69.52 grams.
3. The amount of Sr/TRU solids required for 69.52 grams of sludge solids is:
   69.52 g * Sr/TRU Basis (26.77)/AZ-102 Sludge Basis (287.91) = 6.46 grams.
4. The amount of 15 wt % insoluble solids Sr/TRU precipitate to add is:
   6.46 g / wt % total Solids Sr/TRU (17.65 %) = 36.6 grams.
   Actually used: 36.64 grams.
5. The amount of blended eluate to add:
   69.52 g * Basis for Eluate (39.75)/Basis for AZ-102 (287.91) = 9.6 grams of eluate.
   Actually used: 9.61 grams.

The physical properties for the Test ADD-4 blend are listed in Table 14. Mixing a ~12.5 wt % solids slurry with a smaller amount of a ~15 wt % solids did not significantly change the weight percent solids for the mixture. A sample of the test mixture was submitted for chemical analysis. The results expressed on a wt % oxide basis are shown in Table B- 40. The agreement between the found and the target composition was reasonable, since the target wt % was based upon the originally planned compositions for the waste streams.

Table B- 40: Composition of Test ADD-4 Compared to Target Blend

Oxide	Wt %	Target Wt %	Oxide	Wt %	Target Wt %
Al_2O_3	27.66	23.01	P_2O_5	0.94	1.39
BaO	0.15	0.11	PbO	0.07	0.28
CaO	0.83	1.43	SiO_2	2.25	1.9
CdO	4.94	4.19	SrO	3.34	4.47
CoO	0.03	0.02	TiO_2	0.03	0.03
Cr_2O_3	0.35	0.28	ZnO	0.18	0.12
CuO	0.01	0.08	ZrO	5.51	4.4
Fe_2O_3	44.22	36.39	La_2O_3	1.08	0.89
MgO	0.44	0.36	K_2O	0.08	0.02
MnO	2.36	2.76	Ag_2O	0.11	0.06
MoO_3	0.02	0	CeO_2	0.24	0.17
Na_2O	5.08	9.04	Nd_2O_3	0.1	0.63

Glass Formulations for AZ-101

The glass formulation for the AZ-101 blends was obtained from VSL. Table B- 41lists the formulation provided by VSL. The glass formers used with the AZ-101 blends were borax, lithium hydroxide monohydrate, silica and zinc oxide. Borax provides both B_2O_3 and Na_2O while the other three glass formers provide the remaining oxides necessary for the glass. For the glass made with AZ-101 sludge, AN-107 Sr/TRU precipitate and the AZ-102 blended eluate, one hundred grams of glass should contain 25.57 grams of borax, 17.76 grams of $LiOH \bullet H_2O$, and 45.91 grams of silica. The glass that does not contain any Sr/TRU precipitate should contain 24.31 grams of borax, 17.76 grams of $LiOH \bullet H_2O$, 48.44 grams of silica and 1.97 grams of zinc oxide per 100 grams of glass. These ratios were used with the amount of blend slurry available to determine the amounts of glass formers to add for each test.

Table B- 41 VSL AZ-101 Glass Formulation

	(AZ101 Simulant + AN107 Sr/TRU + AZ102 Eluate)					(AZ101 Simulant + AZ102 Eluate)				
	Composite Waste		Glass Formers	Glass Composition	Glass Oxide from Env D	Composite Waste		Glass Formers	Glass Composition	Glass Oxide from Env D
	Oxide (kg)	Oxide (wt%)	Oxide (wt% of Glass)	Oxide (wt%)	Oxide (wt%)	Oxide (kg)	Oxide (wt%)	Oxide (wt% of Glass)	Oxide (wt%)	Oxide (wt%)
Ag2O	2.54	0.23%		0.08%		2.54	0.26%		0.08%	
Al2O3	116.14	10.36%		3.58%	3.57%	115.64	11.76%		3.57%	3.57%
B2O3	2.82	0.25%	9.91%	10.00%		2.74	0.28%	9.42%	9.50%	
BaO	2.51	0.22%		0.08%		2.50	0.25%		0.08%	
CaO	15.83	1.41%		0.49%		13.36	1.36%		0.41%	
CdO	26.92	2.40%		0.83%		26.92	2.74%		0.83%	
CeO2	3.49	0.31%		0.11%		3.49	0.35%		0.11%	
CoO	3.85	0.34%		0.12%		3.84	0.39%		0.12%	
Cr2O3	3.61	0.32%		0.11%		3.47	0.35%		0.11%	
Cs2O	0.02	0.00%		0.00%		0.02	0.00%		0.00%	
CuO	1.34	0.12%		0.04%		1.29	0.13%		0.04%	
Dy2O3	0.19	0.02%		0.01%		0.19	0.02%		0.01%	
Fe2O3	443.40	39.55%		13.68%	13.29%	430.71	43.80%		13.28%	13.28%
K2O	8.12	0.72%		0.25%		8.12	0.83%		0.25%	
La2O3	14.56	1.30%		0.45%		14.28	1.45%		0.44%	
Li2O	0.00	0.00%	6.00%	6.00%		0.00	0.00%	6.00%	6.00%	
MgO	3.04	0.27%		0.09%		2.82	0.29%		0.09%	
MnO	41.32	3.69%		1.28%		9.05	0.92%		0.28%	
MoO3	0.25	0.02%		0.01%		0.23	0.02%		0.01%	
Na2O	133.64	11.92%	3.81%	7.93%		118.89	12.09%	4.10%	7.77%	
Nd2O3	9.49	0.85%		0.29%		9.49	0.96%		0.29%	
NiO	23.67	2.11%		0.73%		23.61	2.40%		0.73%	
PbO	3.78	0.34%		0.12%		3.71	0.38%		0.11%	
Re2O7	0.22	0.02%		0.01%		0.22	0.02%		0.01%	
Rh2O3	1.30	0.12%		0.04%		1.30	0.13%		0.04%	
RuO2	2.31	0.21%		0.07%		2.31	0.23%		0.07%	
SiO2	32.13	2.87%	45.68%	46.67%		31.85	3.24%	48.20%	49.18%	
SnO	0.03	0.00%		0.00%		0.00	0.00%		0.00%	
SrO	74.86	6.68%		2.31%		1.88	0.19%		0.06%	
TiO2	0.51	0.05%		0.02%		0.48	0.05%		0.01%	
UO2	0.02	0.00%		0.00%		0.02	0.00%		0.00%	
V2O5	0.03	0.00%		0.00%		0.00	0.00%		0.00%	
ZnO	1.26	0.11%		0.04%		1.14	0.12%	1.96%	2.00%	
ZrO2	136.46	12.17%		4.21%	4.20%	136.16	13.85%		4.20%	4.20%
F	1.48	0.13%		0.05%		1.47	0.15%		0.05%	
Cl	0.34	0.03%		0.01%		0.27	0.03%		0.01%	
SO3	8.20	0.73%		0.25%		8.00	0.81%		0.25%	
P2O5	1.44	0.13%		0.04%		1.32	0.13%		0.04%	
TOTAL	1121.111	100.00%	65.40%	100.00%	21.06%	983.320	100.00%	69.68%	100.00%	21.04%
		TOTAL Loading	34.60%				TOTAL Loading	30.32%		
		Env D Loading	30.32%				Env D Loading	30.30%		
			vs 30.23% calculated							

Glass Formulations for AZ-102

The glass formulation for the AZ-102 blends was obtained from VSL. Table B- 42 lists the formulation provided by VSL. The glass formers used with the AZ-102 blends were borax, lithium hydroxide monohydrate, silica and sodium hydroxide. Borax provides both B_2O_3 and some of the Na_2O. The remaining Na_2O was provided by the sodium hydroxide. The remaining two glass formers provide the remaining oxides necessary for the glass. For the glass made with AZ-102 sludge, AN-107 Sr/TRU precipitate and the AZ-102 blended eluate, one hundred grams of glass should contain 10.3 grams of borax, 14.8 grams of $LiOH \bullet H_2O$, 47.61 grams of silica, and 11.38 grams of sodium hydroxide. The glass that does not contain any Sr/TRU precipitate should contain 14.19 grams of borax, 14.8 grams of $LiOH \bullet H_2O$, 48.52 grams of silica and 10.57 grams of sodium hydroxide per 100 grams of glass. These ratios were used with the amount of blend slurry available to determine the amounts of glass formers to add for each test.

Table B- 42: AZ-102 Glass Formulations from VSL

	AZ102 Solid (wt% ox.)	PNNL's Composition of SR/TRU ppt (wt% ox.)	SRS's OLI AZ-102 Eluate (wt% ox.)	Composite Waste W/OUT Tc Eluate (wt% ox)	Glass Formers to be Added (wt% ox in Glass)	Glass Composition (wt% ox)	PNNL"s AZ102 Melt 1 Tc Eluate (wt %)	Composite Waste WITH Tc Eluate (wt% ox)	Glass Formers to be Added (wt% ox in Glass)	Glass Composition (wt% ox)
Ag2O	0.06%	0.00%	0.00%	0.06%		0.019%	0.00%	0.06%		0.019%
Al2O3	25.09%	0.00%	0.00%	23.02%		7.623%	1.83%	23.01%		7.619%
B2O3	0.03%	0.00%	0.77%	0.03%	3.99%	4.000%	12.73%	0.04%	3.99%	4.002%
BaO	0.12%	0.03%	0.00%	0.11%		0.038%	0.04%	0.11%		0.038%
BeO	0.01%	0.00%		0.01%		0.003%	0.00%	0.01%		0.003%
CaO	1.51%	0.61%	0.00%	1.43%		0.474%	0.76%	1.43%		0.474%
CdO	4.57%	0.00%	0.00%	4.19%		1.387%	0.00%	4.19%		1.386%
CeO2	0.19%	0.03%	0.00%	0.17%		0.058%	0.00%	0.17%		0.058%
Cl	0.11%			0.10%		0.034%	4.30%	0.10%		0.034%
CoO	0.02%	0.00%	0.00%	0.02%		0.007%	0.00%	0.02%		0.007%
Cr2O3	0.29%	0.11%	1.05%	0.28%		0.094%	0.25%	0.28%		0.094%
Cs2O			2.73%	0.02%		0.008%		0.02%		0.008%
CuO	0.08%	0.01%	0.00%	0.08%		0.025%	0.00%	0.08%		0.025%
F	0.03%	0.00%		0.02%		0.008%	0.00%	0.02%		0.008%
Fe2O3	39.29%	4.94%	0.01%	36.41%		12.056%	1.72%	36.39%		12.050%
K2O	0.00%	0.00%	2.52%	0.02%		0.008%	3.23%	0.02%		0.008%
La2O3	0.97%	0.01%	0.00%	0.89%		0.296%	0.00%	0.89%		0.296%
Li2O	0.00%	0.00%		0.00%	5.00%	5.000%	0.00%	0.00%	5.00%	5.000%
MgO	0.39%	0.00%	0.00%	0.36%		0.119%	0.02%	0.36%		0.119%
MnO	0.85%	27.02%	0.00%	2.76%		0.915%	0.02%	2.76%		0.915%
MoO3	0.00%	0.00%	0.03%	0.00%		0.000%	0.00%	0.00%		0.000%
Na2O	8.40%	6.77%	89.15%	9.02%	10.53%	13.516%	56.94%	9.04%	10.53%	13.524%
Nd2O3	0.68%	0.04%	0.00%	0.63%		0.208%	0.00%	0.63%		0.208%
NiO	2.50%	0.02%	0.04%	2.29%		0.758%	0.26%	2.29%		0.758%
P2O5	1.49%	0.21%	0.50%	1.39%		0.460%	0.06%	1.39%		0.460%

		PNNL's	SRS's OLI	Composite Waste	Glass Formers	Glass	PNNL"s	Composite Waste		Glass Formers	Glass
	AZ102	Composition of	AZ-102	W/OUT Tc Eluate	to be	Composition	AZ102 Melt 1	WITH Tc Eluate		to be	Composition
	Solid	SR/TRU ppt	Eluate		Added		Tc Eluate			Added	
	(wt% ox.)	(wt% ox.)	(wt% ox.)	(wt% ox)	(wt% ox in Glass)	(wt% ox)	(wt %)	(wt% ox)		(wt% ox in Glass)	(wt% ox)
PbO	0.29%	0.16%	0.08%	0.28%		0.091%	0.00%	0.28%			0.091%
SO3	0.06%	0.00%		0.05%		0.018%		0.05%			0.018%
SiO2	2.06%	0.00%	0.37%	1.89%	47.37%	47.997%	17.81%	1.90%		47.37%	48.000%
SnO2	0.54%	0.00%	0.00%	0.49%		0.163%		0.49%			0.162%
SrO	0.07%	60.00%		4.47%		1.480%	0.00%	4.47%			1.480%
TiO2	0.03%	0.00%		0.03%		0.011%	0.00%	0.03%			0.011%
UO2	5.27%	0.00%	2.74%	4.86%		1.611%	0.00%	4.86%			1.610%
V2O5	0.01%	0.00%		0.01%		0.004%	0.00%	0.01%			0.004%
Y2O3	0.05%	0.00%		0.04%		0.014%	0.00%	0.04%			0.014%
ZnO	0.13%	0.04%	0.00%	0.12%		0.040%	0.02%	0.12%			0.039%
ZrO2	4.80%	0.00%	0.00%	4.41%		1.459%	0.00%	4.40%			1.458%
TOTAL	100.00%	100.00%	100.00%	100.00%	66.890%	100.00%	100.00%	100.00%		66.890%	100.000%
Blending	250.00	20.00	2.479	Total Waste Loading	33.110%		0.1367	Total Loading		33.110%	
Ratio (wt of oxides)			272.48	Envelope D Loading	30.378%		272.62	D Loading		30.363%	
				Al from Enve D	7.623%				Al	7.619%	
				Fe from Enve D	11.936%				Fe	11.930%	
				Zr from Enve D	1.459%				Zr	1.458%	
				(al+fe+zr) from AZ102	21.017%					21.007%	

Table B- 43: OLI Model Results of Blended AZ-102 Eluate

ESP V-6.2	PROCESS:ELBLEND		10/12/2000 PAGE 4	
STREAM:	Blend Eluate			
TO				
FROM Vent C02	frm Storage			
Phases ------->	Aqueous	Solid	Vapor	Organic
Temperature, C	29.6756	29.6756	29.6756	29.6756
Pressure, atm	1.	1.	1.	1.
pH	7.72549			
Total mol/hr	3606.02	2.42085	0.0	0.0
Chemical	mol/hr -------	mol/hr --	mol/hr	mol/hr
H20	3350.21	0.0	0.0	0.0
C02	0.106212	0.0	0.0	0.0
GLUCONACID	9.6899E-07	0.0	0.0	0.0
ACETACID	4.0391E-07	0.0	0.0	0.0
H2SO4	2.8573E-25	0.0	0.0	0.0
HCL	9.6431E-14	0.0	0.0	0.0
HN02	1.8790E-04	0.0	0.0	0.0
HN03	2.2035E-08	0.0	0.0	0.0
N2	0.0205223	0.0	0.0	0.0
02	0.0104382	0.0	0.0	0.0
S03	4.1746E-29	0.0	0.0	0.0
BAC03	1.1803E-07	0.0	0.0	0.0
CSACET	2.1572E-06	0.0	0.0	0.0
CSCL	0.0158577	0.0	0.0	0.0
CSGLYCOL	5.0074E-04	0.0	0.0	0.0
CSN03	0.216461	0.0	0.0	0.0
FEIIICTRT	6.5947E-10	0.0	0.0	0.0
FEIIIHEDTA	1.2611E-09	0.0	0.0	0.0
FEIIIOH3	1.9736E-06	0.0189066	0.0	0.0
FENTA	7.3871E-08	0.0	0.0	0.0
ALOH3	1.3369E-09	0.0	0.0	0.0
GLYCOLACID	1.9115E-05	0.0	0.0	0.0
H21DA	2.7503E-07	0.0	0.0	0.0
H2SIO3	0.0871667	0.0	0.0	0.0
BAGLYCOL2	1.9886E-10	0.0	0.0	0.0
H3AS04	2.6280E-11	0.0	0.0	0.0
H3NTA	5.3357E-15	0.0	0.0	0.0
H3PO4	9.5618E-09	0.0	0.0	0.0
H4EDTA	5.8385E-20	0.0	0.0	0.0

TABLE B- 43: OLI Model of Blended AZ-102Eluate, Cont.

Phases ------- >	Aqueous	Solid	Vapor	Organic
Chemical	mol/hr	mol/hr	mol/hr	mol/hr
BAOX	4.5167E-07	0.0	0.0	0.0
BAS04	3.0958E-06	0.016869	0.0	0.0
BOH3	0.942509	0.0	0.0	0.0
CAC03	1.4262E-05	0.0	0.0	0.0
KCL	9.0421E-04	0.0	0.0	0.0
KGLYCOLAT	0.00131538	0.0	0.0	0.0
CAGLYCOL2	7.1499E-08	0.0	0.0	0.0
NAACET	2.9229E-04	0.0	0.0	0.0
NABOH4	0.0207674	0.0	0.0	0.0
NAGLYCOLAT	0.0946655	0.0	0.0	0.0
NAHC03	1.44913	0.0	0.0	0.0
NAHS103	0.0904845	0.01	0.0	0.0
NAN03	0.555785	0.0	0.0	0.0
NIC204	1.0457E-05	0.0	0.0	0.0
NIGLYCOL2	2.2136E-12	0.0	0.0	0.0
NIOH2	4.3261E-14	0.0	0.0	0.0
NIS04	9.3056E-11	0.0	0.0	0.0
CAS04	2.0053E-05	0.0	0.0	0.0
OXALAC	2.7016E-11	0.0	0.0	0.0
PBC204	7.0052E-05	0.0	0.0	0.0
PBGLYCOL2	1.4194E-11	0.0	0.0	0.0
PBHP04	1.8065E-10	0.0	0.0	0.0
PBN022	2.7099E-06	0.0	0.0	0.0
PEN032	3.3058E-09	0.0	0.0	0.0
PBO	2.1180E-11	0.0	0.0	0.0
S102	0.0989201	0.0	0.0	0.0
CITRAC	1.5419E-13	0.0	0.0	0.0
U02C204	4.7198E-07	0.0	0.0	0.0
U02CL2	1.0758E-14	0.0	0.0	0.0
U02CO3	6.0895E-06	0.0	0.0	0.0
U020H2	1.3572E-08	0.0	0.0	0.0
U02SO4	3.9618E-11	0.0	0.0	0.0
OHION	5.3822E-05	0.0	0.0	0.0
ALACETION	1.2602E-18	0.0	0.0	0.0
ALEDTAION	5.0310E-11	0.0	0.0	0.0
ALION	4.6230E-16	0.0	0.0	0.0
ALOH2ION	7.4188E-12	0.0	0.0	0.0
ALOH4ION	4.4593E-08	0.0	0.0	0.0

TABLE B- 43: OLI Model of Blended AZ-102Eluate, Cont.

Phases ------- >	Aqueous	Solid	Vapor	Organic
Chemical	mol/hr	mol/hr	mol/hr	mol/hr
ALOHION	7.4169E-14	0.0	0.0	0.0
ALS0410N	1.9155E-16	0.0	0.0	0.0
ARS0410N	1.2578E-06	0.0	0.0	0.0
BAACETION	2.7343E-10	0.0	0.0	0.0
BACTRTION	1.0890E-08	0.0	0.0	0.0
BAEDTAION	6.3050E-09	0.0	0.0	0.0
BAGLYCOLION	5.9964E-08	0.0	0.0	0.0
BAHC0310N	2.6335E-06	0.0	0.0	0.0
BAION	2.8932E-05	0.0	0.0	0.0
BANTAION	5.2532E-08	0.0	0.0	0.0
BAOHION	1.3097E-12	0.0	0.0	0.0
BOH4ION	0.0548474	0.0	0.0	0.0
CAACETION	5.8111E-09	0.0	0.0	0.0
CACTRTION	1.3400E-05	0.0	0.0	0.0
CAEDTAION	9.3051E-05	0.0	0.0	0.0
CAGLYCOLION	6.8126E-06	0.0	0.0	0.0
CAH2BO3ION	3.4563E-06	0.0	0.0	0.0
CAH2PO4ION	2.5369E-07	0.0	0.0	0.0
CAHC0310N	6.1666E-05	0.0	0.0	0.0
CAHSI03ION	2.8719E-08	0.0	0.0	0.0
CAION	4.6280E-04	0.0	0.0	0.0
CAN0310N	1.2247E-04	0.0	0.0	0.0
CANTAION	4.9304E-05	0.0	0.0	0.0
CAOHION	9.3027E-10	0.0	0.0	0.0
CAP0410N	2.6493E-06	0.0	0.0	0.0
CITRATION	0.0144824	0.0	0.0	0.0
CLION	11.7792	0.0	0.0	0.0
C0310N	0.159526	0.0	0.0	0.0
CR0410N	0.626696	0.0	0.0	0.0
CSCTRTION	1.3675E-04	0.0	0.0	0.0
CSION	0.642841	0.0	0.0	0.0
CSS0410N	0.00990417	0.0	0.0	0.0
EDTAION	3.8966E-08	0.0	0.0	0.0
FEIIIC204ION	5.2426E-08	0.0	0.0	0.0
FEIIICLION	3.3448E-18	0.0	0.0	0.0
FEIIIEDTAION	0.00502015	0.0	0.0	0.0
FEIIIGLUCOION	2.1458E-16	0.0	0.0	0.0
FEIIIGLYCOION	3.2185E-15	0.0	0.0	0.0
FEIIIION	4.6484E-16	0.0	0.0	0.0

TABLE B- 43: OLI Model of Blended AZ-102Eluate, Cont.

Phases ------- >	Aqueous	Solid	Vapor	Organic
Chemical	mol/hr	mol/hr	mol/hr	mol/hr
FEIIIN03ION	2.3693E-18	0.0	0.0	0.0
FEIIIOH2ION	8.5513E-09	0.0	0.0	0.0
FEIIIOH4ION	9.6438E-08	0.0	0.0	0.0
FEIIIOHION	2.1894E-11	0.0	0.0	0.0
FEIIIS04ION	8.2159E-18	0.0	0.0	0.0
GLUCONAION	0.0269082	0.0	0.0	0.0
GLYCOLATION	0.274058	0.0	0.0	0.0
H2AS04ION	1.3588E-05	0.0	0.0	0.0
H2CITRATION	1.1494E-08	0.0	0.0	0.0
H2EDTAION	1.4281E-08	0.0	0.0	0.0
H2NTAION	5.1008E-09	0.0	0.0	0.0
H2PO4ION	0.0103942	0.0	0.0	0.0
H2SI04ION	7.5677E-08	0.0	0.0	0.0
H3EDTAION	3.4942E-14	0.0	0.0	0.0
H31DAION	9.8546E-13	0.0	0.0	0.0
H3SI04ION	0.00157162	0.0	0.0	0.0
H4NTAION	1.4728E-21	0.0	0.0	0.0
H5EDTAION	8.1108E-26	0.0	0.0	0.0
HAS0410N	0.00141508	0.0	0.0	0.0
HCITRATION	1.1864E-04	0.0	0.0	0.0
HC0310N	6.83996	0.0	0.0	0.0
HCR0410N	0.00428778	0.0	0.0	0.0
HEDTAION	9.1866E-07	0.0	0.0	0.0
HIDAION	0.0620844	0.0	0.0	0.0
HION	1.5071E-06	0.0	0.0	0.0
HNTAION	0.00344011	0.0	0.0	0.0
HOXALATION	1.0353E-04	0.0	0.0	0.0
HP0410N	0.311811	0.0	0.0	0.0
HSI03ION	0.0026636	0.0	0.0	0.0
HS0410N	7.3859E-07	0.0	0.0	0.0
IDAION	0.00574265	0.0	0.0	0.0
KCTRTION	6.7709E-04	0.0	0.0	0.0
KEDTAION	1.4654E-09	0.0	0.0	0.0
KION	2.38808	0.0	0.0	0.0
KS0410N	0.0590995	0.0	0.0	0.0
M00410N	0.0108804	0.0	0.0	0.0
NAC0310N	0.0497212	0.0	0.0	0.0
NACTRTION	0.0580374	0.0	0.0	0.0
NAEDTAION	1.3729E-07	0.0	0.0	0.0

TABLE B- 43: OLI Model of Blended AZ-102Eluate, Cont.

Phases -------- >	Aqueous	Solid	Vapor	Organic
Chemical	mol/hr	mol/hr	mol/hr	mol/hr
NAION	128.849	0.0	0.0	0.0
NANTAION	8.3131E-04	0.0	0.0	0.0
NAS0410N	0.492613	0.0	0.0	0.0
NIACETION	4.6688E-14	0.0	0.0	0.0
NICLION	3.4421E-12	0.0	0.0	0.0
NICTRTION	2.2865E-09	0.0	0.0	0.0
NIEDTAION	0.0217025	0.0	0.0	0.0
NIGLYCOLION	6.9708E-11	0.0	0.0	0.0
NIION	1.5804E-09	0.0	0.0	0.0
NIN03ION	3.3991E-10	0.0	0.0	0.0
NINTAION	1.8203E-05	0.0	0.0	0.0
NIOHEDTAION	1. 0735E-05	0.0	0.0	0.0
NIOHION	2.0009E-12	0.0	0.0	0.0
N0210N	15.3157	0.0	0.0	0.0
N0310N	73.0901	0.0	0.0	0.0
NTAION	6.7519E-05	0.0	0.0	0.0
ACETATEION	4.2606E-05	0.0	0.0	0.0
OXALATION	3.13739	0.0	0.0	0.0
PBACETION	1.9444E-12	0.0	0.0	0.0
PBCLION	3.9683E-09	0.0	0.0	0.0
PBEDTAION	0.0170702	0.0	0.0	0.0
PBGLYCOLION	3.5804E-10	0.0	0.0	0.0
PBION	1.0838E-08	0.0	0.0	0.0
PBN0210N	1.0170E-06	0.0	0.0	0.0
PBN0310N	1.1275E-08	0.0	0.0	0.0
PBNTAION	5.1940E-05	0.0	0.0	0.0
PBOHION	1.5511E-09	0.0	0.0	0.0
P0410N	8.1644E-05	0.0	0.0	0.0
SI03ION	5.1819E-07	0.0	0.0	0.0
S0410N	6.81661	0.0	0.0	0.0

TABLE B- 43: OLI Model of Blended AZ-102Eluate, Cont.

Phases ------- >	Aqueous	Solid	Vapor	Organic
Chemical	mol/hr	mol/hr	mol/hr	mol/hr
TCVII04ION	0.484275	0.0	0.0	0.0
U0220H2ION	5.1305E-14	0.0	0.0	0.0
U02ACION	1.3798E-13	0.0	0.0	0.0
U02C2042ION	1.2039E-04	0.0	0.0	0.0
U02CLION	3.6398E-12	0.0	0.0	0.0
U02CO32ION	0.464755	0.0	0.0	0.0
U02CTRTION	2.6118E-08	0.0	0.0	0.0
U02HEDTAION	1.8033E-12	0.0	0.0	0.0
U0210N	5.2921E-11	0.0	0.0	0.0
U02NTAION	1.2949E-08	0.0	0.0	0.0
U020HION	6.0016E-09	0.0	0.0	0.0
NAALC03OH2	0.0	1.95539	0.0	0.0
NA2C204	0.0	0.343564	0.0	0.0
CAC204.lH20	0.0	0.0760928	0.0	0.0
PBM004	0.0	0.0100275	0.0	0.0
Total g/hr	71332.1	348.364	0.0	0.0
Volume, L/hr	64.4715	0.11796	0.0	0.0
Enthalpy, cal/hr	-2.4549E+08	-1.0689E+06	0.0	0.0
Density, g/L	1106.4	2953.2		
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	85.3729			
Redox Pot, volts	0.0			
E-Con, 1/ohm-cm	0.135226			
E-Con, cm2/ohm-mol	41.7649			
Abs Visc, cP	1.04263			
Rel Visc	1.29744			
Ionic Strength	2.37865			