Hanford Sludge Characterization

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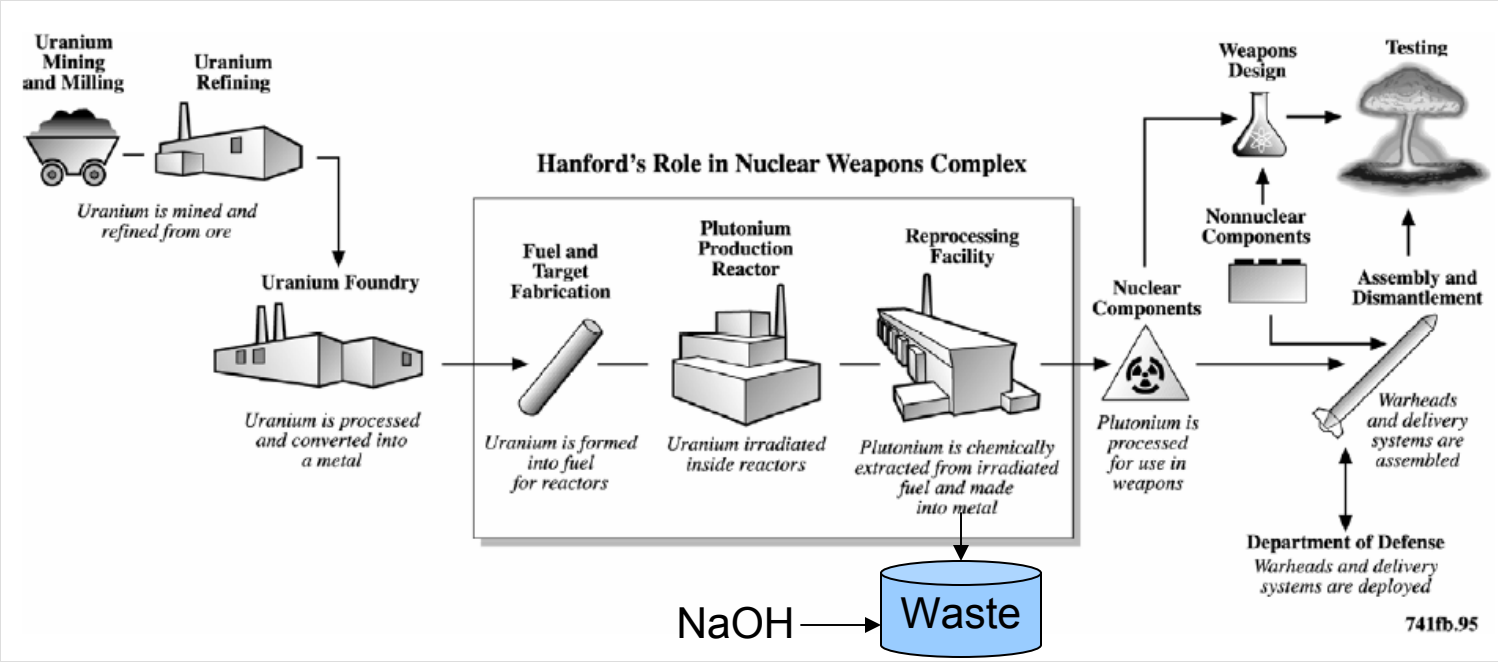
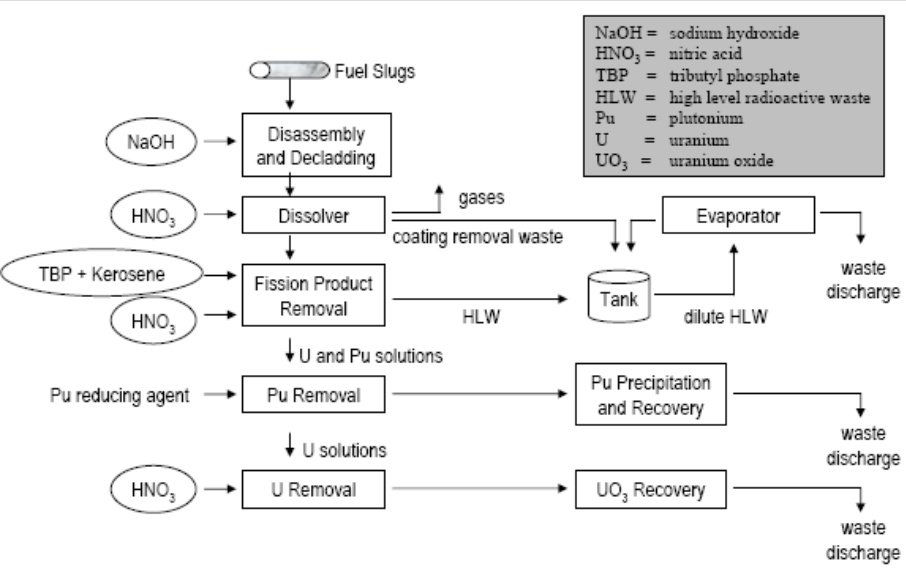
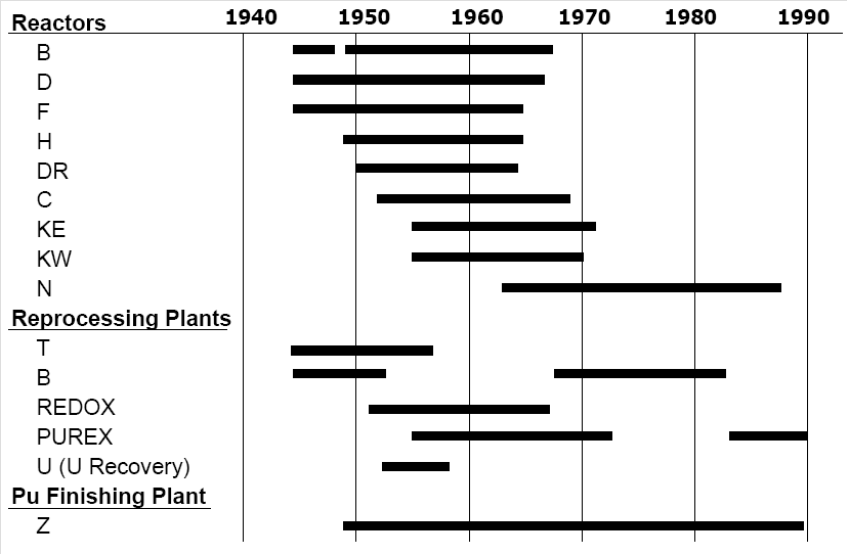
Hanford Waste Generation Processes







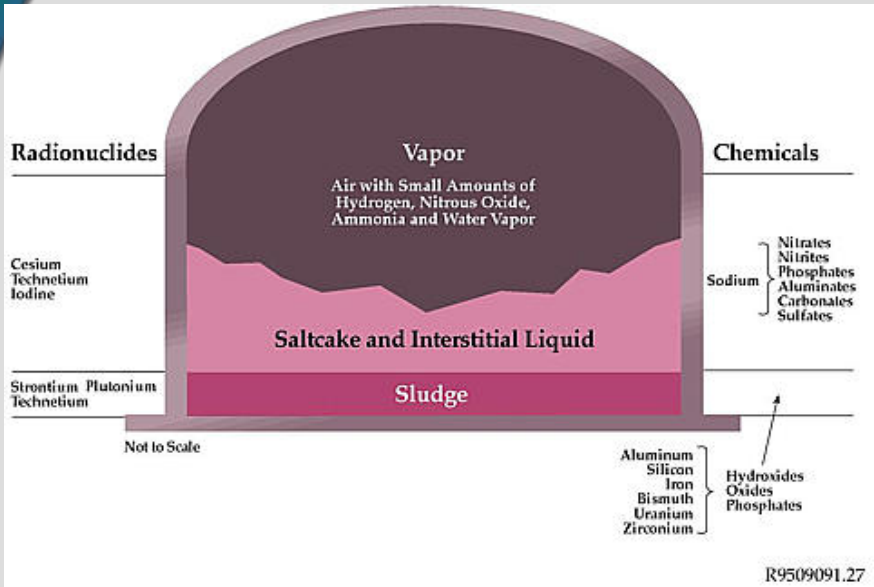
Waste Types

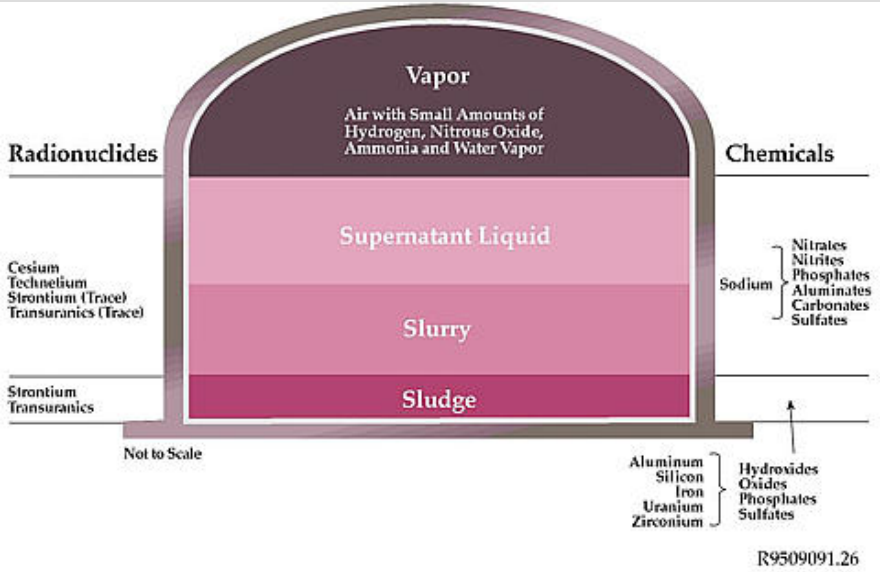
- Several waste types produced due to combinations of varying reactor fuels and reprocessing plant technologies
- Several in-tank treatment processes lead to further waste types
- FeCN process
- CEM, DE

Table 3.1. List of Waste Type Definitions

Waste Type	Definition
1C	$BiPO_4$ first cycle decontamination waste (1944-1956)
1CFeCN	Ferrocyanide sludge from in-farm scavenging of 1C supernatants in TY-Farm (1955-1958)
224	lanthanum fluoride process "224 Building" waste (1952-1956)
2C	$BiPO_4$ second cycle decontamination waste (1944-1956)
A1-SltCk	Saltcake from the first 242-A Evaporator campaign (1977-1980)
A2-SltSlr	saltcake from the second 242-A Evaporator campaign (1981-1994).
AR	Washed Plutonium-Uranium Extraction (PUREX) sludge (1967-1976)
B	high-level acid waste from PUREX processed at B Plant for Sr recovery (1967-1972)
BL	low-level waste from B Plant Sr and Cs recovery operations (1967-1976)
CEM	Portland Cement
CSR	Cesium recovery, supernatant from which Cs has been removed
CWP	PUREX cladding waste (1956-1960 and 1961-1972)
CWR	REDOX cladding waste, aluminum clad fuel (1952-1960 and 1961-1972)
CWZr	zirconium cladding waste (PUREX and REDOX)
DE	diatomaceous earth
HS	hot semi-works ^{90}Sr recovery waste (1962-1967)
MW	$BiPO_4$ process metal waste (1944-1956)
OWW3	PUREX organic wash waste (1968-1972)
P1	PUREX HLW (1956-1962)
P2	PUREX HLW (1963-1967)
P3	PUREX HLW (1983-1988)
PFeCN	Ferrocyanide sludge from in-plant scavenged supernatant (1954-1958)
PL2	PUREX low-level waste (1983-1988)
R (boiling)	boiling REDOX HLW (1952-1966)
R (non-boiling)	non-boiling REDOX HLW (1952-1966)
R-SltCk	Saltcake from self-concentration in S- and SX-Farms (1952-1966)
S1-SltCk	Saltcake from the first 242-S Evaporator campaign using 241-S-102 feed tank (1973-1976)
S2-SltSlr	Saltcake from the second 242-S Evaporator campaign using 241-S-102 feed tank (1976-1980)
SRR	HLW transfers (late B Plant operations)
T2-SltCk	Saltcake from the second 242-T Evaporator campaign using 241-TX-118 feed tank (1965-1976)
TBP	tributyl phosphate waste (from solvent based uranium recovery operations)
TFeCN	ferrocyanide sludge produced by in-tank or in-farm scavenging
TH	PUREX waste from processing of thoria targets
Z	Z Plant waste

Hanford Tank Configurations



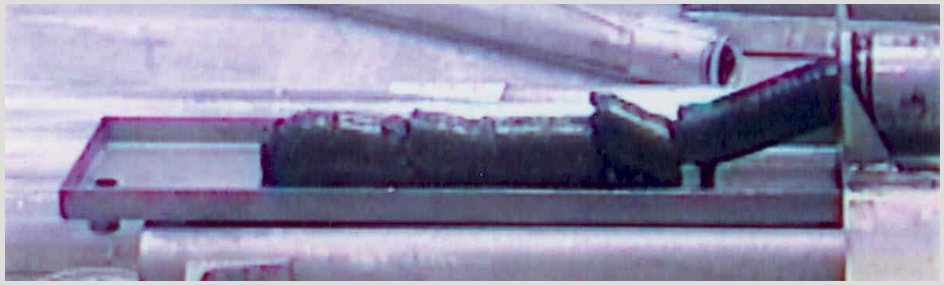


- 177 tanks
  - Single shell (top) and double shell (bottom)
- 53 million gallons of waste
  - 25,000 MT solids
- Composition of sludge contained in 149 single shell tanks
  - 37 Mgal total waste volume; 13 Mgal sludge; 23 Mgal saltcake
  - 17,000 MT solids
- Multiphase suspensions
  - Solid, Liquid, Gas
- nearly every element on Periodic table present
- Heterogeneous: radially and axially
  - Mixing conditions
  - Temperature gradients

Hanford Tank Waste Sampling and Characterization

Estimated Shear Strength: 2,000-4,000 Pa

Hanford Tank B-203, Core 122, Segment 10

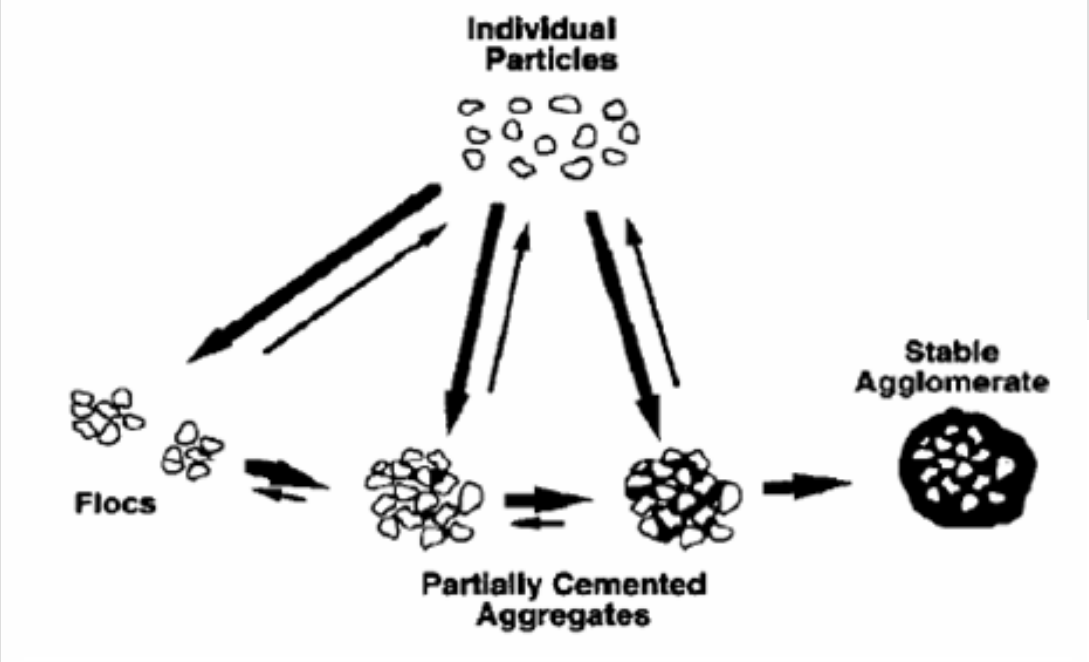


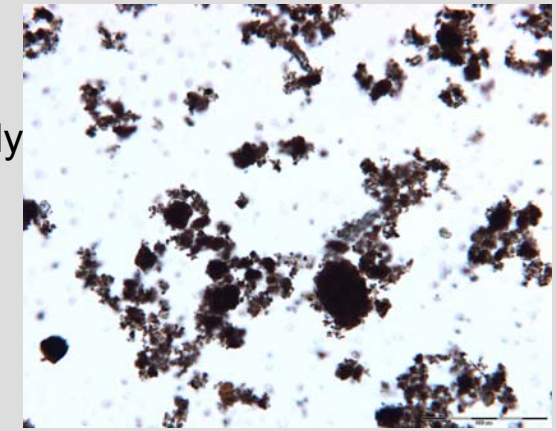
Hanford Tank B-204 Core 114, Segment 8

- Over 20-30 year period, samples from the tanks have been taken and characterized
  - Chemical analysis
    - Anion, cation, and organics
  - Rheological analysis
    - Flow curves
    - Shear strength
  - Physical Properties
    - Sedimentation rates
    - Apparent density
    - Fraction dissolved and undissolved solids
- Key questions:
  - What are the size and density of the sludge particles?
  - How fast does the supernatant layer develop?
  - What is the viscosity of the supernatant layer?
  - What are the flow behaviors of the sludge layer?

How big and dense are the sludge particles? Particle Types

- Individual Particles
  - Crystals
- Flocs
  - Primary particles bound by electrostatic forces
  - Multi-component
  - Low density
  - Easily broken down by moderate shear forces
- Partially Cemented Aggregates
  - Coagulated aggregates
  - Can be chemically bound together
  - Fractal Density
- Stable Agglomerates
  - Agglomerates that eventually become monolithic
  - High density





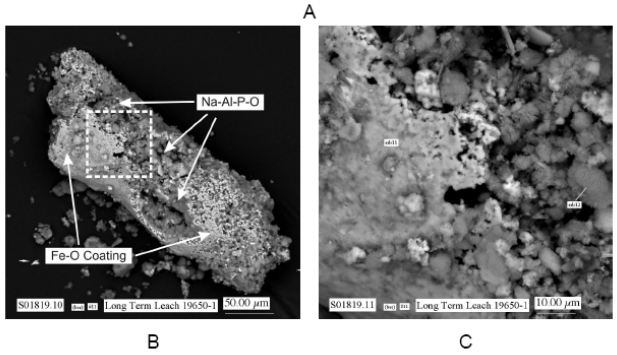


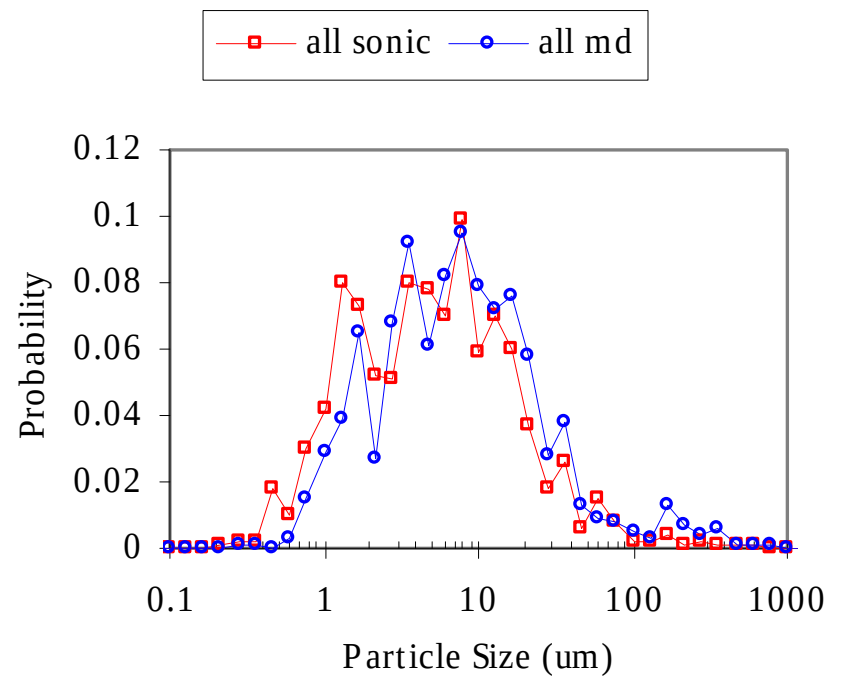
FIGURE S-8. Backscattered-electron SEM micrographs of leached C-204 sludge samples showing preferential dissolution features in an Fe oxide aggregate (micrograph A) and Fe-oxide coating (micrographs B and C). [Micrograph C shows at higher magnification the region marked by the dashed-line square in micrograph B.]

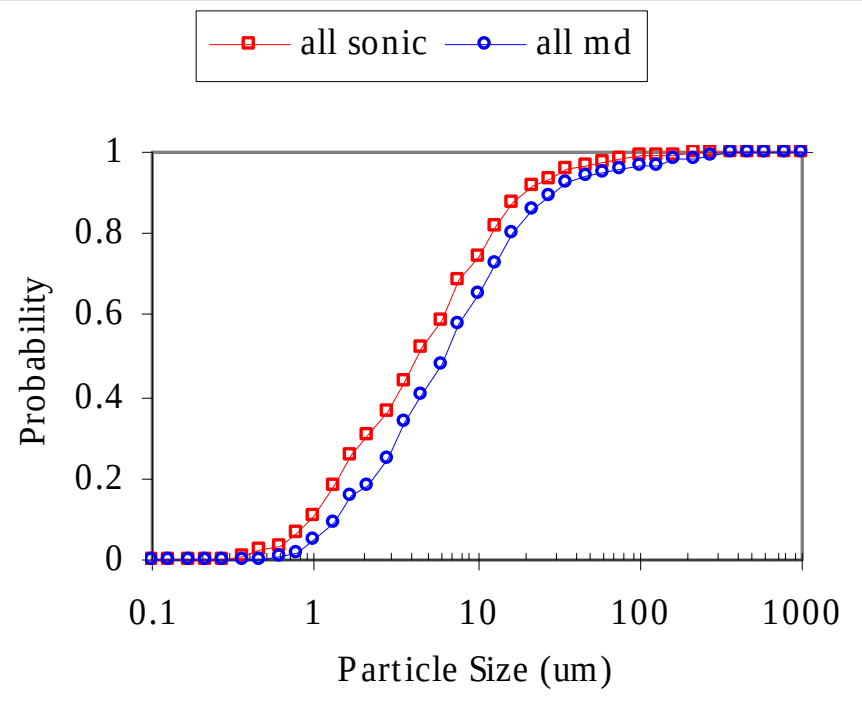
What are the size and density of the sludge particles?

Particle Size Distributions

- "Minimal disturbance" (md) PSD
  - Data collected at minimum turbulence/disturbance conditions
  - Crystals, flocs, cemented aggregates, stable agglomerates
- "Sonicated" (sonic) PSD
  - Data collected during ultrasonic treatment of the sample
  - Crystals, cemented aggregates, stable agglomerates

Particle Size Distributions





Quantile	1%	5%	25%	50%	75%	95%	99%	100%
Sonicated[(a)]	0.39	0.70	1.63	4.39	10.1	33.4	112	774
Minimal Disturbance[(b)]	0.65	1.00	2.80	6.31	14.0	58.6	256	1000

(a) Combined data from 18 sludge tanks.
(b) Combined data from 19 sludge tanks.

What are the size and density of the sludge particles?

Degree of Particle Size Characterization

- Several PSD data sets discarded due to instrument limitations
- Several types remain uncharacterized
  - TBP
  - R (non-boiling)
  - DE

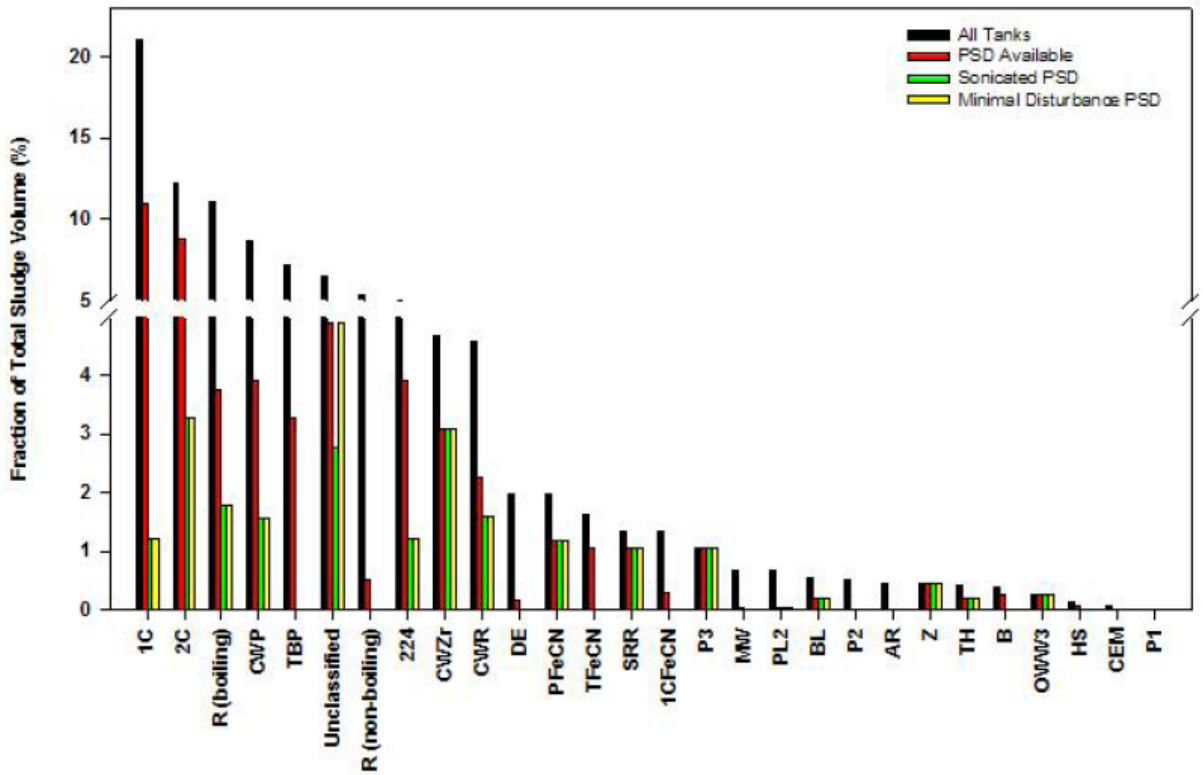
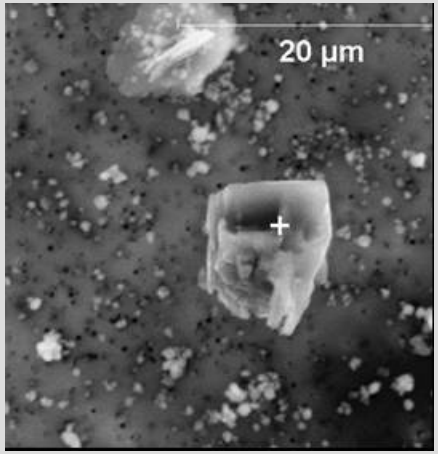


Figure 3.1.1. Volumetric Significance of Composite PSD Analysis. Here, the volume fraction of total sludge solids by waste types (black bars) is compared to the volume fraction with PSD measurements available (red bars), regardless of quality, and the volume fraction down selected for sonicated and minimal disturbance data sets (green and yellow, respectively).

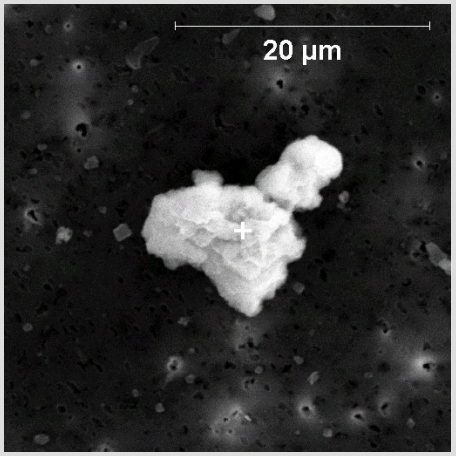
What are the size and density of the sludge particles?

Scanning Electron Micrographs

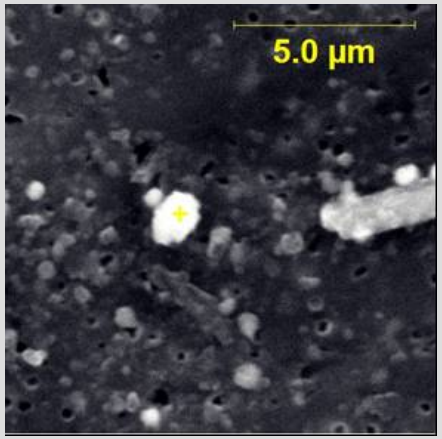
- Maximum Particle and Agglomeration Size
  - Image analysis from SEM and XRD
  - Expert panel elicitation



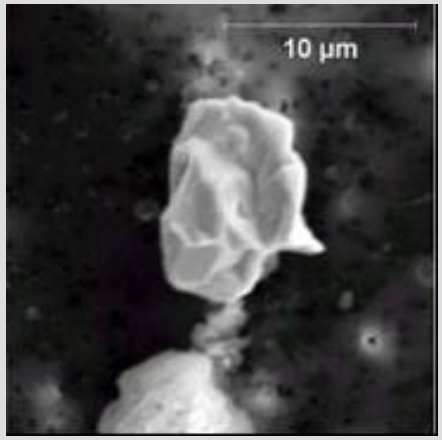
Gibbsite, C-104



$Na_2U_2O_7$, SY-102



Fe_2O_3, AY-102



PuO_2, SY-102

What are the size and density of the sludge particles?

Saltcake species

- The following slides visually show the presence of large (100-500 μm) particles in Hanford saltcake
- Not considered in PSDD assessment
- These species may reprecipitate in the WTP
  - Broad PSD
  - Broad range of particle shapes
  - Broad range of particle densities

500 microns

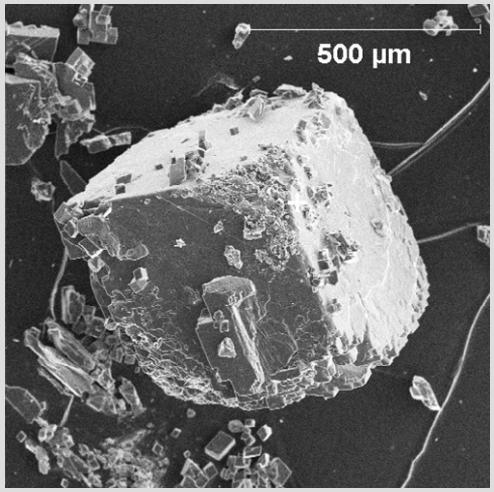


Figure 4.1.2-1. High magnification secondary electron image of original solids from Tank S-112.

500 microns

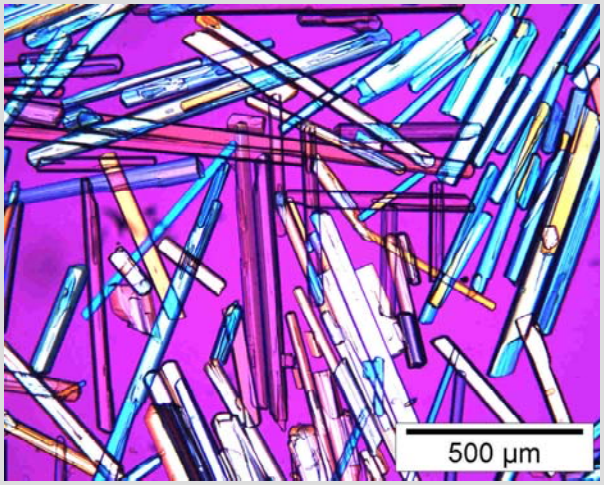


Figure 4.4.2-1. $Na_3PO_4 \cdot 12H_2O$, Tank U-107.

Crystals formed by dissolving U-107 saltcake at 50 °C, then cooling the solution to 23 °C; some of the crystals are thick enough to display first-order interference colors. (See also Figure 3.1.3-3.)

Crossed polars with Red I compensator, 4x objective.

100 microns

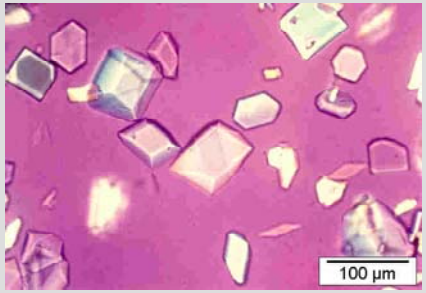


Figure 4.4.2-1. $Na_3PO_4 \cdot 6H_2O$ in tank waste simulant.

Lower hydrate crystal habit, which forms at higher temperatures, is much more compact, and does not form gels or plug pipes the way the 12-hydrate does. The transition temperature, typically ~40-50 °C, depends on ionic strength of solution and other factors.

Crossed polars with Red I compensator, 16x objective.

50 microns

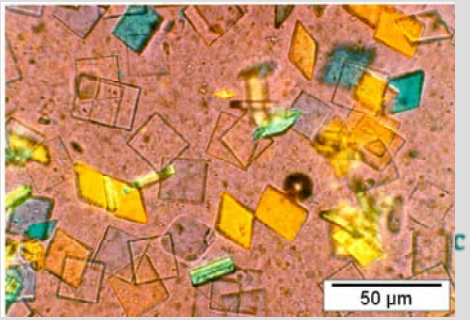


Figure 4.5.1-1. $NaAl(OH)_4$ from a previous simulant, showing the "thin quadratic platelet" form of the crystals (Fricke and Jucaitis 1930). Platelets that lie flat appear to be isotropic because the optic axis is parallel to the light path, but plates tilted slightly appear blue/yellow, revealing the birefringence.

Simplified List of Solid-Phase Compounds

Solid-Phase Compound	Crystal Density (g/mL)	Volume Fraction	Maximum Observed Particle Size (μm)
$Al(OH)_3$, Gibbsite	2.42	0.515	20
$(NaAlSiO_4)_6 \cdot (NaNO_3)_{1.6} \cdot 2H_2O$	2.365	0.166	8
AlOOH, Boehmite	3.01	0.106	0.05
$NaAlCO_3(OH)_2$	2.42	0.095	4.2
Fe_2O_3	5.24	0.041	1.6
$Ca_5OH(PO_4)_3$	3.14	0.020	0.1
$Na_2U_2O_7$	5.617	0.016	15
ZrO_2	5.68	0.011	50
Bi_2O_3	8.9	0.0081	10
SiO_2	2.6	0.0069	100
$Ni(OH)_2$	4.1	0.0055	0.5
MnO_2	5.026	0.0054	10
CaF_2	3.18	0.0023	15
$LaPO_4 \cdot 2H_2O$	6.51	0.0013	3
Ag_2CO_3	6.077	0.000094	4
PuO_2	11.43	0.000013	40

What are the size and density of the sludge particles?

PSDD Modeling

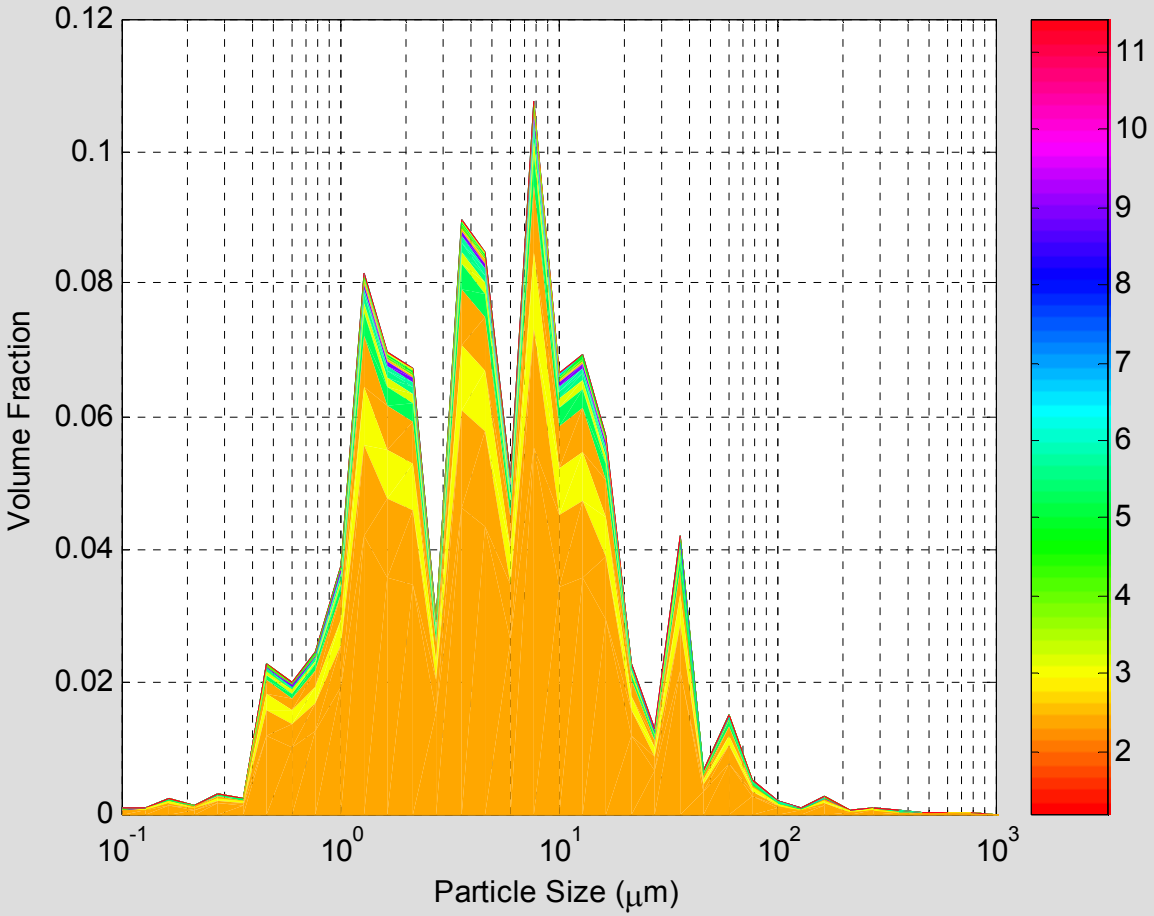
- Monte Carlo simulation approach used.
  - Input parameters:
    - PSD (repeated realizations of composite PSDs)
    - Crystal density
    - Volume fraction
    - Primary particle size (affects Cases 2 and 4)
    - Fractal Dimension
- Representative PSDD is calculated at centroid for respective input distributions.
- Composite PSD must be reproduced and particulate mass must be conserved.

1. Sonicated PSD
   - Crystals, cemented aggregates, and stable agglomerates are assigned crystal density
2. Sonicated PSD
   - Crystals are assigned crystal density
   - Density of cemented aggregates and stable agglomerates assigned via fractal relation
3. Minimal disturbance PSD
   - Crystals, flocs, cemented aggregates, and stable agglomerates are assigned crystal density
4. Minimal disturbance PSD
   - Crystals are assigned crystal density
   - Density of flocs, cemented aggregates, and stable agglomerates assigned via fractal relation

What are the size and density of the sludge particles?

Monte Carlo Modeling Results

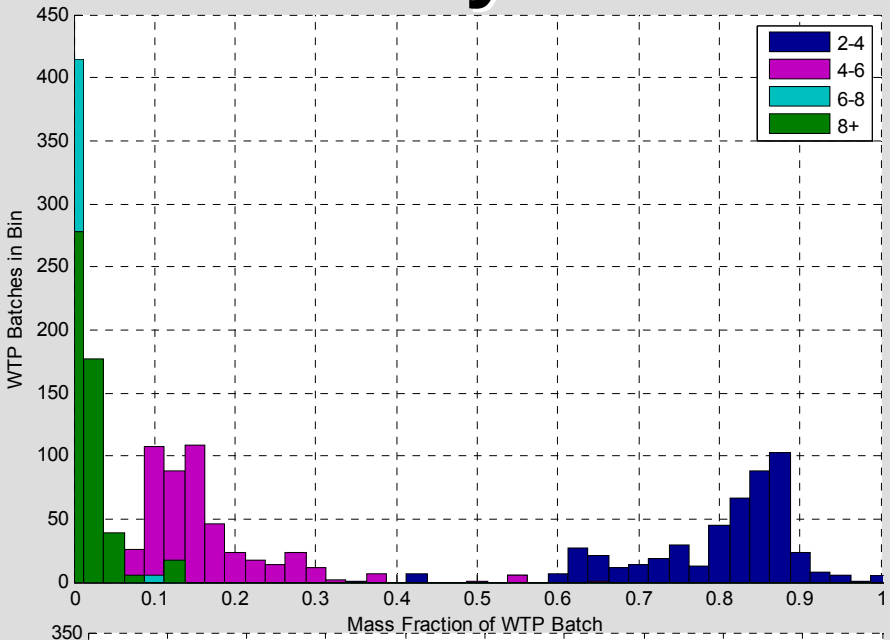
- Feasible solutions to this problem were calculated for each realization while maintaining mass balance and particle size distribution
- Particle size & density relationships for each simulation case were modeled
- Results can be applied to slurry transport and mixing designs
- Example for Case 1 shown on left (colorbar axis is particle specific gravity)
- Particles range from 1 to 100 microns over a density range of 2.5 to 11 g/cc
  - Dilute conditions → settling slurry
  - Concentrated conditions → discrete particles settling in a non-settling matrix

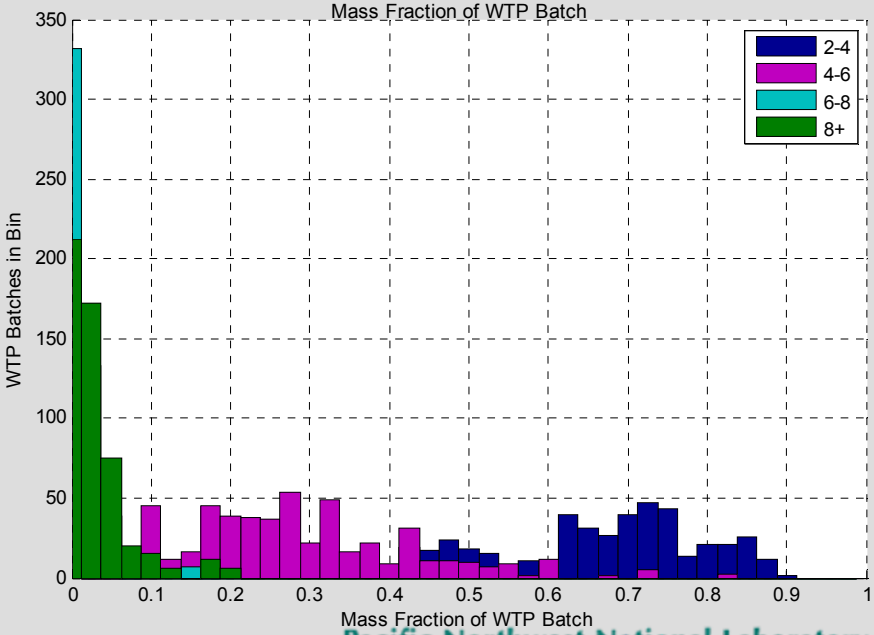


What are the size and density of the sludge particles?

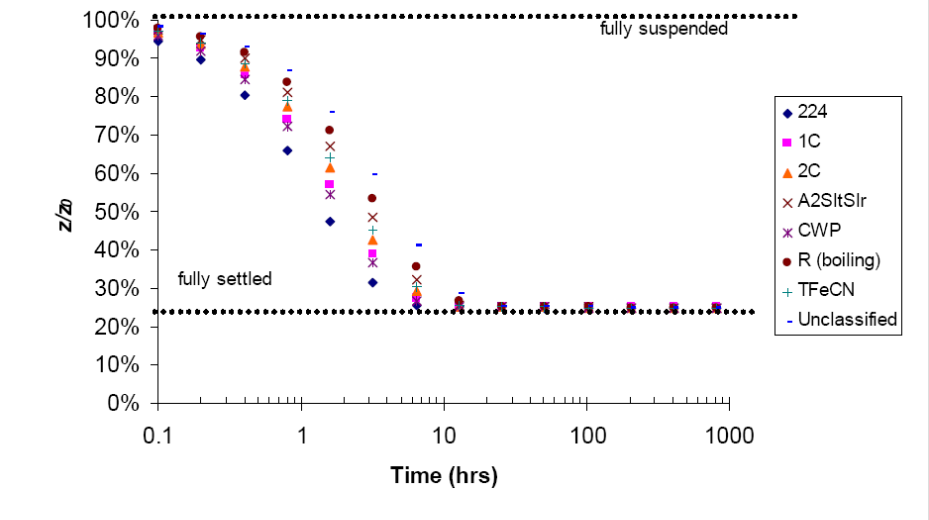
Waste Feed Variability

- 518 WTP batches over 20-30 year processing period
- Colors are groupings of particle density
- Pre-leaching (top)
- Post-leaching approximation (Gibbsite and Boehmite removed; bottom)
- High amount of particles with density of 2-4 g/cc
- 30-80 wt% of slurry contains particles with 4-6 g/cc
- 10-20 wt% of slurry contains particles with 8-10 g/cc
- Particle size and rheological properties will also significantly vary over time
  - Avoid designing to averages and design to anticipated but extreme conditions





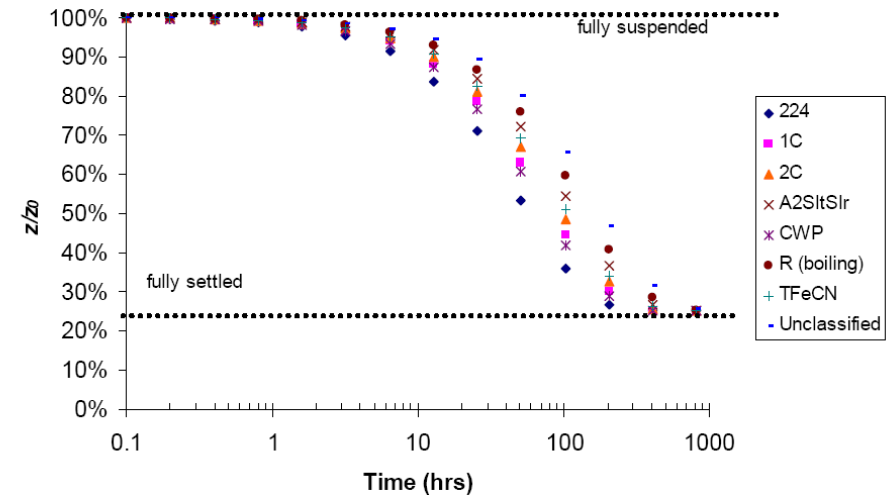
Effect of Process Scale on Sedimentation Time



a) initial interface height is $z_0 = 10$ cm; initial solids concentration of the suspended sample is $\phi = \frac{\phi_{max}}{4}$

- Compressive settling regime observed
- Sedimentation completed within 10 hours at small scale

- Sedimentation completed within 1,000 hours at medium scale

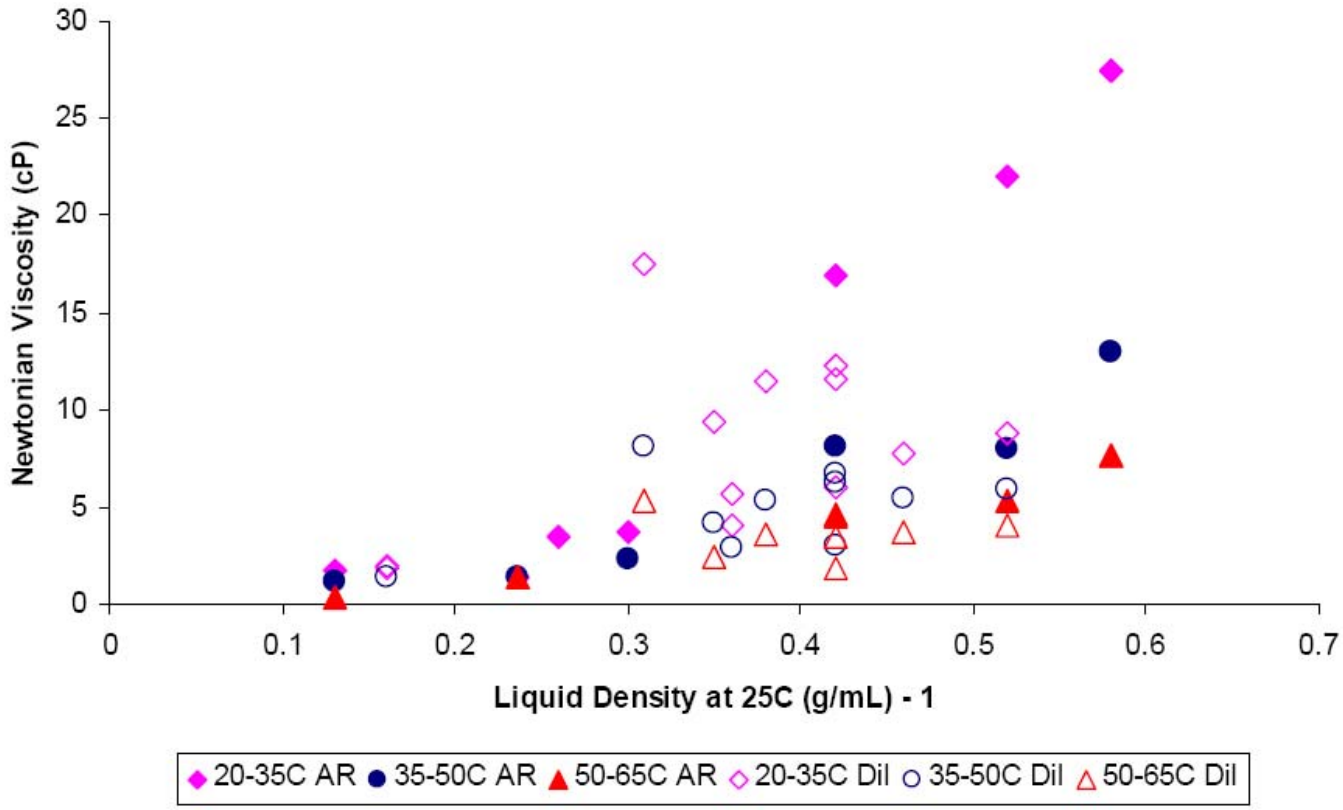


b) initial interface height is $z_0 = 4$ m; initial solids concentration of the suspended sample is $\phi = \frac{\phi_{max}}{4}$

How fast does the supernatant layer develop?

Supernate Viscosity Data

- as-received (AR)
- diluted with Hanford process water (Dil)
- Viscosity ranges from 2-3 cP to 20-30 cP depending on dissolved solids concentration and temperature



(a) Data grouped according to dilution and temperature.

What is the viscosity of the supernatant layer?

Shear Strength Model

- Nomenclature to differentiate between direct measurement techniques and extrapolation from a flow curve
  - static measurements termed "shear strength"
  - Dynamic extrapolations from a flow curve termed "yield stress"
- Thixotropic (time dependent) property
  - Rebuilding of gel structure with time
- Measured with shear vane technique
- Data from AZ-101 pretreated HLW sludge
- Behaves similar to mineral suspensions where full shear strength reached in 24-48 hours while quiescent
- Only data available on restructuring of Hanford HLW sludge

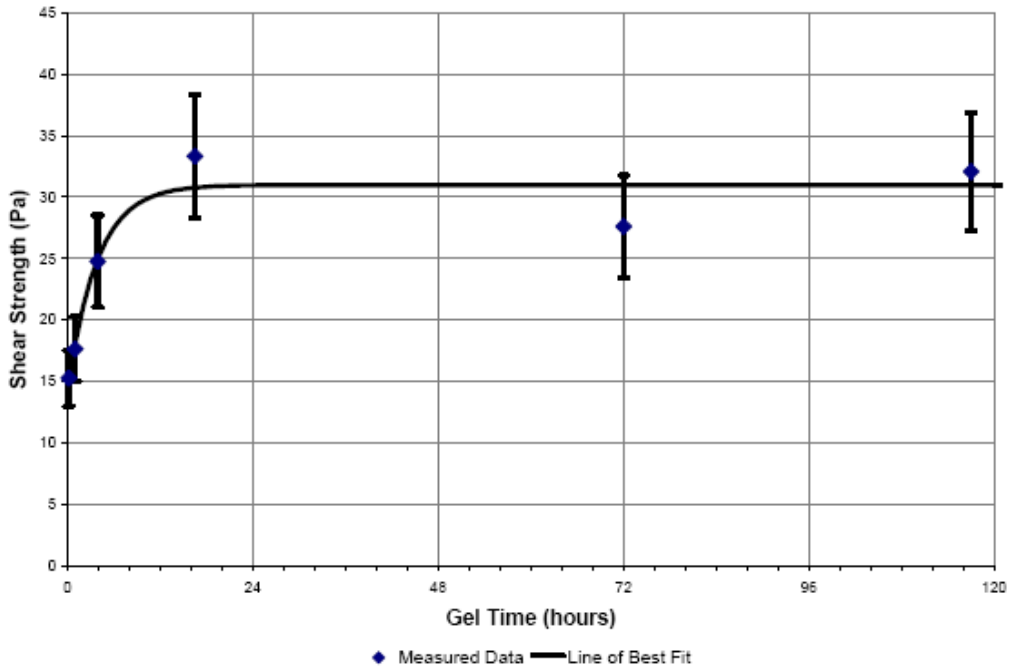
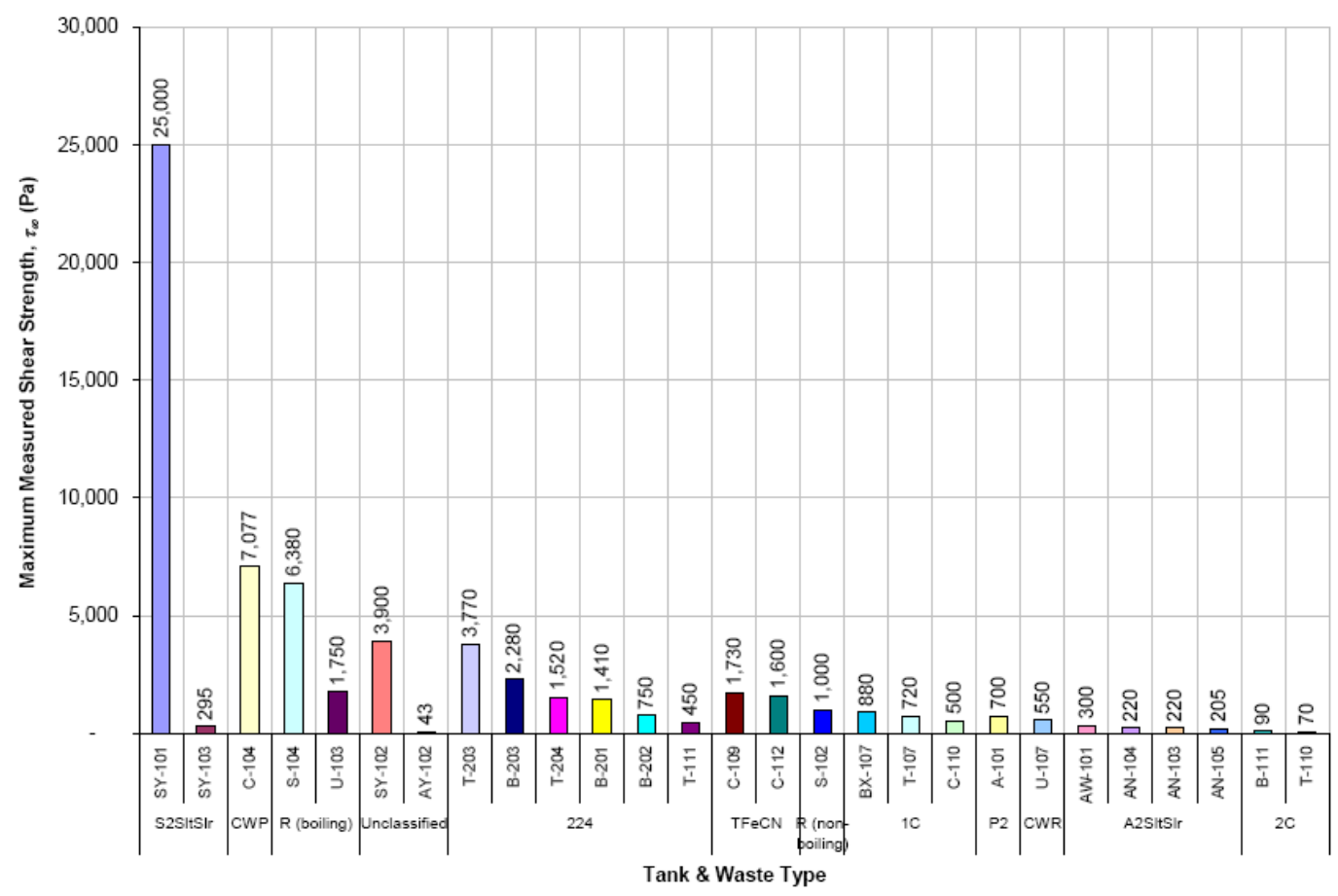


Figure 11.1. Shear Strength as a Function of Gel Time for HLW Pretreated Sludge

What are the flow behaviors of the sludge layer?

Shear Strength Data

- Measured with shear vane technique and penetrometer (in-situ)
- Large range of shear strength values
- SY-101 had large volume of retained gas and should be proportional to a rebuilding structure (shear strength)
- In several tanks the falling ball system was fully supported by a sludge layer (>9,000 Pa)

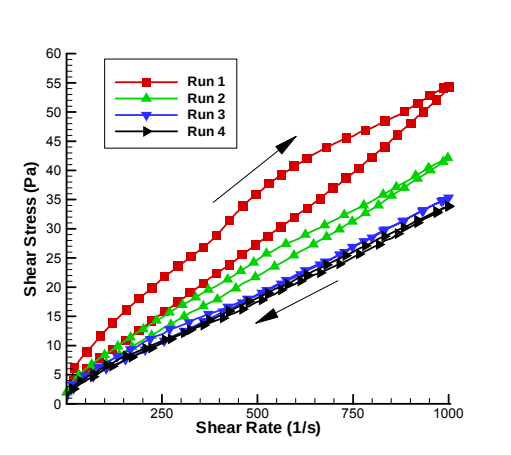


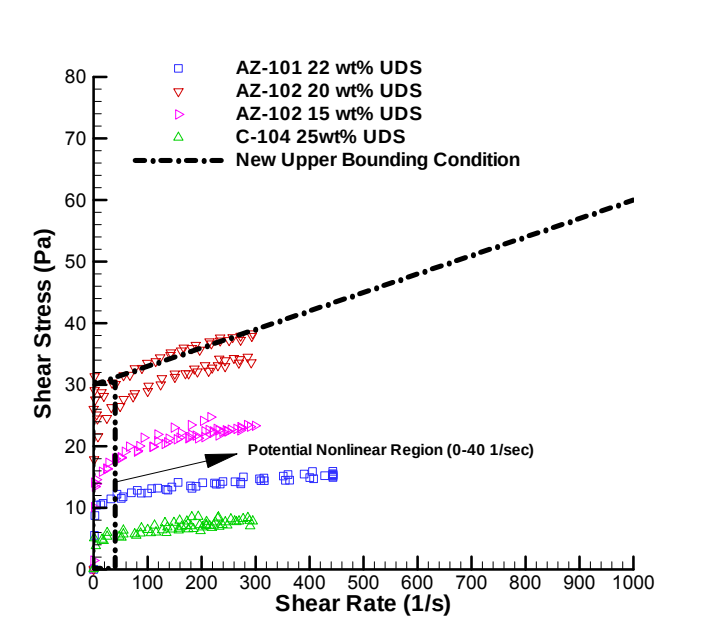
a) Maximum measured shear strength for each Hanford waste tank

What are the flow behaviors of the sludge layer?

Flow Curve Observations

- Ramp up and ramp down (top)
- Hysteresis loops indicate thixotropy (top)
- Runs repeated until equilibrium curve reached
- Viscoplastic behavior observed
- Bingham plastic model used
  - Two parameter model
  - Conservative design
  - Yield stress in model
  - infinite shear rate predicted
- Additional modeling can be performed on thixotropic decay parameters





What are the flow behaviors of the sludge layer?

Maximum Measured Bingham Consistency (Plastic Viscosity) Values

- "Consistency" nomenclature used to eliminate the term viscosity when discussing non-Newtonian fluids
- Measurements taken under a wide range of dilution conditions
- Maximum values typically represent sediment rheology
  - Important design information for plant restart

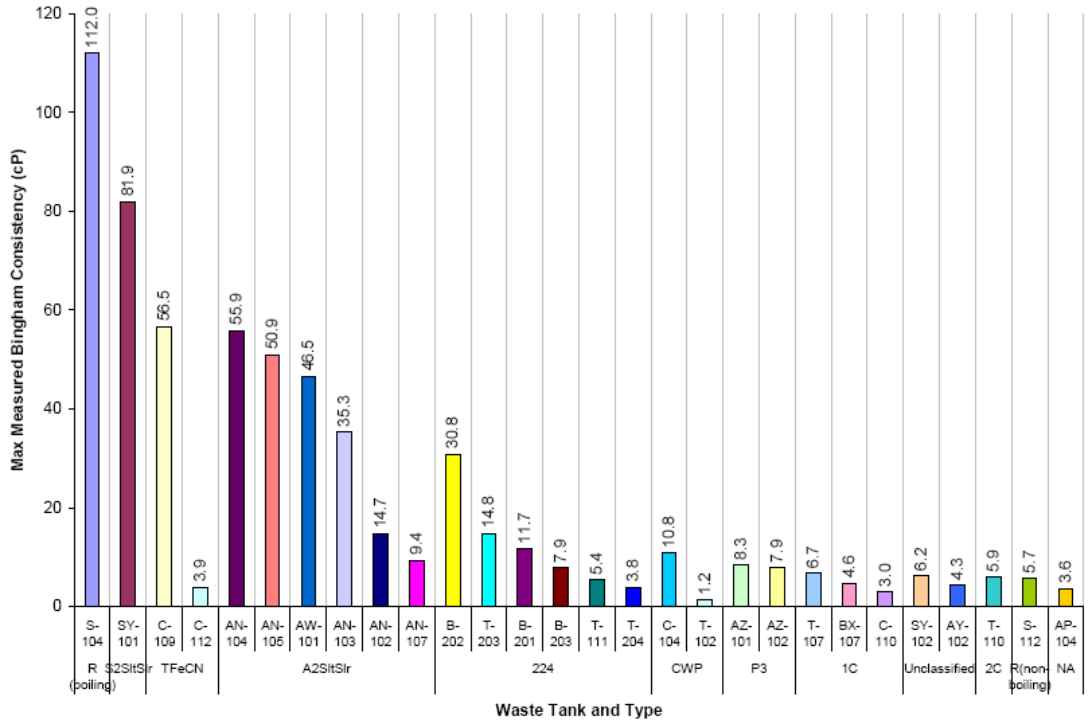


Figure 12.3. Maximum Measured Bingham Consistency for Various Hanford Tanks and Waste Types

What are the flow behaviors of the sludge layer?

Maximum Measured Bingham Yield Stress Values

- Measurements taken under a wide range of dilution conditions
- High range of maximum value represent sediment rheology under gravitational conditions
  - Important design information for plant restart
- Several of the thicker materials could not be accurately measured in viscometer due to wall slip
  - Excessive diluent was added and maximum values are significantly reduced

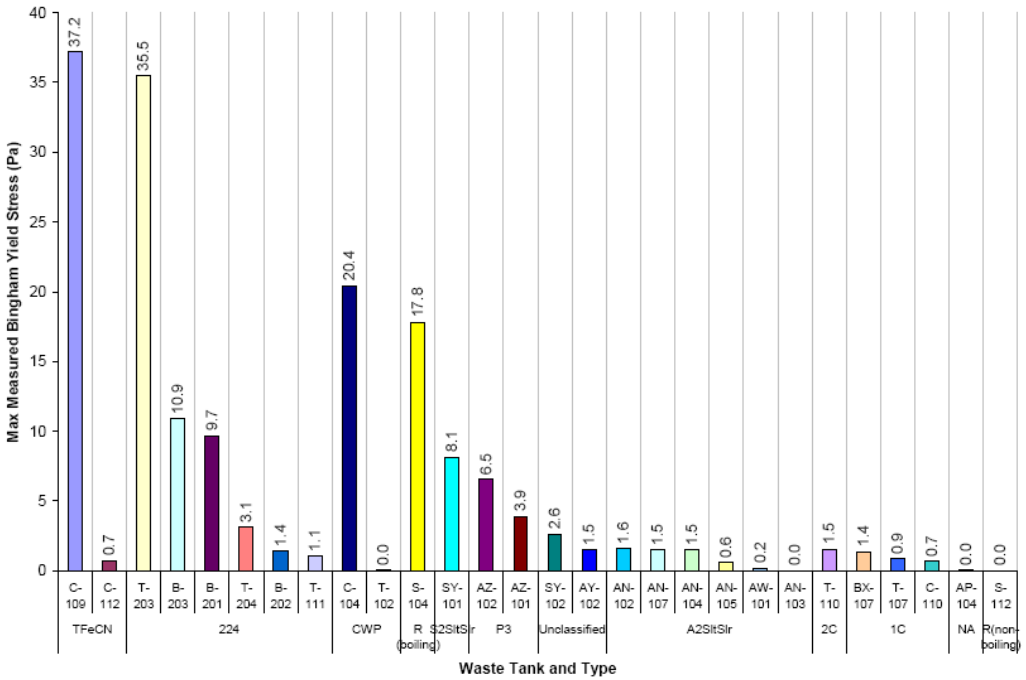
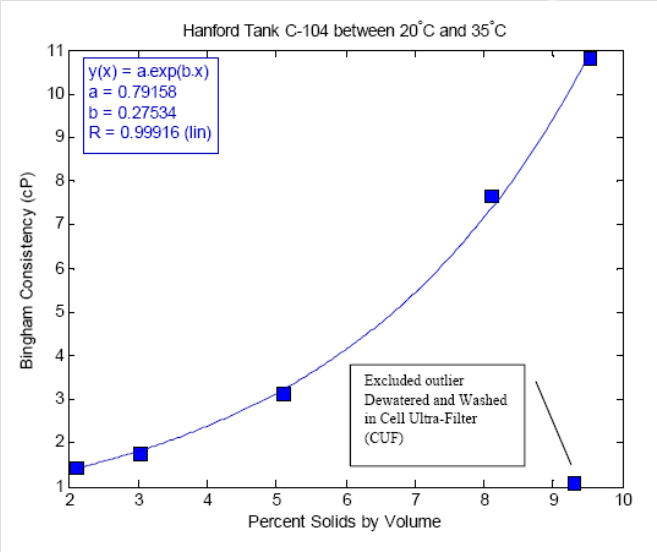


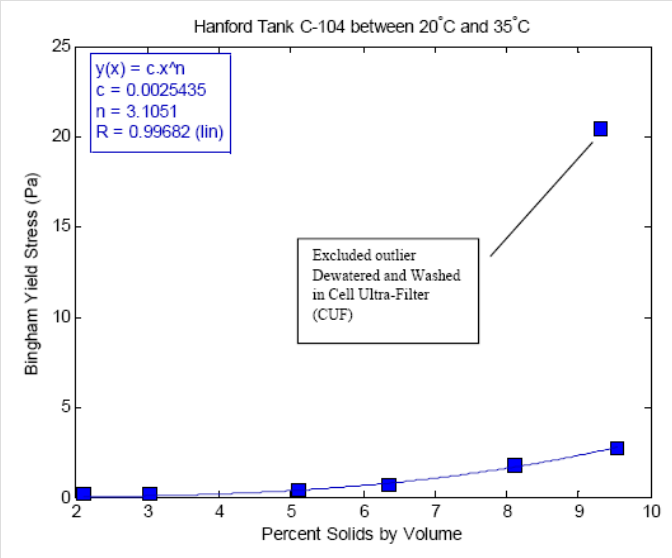
Figure 12.4. Maximum Measured Bingham Yield Stress for Various Hanford Tanks and Waste Types

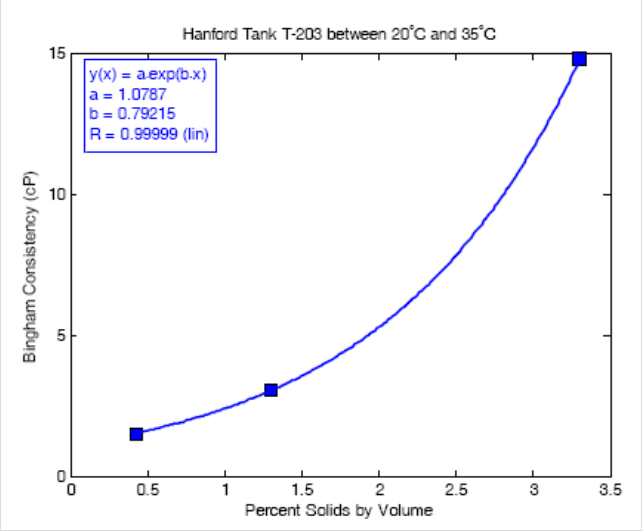
What are the flow behaviors of the sludge layer?

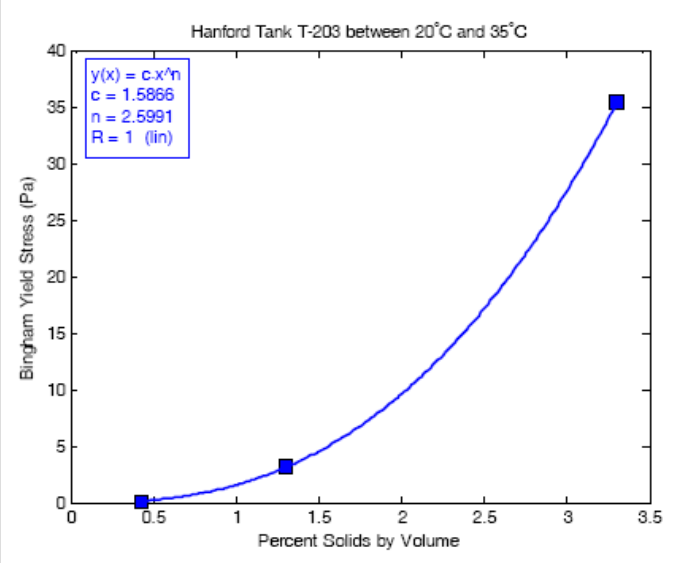
Bingham parameters as function of solids loading

- Empirical equation used to describe data
- Experimental data typically contains 2-3 points
- eliminates possibility of using 3+ parameter models
- Maximum packing fraction varies from tank to tank
  - Top ~10 vol%
  - Bottom ~5 vol%
- Very few of these correlations could be constructed
- Waste tanks should be further rheologically characterized







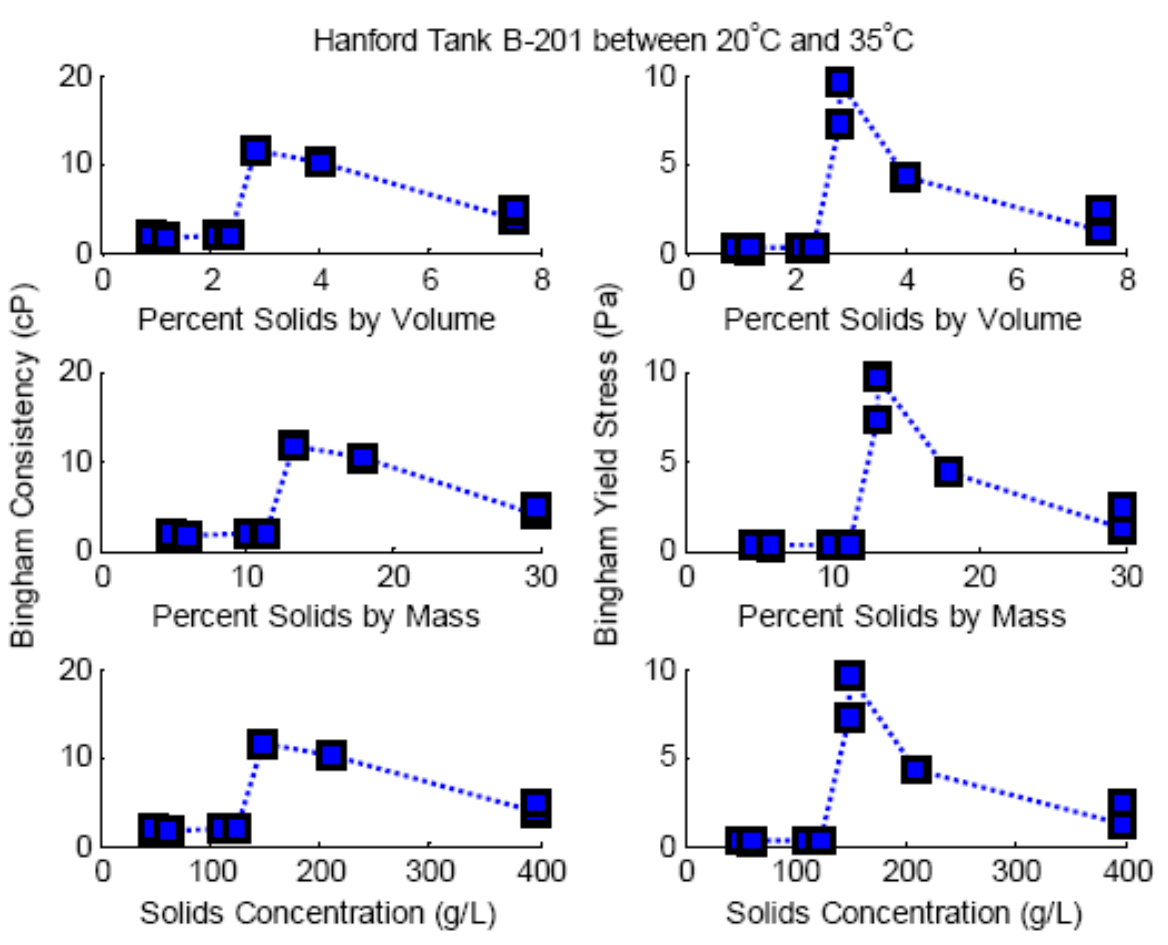


What are the flow behaviors of the sludge layer?

Water Dilution Chemical Effects

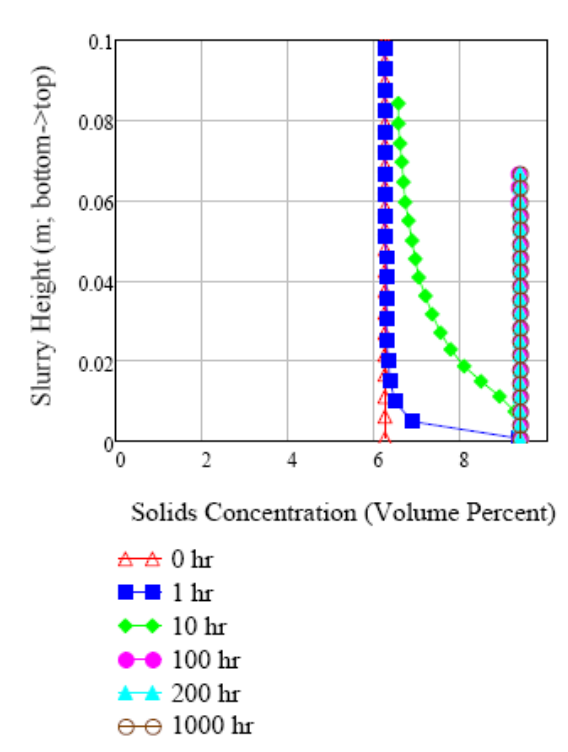
- As dilution with water ↑
- Zeta potential →0
- pH↓ can result in precipitation
- Particle size↕ competing effects of dissolution and precipitation
- Undissolved solids concentration↓

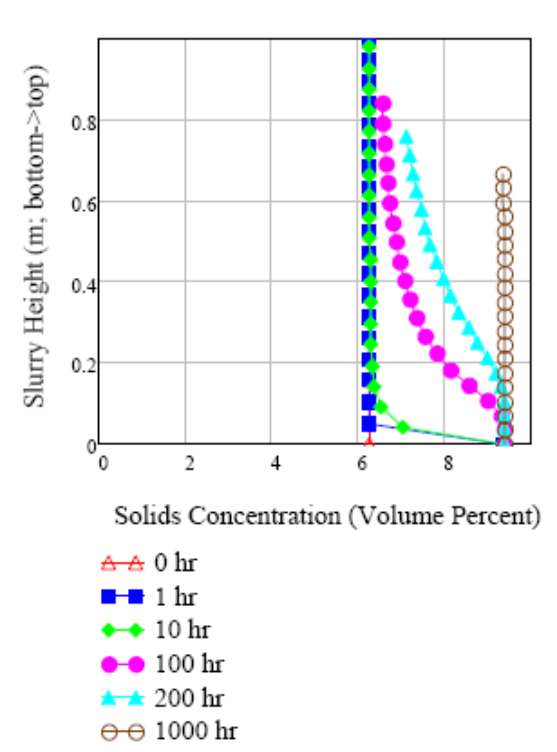
- Resulting rheological properties ↕
  - Maxima can exist during water dilution steps
  - Waste retrieval

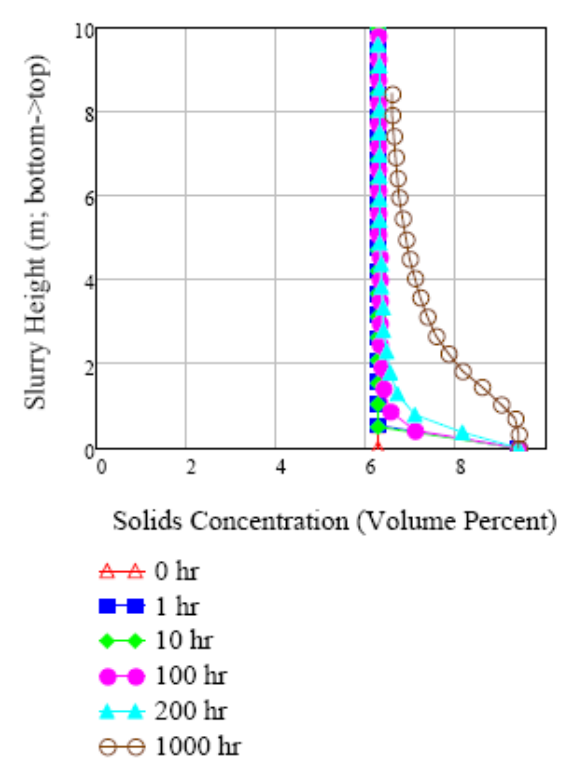


Effect of process scale on sedimentation times

- Calculated sedimentation concentration profiles
  - 0.1 m (left)
  - 1 m (center)
  - 10 m (right)
- Solids concentration profiles develop at a slower rate with increasing process height
- Bottom of tank has highest solids concentration for longest period of time

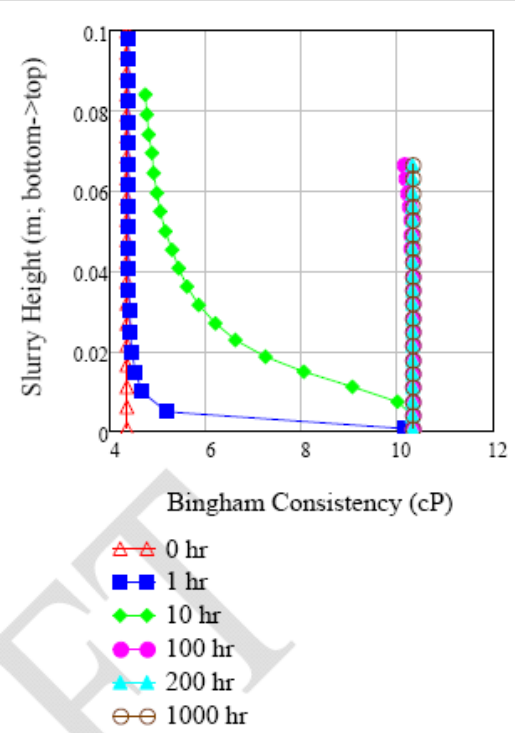


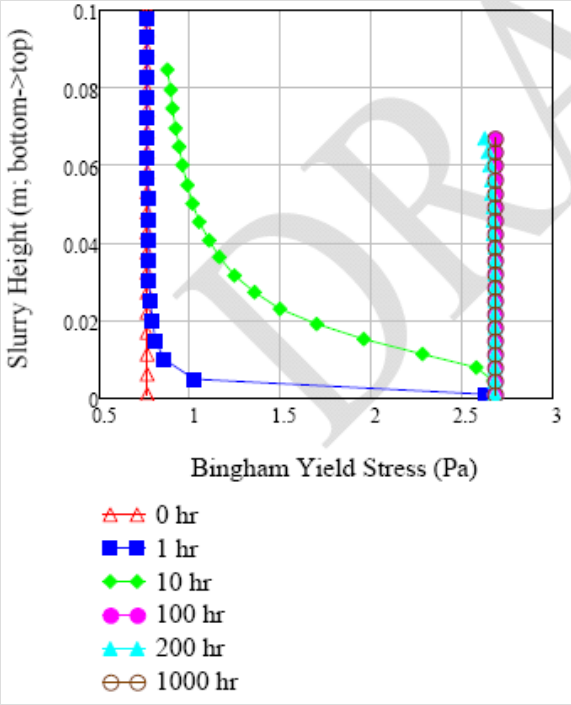


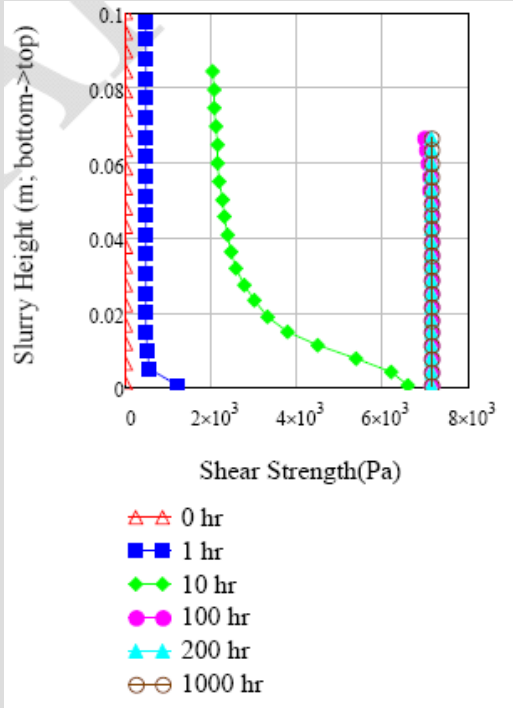


Transient rheological behavior during sedimentation

- 0.1 m starting slurry height
- Fully settle between 10-100 hrs
- Shear strength model account for solids increase and gel time separately
- Thick layer develops from the bottom towards the top with time







Degree of Physical Property Characterization

- Characterization effort was opportunistic rather than comprehensive
- Several types remain uncharacterized in several areas
- Quality of data gathered over 20 year period varies widely with different test objectives, research staff, equipment…

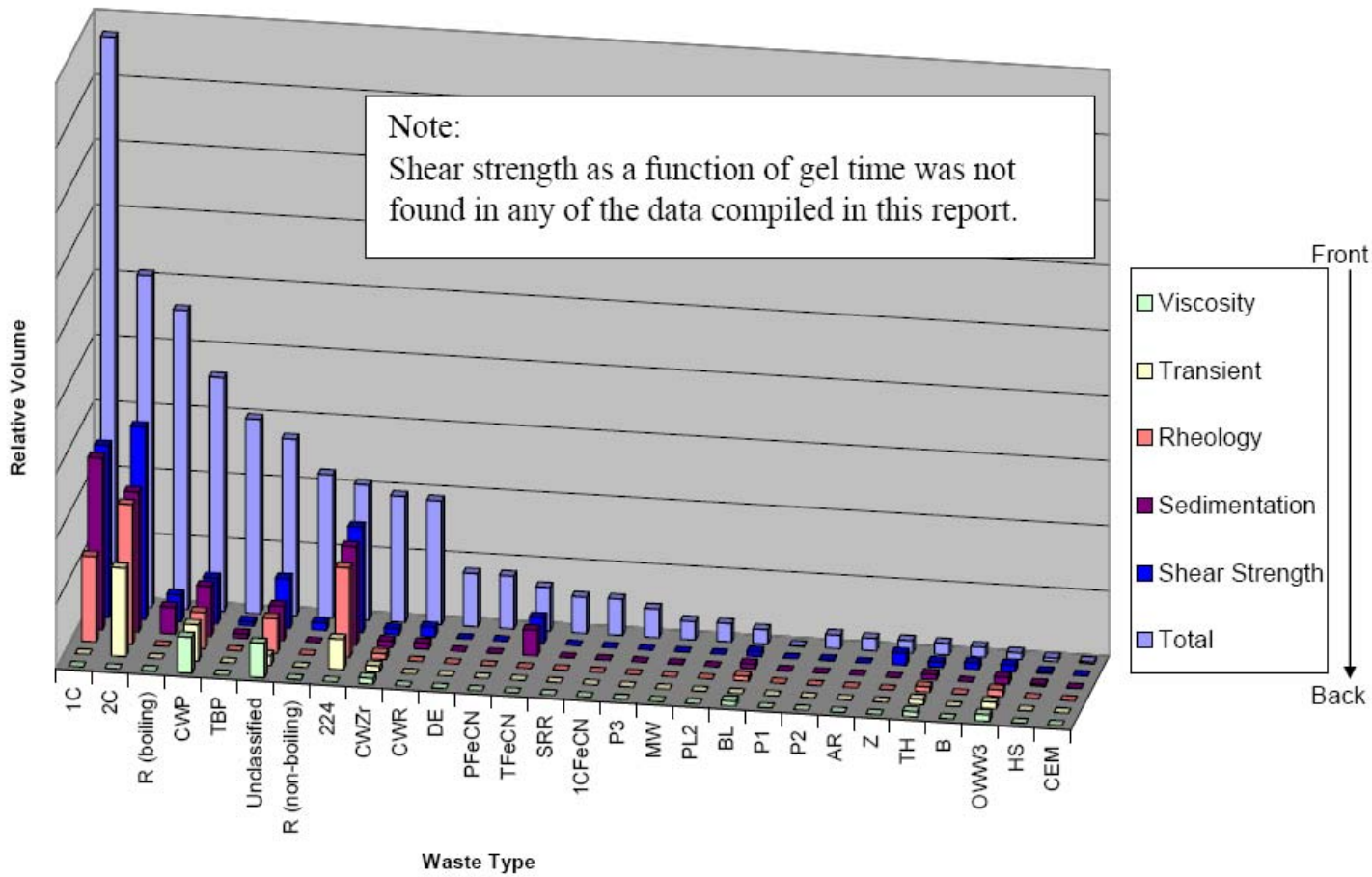


Figure S.6. Relative Volume of Waste Types Modeled Based on Waste Tank Data Available for Liquid Viscosity, Sedimentation, Shear Strength, Rheology, and Transient Modeling Compared with the Total Volume of Each Sludge Waste Type

Summary

Table 14.1. Range of Rheological Parameters and Regrowth Times at Typical Process Scales

Category	Heel Shear strength	Slurry/Sediment Heel Bingham Yield Stress	Slurry/Sediment Heel Bingham Consistency	Supernatant Viscosity
Min[a]	40 Pa	0 Pa	1 cP	1 cP
Median[a]	700 Pa	1.5 Pa	8 cP	8 cP
Max[a]	25,000 Pa	40 Pa	110 cP	30 cP
Tank heel property after 10 hours of sedimentation in process piping (0.1 m sludge height)	25,000 Pa	40 Pa	110 cP	n/a
Tank heel property after 100 hours of sedimentation in a medium-scale vessel (1 m sludge height)	25,000 Pa	40 Pa	110 cP	n/a
Tank heel property after 1000 hours of sedimentation in a large-scale vessel (10 m sludge height)	25,000 Pa	40 Pa	110 cP	n/a

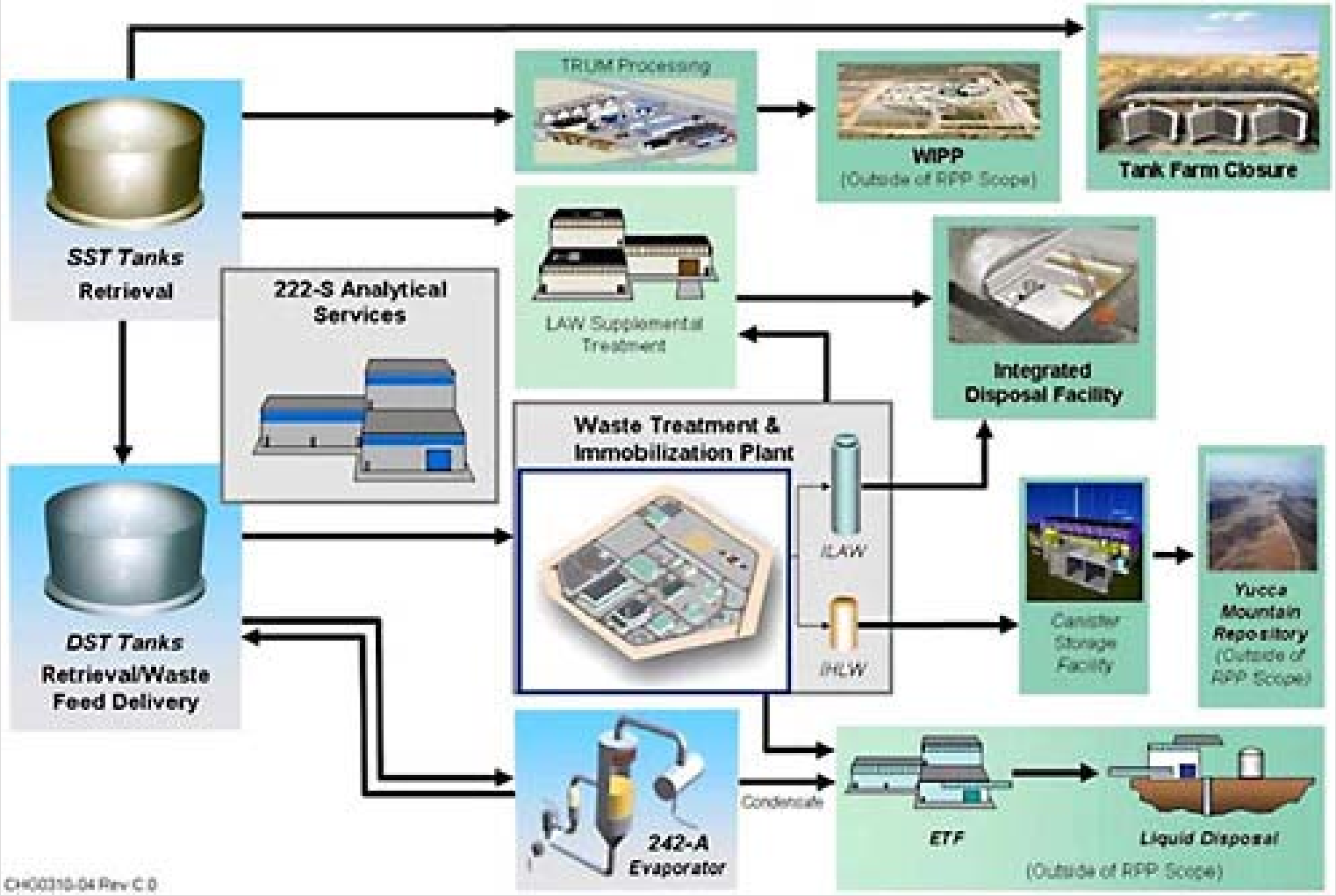
(a) Statistics performed on all compiled data discussed in this report.
n/a – not applicable.

- Particle Size and Density
  - Distributions were decoupled and a set of possible distribution attained via Monte Carlo simulation
- Sedimentation Data
  - Obtained empirical sedimentation models for Hanford sludge
  - Reaches fully settled configuration in the range of several hours to several days with 10 hours as typical value
- Flow Curve Data
  - Bingham parameters were modeled
  - Coupled with sedimentation data to obtain transient equation
  - Can reach values well above 30 cP, 30 Pa within 10 hours
- Shear Strength Data
  - Coupled with sedimentation and Bingham yield stress model for obtain transient equation
  - Can reach values well above 10,000 Pa within 10 hours
- WTP throughput may be rheologically limited due to high rheological properties at design solids concentrations
  - This situation should be anticipated integrated into the baseline plan
- More information at http://www.pnl.gov/rpp-wtp/

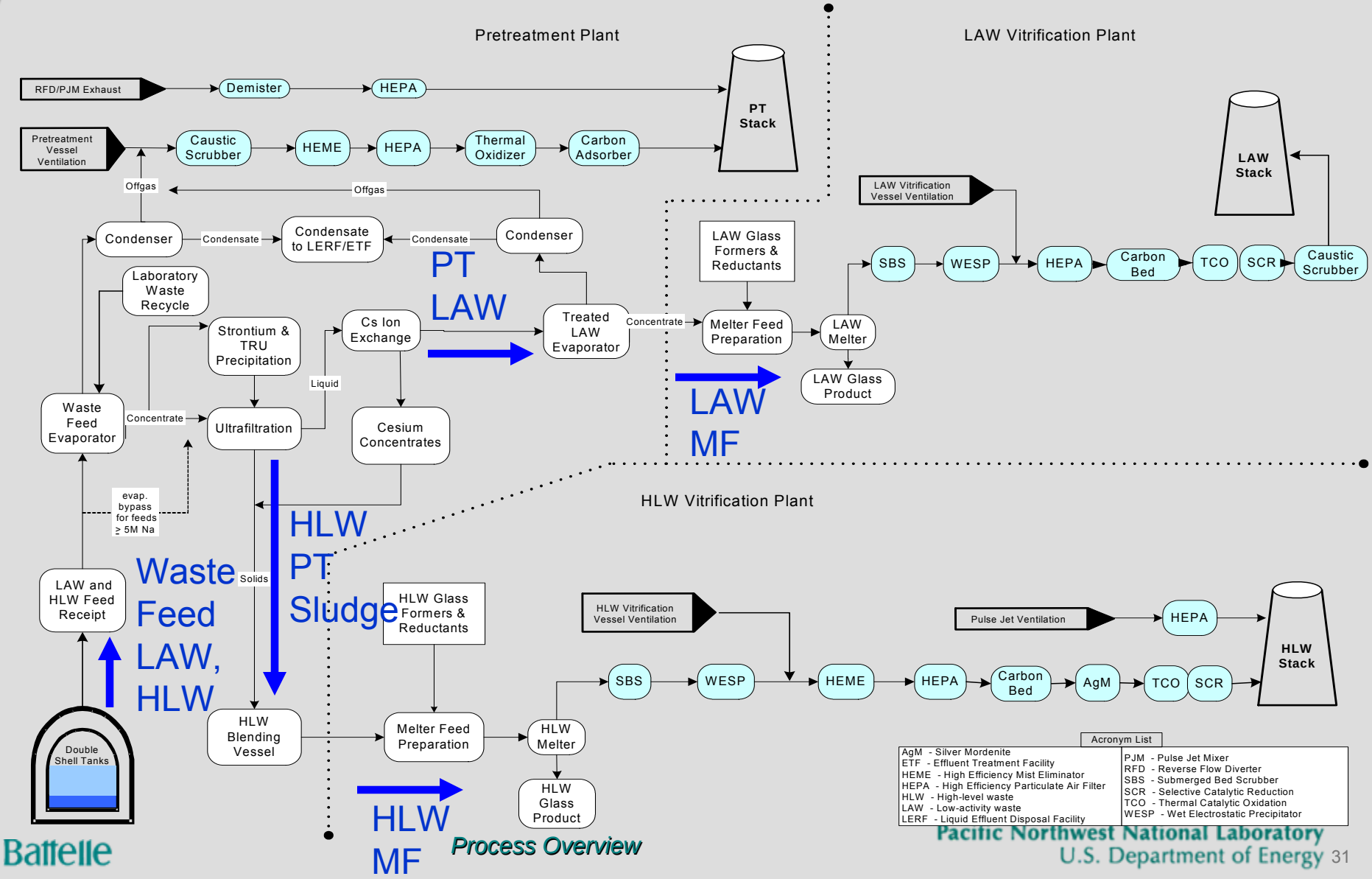
Hanford Sludge Processing

Adam Poloski

Simplified Hanford Waste Process Flow Diagram



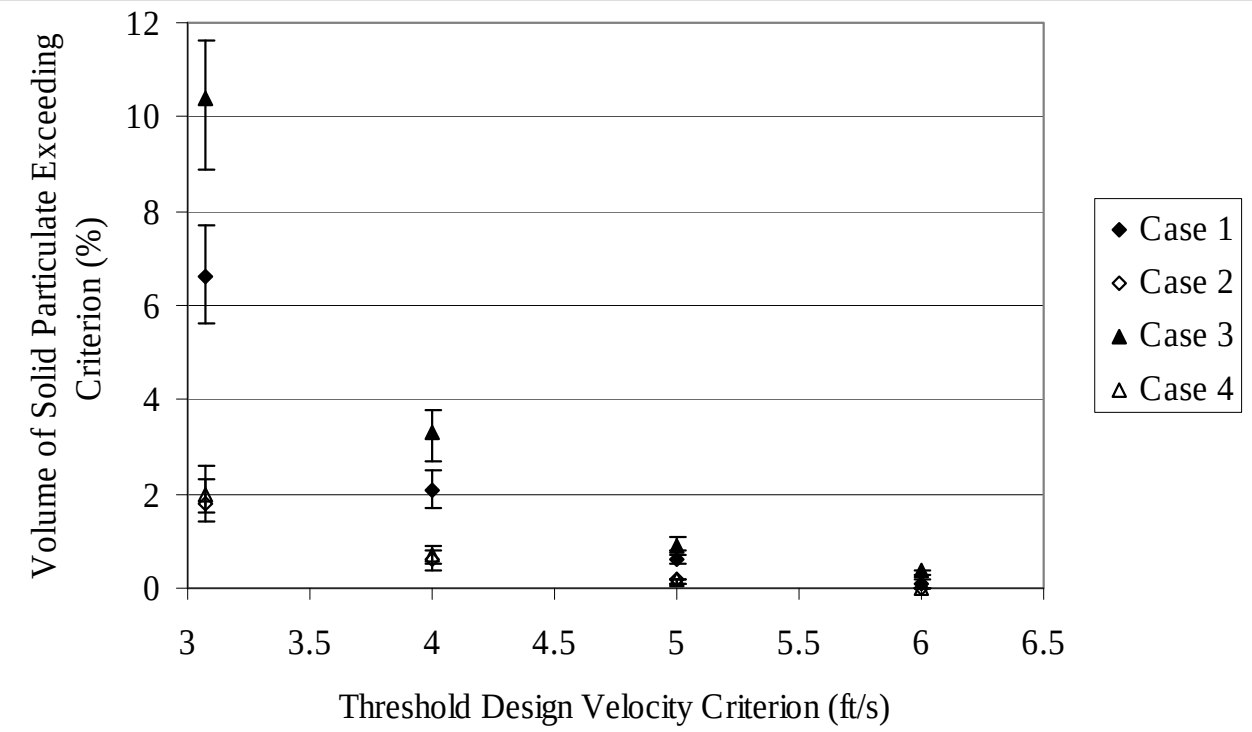
Simplified WTP Process Flow Diagram



Process Overview

Waste Transport – Critical Velocity Calculations

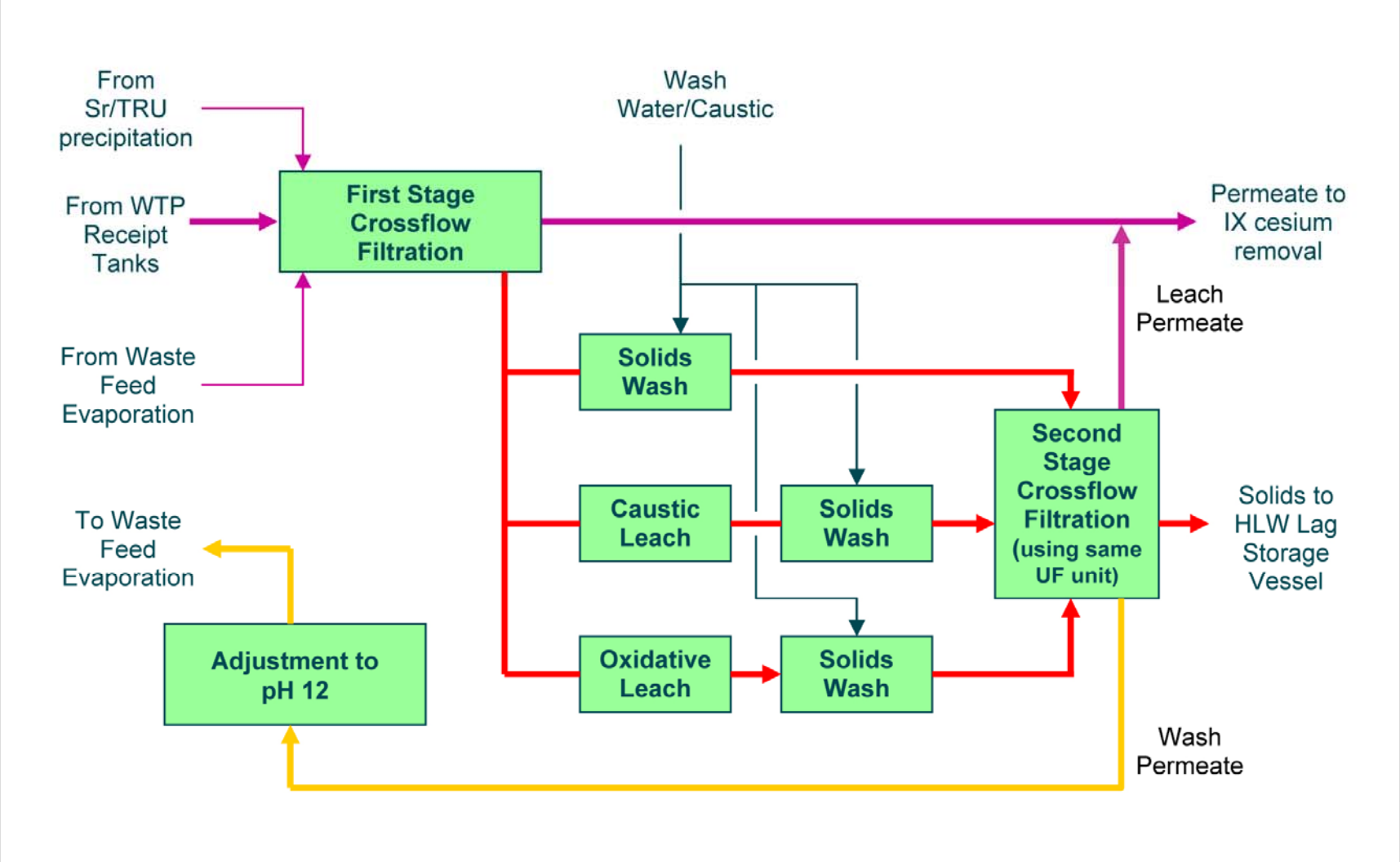
- PSDDs from Monte Carlo results are evaluated
- Oroskar & Turian equation is design basis
- Flow Conditions
  - Pipe diameter = 3 in.
  - Liquid density = 1.2 g/mL
  - Liquid viscosity = 2 cP
  - Mass fraction of solids in flow = 0.154
- Up to 3% of sludge by volume may form a stationary bed in process piping at 4 ft/sec
  - 3.1 ft/sec is WTP design velocity
  - 4 ft/sec with design margin (+30%)
  - Represents 400,000 gallons of sludge
- Experimental flow loop program in place to test Hanford size/density particle scenarios in carrier slurries
  - Complex process geometries
  - line unplugging of chemical precipitates



Critical Velocity Calculations, Case 1 at 3.1 ft/s

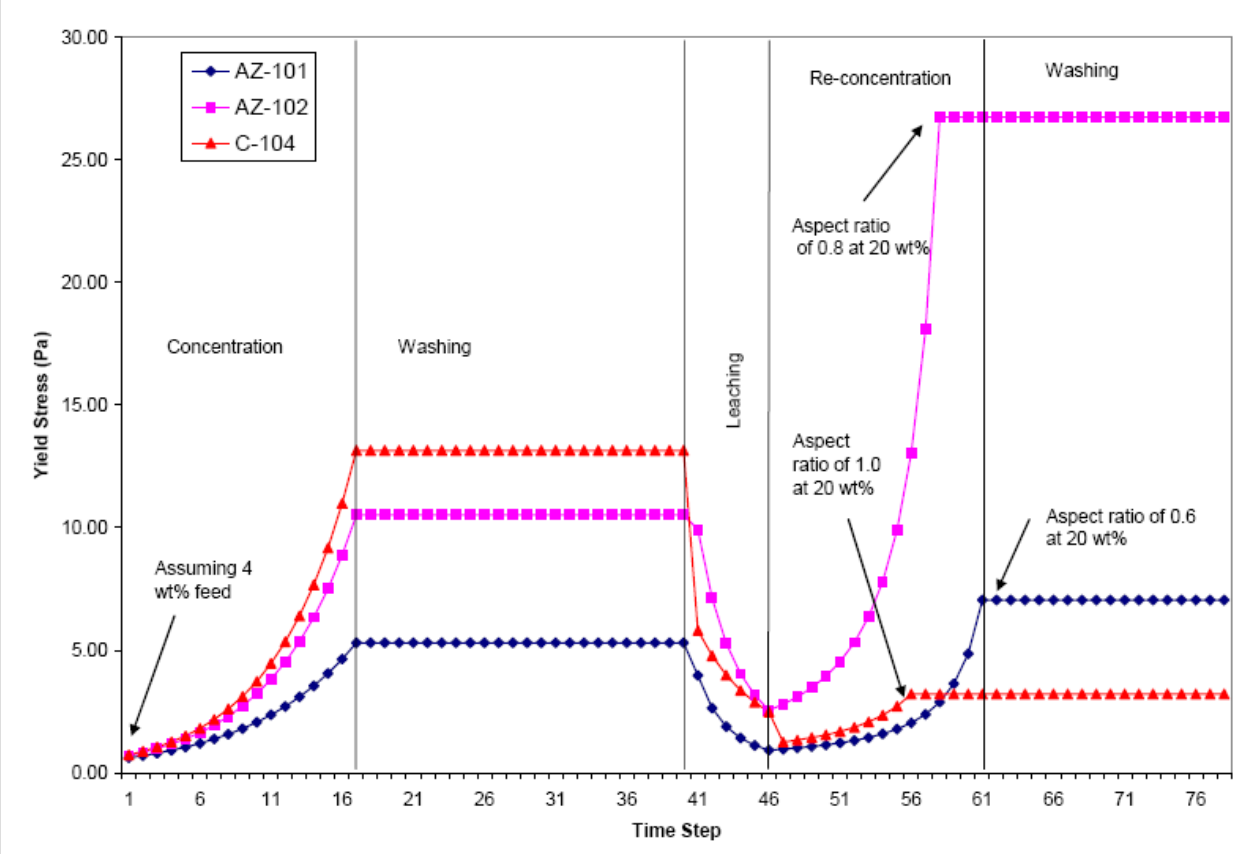
Solid-Phase Compound	Density, g/mL	Representative Case 1 PSDD Volume %	Percent Exceedance
$Al(OH)_3$, Gibbsite	2.42	51.5	1%
$(NaAlSiO_4)_6 \cdot (NaNO_3)_{1.6} \cdot 2H_2O$	2.365	16.6	1%
AlOOH, Boehmite	3.01	10.6	4%
$NaAlCO_3(OH)_2$	2.42	9.5	1%
Fe_2O_3	5.24	4.1	69%
$Ca_5OH(PO_4)_3$	3.14	2.0	7%
$Na_2U_2O_7$	5.617	1.6	74%
ZrO_2	5.68	1.1	74%
Bi_2O_3	8.9	0.81	100%
SiO_2	2.6	0.69	1%
$Ni(OH)_2$	4.1	0.55	31%
MnO_2	5.026	0.54	64%
CaF_2	3.18	0.23	7%
$LaPO_4 \cdot 2H_2O$	6.51	0.13	89%
Ag_2CO_3	6.077	0.0094	81%
PuO_2	11.43	0.0013	100%

Leaching & Filtration PFD



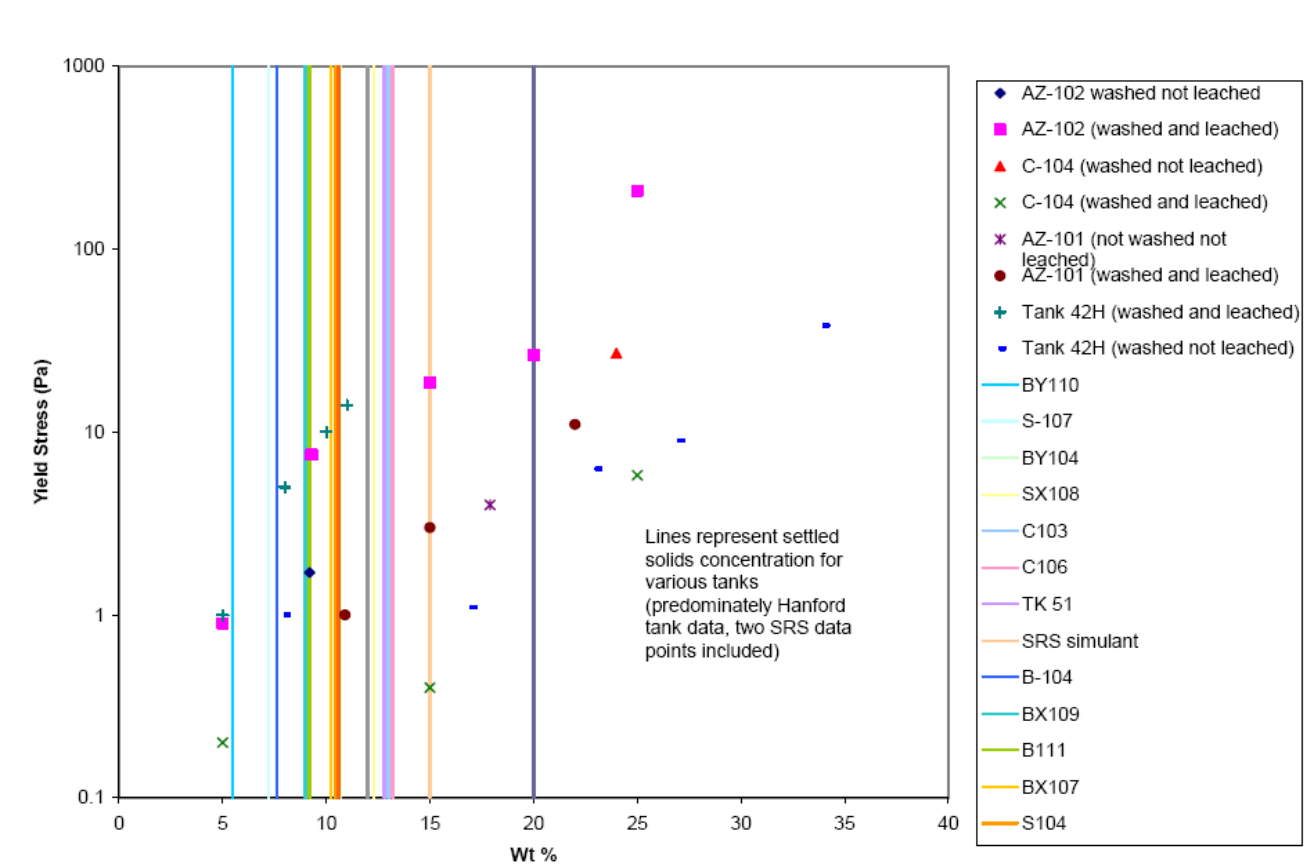
Filtration and Leaching – Predicted Bingham Yield Stress Changes During Leaching and Filtration

- This figure is based on the following set of assumptions.
  - That the feed is initially concentrated to 20 wt% UDS at 17,000 gallons
  - That washing has little impact on yield stress
  - That 5,000 gallons is added during leaching
  - That the changes in rheology caused by leaching occur immediately, before any significant solids dissolution occurs
  - That all the observed dissolution occurs during the leaching process
  - That the waste is concentrated to 20 wt% UDS after leaching.
- Data not available on how rheological properties will change through this process
  - PSD, shape, ionic strength, pH, all vary throughout this process



Comparison of gravitational sedimentation to ultrafilter concentration

- Target solids concentration is 20 wt% during filtration & leaching
- Assumes that maximum wt% solids under gravitational settling conditions ∝ maximum packing fraction
- Dewatering past point achievable due to gravitational sedimentation
- Estimate that 20-30% of HLW waste tanks may exceed 30 Pa yield stress bound during filtration and leaching
- Values of 100 Pa yield stress observed during leaching/filtration
  - Under BNFL
  - Recently under M-12
- Small scale: Moyno pump and mechanical agitators
- Process scale: Centrifugal pump and PJMs
- Large
- More data needed to reduce risk



Process Mixing

- Mixing and suspension of particles in Newtonian and non-Newtonian fluids
- Mechanical agitators, pulse jet mixers (PJMs for bottom of tank), and air spargers (top of tank) utilized for mixing
- Data indicates that sufficient mixing can occur in non-Newtonian fluids with this technique
- Ongoing experimental programs to investigate Newtonian systems
  - Cloud heights
  - Just suspended velocities
  - Blend times

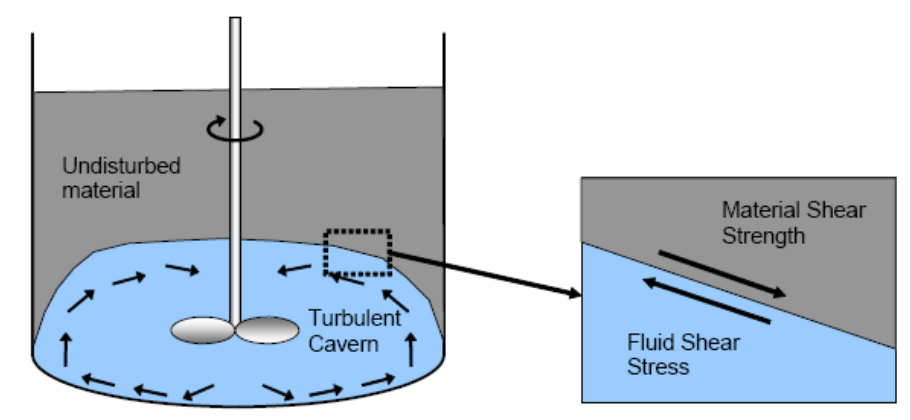


Figure 1.2. Illustrating Cavern Formation in Non-Newtonian Waste

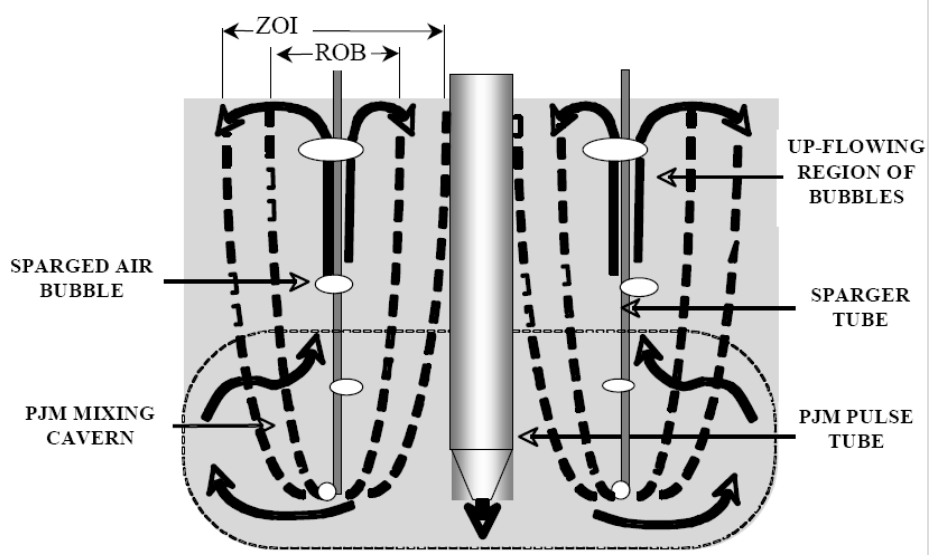


Figure 1.1. Illustration of Hybrid PJM/Sparger Mixing Concept

Gas Retention and Release

- Flammable gases are generated due to thermolysis and radiolysis
- During outages gas holdup will increase in non-Newtonian fluids
- Experimental programs have investigated gas retention and release dynamics under these scenarios
- Antifoam agent changed hold-up values
- Experimental results indicate that
  - Retrained gas released quickly after mixing
  - Minimal buildup of retrained gas through "intermittent operation"

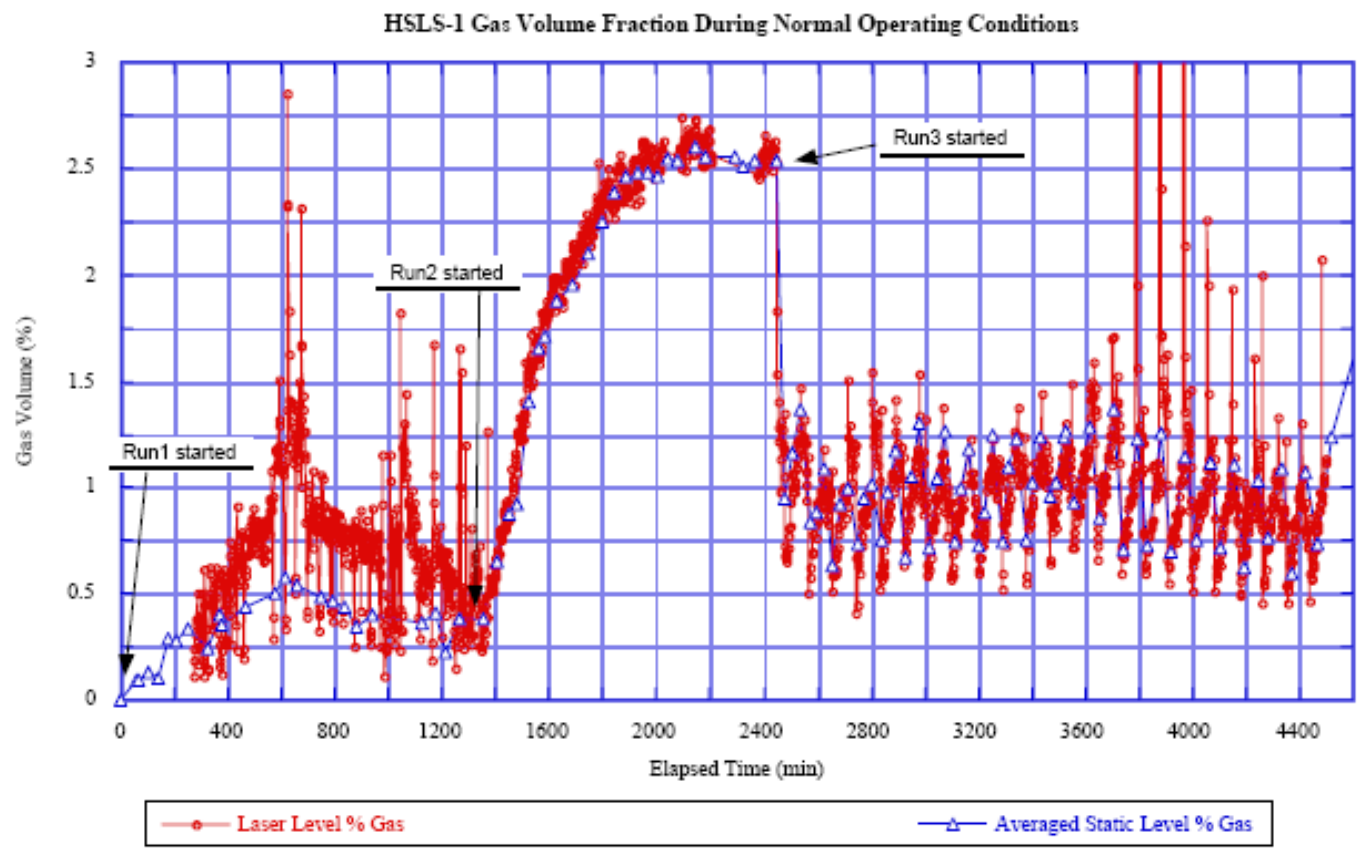


Figure 6.8. Gas Volume Fraction During HSLS-1

Pretreated LAW

- Viscosity of actual waste permeate after washing and leaching
- Limit of 15 cP placed for pumping through IX bed
- IX resin handling issues
  - Saturated conditions exist while processing through IX bed
  - IX resin swells under varying chemical conditions

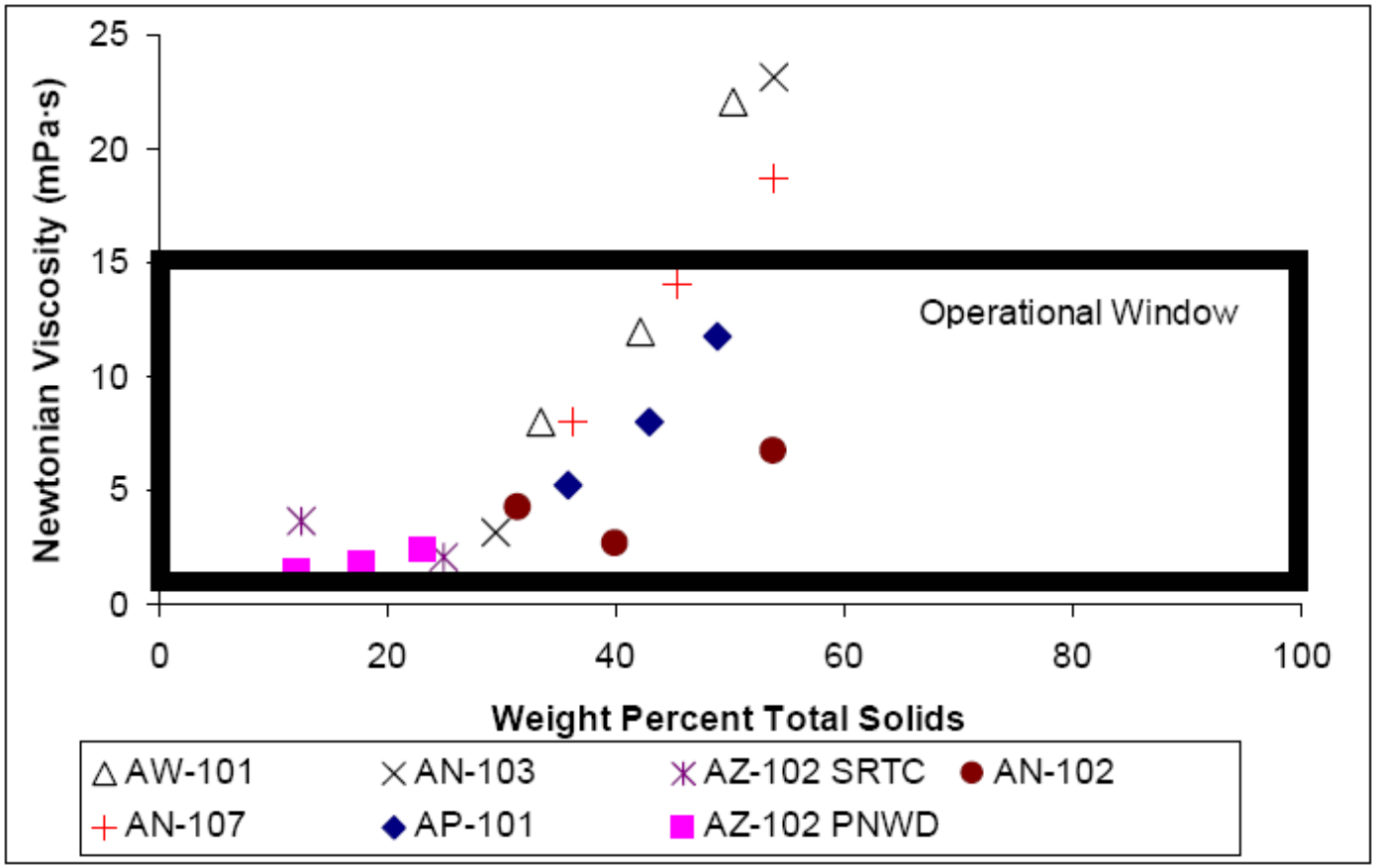


Figure 4.14. Comparison of Actual Data to Proposed Bounding Conditions as a Function of Weight Percent Total Solids for Pretreated LAW at 25°C

Melter Feeds

- Glass Former Chemicals added to pretreated waste feeds prior to vitrification
- Dry solids handling issues very different from slurry handling
- SRNL performed a large amount of work in this area

Table 4.1. Settling Information on Glass-Former Chemicals

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

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

LAW Melter Feed Rheology

- Rheology dominated by large quantities of glass former chemicals
- Properties tend towards a characteristic curve
- Processing limits established at 100 cP and 20 Pa yield stress

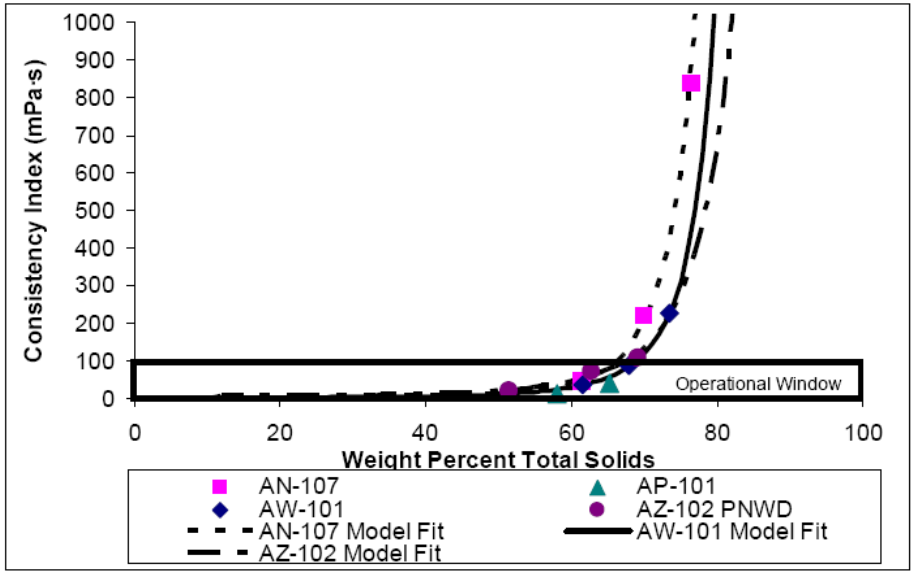


Figure 4.17. Bingham Consistency Index as a Function of Weight Percent Total Solids for LAW Melter Feed at 25°C

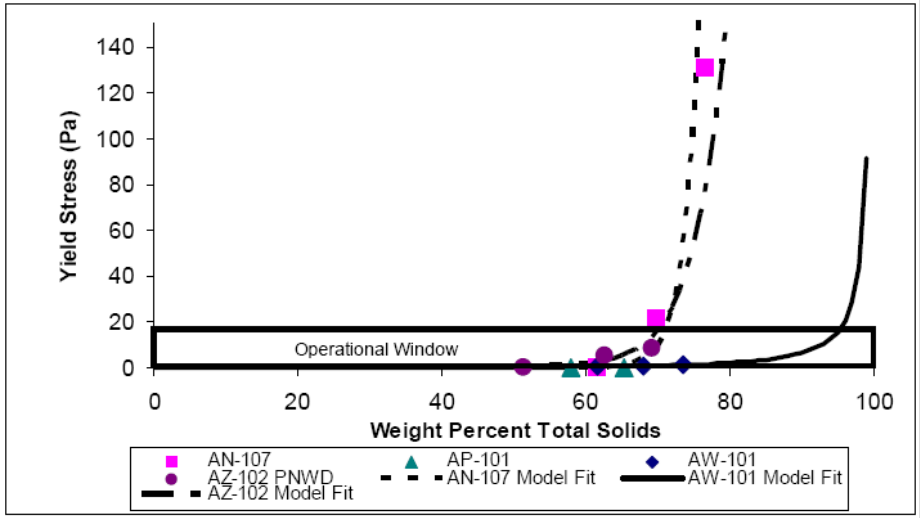


Figure 4.18. Bingham Yield Index as a Function of Weight Percent Total Solids for LAW Melter Feed at 25°C

Affects of aluminate precipitation on pretreated LAW

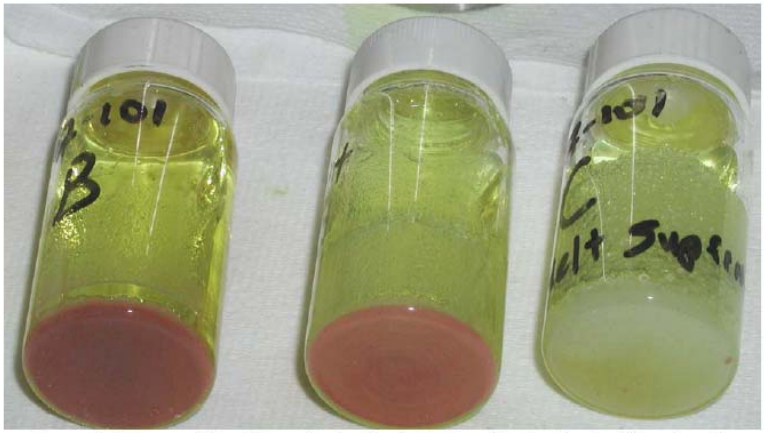
- Boric acid addition
- pH drops
- Aluminate precipitation
- Particle bridging results in high shear strengths

Table 5.2. Summary of Shear Strength Data at 40°C

Sample	Temp.	Shear Strength (Pa)		
		Run 1[a]	Run 2	Run 3
1.75 M Na	40°C	2,430	>11,600	>18,600
2,75 M Na	40°C	>11,600	>11,600	n/a
3.75 M Na	40°C	950	>11,600	n/a

n/a – not applicable

a, samples partially agitated



note: precipitates are white solids; red coloration is due to residual melter feed from decanting

Figure 5.5. Crystalline Precipitate Observed from Decanted AZ-101 Envelope B Melter Feed

a) Settled solids layer when tilted to one side.

b) Settled solids layer before mixing.

c) Settled solids layer during mixing.

Figure 5.6. High Shear Strength of AZ-101 Envelope B Melter Feed During Mixing

HLW Melter Feed

- Rheological properties of actual HLW melter Feed
- Similarly dominated by large quantities of GFCs

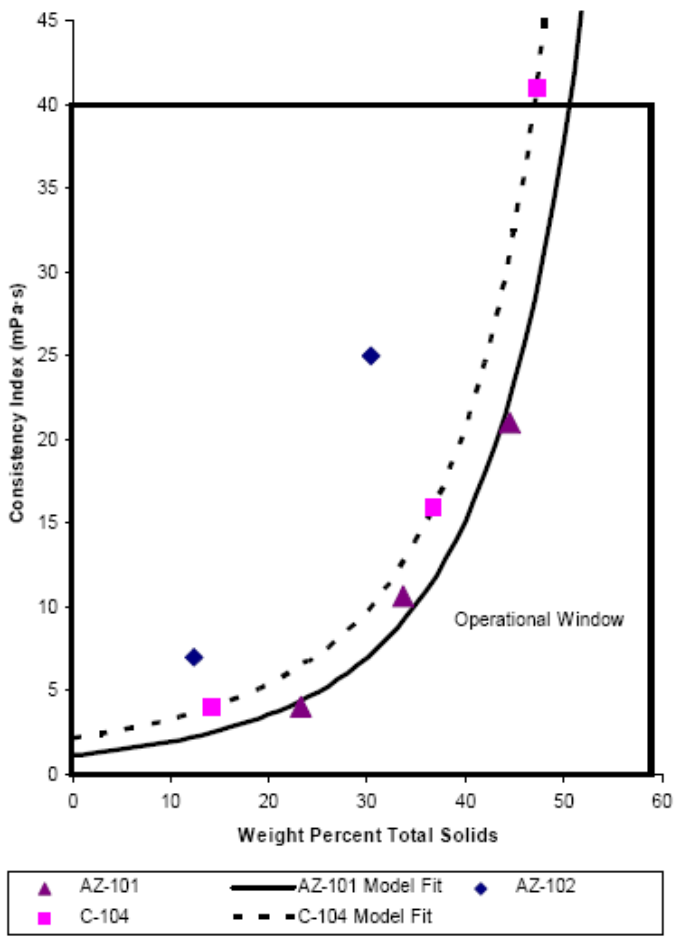


Figure 4.15. Bingham Consistency Index as a Function of Weight-Percent Total Solids for HLW Melter Feed at 25°C

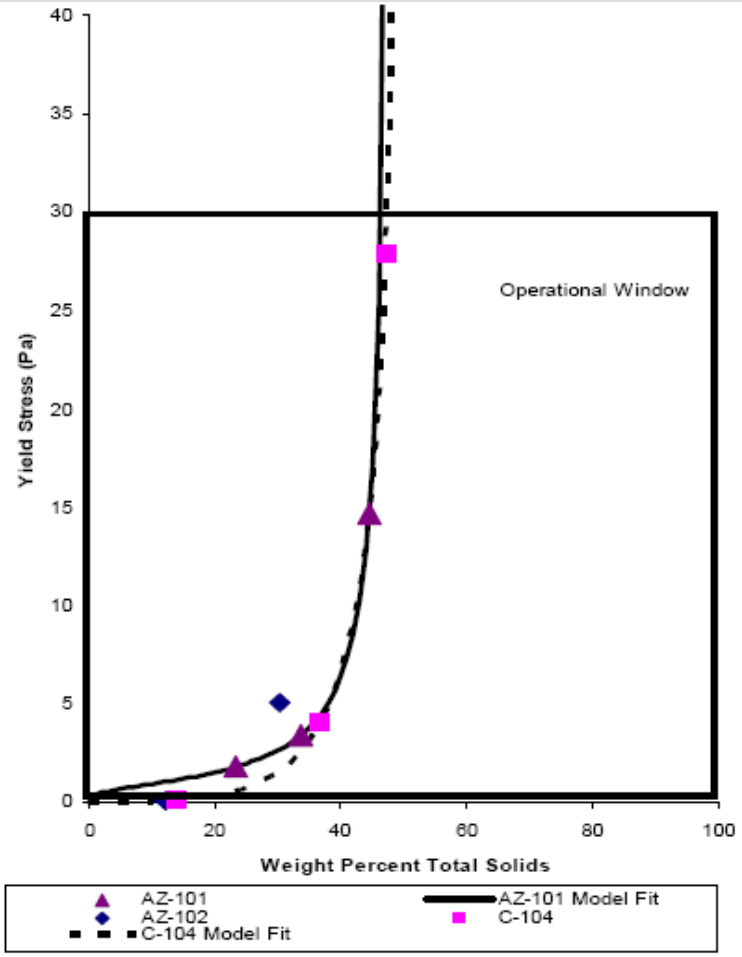


Figure 4.16. Bingham Yield Index as a Function of Weight-Percent Total Solids for HLW Melter Feed at 25°C

LAW Slurry Stream Summary

Table 3.4. Summary of Appendix A Database

Property	LAW Pretreated Waste	LAW Melter Feed
Chemical Composition	varies (see Appendix A)	varies (see Appendix A)
pH	~14	7–14[a]
Particle-Size Distribution (PSD)	n/a	<164 μm
Heat Capacity	n/a	n/a
Bulk Density	1.1–1.5	1.7–1.9
Supernatant Liquid Density	1.1–1.5	1.2–1.6
Vol % Settled Solids	0%	50%–100%
Settling Rate	n/a	n/a
Centrifuged Solids Density	n/a	n/a
Vol % Centrifuged Solids	n/a	n/a
Wt % Centrifuged Solids	n/a	n/a
Wt % Oven Dried Solids	n/a	n/a
Wt % Total Dried Solids	20%–60%	60%–75%
Wt % Undissolved Solids	n/a	n/a
Shear Stress Versus Shear Rate ambient and 40°C	Newtonian	Bingham Plastic
Shear Strength	n/a	n/a
Wt % total oxide	15%–30%	25%–35%

a - addition of acidic GFCs will drop the pH of the LAW pretreated waste this drop in pH can precipitate amphoteric species such as aluminum hydroxide. Aluminum hydroxide precipitation can result in relatively high rheological parameters and processing difficulties.

HLW Slurry Stream Summary

Table 3.3. Summary of Appendix A Database

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

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

Summary

- Waste processing will significantly change all important slurry attributes
  - PSD, density, solids concentration, ionic strength, temperature, pH, zeta potential, particle shape
- Each major waste stream should be fully characterized under these conditions and data supplied to design team
- Waste feed batching complicates this process
- Very limited data exists on the affects of:
  - waste processing on slurry properties
  - slurry properties on waste processing