PNL-10153

Summary Letter Report

Laboratory Testing
In-Tank Sludge Washing

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September 1994

Prepared for Westinghouse Hanford Company
and the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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1.0 Introduction

In-tank washing is being considered as a means of pretreating high-level radioactive waste sludges, such as neutralized current acid waste (NCAW) sludge. For this process, the contents of the tank will be allowed to settle, and the supernatant solution will be decanted and removed. A dilute sodium hydroxide/sodium nitrite wash solution will be added to the settled sludge and the tank contents will be mixed with a mixer pump system to facilitate washing of the sludge. After thorough mixing, the mixer pumps will be shut off and the solids will be allowed to re-settle. After settling, the supernatant solution will be withdrawn from the tank, and the wash cycle will be repeated several times with fresh wash solution.

Core sample data of double shell tank 241-AZ-101 indicate that settling of NCAW solids may be very slow. A complicating factor is that strong thermal currents are expected to be generated from heat produced by radionuclides in the sludge layer at the bottom of the tank. Additionally, there are concerns that during the settling period (i.e., while mixing pumps and air-lift re-circulators are shut off), the radionuclides may heat the residual interstitial water in the sludge to the extent that violent steam discharges (steam bumping) could occur. Finally, there are concerns that during the washing steps sludge settling may be hindered as a result of the reduced ionic strength of the wash solution. To overcome the postulated reduced settling rates during the second and third washing steps, the use of flocculants is being considered.

To address the above concerns and uncertainties associated with in-tank washing, PNL has conducted laboratory testing with simulant tank waste to investigate settling rates, steam bump potential, and the need for and use of flocculating agents.

2.0 Scope

Laboratory tests were conducted to simulate the effects of radiological heating and in-tank washing on the settling behavior of NCAW simulant. The settling tests were performed in two 7-gallon pyrex vessels with each containing 5 gallons of simulant. One vessel was equipped with a heating element to simulate radiological heating. The second vessel was not equipped with a heat source, and relative comparisons of settling rates and supernatant suspended solids concentrations, for heated and ambient NCAW simulant, were made. The experimental set-up was also used to evaluate the potential of the settled sludge to retain steam bubbles which could initiate steam bumping. Additionally, the NCAW simulant solids were analyzed for zeta potential and particle size distribution in order to facilitate the selection of potential settling aids (coagulants and/or flocculants), if the results of the settling tests indicated they were necessary.

It is expected that settling rates obtained from this laboratory testing cannot be directly scaled to estimate settling rates in the actual tanks. However, testing in the laboratory set-up was done with and without heating to determine the relative effects of the radiolytic heating. Additionally, results from the laboratory tests can be used to verify and test computer simulation models of tank settling behavior.

3.0 Conclusions and Recommendations

3.1 Conclusions

The simulated radiological heating did not hinder the settling rates of the NCAW simulant solids. In fact, heating enhanced the settling rates of the simulant. The average initial settling rates for the heated and unheated unwashed simulant were 2.43 and 0.93 cm/hr, respectively, indicating that the simulated radiological heating doubled the initial settling rate. In subsequent testing with washed simulant, heated washed simulant also settled more rapidly than washed simulant at ambient temperatures.

The results of the sludge washing tests showed than even after undergoing three wash cycles, the simulant solids settled quickly. This indicates that it is unlikely that settling aids (coagulants and flocculants) will be required to achieve desired settling rates.

The turbidity measurements of the clarified supernatant for both unwashed and washed NCAW simulant were very low, indicating that the settling process produced essentially a particle free supernatant. For some of the tests conducted, a turbidity reading of zero was achieved in the supernatant after several wash cycles.

The laboratory results showed that steam bumps did not occur even when the boiling point (104°C) of the simulant was achieved in the bottom of the settled sludge layer.

3.2 Recommendations

A continuation of these laboratory tests is recommended to provide additional support for modeling and full-scale design of in-tank processing efforts.

One of the primary objectives of the sludge washing process is to remove trapped interstitial salts in the solids/sludge fraction of the tank waste reducing the amount of high-level solids awaiting vitrification. In order to evaluate the efficacy of salt removal from the sludge washing experiments conducted in FY93, a compositional analysis of the original and washed NCAW simulant should be performed. Cation and anion analyses should be conducted on the original NCAW simulant and samples collected from the three washes conducted in FY93. In addition to cation/anion analyses, zeta potential and particle size distribution should be determined to gain an understanding of the physical/chemical mechanisms that are influencing the settleability of the simulant.

Currently, the settleability of washed NCAW simulant has been investigated. However, the mixing conditions of the proposed full-scale mixer pumps were not simulated in the FY93 testing. Therefore, the impacts of the mixer pump mixing conditions on simulant settleability should be investigated. Before this testing can commence, PNL must be provided with an estimate of the expected shear rate of the mixing pumps in order to effectively simulate the mixing conditions for lab-scale testing.

Work conducted in FY93 involved NCAW simulant. Similar settling investigations with other tank waste stimulants of different compositions should be conducted in FY94. Tank C-106 is of particular interest because it is a high-heat single-shell tank that is expected to be sluiced into an awaiting double-shell tank for possible in-tank reprocessing. Therefore, settling tests of tank C-106 waste simulant is of interest. However, this testing requires that a composition and a recipe for the C-106 simulant be provided. Once a well characterized simulant is provided, settling tests should be conducted similar to the NCAW simulant testing completed in FY93.

4.0 Experimental Methods

4.1 Overall Approach

Settling velocity and turbidity were the essential parameters measured to evaluate the settling behavior of the simulant NCAW tank waste. These parameters were measured both with and without simulated radiological heating, for unwashed and washed NCAW simulant. Testing was conducted in two test vessels containing equal volumes of NCAW simulant, each with the same solids concentration. The test vessel designated to simulate radiological heating contained a heating element that was operated at the required heat flux to simulate the actual heat flux in double shell tank 241-AZ-101. The ambient temperature test vessel did not contain a heat source. Thus, a comparison of settling test results for each vessel was the approach used to isolate the effects of heat on the simulant settleability. Comparisons of settling test results were also made between unwashed and washed simulant to determine the effects of washing on solids settleability.

During each settling test, the heated vessel was monitored for a steam bump potential. Hence, separate steam bump potential tests were not required.

4.2 Experimental Set-Up

4.2.1 NCAW Simulant

Approximately 30 gallons of surplus NCAW simulant from the Retrieval Erosion Corrosion Program was acquired for this work. This simulant was made in Westinghouse Hanford Company's (WHC) Chemical Engineering Laboratory under the direction of BD Bullough. Because the surplus simulant had been stored for several years, its composition and particle size distribution were determined and the results were compared to data obtained from tank 241-AZ-101 core samples (Gray, et al., 1991). The comparison indicated that the surplus simulant matches closely with the core sample data. Provided below is the original composition and recipe for the NCAW simulant (Elmore, et al., 1990).

- Add to 30 gal (~115 L) of water and mix until dissolved:

$NaNO_3$	5.33 kg
$Al(NO_3)_3 9H_2O$	90.89 kg
$Fe(NO_3)_3 9H_2O$	12.40 kg
$Fe_2(SO_4)_3 9H_2O$	8.99 kg
$Cr(NO_3)_3 9H_2O$	1.82 kg
SiO_2	0.19 kg

$Ni(NO_3)_2 6H_2O$	7.04 kg
$ZrO(NO_3)_2$	0.46 kg

- Then add:

HNO_3 (70% sol'n)	12.05 L
H_2SO_4 (98.6% sol'n)	2.57 L
HF (50% sol'n)	1.72 L

- Over 8 hr (beginning at ~92-95°C) slowly meter in ~25 L of sucrose solution (6.64 kg sucrose and 48 g NaOH in 23.54 L H_2O).

- Add makeup water to maintain level of 250 L (~66 gal), digest at a minimum temperature of ~50-60°C, then "neutralize" to pH~13 with (19 M NaOH) caustic solution.

- Add K_2CO_3 (3.15 kg).

- Add H_2O as needed to bring mixture to 100 gal (~380 L).

- Boil for 5 days then store at ~40°C until shipment to PNL for erosion-corrosion test.

4.2.2 Settling Vessels

Two circular, flat-bottom glass vessels were used to contain the NCAW simulant for all of the laboratory testing. The vessels were made of pyrex and had a 7-gallon capacity (12 in. O.D. and 18 in. high). Each vessel was marked with centimeter graduations on its outside wall to monitor the position of the solid/liquid (S/L) interface during a settling test. The graduations were referenced to the inside bottom the vessel so the S/L interface height was the distance (cm) above the inside bottom of the vessel.

Figure 1 illustrates the experimental set-up for the two vessels. Each vessel contained 5 gallons of NCAW simulant. Vessel #1 contained the heating element while contents of vessel #2 were kept at ambient temperature. Vessel #2 is shown with a typical S/L interface height measurement.

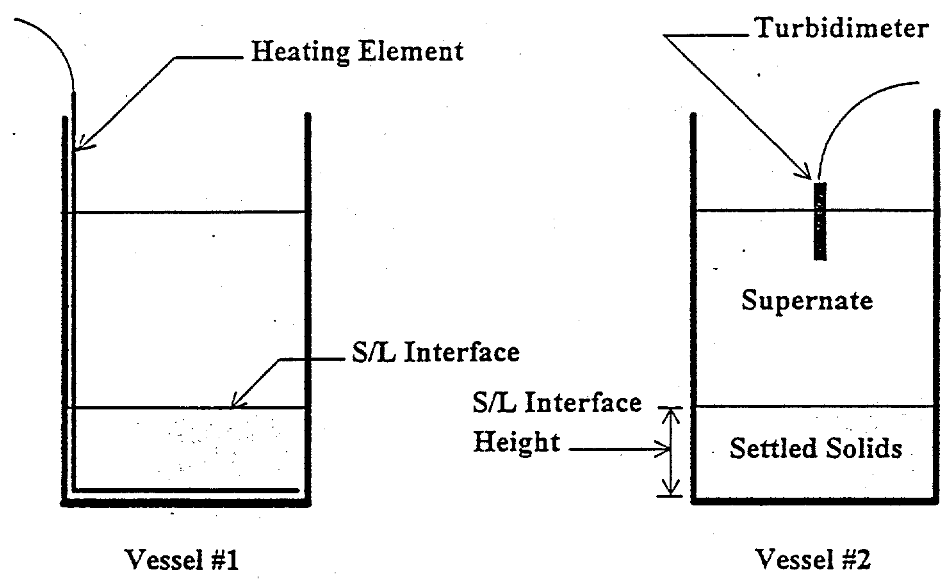

Figure 1. Experimental Set-Up

4.2.3 Simulated Radiological Heating

To simulate the heat generated from a radioactive sludge layer, a Watlow flat spirally coiled heating element (O.D. 11 in.) was used. The element was constructed from a 0.125 in. diameter cable heater approximately 200 in. length. The cable heater was protected with a 304 stainless steel sheath. The rating of the element at 120 volt at 0.6 amp is 73 watts or 0.93 watts/in^2. At 34 volt, 0.2 amps, the heater will put out 6 watts for a flux of 0.08 w/in^2. The output of the heater was controlled with a rheostat.

The element configuration was constructed so the coil rested flush on the bottom of Vessel #1 (see Figure 1). The heating element coils were spaced evenly to ensure a uniform heat flux along the bottom of the vessel. The outside wall and bottom of Vessel #1 were wrapped with two layers of insulation to minimize heat loss through the pyrex. Both vessels were covered to minimize evaporation.

4.3 Experimental Design

All of the test runs performed for this task were conducted using the experimental set-up illustrated in Figure 1. Settling tests for each vessel were conducted concurrently for each test run. 10 gallons of NCAW simulant was used with each vessel containing 5 gallons. To ensure a consistent simulant solids concentration in each vessel, the 10 gallons of simulant was homogenized in a large carbuoy using a drum pump. As the simulant was being homogenized, equal quantities of the carbuoy contents were pumped into each vessel, simultaneously.

According the Westinghouse Hanford Company (WHC) tank farm data, tank 241-AZ-101 supernatant has a uniform temperature of 60°C. In order to simulate this temperature condition for each test run, a heating period was required for Vessel #1 to achieve a uniform temperature of 60°C for the vessel contents. The heating period was initiated by mixing the vessel contents and submerging the heating element. The element was then turned on and operated at full power (72 watts). The vessel contents were periodically mixed to achieve a uniform temperature. The temperature was monitored using five thermocouples placed at fixed positions in Vessel #1. The thermocouples were held in place using the vessel cover, and temperature readings for each thermocouple were recorded with a data logger. The vertical locations of the thermocouples ranged from 1.5 cm above the heating element to 5 cm below the surface of the supernatant. Once the heating period for Vessel #1 was completed, the settling tests for both vessels were initiated.

4.3.1 Settling Tests for Unwashed NCAW Simulant

The first two test runs performed for this task were conducted on unwashed NCAW simulant. The second test run repeated the test conditions of the first test run in order to verify the reproduciblilty of the results. These two test runs were designated Run 1 and Run 2. A test run was initiated by mixing the contents of both vessel to establish identical conditions (i.e., completely mixed NCAW simulant) at time zero. The vessels were then covered to minimize evaporation and the completely mixed simulant was allowed to settle quiescently. The settling behavior of both vessels was monitored by tracking the position of the S/L interface over time. The downward movement of the interface as a function of time was used to determine the settling velocity of the simulant solids. The settling period was terminated when the settling velocity approached zero. Typical settling periods lasted 10 days. Temperature was monitored in both vessels for the duration of the settling period. The turbidity of the clarified supernatant at the designated vertical positions was monitored as a function of time in order to evaluate the particle removal efficiency of the clarified liquid during the settling period. At the start of each settling period, when each vessel contained completely mixed simulant, 40-mL aliquots of simulant were taken from each vessel for suspended solids analysis to verify the solids concentration of each vessel for each test run. Aliquots from each vessel were also taken at the beginning of the heating period. This provided suspended solids data for ambient and heated Vessel #1 simulant for comparison. Also, suspended solids data for two aliquots of Vessel #2 simulant for each test run was obtained to verify the reproducibility of the suspended solids analysis.

4.3.2 Settling Tests for Washed NCAW Simulant

After the unwashed NCAW simulant settling tests were completed, three consecutive simulated sludge washes were conducted using the same five gallons of simulant in each vessel. These sludge washes were designated Wash Cycle 1, Wash Cycle 2 and Wash Cycle 3, and they were conducted concurrently in each vessel.

The first step of a simulated wash cycle was to decant the supernatant from each vessel using a peristaltic pump. Clarified liquid was removed until the final level of the supernatant was 1 cm above the S/L interface of the settled sludge. The volume of supernatant decanted was measured and replaced with an equal volume of wash solution so the 5 gallon volume was maintained in each vessel, for each wash cycle. The wash-solution was 0.01 M NaOH and 0.01 M $NaNO_2$. After wash-solution was pumped into the vessels, the contents were mixed for five minutes and aliquots from each vessel were taken for suspended solids analysis. The contents of Vessel #1 was then heated to 60°C, and the test procedure used for the unwashed settling tests was repeated.

A total of five test runs were conducted for this task; two for unwashed and three for washed NCAW simulant. Run 1 and Run 2 were conducted on washed simulant followed by Wash Cycle 1, Wash Cycle 2 and Wash Cycle 3.

4.3.3 Steam Bump Potential

To assess the potential for steam bumping, tank 241-AZ-101 settling period conditions were simulated (i.e., while mixing pumps and air-lift re-circulators are shut off) using Vessel #1. The settling tests conducted on Vessel #1 for each of the five test runs included a settling period similar to the proposed settling period conditions for tank 241-AZ-101. Therefore, for each settling test conducted, Vessel #1 was monitored for entrapped bubbles in the sludge layer and an increase in the total simulant volume (due to steam bubbles retained on the solid particles), along with the temperature gradient generated by the heating element. These qualitative observations were used as possible indicators of potential steam bumping.

4.4 Analytical Methods

4.4.1 Zeta Potential & Particle Size Distribution

The zeta potential determines whether or not the particles exhibit a net positive or negative surface charge. This is important for assessing the the settlability of colloidal size particles that can remain suspended in solution from electrostatic repulsion. If particle repulsion hinders settling, the use of settling aids such as coagulants and flocculants can be implemented. The distribution of particle sizes is important for assessing which physical and/or chemical mechanisms will impact the settling behavior of the solids under investigation.

The zeta potential and particle size distribution analysis of the NCAW simulant was conducted off-site[1]. The zeta potential analysis was conducted using a Malvern Zetasizer II c. The particle size distribution was determined using two different techniques; a centrifugal analysis and a light scattering analysis. The centrifugal analysis required that the density of the particles be known (3.4 gm/cm^3 was used). The light scattering technique was dependent on particle size, and its sensitivity rapidly decreased for particles larger than 1 μm.

4.4.2 Turbidity

Turbidity is a parameter that serves as an indicator for the presence of particles in dilute (i.e., low suspended particle concentrations) solutions. A turbidity meter utilizes a 90 light scattering technique (Nephelometry) that detects light scattered by particles in the sample. Turbidity values are reported in NTUs (Nephelometric Turbidity Units). The degree of scattering is a function of particle size and particle refractive index. Scattering increases with increasing particle diameter. A BTG Inc. probe-style turbidity meter was used for this task. The probe-style meter allowed in-situ turbidity measurements to be taken eliminating the need to extract samples from the test tanks for analysis in a bench-top style

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[1] Work conducted by Dr R. Zollars, proffessor of chemical engineering, Washington State University.

instrument. In-situ measurements minimized handling of the corrosive simulant (pH~13) during testing and alleviated potential experimental errors associated with extracting representative samples from the same locations at designated time intervals.

During each setting test, turbidity measurements in each vessel's supernatant were taken at various depths (i.e., between the surface level of the supernatant and the S/L interface). Each measurement location (i.e., distance above vessel bottom in cm) was assigned a position number as follows:

#1	29.5 cm
#2	23 cm
#3	18 cm
#4	13 cm

Because the turbidimeter is a light scattering device, the face of the probe could not be positioned near a reflective surface (i.e., the inside wall of the pyrex vessels and the S/L interface). When the probed was placed closer than 5 cm to a reflective surface, the meter gave false-high readings. Therefore, all of the turbidity measurements were taken at the center of each vessel to prevent reflective interferences from the side walls. Also, for the duration of a settling test, the number of measurements taken at each vertical position was dependent on the probe's proximity to the S/L interface to prevent the same type of interference.

The turbidimeter had a linear working range of 0 to 1000 NTUs and it was calibrated with 20 NTU and 200 NTU formazin standards. De-ionized water was used as the 0 NTU standard. Several NCAW simulant standards were also used to correlate NTUs to simulant suspended solids concentration. A sample of completely-mixed (homogeneous) NCAW simulant was used to make the turbidimeter standards. Four standards, 1x, 1.33x, 2x, 4x, were made by diluting the homogeneous sample with NCAW supernatant. A fifth standard was made up of supernatant only. After calibrating the turbidimeter with the formazin standards, the simulant standards were measured. The 1x , 1.33x, and 2x standards had solids concentrations that exceeded the working range of the meter. The average turbidity values of the 4x and supernatant standards were 270 and 5 NTUs, respectively. The suspended solids concentration of the 4x standards was determined experimentally and equaled 0.95% (by mass-dry weight of the solids). Thus, turbidity measurements of diluted NCAW simulant, based on a formazin standards calibration, correlated 270 NTUs equal to a solids concentration of 9500 ppm.

4.4.3 Suspended Solids

A Millipore vacuum filtration apparatus and 0.45-µm filters were used to determine the suspended solids (SS) concentrations of the aliquots taken from each test run. This technique determined the SS concentration by mass ratio (ppm or weight percent) using the dry weight of the solids collected on the 0.45-µm filter. A modified version of Standard Method 2540 D was used (APHA 1992).

5.0 Results

5.1 Characterization of NCAW Simulant

5.1.1 Zeta Potential

The zeta potential analysis was conducted on a sample of completely mixed (homogeneous) NCAW simulant. The analysis required low suspended solids concentrations so the homogeneous sample was diluted. Four separate diluted samples were made and each were analyzed five times. The first sample was diluted with NCAW simulant supernate. The second and third samples were diluted with a combination of supernate and aNaOH solution. The fourth sample was diluted with only the NaOH solution. The NaOH (approximately pH 12 and 0.01 M) was included as sample diluent in order to determine the impacts of the sludge washing on the zeta potential of the washed solids. The average zeta potential values are tabulated in Table 1.

Table 1. Zeta Potential Analysis of NCAW Simulant

Supernate to NaOH Mixture	Average Zeta Potential (mV)
100%:0%	12.24
50%:50%	8.84
25%:75%	-4.08
0%:100%	-18.57

The analysis results indicate that the unwashed NCAW simulant solids exhibit a net positive surface charge of 12.24 mV. However, this surface charge was reversed as the concentration of NaOH in the diluent increased. A charge reversal of 12.24 to -18.57 mV occurred.

5.1.2 Particle Size Distribution

The centrifugal and light scattering analyses indicated an average particle size of 2.70 and 2.24 µm, respectively. The reasonable agreement of the average particle size values suggested that the 3.44 gm/cm^3 density used for the centrifugal analysis is close the actual density of the NCAW simulant solids. The majority of the particles are in the 1 to 5 µm range with a significant tail down to about 0.1 µm.

5.1.3 Boiling Point & Density

The boiling point of the simulant was determined experimentally using a sample of supernate. The experimental results indicated that the boiling point is 104°C. The density of a completely mixed NCAW simulant was also determined experimentally and found to be 1.23 gm/cm^3.

5.2 Effect of Simulated Radiological Heating on Unwashed NCAW Simulant

5.2.1 Run 1

Figure 2 contains the settling curves for both vessels resulting from Run 1. The data is tabulated in Tables A.1 and A.2 of the Appendix for Vessel #1 and Vessel #2, respectively.

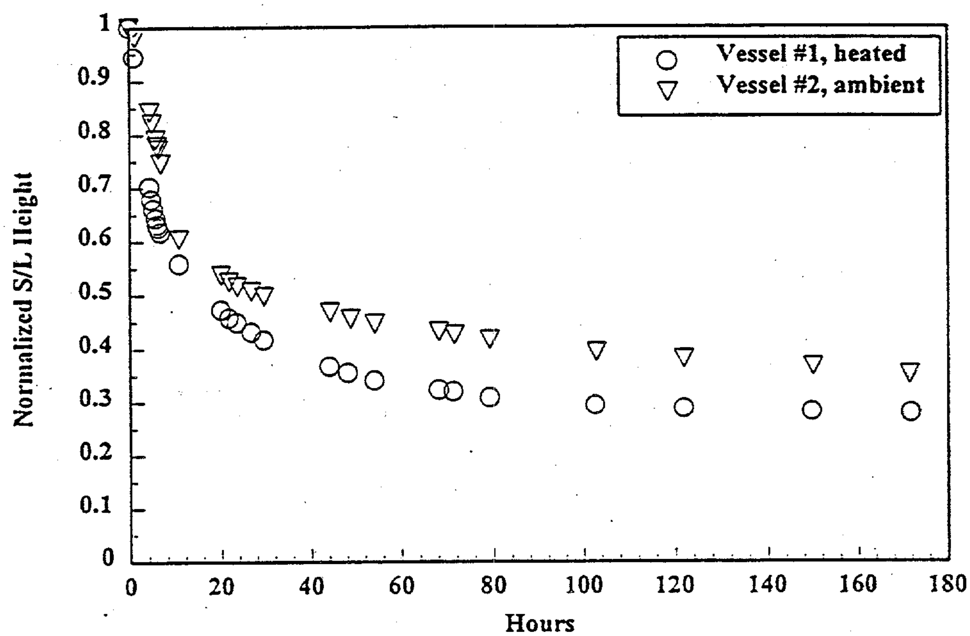

Figure 2. Settling Curves for Run 1, Unwashed NCAW Simulant

The settling curves indicate that the Vessel #1 solids settled both faster and compacted further than the Vessel # 2 solids. Thus, the simulated radiological heating did not produce convective currents strong enough to disrupt settling. Actually, the heating enhanced the settleability of the NCAW simulant. The settling velocities for Vessel #1 exceeded 2 cm/hr during the first 6 hours and then decreased to a final velocity of only 0.14 cm/hr. The settling velocities for Vessel #2 averaged 1.2 cm/hr for the first 10 hours and then decreased to a final velocity of 0.13 cm/hr. This increase in settling velocity for Vessel #1 could be the result of viscosity and/or supernatant density changes due to the elevated simulant temperature.

The average supernate temperature was 47°C while the average sludge temperature at the heating element was 104.5°C. Due to the insulating properties of the settled sludge layer and heat losses at the liquid/air interface, the supernate temperature of 60°C could not be maintained by the heating element operating continuously at full power. However, the lower supernate temperature and the fact that the sludge temperature reached the boiling point at the heating element provided a severe temperature gradient for generating convective currents (i.e., a worst case scenario, providing more extreme termperature gradients for evaluating the effects of convective currents on settling behavior).

The turbidity measurements recorded for Vessel #1 during Run 1 are tabulated in Table A.3 in of the Appendix and plotted in Figure 3. The figure indicates that the supernate turbidity decreases rapidly over time, and the shape of the scatter plot is very similar to the settling curve. The maximum turbidity values occurred in the first 20 hours of the settling period and remained relatively constant for the remainder of the test. After 172 hours, the supernate turbidity values for all four positions were less than 20 NTUs indicating, for the most part, a particle free supernate.

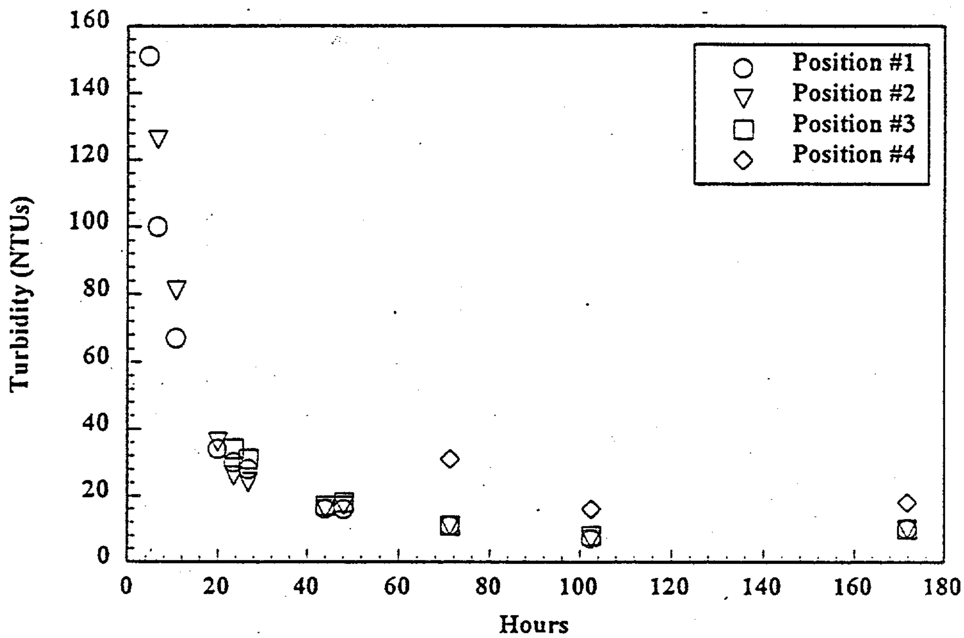

Figure 3. Vessel # 1 Turbidity Measurements for Run 1

The turbidity data for Vessel #2 is presented in a similar fashion in Table A.4 of the Appendix and Figure 4. Similar trends in turbidity values over time for Vessel #2 were observed. The final S/L interface height for Vessel #2 was over 2 cm higher than the final S/L interface height for Vessel #1. This additional height prevented taking turbidity measurements at position #4 because of reflection interferences. The maximum turbidity value was 58 NTUs with a final minimum value of 5 NTUs.

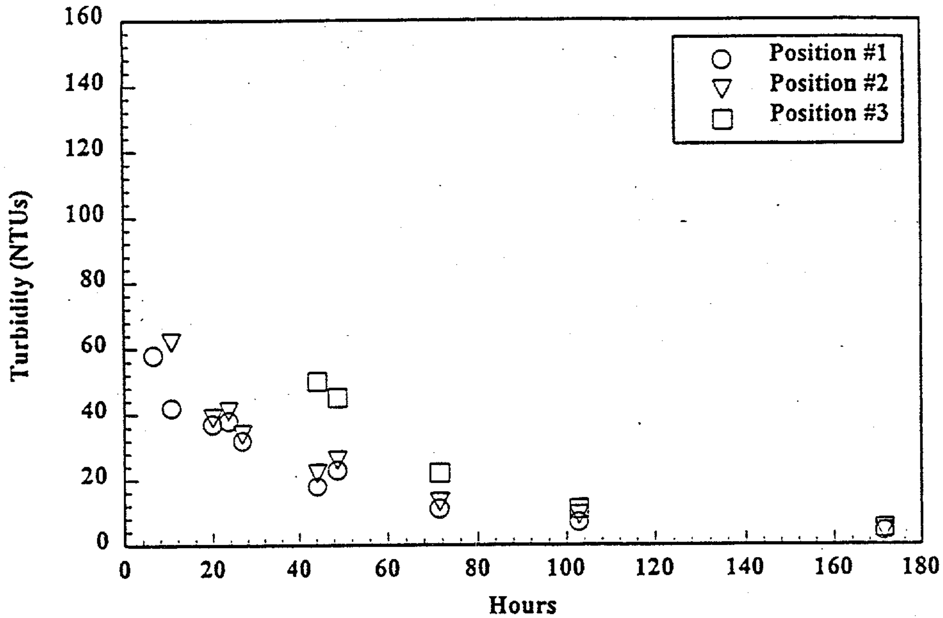

Figure 4. Vessel # 2 Turbidity Measurements for Run 1

5.2.2 Run 2

Figure 5 contains the settling curves for both vessels resulting from Run 2. The data is tabulated in Tables A.5 and A.6 of the Appendix for Vessel #1 and Vessel #2, respectively.

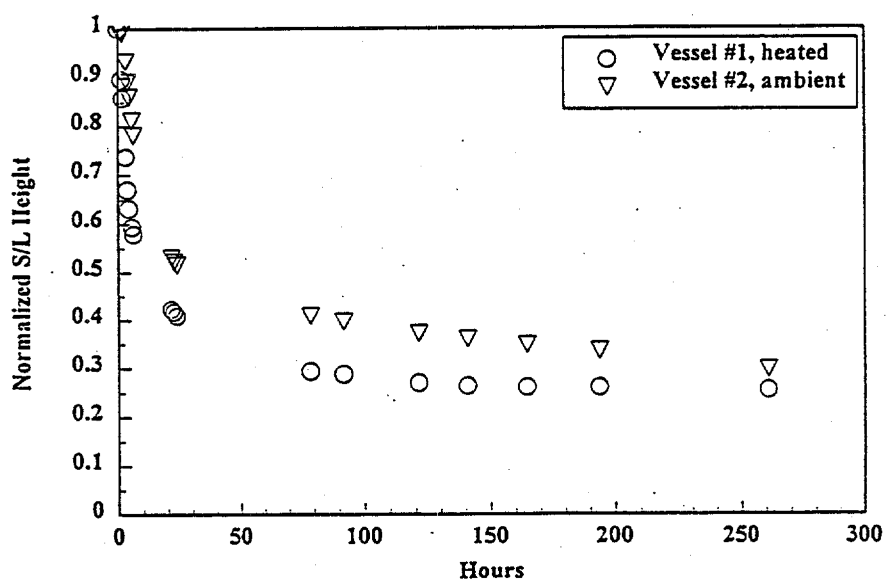

Figure 5. Settling Curves for Run 2, Unwashed NCAW Simulant

The resulting settling curves for Run 2 are very similar to the curves for Run 1 suggested good reproducibility of the settling velocity results. Heating the simulant enhanced the settling velocity of the S/L interface. During the first 6 hours of the settling period, the average velocities were 2.66 and 0.76 for Vessel #1 and Vessel #2, respectively. The average supernatant temperature was 53.6°C while the average temperature of the sludge at the heating element was 105.7°C yielding an average temperature gradient of 52.1°C.

The turbidity measurements for Vessel #1 during Run 2 are tabulated in Tables A.7 the of the Appendix and plotted in Figure 6. The turbidity values are similar to the ones measured for Vessel #1 during Run 1. At the beginning of the run the maximum turbidity value was 140 NTU with a final reading for all four positions of ≤10 NTU. Despite the high initial readings, turbidity decreased rapidly after the first 20 hours.

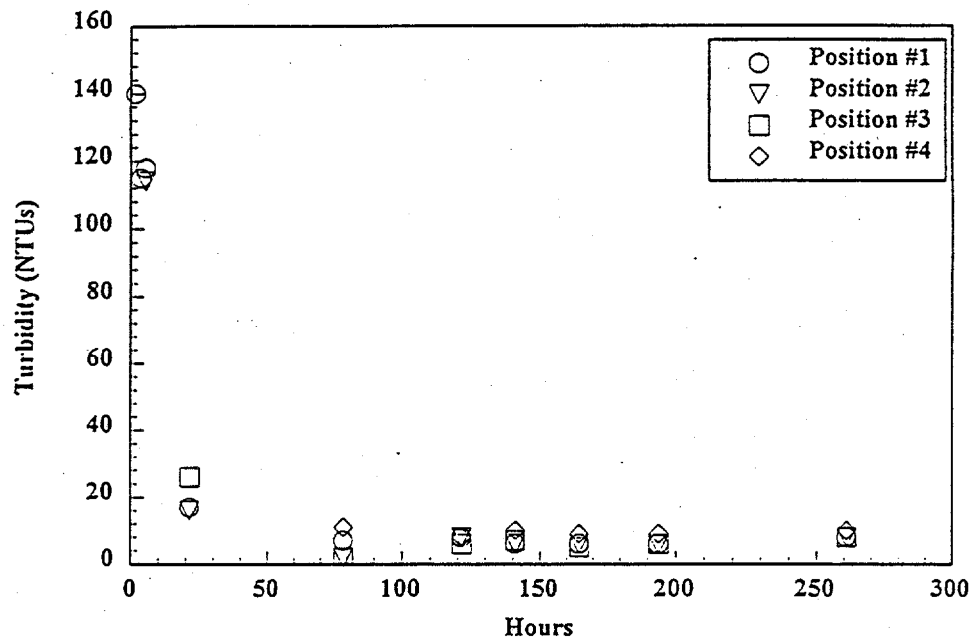

Figure 6. Vessel # 1Turbidity Measurements for Run 2

The turbidity results for Vessel #2 during Run 2 are plotted in Figure 7 and tabulated in Table A.8 of the Appendix. The maximum turbidity reading at the beginning of the run was 65 NTU with a final minimum value of 4 NTU. Similar to the results for Vessel #2 during Run 1, the final position of the S/L interface precluded turbidity measurements at Position #4.

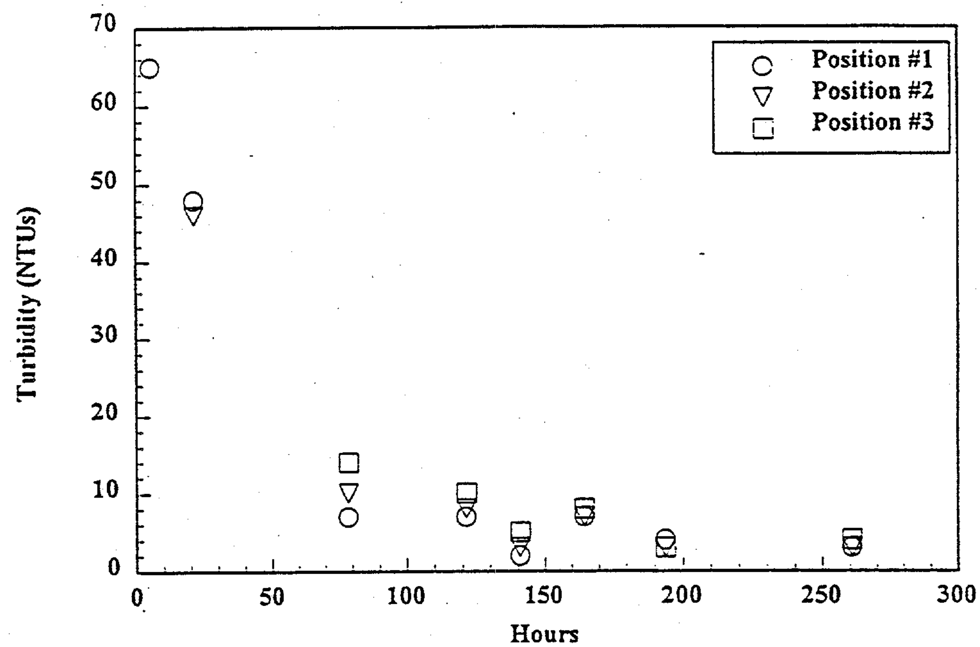

Figure 7. Vessel # 2Turbidity Measurements for Run 2

5.3 Effect of Simulated Radiological Heating on Washed NCAW Simulant

Wash Cycles 1, 2 and 3 results are presented in the same format as Run 1 and Run 2.

5.3.1 Wash Cycle 1

Figure 8 contains the settling curves for both vessels resulting from Wash Cycle 1. The data is tabulated in Tables A.9 and A.10 for Vessel #1 and Vessel #2, respectively. Similar to Runs 1 and 2, the simulated radiological heating enhanced the settling velocity. The only notable difference in the settling curves of Runs 1 and 2 and Wash Cycle 1 is the increase in initial settling velocities in Vessel #1 for the washed simulant. The average settling velocity during the first four hours of the settling period was 4.54 cm/hr for Vessel #1. Vessel #2 had an average settling velocity of 0.82 cm/hr for during the first four hours of the settling period. The decrease in ionic strength of the simulant from the sludge washing did not adversely impact the settleability of the solids. The average supernatant temperature was 51.8°C while the average temperature of the sludge at the heating element was 100.5°C yielding and average temperature gradient of 48.7°C.

The turbidity measurements for Vessel #1 are tabulated in Table A.11 of the Appendix and plotted in Figure 9. Similar to Runs 1 and 2, turbidity decreases rapidly soon after the beginning of the settling period (after the first 4 hours). The maximum turbidity value was 100 NTU with final values for all four positions ≤12 NTU.

The turbidity measurements for Vessel #2 are plotted in Figure 10 and tabulated in Table A.12 of the Appendix. The maximum turbidity was 39 NTU with final values for all three positions of zero. Similar to Runs 1 and 2, the final position of the S/L interface precluded turbidity measurements at Position #4.

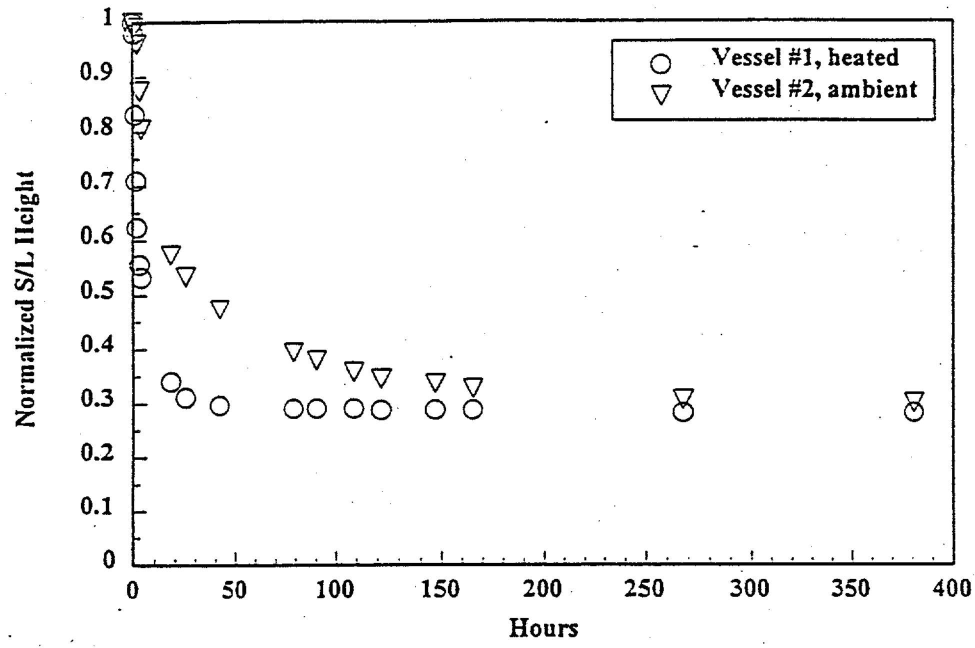

Figure 8. Settling Curves for Wash Cycle 1

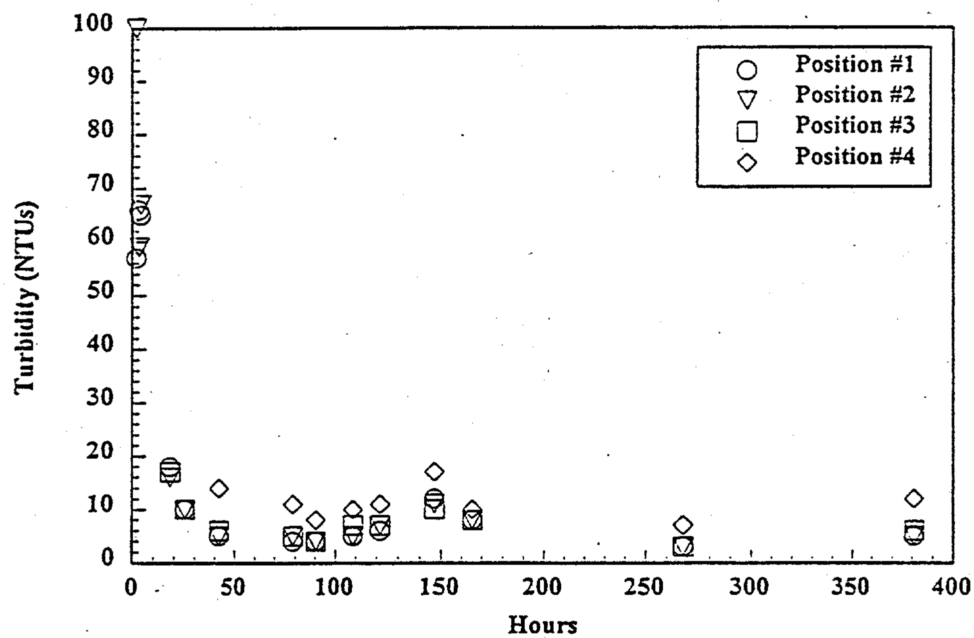

Figure 9. Vessel #1 Turbidity Measurements for Wash Cycle 1.

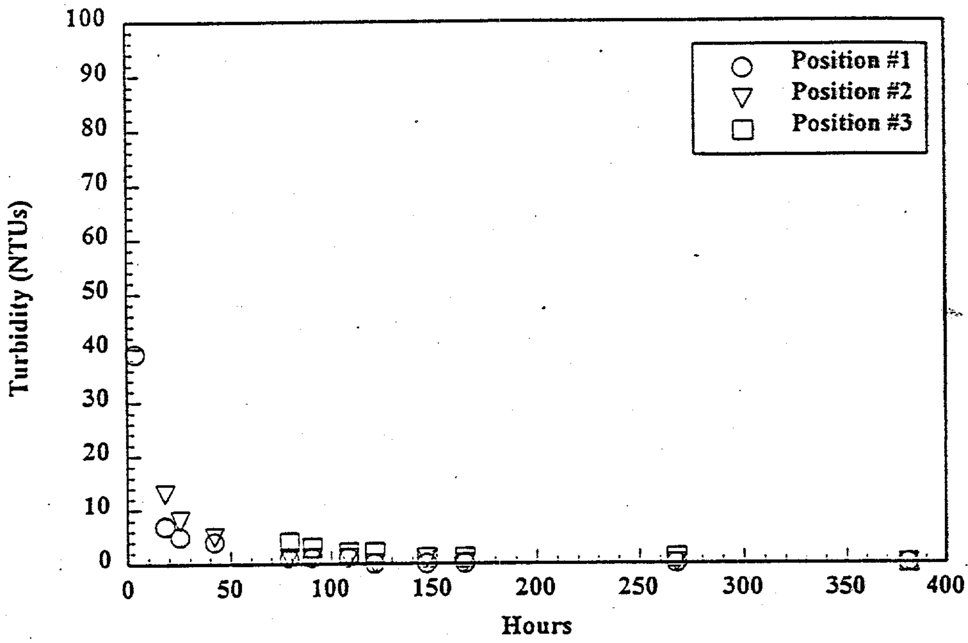

Figure 10. Vessel #2 Turbidity Measurements for Wash Cycle 2

5.3.2 Wash Cycle 2

Figure 11 contains the settling curves for both vessels resulting from Wash Cycle 2. The data is tabulated in Tables A.13 and A.14 of the Appendix. Once again, the settling curves indicate that the simulated radiological heating enhances the settleability of the simulant. The average settling velocities for the first 7 hours of the settling period were 5.59 and 1.40 cm/hr for Vessel #1 and Vessel #2, respectively. The average supernatant temperature was 53.7°C while the average temperature of the sludge at the heating element was 100.2°C yielding and average temperature gradient of 46.5°C.

The turbidity measurements for Vessel #1 are tabulated in Table A.15 of the Appendix and plotted in Figure 12. Similar to previous settling tests, the turbidity decreased rapidly with time. The maximum turbidity values was 85 NTU with final values for all four positions ≤12 NTU.

The turbidity measurements for Vessel #2 are plotted in Figure 13 and tabulated in Table A.16 of the Appendix. The maximum turbidity value was 21 NTU with final values for all three positions ≤1 NTU.

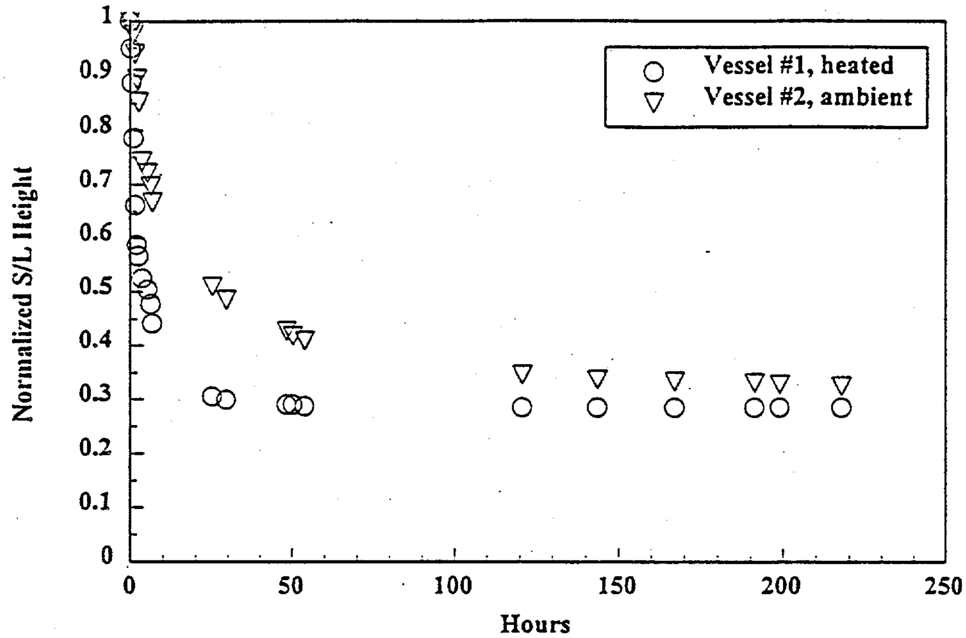

Figure 11. Settling Curves for Wash Cycle 2

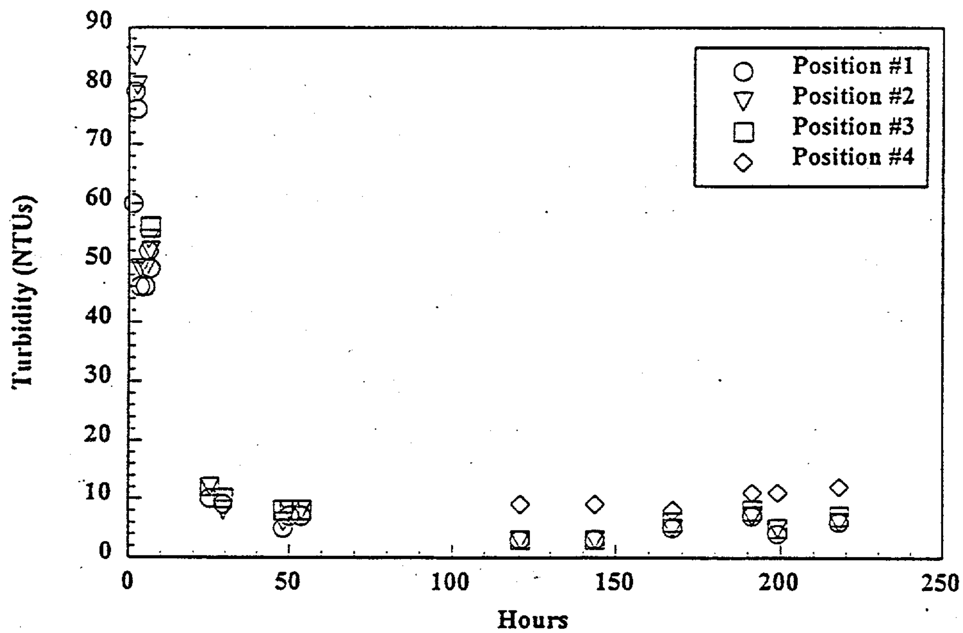

Figure 12. Vessel #1 Turbidity Measurements for Wash Cycle 2

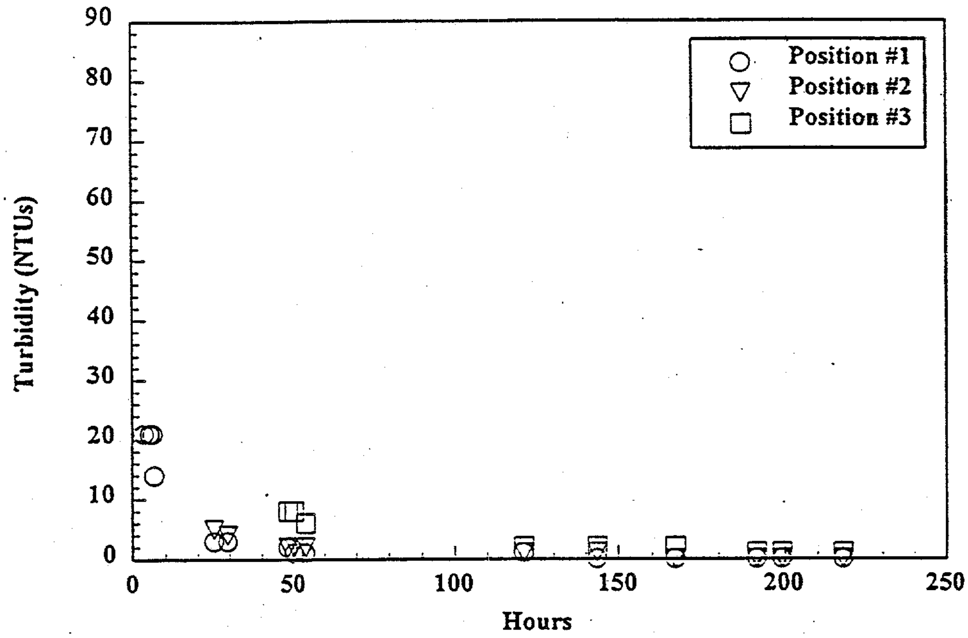

Figure 13. Vessel #2 Turbidity Measurements for Wash Cycle 2

5.3.3 Wash Cycle 3

Figure 14 contains the settling curve results for both vessels for Wash Cycle 3. The data is tabulated in Tables A.17 and A.18 of the Appendix. The settling curves were consistent with the previous test runs and indicated that the simulated heating improved the settleability of the simulant. The average settling velocities for the first 8 hours of the settling period were 6.05 and 1.90 cm/hr for Vessel #1 and Vessel #2, respectively. The average supernatant temperature was 51.3°C while the average temperature of the sludge at the heating element was 102.9°C yielding and average temperature gradient of 51.6°C.

The turbidity measurements for Vessel #1 are tabulated in Table A.19 of the Appendix and plotted in Figure 15. Similar to previous settling tests, the turbidity decreased rapidly with time. The maximum turbidity values was 102 NTU with final values for all four positions ≤14 NTU.

The turbidity measurements for Vessel #2 are plotted in Figure 16 and tabulated in Table A.20 of the Appendix. The maximum turbidity value was 45 NTU with final values for all three positions equal to zero NTU.

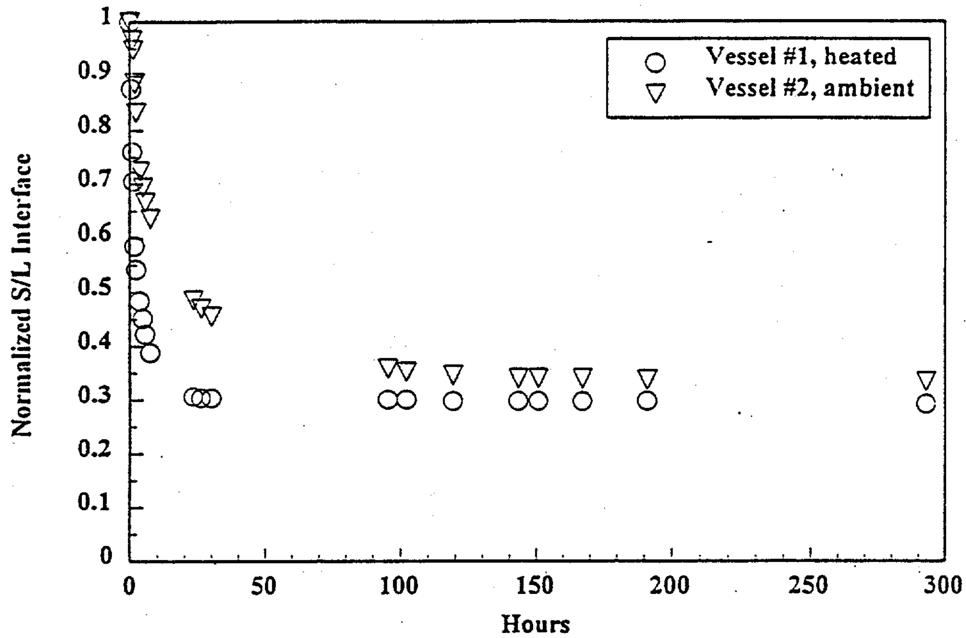

Figure 14. Settling Curves for Wash Cycle 3

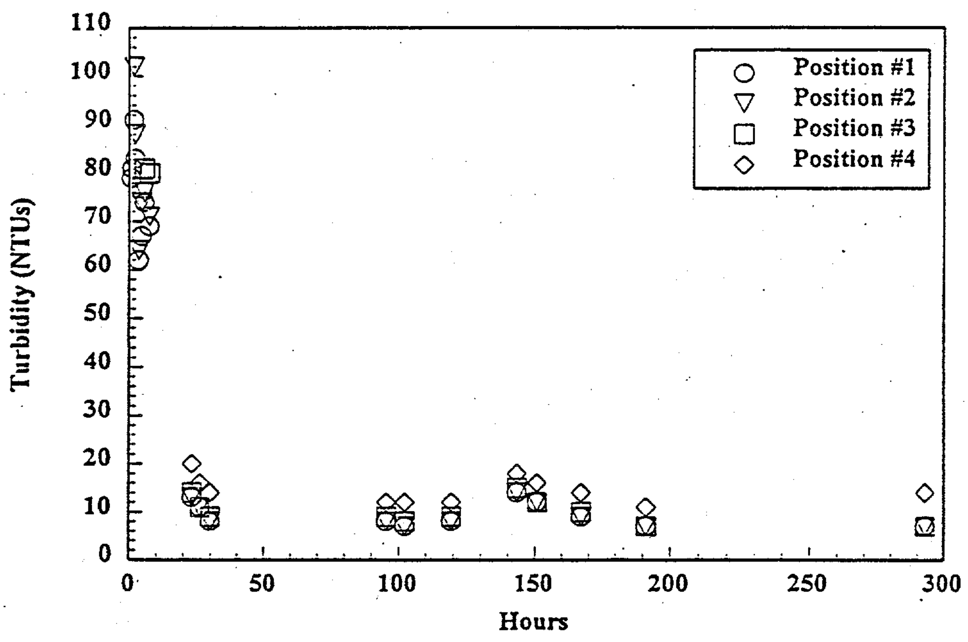

Figure 15. Vessel #1 Turbidity Measurements for Wash Cycle 3

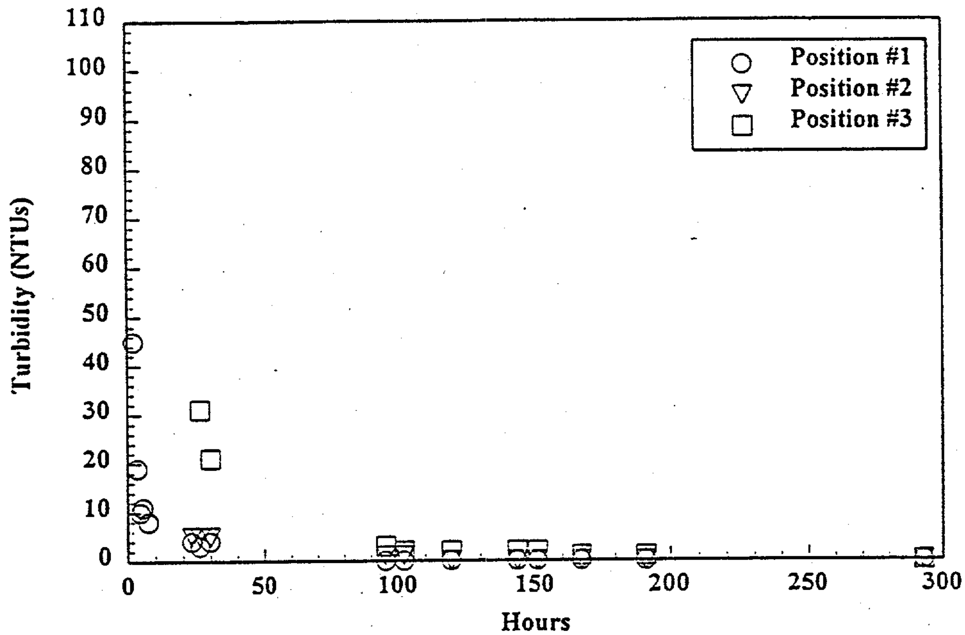

Figure 16. Vessel #2 Turbidity Measurements for Wash Cycle 3

5.4 Steam Bump Potential

Vessel #1 was monitored during all five test runs and no indications of a steam bump potential in the settled sludge layer was observed (such as entrapped bubbles in the sludge layer and an increase in the vessel simulant volume). The average temperature gradient (from the bottom of the sludge layer to the surface of the supernatant) was 51.3°C. Under the test conditions used for this work, a potential steam bump is not likely, even though the boiling temperature of the supernatant was exceeded in the sludge layer.

5.5 Suspended Solids

Two sample aliquots from each vessel for each respective test run were analyzed for suspended solids concentrations after the vessel contents were well mixed. The analysis was conducted twice for each aliquot. For one test run, ambient and heated simulant aliquot was pulled from Vessel #1 with two ambient aliquots were taken from Vessel #2. The average SS concentration for each Vessel #1 aliquot are tabulated in Table A.21 of the Appendix. The SS concentration of the aliquots taken when the simulant was heated are slightly lower than the corresponding ambient aliquot concentrations for Run 1, Run 2 and Wash Cycle 2. An ambient aliquot was not pulled for analysis during Wash Cycle 3. The average suspended solids concentrations ranged from 2.92 to 4.08% (by mass).

The suspended solids concentrations of the Vessel #2 aliquots are tabulated in Table A.22 of the Appendix. The average suspended solids concentrations for Vessel #2 ranged from 4.07 to 5.04% (by mass).

6.0 References

American Public Health Association, American Water Works Association, Water Environment Federation. Standard Methods for the Examination of Water and Wastewater, 18th Edition, American Public Health Association, Washington, DC, 1992.

Elmore MR, HD Smith. Erosion-Corrosion of Carbon Steel in Simulated Neutralized Current Acid Waste Slurry. PNL, 1990.

Gray WJ, ME Peterson, RD Scheele, JM Tingey. Characterization of the Second Core Sample of Neutralized Current Acid Waste from Double Shell Tank 101-AZ. PNL, December, 1991.

7.0 Appendix

Table A.1. Vessel #1 S/L Interface Height and Settling Velocities for Run 1

Date & Time	S/L Height (cm)	Normalized S/L Height (cm)	Duration (hours)	Settling Velocity (cm/hr)
5/10/93 10:30	34	1	0	
5/10/93 11:30	32.1	0.94	1	1.9
5/10/93 14:43	23.9	0.7	4.22	2.4
5/10/93 15:06	23.1	0.68	4.6	2.37
5/10/93 15:30	22.5	0.66	5	2.3
5/10/93 16:05	21.9	0.64	5.58	2.17
5/10/93 16:20	21.5	0.63	5.83	2.14
5/10/93 16:37	21.3	0.63	6.12	2.08
5/10/93 17:01	21	0.62	6.52	1.99
5/10/93 21:11	19	0.56	10.68	1.4
5/11/93 6:31	16.1	0.47	20.02	0.89
5/11/93 8:18	15.6	0.46	21.8	0.84
5/11/93 10:03	15.3	0.45	23.55	0.79
5/11/93 13:18	14.7	0.43	26.8	0.72
5/11/93 16:07	14.2	0.42	29.62	0.67
5/12/93 6:35	12.5	0.37	44.08	0.49
5/12/93 10:42	12.1	0.36	48.2	0.45
5/12/93 16:32	11.6	0.34	54.03	0.41
5/13/93 6:35	11	0.32	68.08	0.34
5/13/93 9:41	10.9	0.32	71.18	0.32
5/13/93 17:42	10.5	0.31	79.2	0.3
5/14/93 17:00	10	0.29	102.5	0.23
5/15/93 12:22	9.8	0.29	121.87	0.2
5/16/93 16:15	9.6	0.28	149.75	0.16
5/17/93 14:18	9.5	0.28	171.8	0.14

Table A.2. Vessel #2 S/L Interface Height and Settling Velocities for Run 1

Date & Time	S/L Height (cm)	Normalized S/L Height (cm)	Duration (hours)	Settling Velocity (cm/hr)
5/10/93 10:30	33.1	1	0	
5/10/93 11:45	32.5	0.98	1.25	0.48
5/10/93 14:49	27.9	0.84	4.32	1.2
5/10/93 15:18	27.2	0.82	4.8	1.23
5/10/93 16:06	26.2	0.79	5.6	1.23
5/10/93 16:19	25.8	0.78	5.82	1.26
5/10/93 16:38	25.6	0.77	6.13	1.22
5/10/93 17:08	24.7	0.75	6.63	1.27
5/10/93 21:11	20	0.6	10.68	1.23
5/11/93 6:32	17.8	0.54	20.03	0.76
5/11/93 8:19	17.4	0.53	21.82	0.72
5/11/93 10:10	17.1	0.52	23.67	0.68
5/11/93 13:18	16.8	0.51	26.8	0.61
5/11/93 16:08	16.5	0.5	29.63	0.56
5/12/93 6:43	15.5	0.47	44.22	0.4
5/12/93 11:21	15.1	0.46	48.85	0.37
5/12/93 16:39	14.8	0.45	54.15	0.34
5/13/93 6:37	14.3	0.43	68.12	0.28
5/13/93 9:58	14.1	0.43	71.47	0.27
5/13/93 17:43	13.8	0.42	79.22	0.24
5/14/93 17:17	13	0.39	102.78	0.2
5/15/93 12:23	12.6	0.38	121.88	0.17
5/16/93 16:30	12.1	0.37	150	0.14
5/17/93 14:00	11.6	0.35	171.5	0.13

Table A.3. Vessel #1 Turbidity Measurements for Run 1

Date & Time	Duration (hours)	Turbidity (NTUs) Position #1	Position #2	Position #3	Position #4
5/10/93 10:30	0				
5/10/93 11:30	1				
5/10/93 14:43	4.22				
5/10/93 15:06	4.6	151			
5/10/93 15:30	5				
5/10/93 16:05	5.58				
5/10/93 16:20	5.83				
5/10/93 16:37	6.12				
5/10/93 17:01	6.52	100	126		
5/10/93 21:11	10.68	67	81		
5/11/93 6:31	20.02	34	36		
5/11/93 8:18	21.8				
5/11/93 10:03	23.55	30	26	34	
5/11/93 13:18	26.8	28	24	31	
5/11/93 16:07	29.62				
5/12/93 6:35	44.08	16	16	17	
5/12/93 10:42	48.2	16	17	18	
5/12/93 16:32	54.03				
5/13/93 6:35	68.08				
5/13/93 9:41	71.18	11	11	11	31
5/13/93 17:42	79.2				
5/14/93 17:00	102.5	7	7	8	16
5/15/93 12:22	121.87				
5/16/93 16:15	149.75				
5/17/93 14:18	171.8	10	10	10	18

Table A.4. Vessel #2 Turbidity Measurements for Run 1

Date & Time	Duration (hours)	Turbidity (NTUs) Position #1	Position #2	Position #3
5/10/93 10:30	0			
5/10/93 11:45	1.25			
5/10/93 14:49	4.32			
5/10/93 15:18	4.8			
5/10/93 16:06	5.6			
5/10/93 16:19	5.82			
5/10/93 16:38	6.13			
5/10/93 17:08	6.63	58		
5/10/93 21:11	10.68	42	62	
5/11/93 6:32	20.03	37	39	
5/11/93 8:19	21.82			
5/11/93 10:10	23.67	38	41	
5/11/93 13:18	26.8	32	34	
5/11/93 16:08	29.63			
5/12/93 6:43	44.22	18	22	50
5/12/93 11:21	48.85	23	26	45
5/12/93 16:39	54.15			
5/13/93 6:37	68.12			
5/13/93 9:58	71.47	11	13	22
5/13/93 17:43	79.22			
5/14/93 17:17	102.78	7	9	11
5/15/93 12:23	121.88			
5/16/93 16:30	150			
5/17/93 14:00	171.5	4	4	5

Table A.5. Vessel #1 S/L Interface Height and Settling Velocities for Run 2

Date & Time	S/L Height (cm)	Normalized S/L Height (cm)	Duration (hours)	Settling Velocity (cm/hr)
6/10/93 10:35	34	1	0	
6/10/93 11:58	30.5	0.9	1.38	2.53
6/10/93 12:22	29.2	0.86	1.78	2.69
6/10/93 13:43	25.1	0.74	3.13	2.84
6/10/93 14:26	22.8	0.67	3.85	2.91
6/10/93 15:01	21.5	0.63	4.43	2.82
6/10/93 16:05	20.2	0.59	5.5	2.51
6/10/93 16:45	19.7	0.58	6.17	2.32
6/11/93 8:00	14.4	0.42	21.42	0.92
6/11/93 9:00	14.2	0.42	22.42	0.88
6/11/93 10:12	13.9	0.41	23.62	0.85
6/13/93 17:15	10	0.29	78.67	0.31
6/14/93 6:25	9.8	0.29	91.83	0.26
6/15/93 12:00	9.2	0.27	121.42	0.2
6/16/93 7:30	9	0.26	140.92	0.18
6/17/93 7:15	8.9	0.26	164.67	0.15
6/18/93 12:30	8.9	0.26	193.92	0.13
6/21/93 7:25	8.7	0.26	260.83	0.1

Table A.6. Vessel #2 S/L Interface Height and Settling Velocities for Run 2

Date & Time	S/L Height (cm)	Normalized S/L Height (cm)	Duration (hours)	Settling Velocity (cm/hr)
6/10/93 10:35	33	1	0	
6/10/93 11:58	32.8	0.99	1.38	0.14
6/10/93 12:22	32.7	0.99	1.78	0.17
6/10/93 13:43	30.8	0.93	3.13	0.7
6/10/93 14:26	29.4	0.89	3.85	0.94
6/10/93 15:01	28.4	0.86	4.43	1.04
6/10/93 16:05	26.8	0.81	5.5	1.13
6/10/93 16:45	25.8	0.78	6.17	1.17
6/11/93 8:00	17.5	0.53	21.42	0.72
6/11/93 9:00	17.2	0.52	22.42	0.7
6/11/93 10:12	17	0.52	23.62	0.68
6/13/93 17:15	13.5	0.41	78.67	0.25
6/14/93 6:25	13.1	0.4	91.83	0.22
6/15/93 12:00	12.3	0.37	121.42	0.17
6/16/93 7:30	11.9	0.36	140.92	0.15
6/17/93 7:15	11.5	0.35	164.67	0.13
6/18/93 12:30	11.1	0.34	193.92	0.11
6/21/93 7:25	9.8	0.3	260.83	0.09

Table A.7. Vessel #1 Turbidity Measurements for Run 2

Date & Time	Duration (hours)	Turbidity (NTUs) Position #1	Position #2	Position #3	Position #4
6/10/93 10:35	0				
6/10/93 11:58	1.38				
6/10/93 12:22	1.78	140			
6/10/93 13:43	3.13				
6/10/93 14:26	3.85	115			
6/10/93 15:01	4.43				
6/10/93 16:05	5.5	118	114		
6/10/93 16:45	6.17				
6/11/93 8:00	21.42	17	16	26	
6/11/93 9:00	22.42				
6/11/93 10:12	23.62				
6/13/93 17:15	78.67	7	2	2	11
6/14/93 6:25	91.83				
6/15/93 12:00	121.42	8	8	6	8
6/16/93 7:30	140.92	6	6	7	10
6/17/93 7:15	164.67	6	6	5	9
6/18/93 12:30	193.92	6	6	6	9
6/21/93 7:25	260.83	8	8	8	10

Table A.8. Vessel #2 Turbidity Measurements for Run 2

Date & Time	Duration (hours)	Turbidity (NTUs) Position #1	Position #2	Position #3
6/10/93 10:35	0			
6/10/93 11:58	1.38			
6/10/93 12:22	1.78			
6/10/93 13:43	3.13			
6/10/93 14:26	3.85			
6/10/93 15:01	4.43			
6/10/93 16:05	5.5	65		
6/10/93 16:45	6.17			
6/11/93 8:00	21.42	48	46	
6/11/93 9:00	22.42			
6/11/93 10:12	23.62			
6/13/93 17:15	78.67	7	10	14
6/14/93 6:25	91.83			
6/15/93 12:00	121.42	7	8	10
6/16/93 7:30	140.92	2	3	5
6/17/93 7:15	164.67	7	7	8
6/18/93 12:30	193.92	4	3	3
6/21/93 7:25	260.83	3	3	4

Table A.9. Vessel #1 S/L Interface Height and Settling Velocities for Wash Cycle 1

Date & Time	S/L Height (cm)	Normalized S/L Height (cm)	Duration (hours)	Settling Velocity (cm/hr)
6/24/93 12:15	33.8	1	0	
6/24/93 12:50	33.1	0.98	0.58	1.2
6/24/93 13:20	28.1	0.83	1.08	5.26
6/24/93 13:55	24	0.71	1.67	5.88
6/24/93 14:15	21.1	0.62	2	6.35
6/24/93 15:30	18.8	0.56	3.25	4.62
6/24/93 16:15	18	0.53	4	3.95
6/25/93 6:25	11.5	0.34	18.17	1.23
6/25/93 13:35	10.5	0.31	25.33	0.92
6/26/93 6:30	10	0.3	42.25	0.56
6/27/93 19:15	9.8	0.29	79	0.3
6/28/93 6:40	9.8	0.29	90.42	0.27
6/29/93 1:00	9.8	0.29	108.75	0.22
6/29/93 13:55	9.7	0.29	121.67	0.2
6/30/93 15:20	9.7	0.29	147.08	0.16
7/1/93 9:40	9.7	0.29	165.42	0.15
7/5/93 16:00	9.5	0.28	267.75	0.09
7/10/93 9:15	9.5	0.28	381	0.06

Table A.10. Vessel #2 S/L Interface Height and Settling Velocities for Wash Cycle 1

Date & Time	S/L Height (cm)	Normalized S/L Height (cm)	Duration (hours)	Settling Velocity (cm/hr)
6/24/93 12:15	32.8	1	0	
6/24/93 12:50	32.5	0.99	0.58	0.51
6/24/93 13:20	32.3	0.98	1.08	0.46
6/24/93 13:55	32.1	0.98	1.67	0.42
6/24/93 14:15	31.5	0.96	2	0.65
6/24/93 15:30	28.7	0.88	3.25	1.26
6/24/93 16:15	26.4	0.8	4	1.6
6/25/93 6:25	18.8	0.57	18.17	0.77
6/25/93 13:35	17.5	0.53	25.33	0.6
6/26/93 6:30	15.5	0.47	42.25	0.41
6/27/93 19:15	12.9	0.39	79	0.25
6/28/93 6:40	12.4	0.38	90.42	0.23
6/29/93 1:00	11.7	0.36	108.75	0.19
6/29/93 13:55	11.3	0.34	121.67	0.18
6/30/93 15:20	11	0.34	147.08	0.15
7/1/93 9:40	10.7	0.33	165.42	0.13
7/5/93 16:00	10	0.3	267.75	0.09
7/10/93 9:15	9.8	0.3	381	0.06

Table A.11. Vessel #1 Turbidity Measurements for Wash Cycle 1

Date & Time	Duration (hours)	Turbidity (NTUs) Position #1	Position #2	Position #3	Position #4
6/24/93 12:15	0				
6/24/93 12:50	0.58				
6/24/93 13:20	1.08				
6/24/93 13:55	1.67				
6/24/93 14:15	2	57	100		
6/24/93 15:30	3.25	66	59		
6/24/93 16:15	4	65	67		
6/25/93 6:25	18.17	18	16	17	
6/25/93 13:35	25.33	10	10	10	
6/26/93 6:30	42.25	5	5	6	14
6/27/93 19:15	79	4	5	5	11
6/28/93 6:40	90.42	4	4	4	8
6/29/93 1:00	108.75	5	5	7	10
6/29/93 13:55	121.67	6	7	7	11
6/30/93 15:20	147.08	12	11	10	17
7/1/93 9:40	165.42	8	8	8	10
7/5/93 16:00	267.75	3	3	3	7
7/10/93 9:15	381	5	5	6	12

Table A.12. Vessel #2 Turbidity Measurements for Wash Cycle 1

Date & Time	Duration (hours)	Turbidity (NTUs) Position #1	Position #2	Position #3	Position #4
6/24/93 12:15	0				
6/24/93 12:50	0.58				
6/24/93 13:20	1.08				
6/24/93 13:55	1.67				
6/24/93 14:15	2				
6/24/93 15:30	3.25				
6/24/93 16:15	4	39			
6/25/93 6:25	18.17	7	13		
6/25/93 13:35	25.33	5	8		
6/26/93 6:30	42.25	4	5		
6/27/93 19:15	79	1	1	4	
6/28/93 6:40	90.42	1	1	3	
6/29/93 1:00	108.75	1	1	2	
6/29/93 13:55	121.67	0	0	2	
6/30/93 15:20	147.08	0	1	1	
7/1/93 9:40	165.42	0	0	1	
7/5/93 16:00	267.75	0	0	1	
7/10/93 9:15	381	0	0	0	

Table A.13. Vessel #1 S/L Interface Height and Settling Velocities for Wash Cycle 2

Date & Time	S/L Height (cm)	Normalized S/L Height (cm)	Duration (hours)	Settling Velocity (cm/hr)
7/14/93 9:38	33.7	1	0	
7/14/93 9:50	32	0.95	0.2	8.5
7/14/93 10:10	29.9	0.89	0.53	7.13
7/14/93 10:40	26.5	0.79	1.03	6.97
7/14/93 11:10	22.3	0.66	1.53	7.43
7/14/93 11:40	19.8	0.59	2.03	6.84
7/14/93 12:10	19.1	0.57	2.53	5.76
7/14/93 13:15	17.7	0.53	3.62	4.42
7/14/93 14:55	17	0.5	5.28	3.16
7/14/93 15:50	16.1	0.48	6.2	2.84
7/14/93 16:20	14.9	0.44	6.7	2.81
7/15/93 10:45	10.3	0.31	25.12	0.93
7/15/93 15:00	10.1	0.3	29.37	0.8
7/16/93 9:50	9.8	0.29	48.2	0.5
7/16/93 11:50	9.8	0.29	50.2	0.48
7/16/93 15:30	9.7	0.29	53.87	0.45
7/19/93 10:30	9.6	0.28	120.87	0.2
7/20/93 9:10	9.6	0.28	143.53	0.17
7/21/93 8:45	9.6	0.28	167.12	0.14
7/22/93 9:00	9.6	0.28	191.37	0.13
7/22/93 16:45	9.6	0.28	199.12	0.12
7/23/93 11:25	9.6	0.28	217.78	0.11

Table A.14. Vessel #2 S/L Interface Height and Settling Velocities for Wash Cycle 2

Date & Time	S/L Height (cm)	Normalized S/L Height (cm)	Duration (hours)	Settling Velocity (cm/hr)
7/14/93 9:38	33	1	0	
7/14/93 10:10	32.5	0.98	0.53	0.94
7/14/93 10:40	32.2	0.98	1.03	0.77
7/14/93 11:10	31	0.94	1.53	1.3
7/14/93 11:40	29.5	0.89	2.03	1.72
7/14/93 12:10	28.1	0.85	2.53	1.93
7/14/93 13:15	24.5	0.74	3.62	2.35
7/14/93 14:55	23.8	0.72	5.28	1.74
7/14/93 15:50	23	0.7	6.2	1.61
7/14/93 16:20	22	0.67	6.7	1.64
7/15/93 10:45	16.8	0.51	25.12	0.64
7/15/93 15:00	16	0.48	29.37	0.58
7/16/93 9:50	14.1	0.43	48.2	0.39
7/16/93 11:50	13.8	0.42	50.2	0.38
7/16/93 15:30	13.5	0.41	53.87	0.36
7/19/93 10:30	11.4	0.35	120.87	0.18
7/20/93 9:10	11.1	0.34	143.53	0.15
7/21/93 8:45	11	0.33	167.12	0.13
7/22/93 9:00	10.9	0.33	191.37	0.12
7/22/93 16:45	10.8	0.33	199.12	0.11
7/23/93 11:25	10.7	0.32	217.78	0.1

Table A.15. Vessel #1 Turbidity Measurements for Wash Cycle 2

Date & Time	Duration (hours)	Turbidity (NTUs) Position #1	Position #2	Position #3	Position #4
7/14/93 9:38	0				
7/14/93 9:50	0.2				
7/14/93 10:10	0.53				
7/14/93 10:40	1.03				
7/14/93 11:10	1.53	60			
7/14/93 11:40	2.03	79	85		
7/14/93 12:10	2.53	76	80		
7/14/93 13:15	3.62	46	49		
7/14/93 14:55	5.28	46	49		
7/14/93 15:50	6.2	52	54		
7/14/93 16:20	6.7	49	52	56	
7/15/93 10:45	25.12	10	12	12	
7/15/93 15:00	29.37	9	8	10	
7/16/93 9:50	48.2	5	6	8	
7/16/93 11:50	50.2	7	8	8	
7/16/93 15:30	53.87	7	8	8	
7/19/93 10:30	120.87	3	3	3	9
7/20/93 9:10	143.53	3	3	3	9
7/21/93 8:45	167.12	5	5	6	8
7/22/93 9:00	191.37	7	7	8	11
7/22/93 16:45	199.12	4	5	5	11
7/23/93 11:25	217.78	6	6	7	12

Table A.16. Vessel #2 Turbidity Measurements for Wash Cycle 2

Date & Time	Duration (hours)	Turbidity (NTUs) Position #1	Position #2	Position #3	Position #4
7/14/93 9:38	0				
7/14/93 10:10	0.53				
7/14/93 10:40	1.03				
7/14/93 11:10	1.53				
7/14/93 11:40	2.03				
7/14/93 12:10	2.53				
7/14/93 13:15	3.62	21			
7/14/93 14:55	5.28	21			
7/14/93 15:50	6.2	21			
7/14/93 16:20	6.7	14			
7/15/93 10:45	25.12	3	5		
7/15/93 15:00	29.37	3	4		
7/16/93 9:50	48.2	2	2	8	
7/16/93 11:50	50.2	1	2	8	
7/16/93 15:30	53.87	1	2	6	
7/19/93 10:30	120.87	1	1	2	
7/20/93 9:10	143.53	0	1	2	
7/21/93 8:45	167.12	0	0	2	
7/22/93 9:00	191.37	0	0	1	
7/22/93 16:45	199.12	0	0	1	
7/23/93 11:25	217.78	0	0	1	

Table A.17. Vessel #1 S/L Interface Height and Settling Velocities for Wash Cycle 3

Date & Time	S/L Height (cm)	Normalized S/L Height (cm)	Duration (hours)	Settling Velocity (cm/hr)
7/29/93 9:33	34.3	1	0	
7/29/93 10:05	30.1	0.88	0.53	7.88
7/29/93 10:30	26.1	0.76	0.95	8.63
7/29/93 10:50	24.2	0.71	1.28	7.87
7/29/93 11:20	20.1	0.59	1.78	7.96
7/29/93 11:50	18.6	0.54	2.28	6.88
7/29/93 13:10	16.6	0.48	3.62	4.89
7/29/93 14:15	15.5	0.45	4.7	4
7/29/93 15:10	14.5	0.42	5.62	3.53
7/29/93 17:00	13.3	0.39	7.45	2.82
7/30/93 8:50	10.5	0.31	23.28	1.02
7/30/93 11:45	10.4	0.3	26.2	0.91
7/30/93 15:35	10.4	0.3	30.03	0.8
8/2/93 9:00	10.3	0.3	95.45	0.25
8/2/93 15:45	10.3	0.3	102.2	0.23
8/3/93 8:50	10.2	0.3	119.28	0.2
8/4/93 8:55	10.2	0.3	143.37	0.17
8/4/93 16:25	10.2	0.3	150.87	0.16
8/5/93 8:50	10.2	0.3	167.28	0.14
8/6/93 8:50	10.2	0.3	191.28	0.13
8/10/93 14:30	10	0.29	292.95	0.08

Table A.18. Vessel #2 S/L Interface Height and Settling Velocities for Wash Cycle 3

Date & Time	S/L Height (cm)	Normalized S/L Height (cm)	Duration (hours)	Settling Velocity (cm/hr)
7/29/93 9:33	33	1	0	
7/29/93 10:30	31.9	0.97	0.95	1.16
7/29/93 10:50	31.3	0.95	1.28	1.32
7/29/93 11:20	29.3	0.89	1.78	2.07
7/29/93 11:50	27.5	0.83	2.28	2.41
7/29/93 13:10	23.9	0.72	3.62	2.52
7/29/93 14:15	22.9	0.69	4.7	2.15
7/29/93 15:10	22	0.67	5.62	1.96
7/29/93 17:00	21	0.64	7.45	1.61
7/30/93 8:50	16	0.48	23.28	0.73
7/30/93 11:45	15.5	0.47	26.2	0.67
7/30/93 15:35	15	0.45	30.03	0.6
8/2/93 9:00	11.8	0.36	95.45	0.22
8/2/93 15:45	11.6	0.35	102.2	0.21
8/3/93 8:50	11.4	0.35	119.28	0.18
8/4/93 8:55	11.2	0.34	143.37	0.15
8/4/93 16:25	11.2	0.34	150.87	0.14
8/5/93 8:50	11.2	0.34	167.28	0.13
8/6/93 8:50	11.1	0.34	191.28	0.11
8/10/93 14:30	11	0.33	292.95	0.08

Table A.19. Vessel #1 Turbidity Measurements for Wash Cycle 2

Date & Time	Duration (hours)	Turbidity (NTUs) Position #1	Position #2	Position #3	Position #4
7/29/93 9:33	0				
7/29/93 10:05	0.53				
7/29/93 10:30	0.95	79			
7/29/93 10:50	1.28	81			
7/29/93 11:20	1.78	91	102		
7/29/93 11:50	2.28	83	88		
7/29/93 13:10	3.62	62	64		
7/29/93 14:15	4.7	67	74	77	
7/29/93 15:10	5.62	74	76	81	
7/29/93 17:00	7.45	69	71	80	
7/30/93 8:50	23.28	13	13	14	20
7/30/93 11:45	26.2	11	11	11	16
7/30/93 15:35	30.03	8	8	9	14
8/2/93 9:00	95.45	8	8	9	12
8/2/93 15:45	102.2	7	7	8	12
8/3/93 8:50	119.28	8	8	9	12
8/4/93 8:55	143.37	14	14	15	18
8/4/93 16:25	150.87	12	12	12	16
8/5/93 8:50	167.28	9	9	10	14
8/6/93 8:50	191.28	7	7	7	11
8/10/93 14:30	292.95	7	7	7	14

Table A.20. Vessel #2 Turbidity Measurements for Wash Cycle 3

Date & Time	Duration (hours)	Turbidity (NTUs) Position #1	Position #2	Position #3	Position #4
7/29/93 9:33	0				
7/29/93 10:30	0.95				
7/29/93 10:50	1.28				
7/29/93 11:20	1.78				
7/29/93 11:50	2.28	45			
7/29/93 13:10	3.62	19			
7/29/93 14:15	4.7	10			
7/29/93 15:10	5.62	11			
7/29/93 17:00	7.45	8			
7/30/93 8:50	23.28	4	5		
7/30/93 11:45	26.2	3	5	31	
7/30/93 15:35	30.03	4	5	21	
8/2/93 9:00	95.45	0	1	3	
8/2/93 15:45	102.2	0	1	2	
8/3/93 8:50	119.28	0	0	2	
8/4/93 8:55	143.37	0	0	2	
8/4/93 16:25	150.87	0	0	2	
8/5/93 8:50	167.28	0	0	1	
8/6/93 8:50	191.28	0	0	1	
8/10/93 14:30	292.95	0	0	0	

Table A.21. Suspended Solids Concentrations for Vessel # 1 Contents

Test Run	Sample Number	Analysis Number	SS (ppm)	SS (wt%)
Run 1	1	1	39,976	4
		2	41,503	4.15
		Average:	**40,739.5**	**4.08**
	2	1	35,917	3.59
		2	36,613	3.66
		Average:	**36,265**	**3.63**
Run 2	1	1	32,085	3.21
		2	32,799	3.28
		Average:	**32,442**	**3.25**
	2	1	28,979	2.9
		2	29,255	2.93
		Average:	**29,117**	**2.92**
Wash Cycle 1	1	1	31,122	3.11
		2	30,677	3.07
		Average:	**30,899.5**	**3.09**
	2	1	31,216	3.12
		2	31,932	3.19
		Average:	**31,574**	**3.16**
Wash Cycle 2	1	1	33,513	3.35
		2	34,020	3.4
		Average:	**33,766.5**	**3.38**
	2	1	32,788	3.28
		2	33,710	3.37
		Average:	**33,249**	**3.33**
Wash Cycle 3	1	1	34,271	3.43
		2	34,028	3.4
		Average:	**34,149.5**	**3.42**

Table A.22. Suspended Solids Concentrations for Vessel # 1 Contents

Test Run	Sample Number	Analysis Number	SS (ppm)	SS (wt%)
Run 1	1	1	41,469.45	4.15
		2	41,539.72	4.15
		Average:	**41,504.58**	**4.15**
	2	1	39,642.41	3.96
		2	40,801.67	4.08
		Average:	**40,222.04**	**4.02**
Run 2	1	1	40,345.16	4.03
		2	40,130.48	4.01
		Average:	**40,237.82**	**4.02**
	2	1	41,360.92	4.14
		2	40,891.12	4.09
		Average:	**41,126.02**	**4.11**
Wash Cycle 1	1	1	47,517.96	4.75
		2	46,818.61	4.68
		Average:	**47,168.29**	**4.72**
	2	1	46,161.13	4.62
		2	47,167.3	4.72
		Average:	**46,664.22**	**4.67**
Wash Cycle 2	1	1	48,903.15	4.89
		2	48,457.37	4.85
		Average:	**48,680.26**	**4.87**
	2	1	45,334.8	4.53
		2	45,286.71	4.53
		Average:	**45,310.75**	**4.53**
Wash Cycle 3	1	1	50,250.71	5.03
		2	50,507.28	5.05
		Average:	**50,378.99**	**5.04**

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