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(RWCT) Simulant Testing in the
PVTD Feed Preparation System**

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S.D. Halstead
R.L. Myers**

**M.R. Beckett
C.J. Freeman
B.K. Hatchell**

March 1996

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest National Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

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Pacific Northwest National Laboratory
Richland, Washington 99352

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1.0 INTRODUCTION

1.1 BACKGROUND

In 1990 the plant design contractor for the Hanford Waste Vitrification Plant (HWVP), Fluor Daniel, issued a technology concerns and data requirements document pertaining to the design issues at that time (WHC-SD-HWV-DP-001). One of the design data items in this document requested design information pertaining to the Recycle Waste Collection Tank (RWCT) in the vitrification plant flow sheet. The RWCT was to routinely receive final canister decontamination sand blast frit and rinse water, Decontamination Waste Treatment Tank (DWTT) bottoms, and melter off-gas Submerged Bed Scrubber (SBS) filter cake. These wastes were to accumulate until finally being batch transferred back to the feed preparation system. Fluor Daniel design specifications in the report showed both the RWCT and DWTT systems as "identical to the Slurry Receipt and Adjustment Tank (SRAT), Slurry Mix Evaporator (SME), and the Melter Feed Tank (MFT), to the degree practical". This included materials of construction for all but the MFT. System requirements for the RWCT, such as agitation, pumping, and evaporation, were left to specifications which required "adequate" functionality.

In order to address the design needs of the RWCT system to meet the performance levels, the Pacific Northwest Laboratory (PNL) Vitrification Technology Development (PVT-D) program undertook a testing effort which used the Feed Preparation Test System (FPTS), in the 324 building highbay, to evaluate its equipment and corresponding performance for a simulant of RWCT slurry. The FPTS is an adaptation of the Defense Waste Processing Facility (DWPF) feed preparation system and represents the initially proposed Hanford Waste Vitrification Plant (HWVP) feed preparation system that was designed by Fluor-Daniel, Inc. This system was previously used (FY-93) to perform SRAT/SME/MFT testing with NCAW based simulants. The data generated during this testing was also used to satisfy the Fluor Daniel design data needs.

1.2 OBJECTIVES

The RWCT testing objectives are listed in the test plan and are repeated in this section. The Specific test objectives for the RWCT test were compiled from two sources: Fluor Daniel HWVP Design Technology Concerns and Data Requirements (D.D. - CBWS 6340) (Fluor Daniel 1990). The following list of the test objectives is divided into groupings which correspond to the sections within this report. Therefore, further information pertaining to these objectives, along with testing results and discussion, can be found in the identified sections.

1.2.1 Mixing Performance (Section 5.0)

Determine the degree of settling/solids accumulation at the tank periphery. (Fluor Need Item 1.1a)

1. Slurry concentration (by wt% total oxides) will be determined in the full-scale test vessel for the RWCT simulant as a function of:

agitator speed (0, 15, 30, 45, 85, 130 rpm)
 sample location (top, middle, and bottom of liquid level)
 slurry height (3250 and 3800 gallons (below top of coils and top agitator blade), 5700 and 7800 gallons (above top of coils and top agitator blade))
 slurry concentration (low, medium, and high)
 baffles (with and without)

2. Pictures will be taken of the empty tank following the completion of slurry testing. Estimates of loss of suspended solids vs. time will be determined and compared with known (or estimated) total solids of tank.

Determine the agitator requirements needed to maintain homogeneity of the RWCT simulant. (Fluor Need Item 1.12a)

1. Slurry concentration (by wt% total oxides) will be determined in the full-scale test vessel for RWCT simulant as a function of:

agitator speed (0, 15, 30, 45, 85, 130 rpm)
 sample location (top, middle, and bottom of liquid level)
 slurry height (3250 and 3800 gallons (below top of coils and top agitator blade), 5700 and 7800 gallons (above top of coils and top agitator blade))
 slurry concentration (low, medium, and high)
 baffles (with and without)

2. Slurry temperature will be measured at different depths.

The ability of the Hydragard sampler to deliver a representative slurry sample will be evaluated.

1. Slurry samples will be obtained via the Hydragard sampler; they will be analyzed (ICP and wt% oxides) and compared with auxiliary samples and known composition.

1.2.2 Pump Priming (Section 6.0)

Determine the supply pressure, flow rate and elapse time required for priming the transfer and sampling pumps in terms of minimizing the amount of priming water required. (Test plan objective 2.2.8)

1. Pump priming requirements will be evaluated as a function of agitator speed (45, 85, 130 rpm) and tank volume (3800, 5700, and 7800 gallons) for the transfer and sample pumps.
2. Sensitivity of pump prime to liquid temperature will be measured at 5700 and 7800 gallons. The temperature will be increased from 40 °C in 10 °C increments until either priming is no longer successful or fluid flow can no longer be sustained after priming.
3. Sensitivity of pump prime to back pressure will be measured at 3800, 5700, and 7800 gallons. The back pressure will be increased from the nominal back pressure until priming is achieved.

1.2.3 Pump Performance (Section 7.0)

Determine the transfer and sampling pump operating performance curves. (Test plan objective 2.2.11)

1. The relationship of pump head vs. flow rate (head-capacity curve) for both the transfer and sampling pumps will be performed at a liquid temperature of 52 °C (125 °F) as a function of:
 - slurry concentration (medium, high)
 - pump speed (1250, 1500, 1785 rpm)

1.2.4 Simulant Flow Characterization (Section 8.0)

Determine pressure drop in piping for appropriate pipe sizes/configuration flow rates. (Test plan objective 2.2.12)

1. The testing conditions will be performed at liquid temperature of 52 °C (125 °F) and a volume of 5700 gallons.

Pressure drop and flow rate will be measured for the slurry through straight sections and long radius elbows for 2", 1", and 1/2" piping. The pressure drop across the Hydragard sampling system will be measured as a function of the sample pump speed. The pump power consumption, speed, and outlet pressure will be measured.

1.2.5 Evaporator and Condenser Performance (Section 9.0)

Determine the effect of varying process parameters on the evaporation rate. (Fluor Need Item 1.1b)

1. Evaporation rates and condensate flow rates will be examined as a function of steam flow to the heating coils (6000, 5200, and 4200 lb/hr) and varying tank volume (7800-5700 gallons) at the nominal off-gas flow rate (approximately 30-50 SCFM) and condenser cooling water flow rate (350 gpm). If necessary, the cooling water flow rate will be adjusted to maintain the condensate temperature below 52 °C (125 °F).
2. Vapor binding, to the extent that it occurs, will be documented.

Determine the liquid carryover during condenser operation. (Fluor Need Item 1.2a)

1. Evaporation rates and condensate flow rates will be examined as a function of steam flow (6000, 5200, and 4200 lb/hr) and varying tank volume (7800-5700 gallons) at the nominal off-gas flow rate (approximately 30-50 SCFM) and condenser cooling water flow rate (350 gpm). If necessary, the cooling water flow rate will be adjusted to maintain the condensate temperature below 52 °C (125 °F).
2. Condensate samples from the condensate line will be taken during all boiling segments. Condensate samples will be measured for wt% total solids; the condensate supernate will be analyzed by ICP and IC to determine solids content.

Determine the heating and cooling coil heat transfer coefficients. (Fluor Need Item 1.3a)

1. Heat transfer rates will be examined as a function of steam flow (6000, 5200, and 4200 lb/hr) and varying tank volume (7800-5700 gallons) at the nominal off-gas flow rate (approximately 30-50 SCFM) and condenser cooling water flow rate (350 gpm). If necessary, the cooling water flow rate will be adjusted to maintain the condensate temperature below 52 °C (125 °F).
2. The energy input from the agitator will be measured as a function of agitation rate (45, 85, and 130 rpm).
3. Heat transfer rates during heating will be determined as a function of slurry temperature (50 °C to 100 °C) at the nominal agitation rate (85 rpm) and air in-leakage/off-gas flow rate. The condenser cooling water flow rate will be varied to obtain < 125 °F condensate.
4. Heat transfer coefficients during cooling will be determined for a cooling water flow rate of approximately 120 gpm.
5. Test parameter data (temperatures, flow, and pressures) of steam, condensates, and gases will be recorded.

1.2.6 Ammonia Dispersion Study (Section 10.0)

1. Ammonia distribution data will be collected in the vent gas, condensate, and tank contents as a function of:

Air flow rates (20, 30, 60, 100, 150, 200, 300 SCFM)
 Slurry pH (4, 6, 8, 10)
 Slurry temperature (35, 50, 60, 100 °C)

1.3 EXPERIMENTAL

The RWCT testing was broken into two main segments; one with and one without tank baffles. The first part of the RWCT test, testing without tank baffles, was performed with diluted NCAW based melter feed. Following the LFCM 8 melter test, the simulated melter feed heel was pumped into HB-13. HB-15 internal components were then washed down with water. A dilute melter feed simulant was then prepared by adding feed preparation condensate and process water with this residual melter feed. This testing involved homogeneity and resuspension efforts for comparing the RWCT simulant test results with the tank baffles installed. The first batch had a target volume of 3800 gallons with a corresponding oxide

loading of 52 g/liter. The second and third batches were 5700 and 7800 gallons, respectively. The fourth batch was made by concentrating from 7800 gallons to 5700 gallons, then pumping enough simulant to HB-13 to leave 3800 gallons remaining.

Following the tests with dilute melter feed simulant, described above, the FPTs tank was cleaned and four baffles were installed 90° to each other. The RWCT tests were then conducted by adding chemicals and condensate/water and mixing four different times for four RWCT batches in the tank. A fifth batch was obtained by concentrating to a lower level. The five batches represent three concentrations (low, medium, high) and four volumes (3900, 4000, 5700, and 7800 gallons).

The RWCT testing was performed in accordance with HWVP test plan addendum HWVP-91-1.2.2.03.03B. Test specific guidance was provided in the RWCT run plan (WTC-006-RWCT-RP01). Call outs from this run plan were then made to the specific test procedures. The test procedures used for the RWCT test included the following:

- WTC-006-FPTS-02 (Slurry Test Loop Testing)
- WTC-006-FPTS-01 (Prototypic Pump Performance Testing and Hydragard Sample Station Pressure Drop Testing)
- WTC-006-RWCT-001 (Procedure for Homogeneity/Resuspension Testing with Recycle Waste Collection Tank (RWCT) Simulant)
- WTC-006-RWCT-002 (Procedure for Ammonia Dispersion Testing in a Laboratory Test System)
- WTC-006-RWCT-003 (Procedure for Preparation of HWVP Recycle Waste Collection Tank (RWCT) Simulant with HWVP 39-4 Frit)

2.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are divided by the individual sections of this report to which they correspond. Therefore, additional information pertaining to the work discussed can be found in its identified section.

2.1 MIXING PERFORMANCE (SECTION 5.0)

- The presence of baffles was not found to make a significant difference, within the accuracies of the data taken, in the mixing and flow patterns achieved in the tank. The same general trends (i.e., minimum agitator speeds required to resuspend the solids) were observed from tests conducted with baffles as the tests conducted without baffles. This finding is further supported by the fact that the agitator in this tank utilizes a radial-axial impeller assembly, which produces vertical flow patterns. The vertical tank baffles which were installed would only increase agitation by baffling radial mixing currents. Therefore, the lack of predominant radial mixing currents in the system may be the reason for the indistinguishable mixing differences before and after the baffle installation.
- For process volumes below the top of the FPTs tank coils (<5000 gallons), agitator speeds in excess of 85 rpm were required to a steady solids concentration within the tank. However, even at these agitator speeds large amounts of scatter was observed in the solids concentration data compared to the data taken at higher tank volumes. This effect is a result of poor homogeneity for the larger glass frit particles in the simulant caused by the upper agitator impeller not being completely covered at these levels. On the other hand, process volumes above the level of the coils (>5000 gallons, both impellers fully covered) required agitator speeds as low as 45 rpm to obtain homogeneous mixtures of the RWCT and diluted NCAW melter feed simulants.
- At the points when homogeneous tank contents were achieved during the tests, the Hydragard sampler appeared to produce the most representative samples. It is believed that one of the baffles, placed near the Auxiliary sample pump intake, may have caused slight differences in the samples collected from this system.
- The agitator power requirements were found to increase with concentration, tank volume, and agitator speed. Simulants that contained higher percentages of fast settling solid material (glass frit versus diatomaceous earth or zeolite) required more power to achieve a homogenous suspension than simulants which contained lower percentages of these materials.

2.2 PUMP PRIMING (SECTION 6.0)

- Successful and unsuccessful water primes of the transfer and sample pumps were recorded for each variation in system and operating conditions with the RWCT simulant. The

sample pump had successful water primes for each condition tested except for the test performed at the lowest tank volume (4100 gallons) and highest agitator speed (130 rpm). The transfer pump showed successful priming operations, at the various system and operating conditions, for a back pressure of 40 psi. Back pressures lower and higher than this value resulted in water prime losses for at least one condition. Additionally, information was found which supports the ability to prime the pump based on the time required to reach a steady discharge pressure. By operating the pumps in this fashion, as opposed to a set conservative amount of prime water, the total volume of prime water added to the tank may be reduced for any slurry type.

2.3 PUMP PERFORMANCE (SECTION 7.0)

- The performance curves for each of the system pumps were comparable to those obtained with concentrated NCAW waste simulant. Since previous testing showed successful pump operation with much higher viscosity/solids content material (i.e. NCAW melter feed), these pump should have successful application to RWCT material transport.

2.4 SIMULANT FLOW CHARACTERIZATION (SECTION 8.0)

- A correlation for the pressure drop of RWCT simulant as a function of flow-rate for various sized pipes was generated. This correlation was then compared tests conducted with water to show the relative differences in the simulant. Pressure drops across 90° long radius elbows for each of the various pipe sizes were also measured using the RWCT simulant and water.

2.5 EVAPORATOR AND CONDENSER PERFORMANCE (SECTION 9.0)

- Evaporator testing was conducted to determine heating, boiling, and cooling heat transfer coefficients for the tank coils. In addition fouling of the heat transfer surfaces was measured as a function of time, heat flux, composition, and degree of agitation. Condenser performance was also determined as a function of boil-up rate. The RWCT tests results were compared with data already documented for processing of water and NCAW simulant. The average heat transfer coefficient for RWCT simulant during heating, boiling, and cooling was very close to the NCAW simulant data. This indicates that no significant degradation of the heat transfer capacity of the coils has occurred between the NCAW and RWCT tests, and the cleaning procedure used to remove the caked on melter feed left from the NCAW campaign was successful. In addition, the reduction in steam header pressure from 130 psia to 100 psia did not have a significant effect on heating performance. During testing with water and NCAW, as well as the RWCT simulant, there was no evidence of vapor binding during the boiling segments.

- The condenser was able to subcool the condensate below 125 °F (the target value) for all evaporation rates. The condenser heat transfer coefficient was slightly less during RWCT testing than in NCAW testing, although the small variation may be more of an artifact of uncontrolled process variables, such as the ambient temperature that the cooling water tower rejects heat to, rather than the effect of different simulants.

2.6 AMMONIA DISPERSION STUDY (SECTION 10.0)

- Ammonia dispersion testing was deleted from the full-scale RWCT test after ammonia unexplainably disappeared during laboratory tests. It became apparent after laboratory-scale testing that there may have been more than one possibility for the ammonia disappearance; adsorption of ammonia ions onto the solids already present, a decomposition reaction of ammonia ion with nitrite, or a combination of both. It is recommended that future testing be prefaced with further laboratory-scale work to explain this phenomenon.

3.0 PROCESS TEST EQUIPMENT

The FPTs consists of process equipment, support equipment, and measuring and test (including control) equipment. Process equipment used during RWCT testing included the test vessel, heat transfer coils, condenser, transfer pump, agitator, sample system, slurry test loop, and auxiliary sample system. Figure 3.1 shows a schematic of the Feed Preparation Test System. For flow characterization testing in the slurry test loop another feed tank (HB-34) equipped with a transfer pump, agitator and thermocouple was used. Support equipment, used for testing but not being tested, includes the High Bay crane, steam supply and condensate return, Air and water services, the off-gas system, and the condensate tank, HB-14. Measuring and test equipment includes the MICON control system, data acquisition system, and test instrumentation. The equipment and its functions are described in this section.

Figure 3.1 RWCT Test System Schematic

3.1 FPTs PROCESS EQUIPMENT

3.1.1 Test Vessel

The purpose of the test vessel (tank HB-15) is to receive, hold and process the simulated waste slurries and maintain slurry homogeneity. For the purposes of the present testing, the test vessel is a full-scale representation of the RWCT. Vessel fabrication details are given in Richmond Machine and Fabricating drawings D-10183-1 through D-10183-3 in Appendix A. The vessel has a 12 foot inside diameter, is 16-1/2-feet tall, and has a total capacity of 9,400 gal. The totally enclosed vessel is constructed from Carpenter 20 Cb-3 steel with the exception of the support structure which is fabricated from carbon steel. The overall vessel height, including the support structure, is 18 feet. The vessel has a 2:1 elliptical head equipped with 25 standard pipe flange nozzles ranging in size from 3 to 72 inches. These flanged penetrations are used to support the condenser, transfer and sample pumps, center coils, agitator, in-tank viewing camera/sight flange, data acquisition/control instrumentation as well as chemical addition, water, condensate reflux, and vent lines.

Although not prototypic to the DWPF design, the test vessel was equipped with four removable 3/8 inch by 12 inch by 150 inch baffles. These baffles were installed on the sides of the test vessel in a cross configuration to each other and was used specifically for the RWCT test. The test vessel is equipped with a probe for obtaining pH measurements. Six guides are attached to the shell near the bottom of the vessel and are centered on nozzles designed for the Holledge level detector (not used during RWCT), the thermowell, the sample and transfer pumps, the auxiliary level detector, and the auxiliary sample system. The guides function to support these components against radial deflection from slurry impingement. The vessel bottom head is flat with a 2-3/8 inch inside knuckle radius transition to the straight flange. The floor slopes 1/4 inch per foot toward a sump located near the vessel wall. An agitator shaft guide is welded at the center of the bottom head. This guide is to protect the coil assembly against unstable shaft deflection and is designed such that it does not contact the shaft during normal operation.

The vessel is supported by eight wide flange I-beams running underneath the bottom head. The I-beams are attached to a 3/4 inch thick skirt which is formed around the lower quadrant of the vessel exterior. Three wide flange I-beams serve as the vessel support legs. These legs are attached to the skirt on 120° radial centerline. Via the support legs, the vessel is mounted to three strain gauge type load cells to allow weight measurement of the contents. The vessel can be completely drained using a 2 inch line which is connected to the sump. The drain line is routed to an air operated double diaphragm pump designated P-1003. Using this pump, the tank contents can be discharged to tank HB-13. Additionally, pump P-1003 can be used to transfer solution through the Hydragard sample station via the sample cooler. The vessel is vented through the condenser to the facility Process Off Gas (POG) system. A regulating valve is installed in the off-gas line to maintain vessel pressure at a level set in the MICON control system. Air flow will be a function of process conditions (i.e. boil down and off-gas flow) as well as air in-leakage through pump and agitator shaft seals. Air flow into the vessel can be increased via the air inlet line flow

control valve. An emergency vent to outside atmosphere operates automatically from the MICON controller, opening at a pre-set tank pressure to prevent over-pressurization, and will fail in the open position on loss of air or electrical supply.

The test vessel is covered by approximately 1500 sq. ft. of 6-mm thick MICROTHERM insulation on its vertical surfaces. The insulation is covered with a stainless steel sheeting to maintain an R value of 1.51. The design is similar to the HWVP design basis which is two layers of MICROTHERM (3 mm each) covered with stainless steel (R value = 1.51).

3.1.2 Heat Transfer Coils

The purpose of the heat transfer coils is to heat, cool and evaporate the simulated waste slurries in the test vessel. The heat transfer or center coil assembly is shown on Richmond Machine and Fabrication construction drawing D-10183-4 in Appendix A. The assembly consists of three sets of coils suspended from an 86-1/2-inch diameter by 2-1/4-inch thick Carpenter 20 Cb-3 flange. This flange is mounted to the head of the test vessel. The coils are constructed from 2 inch schedule 40 Hastelloy Alloy C-276 pipe. Each set of coils consists of 19 rows on a 3.5 inch pitch. The inner water cooling coils have a centerline diameter of 46.5 inches. The middle and outer sets are steam coils and have centerline diameters of 52.5 and 58.5 inches, respectively. Air lines are attached to the steam and water supply inlets to allow residual condensate or water to be discharged prior to assembly removal for inspection.

The heat transfer area of the cooling coil is 143.9 ft². The combined heat transfer area of the two steam coils is 343.5 ft². The heating/cooling coil arrangement for the FPTs is similar to that of the HWVP. Table 3.1.1 summarizes the HWVP and FPTs heating/cooling coil heat transfer surface area. Modifications were made to stabilize the coils to protect against deflection by fluid currents generated by the agitator. These modifications were made in accordance with those performed at DWPF and included stiffening the structural supports of the heat transfer coil by the addition of reinforcing plate, channel and formed angle cross bracing.

Table 3.1.1 Surface Area Differences between HWVP and FPTs Heating/Cooling Coils

	<u>HWVP</u>	<u>FPTS</u>
SRAT/SME Heating	340 ft ²	343 ft ²
SRAT/SME Cooling	140 ft ²	144 ft ²
MFT Heating	N/A	343 ft ²
MFT Cooling	300 ft ²	144 ft ²

3.1.3 Condenser

The purpose of the condenser is to condense vapors produced from heating the test vessel contents and produce a high solids Decontamination Factor between the slurry and condensate. The condenser is a full-scale representative prototype of the SRAT/SME condenser (excluding remote features) and is shown on sheets 1 and 2 of Alaskan Copper Works fabrication drawing M-4636 in Appendix A. The condenser has an overall height of 14 feet and is constructed from stainless steel. The condenser shell, which is 24 inches in diameter, encloses 314 sst vertical tubes, 0.75 inch diameter by 14 BWG wall thickness by 88 inch long. The tubes, which have an inside heat transfer area of 373.8 ft^2 , surround a 6 inch central riser which is insulated from the shell side cooling water by an 8 inch pipe. A removable Chevron-type mist eliminator and a condenser baffle in the condenser minimize non-condensable carryover.

Vapors from the SRAT/SME are drawn up the riser and then down through the tube bundle. A flow meter mounted in a trap in the condensate exit line measures the rate and amount of condensate generated. Condensate samples are removed via two sample ports located in the trap. The condensate can be refluxed back to the test vessel or collected in tank HB-14. The non-condensables will be sampled through a port in the off gas line prior to being exhausted to the facility off gas system. Cooling water flow as well as inlet and outlet pressure and temperatures are monitored to determine the condenser heat transfer coefficients and shell side pressure drop.

3.1.4 Agitator

The agitator in the test vessel is designed to mix and suspend solids in the simulated waste slurry. The agitator assembly, shown in the Philadelphia Mixer outline dimension drawing 90EUZ0631-1 in Appendix A, is comprised of a drive motor, gear box, and agitator shaft with impellers. The overall assembly length is approximately 23 feet. The drive motor is a 100-hp TEFC high efficiency motor, controlled by a variable speed AC drive controller. This controller allows variable shaft speed control from 14 to 130 rpm by varying the motor operating frequency from 6 to 60 Hz. The gear box is equipped with an auxiliary oil pump to assure adequate gear lubrication during operation at lower speeds. The controller is equipped with a process control interface so that the agitator can be operated from the MICON control system. The controller is also equipped with voltage, amperage, and frequency indicators. The agitator shaft, which is approximately 18-feet long, is attached to the gear box output shaft utilizing a hydraulic coupling developed by I. E. Dupont. The Hydraulic Coupling is constructed from Nitronic-60. The agitator shaft is constructed from Hastelloy Alloy C-276 and is equipped with two 36 inch diameter impellers.

The bottom impeller is a 4 blade vertically flat (radial) type which is located approximately 7 inches above the vessel floor. Two of the radial impeller blades are constructed from Hastelloy Alloy C-276 and two of the blades are constructed from Hastelloy Alloy C-22. The second impeller, located 60 inches above the radial impeller, is a 3 blade hydrofoil or turbine type impeller constructed from Hastelloy Alloy C-276.

3.1.5 Slurry Transfer/Feed and Sample Pumps

The slurry transfer pump, shown in Lawrence Pump fabrication drawing M46313 in Appendix A, is a vertical cantilevered centrifugal type variable speed pump which is used to transfer feed out of the vessel. The transfer pump is also used as the melter feed pump because the DWPF design specifications for both pumps are identical. The pump is driven by a 20-hp TEFC electric motor via a variable speed AC controller. The motor can be controlled from the MICON control station, or can be manually operated using a rheostat mounted at the controller. The controller is located on the west wall, northwest corner, of the 324 building High Bay third floor. The pump has a 100 gpm design transfer capacity utilizing a 2 inch discharge. The pump intake is equipped with a 2 inch water priming system. The pump impeller and casing are constructed from stellite, while the remainder of the pump is fabricated from stainless steel.

The sample pump, shown on Lawrence Pump fabrication drawing M46315 in Appendix A, is used to recirculate slurry through the sample system and is similar in construction to the transfer pump. The pump is driven by a 15-hp TEFC electric motor and has a maximum capacity of 58 gpm. The motor controller operating features and physical location are the same as those described for the transfer pump. The variable speed pump is designed such that a majority of the slurry is discharged directly back into the vessel through a ceramic restriction orifice which is installed into the outlet line. Therefore, during maximum operating speed it is expected that approximately 48 gpm of slurry will be discharged back into the vessel while approximately 10 gpm is circulated through the sample station.

3.1.6 Sample System

The sample system is designed to transfer simulated waste slurry from the tank to the Hydragard Sampler. The sample pump, which is used to circulate slurry through the system, is similar to the slurry transfer/melter feed pump and is described in Section 3.1.5.

The sample station, shown on sheet 1 of drawing SK-3-28257 in Appendix A, consists of the following:

- one 2-way FUJIKIN valve
- one 3-way FUJIKIN valve
- one standard ball valve
- Hydragard in-line sampler
- flow meter
- pressure transmitter

Slurry is transferred to the station through 1/2 inch schedule 40 stainless steel pipe via the sample pump. This line is connected to the 2-way FUJIKIN valve. From the valve the slurry is routed to the Hydragard sampler. Between the 3-way valve and the sampler are the pressure gauge and the flow element. The 1/2 inch schedule 40 return line exits the station through the 3-way FUJIKIN valve and is routed back to the vessel through a connection on the sample pump flange. When the

sampler is engaged to draw a sample, the slurry flows through the sampler to an overflow container via several feet of polymer tubing. The 3-way and standard ball valves are operated as required to either obtain a sample or back-flush the lines with water.

3.1.7 Auxiliary Sample System

An auxiliary sample system consists of an air-driven pump, a sampling port, and seven sample lines that penetrate the top of the test vessel through a flange. The seven sample lines extend to different elevations in the tank, allowing the collection of samples from the test vessel at different elevations. The seven sample lines are valved into a main line that runs through the pump and sampling port and back to the test vessel. Process water is also valved into the main sample line to allow the flushing of all sample lines after use.

3.1.8 Thermowell

The FPTS stainless steel thermowell design utilizes six replaceable thermocouples to provide temperature profile data on test vessel contents. The guard pipe and thermowell tube support/attachment details mimic the designs developed for the DWPF thermowell assembly. The FPTS thermowell is shown on drawing SK-3-28256 in Appendix A. The DWPF thermowell is shown in Bechtel drawing W 752129 in Appendix A.

3.2 SLURRY TEST LOOP

The Slurry Test Loop (STL) is designed to measure the pressure drop that occurs from flow of slurries in various sizes of pipes and elbows. A schematic of the slurry transfer test loop is shown on the drawing worksheet WSHT-SIPT-022 in Appendix A and in Figure 3.2.2. The instrument labeling for these drawings is shown in Appendix B. The test loop is composed of five line sizes (1/2, 1, 1 1/2, 2, and 3 inches in diameter), each schedule 40 type 304L stainless steel pipe. Ball valves are used to direct and control the flow in each of the five pipe sizes in the loop. Magnetic flow meters are located so that the flow rate in each test section can be measured. Each of the five differently sized pipe sections has a test section of straight pipe and a test section containing a standard long radius 90° elbow. A Rosemount model 3051 differential pressure transmitter is connected to remote seal assemblies installed on the upstream and downstream ends of each test section. Direct 1/16" pressure taps are also used to measure the pressure drop on the elbow sections. Valved in ports are used to sample the slurry at the two inch inlet and outlet. The slurry test loop is tied into the melter feed transfer loop and the Frit Slurry Feed Tank (FSFT) HB-34 on the High Bay third floor (shown in Figure 3.2.1). The RWCT slurry was pumped from HB-15 to this system for STL testing in order to minimize testing conflicts with the HB-15 equipment.

3.2.1 Frit Slurry Feed Tank (HB-34)

Part of the RWCT simulant, approximately 500 gallons, was pumped into tank HB-34 and used for the STL testing. Tank HB-34, located on the third floor of the High Bay, is 5 feet in diameter

by 7 feet 8 inches in height and has a maximum capacity of 685 gallons and a normal operating capacity of 500 gallons. There are penetrations to support a center-mounted agitator, an internal coil, chemical addition lines, water lines, as well as process monitoring instrumentation. The frit slurry feed tank, HB-34, is equipped with a thermowell in which a type J thermocouple, TI-3400, resides. The thermocouple measures the temperature of the vessel contents and is calibrated within a range of 0 to 750 °C. The feed tank is also equipped with a single internal heating/cooling heat transfer coil, and a Princo level probe, LI-3400, which were not used during STL testing with RWCT simulant.

Tank HB-34 is equipped with an agitator to keep the solids suspended. A schematic of the equipment used is shown in Appendix A as well as in Figure 3.2.1. The mixture in tank HB-34 was kept homogenous and well mixed by running the agitator throughout testing and pumping the contents in HB-34 through the STL approximately every few minutes.

Figure 3.2.1 Slurry Test System, 3rd Floor High Bay, 324 Building

Figure 3.2.2 Frit Slurry Test System, 2nd Floor High Bay, 324 Building

3.2.2 Transfer Pump (P-2011)

A centrifugal transfer pump, P-2011, located at the outlet of Tank HB-34 was used to pump the RWCT simulant through the slurry test loop. This Peerless feed pump was driven via a 5 horsepower electrical motor and can supply 150 gpm against a 60 psi discharge pressure.

3.2.3 Variable Speed Agitator (AG-2006)

Vessel HB-34 is equipped with a Sharpe agitator which has two impellers mounted on a single shaft, both 15 inch diameter axial flow impellers. The lower impeller is mounted 8 inches (20 cm) above the bottom of the vessel on the bottom of the shaft and the upper impeller is mounted 24 inches (61 cm) from the bottom of the shaft. A 2 horsepower variable speed electric motor is coupled to a reduction gear which will rotate the shaft at a maximum rate of 124 rpm. The agitator was operated at 80% of full power during the STL test with RWCT waste simulant.

3.3 SUPPORT EQUIPMENT

Miscellaneous support equipment is required to test in the FPTs. The following includes the function and description of each component/system.

3.3.1 High Bay Crane

The 324 Building High Bay is equipped with a 5-ton capacity crane for use in handling major equipment components (i.e. sample and transfer pumps, agitator, coil assembly, etc.) for maintenance and/or inspection purposes. The crane has a 48 foot lifting clearance and will also be used to handle bulk chemicals during slurry preparation.

3.3.2 Steam Supply and Condensate Return

The steam coil assembly is supplied by a 6 inch header located in the northwest corner of the facility. The steam source is the 300 Area power plant. Pressure at the header is approximately 90 psig at a temperature of 318° F. The HWVP plant design steam pressure is 150 psig. Tests at Savannah River Laboratory indicate the design boil-up rate of 10 gpm can be acquired. Reduced steam pressure is not expected to impact the quality or extent of tests. Steam condensate is returned to the powerhouse via a 4 inch condensate header which is also located in the northwest corner of the facility.

3.3.3 Air and Water Services

Air and water services are also supplied from the 300 area power house. All water service to the FPTs (coiling coils, condenser, flush water, etc.) is supplied by two 2-inch water lines which are routed on both the first and second floors, along the east and west walls, of High Bay. Water pressure at the 6-inch building header is 60 psig.

The instrument air source is a 1-inch line routed along the east wall on the second floor. This run terminates at an air dryer located above the fume hood which was installed specifically to support FPTS operations. The 60 psig air pressure is reduced at the dryer to 15 psig before distribution to the miscellaneous differential pressure transmitters and I/P converters which comprise a portion of the FPTS monitoring and control systems.

3.3.4 Process Off-Gas System

The source of the High Bay process Off Gas system is a blower located in the 324 building tank pit. The blower has an 800 SCFM capacity operating at -140 inches H₂O. The blower exhausts to the zone two tunnel and exits the facility stack after passing through one set of HEPA filters. Tanks HB-14 and HB-15 are tied into the POG blower via a 6 inch header which runs along the east wall on the second floor of High Bay. Should off gas conditions warrant, the existing PSCM submerged bed scrubber and high efficiency mist eliminator can be valved into the system.

3.3.5 Tank HB-14

A stainless steel tank which measures approximately 9-ft diameter by 9-ft. high has been installed for use as the Slurry Mix Evaporator Condensate Tank (SMECT). The tank, designated HB-14, has a 3800 gallon operating volume and is the primary receiver for condensate generated from SRAT/SME condenser operations. Tank instrumentation includes a capacitance probe for real time level measurement and a pH probe for on-line condensate pH measurement. The tank is located in the northeast corner of the High Bay first floor and is equipped with an air sparge system. The sparge system will be used to obtain representative pH measurements and may be used in the event that chemical additions are required to neutralize the condensate. The sparge system may also be used to resuspend particulates should any be carried over from the condensing process. The vessel does not have an agitator due to limited clearance above the tank. Tank HB-14 also serves as an emergency over flow containment vessel for HB-15. The tank HB-14 bottom side drain is attached to double diaphragm air operated pump P-1400. The pump outlet is routed to a header that allows solution to be transferred to the process sewer, HB-13, or HB-15.

3.4 MEASURING AND TEST EQUIPMENT

The measuring and test equipment (M&TE) list covers the control system, data acquisition system, and off-gas sampling system. This list is shown in Appendix B. Additionally, the piping and instrumentation diagram (P&ID) is given in Appendix A. Process control, data acquisition, off-gas sampling equipment and test instrumentation are described in the following sections.

3.4.1 Process Control System

The control system monitors process variables, controls the operation of equipment, and automatically initiates sequences of actions according to specified interlocks. It functions in

parallel with the data acquisition system by sharing the sensor signals with the data acquisition system. The primary components of the control system are four MICON P-200 controllers, termination panels, and two operator consoles. Each MICON controller provides 15 analog inputs, eight analog outputs, eight discrete (on/off) outputs, and sixteen discrete inputs. It has eight programmable control loops, each of which controls one of the analog outputs. Each operator console provides a cathode ray tube (CRT) display and a dedicated keyboard. The CRTs can display either text-based or graphical images. Text displays are specified as part of the configuration process. Graphical displays are designed separately using supplied graphical building blocks. During operation the operator can select from among the previously defined displays. The operator keyboards are special process control keyboards designed for easy access to control functions. They employ touch-sensitive membrane switches to ensure reliable operation in dirty environments.

The control system controls the behavior of process components based on specified set points and real-time process data, and initiates sequences of steps based on defined process interlocks. Approximately eighty process variables are monitored throughout the process, mostly temperatures, pressures, and flow rates.

3.4.2 Data Acquisition System

The Data Acquisition System (DAS) is comprised of three physical parts:

- a. Acquisition Unit - Hewlett Packard HP-3852 Scanning Voltmeter.
- b. Processing Unit - INTEL 80386-based AT-Architecture Computer.
- c. IEEE-488 Communications Interface with remote extenders.

The HP-3852 is installed in an equipment cabinet along with the MICON process controllers. It parallels the MICON controllers, and performs all Engineering Unit Conversions on the data acquired from its internal Analog-Digital Converters (ADC). It contains internal memory to allow initial buffering of the converted data, prior to transmission to the host Processing Unit. Communications between the HP-3852 and the Processing Unit computer is accomplished by means of an IEEE-488 parallel instrumentation bus. Since the HP-3852 and the computer are physically separated by a significant distance, remote extenders are used to extend the range of the IEEE-488 bus. The Processing Unit accepts the converted data from the Acquisition Unit, performs alarm range checking, displays user-selected data values in both textual and graphical forms, and provides data archiving facilities.

The Processing Unit is an INTEL 80386 Central Processing Unit (CPU) operating on an Industry Standard Architecture (ISA) bus. This is the original IBM PC-AT bus. The Processing Unit contains a minimum of one fixed disk of ≥ 100 Mbytes formatted capacity, and a streaming tape cartridge unit for data archiving.

The DAS software was designed, developed, and validated in accordance with PNL-MA-70 requirements. User interface functions are password-protected to prevent unauthorized or

inadvertent disruption of the application. The software is designed so that transfer of acquired data from the HP-3852 can be temporarily suspended during data archiving operations. The data acquisition on the HP-3852 will be undisturbed during this time. Once an operator has initiated the data archiving, actual transfer of the data files will be accomplished by the computer application. At the end of the archiving process, the user will be prompted to remove the archive tape cartridge and store it in the long term storage area.

3.4.3 Test Instrumentation

Measuring and test equipment includes sensors for pressure, flow, temperature, etc. Refer to the M&TE list in Appendix B for a detailed list of measurements. Each individual test procedure will identify which of the measurements on the M&TE list are required for that particular test. All instruments that provide data for the test shall be calibrated in accordance with quality assurance requirements as defined by PNL-MA-70 (PAP-70-1201).

4.0 ANALYTICAL

4.1 BACKGROUND

A number of physical chemical analyses were performed in support of the RWCT testing. These analyses were performed to verify and characterize the chemical composition of the waste simulant after each phase of the simulant makeup and to obtain the data required for specific tests. There were a total of five phases in the simulant makeup, the first four of which involved the addition of chemicals and water to FPTs tank. The fifth simulant makeup phase consisted of concentrating the simulant in the tank from 7800 gallons to 5700 gallons. The detailed chemical analyses are included in Appendix C.

Tank homogeneity testing required multiple samples at various tank levels obtained from both the auxiliary sampler and the Hydragard sampler. These samples were used to identify sampling and analytical error as well as statistical variations due to mixing. A few other tests also required sampling, such as pump priming which involved the addition of significant amounts of water which could effect the simulant concentration.

When a sample was collected, it was identified with a unique sample identification number, as required by the test plan, and entered on a sample log sheet. When submitted for analysis, an Analytical Request Form (ARF) was completed, identifying the sample and the required analysis. Table 4.1.1 shows the test activity and run plan reference during which each RWCT sample was taken, the number and size of the samples, the type of analysis performed, and the sample identification numbers. The descriptions for each of the individual analyses are given in Section 4.2. The intended rheology analysis, which would have determined viscosity and shear rate, was canceled due to the difficulty in obtaining meaningful data for the dilute simulant with the available equipment. A more thorough description of this limitation is given in Section 8.4.1.

Table 4.1.1 RWCT Testing and Sampling Activities (Part 1)

Sample Activity by Run Plan Section	Tank Vol (gallons)	No. of Samples	Sample Size	Sample I.D	Sample Date	Comments
Sect. 2.3, Simulant Preparation	3200	2	100 ml	SIPT3-2.3.1 & 2.3.2	1/13/94	None
Sect. 2.4, Simulant Characterization	3200	3	100 ml	SIPT3-2.4.1 thru 2.4.3	1/17/94	None
Sect. 2.4, Simulant Characterization	3200	3	1 Liter	RWCT-2.2.4 thru 2.2.6	1/17/94	Rheology analysis canceled
Sect. 3.1, Homogeneity/Resuspension	4140	84	30 ml	RWCT-3.1.1 thru 3.1.95	1/17/94	Auxiliary Sampler, 1-49,51, 52, 54-59, 62-66, 68-71, 73, 74, 76-78, 80-83, 86-89, 91-95
Sect. 3.1, Homogeneity/Resuspension	4140	12	15 ml	RWCT-3.1.50 thru 3.1.96	1/17/94	Hydragard Sampler, all others.
Sect. 4.2, Simulant Preparation	4250	2	100 ml	RWCT-4.2.1 & 4.2.2	1/19/94	Second batch--simulant preparation.
Sect. 4.3, Simulant Characterization	4250	3	100 ml	RWCT-4.2.1 thru 4.2.3	1/20/94	Simulant Characterization
Sect. 4.3, Simulant Characterization	4250	3	1 Liter	RWCT-4.2.4 thru 4.2.6	1/20/94	Rheology analysis canceled
Sect. 5.1, Homogeneity/Resuspension	4250	84	30 ml	RWCT-5.1.1 thru 5.2.96	1/20/94	Auxiliary Sampler, 1-49,51, 52, 54-59, 62-66, 68-71, 73, 74, 76-78, 80-83, 86-89, 91-95
Sect. 5.1, Homogeneity/Resuspension	4250	12	15 ml	RWCT-5.1.50 thru 5.1.95	1/20/94	Hydragard Sampler, all others.
Sect. 6.4, Pump Priming	4600	3	100 ml	RWCT-6.4.1 thru 6.4.3	1/27/94	None
Sect. 7.2, Simulant Preparation in HB-15, Third Batch	5400	2	100 ml	RWCT-7.2.1 & 7.2.2	1/31/94	None
Sect. 7.3, Simulant Characterization	5400	3	100 ml	RWCT-7.3.1 thru 7.3.3	2/1/94	None
Sect. 7.3, Simulant Characterization	5400	3	1 Liter	RWCT-7.3.4 thru 7.3.6	2/1/94	Rheology analysis canceled
Sect. 8.2 & 8.3, Settling	5400	15	30ml	RWCT-8.2.1-15	1/31/94	Auxiliary Sampler
Sect. 8.2 & 8.3, Settling	5400	3	30ml	RWCT-8.2.16-18	2/1/94	Auxiliary Sampler
Sect. 8.4, Homogeneity/Resuspension	5430	84	30 ml	RWCT-8.4.1 thru 8.4.96	2/1/94	Auxiliary Sampler, 1-49,51, 52, 54-59, 62-66, 68-71, 73, 74, 76-78, 80-83, 86-89, 91-95
Sect. 8.4, Hom/Resuspension	5430	12	15 ml	RWCT-8.4.50-95	2/1/94	Homogeneity: Hydragard, all others.
Sect. 8.5, Hom/Resuspension	5430	12	30 ml	RWCT-8.5.1-15	2/1/94	Auxiliary Sampler, 1-8, 10, 11, 13, 14.
Sect. 8.5, Hom/Resuspension	5430	3	15 ml	RWCT-8.5.9, 8.5.12, 8.5.15	2/1/94	Hydragard Sampler, 9, 12, 15.

Table 4.1.2 RWCT Testing and Sampling Activities (Part 2)

Sample Activity by Run Plan Section	Tank Vol (gallons)	No. of Samples	Sample Size	Sample I.D	Sample Date	Comments
Sect. 9.1, Slurry Test Loop	5480	2	100 ml	RWCT-9.1.1 & 9.1.2	2/21/94	Analysis canceled
Sect. 10.2, Simulant Preparation	7900	2	100 ml	RWCT-10.2.1 & 2	2/22/94	None
Sect. 10.3, Simulant Characterization	7900	3	100 ml	RWCT-10.3.1 thru 3	2/23/94	None
Sect. 10.3, Simulant Characterization	7900	3	1 Liter	RWCT-10.3.4 thru 6	2/23/94	Rheology analysis canceled
Sect. 11.1, Homogeneity/Resuspension	7900	84	30 ml	RWCT-11.1.1 thru 96	2/23/94	Auxiliary Sampler, 1-49, 51, 52, 54-59, 62-66, 68-71, 73, 74, 76-78, 80-83, 86-89, 91-95 Hydragard, all others.
Sect. 11.1, Hom/Resuspension	7900	12	15 ml	RWCT-11.50 thru 11.1.96	2/23/94	
Sect. 12.1, Evaporator/Condenser	7960	9	100 ml	RWCT-13.1.1-9	2/25/94	None
Sect. 14.2, Pump Priming	8180	3	30 ml	RWCT-14.2.4 thru 6	3/1/94	None
Archive	8180	2	30 ml	RWCT-14.2.7 & 8	3/1/94	None
Sect. 14.2, Pump Priming	8180	3	100 ml	RWCT-14.2.1 thru 3	3/1/94	None
Sect. 15.2, Simulant Preparation	5960	3	1 L	RWCT 15.2.1 thru 15.2.33	3/7/94	None
Archive	5960	2	100 ml	RWCT 15.2.4 & 15.2.5	3/7/94	None
Archive	5960	5	30 ml	RWCT 15.2.6 thru 15.2.10	3/7/94	None
Sect. 15.2, Simulant Characterization	5960	3	100 ml	RWCT 15.2.17-19	3/10/94	None
Sect. 15.2, Simulant Characterization	5960	6	30 ml	RWCT 5.2.11 thru 16	3/10/94	None
Continued	5960	3	1 Liter	RWCT 5.2.20 thru 15.2.22	3/10/94	Rheology analysis canceled
Sect. 16.2, Settling	5960	18	30 ml	RWCT 16.2.1 thru 16.2.18	3/10/94	
Sect. 16.4, Homogeneity/Resuspension	5960	84	30 ml	RWCT 16.4.1 thru 16.4.96	3/10/94	Auxiliary Sampler, 1-49, 51, 52, 54-59, 62-66, 68-71, 73, 74, 76-78, 80-83, 86-89, 91-95 Hydragard, all others.
Sect. 16.4, Hom/Resuspension	5960	12	15 ml	RWCT 16.4.50-95 15	3/10/94	
Continued	5960	12	30 ml	RWCT 16.5.1-15	3/10/94	Auxiliary Sampler, 1-8, 10, 11, 13, 14.
Continued	5960	3	15 ml	RWCT 6.5.9, 12, & 15	3/10/94	Hydragard Sampler, 9, 12, 15.
Sect. 17.2, Pump Priming	6200	3	30 ml	RWCT 7.2.1 thru 17.2.3	3/16/94	None

4.2 DESCRIPTION OF ANALYTICAL PROCEDURES

The following descriptions clarify the analytical techniques and instruments used for RWCT testing and refer to the detailed analytical procedures. Except for the settling rate, all of the analyses were done in accordance with Impact Level II Quality Assurance requirements (See PNL QA Manual, PNL-MA-70). The settling rate analyses were performed for information only, as no approved procedure existed for that analysis.

Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES)

ICP-AES is an analytical instrument used for simultaneous multielement cation determination. A Thermo-Jarrel Ash Model ICAP 61E instrument was used for these analyses. Solid and slurry samples are either fused (see Fusion description below) or dissolved in mineral acid (usually nitric or hydrochloric acid) in order to form a solution which can be analyzed by the machine. Liquid or aqueous samples are either diluted in mineral acid or analyzed directly (with a mineral acid spike). The RWCT samples were analyzed and reported on a wet weight basis unless otherwise specified. These analyses were obtained by the Analytical and Process Support Laboratory (APSL) procedure APSL-14.

Ion Chromatography (IC)

IC is a process by which the concentration of solublized anions are determined. The RWCT IC analyses were performed in accordance with procedure APSL-12, "Operation of the DIONEX DX-300 Series Ion Chromatography System". Typically, a sample of slurry is leached with an appropriate amount of deionized water as to assure that the sample is not saturated with a certain species. The leachate of the sample is then injected into the Dionex DX-300 IC System and the anions measured by separation through an analytical column. The high ionic strength eluant carries the sample into the column where it preferentially elutes and separates the anions from the column. The eluted solution is then passed into a suppresser cell. The hydrogen ions in the suppresser cell combine with the species in the samples forming their acidic species, while simultaneously, the sodium diffuses into the regenerant solution (A dilute solution of sulfuric acid). The solution is then passed into a conductivity cell where the conductivity of these highly acidic species is measured. Retention time and peak area, at this point, determine the anion and its concentration. Mixed standards of known concentration are analyzed along with the samples. IC measures fluoride, chloride, formate, nitrate, sulfate, nitrite, phosphate, and oxalate species.

Fusion

This is a method for the dissolution of solid and slurry/sludge samples that contain high

concentrations of silicates and/or refractory compounds which would not readily dissolve in mineral acids. Alkali metal peroxides, usually sodium or potassium, are added as part of the fusion. Typically, both of these peroxides are used in order to correct for the presence of one another in the results. As a result, most of the major metal ions are analyzed twice for each sample. Acid is also added to the fusions to further dissolve the sample and prevent any type of matrix effects. This technique is used for preparing samples for ICP and follows procedure APSL-03.

Density or Specific Gravity

Density is the mass per unit volume of the sample. Specific gravity is the ratio of the density of the sample to the density of water at the same temperature. The density was measured for the specified RWCT samples according to procedure APSL-11. Samples were shaken and either poured or pipetted into a 15 mL centrifuge tube graduated at subdivisions of 0.1 mL. These samples were then centrifuged (because the tube graduations are hard to read through the slurry) and the volume read and recorded.

Weight Percent (wt%) Total Solids

The weight percent total solids is the percentage of mass of the sample that remains after removing all free water by drying in a furnace at 103 -105°C for approximately 24 hours. This data was obtained according to the procedure APSL-05.

Weight Percent (wt%) Solids (Solids Layer, Decanted Supernate)

The weight percent solids is equal to the mass of solids remaining after centrifuging a sample, decanting the supernate, and drying the precipitate at 103-105°C for approximately 24 hours. The results of this procedure yield the true solid phase concentration since significant amounts of dissolved salts can reside in the liquid phase of a slurry. This analysis was used for the homogeneity analyses in Section 5. Because the RWCT samples settled fairly quickly, the entire sample was used for most of the analyses. This testing was done in accordance with procedure APSL-08.

Weight Percent (wt%) Total Oxides

The percentage of the mass of the sample that remains after converting all non-volatile elements to oxides at 1000°C for approximately 2 hours, in a porcelain or alumina crucible. This measurement was obtained according to the procedure APSL-06.

pH

pH is defined as $-\log [H^+]$. It is applicable to aqueous solutions or slurries only. (The scale is defined as: $0 < \text{pH} < 7$ = acidic, 7 = neutral, $7 < \text{pH}$ = basic). A pH meter calibrated each time a sample or set of samples were tested was used. This testing was performed for indication purposes only.

4.3 TEST SIMULANT COMPOSITIONS

This section describes the target chemical concentrations for each of the simulants tested. The first part of the RWCT test, testing without tank baffles, was performed with diluted NCAW based melter feed heel. This testing involved homogeneity and resuspension efforts for comparing to the RWCT simulant test results with the tank baffles installed. The following section provides the target compositions of the dilute NCAW melter feed test, as well as the target and measured compositions of the five batches of simulant made up for the RWCT tests. The results of simulant analyses performed in support of specific tests (i.e., settling, resuspension, homogeneity, pump priming, evaporator/condenser, etc.) are described in the sections where those test results are reported.

4.3.1 Dilute NCAW Melter Feed Simulant

The desired target compositions for the RWCT test were given in the Addendum to Test Plan Number HWVP-91-1.2.2.03.03B, Revision 1, for Slurry-Integrated Performance Testing (SIPT). The first batch had a target volume of 3800 gallons with a corresponding oxide loading of 52 g/liter. The second and third batches were 5700 and 7800 gallons, respectively, and had the same target oxide loading. The fourth batch was made by concentrating from 7800 gallons to 5700 gallons, then pumping enough simulant to HB-13 to leave 3800 gallons remaining for the final batch. This final batch had an oxide loading of approximately 75 g/liter.

Samples from homogeneity and resuspension tests performed on each batch were analyzed and are reported in Section 5.0. The target compositions of the dilute NCAW melter feed are given in Table 4.3.1, below. Note that the total concentrations in this table are higher than the oxide loadings previously given. This difference is due to the changes in non-oxide compounds to oxides when fired for oxide loading analysis.

Table 4.3.1: Dilute NCAW Melter Feed Target Concentrations

Material Name	Target Comp. #1 (g/L)	Target Comp. #1 (g/L)	Material Name	Target Comp. #1 (g/L)	Target Comp. #1 (g/L)
Al	0.724	0.989	Na ₃ PO ₄	0.465	0.634
Ag(NO ₃)	0.028	0.038	NaCl	0.079	0.107
B	0.009	0.012	NaI	0.004	0.005
B ₂ O ₃	7.085	9.674	NaNO ₂	3.747	5.116
Ba(OH) ₂ x 8 H ₂ O	0.058	0.079	NaNO ₃	1.567	2.140
Ca	0.043	0.059	Nb ₂ O ₅	0.002	0.003
Ca(OH) ₂	0.086	0.118	**Nd(OH) ₃ x 42.58%	0.576	0.786
CdO	0.065	0.089	NdF ₃	0.043	0.059
Cd(OH) ₂	0.563	0.768	Ni	0.274	0.375
Ce(NO ₃) ₃ x 6 H ₂ O	0.258	0.352	Pb(NO ₃) ₂	0.154	0.210
Cr(NO ₃) ₃ x 9 H ₂ O	0.219	0.299	**Pr(OH) ₃ x 54.82%	0.028	0.038
Cs(NO ₃)	0.133	0.181	Rb(NO ₃)	0.012	0.017
Cu(SO ₄) x 5 H ₂ O	0.123	0.168	Sb ₂ O ₃	0.001	0.001
Diatomaceous Earth	0.619	0.845	SeO ₂	0.003	0.003
Fe	3.079	4.204	Si	0.027	0.036
GeO ₂	2.5E-5	3.4E-5	SiO ₂	26.448	36.111
90 wt% HCOOH	6.147	8.393	Sm(NO ₃) ₃ x 6 H ₂ O	0.030	0.042
KMnO ₄	0.034	0.046	SnSO ₄	0.003	0.004
KOH	0.037	0.051	Sr(NO ₃) ₂	0.039	0.053
**La(OH) ₃ x 43.35%	0.096	0.131	Ta ₂ O ₅	0.001	0.001
LaF ₃	0.011	0.015	TeO ₂	0.016	0.022
LiO ₂	2.480	3.386	Ti	0.004	0.006
Mg(NO ₃) ₂ x 6 H ₂ O	0.555	0.758	TiO ₂	0.097	0.132
Mn	0.224	0.306	Y(OH) ₃	0.016	0.022
MoO ₃	0.089	0.121	Zeolite	0.310	0.423
Na	0.115	0.157	Zn(OH) ₂	0.065	0.089
Na ₂ C ₂ O ₄	0.349	0.477	Zr	1.549	2.114
Na ₂ CO ₃	1.658	2.264	Zr(OH) ₄	0.038	0.052
Na ₂ SO ₄	0.115	0.157	Totals	60.60	82.74

4.3.2 RWCT Simulant

A total of five different RWCT simulants were made for testing. The fifth batch was obtained by concentrating batch #4 to a lower level. The five batches represent three concentrations (low, medium, high) and four volumes (3900, 4000, 5700, and 7800 gallons). The relative amounts of solids added to make each of the RWCT simulant batches are shown in Table 4.3.2, below.

Table 4.3.2. Target Composition of RWCT Simulant Solid Additives

Compound Name	Solids Composition (wt%)
CdO	0.91
Diatomaceous Earth	9.05
90 wt% HCOOH	0.54
70 wt% HNO ₃	1.51
KMnO ₄	0.49
Na ₂ C ₂ O ₄	3.41
Na ₃ PO ₄	2.09
NaCl	0.03
NaNO ₃	23.39
Zeolite	4.52
Frit	54.06
Solids Total	100

Approximate Composition of Diatomaceous Earth:

91.1% SiO₂, 4.0% Al₂O₃, 1.3% Fe₂O₃, 0.2% P₂O₅, 0.2% TiO₂, 0.5% CaO, 0.6% MgO, and 1.1% Na₂O, K₂O

Approximate Composition of Zeolite:

68.12% SiO₂, 17.51% Al₂O₃, 7.63% Na₂O, 3.81% Fe₂O₃, 1.1% CaO, 0.78% MgO, 0.57% P₂O₅, and 0.49% TiO₂

Approximate Composition of Frit:

70% SiO₂, 14% B₂O₃, 5% Li₂O, 9% Na₂O, 1% CaO, and 1% MgO

Using the target information shown in Table 4.3.2 along with the individual batch target volumes and concentrations, the corresponding cation and anion targets can be obtained for comparison to measured ICP and IC results. These target ion concentrations are shown in Tables 4.3.3 through 4.3.7. Each of these tables has the ion target values as well as ICP and IC analyses from three separate samples. Note that the tank volumes shown for each batch are the target volumes and may vary slightly from the actual volumes. This analytical information, along with all of the analytical data for the test, is given in Appendix C.

Table 4.3.3 RWCT Simulant Concentration for Batch #1
(Tank Volume = 3900 gal, Specific Gravity = 0.99)

Ion	Slurry Target Conc. (1) (ug/g)	Slurry Concentration per ICP/IC (2) (ug/g)		
		Sample 1	Sample 2	Sample 3
Cd	230	209	209	162
Si	6631	4682	6006	3667
Al	176	180	193	148
Fe	59	119	128	95
P	120	133	132	107
Ti	12	13	15	12
Ca	133	112	154	116
Mg	110	82	106	81
Mn	41	49	49	38
Na	3562	2334	2629	2050
K	59	< Det.	< Det.	< Det.
B	677	440	596	453
Li	360	239	325	247
Zn	0	41	42	42
Zr	0	28	35	24
NO3	5230	4890	4839	4799
HCOO	154	100	88	96
PO4	350	222	244	297
Cl	5	< Det.	< Det.	< Det.
(COOH)2	0	310	323	315

Table 4.3.4 RWCT Simulant Concentration for Batch #2
(Tank Volume = 4000 gal, Specific Gravity = 1.02)

Ion	Slurry Target Conc. (1) (ug/g)	Slurry Concentration per ICP/IC (2) (ug/g)		
		Sample 1	Sample 2	Sample 3
Cd	499	446	423	470
Si	14415	8817	10262	17761
Al	384	372	366	437
Fe	129	198	150	189
P	260	271	239	255
Ti	26	23	22	35
Ca	289	234	276	458
Mg	239	150	186	328
Mn	88	103	94	95
Na	7743	5891	7049	7629
K	129	< Det.	< Det.	< Det.
B	1472	720	1100	1948
Li	782	416	525	1058
Zn	0	286	305	319
Zr	0	31	35	32
NO3	11368	10872	10462	10809
HCOO	335	177	172	181
PO4	761	< Det.	< Det.	< Det.
Cl	11	< Det.	< Det.	< Det.
(COOH)2	0	673	653	671

Table 4.3.5 RWCT Simulant Concentration for Batch #3
(Tank Volume = 5700 gal, Specific Gravity = 1.02)

Ion	Slurry Target Conc. (1) (ug/g)	Slurry Concentration per ICP/IC (2) (ug/g)		
		Sample 1	Sample 2	Sample 3
Cd	536	454	478	483
Si	15999	10295	11671	13180
Al	412	393	564	460
Fe	138	206	209	198
P	403	285	283	291
Ti	27	26	30	30
Ca	305	284	317	321
Mg	114	183	210	237
Mn	95	105	113	114
Na	6645	5883	7960	8010
K	130	< Det.	< Det.	< Det.
B	2259	969	1098	1272
Li	1176	527	590	685
Zn	0	312	601	335
Zr	0	27	38	38
NO3	12511	12247	12189	12290
HCOO	324	414	412	416
PO4	817	834	1046	672
Cl	12	< Det.	< Det.	< Det.
(COOH)2	0	1838	1793	1802

Table 4.3.6 RWCT Simulant Concentration for Batch #4
(Tank Volume = 7800 gal, Specific Gravity = 1.00)

Ion	Slurry Target Conc. (1) (ug/g)	Slurry Concentration per ICP/IC (2) (ug/g)		
		Sample 1	Sample 2	Sample 3
Cd	536	357	393	430
Si	15483	9106	13868	15424
Al	412	351	427	462
Fe	138	160	181	186
P	551	255	252	270
Ti	27	23	31	34
Ca	313	249	350	367
Mg	258	165	254	275
Mn	95	89	98	105
Na	8341	4234	6275	6897
K	138	< Det.	< Det.	< Det.
B	1581	886	1360	1539
Li	840	374	741	830
Zn	0	295	315	317
Zr	0	17	28	30
NO3	12210	11579	11522	11442
HCOO	324	191	190	209
PO4	817	621	620	585
Cl	12	< Det.	< Det.	< Det.
(COOH)2	0	734	699	684

Table 4.3.7 RWCT Simulant Concentration for Batch #5
(Tank Volume = 5700 gal, Specific Gravity = 1.05)

Ion	Slurry Target Conc. (1) (ug/g)	Slurry Concentration per ICP/IC (2) (ug/g)		
		Sample 1	Sample 2	Sample 3
Cd	698	624	556	604
Si	20179	23533	16967	21066
Al	537	700	566	625
Fe	180	305	250	285
P	386	393	342	389
Ti	36	53	38	47
Ca	404	589	408	500
Mg	334	448	296	280
Mn	131	145	139	144
Na	11286	11823	9412	11159
K	187	< Det.	< Det.	< Det.
B	2061	2549	1634	2146
Li	1094	1384	897	1186
Zn	0	332	308	328
Zr	0	50	40	47
NO3	16878	15233	14899	14945
HCOO	448	452	497	471
PO4	1129	1061	718	707
Cl	17	< Det.	< Det.	< Det.
(COOH)2	0	1049	970	1063

The analytical values shown in the five previous tables show obvious variation in the frit specific cations. These are mainly silicon and boron. The reason for these fluctuations is due to the degree of homogeneity of these large particles in the tank when these samples were taken. The following section will discuss this in more detail.

5.0 MIXING PERFORMANCE

5.1 BACKGROUND

In order to verify that a uniform, homogeneous, slurry composition can be achieved in the RWCT, slurry composition profiles within the FPTs tank were observed for each set of tank processing conditions. The agitator speeds required to reach and maintain homogeneity in the tank were studied for these various conditions and tank levels. Additionally, some observations quantifying solids settling (expected to be most predominant at the tank periphery) were performed.

Homogeneity was determined by measuring the total solids content and specific gravity for various liquid heights at steady state conditions (a zero gradient indicates uniformity).

Homogeneity was also evaluated by observing the temperature of the tank contents at different depths during heating and cooling (no difference in temperature may indicate uniformity). The process and equipment areas evaluated included sampler performance (accuracy and precision) and slurry homogeneity and resuspension as a function of agitator speed, sampling height, and slurry concentration. During the tests, the process variables changed included agitator speed, slurry level, and slurry concentration.

An important aspect of the RWCT test was that homogeneity and resuspension testing was performed with and without the presence of four removable 3/8-inch by 12-inch by 150-inch baffles. These baffles were added to the tank walls of the process vessel and were intended to improve the mixing conditions as well as preserve consistency with Fluor Daniel design. Testing without baffles was performed using a diluted melter feed heel shortly after the completion of NCAW 1 (SIPT 2) testing. (Reference: Letter from R.A. Smith to J.M. Creer, May 4, 1993, "Modifications to Recycle Waste Collection Tank Test Activities," 9353662). The results of the homogeneity and resuspension testing without baffles are reported in Section 5.4.

5.2 TESTING PROCEDURES

5.2.1 Homogeneity, Resuspension and Settling

The objective of homogeneity and resuspension testing with the RWCT simulant was to determine the ability of the full-scale prototypic mixing equipment to produce a homogeneous agitated slurry, to evaluate the ability of the Hydragard sampler to collect a representative sample, and to determine the ability of the solids to resuspend after a prescribed amount of settling time. Slurry homogeneity was evaluated by comparing the weight fraction solids from various locations within the tank during any one set of process conditions. This data also enabled the minimum agitator speed required to resuspend the settled solids to be determined. The Hydragard sampler's ability to collect a representative sample was compared with the Auxiliary sampler and previous data. Slurry samples were obtained at approximately six inches from the bottom of the tank using the Hydragard sampler and at three locations using the Auxiliary sampler.

To perform homogeneity and resuspension testing, the agitator was shut off the night before to

allow the solids to settle. The first set of homogeneity samples was taken at zero agitation; this helped determine the level of solids buildup along the tank periphery. The agitator was then started and gradually brought up to 15 rpm. After 30 minutes, the second set of homogeneity samples was taken. This process was repeated as the agitator speed increased to 30, 45, 85, and 130 rpm, respectively. The Hydragard sample pump was shut off for the first four agitator speeds (0, 15, 30, 45 rpm) and reengaged for the last three agitator speeds (45, 85, 130 rpm). The discharge of the Hydragard sample pump has been shown to have a significant effect on the tank mixing capabilities at the lower agitator speeds (it helps to resuspend the solids); these effects were observed up to 45 rpm.

A series of five homogeneity and resuspension tests were performed (with and without baffles) to determine the level of homogeneity under a variety of process conditions. Tests were conducted to measure the specific gravity and weight fraction solids as a function of agitator speed, sampling height, and slurry type/concentration. Table 5.2.1 summarizes the testing parameters.

Table 5.2.1: Summary of Homogeneity and Resuspension Tests

Test #	Simulant*	Description	Tank Volume (Gallons)	Tank Level (Inches)**	Agitator Speeds (rpm)	Sample Heights (Inches)
1	Dilute M.F.	W/out Baffles	3800	55	0,15,30,45,85,130	6,24,48
2	Dilute M.F.	W/out Baffles	5700	82	0,15,30,45,85,130	6,24,48
3	Dilute M.F.	W/out Baffles	7800	113	0,15,30,45,85,130	6,84,102
4	Dilute M.F.	W/out Baffles	7800	113	0,130	6,84,102
5	Dilute M.F.	W/out Baffles	3800	55	85,130	6,24,48
1	RWCT	With Baffles	3900	56	0,15,30,45,85,130	6,24,48
2	RWCT	With Baffles	4100	59	0,15,30,45,85,130	6,24,48
3	RWCT	With Baffles	5700	82	0,15,30,45,85,130	6,24,48
4	RWCT	With Baffles	7800	113	0,15,30,45,85,130	6,84,102
5	RWCT	With Baffles	5700	82	0,15,30,45,85,130	6,48,78

* Dilute M.F. = Diluted NCAW Simulant-Based Melter Feed (Tank Heel)

RWCT = Recycle Waste Collection Tank Simulant

** Height in inches from the tank bottom

For homogeneity and resuspension testing without baffles, the Hydragard sample pump was turned on for the first four agitator speeds (0, 15, 30, 45 rpm) and left on for the last three (45, 85, 130 rpm) for the first 3800 gallon test. Solids resuspension vs. time was evaluated as a separate test at 7800 gallons (0 to 130 rpm). Only two speeds (85, 130 rpm) were used for the second test at 3800 gallons.

For homogeneity and resuspension testing with baffles, additional samples were taken just after the agitator was shut off (while the solids were settling) at 5700 gallons (both process

concentrations). Five sets of samples were taken at different sampling locations (top, middle, bottom) as a function of time. ICP and IC analyses were performed to determine the extent and nature of the settling solids present in the slurry. This allowed a comparison to be made between the Auxiliary and the Hydragard samplers, as well as to quantify the settling times for the different materials contained within the solid phase of the slurry. The target time intervals were based on the results of lab-scale tests.

The following procedure was used for homogeneity and resuspension testing as per test procedure WTC-006-RWCT-001, Procedure for Homogeneity/Resuspension Testing with Recycle Waste Collection Tank (RWCT) Simulant.

- 1) The agitator was shut off to allow the solids to settle overnight.
- 2) The liquid volume and concentration were verified.
- 3) The pump for the Auxiliary sampling system was started and the contents of the tank were allowed to circulate through the sampling systems for at least 5 minutes.
- 4) The first set of 12 samples were taken at 0 rpm (four sets of three samples) in a specified order. A recirculation time of one minute was allowed between samples.
- 5) The agitator speed was adjusted to 15 rpm and maintained for at least 30 minutes before initiating sampling activities. The assumption was made that 30 minutes was enough time for steady-state (i.e., homogeneous) conditions to develop.
- 6) The second set of 12 samples were taken at 15 rpm (four sets of three samples) in a specified random order. A recirculation time of one minute was allowed between samples.
- 7) The agitator speed was adjusted to 30 rpm and maintained for at least 30 minutes before initiating sampling activities.
- 8) The third set of 12 samples were taken at 30 rpm (four sets of three samples) in a specified random order. A recirculation time of one minute was allowed between samples.
- 9) The agitator speed was adjusted to 45 rpm and maintained for at least 30 minutes before initiating sampling activities.
- 10) The last set of 12 samples were taken at 45 rpm (four sets of three samples) in a specified random order. A recirculation time of one minute was allowed between samples.
- 11) The sample pump for the Hydragard sampling system was started. The contents of the tank were allowed to circulate through the sampling systems for at least 5 minutes.
- 12) The first set of 16 samples were taken at 45 rpm (four sets of four samples) in a specified order. A recirculation time of one minute was allowed between samples.
- 13) The agitator speed was adjusted to 85 rpm and maintained for at least 30 minutes before initiating sampling activities.
- 14) The second set of 16 samples were taken at 85 rpm (four sets of four samples) in a specified random order. A recirculation time of one minute was allowed between samples.
- 15) The agitator speed was adjusted to 130 rpm and maintained for at least 30 minutes before initiating sampling activities.
- 16) The last set of 16 samples were taken at 130 rpm (four sets of four samples) in a specified random order. A recirculation time of one minute was allowed between samples.

- 17) The sampling systems were flushed, the sampling pumps were shut off, and the agitator speed was set at 85 rpm (nominal process conditions).

5.2.2 Sampling

For the purposes of these tests, a minimum number of samples had to be established in order to satisfy a criteria for statistical analysis. The required (minimum) number of samples at each process condition is dependent on a number of factors, some of which can be directly controlled based on the experimental objectives. These factors include the size of the standard deviation of replicate samples and analyses, the probability of making erroneous conclusions from statistically designed tests concerning the homogeneity of the slurries, and the desired detectable differences between the average weight percent solids and densities at different locations.

Four samples at each of the four Auxiliary sampler locations for each process condition results in at least a 95% probability of detecting a true difference of at least 2 total weight percent between any two of the sample concentration means. This determination assumes that there is a 5% probability of concluding either that the mix is not homogeneous when in fact it is homogeneous or that the slurry is homogeneous when it is not. For each homogeneity and resuspension test, four sets of three to four samples were taken in random order for each agitator speed. (Total: 12 to 16 samples for each agitator speed and 96 samples per test). Three of the samples were taken at different tank levels using the Auxiliary sampler. In general, the three Auxiliary locations were designated as: (1) One sample at approximately the same depth as the Hydragard sample pump intake; (2) One sample at about 1-2 feet below the slurry surface; (3) One sample immediately below the slurry surface. The fourth sample was taken using the prototypic Hydragard Sampler, denoted with an 'H'. The inlet for the Hydragard sampler is located approximately six inches from the bottom of the tank. Table 5.2.2 shows each of the four sampling locations as a function of process tank volume. Note that the relative locations of (2) and (3) of the auxiliary sampling system change with the process tank volume.

Table 5.2.2: Sampling Locations Used at Each Volume

Sampling Location (Instrument)	Sampling System	Sampler Height (from bottom)	Sample Label, 3800-4100 gallons	Sample Label, 5700 gallons	Sample Label, 7800 gallons
Hydragard	Hydragard	0' 6"	(H)	(H)	(H)
SPL 3/4-V01	Auxiliary	0' 6"	(1)	(1)	(1)
SPL 3/4-V02	Auxiliary	2' 0"	(2)	(2)	
SPL 3/4-V03	Auxiliary	4' 0"	(3)	(3)/(2)	
SPL 3/4-V04	Auxiliary	6' 6"		(3)	
SPL 3/4-V05	Auxiliary	7' 0"			(2)
SPL 3/4-V06	Auxiliary	8' 6"			(3)

5.3 MIXING STUDIES WITH RWCT SIMULANT

5.3.1 Homogeneity Studies

In a homogeneous tank, the solids distribution and elemental chemical composition are required to be uniform. The temperature of the tank contents would also tend to be uniform. Two factors must be considered when considering homogeneity: 1) the sample or measuring point must represent the vessel contents; 2) the sampling and analytical system must obtain accurate and reproducible results. Samples were taken of each slurry type under various testing conditions at different tank heights. A comparison was made between the calculated solids (based on chemical addition) and the average solids (based on sampling) during homogeneity testing. From an analytical standpoint, it was determined that the Hydragard sampler gave representative samples at 85 and 130 rpm for all the process volumes tested. The results of this comparison are given in Table 5.3.1 below.

Table 5.3.1: Comparison of Calculated to Measured Slurry Properties

Simulant	Description	Process Volume, gal	Calculated Solids (Target), wt%*	Average Solids (Measured), wt%**	Difference, wt%
RWCT	With Baffles	3900	1.95	2.09	7.4
RWCT	With Baffles	4100	4.20	4.07	3.1
RWCT	With Baffles	5700	4.54	4.68	3.2
RWCT	With Baffles	7800	4.52	4.38	3.0
RWCT	With Baffles	5700	6.16	5.68	7.7

* The calculated solids include CdO, Diatomaceous Earth, Zeolite, and Frit.

** The average solids are based on averages of samples taken at 85 and 130 rpm using the Hydragard sampler.

Comparisons of sample analyses were also made as a function of tank height for the different slurry types, slurry heights, and agitator speeds. No difference in concentration at different sampler levels implies homogeneity. For the purposes of this study, a zero concentration gradient is defined to be less than a 5% difference between the average concentrations taken from any two heights. Scatter in the data points, average values, and range of values were considered when comparing sets of concentrations.

The error bars shown in the following plots illustrate how important the standard deviation is to the validity of the sample values. A long error bar would convey a large standard deviation (bad reproducibility) while a shorter error bar would convey a smaller standard deviation (better reproducibility). Figures 5.3.1 through 5.3.5 show a comparison between all the sample locations as a function of agitator speed. Each symbol represents the average of all the samples taken for each sample location. Duplicate symbols are present at 45 rpm since testing was conducted twice (sample pump on vs. sample pump off) at this agitator speed. The closeness of these symbols relative to one another is one way of evaluating tank homogeneity.

Figure 5.3.1: RWCT Homogeneity Test #1 (3900 gallon tank level, with baffles)

The data in Figure 5.3.1 show a high degree of scatter at all of the agitator speeds. Indeed, this may suggest that homogeneity was never achieved at any of those speeds. However, this tank level did not completely cover the top (axial) impeller on the agitator. Complete coverage of both agitator impellers is required for proper mixing. This claim will be supported in the following data which was collected at tank levels which fully covered both agitator impellers.

Figure 5.3.2: RWCT Homogeneity Test #2 (4100 gallon tank level, with baffles)

At 4100 gallons, as shown in Figure 5.3.2, it appeared as though homogeneity may have been achieved between 85 and 130 rpm. This data suggests better mixing than what was present at 3900 gallons. The error bars are still significantly large, which implies high standard deviations and large amounts of scatter. It is interesting to note that of the higher agitator speeds, the least amount of scatter occurred at 85 rpm.

Figure 5.3.3: RWCT Homogeneity Test #3 (5700 gallon tank level, with baffles)

At 5700 gallons, as shown in Figure 5.3.3, it appeared as though homogeneity was achieved between 45 and 85 rpm. This shows the best mixing data of any in the first three plots, as the power to volume ratio is the highest at this volume (this is the point at which both impellers just become covered with liquid). The error bars are significantly smaller, which means smaller amounts of data scatter. As shown at 4100 gallons, the least amount of scatter seems to occur at 85 rpm. This may have occurred since the flow patterns were ideal at that agitator speed.

Figure 5.3.4: RWCT Homogeneity Test #4 (7800 gallon tank level, with baffles)

At 7800 gallons, as shown in Figure 5.3.4, it appeared again as though homogeneity was achieved between 45 and 85 rpm. Although this figure shows good mixing results, the data is not as tight as what was found at 5700 gallons.

Figure 5.3.5: RWCT Homogeneity Test #5 (5700 gallon tank level, with baffles)

At 5700 gallons (concentrated), as shown in Figure 5.3.5, it appeared as though homogeneity was achieved between 45 and 85 rpm. Since the power to volume ratio is the highest at this volume, the mixing at this volume is expected to be superior. The error bars are significantly lower, which means lower standard deviations and smaller amounts of scatter. As shown previously at 5700 gallons, the least amount of scatter seems to occur at 85 rpm. This supports the fact that the flow patterns may be slightly disrupted at 130 rpm for ideal suspension of solids.

Some conclusions can be inferred about the level of homogeneity that was observed during RWCT testing. At 3900 gallons, the scatter in the samples was too great to support any conclusion that homogeneity was achieved at any agitator speed. However, this was expected

since the top agitator impeller was not covered at this tank level. At 4100 gallons, the point at which homogeneity was achieved seemed to be greater than 85 rpm and at 5700 and 7800 gallons, this point appeared to occur just over 45 rpm. Another observation was that the optimum agitator speed seemed to be 85 rpm for tests run at the lower process volumes (4100 and 5700 gallons). The agitator speeds of 85 or 130 rpm seemed equally optimum at the higher volume (7800 gallons). This phenomenon may be due to the different flow patterns that result as a function of volume.

At the point at which homogeneity existed, the Hydragard sampler seemed to produce the most representative samples. The scattering in the samples taken from the Auxiliary samplers suggest that there were non uniform flow patterns at the pump intake. It is believed that one of the baffles, placed near the Auxiliary pump intake, may have slightly disrupted these flow patterns. However, these effects were lessened at the higher agitator speeds when homogeneity was achieved. The degree of homogeneity in the process test vessel was also evaluated by examining the temperature at different levels. If the temperatures at different elevations were the same throughout the test vessel, then general homogeneity may be inferred. Three to four thermowell sensors: TI-1046 (26"), TI-1045 (54"), TI-1044 (80"), and TI-1043 (106") were used to determine temperature, which depended on how high the liquid level was. The temperatures during testing, as given by the thermowell sensors, differed by no more than 0.5 °C. However, the calibration of the sensors was accurate only to 2.2 °C. From these results, it may be inferred that the vessel temperature appeared homogeneous at all process conditions.

5.3.2 Settling Studies

Settling tests were performed in the FPTS tank during two of the RWCT segments. Both tests consisted of turning off the agitator, from a 130 rpm steady operation segment, and collecting samples from the Auxiliary sampling ports over established time intervals. These intervals corresponded to sampling times at 0, 10, 30, 60, 120, and 1440 minutes after turning power off to the agitator. Both settling tests were performed at a tank volume of 5700 gallons and each corresponded to the two RWCT simulant concentrations prepared for this target level. Settling samples from the lower simulant concentration test were analyzed for cation concentration by ICP (see Appendix C). Alternatively, the samples collected during higher simulant concentration testing were analyzed for solids concentration.

The lower RWCT simulant concentration testing was performed in accordance with Section 8.2 of the RWCT Run Plan (WTC-006-RWCT-001). The results of the ICP analyses of the settling samples are shown in Appendix C. The retrievable solids content was below detection limits for the 30 minute and greater samples for all levels except the lowest (level 1), for which solids were retrievable in the 30 minute sample. The main use of the cation concentration information was to evaluate the separation of the larger frit particles from the smaller sized particles in the simulant while settling occurred. In order to make this comparison, both frit specific and non-frit specific cations were identified which were known to exist in the simulant in a solid phase only. The zeolite and diatomaceous earth portions of the RWCT simulant share many of the oxides for

which the frit is composed. The only component which was almost exclusively specific to the frit was boron oxide. Similarly, a solid phase material which was exclusive to the non-frit material was cadmium oxide. Therefore, boron and cadmium were used to evaluate frit and non-frit particle separation during the settling tests.

In order to compare the ICP results, the boron weight was divided by the sum of the boron and the cadmium masses. Additionally, this same value was calculated using the target concentrations of the RWCT simulant in the system at the time of the test. All of these partitioning values are shown in Table 5.3.2.

Table 5.3.2: Solid Phase Partitioning of RWCT Components During Settling

Settling Time	Boron(mass) / (Boron(mass) + Cadmium(mass))			
	Target	Sampler Level 1	Sampler Level 2	Sampler Level 3
0 min	0.75	0.70	0.69	0.71
10 min	—	0.21	0.19	0.22
30 min	—	0.17	—	—

The initial tank sample values (time = 0) in Table 5.3.2 are relatively consistent at various heights for each of the sampler levels. This would suggest a homogenous solids phase at each of those levels. The same consistency at various heights is seen in the 10 minute samples. Some difference can be seen between the zero time samples and the target based value, shown in the table. This difference is approximately 7%. The most likely source of this difference is the errors associated with obtaining the target levels in the tank when water was added for simulant make-up.

Table 5.3.2 also shows that the 30 minute partitioning value still has a fairly high solid phase boron content close to the tank bottom. This is most likely due to the location of the level 1 sample port. The level 1 sample port is located near the bottom of the tank and sees an intermittent increase in solids content during settling until the solids layer compacts below that level. This trend was seen in the second settling experiment, when solids content was analyzed instead of cation concentration.

The second settling experiment was performed in accordance with Section 16.2 of the RWCT Run Plan. This procedure was identical to the first settling test with the exception of the analyses performed on the samples. The solids weight percent was measured for these samples instead of cation concentration. These samples were centrifuged and the supernate decanted before the solids layer was dried and weighed which is similar to the homogeneity sampling. The results of the second settling test are given in Appendix C and plotted in Figure 5.3.6.

Figure 5.3.6: Settling Rates (Wt% Solids over Time) of RWCT Simulant

The trends in Figure 5.3.6 show that the solids content from the two highest sampler levels constantly dropped to near zero within the first 30 minutes. These results are consistent with the findings in the first settling test which claimed unretrievable solids in the settling samples beyond this time. However, the data from the first (lowest) sampler level shows the intermittent increase in solids content previously mentioned. This build-up reflects the time in which the solids layer was still compacting at the bottom of the tank. In the time it took to take the samples at $t = 0$, the tank contents became non-homogeneous; this implies a rapid settling rate.

Similar observations were made during settling experiments in the laboratory. Volume percents were reported as a function of time for both the top of the solids phase layer, as it settled on the bottom of container. The data from these experiments is given in Appendix C. In all of these tests, the glass frit portion of the solids layer almost completely formed within one minute of the settling time. These findings are consistent with the tank settling test results where the bulk of the settling occurred within the first 10 minutes of agitator shut-off and virtually all solids were settled out of the fluid within 30 minutes of agitator shutdown. The speculated layer compacting in the tank was also observed during the laboratory settling experiments.

5.3.3 Resuspension Study

Although no settling tests were performed with the dilute NCAW melter feed, a resuspension test was performed with this material at a 7800 gallon tank level, without the baffles installed. The agitator was first shut off overnight to allow the solids to settle. In order to start the resuspension test the agitator was turned on and immediately adjusted to 130 rpm. The plot of the results from this experiment are shown in Figure 5.3.7.

Figure 5.3.7: Dilute NCAW Melter Feed Resuspension Test
(7800 gallon tank level, without baffles)

The solids seemed to resuspend rather rapidly and appeared to have distributed equally throughout the tank within the first 30 minutes. After this point, the solids concentration appears to remain relatively constant.

5.4 COMPARISON OF TANK HOMOGENEITY WITH AND WITHOUT BAFFLES

The proper design of tank baffles is important in obtaining satisfactory mixing results. Adequate baffling can assure good mixing by providing a flow pattern that carries throughout the entire batch. Excessive baffling (also called "over baffling") will actually reduce the mass flow and will localize the mixing, and can result in poor process performance. A proper mixing environment includes proper tank and baffle designs and the efficient use of applied power (Oldshue, 1983).

Weight percent oxides were analyzed for the dilute NCAW melter feed simulant homogeneity samples. However, weight percent solids were later employed for the prepared RWCT simulant, as seen in Section 5.3.1. The results of the two sets of tests, baffles (dilute NCAW melter feed simulant) and no baffles (RWCT simulant), can be compared on the basis of the point at which homogeneity was achieved. Plots for the tests without baffles, similar to those generated in the last section, were employed for this comparison. These are shown as Figures 5.4.1 through 5.4.4.

Figure 5.4.1: Dilute NCAW Melter Feed Homogeneity Test #1
(3800 gallon tank level, without baffles)

At 3800 gallons, as shown in Figure 5.4.1, it appeared as though homogeneity may have been achieved between 85 and 130 rpm. This however, seems to show better mixing than what was present at 3900 gallons in the tests with baffles present. The error bars are a little smaller for this test (compared to the test with baffles) but are still higher than the error bars present at the higher volumes tested. The main reason for the smaller error bar size in this data may be attributable to the fact that oxide content was determined and not solid content. The nature of the variation magnitude may be different depending on the analysis technique. Solids content was used for the RWCT simulant (with baffles) rather than oxide content since vitrification was not performed at

the conclusion of testing.

Figure 5.4.2: Dilute NCAW Melter Feed Homogeneity Test #2
(5700 gallon tank level, without baffles)

At 5700 gallons, as shown in Figure 5.4.2, it appeared as though homogeneity was achieved between 45 and 85 rpm. The error bars are significantly lower, which means lower standard deviations and smaller amounts of scatter. As seen previously in the RWCT results at this level, the least amount of scatter seems to occur at 85 rpm.

Figure 5.4.3: Dilute NCAW Melter Feed Homogeneity Test #3
(7800 gallon tank level, without baffles)

At 7800 gallons, as shown in Figure 5.4.3, it again appeared as though homogeneity was achieved between 45 and 85 rpm. This degree of homogeneity was also observed during the RWCT tests, with baffles. The amount of scatter at 85 and 130 rpm is roughly the same, which implies that the flow patterns are volume dependent.

Figure 5.4.4: Dilute NCAW Melter Feed Homogeneity Test #5
(3800 gallon tank level, without baffles)

At 3800 gallons (higher concentration), as shown in Figure 5.4.4, it appeared as though homogeneity may have been achieved between 85 and 130 rpm. This, however, seems to show better mixing than what was present at 3900 gallons with baffles. The interesting fact is that the most amount of scatter occurs at 85 rpm. This leads us to believe that the mixing flow patterns are not optimum for solids suspension.

Some conclusions can be inferred about the degree of homogeneity that was observed during RWCT testing without baffles. As more volume became available to fully resuspend the solids, the scatter in the samples became less apparent. In general, when the fluid level is below the heating/cooling coils (less than ~5000 gallons), normal circulation and mixing patterns cannot be achieved and higher agitation rates are needed to get the flow through the coils. In fact, homogeneity most likely occurred at the higher agitator speeds and the higher process volumes.

At 3900 gallons, the point at which homogeneity was achieved seemed to be greater than 85 rpm and at 5700 and 7800 gallons, this point occurred above 45 rpm. It was apparent in both sets of tests that 5700 gallons was the optimum volume for mixing and suspension of solids.

As was observed in the RWCT tests with baffles, the Hydragard sampler produced the highest solids contents compared to the samples taken from the Auxiliary samplers. It is believed that orientation of the Hydragard sampler made it easier to collect solids much like a solids collection pot. At the point at which homogeneity existed, the Hydragard sampler seemed to produce the most representative samples.

Even though the mixing seemed to be slightly better in the tests without baffles, there really is no significant mixing difference between either sets of tests. An important consideration is that the solids present in the dilute NCAW melter feed waste simulant (tests without baffles) were easier to suspend than the solids present in the RWCT simulant (tests with baffles), since a greater percentage of frit particles were present in the later simulant. The same general trends were observed from tests conducted with baffles as tests conducted without baffles. In conclusion, it is not within the accuracy of the data taken to discern significant differences in the mixing and flow patterns within the FPTs tank before and after the baffle addition. This finding is supported by the fact that the agitator in this tank utilizes a radial-axial impeller assembly. The resultant mixing patterns from this assembly are expected to be predominantly vertical. The vertical tank baffles which were installed would only increase agitation by baffling radial mixing currents. Therefore, the lack of predominant radial mixing currents in the system may be the reason for the indistinguishable mixing differences before and after the baffle installation.

5.5 TANK AGITATOR POWER REQUIREMENTS FOR RWCT SIMULANT

One of the objectives established for RWCT equipment performance is to determine the agitator speed, power, and time required for solids to resuspend in the slurry after settling has occurred. Homogeneity and resuspension tests have been performed which relate agitator power to agitator current, power number, and agitator speed.

5.5.1 Theory

In terms of agitation, power is defined as the product of rotational speed and applied torque. Torque is determined by integrating the pressure distribution over the surface of the agitator blade. The FPTs agitation system employs a 4 blade radial impeller 7 inches from the bottom of the tank and a 3 blade turbine (flat plate-style blades) 60 inches from the bottom impeller. The dual blade system provides two complimentary flow patterns; a radial flow pattern from the bottom set of impellers and an axial flow pattern from the turbine impellers. Correlations for finding the power for this type of system are based on two dimensionless parameters, shown as:

- 1) N_{Re} Reynolds Number, $Dv\rho/\mu = D^2N\rho/\mu$

where: D = Impeller Diameter (36 inches for FPTs)
 $v = DN$, Velocity
 N = Agitator Speed
 ρ = Density
 μ = Viscosity (water = 993×10^{-6} kg/(m*s))

- 2) N_p , Power Number, $Pg_c/\rho N^3 D^5$

where: P = Agitator Power
 g_c = Gravitational Constant

The Reynolds number is defined as the inertial force divided by the viscous forces. The power number relates the imposed forces to the inertial forces and is a function of both the Reynolds number and the Froude number.

Figure 5.5.1, below, shows the logarithmic correlation as N_p vs. N_{Re} for flat-blade turbine systems. Note that this figure shows a standard correlation for tanks with one set of blades only.

Figure 5.5.1: N_p vs. N_{Re} for Single Flat-Bladed Impeller Systems

Large values of the Reynolds number (above 10^4 for the curves in Figure 5.5.1) indicate turbulent agitation, where the inertial forces dominate the viscous forces. Therefore, viscosity has little effect on agitator power requirements in that range of Reynolds numbers. In passing through the transitional range to the laminar range, the effect of viscosity on power consumption becomes increasingly significant. At very low values of the Reynolds number, laminar agitation exists and the power number varies inversely with Reynolds number (or directly with viscosity remaining constant). A fixed, dimensionless pressure distribution along the impeller blade means that the power number is a constant at high Reynolds numbers. Figure 5.5.1 shows that curve 2 becomes constant at $N_p = 4$ and at the higher Reynolds numbers. For this condition, the power number can be reduced and an expression for the power derived as follows:

$$P = 4 \rho N^3 D^5$$

Note that according to the developed equation, the power varies with the agitator speed to the third power. Another parameter that is constant in the turbulent region is the velocity distribution. In fluid agitation, the direction as well as the magnitude of the velocity is important. The directions of the velocity flow vectors throughout an agitated vessel are, by definition, the flow pattern. Flow patterns at high Reynolds numbers have particular practical importance. (Dickey and Fenic, 1976).

Figure 5.5.2, below, shows the same type of logarithmic correlation for N_p vs. N_{Re} using values derived during RWCT testing (with baffles). Remember that the FPTs tank uses two sets of impeller blades, unlike the equipment data described previously.

Figure 5.5.2: N_p vs. N_{Re} for the FPTs During RWCT Simulant Testing

This figure shows that for the FPTs agitation system, the Reynolds number was above 10^5 for each agitator speed (15 through 130 rpm). This varies from the theoretical plot by a factor of 10. However, note that a downward trend in N_p occurs until approximately 2×10^6 . This suggests that full system turbulence may not have been met until that Reynolds number. As seen in the figure, the point of inflection that occurs around $N_{Re} = 2 \times 10^6$ corresponds to an agitator speed near 85 rpm for each tank level. Since agitator speeds of 85 and 130 rpm showed the most consistent homogeneity results in the RWCT tests (Sections 5.3.1 and 5.4), the power number results in Figure 5.5.2 may offer supporting information to those findings.

Figure 5.5.3, below, shows tank agitator power vs. tank agitator speed as observed during all phases of RWCT testing. The tank agitator power (in kW) was measured with a motor load sensor. The agitator power, speed, current, and voltage were also collected. As seen from curve fit correlation in Figure 5.5.3, the power varies with the agitator speed to the 2.8 power, which is similar to the theoretical correlation derived earlier.

Figure 5.5.3: Tank Agitator Power vs. Agitator Speed for RWCT Simulant Testing

Typical motor performance curves can be used to determine the horsepower and speed requirements for that unit. These requirements can be measured by reading the amperes drawn by the motor at maximum load and comparing this with the full-load amperes of the drive motor. The line voltage can also be measured and values for the motor power factor and motor efficiency can be determined at the approximate percentage load of the motor. The three-phase motor power consumption is governed by the following relationship:

$$P = \sqrt{3} E_L I_L \times (PF)$$

where: P = Power into balanced three-phase system, in kW
 E_L = Line voltage, in volts
 I_L = Line current, in amps
 PF = Power factor

The data obtained during RWCT testing was used to calculate the power factor as a function of agitator power and agitator current. The power factor was plotted against agitator power (see Figure 5.5.4) and was compared directly to standard motor performance curves. It was determined that the shape of the curve was indeed representative of standard motor performance curves.

Figure 5.5.4: Power Factor vs. Agitator Power for RWCT Simulant Testing

5.5.2 Comparisons to Water and NCAW-1 Materials

In general, it was found that the agitator power varies directly with agitator current as illustrated in Figure 5.5.5. This linear relationship made it possible to make a direct comparison for the power requirements of water compared to the power requirements of NCAW-1 simulants. Since agitator power was not measured during previous testing, agitator current was used to quantify the power requirements for these simulants.

Figure 5.5.5: Tank Agitator Power vs. Agitator Current for RWCT Simulant Testing

Table 5.5.1 shows the agitator current at each agitator speed as a function of simulant and tank volume. Agitator current was found to vary with both concentration and tank volume. Furthermore, these effects were enhanced at the higher agitator speeds, especially at 130 rpm. For example, NCAW melter feed shows a 31% increase in current draw as compared to water. On the other hand, simulants of similar concentration (i.e. concentrated NCAW waste simulant) increased by 17% at 7800 gallons and by 8% at 5700 gallons. RWCT simulant, however, increased by 21% at 7800 gallons and by 10% at 5700 gallons as compared to water. Even though the concentrated NCAW simulants were more dense and viscous than the RWCT simulants, the RWCT simulants contained greater amounts of frit which was more difficult to suspend than normal dissolved solids.

When comparing simulants of similar volume (i.e., 5700 gallons), dilute NCAW waste simulant (at a low tank level) essentially drew the same current as water, while concentrated NCAW waste simulant (at a low tank level) increased by 8%, dilute RWCT simulant was higher than water by around 10%, and concentrated RWCT simulant by 14%.

Table 5.5.1: FPTS Agitator Current Requirements as a Function of Simulant Type
(The numbers in parenthesis indicate percent differences from that of water)

Simulant	Tank Volume (Gallons)	Agitator Current (Amps) @ 45 rpm	Agitator Current (Amps) @ 85 rpm	Agitator Current (Amps) @ 130 rpm
Water	5400	24.50	33.80	55.80
Low Level Dilute	5700	24.50 (0.00)	33.75 (-0.15)	55.50 (-0.54)
High Level Dilute	7800	24.00 (-2.04)	34.75 (+2.81)	61.25 (+10.22)
Low Level Concentrated	5700	24.75 (+1.02)	35.50 (+5.03)	60.50 (+8.42)
High Level Concentrated	7800	25.00 (+2.04)	38.00 (+12.43)	65.50 (+17.38)
Formated	6500	25.00 (+2.04)	36.25 (+7.25)	60.00 (+7.53)
Melter Feed	7100	—	—	73.50 (+31.72)
Dilute RWCT	3900	25.25 (+3.06)	34.75 (+2.81)	57.50 (+3.05)
RWCT	4100	25.50 (+4.08)	35.50 (+5.03)	58.50 (+4.84)
RWCT	5700	25.50 (+4.08)	35.50 (+5.03)	61.50 (+10.22)
RWCT	7800	24.75 (+1.02)	37.50 (+10.95)	67.50 (+20.97)
Concentrated RWCT	5700	25.25 (+3.06)	37.00 (+9.47)	63.50 (+13.80)

6.0 PUMP PRIMING

6.1 BACKGROUND

The Sample and Feed-transfer pumps were tested for their ability to start and maintain flow under various process conditions using the RWCT simulant. Each pump is similar in size and construction, however, each of the piping configurations fed by the two pumps differ considerably. The sample and feed transfer pumps are vertical cantilever centrifugal types driven by 15 and 20 horsepower electric motors, respectively. Each pump has a water priming system which injects water up through the suction tube into the pump chamber via an electric solenoid valve. The pump start is operated through a distributive control system which automatically sequences the prime water valve open for a predetermined time when the pump is started to initiate pump suction. The purpose of this test was to determine the effect of the liquid level, liquid concentration, liquid temperature and, agitator speed on the priming of each pump. In addition, the pump priming operation itself was studied such that total prime water additions could be reduced as much as possible.

6.2 PRIMING STUDIES WITH RWCT SIMULANT

Tests were conducted, per SIPT Run Plan WTC-006-RWCT-RP01, at two slurry concentrations, three liquid levels, three agitator speeds and six slurry temperatures (see Tables 6.2.1 and 6.2.2). Additionally, the feed-transfer pump was tested using four different pump discharge back pressure settings. These settings simulated differing pump discharge head pressures that may be caused from changes in piping configurations. The changes in the other parameters were used to test the pumps ability to operate under less than ideal conditions.

During the pump priming tests the Data Acquisition System (DAS) was configured to record, at one second intervals, the following pump parameters: speed, current draw, discharge pressure and flow rate. The data was then reviewed and the minimum time required for the pump to reach its maximum discharge pressure was determined. This time was then called the minimum priming time (see Figure 6.2.1). These priming times were then assessed against the changes in the RWCT simulant concentration, fluid level, agitator speed and temperature in order to evaluate the impacts of the condition changes.

Figure 6.2.1. Typical Pump Discharge Pressure Plot During Priming

Table 6.2.1: Feed-transfer Pump Prime Test Matrix (with RWCT simulant)

Tank Volume (gallons)	Slurry Conc (wt% Solids)	Agitator Speed (rpm)	Temperature (°C)	Pump Disch Press (psi)
4100	4.07	45,85,130	50	10,25,40,50
5700	4.68	85	40,50,60,70,80,90	10
5700	4.68	45,85,130	50	10,25,40,50
7800	4.38	85	40,50,60,70,80,90	10,25
5700	5.68	85	40,50,60,70,80,90	10,25,40

Table 6.2.2: Sample Pump Prime Test Matrix (with RWCT simulant)

Tank Volume (gallons)	Slurry Conc (wt% Solids)	Agitator Speed (rpm)	Temperature (°C)
4100	4.07	45,85,130	50
5700	4.68	85	40,50,60,70,80,90
5700	4.68	45,85,130	50
7800	4.38	85	40,50,60,70,80,90
5700	5.68	85	40,50,60,70,80,90

6.2.1 Sample Pump

The maximum pump discharge pressure of the sample pump was not adjustable like that of the transfer pump. Therefore, this single maximum discharge pressure ranged between 44.5 and 51.3 psi with the priming time required varying from 14 to 19 seconds (see Table 6.2.3 and Figure 6.2.2). This data, for the RWCT simulant, showed that there was no significant effect on the pump starting and operation due to changes in simulant concentration, liquid level, average slurry temperature or agitator speed. The sample pump appeared to be capable of starting under almost any conditions that existed within the tank using the RWCT simulant, with one exception. When the agitator was operating at maximum speed (130 rpm) and the tank level was at 4000 gallons, neither the sample or feed transfer pump started. The most probable cause for this event was the air being entrained into the slurry by the agitator. It should also be noted that the sample pump performed with this same consistency for the NCAW/HWVP waste simulant and the NCAW/HWVP melter feed studied during FY-93 testing in the same system. The in-vessel restriction orifice, which produces the elevated back pressure for the sample pump, is the most probable reason for this pump's excellent starting capabilities.

Table 6.2.3. Sample Pump Priming Data

TANK VOLUME (GAL)	SLURRY CONC. (WT% SOLIDS)	TEMP. (°F)	AGITATOR SPEED (RPM)	ADJUSTED TARGET PUMP DISCHARGE PRES. (PSI)	MINIMUM PUMP PRIME TIME (SEC)	MEASURED MAXIMUM PUMP DISCHARGE PRES. (PSI)	COMMENTS
~4000	3.8	115.9	45	N/A	15	45.8	
~4000	3.8	115.9	85	N/A	18	44.5	
~4000	3.8	115.9	130	N/A	0	0.0	LOST PRIME
~5700	4.3	126.7	45	N/A	15	46.9	
~5700	4.3	126.7	85	N/A	15	46.5	
~5700	4.3	126.7	130	N/A	17	45.4	
~5700	4.3	104.5	85	N/A	16	46.5	
~5700	4.3	123.3	85	N/A	16	46.4	
~5700	4.3	140.0	85	N/A	15	46.5	
~5700	4.3	158.4	85	N/A	15	46.7	
~5700	4.3	176.7	85	N/A	16	46.7	
~5700	4.3	192.7	85	N/A	15	46.6	
~7800	4.1	103.5	85	N/A	18	51.3	
~7800	4.1	140.5	85	N/A	15	47.3	
~7800	4.1	158.7	85	N/A	15	47.1	
~7800	4.1	176.9	85	N/A	15	47.3	
~7800	4.1	195.4	85	N/A	19	47.3	
~5700	5.2	104.0	85	N/A	17	47.0	
~5700	5.2	122.7	85	N/A	15	46.7	
~5700	5.2	140.0	85	N/A	15	46.8	
~5700	5.2	158.7	85	N/A	15	46.6	
~5700	5.2	176.2	85	N/A	16	46.8	
~5700	5.2	195.8	85	N/A	14	46.6

Figure 6.2.2. Sample Pump: Minimum Priming Time for RWCT Simulant vs. Tank Temperature at Various Tank Levels. Agitator Speed is 85 rpm.

6.2.2 Feed-Transfer Pump

The feed-transfer pump was tested in the same manner as the sample pump with the added ability of being able to change the back pressure (pump head) by adjusting a valve in the pump discharge line. This valve was calibrated to provide settings of approximately 10, 25, 40 and 50 psi of back pressure to the pump during test operations. Even though some back pressure is required for starting these types of pumps, testing showed that the feed-transfer pump had some limitations on the amount of back pressure used for priming. With the liquid level at 3800 gallons, average temperature 116 °F (47 °C), and the agitator operating at a maximum speed of 130 rpm, the pump required the back pressure adjustment valve to be set at either the 25 or 40 psi setting in order to start and maintain flow. Both the 10 and 50 psi settings resulted in a pump prime loss for these tests, (see Figure 6.2.3).

**Figure 6.2.3. Transfer Pump Priming Plot for RWCT Dilute Simulant:
Minimum Priming Time vs. Pump Back Pressure at Various Agitator Speeds
[Tank Level of 4000 gallons and a Temperature of 117 °F (47 °C)]**

When the liquid level was at 5700 gallons with an average temperature of 127° F (53 °C), the feed-transfer pump started for all of the agitator speeds tested (see Figure 6.2.4). Figure 6.2.5 shows the results of pump priming the RWCT simulant at a tank level of 5700 gallons and agitator speed of 85 rpm as a function of temperature. It was observed that the pump required more back pressure as the temperature of the slurry increased. At a tank level of 5700 gallons, agitator speed of 85 rpm and back pressure valve set at 10 psi, the pump would not maintain liquid flow over 140 °F (60 °C). With the other parameters remaining constant, and a 25 psi back pressure, the pump would operate up to 176° F (80 °C). In order to prime at 194° F (90 °C), the back pressure had to be increased to 40 psi.

Figure 6.2.4. Transfer Pump Priming for RWCT Simulant:
Minimum Priming Time vs. Pump Back Pressure Setting at Various Agitator Speeds
 [Tank Level of 5700 gallons and Tank Temperature of 127 °F (53 °C)]

Figure 6.2.5. Transfer Pump Priming Plot for RWCT Concentrated Simulant:
Minimum Priming Time vs. Tank Temperature at Various Back Pressures
 [Tank Level of 5700 gallons and Agitator Speed of 85 rpm]

When the tank level was at 7800 gallons with the agitator speed at 85 rpm, a back pressure of 10 psi was sufficient to maintain flow up to 158 °F (70 °C) with 25 psi back pressure being adequate to reach 194 °F (90 °C) (see Figure 6.2.6). These tests show that the feed-transfer pump can start and maintain flow if there is at least 25 psi back pressure to the pump and a liquid temperature below 176° F (80 °C) (see Table 6.2.4). However, starting reliability would be improved if the back pressure to the pump were increased to 40 psi while maintaining the liquid temperature below 158° F (70°C).

Figure 6.2.6. Transfer Pump Priming for RWCT Dilute Simulant:
Minimum Priming Time vs. Tank Temperature at Various Back Pressures.
[Tank Level is 7800 gallons and Agitator Speed is 85 rpm]

Table 6.2.4. Feed Transfer Pump Priming Data

Tank Volume (gal)	Wt% Solids in Slurry	Temp. (°F)	Agitator Speed (rpm)	Target Pump Discharge Pres. (psi)	Minimum Priming Time (sec)	Maximum Discharge Pres. (psi)	Comments
~4000	3.8	116.8	45	10	9	16.9	
~4000	3.8	119.7	85	10	0	0.0	LOST PRIME
~4000	3.8	119.7	85	10	0	0.0	LOST PRIME
~4000	3.8	116.2	130	10	0	0.0	LOST PRIME
~4000	3.8	116.8	45	25	14	35.3	
~4000	3.8	119.7	85	25	11	34.9	
~4000	3.8	119.7	85	25	7	33.8	
~4000	3.8	119.7	85	25	11	34.1	
~4000	3.8	116.2	130	25	10	29.3	
~4000	3.8	116.8	45	40	17	42.5	
~4000	3.8	119.7	85	40	12	42.6	
~4000	3.8	116.2	130	40	13	39.7	
~4000	3.8	116.8	45	50	17	56.0	
~4000	3.8	119.7	85	50	20	54.6	
~4000	3.8	116.2	130	50	0	0.0	LOST PRIME
~5700	4.3	126.7	45	10	9	17.4	
~5700	4.3	126.7	85	10	9	18.5	
~5700	4.3	126.7	45	25	16	36.3	
~5700	4.3	126.7	85	25	15	35.8	
~5700	4.3	126.7	45	40	16	43.5	
~5700	4.3	126.7	85	40	12	43.3	
~5700	4.3	126.7	45	50	21	57.2	
~5700	4.3	126.7	85	50	16	56.4	
~5700	4.3	123.3	85	10	9	17.4	
~5700	4.3	159.3	85	25	14	34.2	
~5700	4.3	176.7	85	25	10	33.1	
~7800	4.1	103.5	85	10	15	18.7	
~7800	4.1	122.7	85	10	10	18.3	
~7800	4.1	140.2	85	10	10	17.8	
~7800	4.1	158.5	85	10	9	17.0	
~7800	4.1	176.0	85	10	0	0.0	LOST PRIME
~7800	4.1	176.0	85	25	11	34.7	
~7800	4.1	194.5	85	25	11	31.2	
~5700	5.2	103.8	85	10	9	18.2	
~5700	5.2	122.5	85	10	9	17.2	
~5700	5.2	139.6	85	10	9	16.9	
~5700	5.2	157.6	85	10	0	0.0	LOST PRIME
~5700	5.2	157.6	85	25	13	34.6	
~5700	5.2	175.3	85	25	11	32.7	
~5700	5.2	193.8	85	25	0	0.0	LOST PRIME
~5700	5.2	193.8	85	40	14	44.5	

6.3 RECOMMENDATIONS FOR FUTURE WORK

In addition to providing the discrete reporting of successful and unsuccessful pump primings in this section, the value of "minimum prime time" has also been reported. Figure 6.2.1 shows how this value was determined from the data taken during RWCT testing. The minimum prime time was denoted since it is expected to be the minimum possible time (or consequently prime water volume) for which a successful pump prime is even possible. In order to test this theory, two additional tests were performed on the feed-transfer pump to determine if the pump was capable of starting and maintaining flow when the priming time was reduced to this minimum priming time. Data was taken from two previous priming tests, 25 and 40 psi back pressures, was analyzed and the minimum priming times determined. Next, the pump prime water solenoid time was set to this value, as well as two slightly higher values (approximately two and three times higher). Indeed, successful pump primes were achieved for each back pressure settings for all of these priming times. As a result, a recommendation for future work would be to investigate minimizing the priming times in this same manner via the pump priming control system. The control system is capable of monitoring the pump outlet pressure and stopping the prime water flow once a steady back pressure is achieved. As shown by the varying minimum priming times reported in this section, a wide range of prime water totals may be required. Therefore, by adjusting this usage on-line the prime water may be potentially minimized for any slurry type and/or system operating condition.

7.2 PUMP PERFORMANCE WITH RWCT SIMULANT

Pump performance is typically evaluated by two criteria; capacity and head. Capacity corresponds to the flow rate of fluid through a pump and head is the total pressure difference across the pump. The total head (H) equals the discharge head (H_d) minus the suction head (H_s). To characterize the pumps the flow rate is varied and the discharge pressures recorded while the pump is held at a constant speed. The discharge pressures are then converted to total head values and plotted vs. flow rate (capacity). Information on the calculations used to generate these pump parameters can be found in Appendix F

The transfer pump has a maximum capacity of 205 gpm, with the 2 inch diameter discharge being utilized. Additionally, the transfer pump intake utilizes a 2 inch water line priming system. The sample pump has a 58 gpm maximum capacity with a 1/2 inch diameter discharge line. The sample pump is designed to allow the majority of the slurry to be discharged directly back into the vessel through a ceramic restriction orifice installed into the outlet line. Therefore, during maximum operating capacity, approximately 48 gpm of slurry is discharged back into the vessel while permitting 10 gpm of slurry to pass through the sample system.

7.2.1 Sample Pump Characterization

The pump characterization test procedure (WTC-006-FPTS-01, Rev 0) contains the detailed guidelines utilized in obtaining the pump characterization data. Section 10.1 describes sample pump characterization and Section 10.2 describes transfer pump characterization. The two way and three way Fujikin valves were initially in a fully open position. The three way Fujikin valve was then positioned to achieve maximum flow in the sampling system and the sample pump speed was adjusted to the target test speed (1680, 1485, or 1255 rpm). At this point the system was allowed to operate with no further adjustments for a minimum of two minutes to allow for it to stabilize. The flow rate was then lowered in 1 gpm increments with the discharge valve, pausing at each point to allow the system to stabilize, and the corresponding discharge pressure data was recorded by the data acquisition system.

The recorded sample pump discharge pressure data for the RWCT simulant was converted into total head (feet of water) and plotted against the flowrate (gpm). This information is shown in Figure 7.2.1, below.

Figure 7.2.1 Sample Pump Characterization with RWCT Simulant

As shown in Figure 7.2.1 increased pump speeds resulted in a uniform total head increase. At 1680 rpm, the average total head was approximately 112 feet of water over all tested flowrates. At 1485 rpm, the total head was approximately 90 feet and at 1255 rpm, the total head was approximately 65 feet.

7.2.2 Transfer Pump Characterization

For the transfer pump characterization the pump was started and adjusted to the target speed (1640, 1500, or 1250 rpm). The flow rate was started at its maximum (outlet valve full open) and then decreased in 10 gpm increments while allowing a two minute minimum stabilization period for the discharge pressure data to be acquired.

Figure 7.2.2 shows the transfer pump total head versus flowrate data acquired with the RWCT simulant. The same sort of dependency upon pump speed is evident in this figure as was seen for the sample pump data. At a pump speed of 1640 rpm, the average total head was approximately 122 feet of water. At 1500 rpm, the total head ranged from 89 to 110 feet of water with the average being approximately 100 feet of water. Finally, at 1250 rpm, the average total head was approximately 68 feet of water. The sharp downward trends at the extreme ends of the head-capacity curves were a result of the pump speed transition points.

Figure 7.2.2 Transfer Pump Characterization with RWCT Simulant

7.3 PUMP PERFORMANCE COMPARISONS

Additional pumping information can be attained by comparing the RWCT simulant data with the data previously generated with water and the NCAW simulants in the FPTs system. However, much of this previous testing was performed at slightly different process conditions which made exact comparisons with the RWCT data impossible. These process condition differences consisted of agitator speed, fluid temperature, and tank volume.

7.3.1 Operating Condition Impacts on Pump Characterization Data

The majority of the previously taken pump data was obtained at agitator speeds of 130 rpm. However, an agitator speed of 85 rpm was used throughout RWCT simulant testing. Figure 7.3.1 shows the transfer pump head-capacity curves for water generated at two different pump speeds and at two different agitation speeds.

Figure 7.3.1 Transfer Pump Characterization with Water as a Function of Tank Agitator Speed

Figure 7.3.1 shows that the pump speed greatly affects the total head measurements while the agitator speed has little or no effect. As a result the differences in agitator speed were not considered when selecting the slurry data comparisons. Previous tests also showed that the temperature has a negligible effect on the head-capacity curve (see Figure 7.3.2). Therefore, small differences in tank fluid temperatures were also not considered while selecting the comparison tests.

Figure 7.3.2 Transfer Pump Characterization with Dilute NCAW Waste Simulant as a Function of Temperature

The affects of tank volume differences on the pump curves were also available from previous testing data. Figure 7.3.3 shows the pump characterization curve for dilute NCAW waste simulant at both 8000 and 5600 gallons, for the same remaining conditions. This figure shows large differences in the resulting pump curves for the two different volumes. This effect is due to the amount the suction size of the pump is submerged in the fluid. As a result careful consideration was placed on tank volume when selecting plots to compare to the RWCT simulant.

Figure 7.3.3 Transfer Pump Characterization with Dilute NCAW Waste Simulant as a Function of Tank Volume

One other difference between the transfer pump characterization data taken with water versus all of the other simulants tested was that the pump ran through the melter feed loop and did not by-passed this loop as the other simulant tests did. The melter feed loop is comprised of various bends, a restriction orifice, and extra pipe length versus the by-pass. However, this equipment change did not significantly changed the head-capacity results. Indeed, the usefulness of these pump curves is that they can be used to estimate pump outlet pressures for any down line piping system regardless of the configuration.

7.3.2 RWCT and Water Pump Performance Comparison

Comparison plots, for the sample and transfer pumps, between RWCT simulant and water are shown in Figures 7.3.4 and 7.3.5, respectively. The RWCT simulant contained 5% solids and had a slightly higher density than water. At a given flowrate, the fluid with a higher density generally requires greater pumping effort. Therefore, head-capacity curves for RWCT simulant are expected to be higher than those for water under similar conditions.

Figure 7.3.4 Sample Pump Performance Comparisons with Water and RWCT Simulant

Figure 7.3.5 Transfer Pump Performance Comparisons with Water and RWCT Simulant

Both Figure 7.3.4 and 7.3.5 show that the head capacities for the RWCT simulant close to that of water at all of the pump speeds. The slight differences in total head at the highest speed, in both figures, may be attributable to the slight pump speed differences and the tank volume differences shown. Figure 7.3.5 shows that the water data was taken at a highest pump speed setting of 1670

rpm and a tank volume of 5600 gallons while the RWCT simulant data was taken at a pump speed of 1640 rpm and a tank volume of 5900 gallons. Although these differences are small, the result is a total head-capacity curve for water equal to or slightly higher than that for the RWCT simulant. The previously mentioned equipment change in the transfer pump down line piping is evident in Figure 7.3.5. This change caused the attainable maximum flowrates to be different for each system. The melter feed loop piping limited the maximum flow rate of water to approximately 100 gpm while the by-pass enabled flow rates of twice that much.

7.3.3 RWCT and NCAW Waste Simulant Pump Performance Comparison

In order to gauge RWCT simulant behavior in the FPTs system the pump performance information was also compared to some of the information generated during NCAW simulant test. Due to the differences in testing conditions (see Section 7.3.1), the only slurry which could be reasonably compared was the concentrated NCAW waste simulant. Table 7.3.1 shows the pump testing information for both of these simulants.

Table 7.3.1 Comparison of RWCT and Concentrated NCAW Waste Simulant Testing Conditions

	RWCT Simulant	Concentrated NCAW Waste Simulant	Expected Effect Due to Difference
Agitator Speed	85 rpm	85 rpm	none
Tank Volume	~5900 gallons	~6000 gallons	negligible
Temperature	54°C	52°C	negligible
Speed of Sample and Transfer Pumps	1670 rpm 1500 rpm 1250 rpm	1640 rpm 1500 rpm 1250 rpm	Slight increase in RWCT Head none none
Wt% Solids	5.0 %	15.55 %	Increase in NCAW Head

Table 7.3.1 shows that the NCAW waste simulant had a solids loading of over 15%. However, these particles are primarily fines compared to the large amounts of frit in the RWCT simulant. Still, the much higher solids loading in the NCAW waste simulant would be expected to have a significant effect on the head pressure required even though the NCAW simulant consists of fine particles. Therefore, the head-capacity curves for RWCT simulant were expected to be lower than those for the concentrated NCAW under similar conditions. A head-capacity comparison plot between RWCT simulant and the concentrated NCAW waste simulant is shown in Figure 7.3.6. This figure shows the concentrated NCAW waste simulant data almost directly superimposed over the RWCT simulant points, despite the solids concentration difference.

Figure 7.3.6 Transfer Pump Performance Comparisons with RWCT and Concentrated NCAW Waste Simulant

7.4 CONCLUSIONS

The FPTs transfer and sample pump head-capacity behavior for the RWCT simulant was close to that measured for water. Additionally, the RWCT material behaved similar to concentrated NCAW waste simulant in the transfer pump. Since the FPTs pumps were shown to be able to adequately maintain flow with NCAW simulants, which have equal to and greater head-capacity demands as the RWCT simulant, no variation of an RWCT material would be expected to exceed the capacity of the system. As a result, the FPTs pump design and configuration should be directly transferable to the pumps proposed for the RWCT.

8.0 SIMULANT FLOW CHARACTERIZATION

8.1 BACKGROUND

The pressure drop data of specific fluids due to friction in straight sections pipe and elbows are required in sizing piping systems and pumps. This section describes the methodology, results, and conclusions from pressure drop versus flow measurements of RWCT simulant in straight and 90 degree long radius elbow sections of pipe. The test system used for the pressure drop versus flow characterization of slurries has been denoted as the Slurry Test Loop (STL).

8.2 SLURRY TEST LOOP DESCRIPTION

The RWCT simulant was pumped through 3 in., 2 in., 1 1/2 in., 1 in. and 1/2 in. stainless steel schedule 40 straight and 90 degree long-radius elbow sections of pipes. The fluid velocity was varied through the piping from 3 to 10 feet per second in increments of 1 foot per second. Table 8.2.1 shows the target flow-rates. The results of RWCT simulant testing were compared to water testing results done for acceptance testing of the slurry test loop instrumentation. Fluid temperatures were measured but not controlled during testing.

In order to eliminate equipment testing conflicts, the RWCT simulant was transferred to a small tank (HB-34) and pumped from there through the test loop. Approximately 500 gallons of RWCT simulant was transferred from the FPTs (HB-15) to HB-34. The dilute RWCT simulant had a density of approximately 1.03 g/ml and contained 4.3 wt% solids. Table 8.2.2 shown below summarizes the target wt% solids, wt% overall composition, and concentrations of the RWCT simulant tested in the test loop. The RWCT simulant used in STL testing was assumed to be a representative sample of well mixed RWCT slurry in tank HB-15, see the homogeneity data in Section 5.0.

Table 8.2.1. Desired Flow-Rates in RWCT STL Testing

Velocity (ft/s)	Flow Rate in 3 inch Pipe	Flow Rate in 2 inch Pipe	Flow Rate in 1.5 inch Pipe	Flow Rate in 1 inch Pipe	Flow Rate in 1/2 inch Pipe
10	230.4	104.9	63.5	27.0	9.4
9	207.4	94.4	57.1	24.3	8.5
8	184.3	83.9	50.8	21.6	7.5
7	161.3	73.4	44.4	18.9	6.6
6	138.3	62.9	38.1	16.2	5.6
5	115.2	52.4	31.7	13.5	4.7
4	92.2	42.0	25.4	10.8	3.8
3	69.1	31.5	19.0	8.1	2.8

Table 8.2.2. Target Composition of RWCT Simulant used in STL Testing

Diatomaceous Earth	The approximate composition of Diatomaceous Earth (Standard Super Cell) is (by weight): 91.1% SiO ₂ , 4.0% Al ₂ O ₃ , 1.3% Fe ₂ O ₃ , 0.2% P ₂ O ₅ , 0.2% TiO ₂ , 0.5% CaO, 0.6% MgO, and 1.1% Na ₂ O, K ₂ O
Zeolite	The approximate composition of Zeolite (IE-96) is (by weight): 68.12% SiO ₂ , 17.51% Al ₂ O ₃ , 7.63% Na ₂ O, 3.81% Fe ₂ O ₃ , 1.1% CaO, 0.78% MgO, 0.57% P ₂ O ₅ , and 0.49% TiO ₂
Frit	The approximate composition of frit is (by weight): 70% SiO ₂ , 14% B ₂ O ₃ , 5% Li ₂ O, 9% Na ₂ O, 1% CaO, and 1% MgO

Compound	Solids Composition (wt%)	Overall Composition (wt%)	Solids Composition (g/L)
CdO	0.907	0.060	0.612
Diatomaceous Earth	9.046	0.599	6.103
90 wt% HCOOH	0.545	0.036	0.368
70 wt% HNO ₃	1.511	0.100	1.020
KMnO ₄	0.493	0.033	0.333
Na ₂ C ₂ O ₄	3.409	0.226	2.300
Na ₃ PO ₄	2.089	0.138	1.409
NaCl	0.030	0.002	0.020
NaNO ₃	23.391	1.548	15.781
Zeolite	4.523	0.299	3.052
Frit	54.056	3.578	36.469
Solids Subtotal	100.00	6.62	67.47
Water	n/a	93.381	n/a
Totals	100.00	100.00	67.47

A description of the tank, its agitator, and transfer pump are described in Section 3.1. The mixture in tank HB-34 was expected to have been well mixed since the agitator was running throughout testing. In addition the contents in HB-34 (~450 gallons operating level) were turned over and pumped through the test loop approximately every few minutes. These operational factors were also supported by visual inspections of the tank contents.

The feed line to the slurry test loop was equipped with a 1/2 in. 90 psi process air line as well as a 1 in. 90 psi water line for flushing the lines clean. The flow-rate in each specific test line was controlled by downstream valving. Magnetic flow-meters were located in each line so that the flow-rates could be measured. Differential pressure transmitters connected to remote seal assemblies measure the pressure drop across straight sections and long radius elbow sections of each line size. Direct taps were also available on all the elbow sections (except the 3 in. assembly) to verify the data from the remote seal units. Valve ports were also used to sample slurry at the inlet and outlet of the test loop.

Endress and Hauser FTI-1943 Variomag magnetic flow-meters were located in the 1/2 in. (FI-0203), 1 in. (FI-0202), 1 1/2 in. (FI-0204), and in the initial 3 in. (FI-0205) supply line to the STL. Using these flow-meters, the flow-rate through all lines in the test loop could be measured. All of these flow-meters had Teflon liners. The 1/2 in. and 1 in. flow-meters had 316SS

measuring electrodes while the 1 1/2 in. and 3 in. flow-meters had Hastelloy electrodes.

The pressure drop in straight sections and long radius elbow sections of pipe was measured by two types of transmitters. These were:

- PIC W24 Type TF Flow Through Remote Seals (PI Instruments, Inc.)
- Rosemount 3051CD Smart Differential Pressure Transmitters

These pressure transmitters were located on all 5 line sizes tested. Table 8.2.3. summarizes the dimensions and locations of the remote seal assemblies on the straight pipe sections. Table 8.2.4. summarizes the dimensions and locations of the remote seal assemblies on the elbow pipe sections.

Table 8.2.3. Dimensions of Straight Section Pressure Sensor Placements

Straight Section Pipe Size and M&TE No.	Distance between Pressure Sensors	Minimum Distance from Pipe Fittings (Elbows, etc.)
3 in. (PI-0210)	17.4 ft.	8 ft.
2 in. (PI-0202)	22 ft.	7 ft.
1 1/2 in. (PI-0208)	18.4 ft.	5 ft.
1 in. (PI-0204)	25 ft.	4 ft.
1/2 in. (PI-0206)	25 ft.	2 ft.

Table 8.2.4. Dimensions of Elbow Section Remote Seal Pressure Sensor Placements

Elbow Section Pipe Size and M&TE No.	Remote Seal Sensor Upstream Distance (from Elbow)	Remote Seal Sensor Downstream Distance (from Elbow)
3 in. (PI-0209)	111 inches	91 1/2 inches
2 in. (PI-0201)	117 inches	81 inches
1 1/2 in. (PI-0207)	33 1/2 inches	59 inches
1 in. (PI-0203)	29 inches	47 inches
1/2 in. (PI-0205)	27 1/2 inches	24 3/8 inches

The results from water testing of the elbow sections with remote seal instruments indicated that they were reading between 30% - 300% higher than expected literature results. Due to this discrepancy, 1/16 inch taps were drilled into the tops of the 1/2 in., 1 in., 1 1/2 in., and 2 in. elbow sections to verify the remote seal results. These taps were attached to a Rosemount 3051CD pressure transmitter (PI-0211) via 3/8 in. plastic tubing and Swagelok fittings. Prior to any measurements, the 3/8 in. tubing was filled with water to displace any air. Water was periodically added to the differential pressure lines in order to fill and flush out any solids in the pressure tap holes. No problems with clogging of the water filled pressure tap lines were observed.

Subsequent water pressure drop testing with the taps indicated that the remote seals pressure units in the elbow section were reading much higher. The pressure drop data taken with 1/16 in. taps corresponded substantially better with expected literature values than remote seal data and was therefore used in the RWCT elbow pressure drop analysis. Elbow section remote seal data

was used to confirm changes in the elbow contribution pressure drop between water and RWCT simulant. Table 8.2.5 describes the locations of the taps within each elbow section.

Table 8.2.5. Dimensions of Elbow Section Direct Pressure Tap Placements

Elbow Section Pipe Size	Pressure Tap Distance from Elbow (Upstream)	Pressure Tap Distance from Elbow (Downstream)
2 in.	4 in.	72 1/2 in.
1 1/2 in.	1 1/4 in.	51 1/2 in.
1 in.	1 1/8 in.	41 1/8 in.
1/2 in.	1 in.	19 1/4 in.

8.3 WATER TESTING

Prior to Slurry Test Loop testing, the instruments in the test loop were tested with water to insure correct readings. Water was pumped through the test loop over the flow ranges shown in Table 8.2.1. The results of the water testing (shown in Appendix D) indicated that the straight section differential pressures (measured using remote seals) fell within expected values of smooth (roughness = 0 ft) and commercial (roughness = .00015 ft) Schedule 40 pipe. These differential pressures were closer to the pressure drops expected in smooth pipe.

The expected pressure drop due to friction in the pipe was calculated by using the Fanning/Darcy equation (Sakiadis 1984):

$$\frac{\Delta P}{L} = \left(\frac{4f}{D} \right) \frac{V^2}{2g_c} \rho \quad (\text{Equation 8.3.1})$$

The friction factor, f , for water was calculated using the Colebrook equation (Sakiadis 1984):

$$\frac{1}{\sqrt{f}} = -4 \cdot \log \left(\frac{\varepsilon}{3.7D} + \frac{1.256}{\text{Re} \sqrt{f}} \right) \quad (\text{Equation 8.3.2})$$

Where $\Delta P/L$ is the pressure drop per length of pipe, psi/ft

V is the velocity, ft/sec

f is the friction factor

ε is the roughness of the pipe, ft.

D is the pipe diameter, ft.

Re is the Reynolds number = $\rho DV/\mu$, dimensionless

ρ is the fluid density, lb/ft³

μ is the fluid (water) viscosity, lbm / (ft sec)

μ (T in °K) = $-24.7 + 4.21\text{E}3/\text{T} + 4.53\text{E}-2*\text{T} - 3.38\text{E}-5 \text{ T}^2$ [=] cp (Reid et. al. 1987)

g_c is the gravitational constant, 32.2 ft/sec²

The Shacham correlation, shown below, was also used to calculate the f and is within 1% of the Colebrook equation. This was used in some calculations because it does not require an iterative solution.

Shacham Correlation (Olujić 1981):

$$f = \frac{1}{4} \left\{ -2 \log \left(\frac{\varepsilon/D}{3.7} - \frac{5.02}{Re} \log \left(\frac{\varepsilon/D}{3.7} + \frac{14.5}{Re} \right) \right) \right\}^{-2} \quad (\text{Equation 8.3.3})$$

The straight section pressure drop data was converted into a friction factor vs. Reynolds number plot. This data is shown below in Figure 8.3.1. The Shacham equation was used to estimate the roughness of the pipes the straight sections in the test loop. An average relative roughness, ε/D , of .00015 was found for the slurry test loop. This relative roughness relates closely to a smooth pipe in the flow-range tested. A curve fit ($y=ax^b$) of the water friction factor data is also shown in Figure 8.3.1. The curve fit had an R^2 value of 0.86. Scatter in the friction factor data is probably due to differences in the individual pipe roughnesses.

Figure 8.3.1. Friction factor vs. Reynolds Number for Water

Extracting the elbow pressure drop was difficult because the measured elbow section pressure drops were small. Although the entire elbow section pressure drop fell within expected values for commercial and smooth pipe, the elbow only pressure drops differed significantly from expected, especially for the smaller pipe sizes (1/2 in. and 1 in.). To calculate the experimental elbow only pressure drop, the straight lengths in the elbow section were subtracted out from the elbow section pressure drop ($\Delta P_{\text{elbow only}} = \Delta P_{\text{elbow section}} - L_{\text{straight length in elbow section}} * (\Delta P/L)_{\text{straight section}}$). The straight lengths in the equation were the measured lengths from the center of the pressure transmitter remote seal to the elbow weld. The pressure drop per length of

the straight section ($\Delta P/L$ *straight section*) was calculated by dividing the measurement from the straight section differential pressure transmitters by the distance between the pressure transmitters. The expected elbow pressure drop was calculated by multiplying the expected pressure drop/length by the equivalent lengths of straight pipe due to the elbow. The expected pressure drop/length was calculated for both smooth and commercial pipe over the experimental flow-range using the Colebrook equation. Table 8.3.1. shows literature values (from Perry's Chemical Engineers' Handbook) for the equivalent length/diameter values used in calculating the expected elbow pressure drop. An uncertainty of 25% is associated with these literature values.

Table 8.3.1. Literature Values for Equivalent Lengths of Straight Section
Pressure Drop due to 90° Long Radius Elbows

Elbow Section	Bend Radius / Diameter	Equivalent Lengths / Diameter
3 in. (3.068 in. i.d.)	1.47	14
2 in. (2.067 in. i.d.)	1.45	14
1 1/2 in. (1.66 in. i.d.)	1.40	14
1 in. (1.049 in. i.d.)	1.43	14
1/2 in. (.622 in. i.d.)	2.41	9.5

*Perry's Chemical Engineers' Handbook, sixth edition, pg. 3-39, Fig. 3-43.

The pressure drops measured by the remote seal units in the elbow sections were between 30 to 300% higher than literature values. Because of concern about the difference between expected and experimental results of the remote seal units, 1/16 in. diameter pressure taps were installed on the 1/2 in., 1 in., 1 1/2 in., and 2 in. elbow sections as described earlier. The pressure transmission lines were purged of air by filling them up with water and bleeding the lines. After subtracting out the straight sections, the water tap elbow only results were much lower than elbow only results calculated from the remote seal pressure transmitters. The 1 in. and 1 1/2 in. experimental elbow water tap results fell within expected results for smooth and commercial roughness pipe. In general elbow only pressure drops measured by 1/16 in. taps were close to or lower than expected values for smooth pipe.

The pressure drop due to the elbow was also evaluated by calculating the ratio of equivalent lengths of straight pipe pressure drop to diameter (Le/D) and comparing experimental results with expected literature. The location of the remote seal pressure units and 1/16 in. taps were located such that the elbow contribution to the elbow section pressure drop was significant. Table 8.3.2 summarizes the elbow contribution to the elbow section pressure drop in the flow-range tested for the 1/16 in. tap. The Le/D was calculated using the following equation:

$$\frac{Le}{D} = \frac{\Delta P_{elbow only}}{(\Delta P / L)_{straight section} (D)} \quad \text{(Equation 8.3.4)}$$

Table 8.3.2. Estimated Contribution of Elbow to Elbow Section Pressure Drop in the Flow-Range Tested

Test Section	Elbow Pressure Drop Contribution	
	~ 3 ft/sec	~ 10 ft/sec
2 in.	25%	20%
1 1/2 in.	50%	29%
1 in.	17%	22%
1/2 in.	17%	15%

Figure 8.3.2 shows the calculated equivalent lengths of straight section pressure drop using the remote seal pressure sensors. The calculated L_e/D using remote seal pressure data was between 35% to 300% higher than that reported by literature. The L_e/D calculated using 1/16 in. tap data was closer to literature and is lower than the remote seal data. The calculated L_e/D was lower at the higher flow-rates and increased as the flow-rate was decreased. The 1/2 in. elbow section L_e/D value was much higher than literature and was not lower than the other lines as predicted by literature. Calculated L_e/D values at each flow-rate tested for the direct pressure tap measurements are shown in Figure 8.3.3. The remote seal L_e/D increased with decreasing line size. The water tap data corresponded closer to literature values and agrees with the literature prediction that the 1/2 in. line has a lower L_e/D value than the other line sizes. The literature L_e/D values seem to be in the median of L_e/D values as measured by water taps. The 1/2 in. line as predicted by literature had a lower L_e/D than the other elbow sections because it was a less sharp bend and had a higher bend radius/diameter.

Table 8.3.3 summarizes the L_e/D values as measured by the remote seal unit and 1/16 in. tap measurements. The remote seal units in the elbow sections measure higher pressure drops than expected literature values and water tap measurements. The 1/2 in. line in the direct tap pressure measurement resulted in a lower L_e/D than the other elbow sections (as predicted by literature) while the remote seal measurement of the same pressure drop was higher. Due to the discrepancies between remote seal data and expected literature results, the water tap data will be reported in this report for the 1/2 in., 1 in., 1 1/2 in. and 2 in. line sizes. No direct taps were added to the 3 in. elbow section; therefore remote seal results will be presented for this elbow section.

Table 8.3.3. Summary of Water L_e/D s at High Flow-Rates (>8 ft/sec)

Test Section	Remote Seal Data L_e/D	1/16 in. Tap Data L_e/D	Literature Values
1/2 in.	28	5	9.5
1 in.	24	18	14
1 1/2 in.	24	14	14
2 in.	14	6	14
3 in.	19	none	14

Figure 8.3.2. Water Test: Elbow Section Pressure Drops as measured by Remote Seal Sensors

Figure 8.3.3. Water Test: Elbow Section Pressure Drop as measured by 1/16 in. Taps

8.4 RWCT SIMULANT TESTING

STL testing of the RWCT simulant occurred over two days. The Frit Slurry Makeup and Transfer Testing Procedure (TP93-SIPT-01) was followed for the test. However, some aspects of this procedure did not apply to the test, such as feed makeup specifics, settling assessment, line configuration, and flushing. These deviations were noted in the work place copy of the RWCT

run plan.

Once the transfer of approximately 450 gallons of RWCT simulant was made into HB-34, the agitator was started and set to 80% of full range. The data set used in analyzing the test loop data was obtained by the HFDAS in the 324 building high-bay control room. Data was logged every fifteen seconds from the pressure, flow, and temperature transmitters. After a valve change was made to modify flow rate, 30-60 seconds was allowed for the system to come to steady-state. Data was then collected over a three minute interval.

The 3 in. line was tested during the first day of testing. The flow was initially set to the maximum obtainable flow-rate (~230 gpm). The flow in the line was varied in increments of 20 gpm by restricting a downstream valve on the 3 in. line. As the flow in the line was decreased, the 1 1/2 in. line was opened (~80 gpm) to maintain a high pump throughput. The line was valved down at the beginning of the test to insure that the 3 in. line was full of liquid. The flow measured by the 3 in. flow-meter (FI-0205) fluctuated much more than that of water testing. After the test was completed, the transfer pump was shut off and the simulant in the test line was immediately air blown back to HB-34.

The 2 in., 1 1/2 in., 1 in. and 1/2 in. lines were tested during the second test day. When testing individual lines, another line (usually the 1 1/2 in. line) was opened to keep the throughput of the pump high. Each line was initially tested at its highest flow-rate followed by the lower flow-rate measurements by throttling a downstream valve. The 2 in. line was tested initially. The flow-rate was set to the maximum target (~105 gpm) and was lowered in ~10 gpm increments. After testing the 2 in. line, the 1 1/2 in. line was tested. The 1 1/2 in. line was initially set to the maximum desired flow (~64 gpm) and the 2 in. line was opened fully. The 1 1/2 in. line was varied in ~6 gpm increments. For testing the 1 in. line, the 2 in. line was closed and the 1 1/2 in. line was kept open (~80 gpm). The 1 in. flow was initially set to the maximum flow (~30 gpm) and was lowered in ~3 gpm increments. After 1 in. testing, the 1 in. line was closed while the 1 1/2 in. and 2 in. lines were kept open. The 1/2 in. line was then opened and the flow set to the initial maximum target (~10 gpm) then lowered in ~1 gpm increments. At the conclusion of all testing, the lines were air flushed back to HB-34. There were no apparent problems with plugging in the STL system throughout any of the testing phases. Air and water flushing of lines were successful in keeping the lines clean.

The temperature of the water during water testing was slightly different from the RWCT simulant temperature. Therefore shown in Appendix D are pressure drop versus flow comparisons of the water test results and RWCT test results. The water test results were temperature corrected to the RWCT simulant temperatures to account for any temperature dependence of viscosity differences in the water baseline comparisons. Table 8.4.1. summarizes the average test temperatures of acceptance water testing as well as RWCT simulant testing. A sample calculation of the temperature correction is attached in Appendix D.

Table 8.4.1. Average Test Fluid Temperature, in °C

Pipe Diameter	3 in.	2 in.	1 1/2 in.	1 in.	1/2 in.
Water	27	29	34	19	38
RWCT Simulant	49	41	45	48	50

The data from water and RWCT simulant testing were curve fit, in the flow-range tested, to a second order polynomial. The errors associated with the curve fit were taken into account in calculating the error in the Le/D plots.

8.4.1 Straight Pipe Results

Several approaches were used to try to characterize the pressure drop of RWCT simulant. The Durand and Condolios correlation was investigated; unfortunately, this correlation requires the solid particle size and volume % solids in the mixture (Govier and Aziz 1982). Since the RWCT simulant is a heterogeneous mixture, a distribution of solid particle sizes and the volume % solids are not easily obtained. Another approach was to plot the friction factor of the RWCT simulant data versus the Reynolds number. The viscosity used in the Reynolds number was calculated using several viscosity correlations assuming a pseudo-homogeneous suspension (e.g. Thomas Equation and Guth and Simha Equation in Govier and Aziz 1982). However, these viscosity correlations did not improve the fit of the data versus assuming a water viscosity. Also at lower flow velocities, the pseudohomogeneous assumption fails as solids settle and a concentration gradient form in the liquid.

Direct viscosity measurements of the RWCT simulant were impossible to obtain due to the time dependent nature of the fluid. The solids in the mixture begin settling out immediately without agitation. Therefore, frit particles in the mixture would settle rapidly during a rheogram analysis, which requires that measurements be taken under laminar flow. Since the characteristic time of the liquid (the fast settling time) was shorter than the experimental time required to attain an adequate rheology measurement, there was no adequate method for the measurement of RWCT simulant viscosities. Even the attachment of an impeller onto one of these machines, in order to keep the particles suspended, is limited since standards or correlations are not available for such systems.

Another approach to characterize the viscosity of the mixture was to calculate the friction factor from the pressure drop data and using a friction factor versus Reynolds number correlation such as the Fanning equation. The published correlations of friction factor versus Reynolds numbers (e.g. equation 5.1.1.2) are valid for Newtonian fluids. The viscosity of Newtonian fluids should be constant as a function of shear rate (and therefore velocity). Given a friction factor and assuming a relative roughness (ϵ/D) of .00015, the Reynolds number could be calculated from equation 5.1.1.2. For a particular density, velocity, and pipe diameter, the viscosity of the mixture could be calculated. For this calculated viscosity value to be valid, the fluid must be Newtonian

and the viscosity nearly constant at the various velocities (and shear rates). Calculations were done for the 1/2 inch pipe at the RWCT concentration. Using the above method to calculate the viscosity, the viscosity did not remain constant but increased with increasing velocities (shear rate). Since the friction factor versus Reynolds number correlation used is valid only for Newtonian fluids in which the viscosity remains constant with shear rate, this method of correlating the data was rejected. Also the resistance of the mixture to flow should increase as flow-rate is decreased as the solids are less suspended and concentration gradients form in the fluid.

In order to compare the RWCT simulant pressure drops with the water test results, the Fanning friction factor (solve for f in Equation 8.3.1.) was calculated from the raw RWCT simulant STL testing data. A sample friction factor calculation is shown in Appendix D. The friction factor for RWCT simulant and water tests in all the pipe sizes was plotted versus velocity and is shown in Figure 8.4.1. The calculated friction factor for water was not temperature corrected to RWCT temperature. The curve fit of friction factor with errors as a function of velocity is summarized in Equation 8.4.1.

$$f = 8.019 E-3 \pm 4.33 E-4 V^{-0.2743 \pm 0.0294} \quad R^2 = 0.68 \quad (\text{Equation 8.4.1})$$

Figure 8.4.1. f versus V for RWCT Simulant and Water (with standard errors)

The RWCT simulant friction factor is greater than water at the higher velocities and less than water at the lower velocities. A reduction in pressure drop from water has been noted in literature (e.g. Gaessler in Govier and Aziz 1982) for certain liquid/solids mixtures containing concentrations of fine particles. Govier and Aziz suggest that the finer particles in the mixture act as turbulence suppressers and therefore cause a reduction in the pressure gradient below water. At the lower velocities, it is suspected that the solid particles are less suspended and concentration gradients form in the water which increase the resistance to flow and increase the pressure drop above water. The effect of temperature on viscosity may also affect the pressure drop since the RWCT simulant tests were conducted at a higher temperature than water testing and liquid viscosity decreases with increasing temperature. Lower viscosity fluids have less resistance to flow and thus a smaller pressure drop. Shown in appendix D are the RWCT testing results compared to the water testing results. The water testing results were adjusted to RWCT test temperatures (sample calculation and comparison plots shown in Appendix D) and the water pressure drop curves were shifted down 5% to 7% because of the effect of viscosity on temperature. This would have affected the friction factor plot above by shifting the water curve down slightly.

8.4.2 Long Radius Elbow Results

Elbow section pressure drops between the RWCT simulant and water were compared by calculating the Le/D for RWCT simulant. The calculations performed using RWCT simulant pressure drop data were identical to the water calculations. Raw RWCT elbow pressure drop data was actually lower than temperature corrected water results for most line sizes. Figure 8.4.2 shows the RWCT simulant Le/D for the elbow sections as measured at the 1/16 in. taps. Similar to water, the Le/D values increased with decreasing flow-rate. At higher flow-rates, the Le/D values are almost constant. Table 8.4.2 compares the Le/D values between the RWCT simulant and water at high flow-rates. They indicate that the Le/D values between RWCT simulant and water were a little lower for most of the line sizes. As stated earlier, a reduction in pressure drop from water has been noted in literature for certain liquid/solid mixtures containing concentrations of fine particles and that this may be due to the finer particles in the mixture acting as turbulence suppressers.

The RWCT simulant pressure drop in the 1/2 in. elbow was much lower than the water pressure drop data and deviated from the results of the other line tests. The Le/D in the other line sizes remained essentially the same or just a bit lower than water tap Le/D values. The Le/D calculated using remote seal sensor data indicated that the Le/D values remained essentially the same or slightly lower during all the tests and agreed with the tap data. The 1/2 in. line Le/D value calculated using the remote seal data was essentially the same for water and RWCT simulant. This leads to the conclusion that there may have been some systematic error in the 1/2" line tap data. The Le/D value for the RWCT simulant in the 1/2 in. line should have been approximately the same as water rather than the much lower value measured. Thus, a recommended literature Le/D value of 9.5 would be a conservative value to use for the 1/2 in. line elbow. Table 8.4.2. includes the Le/D results at high velocities taken with the remote seal units. The calculated Le/D

for the RWCT simulant using remote seal data to measure the pressure drops are either the same or lower than Le/D calculated for water data for most of the test lines.

Figure 8.4.2. RWCT Simulant Elbow Le/D versus Velocity

Table 8.4.2. RWCT Le/D at High Flow-Rates (>8 ft/sec)

Pipe Diameter	1/16 in. Tap Data Le/D (Water Le/D)	Remote Seal Data Le/D (Water Le/D)
1/2 in.	-3 ± 3 (5)	27 ± 1 (28)
1 in.	19 ± 4 (18)	28 ± 5 (24)
1 1/2 in.	13 ± 4 (14)	24 ± 4 (24)
2 in.	4 ± 4 (6)	13 ± 11 (14)
3 in.	13 ± 10 (19)	13 ± 10 (19)

8.5 CONCLUSIONS

The straight section pressure drops for RWCT simulant were slightly higher than water and can be obtained from the curve-fit of the data shown in Figure 8.4.2. To estimate the RWCT simulant pressure drop, first the friction factor for RWCT simulant can be calculated for a particular velocity and the pressure drop per length of pipe can be calculated for a pipe diameter.

$$f_{RWCT \text{ Simulant}} = 8.019 E-3 (V)^{-0.2743} \quad (\text{Equation 8.5.1})$$

V is the mixture velocity, 3 ft./sec. $< V < 10$ ft./sec.

$$\frac{\Delta P}{L} = \left(\frac{4 f_{RWCT \text{ Simulant}}}{D} \right) \frac{V^2}{2g_c} \rho \quad (\text{Equation 8.5.2})$$

The RWCT simulant did not show an increase over water in the pressure drop due to the long radius elbows. The Le/D calculated using RWCT simulant was either equal to or lower than water results. Because the Le/D values increased with decreasing flows a conservative value Le/D value of 20 should be used for the 1 in., 1 1/2 in., 2 in. and 3 in. elbows to cover the 3-10 ft/sec flow-range. For the 1/2 in. elbow, the literature Le/D value of 9.5 provides a conservative value. The 1/2 in. elbow has a lower Le/D value because it has a higher bend radius/diameter and is therefore a less sharp bend than the other elbows. Table 8.5.1 summarizes recommended Le/D values for the elbow sections.

Table 8.5.1. Summary of Recommended Le/D Values

Long Radius Elbow	Bend Radius / Diameter	Recommended Le/D
1/2 in.	2.41	9.5
1 in.	1.43	20
1 1/2 in.	1.40	20
2 in.	1.45	20
3 in.	1.47	20

As a result the estimated pressure drop due friction of RWCT simulant flowing in a piping configuration of Schedule 40 stainless steel pipe and long radius elbows can be calculated as follows:

$$\Delta P = \left(\frac{\Delta P}{L} \right) \cdot \left(L_{st} + n \cdot \frac{Le}{D} \cdot D \right) \quad (\text{Equation 8.5.3})$$

Where

ΔP is the pressure drop in the section of piping.

$\Delta P/L$ is the pressure drop per length as calculated in equation 8.5.2

L_{st} is the length of straight section in the piping, ft.

n is the number of 90 degree long radius elbow bends

Le/D is from Table 8.5.1.

D is the pipe diameter, ft.

9.0 EVAPORATOR AND CONDENSER PERFORMANCE

9.1 BACKGROUND

The heating and cooling coil heat transfer areas in the FPTs tank and condenser were based on process heating, boiling, and cooling requirements and on calculated heat transfer coefficients. These coefficients relied on textbook correlations and assumed values for fouling and viscosity. Furthermore, the nature and effect of the boiling process on heat transfer was estimated, including the potential for vapor binding.

9.1.1 Objectives

The general evaporator/condenser test objectives for simulants studied in the FPTs are listed as follows:

- Determine extent of vapor binding of the tank coils.
- Determine heating, boiling, and cooling heat transfer coefficients for the tank coils.
- Determine the energy input from agitation.
- Determine external heat losses from the tank.
- Determine fouling of the heat transfer surfaces as a function of time, heat flux, composition, and degree of agitation.
- Determine condenser performance as a function of boil-up rate.

The specific testing objectives used for RWCT simulant testing are listed as follows:

- Report coil heat transfer coefficients during heating as a function of slurry temperature (from 125°F to boiling) at the nominal agitation speed (85 rpm).
- Report coil heat transfer coefficients during boiling as a function of steam flow (4200 to 6000 lb/hr) at the nominal agitation speed (85 rpm) for all slurry concentrations.
- Report coil heat transfer coefficients during boiling as a function of agitation speed (45, 85, and 130 rpm) at a constant steam flow rate.
- Report coil heat transfer coefficients during cooling from process boiling to 125°F for a cooling coil flow rate of 120 gpm and nominal agitation rate (85 rpm).
- Report any occurrence of vapor binding around steam coils during boiling. Vapor binding is apparent when an increase in steam flow causes a decrease in the apparent heat transfer rate and boil-up rate.

9.1.2 Test Procedures

The following general procedure was used for the RWCT evaporator/condenser test. During this test, condensate generated during boiling was recycled back into the evaporator (refluxed). The condensate was also recycled during the NCAW evaporator/condenser tests, so the presented

data for RWCT is consistent with the NCAW data. When the condensate is refluxed from the outlet of the condenser to the evaporator, the condensate must be reheated from the condenser outlet temperature to the boiling temperature. This will result in a reduction in the maximum boil-up rate of approximately 8%. The liquid level in the tank during the evaporator/condenser test ranged from 8100 to 8300 gallons.

1. The process liquid in the evaporator tank was heated from below 52°C (125°F) to boiling at the maximum steam flow rate while maintaining the agitation speed at 85 rpm. Initially, the steam flow was increased slowly to limit thermal transients.
2. The process liquid in the evaporator tank was boiled using steam flow rates of 6000, 5200, and 4200 lb/hr while maintaining the agitation speed at 85 rpm.
3. The process liquid in the evaporator tank was then boiled at agitation speeds of 45 and 130 rpm while maintaining a steam flow rate of 5200 lb/hr.
4. The process liquid in the evaporator tank was then cooled from boiling to 52°C (125°F) using cooling water at 120 gpm while maintaining the agitation speed at 85 rpm.

9.2 EVAPORATOR PERFORMANCE

The RWCT tests results were compared with data already documented for processing of water and NCAW simulant. Note that the steam flow header pressure for NCAW 1 testing was 130 psia. This pressure was reduced to approximately 100 psia for RWCT testing. Calculations have shown that, for a given mass flow rate, the total heat transferred by 110 and 130 psia saturated steam are nearly equal. The enthalpy of condensation (h_{fg}) decreases with increasing pressure, which will reduce the heat of condensation. The saturation temperature increases with increasing pressure, which will increase the heat transferred by subcooling the process steam condensate. The two effects offset each other, and the net effect for steam in this pressure range is negligible.

The evaporator heat transfer data from the NCAW campaign was originally published in (Hatchell et.al., 1993). The equations that were used to extract the heat transfer coefficients from test data can be found in the calculation included in Appendix E.

9.2.1 Batch Heating

Heating of process liquid was initiated at low steam flow (to avoid thermal shock) and increased slowly to maximum steam flow (approximately 7200 lb/hr). The agitator speed was held constant at 85 rpm during this heat-up time. The history of the coil heat transfer coefficients during heat-up for initial water runs, dilute NCAW waste simulant (high and low tank levels), and the RWCT simulant is provided in Figure 9.2.1. The heat transfer coefficients during heating for NCAW dilute and RWCT are very close, while the heat transfer coefficient for water is somewhat lower. This is because the steam flow rate during water testing was somewhat lower (5200 lb/hr for

water vs. 7200-7500 lb/hr for NCAW and RWCT)

Figure 9.2.1 Overall Heat Transfer Coefficients as a Function of Simulant Temperature (Pre-Boiling)

Table 9.2.1 provides heat up times; process volume, and heat transfer coefficients for the heating periods for the different slurries. In this table, heat transfer coefficients are provided in terms of average instantaneous (computed by averaging the time history of the heat transfer coefficients) and overall heat transfer coefficients, which is based on the batch heating closed form formula. In general, the transient heat transfer coefficient during batch heating of the RWCT simulant was very close the dilute NCAW waste simulant data, as expected. For the NCAW 1 test; the heating coefficient during initial heat-up was somewhat higher; however, this was due to the initial batch temperature being 125°F before heating was initiated. The RWCT batch, on the other hand, was initially at room temperature and the transient effects were not present. The average instantaneous heat transfer coefficient for RWCT is quite close to the NCAW simulant data, whereas the overall heat transfer coefficient is somewhat higher. This indicates that no significant degradation of the heat transfer capacity of the coils has occurred between the NCAW 1 and RWCT tests and that the cleaning procedure used to remove the caked on melter feed left from the NCAW 1 campaign was successful. In addition, the reduction in steam header pressure from 130 psia to 100 psia did not have a significant effect on heating performance.

Note that the overall heat transfer coefficients (U_o) are much lower than the instantaneous values (U_i), apparently because the equation used to determine U_o is inadequate for this situation. This is primarily because the equation assumes an isothermal heating medium and neglects cooling of the steam condensate; a large amount of heat is transferred by subcooling the steam condensate,

and this occurs over a smaller temperature difference between the process and coil-side. It is believed that U_i gives a better indication of heat transfer performance, but U_o may be more useful in conservatively predicting heating times. Also, since Savannah River Laboratory only publishes overall heat transfer coefficients, it is necessary to calculate U_o to compare to historical data.

Table 9.2.1 Heat Transfer Information for RWCT and Other Simulants (During Heat up)

Test Simulant	Water	NCAW Dilute Waste Simulant	NCAW Dilute Waste Simulant	NCAW Concen. Waste Simulant	NCAW Concen. Waste Simulant	NCAW Formated W.S.	NCAW Melter Feed	RWCT Simulant
Weight % Solids	0.0%	4.2%	4.4%	15.5%	15.5%	19.0%	41.0%	4.5%
Specific Gravity	1	1.03	1.03	1.11	1.11	1.13	1.4	1.03
Specific Heat*, Btu/lb°F	1.00	1.00	1.00	0.90	0.90	0.90	0.79	1.00
Start Time	10:07	7:35	8:13	8:41	13:40	9:42	15:46	9:32
End Time	11:19	8:10	9:00	9:10	14:36	10:40	18:01	10:20
Elapsed Time, hrs	1.20	0.58	0.78	0.48	0.93	0.97	2.25	0.80
Volume, gal	8,272	5,887	7,627	5,656	8,035	7,069	6,562	8,312
Average Steam Flow, lb/hr	5190	7084	6934	6602	5985	5324	2652	7157
Start Temp, °F	126	129	127	146	127	125	128	125
End Temp, °F	210	209	210	210	210	210	212	208
Average Instantaneous U, Btu/Hr ft ² °F	161	189	196	181	159	154	53	186
Overall U, Btu/Hr ft ² °F	78	122	125	123	117	110	43	137

*from (Baron, 1987)

9.2.2 Boiling

The boil-up rate and the heat transfer coefficient were determined for the RWCT simulant as a function of steam flow and agitation speed. In addition, the presence and extent of vapor binding was evaluated. Evaporator and condenser performance spreadsheets (see Appendix E) provide heat transfer coefficients, pressure drop across steam coils, evaporation rate, and energy balance results during boiling. Each spreadsheet is divided into segments of constant evaporation rate, where process variables were essentially constant.

The effect of steam flow on the evaporation rate and heat transfer coefficient is shown in Figures 9.2.2 and 9.2.3, respectively, for water, dilute NCAW waste simulant, and the RWCT simulant.

Figure 9.2.2 Evaporation Rates versus Steam Flow for RWCT and Other Simulants

Figure 9.2.3 Heat Transfer Coefficients versus Steam Flow for RWCT and Other Simulants

As seen in Figure 9.2.2, the relationship between steam flow and process evaporation is linear. Figure 9.2.3 shows that the boiling heat transfer coefficients increase with steam flow. The heat transfer coefficient will increase with steam flow until the heat flux exceeds a threshold value, and vapor binding occurs around the outside of the steam coils. Also note from this figure that the heat transfer coefficients of the dilute NCAW and RWCT simulants, during boiling, were nearly the same as those for water.

The effect of agitator speed on the heat transfer coefficient is shown in Figure 9.2.4 for water, dilute NCAW waste simulant, and RWCT simulant at 5200 lb/hr steam flow. As seen from this figure, for this set of conditions, increasing the agitator speed provided a modest increase in the heat transfer coefficient, which is likely due to the decrease in thickness of the laminar layer around the coils.

Figure 9.2.4 Heat Transfer Coefficients versus Agitator Speed for RWCT and Other Simulants

Vapor binding around heating coils during boiling is caused by a combination of high viscosity and high wall temperatures which can result in the formation of a blanket of water vapor around a heat transfer surface. An increase in heating coil steam flow that results in a decrease in the evaporator heat transfer coefficient and evaporation rate would have been an indication of vapor binding. During testing with water and dilute NCAW simulant, as well as the RWCT simulant, there was no evidence of vapor binding during the boiling segments. Increasing the steam flow, which will increase the coil wall temperature, was found to increase the heat transfer coefficient and the evaporation rate for all steam flows up to 6000 lb/hr.

9.2.3 Batch Cooling

Batches of process liquid were cooled from boiling to 125°F with a cooling water flow of 120 gpm. During cooling, the agitator speed was held constant at 85 rpm. The history of the coil heat transfer coefficients during cooling periods for initial water runs, dilute NCAW simulant, and RWCT simulant runs is shown in Figure 9.2.5.

Figure 9.2.5 Heat Transfer Coefficients versus Simulant Temperature During Cooling

The fluctuations in the data in Figure 9.2.5 are caused by cycling of the cooling tower fans. Table 9.2.2 provides cool-down times, process volume, and heat transfer coefficients for cooling periods for the different slurries. In this table, heat transfer coefficients are provided in terms of average instantaneous heat transfer coefficients (computed by averaging the time history of the heat transfer data) and overall heat transfer coefficients, which are based on the batch cooling closed form formula. In general, the transient cooling heat transfer coefficient for RWCT simulant was very close to the dilute NCAW waste simulant data, as expected. The average instantaneous and overall heat transfer coefficient for the RWCT simulant was close to that for the NCAW material. Supporting the previous finding, no significant degradation of the heat transfer capacity of the coils has occurred and the cleaning procedure used to remove the caked on melter feed left from the NCAW 1 campaign was successful. Also note that the average instantaneous and the overall heat transfer coefficients are in very good agreement, indicating that the assumptions used to establish the overall heat transfer equation were reasonable.

Table 9.2.2 Heat Transfer Information for RWCT and Other Simulants (During Cooling)

Test Simulant	Water	NCAW Dilute Waste Simulant	NCAW Dilute Waste Simulant	NCAW Concen. Waste Simulant	NCAW Concen. Waste Simulant	NCAW Formated W.S.	NCAW Melter Feed	RWCT Simulant
Weight % Solids	0.0%	4.2%	4.4%	15.5%	15.5%	19.0%	41.0%	4.5%
Specific Gravity	1	1.03	1.03	1.11	1.11	1.13	1.4	1.03
Specific Heat*, Btu/lb°F	1.00	1.00	1.00	0.90	0.90	0.90	0.79	1.00
Start Time	15:39	17:02	17:05	16:12	13:48	7:18	20:13	15:22
End Time	17:16	18:57	19:41	18:22	17:05	9:46	0:48	17:48
Elapsed Time, hrs	1.62	1.92	2.60	2.17	3.28	2.47	4.58	2.44
Volume, gal	5,405	5,751	7,425	5,488	7,870	6,548	6,463	8,118
Average Cooling Water Flow, gpm	122	118	116	119	120	115	115	120
Start Temp, °F	205	204	207	207	208	207	212	207
End Temp, °F	125	125	125	125	125	125	125	125
Average Instantaneous U, Btu/Hr ft ² °F	271	267	265	218	207	219	105	263
Overall U, Btu/Hr ft ² °F	241	260	260	200	192	215	114	263

*Savannah River Data

9.3 CONDENSER PERFORMANCE

Condenser heat transfer coefficient versus evaporation rate data for dilute NCAW waste simulant and RWCT simulant are provided in Figure 9.3.1. The condenser heat transfer data from the NCAW campaign was originally published in (Hatchell, 1993). During these tests, the condenser cooling water was held constant at 350 gpm and condensate was recycled back into the evaporator tank.

The experimental condenser heat transfer coefficient was determined from Fourier's Law (see Kern, 1950, page 86):

$$Q = U A T_w$$

Where

Q	=	Total heat transferred
U	=	Overall condenser heat transfer coefficient
A	=	Tube outside heat transfer area
T_w	=	Weighted temperature difference between cooling water and the process

The total heat transferred, Q , is the sum of the energy required to condense the process vapor plus the energy required to subcool the condensate. The tube outside surface area was found to be 450.6 ft². To calculate the weighted temperature difference, T_w , it was first necessary to calculate separately the log mean temperature difference between the cooling water and the process for both the condensing phase and the subcooling phase. These temperature differences were then weighted by the amount of energy transferred in each phase to determine the overall, weighted temperature difference. Since the condenser is a one-pass tube and shell (1-1) counter flow heat exchanger, no further correction factor is needed. This method is illustrated in the calculations in Appendix E (see also Kern, 1950, page 291).

Figure 9.3.1 Condenser Heat Transfer Coefficient as a Function of Boil-up Rate

Condensate temperature versus evaporation rate is provided in Figure 9.3.2. The condenser was able to subcool the condensate below 125 °F (the target value) for all evaporation rates. Note that no effort was made to control the condensate temperature; rather, a constant 350 gpm

cooling water flow rate was used, which provided more than adequate cooling.

Figure 9.3.2 Condensate Temperature as a Function of Boil-up Rate

The condenser heat transfer coefficient was slightly less during RWCT testing than in dilute NCAW simulant testing, even though the condensate temperature during the RWCT test was approximately 5°F lower than during dilute NCAW simulant testing. These small variation may be more of an artifact of uncontrolled process variables, such as the ambient temperature that the cooling water tower rejects heat to, rather than the effect of different simulants.

10.0 AMMONIA DISPERSION STUDY

10.1 BACKGROUND

Ammonia dispersion testing was designed to support HWVP material balance results previously established. The planned testing approach was to have ammonium hydroxide added to the full-scale process test vessel immediately following the completion of the pumping tests at 7800 gallons. Ammonia distribution data would be collected in the vent gas, condensate, and tank contents as a function of air flow rate (20, 30, 50, 60, 100, 150, 200, 300 SCFM), slurry pH (4, 6, 8, 10), and slurry temperature (35, 50, 60, 100 °C). The pH would also be adjusted with NaOH (to increase the pH) and with HNO₃ (to decrease the pH). Analysis for ammonia ions would have been performed by SIE (specific ion electrode).

Prior to full-scale testing, a laboratory-scale test was performed at two testing conditions (pH=10, T=100 °C and pH=10, T=50 °C) in order to identify any potential hazards that might be associated with testing in the full-scale test system and to better understand the evaporation rates of ammonia.

10.2 LABORATORY EXPERIMENTAL

Test activities performed in the laboratory-scale test system were used to support the ammonia dispersion tests in the large-scale test vessel. Aqueous ammonia was added to each of three media during this test procedure: These were: 1) DI water; 2) NCAW formatted waste simulant at 150 g total oxides/L; 3) RWCT waste simulant at 55 g total oxides/L (made up of NCAW recycle waste simulant and HWVP 39-4 process frit). The target ammonia concentration was 0.1 M.

The laboratory-scale test system consisted of a 2-liter vessel (evaporator) with six ports, a mass flow controller, laboratory-scale mixer, condenser, pH probe, heating mantle, thermocouple and thermostat for pH probe, sampling port, and a peristaltic pump. Also included was tubing for the addition of chemicals, 30-ml sample bottles, and a scrubber setup: flask, stoppers, tubes, scrubbing solution (0.1 M HCl). The scrubbing system was connected to the offgas line. The offgas line flowed into a stoppered flask which contained 0.1 M HCl scrubbing solution. The 2 liter reaction vessel had six ports which were used for the pH probe (and thermostat for pH probe), temperature controller, mixer, an offgas line connected to a mass flow controller (a device which sets the air flowrate to a prescribed value in L/min), a sampling port, and a chemical addition port.

Once the setup was assembled, the ammonia was added to the simulant being tested. Samples of the simulant were taken before and after ammonia addition. After NaOH additions, the solution pH was raised to between 9.5 to 10, and the solution temperature was raised to boiling (100 °C). Samples were taken at the point at which boiling was reached and one hour after boiling was reached. Finally, a sample was taken after the solution reached 50 °C while cooling. In addition, samples were taken of the scrubbers and of the condensate; these contents were analyzed for

ammonia content.

10.3 RESULTS

The ammonia laboratory-scale test was conducted on 9/3/93, 9/7/93, and 9/8/93 in the 325 building. Three different tests were run: one with water, one with archived recycle waste simulant with 39-4 frit, and one with archived formatted waste simulant. From examining the pH, it seemed as though similar amounts of ammonia were released for each test at the same conditions. The samples were taken to the analytical lab to be evaluated.

Using SIE analysis, ammonia was tracked in the vessel, condensate, and scrubbers at the end of the test. Roughly 80% of the ammonia was recovered in the water test. However, only 7% and 14% of the ammonia was recovered for the other two tests, respectively. This would seem to indicate adsorption of ammonia onto the solids in solution, a reaction(s), or both. Table 10.3.1 summarizes the results of the laboratory-scale ammonia study. Figure 10.3.1 shows a graphical analysis of where the ammonia went (i.e. the vessel vs. the scrubbers vs. the condensate, etc.).

In order to try to answer some of the questions at hand, the analytical laboratory performed their own lab-scale tests. They added NaNO_2 to H_2SO_4 in a small test vessel. The combination of these two compounds produced NO_x , which traveled through the offgas line into a scrubber containing 0.5 M HCl and NH_4Cl . They performed SIE (specific ion electrode) analysis on ammonia before and after the NO_x was allowed to interact with ammonia. They found that the NO_x destroyed some of the ammonia ion in the scrubber. SRL (Savannah River Laboratory) found that NH_4NO_3 was formed from the reaction of these compounds in the offgas line.

Table 10.3.1: Ammonia Results from Laboratory-Scale Tests Run 9/3/93 to 9/8/93

Description	Customer ID	NH ₃ , mg/L	Mass, g	Density, g/ml	Volume, ml	NH ₃ , moles
Water - After NH ₃ addition	RWCT Lab-1	1200.00	1210.00	1.00	1210.00	8.54E-02
Water - Before 1 hour	RWCT Lab-2	100.00	1210.00	1.00	1210.00	7.12E-03
Water - After 1 hour	RWCT Lab-3	20.00	1210.00	1.00	1210.00	1.42E-03
Water - At 50 °C	RWCT Lab-4	4.80	1017.60	1.00	1017.60	2.87E-04
Water - Scrubber #1	RWCT Lab-5	5200.00	334.60	1.19	281.89	8.62E-02
Water - Scrubber #2	RWCT Lab-6	350.00	311.60	1.19	262.51	5.40E-03
Water - Condensate	RWCT Lab-7	180.00	200.00	1.00	200.00	2.12E-03
Total Moles NH ₃ at start (theoretical)	0.120					
Total Moles NH ₃ at start (measured)	0.085					
Total Moles NH ₃ at end	0.094					
Total moles missing	0.026					
Percentage missing	21.638					
Recycle/Frit - Before NH ₃ addition	RWCT Lab-8	0.00	1245.70	1.04	1197.79	0.00E+00
Recycle/Frit - After NH ₃ addition	RWCT Lab-9	1400.00	1255.00	1.04	1206.73	9.94E-02
Recycle/Frit - Before 1 hour	RWCT Lab-10	260.00	1255.00	1.04	1206.73	1.85E-02
Recycle/Frit - After 1 hour	RWCT Lab-11	200.00	1255.00	1.04	1206.73	1.42E-02
Recycle/Frit - At 50 °C	RWCT Lab-12	1.90	1018.20	1.04	979.04	1.09E-04
Recycle/Frit - Scrubber #1	RWCT Lab-13	170.00	361.40	1.19	304.47	3.04E-03
Recycle/Frit - Scrubber #2	RWCT Lab-14	0.50	362.60	1.19	305.48	8.98E-06
Recycle/Frit - Condensate	RWCT Lab-15	340.00	281.10	1.00	281.10	5.62E-03
Total Moles NH ₃ at start (theoretical)	0.120					
Total Moles NH ₃ at start (measured)	0.099					
Total Moles NH ₃ at end	0.009					
Total moles missing	0.111					
Percentage missing	92.679					
Formated- After NH ₃ addition	RWCT Lab-16	1400.00	1344.00	1.10	1221.82	1.01E-01
Formated - Before 1 hour	RWCT Lab-17	540.00	1344.00	1.10	1221.82	3.88E-02
Formated - After 1 hour	RWCT Lab-18	105.00	1344.00	1.10	1221.82	7.55E-03
Formated - At 50 °C	RWCT Lab-19	33.00	1373.20	1.10	1248.36	2.42E-03
Formated - Scrubber #1	RWCT Lab-20	390.00	409.60	1.19	345.07	7.92E-03
Formated - Scrubber #2	RWCT Lab-21	1.90	413.80	1.19	348.61	3.90E-05
Formated - Condensate	RWCT Lab-22	1150.00	132.20	1.00	132.20	8.94E-03
Total Moles NH ₃ at start (theoretical)	0.120					
Total Moles NH ₃ at start (measured)	0.101					
Total Moles NH ₃ at end	0.019					
Total moles missing	0.101					
Percentage missing	83.899

Figure 10.3.1: Ammonia Release from Various Sources (Target = 12 moles)

After laboratory-scale testing, it became apparent that there may be more than one possibility for the ammonia disappearance. Due to these uncertainties, the decision was made to drop the ammonia dispersion test to be run during full-scale RWCT testing.

11.0 REFERENCES

WHC-SD-HWV-DP-001, Revision 6, October 1992, Hanford Waste Vitrification Plant Project Technical Data Package, Richland, Washington.

Test Plan No. HWVP-91-1.2.2.03.03B, Rev. 1, April 1992, Recycle Waste Collection Tank (RWCT) Testing: Addendum to Test Plan for Slurry Integrated Performance Testing (SIPT) Hanford Waste Vitrification Program, Pacific Northwest Laboratory, Richland, Washington.

Dickey, David S., and John G. Fenic, January 5, 1976, "Dimensional Analysis for Fluid Agitation Systems", Chemical Engineering, p.11.

Dickey, David S., and Richard W. Hicks, February 2, 1976, "Fundamentals of Agitation", Chemical Engineering, p.17.

HWVP-91-1.2.2.03.03B., Revision 1, April 21, 1992, Test Plan for Slurry-Integrated Performance Testing (SIPT) Hanford Waste Vitrification Program, Richland, Washington.

Oldshue, James Y., 1983, Fluid Mixing Technology, McGraw Hill Publications Co., New York, N.Y.

Scheaffer, R.L., and J.T. McClave., 1986, Probability and Statistics for Engineers, PWS Publishers, Boston, Massachusetts.

Gover, GW; Aziz, K. The Flow of Complex Mixtures in Pipes. Malabar, FL: Robert E. Krieger Publishing Company, Inc; 1982.

Sakiadis, Byron C. Fluid and Particle Mechanics. In: Perry, Robert; Green, Don W, eds. Perry's Chemical Engineers' Handbook: Sixth Edition. New York: McGraw-Hill Book Company; 1984: Section 5.

Olujic, Zarko. "Compute friction factors fast for flow in pipes." Chemical Engineering. 1981 December 14; 91 - 93.

Reid, Robert C; Prausnitz, John M.; Poling, Bruce E. The Properties of Gases & Liquids: Fourth Edition. New York: McGraw-Hill, Inc; 1987. pg. 441.

Mezger, Thomas. Short Course in Rheology. Germany: Paar Physica; 1991.

(Bird, R. Byron; Stewart, Warren E.; Lightfoot, Edwin N. Transport Phenomena. New York: John Wiley & Sons; 1960.

Schramm, Gebhard. Introduction to Practical Viscometry. West Germany: Haake; 1981.

APPENDIX A

GENERAL NOTES
(UNLESS OTHERWISE SPECIFIED)

-
- Diagram illustrating the components of the P1000 Series Unimount Channel and Unimount Pipe Clamps:
- STANDARD BEAM CLAMP FOR 60
 - CHANNEL BEAM
 - 61/2" THREADED HOOKER ROD
 - UNIMOUNT CHANNEL P1000 60
 - UNIMOUNT PIPE CLAMP FOR P1000 SERIES, TYP

DETAIL I

ENGINEERING WORKSHEET			
Battelle Pacific Northwest Lab Dr. J. VARNER Date 11/2/78		Title HWVP-SIPT SLURRY TEST LOOP ADDITION	
Engineer R. MOKAY Date 7/15/78	Worksheet No. HWST-SIPT-022	Impact Level II	
Reviewed by S. H. HARRIS Date 8/1/78	Ref. Org. HWST-SIPT-011	Sheet 3 of 3	

APPENDIX B

APPENDIX B - MEASURING & TEST EQUIPMENT LIST

INSTRUMENT TAG NUMBER	ASSOCIATED EQUIPMENT	LOCATION	DESCRIPTION	FUNCTION	MANUFACTURER
AE 014	HB-14	HB-14	PHM85 pH METER	ELEMENT	PHOENIX ELECT CO
AT 014	HB-14	HB-14	PHM85 pH METER	TRANSMITTER	RADIOMETER
AE 1001	HB-15	HB-15	PHM85 pH METER	ELEMENT	PHOENIX ELECT CO
AT 1001	HB-15	HB-15	pH PROBE COPENHAGEN	TRANSMITTER	RADIOMETER
FE 901	CD-1000	PRC-3-01	CONDENSATE FLOW	FLOW ELEMENT	ENDRESS & HAUSER
FT 901	CD-1000	RACK 2	CONDENSATE FLOW	TRANSMITTER	ENDRESS & HAUSER
FE 902	TK-900	P-1-02	CHEM ADD TO HB-15	FLOW ELEMENT	ENDRESS & HAUSER
FT 902	TK-900	RACK 1	CHEM ADD TO HB-15	TRANSMITTER	ENDRESS & HAUSER
FE 903	P-901	CA-1/2-01	FORMIC ADD TO HB-15	FLOW ELEMENT	ENDRESS & HAUSER
FT 903	P-901	FUME HOOD	FORMIC ADDITION FLOW	TRANSMITT	ERENDRESS & HAUSER
FE 1001	E-1001/E-1002	PRS-4-01	STEAM SUPPLY	FLOW ELEMENT	FISCHER PORTER
FT 1001	E-1001/E-1002	RACK 1	STEAM SUPPLY	TRANSMITTER	FISCHER PORTER
FE 1002	CD-1000/HB-15	LPW-2-01	SUPPORT SERVICES	FLOW ELEMENT	ENDRESS & HAUSER
FT 1002	CD-1000/HB-15	RACK 2	SUPPORT SERVICES	TRANSMITTER	ENDRESS & HAUSER
FE 1003	E-1003	PSW-2-02	COOLING WATER FLOW	FLOW ELEMENT	ENDRESS & HAUSER
FT 1003	E-1003	RACK 1	COOLING WATER FLOW	TRANSMITTER	ENDRESS & HAUSER
FE 1010	P-1002	LWP-1 1/2-01	FLUSH WATER FLOW	FLOW ELEMENT	ENDRESS & HAUSER
FT 1010	P-1002	RACK 1	FLUSH WATER FLOW	TRANSMITTER	ENDRESS & HAUSER
FE 1011	HYDRAGARD	SAMPLER	SAMPLER FEED FLOW	FLOW ELEMENT	KROHNE
FT 1011	HYDRAGARD	SAMPLER	SAMPLER FEED FLOW	TRANSMITTER	KROHNE
FE 1013	HB-15	P-2-06	CHEM ADD FROM HB-13	FLOW ELEMENT	ENDRESS & HAUSER
FT 1013	HB-15	RACK 1	CHEM ADD FROM HB-13	TRANSMITTER	ENDRESS & HAUSER
FE 1021	P-1101	LPW-2-09	PRIME WATER FLOW	FLOW ELEMENT	ENDRESS & HAUSER
FT 1021	P-1101	RACK 1	PRIME WATER FLOW	TRANSMITTER	ENDRESS & HAUSER
FE 1022	HYDRAGARD	LPW-1/2-01	HYDRAGARD FLUSH WATER	FLOW ELEMENT	ENDRESS & HAUSER
FT 1022	HYDRAGARD	SAMPLER	HYDRAGARD FLUSH WATER	TRANSMITTER	ENDRESS & HAUSER
FE 1023	FEED NOZZLE	P-3/8-01	FEED FLOW	FLOW ELEMENT	KROHNE
FT 1023	FEED NOZZLE	EDL-102	FEED FLOW	TRANSMITTER	KROHNE
FE 1024	P-1101	P-2-03	TRANSFER LINE FLOW	FLOW ELEMENT	KROHNE
FT 1024	P-1101	RACK 1	TRANSFER LINE FLOW	TRANSMITTER	KROHNE
FE 1101	CD-1000	LPW-1-02	MIST ELIM FLUSH WATER	FLOW ELEMENT	ENDRESS & HAUSER
FT 1101	CD-1000	RACK 2	MIST ELIM FLUSH WATER	INDICATOR	ENDRESS & HAUSER
FE 1102	CD-1000	PRW-4-01	COOLING WATER FLOW	FLOW ELEMENT	ENDRESS & HAUSER
FT 1102	CD-1000	PRW-4-01	COOLING WATER FLOW	TRANSMITTER	ENDRESS & HAUSER
FE 1103	CD-1000	VOG-3-01	OFFGAS FLOW	FLOW ELEMENT	EG & G
FT 1103	CD-1000	RACK 2	OFFGAS FLOW	TRANSMITTER	EG & G
FT 1051	HB-15	PLA-1-05	AIR SUPPLY FLOW	FLOW INDICATOR	OMEGA ENGINEERING
FT 1111	CD-1000	LPW-2-01	COND FLUSH WATER FLOW	FLOW INDICATOR	FISCHER PORTER
FY 902	TK-900	RACK 1	CHEM ADD FROM TK-900	FLOW CONTROL	MOORE INDUSTRIES
FY 1013	HB-15	RACK 1	CHEM ADD FROM HB-13	FLOW CONTROL	MOORE INDUSTRIES
FY 1014	HB-15	RACK 1	HB-15 PURGE AIR CONTROL	FLOW CONTROL	MOORE INDUSTRIES
LE/LT 1400	HB-14	HB-14	LEVEL PROBE	LIQUID LEVEL	BINDICATOR
PDE/PT 1002	HB-15	RACK 1	HOLLEDGE DETECTOR	D/P TRANSMITTER	ROSEMOUNT
PDE/PT 1003	HB-15	RACK 1	HOLLEDGE DETECTOR	D/P TRANSMITTER	ROSEMOUNT
PDE/PT 1004	HB-15	RACK 1	HOLLEDGE DETECTOR	D/P TRANSMITTER	ROSEMOUNT
PDE/PT 1005	HB-15	RACK 2	HOLLEDGE DETECTOR	D/P TRANSMITTER	ROSEMOUNT
PDE/PT 1105	CD-1000	RACK 2	MIST ELIMINATOR	D/P TRANSMITTER	ROSEMOUNT
PT 1011	HYDRAGARD	HYDRAGARD	SAMPLER FEED	PRESS INDICATOR	RED VALVE
PT 1001	E-1001/E-1002	RACK 1	COIL STEAM SUPPLY	TRANSMITTER	ROSEMOUNT
PT 1012	P-1002	SPL-1/2-02	SAMPLE PUMP DISCHARGE PRESS	TRANSMITTER	ROSEMOUNT
PE 1012	P-1002	SPL-1/2-02	SAMPLE PUMP DISCHARGE PRESS	PRESS TAP	ROSEMOUNT
PT 1020	P-1101	P-2-04	CROSSFLOW STRAINER	TRANSMITTER	ROSEMOUNT
PE 1020	P-1101	P-2-04	CROSSFLOW STRAINER	ELEMENT	ROSEMOUNT
PT 1021	E-1001/E-1002	LOCAL	STEAM HEADER	TRANSMITTER	ROSEMOUNT
PT 1022	E-1002	RACK 1	CONDENSATE OUT	TRANSMITTER	ROSEMOUNT
PT 1023	E-1001	RACK 1	CONDENSATE OUT	TRANSMITTER	ROSEMOUNT
PT 1024	E-1003	RACK 1	E-1003 COIL INLET PRESS	TRANSMITTER	ROSEMOUNT
PT 1025	E-1001	RACK 1	E-1003 COIL OUTLET PRESS	TRANSMITTER	ROSEMOUNT
PT 1031	P-1101	P-2-03	TRANS-FEED PUMP DISCH PRESS	TRANSMITTER	ROSEMOUNT
PE 1031	P-1101	P-2-03	TRANS-FEED PUMP DISCH PRESS	ELEMENT	ROSEMOUNT
PT 1032	P-1101	P-2-04	FEED RECYCLE LOOP RETURN PRESS	TRANSMITTER	ROSEMOUNT
PE 1032	P-1101	P-2-04	FEED RECYCLE LOOP RETURN PRESS	ELEMENT	ROSEMOUNT
PT 1033	P-1101	P-3/8-01	MELTER FEED LINE 3-WAY BK PRESS	TRANSMITTER	ROSEMOUNT
PE 1033	P-1101	P-3/8-01	MELTER FEED LINE 3-WAY BK PRESS	ELEMENT	ROSEMOUNT
PT 1034	P-1101	P-3/8-01	MELTER FEED NOZZLE BK PRESS	TRANSMITTER	ROSEMOUNT
PE 1034	P-1101	P-3/8-01	MELTER FEED NOZZLE BK PRESS	ELEMENT	ROSEMOUNT

<u>INSTRUMENT TAGNUMBER</u>	<u>ASSOCIATED EQUIPMENT</u>	<u>LOCATION</u>	<u>DESCRIPTION</u>	<u>FUNCTION</u>	<u>MANUFACTURER</u>
PT 1051	HB-15	RACK 1	AIR SUPPLY	TRANSMITTER	ROSEMOUNT
PT 1101	CD-1000	RACK 2	COOLING WATER IN	TRANSMITTER	ROSEMOUNT
PT 1102	CD-1000	RACK 1	CONDENSER COOL H2O OUT PRES	TRANSMITTER	ROSEMOUNT
PT 1103	CD-1000	RACK 2	CONDENSER PRESS	TRANSMITTER	ROSEMOUNT
PY 1000	HB-15	RACK 1	OFFGAS VACUUM CONTROL	PRESS CONTROL	MOORE INDUSTRIES
PY 1001	E-1001/E-1002	RACK 1	STEAM CONTROL	PRESS CONTROL	MOORE INDUSTRIES
TE 1031	E-1003	PSW-2-02	COOLING WATER IN	RTD	ROSEMOUNT
TT 1031	E-1003	RACK 1	COOLING WATER IN	TRANSMITTER	ROSEMOUNT
TE 1032	E-1003	PRW-2-02	COOLING WATER OUT	RTD	ROSEMOUNT
TT 1032	E-1003	RACK 1	COOLING WATER OUT	TRANSMITTER	ROSEMOUNT
TE 1033	P-1101	P-2-04	FEED RECYCLE LOOP TEMP	ELEMENT	ROSEMOUNT
TT 1033	P-1101	P-2-04	FEED RECYCLE LOOP TEMP	TRANSMITTER	ROSEMOUNT
TE 1041	HB-15	THERMOWELL	HB-15 TEMP	THERMOCOUPLE	EUSTIS CO. INC.
TT 1041	HB-15	RACK 1	HB-15 TEMP	TRANSMITTER	ROSEMOUNT
TE 1042	HB-15	THERMOWELL	HB-15 TEMP	THERMOCOUPLE	EUSTIS CO. INC.
TT 1042	HB-15	RACK 1	HB-15 TEMP	TRANSMITTER	ROSEMOUNT
TE 1043	HB-15	THERMOWELL	HB-15 TEMP	THERMOCOUPLE	EUSTIS CO. INC.
TT 1043	HB-15	RACK 1	HB-15 TEMP	TRANSMITTER	ROSEMOUNT
TE 1044	HB-15	THERMOWELL	HB-15 TEMP	THERMOCOUPLE	EUSTIS CO. INC.
TT 1044	HB-15	RACK 1	HB-15 TEMP	TRANSMITTER	ROSEMOUNT
TE 1045	HB-15	THERMOWELL	HB-15 TEMP	THERMOCOUPLE	EUSTIS CO. INC.
TT 1045	HB-15	RACK 1	HB-15 TEMP	TRANSMITTER	ROSEMOUNT
TE 1046	HB-15	THERMOWELL	HB-15 TEMP	THERMOCOUPLE	EUSTIS CO. INC.
TT 1046	HB-15	RACK 1	HB-15 TEMP	TRANSMITTER	ROSEMOUNT
TE 1047	E-1001/E-1002	PRS-4-01	STEAM SUPPLY	RTD	ROSEMOUNT
TT 1047	E-1001/E-1002	RACK 1	STEAM SUPPLY	TRANSMITTER	ROSEMOUNT
TE 1051	HB-15	PLA-1-05	AIR PURGE SUPPLY	RTD	ROSEMOUNT
TT 1051	HB-15	RACK 1	AIR PURGE SUPPLY	TRANSMITTER	ROSEMOUNT
TE 1052	E-1001	PSC-1-01	CONDENSATE OUT	RTD	ROSEMOUNT
TT 1052	E-1001	RACK 1	CONDENSATE OUT	TRANSMITTER	ROSEMOUNT
TE 1053	E-1002	PSC-1-03	CONDENSATE OUT	RTD	ROSEMOUNT
TT 1053	E-1002	RACK 1	CONDENSATE OUT	TRANSMITTER	ROSEMOUNT
TE 1101	CD-1000	CD-1000	CONDENSER TEMP	RTD	ROSEMOUNT
TT 1101	CD-1000	RACK 2	CONDENSER TEMP	TRANSMITTER	ROSEMOUNT
TE 1102	CD-1000	PRW-2-01	COOLING WATER OUT	RTD	ROSEMOUNT
TT 1102	CD-1000	RACK 2	COOLING WATER OUT	TRANSMITTER	ROSEMOUNT
TE 1103	CD-1000	PRC-3-01	CONDENSATE OUT	RTD	ROSEMOUNT
TT 1103	CD-1000	RACK 2	CONDENSATE OUT	TRANSMITTER	ROSEMOUNT
TE 1104	CD-1000	PSW-2-01	COOLING WATER IN	RTD	ROSEMOUNT
TT 1104	CD-1000	RACK 2	COOLING WATER IN	TRANSMITTER	ROSEMOUNT
TE 1105	CD-1000	VOG-3-01	OFFGAS OUT	RTD	ROSEMOUNT
TT 1105	CD-1000	RACK 2	OFFGAS OUT	TRANSMITTER	ROSEMOUNT
WE 901	TK-900	TK-900	LOAD CELL	STRAIN GAGE	KISTLER-MORSE
WE 902	TK-900	TK-900	LOAD CELL	STRAIN GAGE	KISTLER-MORSE
WE 903	TK-900	TK-900	LOAD CELL	STRAIN GAGE	KISTLER-MORSE
WT 900	TK-900	TK-900	TOTALIZER	TANK WEIGHT	KISTLER-MORSE
WE 1001	HB-15	HB-15	LOAD CELL	STRAIN GAGE	KISTLER-MORSE
WE 1002	HB-15	HB-15	LOAD CELL	STRAIN GAGE	KISTLER-MORSE
WE 1003	HB-15	HB-15	LOAD CELL	STRAIN GAGE	KISTLER-MORSE
WT 1000	HB-15	HB-15	TOTALIZER	TANK WEIGHT	KISTLER-MORSE
SY 1000	AG-1000	AG-1000	AGITATOR SPEED	INPUT	ELECTRO SENSORS
II 1000	AG-1000	CONTROLLER	AGITATOR CURRENT	INPUT	ROCHESTER INST. INC.
EI 1000	AG-1000	CONTROLLER	AGITATOR VOLTAGE	INPUT	NEWPORT ELECTRONICS
SY 1010	P-1002	P-1002	PUMP SPEED	INPUT	ELECTRO SENSORS
II 1010	P-1002	CONTROLLER	PUMP CURRENT	INPUT	ROCHESTER INST. INC.
EI 1010	P-1002	CONTROLLER	SAMPLE PUMP VOLTAGE	INPUT	NEWPORT ELECTRONICS
SY 1020	P-1101	P-1101	PUMP SPEED	INPUT	ELECTRO SENSORS
II 1020	P-1101	CONTROLLER	PUMP CURRENT	INPUT	ROCHESTER INST. INC.
EI 1020	P-1101	CONTROLLER	TRANSFER/FEED PUMP VOLTAGE	INPUT	NEWPORT ELECTRONICS
0051453-T	P-1101	1/2" STL	1/2" SLURRY TEST LOOP	TRANSMITTER	ROSEMOUNT
0051453-E	P-1101	1/2" STL	1/2" SLURRY TEST LOOP	ELEMENT	ROSEMOUNT
0051454-T	P-1101	1/2" STL	1/2" SLURRY TEST LOOP	TRANSMITTER	ROSEMOUNT
0051454-E	P-1101	1/2" STL	1/2" SLURRY TEST LOOP	ELEMENT	ROSEMOUNT
0051719-T	P-1101	1" STL	1" SLURRY TEST LOOP	TRANSMITTER	ROSEMOUNT
0051719-E	P-1101	1" STL	1" SLURRY TEST LOOP	ELEMENT	ROSEMOUNT
0051720-T	P-1101	1" STL	1" SLURRY TEST LOOP	TRANSMITTER	ROSEMOUNT
0051720-E	P-1101	1" STL	1" SLURRY TEST LOOP	ELEMENT	ROSEMOUNT
0051721-T	P-1101	2" STL	2" SLURRY TEST LOOP	TRANSMITTER	ROSEMOUNT
0051721-E	P-1101	2" STL	2" SLURRY TEST LOOP	ELEMENT	ROSEMOUNT
0051722-T	P-1101	2" STL	2" SLURRY TEST LOOP	TRANSMITTER	ROSEMOUNT
0051722-E	P-1101	2" STL	2" SLURRY TEST LOOP	ELEMENT	ROSEMOUNT

<u>INSTRUMENT TAG NUMBER</u>	<u>ASSOCIATED EQUIPMENT</u>	<u>LOCATION</u>	<u>DESCRIPTION</u>	<u>FUNCTION</u>	<u>MANUFACTURER</u>
147-31-04-005	CD-1000	VOG-3-01	OFFGAS FLOW	TRANSMITTER	DWYER
147-45-02-005	N/A	N/A	MULTIMETER	INDICATION	FLUKE
147-45-02-006	N/A	N/A	MULTIMETER	INDICATION	FLUKE
999-31-04-104	N/A	N/A	HAND HELD PRESS READOUT	INDICATION	ROCHESTER INST. INC.

INSTRUMENT TAG NUMBER	PART NUMBER	CALIB SERIAL NUMBER	CALIB LEVEL	CALIB DATE FREQ	INSTRUMENT DUE	RANGE	OUTPUT	% ERROR
AE 014	PHZ774739-NB-040-CHV	NONE	3	N/A	N/A	0-14 pH	N/A	N/A
AT 014	PHM85-2	92R24N02	3	N/A	N/A	0-14 pH	RS-232	N/A
AE 1001	PHZ774739-NB-040-CHV	NONE	3	N/A	N/A	0-14 pH	N/A	N/A
AT 1001	PHM85-2	92R24N05	3	N/A	N/A	0-14 pH	RS-232	N/A
FE 901	FTI194301TFSSA1GP3RCNE	1943-077943190	1	12	FEB-92	1-10 GPM	N/A	+/-1%
FT 901	FTI194301TFSSA1GP3RCNE	1943-077943190	1	12	FEB-92	0-13 GPM	4-20 MA	+/-1%
FE 902	FTI194301TFSSA1GP3RCNE	1943-077953190	1	12	FEB-92	4-42 GPM	N/A	+/-1%
FT 902	FTI194301TFSSA1GP3RCNE	1943-077953190	1	12	FEB-92	0-53 GPM	4-20 MA	+/-1%
FE 903	FTI19411DDTFHCN4GP3SPSSRCNESP	1941-082550691	1	12	FEB-92	0-3 GPM	N/A	+/-1%
FT 903	FTI19411DDTFHCN4GP3SPSSRCNESP	1941-082550691	1	12	FEB-92	0-3 GPM	4-20 MA	+/-1%
FE 1001	10LV3201AFCB	8911A0629A0002	1	12	FEB-92	36-527GPM	N/A	+/-0.75%
FT 1001	50LV3211B1FB	8911A0629A0003	1	12	FEB-92	0-7500 PPH	4-20 MA	+/-0.75%
FE 1002	FTI194302TFSSA1GP3RCNE	1943-077963090	1	12	FEB-92	20-200GPM	N/A	+/-1%
FT 1002	FTI194302TFSSA1GP3RCNE	1943-077963090	1	12	FEB-92	0-310 GPM	4-20 MA	+/-1%
FE 1003	FTI194302TFSSA1GP3RCNE	1943-077973090	1	12	FEB-92	10-100GPM	N/A	+/-1%
FT 1003	FTI194302TFSSA1GP3RCNE	1943-077973090	1	12	FEB-92	0-125 GPM	4-20 MA	+/-1%
FE 1010	FTI19430FTFSSA1GP3RCNE	1943-077992590	1	12	FEB-92	10-100GPM	N/A	+/-1%
FT 1010	FTI19430FTFSSA1GP3RCNE	1943-077992589	1	12	FEB-92	0-125 GPM	4-20 MA	+/-1%
FE 1011	X-1000	901880-CS	1	12	FEB-92	0-6 GPM	N/A	+/-0.2%
FT 1011	SC-100	8526286	1	12	FEB-92	0-5 GPM	4-20 MA	+/-0.2%
FE 1013	FTI194302TFSSA1GP3RCNE	1943-077983090	1	12	FEB-92	14-135GPM	N/A	+/-1%
FT 1013	FTI194302TFSSA1GP3RCNE	1943-077983090	1	12	FEB-92	0-170 GPM	4-20 MA	+/-1%
FE 1021	FTI194302TFSSA1GP3RCNE	1943-078013090	1	12	FEB-92	10-100GPM	N/A	+/-1%
FT 1021	FTI194302TFSSA1GP3RCNE	1943-078013090	1	12	FEB-92	0-125 GPM	4-20 MA	+/-1%
FE 1022	FTI19430DTFSSA1GP3RCNE	1943-078002590	1	12	FEB-92	0.1-1 GPM	N/A	+/-1%
FT 1022	FTI19430DTFSSA1GP3RCNE	1943-078002589	1	12	FEB-92	0-2 GPM	4-20 MA	+/-1%
FE 1023	X-1000	90293-CS	1	12	FEB-92	0-3.4 GPM	N/A	+/-0.3%
FT 1023	SC-100	8526274	1	12	FEB-92	0-7.5 GPM	4-20 MA	+/-0.3%
FE 1024	X-1000	893620-A6	1	12	FEB-92	0-66 GPM	N/A	+/-0.3%
FT 1024	SC-100	8525900	1	12	FEB-92	0-100 GPM	4-20 MA	+/-0.3%
FE 1101	FTI194301TFSSA1GP3RCNE	1943-077933190	1	12	FEB-92	1-10 GPM	N/A	+/-1%
FT 1101	FTI194301TFSSA1GP3RCNE	1943-077933190	1	12	FEB-92	0-13 GPM	4-20 MA	+/-1%
FE 1102	FTI194304TFTAA1HL300NE	1943-088573491	1	12	AUG-92	0-400 GPM	N/A	+/-1%
FT 1102	FTI194304TFTAA1HL300NE	1943-088573491	1	12	AUG-92	0-400 GPM	4-20 MA	+/-1%
FE 1103	10LV3201ACBC	90W007458	1	12	FEB-92	0-92 SCFM	N/A	+/-1.5%
FT 1103	50LV3212B1CC	90W007459	1	12	FEB-92	0-92 SCFM	4-20 MA	+/-1.5%
FI 1051	FSK-9165	NONE	3	N/A	N/A	0-450 SCFM	N/A	N/A
FI 1111	10A5001X	8911A0629A0001	1	12	FEB-92	8.8-15GPM	N/A	+/-1%
FY 902	IPT	630742	3	N/A	N/A	4-20 MA	3-15 PSI	N/A
FY 1013	IPT	630743	3	N/A	N/A	4-20 MA	3-15 PSI	N/A
FY 1014	IPT	630748	3	N/A	N/A	4-20 MA	3-15 PSI	N/A
LE/LT 1400	CL3G1CB9620	NONE	3	N/A	N/A	0-96 INCHES	4-20 MA	N/A
PDE/PT 1002	3051CD2A22A1AB4J2M5	070019687	1	12	FEB-92	0-250"H2O	4-20 MA	+/- 0.1%
PDE/PT 1003	3051CD2A22A1AB4J2M5	070019688	1	12	FEB-92	0-250"H2O	4-20 MA	+/- 0.1%
PDE/PT 1004	3051CG2A22A1AB4J2M5	070019772	1	12	JUN-92	-20-+80"H2O	4-20 MA+/-	0.1%
PDE/PT 1005	3051CD2A22A1AB4J2M5	070019773	1	12	FEB-92	0-250"H2O	4-20 MA	+/- 0.1%
PDE/PT 1105								
PI 1011	TYPE 42	90-5457	1	12	APR-92	0-60 PSI	N/A	+/- 2%
PT 1001	3051CG4A22A1AB4J2M5	070019380	1	12	FEB-92	0-300 PSI	4-20 MA	+/-0.1%
PT 1012	3051CG4A22A1AS1B4M5	070049807	1	12	JUN-92	0-100 PSI	4-20 MA	+/-0.1%
PE 1012	W24IT	NONE	1	12	JUN-92	0-1250PSI	N/A	+/-0.1%
PT 1020	3051CG4A22A1AB4J2M5	0023102	1	12	FEB-92	0-300 PSI	4-20 MA	+/-0.1%
PE 1020	W24TF	NONE	1	12	FEB-92	0-275 PSI	N/A	+/-0.1%
PT 1021	3051CG4A22A1AB4J2M5	070019381	1	12	FEB-92	0-300 PSI	4-20 MA	+/-0.1%
PT 1022	3051CG4A22A1AB4J2M5	070019382	1	12	FEB-92	0-300 PSI	4-20 MA	+/-0.1%
PT 1023	3051CG4A22A1AB4J2M5	070019383	1	12	FEB-92	0-300 PSI	4-20 MA	+/-0.1%
PT 1024	3051CG4A22A1AB4M5	070046608	1	12	MAY-92	0-100 PSI	4-20 MA	+/-0.1%
PT 1025	3051CG4A22A1AB4M5	070046609	1	12	MAY-92	0-100 PSI	4-20 MA	+/-0.1%
PT 1031	3051CG4A22A1AS1B4M5	070049806	1	12	JUN-92	0-70 PSI	4-20 MA	+/-0.1%
PE 1031	W24TF	NONE	1	12	JUN-92	0-275 PSI	N/A	+/-0.1%

INSTRUMENT TAGNUMBER	PART NUMBER	CALIB CALIB DATE INSTRUMENT			RANGE	OUTPUT	%ERROR
		SERIALNUMBER	LEVEL	FREQ DUE			
PT 1032	3051CG4A22A1AS1B4M5	070049805	1	12 JUN-92	0-70 PSI	4-20 MA	+/-0.1%
PE 1032	W24TF	NONE	1	12 JUN-92	0-275 PSI	N/A	+/-0.1%
PT 1033	3051CG4A22A1AS1B4M5	070047087	1	12 MAY-92	0-50 PSI	4-20 MA	+/-0.1%
PE 1033	W24TF	NONE	1	12 MAY-92	0-275 PSI	N/A	+/-0.1%
PT 1034	3051CG4A22A1AS1B4M5	070047086	1	12 MAY-92	0-50 PSI	4-20 MA	+/-0.1%
PE 1034	W24TF	NONE	1	12 MAY-92	0-275 PSI	N/A	+/-0.1%
PT 1051	3051CG4A22A1AB4J2M5	070019384	1	12 FEB-92	0-300 PSI	4-20 MA	+/-0.1%
PT 1101	3051CG4A22A1AB4J2M5	070019385	1	12 FEB-92	0-300 PSI	4-20 MA	+/-0.1%
PT 1102	3051CG4A22A1AB4M5	070046607	1	12 MAY-92	0-100 PSI	4-20 MA	+/-0.1%
PT 1103	3051CG4A22A1AB4J2M5	070019386	1	12 FEB-92	0-300 PSI	4-20 MA	+/-0.1%
PY 1000	IPT	639875	3	N/A N/A	4-20 MA	3-15 PSI	N/A
PY 1001	IPT	634631	3	N/A N/A	4-20 MA	3-15 PSI	N/A
TE 1031	0058C-1200-C01	0315519	1	12 MAR-92	0-100 C	N/A	+/-0.05%
TT 1031	3044A1B1M1	55022663	1	12 FEB-92	0-100 C	4-20 MA	+/-0.14%
TE 1032	0058C-1200-C01	0315520	1	12 MAR-92	0-100 C	N/A	+/-0.05%
TT 1032	3044A1B1M1	55022664	1	12 FEB-92	0-100 C	4-20 MA	+/-0.14%
TE 1033							
TT 1033							
TE 1041	4189	999-78-02-087-319	1	12 MAR-92	0-100 C	N/A +/- 2.2%	
TT 1041	0444TJ1U1A2E5	480359836	1	12 FEB-92	0-300 C	4-20 MA	+/-0.2%
TE 1042	4189	999-78-02-087-320	1	12 MAR-92	0-100 C	N/A +/- 2.2%	
TT 1042	0444TJ1U1A2E5	480359837	1	12 FEB-92	0-300 C	4-20 MA	+/-0.2%
TE 1043	4189	999-78-02-087-329	1	12 MAR-92	0-100 C	N/A +/- 2.2%	
TT 1043	0444TJ1U1A2E5	480359838	1	12 FEB-92	0-300 C	4-20 MA	+/-0.2%
TE 1044	4189	999-78-02-087-328	1	12 MAR-92	0-100 C	N/A +/- 2.2%	
TT 1044	0444TJ1U1A2E5	480359839	1	12 FEB-92	0-300 C	4-20 MA	+/-0.2%
TE 1045	4189	999-78-02-087-318	1	12 MAR-92	0-100 C	N/A +/- 2.2%	
TT 1045	0444TJ1U1A2E5	480359840	1	12 FEB-92	0-300 C	4-20 MA	+/-0.2%
TE 1046	4189	999-78-02-087-330	1	12 MAR-92	0-100 C	N/A +/- 2.2%	
TT 1046	0444TJ1U1A2E5	480359841	1	12 FEB-92	0-300 C	4-20 MA	+/-0.2%
TE 1047	0058C-1200-C01	0315521	1	12 MAR-92	0-100 C	N/A	+/-0.05%
TT 1047	3044A1B1M1	550022665	1	12 JUN-92	0-100 C	4-20 MA	+/-0.14%
TE 1051	0058C-1200-C01	0315529	1	12 MAR-92	0-100 C	N/A	+/-0.05%
TT 1051	3044A1B1M1	550022673	1	12 FEB-92	0-100 C	4-20 MA	+/-0.14%
TE 1052	0058C-1200-C01	0315522	1	12 MAR-92	0-100 C	N/A	+/-0.05%
TT 1052	3044A1B1M1	550022666	1	12 JUN-92	0-100 C	4-20 MA	+/-0.14%
TE 1053	0058C-1200-C01	0315523	1	12 MAR-92	0-100 C	N/A	+/-0.05%
TT 1053	3044A1B1M1	550033102	1	12 JUL-92	0-200 C	4-20 MA	+/-0.14%
TE 1101	0058C-1200-C01	0315524	1	12 MAR-92	0-100 C	N/A	+/-0.05%
TT 1101	3044A1B1M1	550022668	1	12 FEB-92	0-100 C	4-20 MA	+/-0.14%
TE 1102	0058C-1200-C01	0315525	1	12 MAR-92	0-100 C	N/A	+/-0.05%
TT 1102	3044A1B1M1	550022669	1	12 FEB-92	0-100 C	4-20 MA	+/-0.14%
TE 1103	0058C-1200-C01	0315526	1	12 MAR-92	0-100 C	N/A	+/-0.05%
TT 1103	3044A1B1M1	550022670	1	12 FEB-92	0-100 C	4-20 MA	+/-0.14%
TE 1104	0058C-1200-C01	0315527	1	12 MAR-92	0-100 C	N/A	+/-0.05%
TT 1104	3044A1B1M1	550022671	1	12 FEB-92	0-100 C	4-20 MA	+/-0.14%
TE 1105	0058C-1200-C01	0315528	1	12 MAR-92	0-100 C	N/A	+/-0.05%
TT 1105	3044A1B1M1	550022672	1	12 FEB-92	0-100 C	4-20 MA	+/-0.14%
WE 901	D2-200D	4601	1	12 FEB-92	0-2000#	N/A	+/-0.2%
WE 902	D2-200D	4602	1	12 FEB-92	0-2000#	N/A	+/-0.2%
WE 903	D2-200D	4603	1	12 FEB-92	0-2000#	N/A	+/-0.2%
WT 900	1020-XI	637	1	12 FEB-92	0-6000#	4-20 MA	+/-0.05MA
WE 1001	SI-050K	3892	1	12 FEB-92	0-50000#	N/A	+/-0.25%
WE 1002	SI-050K	3891	1	12 FEB-92	0-50000#	N/A	+/-0.25%
WE 1003	SI-050K	3890	1	12 FEB-92	0-50000#	N/A	+/-0.25%
WT 1000	1020-XI	638	1	12 FEB-92	0-150000#	4-20 MA	+/-0.05MA
SY 1000	DISC10C	40773	1	12 AUG-92	0-200 RPM	4-20 MA	+/-0.05
II 1000	CCC1BC5E1XAF6020	R36431-323			0-150 AMP	4-20 MA	
EI 1000	Q2040CVR6	910321B			0-440 VAC	4-20 MA	
SY 1010	DISC10C	33781-2	3	N/A N/A	0-2000 RPM	4-20 MA	N/A
II 1010	CCC1BC5E1XAF6020	R36431-320			0-50 AMP	4-20 MA	
EI 1010	Q2040CVR6	910321C			0-440 VAC	4-20 MA	
SY 1020	DISC10C	31979-4	3	N/A N/A	0-2000 RPM	4-20 MA	N/A
II 1020	CCC1BC5E1XAF6020	R36431-319			0-50 AMP	4-20 MA	
EI 1020	Q2040CVR6	910321D			0-440 VAC	4-20 MA	
0051453-T	3051CG4A22A1AS1B4M5	0051453	1	12 JUL-92	0-100 PSI	4-20 MA	+/-0.1%
0051453-E	W24TF	NONE	1	12 JUL-92	0-275 PSI	N/A	+/-0.1%
0051454-T	3051CG4A22A1AS1B4M5	0051454	1	12 JUL-92	0-100 PSI	4-20 MA	+/-0.1%
0051454-E	W24TF	NONE	1	12 JUL-92	0-275 PSI	N/A	+/-0.1%
0051719-T	3051CG4A22A1AS1B4M5	0051719	1	12 JUL-92	0-100 PSI	4-20 MA	+/-0.1%
0051719-E	W24TF	NONE	1	12 JUL-92	0-275 PSI	N/A	+/-0.1%

INSTRUMENT TAG NUMBER	PART NUMBER	CALIB SERIAL NUMBER	CALIB LEVEL	DATE FREQ	INSTRUMENT DUE	RANGE	OUTPUT	%ERROR
0051720-T	3051CG4A22A1AS1B4M5	0051720	1	12	JUL-92	0-100 PSI	4-20 MA	+/-0.1%
0051720-E	W24TT	NONE	1	12	JUL-92	0-275 PSI	N/A	+/-0.1%
0051721-T	3051CG4A22A1AS1B4M5	0051721	1	12	JUL-92	0-100 PSI	4-20 MA	+/-0.1%
0051721-E	W24TT	NONE	1	12	JUL-92	0-275 PSI	N/A	+/-0.1%
0051722-T	3051CG4A22A1AS1B4M5	0051722	1	12	JUL-92	0-100 PSI	4-20 MA	+/-0.1%
0051722-E	W24TT	NONE	1	12	JUL-92	0-275 PSI	N/A	+/-0.1%
147-31-04-005	605-10	NONE	1	12	SEP-92	0-10 IN H2O	4-20 MA	+/-2.0%
147-45-08-005	8050A	4705069	1	6	NOV-91	N/A	N/A	VARIOUS
147-45-08-006	77	52341662	1	6	NOV-91	N/A	N/A	VARIOUS
999-31-04-104	DPG-600G-10	999-31-04-104	1	12	JUN-92	0-250 IN-H2O	N/A +/- 0.1%	

APPENDIX C

sample Number	Wt% Solids (Solids Layer)	Wt% Oxide pH (Total Sample)	Density (g/mL)	Test Activity	Comments
SIPT3-2.3.1		1.68	1.02	Simulant Makeup	Performed ICP and IC Analyses
SIPT3-2.3.2		2.23	1.02	Simulant Makeup	Performed ICP and IC Analyses
RWCT - 2.4.1	0.40%		0.99	Characterization	Performed ICP and IC Analyses
RWCT - 2.4.2	0.40%		0.99	Characterization	Performed ICP and IC Analyses
RWCT - 2.4.3	0.42%		1.00	Characterization	Performed ICP and IC Analyses
RWCT - 3.1.1				Homogeneity/Resuspension	Lost Sample Data
RWCT - 3.1.2	-0.01%		0.98	Homogeneity/Resuspension	
RWCT - 3.1.3	-0.03%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.4	-0.01%		0.98	Homogeneity/Resuspension	
RWCT - 3.1.5	-0.03%		0.98	Homogeneity/Resuspension	
RWCT - 3.1.6	0.01%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.7	-0.02%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.8	0.00%		1.01	Homogeneity/Resuspension	
RWCT - 3.1.9	0.00%		0.98	Homogeneity/Resuspension	
RWCT - 3.1.10	0.00%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.11	0.01%		0.98	Homogeneity/Resuspension	
RWCT - 3.1.12	0.00%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.13	0.30%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.14	0.25%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.15	0.32%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.16	0.29%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.17	0.33%		0.97	Homogeneity/Resuspension	
RWCT - 3.1.18	0.26%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.19	0.24%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.20	0.31%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.21	0.31%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.22	0.28%		0.98	Homogeneity/Resuspension	
RWCT - 3.1.23	0.29%		0.98	Homogeneity/Resuspension	
RWCT - 3.1.24	0.32%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.25	0.77%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.26				Homogeneity/Resuspension	Lost Sample Data
RWCT - 3.1.27	0.87%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.28	0.76%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.29	0.77%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.30	0.83%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.31	0.86%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.32	0.87%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.33	0.94%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.34	0.89%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.35	0.74%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.36	0.84%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.37	1.37%		0.92	Homogeneity/Resuspension	
RWCT - 3.1.38	1.18%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.39	1.70%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.40	1.33%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.41	1.50%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.42	1.19%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.43	1.43%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.44	1.20%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.45	1.24%		1.00	Homogeneity/Resuspension	

Sample Number	Wt% Solids (Solids Layer)	Wt% Oxide pH (Total Sample)	Density (g/mL)	Test Activity	Comments
RWCT - 3.1.46	1.42%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.47	1.31%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.48	1.64%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.49	2.33%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.50	1.66%		0.98	Homogeneity/Resuspension	
RWCT - 3.1.51	1.42%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.52	0.72%		0.98	Homogeneity/Resuspension	
RWCT - 3.1.53	1.54%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.54	1.23%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.55	1.23%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.56	1.18%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.57	1.23%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.58	1.38%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.59	0.39%		0.98	Homogeneity/Resuspension	
RWCT - 3.1.60	1.39%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.61	1.53%		1.01	Homogeneity/Resuspension	
RWCT - 3.1.62	1.43%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.63	1.22%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.64	0.44%		0.98	Homogeneity/Resuspension	
RWCT - 3.1.65	1.50%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.66	1.40%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.67	2.02%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.68	0.50%		0.99	Homogeneity/Resuspension	
T - 3.1.69	1.43%		0.99	Homogeneity/Resuspension	
- 3.1.70	1.64%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.71	1.38%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.72	2.04%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.73	0.40%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.74	1.77%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.75	2.09%		1.01	Homogeneity/Resuspension	
RWCT - 3.1.76	1.43%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.77	0.53%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.78	0.42%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.79	2.28%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.80	1.86%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.81	2.02%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.82	1.62%		0.98	Homogeneity/Resuspension	
RWCT - 3.1.83	0.61%		0.97	Homogeneity/Resuspension	
RWCT - 3.1.84	1.84%			Homogeneity/Resuspension	Lost Sample Data
RWCT - 3.1.85	2.01%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.86	0.37%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.87	1.91%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.88	0.43%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.89	1.98%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.90	1.89%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.91	1.47%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.92	0.38%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.93	1.94%		1.00	Homogeneity/Resuspension	
RWCT - 3.1.94	0.37%		0.99	Homogeneity/Resuspension	
RWCT - 3.1.95	2.42%		0.99	Homogeneity/Resuspension	
- 3.1.96	2.57%		0.99	Homogeneity/Resuspension	

Sample Number	Wt% Solids (Solids Layer)	Wt% Oxide pH (Total Sample)	Density (g/mL)	Test Activity	Comments	
RWCT - 4.2.1	N.M.		N.M.	Simulant makeup	Measured Total Solids/Performed IC/ICP on Dried Sample	
RWCT - 4.2.2	N.M.		N.M.	Simulant makeup	Measured Total Solids/Performed IC/ICP on Dried Sample	
RWCT - 4.2.1	2.89%, 5.47%, 2.48%	8.81	N.M.	1.02, 1.04, 1.02	Second Characterization	Performed Settling Rate, IC and Triplicate ICP Analyses
RWCT - 4.2.2	3.01%, 3.19%, 3.02%	8.97	N.M.	1.02, 1.01, 1.02	Second Characterization	Performed Settling Rate, IC and Triplicate ICP Analyses
RWCT - 4.2.3	3.16%, 5.16%, 2.70%	9.22	N.M.	1.02, 1.02, 1.02	Second Characterization	Performed Settling Rate, IC and Triplicate ICP Analyses
RWCT - 5.1.1	-0.03%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.2	-0.03%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.3	-0.01%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.4	-0.02%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.5	0.00%		0.98	Homogeneity/Resuspension		
RWCT - 5.1.6	-0.01%		0.98	Homogeneity/Resuspension		
RWCT - 5.1.7	0.00%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.8	3.12%		1.01	Homogeneity/Resuspension		
RWCT - 5.1.9	0.08%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.10	0.06%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.11	0.04%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.12	0.04%		0.98	Homogeneity/Resuspension		
RWCT - 5.1.13	0.79%		0.98	Homogeneity/Resuspension		
RWCT - 5.1.14	0.74%		0.98	Homogeneity/Resuspension		
RWCT - 5.1.15	0.74%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.16	0.69%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.17	0.71%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.18	0.67%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.19	1.90%		0.98	Homogeneity/Resuspension		
RWCT - 5.1.20	0.68%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.21	0.68%		1.00	Homogeneity/Resuspension		
RWCT - 5.1.22	0.68%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.23	0.67%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.24	0.76%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.25	1.52%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.26	1.84%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.27	1.39%		1.00	Homogeneity/Resuspension		
RWCT - 5.1.28	1.62%		1.00	Homogeneity/Resuspension		
RWCT - 5.1.29	1.03%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.30	1.59%		1.00	Homogeneity/Resuspension		
RWCT - 5.1.31	1.81%		1.00	Homogeneity/Resuspension		
RWCT - 5.1.32	1.29%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.33	1.74%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.34	1.37%		1.00	Homogeneity/Resuspension		
RWCT - 5.1.35	1.59%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.36	1.35%		1.00	Homogeneity/Resuspension		
RWCT - 5.1.37	4.17%		1.00	Homogeneity/Resuspension		
RWCT - 5.1.38	0.01%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.39	2.91%		1.01	Homogeneity/Resuspension		
RWCT - 5.1.40	3.24%		1.00	Homogeneity/Resuspension		
RWCT - 5.1.41	3.19%		0.99	Homogeneity/Resuspension		
RWCT - 5.1.42	2.47%		1.00	Homogeneity/Resuspension		
RWCT - 5.1.43	1.80%			Homogeneity/Resuspension	Lost Sample	
RWCT - 5.1.44	2.65%		1.00	Homogeneity/Resuspension		
RWCT - 5.1.45	3.52%		0.99	Homogeneity/Resuspension		

Sample Number	Wt% Solids (Solids Layer)	Wt% Oxide pH (Total Sample)	Density (g/mL)	Test Activity	Comments
RWCT - 5.1.46				Homogeneity/Resuspension	Lost Sample
RWCT - 5.1.47	2.76%		1.00	Homogeneity/Resuspension	
RWCT - 5.1.48				Homogeneity/Resuspension	Lost Sample
RWCT - 5.1.49	3.36%		1.02	Homogeneity/Resuspension	
RWCT - 5.1.50	3.37%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.51	3.21%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.52	2.83%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.53	3.46%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.54	3.24%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.55	2.58%		1.00	Homogeneity/Resuspension	
RWCT - 5.1.56	3.15%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.57	2.85%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.58	3.23%		1.00	Homogeneity/Resuspension	
RWCT - 5.1.59	3.09%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.60	3.40%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.61	3.32%		1.00	Homogeneity/Resuspension	
RWCT - 5.1.62	3.09%		1.00	Homogeneity/Resuspension	
RWCT - 5.1.63	3.16%		1.00	Homogeneity/Resuspension	
RWCT - 5.1.64	3.75%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.65	3.24%		1.00	Homogeneity/Resuspension	
RWCT - 5.1.66	3.15%		1.00	Homogeneity/Resuspension	
RWCT - 5.1.67	4.39%		1.02	Homogeneity/Resuspension	
RWCT - 5.1.68	3.63%		1.00	Homogeneity/Resuspension	
RWCT - 5.1.69	4.03%		0.97	Homogeneity/Resuspension	
RWCT - 5.1.70	4.07%		1.00	Homogeneity/Resuspension	
RWCT - 5.1.71	3.38%		1.00	Homogeneity/Resuspension	
RWCT - 5.1.72	4.82%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.73	3.48%		0.93	Homogeneity/Resuspension	
RWCT - 5.1.74	3.87%		1.00	Homogeneity/Resuspension	
RWCT - 5.1.75	4.65%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.76	3.90%		1.00	Homogeneity/Resuspension	
RWCT - 5.1.77	3.57%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.78	4.49%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.79	4.58%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.80	4.33%		1.00	Homogeneity/Resuspension	
RWCT - 5.1.81	3.63%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.82	3.42%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.83	3.67%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.84	4.12%		1.00	Homogeneity/Resuspension	
RWCT - 5.1.85	4.44%		1.00	Homogeneity/Resuspension	
RWCT - 5.1.86	3.45%		1.00	Homogeneity/Resuspension	
RWCT - 5.1.87	4.07%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.88	3.61%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.89	4.69%		1.02	Homogeneity/Resuspension	
RWCT - 5.1.90	1.64%		0.99	Homogeneity/Resuspension	
RWCT - 5.1.91	3.46%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.92	3.90%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.93	3.16%		1.00	Homogeneity/Resuspension	
RWCT - 5.1.94	4.19%		1.01	Homogeneity/Resuspension	
RWCT - 5.1.95	4.87%		1.01	Homogeneity/Resuspension	

Sample Number	Wt% Solids (Solids Layer)	Wt% Oxide pH (Total Sample)	Density (g/mL)	Test Activity	Comments
RWCT - 5.1.98	4.28%		1.01	Homogeneity/Resuspension	
RWCT - 8.4.1	2.38%, 2.23%, 5.13%		1.02, 1.03, 1.01	Pump Priming	
RWCT - 8.4.2	2.20%, 2.33%, 7.99%		1.02, 1.04, 1.01	Pump Priming	
RWCT - 8.4.3	1.99%, 2.39%, 4.44%		1.02, 1.01, 1.01	Pump Priming	
RWCT - 7.2.1	8.01%	1.04%	1.03	Characterization	Performed ICP and IC Analyses
RWCT - 7.2.2	7.91%	3.58%	1.04	Characterization	Performed ICP and IC Analyses
RWCT - 8.2.1				Settling	Performed ICP Analysis
RWCT - 8.2.2				Settling	Performed ICP Analysis
RWCT - 8.2.3				Settling	Performed ICP Analysis
RWCT - 8.2.4				Settling	Performed ICP Analysis
RWCT - 8.2.5				Settling	Performed ICP Analysis
RWCT - 8.2.6				Settling	Performed ICP Analysis
RWCT - 8.2.7				Settling	Not Measured
RWCT - 8.2.8				Settling	Insufficient Amount of Solids For Analysis
RWCT - 8.2.9				Settling	Performed ICP Analysis
RWCT - 8.2.10				Settling	Insufficient Amount of Solids For Analysis
RWCT - 8.2.11				Settling	Insufficient Amount of Solids For Analysis
RWCT - 8.2.12				Settling	Insufficient Amount of Solids For Analysis
RWCT - 8.2.13				Settling	Insufficient Amount of Solids For Analysis
RWCT - 8.2.14				Settling	Insufficient Amount of Solids For Analysis
RWCT - 8.2.15				Settling	Insufficient Amount of Solids For Analysis
RWCT - 8.2.16				Settling	Insufficient Amount of Solids For Analysis
RWCT - 8.2.17				Settling	Insufficient Amount of Solids For Analysis
RWCT - 8.2.18				Settling	Insufficient Amount of Solids For Analysis
RWCT - 8.5.1				Homogeneity Resuspension	Performed ICP Analysis
RWCT - 8.5.2				Homogeneity Resuspension	Performed ICP Analysis
RWCT - 8.5.3				Homogeneity Resuspension	Performed ICP Analysis
RWCT - 8.5.4				Homogeneity Resuspension	Performed ICP Analysis
RWCT - 8.5.5				Homogeneity Resuspension	Performed ICP Analysis
RWCT - 8.5.6				Homogeneity Resuspension	Performed ICP Analysis
RWCT - 8.5.7				Homogeneity Resuspension	Performed ICP Analysis
RWCT - 8.5.8				Homogeneity Resuspension	Performed ICP Analysis
RWCT - 8.5.9				Homogeneity Resuspension	Performed ICP Analysis
RWCT - 8.5.10				Homogeneity Resuspension	Performed ICP Analysis
RWCT - 8.5.11				Homogeneity Resuspension	Performed ICP Analysis
RWCT - 8.5.12				Homogeneity Resuspension	Performed ICP Analysis
RWCT - 8.5.13				Homogeneity Resuspension	Performed ICP Analysis
RWCT - 8.5.14				Homogeneity Resuspension	Performed ICP Analysis
RWCT - 8.5.15				Homogeneity Resuspension	Performed ICP Analysis
RWCT - 7.3.1	N.M	9.38	N.M	N.M	Performed Settling Rate, IC and Triplicate ICP Analyses
RWCT - 7.3.2	N.M	9.39	N.M	N.M	Performed Settling Rate, IC and Triplicate ICP Analyses
RWCT - 7.3.3	N.M	9.33	N.M	N.M	Performed Settling Rate, IC and Triplicate ICP Analyses
RWCT - 8.4.1	0.00%		0.99	Homogeneity Resuspension	
RWCT - 8.4.2	0.00%		0.98	Homogeneity Resuspension	
RWCT - 8.4.3	0.01%		0.99	Homogeneity Resuspension	
RWCT - 8.4.4	0.00%		0.98	Homogeneity Resuspension	
RWCT - 8.4.5	0.00%		0.99	Homogeneity Resuspension	
RWCT - 8.4.6	0.00%		0.99	Homogeneity Resuspension	
RWCT - 8.4.7	0.01%		0.99	Homogeneity Resuspension	
RWCT - 8.4.8	0.00%		0.98	Homogeneity Resuspension	

Sample Number	Wt% Solids (Solids Layer)	Wt% Oxide pH (Total Sample)	Density (g/mL)	Test Activity	Comments
RWCT - 8.4.9	-0.01%		0.99	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.10	0.00%		0.99	Homogeneity Resuspension	
RWCT - 8.4.11	0.01%		0.98	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.12	0.00%		0.99	Homogeneity Resuspension	
RWCT - 8.4.13	1.18%		1.00	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.14	1.15%		0.99	Homogeneity Resuspension	
RWCT - 8.4.15	1.13%		0.99	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.16	1.07%		0.99	Homogeneity Resuspension	
RWCT - 8.4.17	1.09%		1.00	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.18	1.07%		0.99	Homogeneity Resuspension	
RWCT - 8.4.19	1.08%		0.99	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.20	1.14%		1.00	Homogeneity Resuspension	
RWCT - 8.4.21	1.10%		1.00	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.22	1.11%		1.00	Homogeneity Resuspension	
RWCT - 8.4.23	1.08%		1.00	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.24	1.08%		0.99	Homogeneity Resuspension	
RWCT - 8.4.25	2.57%		1.02	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.26	1.96%		1.01	Homogeneity Resuspension	
RWCT - 8.4.27	2.78%		1.01	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.28	2.59%		1.02	Homogeneity Resuspension	
RWCT - 8.4.29	2.88%		1.01	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.30	2.41%		1.01	Homogeneity Resuspension	
RWCT - 8.4.31	2.74%		1.02	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.32	2.61%		1.01	Homogeneity Resuspension	
RWCT - 8.4.33	2.50%		1.00	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.34	2.75%		1.02	Homogeneity Resuspension	
RWCT - 8.4.35	2.53%		1.03	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.36	2.50%		1.00	Homogeneity Resuspension	
RWCT - 8.4.37	4.24%		1.02	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.38	4.23%		1.03	Homogeneity Resuspension	
RWCT - 8.4.39	4.20%		1.01	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.40	4.13%		1.02	Homogeneity Resuspension	
RWCT - 8.4.41	4.20%		1.03	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.42	3.98%		1.02	Homogeneity Resuspension	
RWCT - 8.4.43	3.99%		1.02	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.44	1.60%		1.00	Homogeneity Resuspension	
RWCT - 8.4.45	4.25%		1.02	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.46	3.00%		1.02	Homogeneity Resuspension	
RWCT - 8.4.47	3.96%		1.02	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.48	5.70%		1.03	Homogeneity Resuspension	
RWCT - 8.4.49	3.57%		1.01	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.50	4.85%		1.03	Homogeneity Resuspension	
RWCT - 8.4.51	4.89%		1.02	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.52	3.90%		1.01	Homogeneity Resuspension	
RWCT - 8.4.53	3.27%		1.02	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.54	AE		AE	Homogeneity Resuspension	
RWCT - 8.4.55	3.52%		1.01	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.56	3.37%		1.01	Homogeneity Resuspension	
RWCT - 8.4.57	3.94%		1.02	Homogeneity Resuspension	Lost Sample Data
RWCT - 8.4.58	1.38%		1.02	Homogeneity Resuspension	

Sample Number	Wt% Solids (Solids Layer)	Wt% Oxide pH (Total Sample)	Density (g/mL)	Test Activity	Comments
RWCT - 8.4.59	3.71%		1.02	Homogeneity Resuspension	
RWCT - 8.4.60	4.14%		1.02	Homogeneity Resuspension	
RWCT - 8.4.61	4.31%		1.02	Homogeneity Resuspension	
RWCT - 8.4.62	4.19%		1.00	Homogeneity Resuspension	
RWCT - 8.4.63	3.79%		1.01	Homogeneity Resuspension	
RWCT - 8.4.64	4.16%		1.01	Homogeneity Resuspension	
RWCT - 8.4.65	4.36%		1.01	Homogeneity Resuspension	
RWCT - 8.4.66	3.84%		1.01	Homogeneity Resuspension	
RWCT - 8.4.67	4.35%		1.01	Homogeneity Resuspension	
RWCT - 8.4.68	4.53%		1.02	Homogeneity Resuspension	
RWCT - 8.4.69	4.27%		1.02	Homogeneity Resuspension	
RWCT - 8.4.70	4.56%		1.02	Homogeneity Resuspension	
RWCT - 8.4.71	3.95%		1.01	Homogeneity Resuspension	
RWCT - 8.4.72	4.14%		1.01	Homogeneity Resuspension	
RWCT - 8.4.73	4.37%		1.00	Homogeneity Resuspension	
RWCT - 8.4.74	4.61%		1.00	Homogeneity Resuspension	
RWCT - 8.4.75	4.90%		1.02	Homogeneity Resuspension	
RWCT - 8.4.76	4.26%		1.01	Homogeneity Resuspension	
RWCT - 8.4.77	4.50%		1.01	Homogeneity Resuspension	
RWCT - 8.4.78	4.66%		1.01	Homogeneity Resuspension	
RWCT - 8.4.79	2.44%		1.01	Homogeneity Resuspension	
RWCT - 8.4.80	4.06%		1.01	Homogeneity Resuspension	
RWCT - 8.4.81	4.51%		1.02	Homogeneity Resuspension	
RWCT - 8.4.82	3.87%		1.01	Homogeneity Resuspension	
RWCT - 8.4.83	3.85%		1.01	Homogeneity Resuspension	
RWCT - 8.4.84	5.17%		1.03	Homogeneity Resuspension	
RWCT - 8.4.85	4.44%		1.03	Homogeneity Resuspension	
RWCT - 8.4.86	3.72%		1.00	Homogeneity Resuspension	
RWCT - 8.4.87	4.38%		0.99	Homogeneity Resuspension	
RWCT - 8.4.88	3.72%		1.00	Homogeneity Resuspension	
RWCT - 8.4.89	4.60%		1.01	Homogeneity Resuspension	
RWCT - 8.4.90	5.20%		1.03	Homogeneity Resuspension	
RWCT - 8.4.91	4.04%		1.01	Homogeneity Resuspension	
RWCT - 8.4.92	3.88%		1.05	Homogeneity Resuspension	
RWCT - 8.4.93	4.04%		1.01	Homogeneity Resuspension	
RWCT - 8.4.94	3.93%		1.01	Homogeneity Resuspension	
RWCT - 8.4.95	4.08%		1.01	Homogeneity Resuspension	
RWCT - 8.4.96	4.80%		1.03	Homogeneity Resuspension	
RWCT - 10.2.1	6.76%	8.33%	1.02	Simulant Makeup	Performed ICP and IC Analyses
RWCT - 10.2.2	7.17%	6.16%	1.03	Simulant Makeup	Performed ICP and IC Analyses
RWCT - 10.3.1	NM	10.1	NM	Characterization	Performed Settling Rate, IC and Triplicate ICP Analyses
RWCT - 10.3.2	NM	10.1	NM	Characterization	Performed Settling Rate, IC and Triplicate ICP Analyses
RWCT - 10.3.3	NM	10.1	NM	Characterization	Performed Settling Rate, IC and Triplicate ICP Analyses
RWCT - 11.1.1	-0.03%		0.99	Homogeneity Resuspension	
RWCT - 11.1.2	-0.03%		0.99	Homogeneity Resuspension	
RWCT - 11.1.3	0.01%		0.98	Homogeneity Resuspension	
RWCT - 11.1.4	0.01%		0.99	Homogeneity Resuspension	
RWCT - 11.1.5	-0.04%		0.99	Homogeneity Resuspension	
RWCT - 11.1.6	-0.04%		0.98	Homogeneity Resuspension	
RWCT - 11.1.7	-0.04%		0.98	Homogeneity Resuspension	

Sample Number	Wt% Solids (Solids Layer)	Wt% Oxide pH (Total Sample)	Density (g/mL)	Test Activity	Comments
RWCT - 11.1.8	-0.04%		0.99	Homogeneity Resuspension	
RWCT - 11.1.9	0.01%		0.98	Homogeneity Resuspension	
RWCT - 11.1.10	0.01%		0.99	Homogeneity Resuspension	
RWCT - 11.1.11	0.01%		0.98	Homogeneity Resuspension	
RWCT - 11.1.12	0.00%		0.98	Homogeneity Resuspension	
RWCT - 11.1.13	0.12%		0.98	Homogeneity Resuspension	
RWCT - 11.1.14	0.07%		0.99	Homogeneity Resuspension	
RWCT - 11.1.15	1.77%		0.99	Homogeneity Resuspension	
RWCT - 11.1.16	1.84%		1.00	Homogeneity Resuspension	
RWCT - 11.1.17	0.07%		0.99	Homogeneity Resuspension	
RWCT - 11.1.18	0.14%		1.00	Homogeneity Resuspension	
RWCT - 11.1.19	0.08%		0.99	Homogeneity Resuspension	
RWCT - 11.1.20	0.14%		1.05	Homogeneity Resuspension	
RWCT - 11.1.21	1.96%		1.00	Homogeneity Resuspension	
RWCT - 11.1.22	0.15%		1.00	Homogeneity Resuspension	
RWCT - 11.1.23	0.10%		0.98	Homogeneity Resuspension	
RWCT - 11.1.24	1.79%		1.00	Homogeneity Resuspension	
RWCT - 11.1.25	2.49%		1.00	Homogeneity Resuspension	
RWCT - 11.1.26	3.47%		1.00	Homogeneity Resuspension	
RWCT - 11.1.27	0.42%		0.99	Homogeneity Resuspension	
WT - 11.1.28	2.28%		1.00	Homogeneity Resuspension	
- 11.1.29	3.57%		1.01	Homogeneity Resuspension	
RWCT - 11.1.30	0.44%		0.99	Homogeneity Resuspension	
RWCT - 11.1.31	3.74%		1.02	Homogeneity Resuspension	
RWCT - 11.1.32	2.32%		1.01	Homogeneity Resuspension	
RWCT - 11.1.33	0.81%		0.99	Homogeneity Resuspension	
RWCT - 11.1.34	3.60%		1.01	Homogeneity Resuspension	
RWCT - 11.1.35	0.42%		0.99	Homogeneity Resuspension	
RWCT - 11.1.36	2.74%		1.01	Homogeneity Resuspension	
RWCT - 11.1.37	4.09%		1.01	Homogeneity Resuspension	
RWCT - 11.1.38	4.40%		1.01	Homogeneity Resuspension	
RWCT - 11.1.39	2.79%		1.00	Homogeneity Resuspension	
RWCT - 11.1.40	4.21%		1.01	Homogeneity Resuspension	
RWCT - 11.1.41	4.21%		1.00	Homogeneity Resuspension	
RWCT - 11.1.42	3.19%		1.00	Homogeneity Resuspension	
RWCT - 11.1.43	4.23%		1.02	Homogeneity Resuspension	
RWCT - 11.1.44	3.21%		0.99	Homogeneity Resuspension	
RWCT - 11.1.45	4.14%		1.00	Homogeneity Resuspension	
RWCT - 11.1.46	3.80%		1.01	Homogeneity Resuspension	
RWCT - 11.1.47	3.05%		1.00	Homogeneity Resuspension	
RWCT - 11.1.48	4.19%		1.02	Homogeneity Resuspension	
RWCT - 11.1.49	3.30%		1.01	Homogeneity Resuspension	
RWCT - 11.1.50	4.60%		1.02	Homogeneity Resuspension	
RWCT - 11.1.51	4.06%		1.01	Homogeneity Resuspension	
RWCT - 11.1.52	2.11%		1.00	Homogeneity Resuspension	
RWCT - 11.1.53	4.86%		1.02	Homogeneity Resuspension	
RWCT - 11.1.54	4.27%		1.02	Homogeneity Resuspension	
RWCT - 11.1.55	3.88%		1.01	Homogeneity Resuspension	
RWCT - 11.1.56	2.04%		1.00	Homogeneity Resuspension	
RWCT - 11.1.57	3.37%		1.01	Homogeneity Resuspension	

Sample Number	Wt% Solids (Solids Layer)	Wt% Oxide pH (Total Sample)	Density (g/mL)	Test Activity	Comments
RWCT - 11.1.58	1.79%		1.00	Homogeneity Resuspension	
RWCT - 11.1.59	4.02%		1.01	Homogeneity Resuspension	
RWCT - 11.1.60	4.38%		1.01	Homogeneity Resuspension	
RWCT - 11.1.61	4.30%		1.01	Homogeneity Resuspension	
RWCT - 11.1.62	3.17%		1.01	Homogeneity Resuspension	
RWCT - 11.1.63	2.03%		1.00	Homogeneity Resuspension	
RWCT - 11.1.64	4.81%		1.02	Homogeneity Resuspension	
RWCT - 11.1.65	5.04%		1.00	Homogeneity Resuspension	
RWCT - 11.1.66	2.95%		1.02	Homogeneity Resuspension	
RWCT - 11.1.67	4.46%		1.02	Homogeneity Resuspension	
RWCT - 11.1.68	3.80%		1.01	Homogeneity Resuspension	
RWCT - 11.1.69	3.89%		1.01	Homogeneity Resuspension	
RWCT - 11.1.70	3.75%		1.01	Homogeneity Resuspension	
RWCT - 11.1.71	3.80%		1.01	Homogeneity Resuspension	
RWCT - 11.1.72	4.22%		1.02	Homogeneity Resuspension	
RWCT - 11.1.73	4.42%		1.01	Homogeneity Resuspension	
RWCT - 11.1.74	4.22%		1.01	Homogeneity Resuspension	
RWCT - 11.1.75	4.41%		1.02	Homogeneity Resuspension	
RWCT - 11.1.76	3.87%		1.01	Homogeneity Resuspension	
RWCT - 11.1.77	3.99%		0.98	Homogeneity Resuspension	
RWCT - 11.1.78	3.42%		1.01	Homogeneity Resuspension	
RWCT - 11.1.79	5.07%		1.02	Homogeneity Resuspension	
RWCT - 11.1.80	3.89%		1.01	Homogeneity Resuspension	
RWCT - 11.1.81	3.79%		1.01	Homogeneity Resuspension	
RWCT - 11.1.82	3.82%		1.01	Homogeneity Resuspension	
RWCT - 11.1.83	3.83%		1.01	Homogeneity Resuspension	
RWCT - 11.1.84	4.81%		1.02	Homogeneity Resuspension	
RWCT - 11.1.85	4.64%		1.00	Homogeneity Resuspension	
RWCT - 11.1.86	4.33%		1.02	Homogeneity Resuspension	
RWCT - 11.1.87	4.03%		0.98	Homogeneity Resuspension	
RWCT - 11.1.88	3.97%		1.01	Homogeneity Resuspension	
RWCT - 11.1.89	3.81%		1.01	Homogeneity Resuspension	
RWCT - 11.1.90	3.74%		1.01	Homogeneity Resuspension	
RWCT - 11.1.91	3.99%		1.01	Homogeneity Resuspension	
RWCT - 11.1.92	3.71%		1.02	Homogeneity Resuspension	
RWCT - 11.1.93	3.88%		1.03	Homogeneity Resuspension	
RWCT - 11.1.94	4.49%		1.02	Homogeneity Resuspension	
RWCT - 11.1.95	3.48%		1.03	Homogeneity Resuspension	
RWCT - 11.1.96	4.63%		1.01	Homogeneity Resuspension	
RWCT - 13.1.1				Evaporator/Condenser	Performed ICP and IC Analyses on Aqueous Samples
RWCT - 13.1.2				Evaporator/Condenser	Performed ICP and IC Analyses on Aqueous Samples
RWCT - 13.1.3				Evaporator/Condenser	Performed ICP and IC Analyses on Aqueous Samples
RWCT - 13.1.4				Evaporator/Condenser	Performed ICP and IC Analyses on Aqueous Samples
RWCT - 13.1.5				Evaporator/Condenser	Performed ICP and IC Analyses on Aqueous Samples
RWCT - 13.1.6				Evaporator/Condenser	Performed ICP and IC Analyses on Aqueous Samples
RWCT - 13.1.7				Evaporator/Condenser	Performed ICP and IC Analyses on Aqueous Samples
RWCT - 13.1.8				Evaporator/Condenser	Performed ICP and IC Analyses on Aqueous Samples
RWCT - 13.1.9				Evaporator/Condenser	Performed ICP and IC Analyses on Aqueous Samples
RWCT - 14.2.1	7.61%			Pump Priming	
RWCT - 14.2.2	4.46%			Pump Priming	

Sample Number	Wt% Solids (Solids Layer)	Wt% Oxide pH (Total Sample)	Density (g/mL)	Test Activity	Comments
RWCT - 14.2.3	7.15%			Pump Priming	
RWCT - 14.2.4	4.15%		1.01	Pump Priming	
RWCT - 14.2.5	3.24%		1.00	Pump Priming	
RWCT - 14.2.6	2.41%		1.00	Pump Priming	
RWCT - 16.4.1	-39.04%		1.01	Homogeneity Resuspension	
RWCT - 16.4.2	-40.12%		1.00	Homogeneity Resuspension	
RWCT - 16.4.3	-39.81%		1.00	Homogeneity Resuspension	
RWCT - 16.4.4	-40.03%		1.00	Homogeneity Resuspension	
RWCT - 16.4.5	-42.08%		0.99	Homogeneity Resuspension	
RWCT - 16.4.6	-38.64%		1.00	Homogeneity Resuspension	
RWCT - 16.4.7	-42.17%		1.01	Homogeneity Resuspension	
RWCT - 16.4.8	-51.14%		1.00	Homogeneity Resuspension	
RWCT - 16.4.9	-52.08%		1.00	Homogeneity Resuspension	
RWCT - 16.4.10	-35.22%		1.00	Homogeneity Resuspension	
RWCT - 16.4.11	-48.71%		0.91	Homogeneity Resuspension	
RWCT - 16.4.12	-39.43%		0.99	Homogeneity Resuspension	
RWCT - 16.4.13	1.72%		1.01	Homogeneity Resuspension	
RWCT - 16.4.14	0.18%		0.99	Homogeneity Resuspension	
RWCT - 16.4.15	1.87%		1.00	Homogeneity Resuspension	
RWCT - 16.4.16	1.86%		1.01	Homogeneity Resuspension	
RWCT - 16.4.17	0.32%		1.00	Homogeneity Resuspension	
RWCT - 16.4.18	1.74%		1.00	Homogeneity Resuspension	
RWCT - 16.4.19	0.41%		1.00	Homogeneity Resuspension	
RWCT - 16.4.20	1.59%		1.01	Homogeneity Resuspension	
RWCT - 16.4.21	1.90%		1.01	Homogeneity Resuspension	
RWCT - 16.4.22	1.83%		1.01	Homogeneity Resuspension	
RWCT - 16.4.23	0.58%		1.00	Homogeneity Resuspension	
RWCT - 16.4.24	1.80%		1.01	Homogeneity Resuspension	
RWCT - 16.4.25	3.74%		1.01	Homogeneity Resuspension	
RWCT - 16.4.26	3.88%		1.01	Homogeneity Resuspension	
RWCT - 16.4.27	3.31%		1.02	Homogeneity Resuspension	
RWCT - 16.4.28	3.83%		1.02	Homogeneity Resuspension	
RWCT - 16.4.29	3.88%		1.02	Homogeneity Resuspension	
RWCT - 16.4.30	3.51%		1.01	Homogeneity Resuspension	
RWCT - 16.4.31	4.04%		1.02	Homogeneity Resuspension	
RWCT - 16.4.32	3.93%		AE	Homogeneity Resuspension	
RWCT - 16.4.33	3.43%		1.01	Homogeneity Resuspension	
RWCT - 16.4.34	4.13%		1.07	Homogeneity Resuspension	
RWCT - 16.4.35	3.11%		1.01	Homogeneity Resuspension	
RWCT - 16.4.36	3.57%		1.02	Homogeneity Resuspension	
RWCT - 16.4.37	5.06%		1.02	Homogeneity Resuspension	
RWCT - 16.4.38	5.14%		1.03	Homogeneity Resuspension	
RWCT - 16.4.39	4.55%		1.01	Homogeneity Resuspension	
RWCT - 16.4.40	5.06%		1.03	Homogeneity Resuspension	
RWCT - 16.4.41	5.08%		1.03	Homogeneity Resuspension	
RWCT - 16.4.42	4.79%		1.02	Homogeneity Resuspension	
RWCT - 16.4.43	5.42%		1.03	Homogeneity Resuspension	
RWCT - 16.4.44	4.60%		1.02	Homogeneity Resuspension	
RWCT - 16.4.45	5.31%		1.02	Homogeneity Resuspension	
RWCT - 16.4.46	4.59%		1.02	Homogeneity Resuspension	

Sample Number	Wt% Solids (Solids Layer)	Wt% Oxide pH (Total Sample)	Density (g/mL)	Test Activity	Comments
RWCT - 16.4.47	4.88%		1.02	Homogeneity Resuspension	
RWCT - 16.4.48	5.45%		1.03	Homogeneity Resuspension	
RWCT - 16.4.49	4.82%		1.02	Homogeneity Resuspension	
RWCT - 16.4.50	5.10%		1.02	Homogeneity Resuspension	
RWCT - 16.4.51	5.28%		1.02	Homogeneity Resuspension	
RWCT - 16.4.52	4.54%		1.02	Homogeneity Resuspension	
RWCT - 16.4.53	5.07%		1.01	Homogeneity Resuspension	
RWCT - 16.4.54	5.10%		1.01	Homogeneity Resuspension	
RWCT - 16.4.55	5.06%		1.03	Homogeneity Resuspension	
RWCT - 16.4.56	2.50%		1.00	Homogeneity Resuspension	
RWCT - 16.4.57	4.34%		1.03	Homogeneity Resuspension	
RWCT - 16.4.58	4.26%		1.02	Homogeneity Resuspension	
RWCT - 16.4.59	4.79%		1.03	Homogeneity Resuspension	
RWCT - 16.4.60	5.58%		1.01	Homogeneity Resuspension	
RWCT - 16.4.61	5.18%		1.03	Homogeneity Resuspension	
RWCT - 16.4.62	4.85%		1.03	Homogeneity Resuspension	
RWCT - 16.4.63	4.56%		1.02	Homogeneity Resuspension	
RWCT - 16.4.64	5.26%		1.02	Homogeneity Resuspension	
RWCT - 16.4.65	5.06%		1.02	Homogeneity Resuspension	
RWCT - 16.4.66	5.22%		1.02	Homogeneity Resuspension	
RWCT - 16.4.67	5.32%		1.02	Homogeneity Resuspension	
RWCT - 16.4.68	4.82%		1.02	Homogeneity Resuspension	
TT - 16.4.69	5.18%		1.02	Homogeneity Resuspension	
TT - 16.4.70	5.43%		1.03	Homogeneity Resuspension	
RWCT - 16.4.71	5.05%		1.03	Homogeneity Resuspension	
RWCT - 16.4.72	5.76%		1.03	Homogeneity Resuspension	
RWCT - 16.4.73	5.14%		1.02	Homogeneity Resuspension	
RWCT - 16.4.74	5.31%		1.02	Homogeneity Resuspension	
RWCT - 16.4.75	5.88%		1.03	Homogeneity Resuspension	
RWCT - 16.4.76	5.11%		1.02	Homogeneity Resuspension	
RWCT - 16.4.77	4.69%		1.03	Homogeneity Resuspension	
RWCT - 16.4.78	5.49%		1.02	Homogeneity Resuspension	
RWCT - 16.4.79	5.04%		1.03	Homogeneity Resuspension	
RWCT - 16.4.80	3.01%		1.01	Homogeneity Resuspension	
RWCT - 16.4.81	5.32%		1.03	Homogeneity Resuspension	
RWCT - 16.4.82	5.15%		1.02	Homogeneity Resuspension	
RWCT - 16.4.83	5.07%		1.03	Homogeneity Resuspension	
RWCT - 16.4.84	5.58%		1.02	Homogeneity Resuspension	
RWCT - 16.4.85	5.45%		1.02	Homogeneity Resuspension	
RWCT - 16.4.86	5.24%		1.02	Homogeneity Resuspension	
RWCT - 16.4.87	4.00%		1.01	Homogeneity Resuspension	
RWCT - 16.4.88	5.00%		1.03	Homogeneity Resuspension	
RWCT - 16.4.89	5.18%		1.02	Homogeneity Resuspension	
RWCT - 16.4.90	6.27%		1.03	Homogeneity Resuspension	
RWCT - 16.4.91	6.10%		1.03	Homogeneity Resuspension	
RWCT - 16.4.92	5.07%		1.03	Homogeneity Resuspension	
RWCT - 16.4.93	5.13%		1.03	Homogeneity Resuspension	
RWCT - 16.4.94	5.11%		1.03	Homogeneity Resuspension	
RWCT - 16.4.95	3.67%		1.02	Homogeneity Resuspension	
TT - 16.4.96	6.15%		1.03	Homogeneity Resuspension	

Sample Number	Wt% Solids (Solids Layer)	Wt% Oxide pH (Total Sample)	Density (g/mL)	Test Activity	Comments
RWCT - 15.2.11	5.30%		1.08	Characterization	
RWCT - 15.2.12	7.92%	10.2	6.14%	Characterization	Total Solids
RWCT - 15.2.13	5.81%		1.03	Characterization	
RWCT - 15.2.14	9.41%	10.2	6.66%	Characterization	Total Solids
RWCT - 15.2.15	5.25%		1.03	Characterization	
RWCT - 15.2.16	7.53%	10.2	5.45%	Characterization	Total Solids
RWCT - 15.2.17				Characterization	Performed Settling Rate, IC and Triplicate ICP Analyses
RWCT - 15.2.18				Characterization	Performed Settling Rate, IC and Triplicate ICP Analyses
RWCT - 15.2.19				Characterization	Performed Settling Rate, IC and Triplicate ICP Analyses
RWCT - 16.2.1	4.72%		1.02	Settling	
RWCT - 16.2.2	4.28%		1.06	Settling	
RWCT - 16.2.3	1.33%		0.99	Settling	
RWCT - 16.2.4	1.89%		1.09	Settling	
RWCT - 16.2.5	1.19%		1.00	Settling	
RWCT - 16.2.6	0.08%		0.99	Settling	
RWCT - 16.2.7	5.42%		1.02	Settling	
RWCT - 16.2.8	0.00%		0.99	Settling	
RWCT - 16.2.9	0.04%		0.99	Settling	
RWCT - 16.2.10	6.15%		1.03	Settling	
RWCT - 16.2.11	0.06%		0.99	Settling	
RWCT - 16.2.12	0.04%		0.99	Settling	
RWCT - 16.2.13	0.09%		0.99	Settling	
RWCT - 16.2.14	0.05%		1.00	Settling	
RWCT - 16.2.15	0.04%		0.99	Settling	
RWCT - 16.2.16	0.04%		0.99	Settling	
RWCT - 16.2.17	0.00%		0.99	Settling	
RWCT - 16.2.18	0.03%		0.99	Settling	
RWCT - 16.5.1	0.97%		1.00	Homogeneity Resuspension	
RWCT - 16.5.2	2.05%		1.01	Homogeneity Resuspension	
RWCT - 16.5.3	4.86%		1.03	Homogeneity Resuspension	
RWCT - 16.5.4	2.98%		1.01	Homogeneity Resuspension	
RWCT - 16.5.5	3.61%		1.01	Homogeneity Resuspension	
RWCT - 16.5.6	5.24%		0.93	Homogeneity Resuspension	
RWCT - 16.5.7	4.36%		1.01	Homogeneity Resuspension	
RWCT - 16.5.8	5.23%		1.02	Homogeneity Resuspension	
RWCT - 16.5.9	4.93%		1.02	Homogeneity Resuspension	
RWCT - 16.5.10	4.72%		1.02	Homogeneity Resuspension	
RWCT - 16.5.11	5.60%		1.03	Homogeneity Resuspension	
RWCT - 16.5.12	6.34%		1.03	Homogeneity Resuspension	
RWCT - 16.5.13	5.19%		1.02	Homogeneity Resuspension	
RWCT - 16.5.14	5.11%		1.16	Homogeneity Resuspension	
RWCT - 16.5.15	5.79%		1.04	Homogeneity Resuspension	
RWCT-17.2.1	5.13%		1.03	Pump Priming	
RWCT-17.2.2	5.03%		1.03	Pump Priming	
RWCT-17.2.3	4.71%		1.02	Pump Priming	

NM = Not Measured

CHARACTERIZATION

ICP ANALYSIS

RWCT - 2.4.1

RWCT - 2.4.2

Element	Estimated Det. Limit (PPM)	Conc. (KOH Fusion) (PPM)	Conc. (Na2O2 Fusion) (PPM)	Average Concentration (PPM)	Element	Conc. (KOH Fusion) (PPM)	Conc. (Na2O2 Fusion) (PPM)	Average Concentration (PPM)
Ag	0.005	7	-1	3	Ag	8	-1	4
Al	0.03	179	181	180	Al	203	183	193
B	0.01	398	481	440	B	658	534	596
Ba	0.003	2	3	3	Ba	3	3	3
Be	0.003	-1	-1	-1	Be	-1	-1	-1
Bi	0.06	-12	-12	-12	Bi	-12	-12	-12
Ca	0.01	97	152	97	Ca	141	166	141
Cd	0.006	209	209	209	Cd	210	208	209
Ce	0.04	-8	27	-8	Ce	-8	40	-8
Co	0.01	-2	-2	-2	Co	-2	-2	-2
Cr	0.02	-4	-4	-4	Cr	-4	-4	-4
Cu	0.006	-1	-1	-1	Cu	4	6	5
Dy	0.006	-1	-1	-1	Dy	-1	-1	-1
Eu	0.004	-1	-1	-1	Eu	-1	-1	-1
Fe	0.005	116	122	119	Fe	131	124	128
K	0.3		-59	-59	K		-59	-59
La	0.01	2	3	3	La	2	3	3
Li	0.005	212	265	239	Li	355	294	325
Mg	0.06	76	87	82	Mg	117	94	106
Mn	0.003	49	49	49	Mn	49	49	49
Mo	0.01	-2	-2	-2	Mo	-2	-2	-2
Na	0.05	2334		2334	Na	2629		2629
Nd	0.02	10	19	15	Nd	11	17	-12
Ni	0.02		11	11	Ni		11	11
P	0.08	135	131	133	P	134	129	132
Pb	0.08	-16	-16	-16	Pb	-16	-16	-16
S	0.08	-16	-16	-16	S	-16	-16	-16
Si	0.01	4396	4967	4682	Si	6577	5434	6006
Sn	0.08	-16	-16	-16	Sn	-16	-16	-16
Sr	0.003	1	3	2	Sr	1	3	2
Te	0.06	-12	-12	-12	Te	-12	-12	-12
Ti	0.003	13	13	13	Ti	16	14	15
V	0.01	-2	-2	-2	V	-2	-2	-2
Y	0.003	-1	-1	-1	Y	-1	-1	-1
Zn	0.01	41	41	41	Zn	41	43	42
Zr	0.01	28		28	Zr	35		35
Sample Wt		10.1607	10.1709		Sample Wt	10.2049	10.1932	
DF		2000	2000		DF	2000	2000	

IC ANALYSIS

RWCT - 2.4.1

RWCT - 2.4.2

RWCT - 2.4.3

	Estimated Det. Limit (PPM)	Conc. (PPM)	Conc. (PPM)	Conc. (PPM)
Fluoride	0.5	-51	-58	-50
Chloride	0.5	-51	-58	-50
Nitrite	1.0	-102	-116	-99
Nitrate	1.0	4890	4839	4799
Phosphate	1.0	222	14	297
Sulfate	1.0	-102	-11	-99
Oxalate	1.0	310	323	315
Formate	1.0	100	88	96
Water Leach DF		51.1	58.03	49.7
DF		2	2	2

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

SIMULANT CHARACTERIZATION ICP ANALYSIS

RWCT - 2.4.1					RWCT - 2.4.2			
Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)	Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	0.005	7	-1	-1	Ag	8	-1	-1
Al	0.03	179	181	180	Al	203	183	193
B	0.01	398	481	439.5	B	658	534	596
Ba	0.003	2	3	2.5	Ba	3	3	3
Be	0.003	-1	-1	-1	Be	-1	-1	-1
Bi	0.06	-12	-12	-12	Bi	-12	-12	-12
Ca	0.01	97	0	97	Ca	141	166	121
Cd	0.006	209	209	209	Cd	210	208	209
Ce	0.04	-8	27	-8	Ce	-8	40	-8
Co	0.01	-2	-2	-2	Co	-2	-2	-2
Cr	0.02	-4	-4	-4	Cr	-4	-4	-4
Cu	0.006	-1	-1	-1	Cu	4	6	5
Dy	0.006	-1	-1	-1	Dy	-1	-1	-1
Eu	0.004	-1	-1	-1	Eu	-1	-1	-1
Fe	0.005	116	122	119	Fe	131	124	127.5
K	0.3		-59	-59	K		-59	-59
La	0.01	2	3	2.5	La	2	3	2.5
Li	0.005	212	265	238.5	Li	355	294	324.5
Mg	0.06	76	87	81.5	Mg	117	94	105.5
Mn	0.003	49	49	49	Mn	49	49	49
Mo	0.01	-2	-2	-2	Mo	-2	-2	-2
Na	0.05	2334		2334	Na	2629		2629
Nd	0.02	10	19	14.5	Nd	11	17	14
Ni	0.02		11	11	Ni		11	11
P	0.08	135	131	133	P	134	129	131.5
Pb	0.08	-16	-16	-16	Pb	-16	-16	-16
S	0.08	-16	-16	-16	S	-16	-16	-16
Si	0.01	4396	4967	4681.5	Si	6577	5434	6005.5
Sn	0.08	-16	-16	-16	Sn	-16	-16	-16
Sr	0.003	1	3	2	Sr	1	3	2
Te	0.06	-12	-12	-12	Te	-12	-12	-12
Ti	0.003	13	13	13	Ti	16	14	15
V	0.01	-2	-2	-2	V	-2	-2	-2
Y	0.003	-1	-1	-1	Y	-1	-1	-1
Zn	0.01	41	41	41	Zn	41	43	42
Zr	0.01	28		28	Zr	35		35
Sample Wt		10.1607	10.1709		Sample Wt	10.2049	10.1932	
DF		2000	2000		DF	2000	2000	

IC ANALYSIS

RWCT - 2.4.1		RWCT - 2.4.2		WCT - 2.4.3
Estimated Det. Limit (ppm)	Conc. (ppm)	Conc. (ppm)	Conc. (ppm)	Conc. (ppm)
Fluoride	0.5	0	0	0
Chloride	0.5	0	21	0
Nitrite	1.0	0	0	0
Nitrate	1.0	4890	4839	4799
Phosphate	1.0	222	244	297
Sulfate	1.0	11	17	38
Oxalate	1.0	310	323	315
Formate	1.0	100	88	96
each DF	51.1	Water Leach DF	58.03	Water Leach DF
DF	2	DF	2	DF

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

**CHARACTERIZATION
(CONTINUED)
ICP ANALYSIS**

RWCT - 2.4.3			
Element	Conc. (KOH Fusion)	Conc. (Na2O2 Fusion)	Average Concentration
	(ppm)	(ppm)	(ppm)
Ag	5	1	3
Al	153	143	148
B	453	453	453
Ba	4	2	3
Be	-1	-1	-1
Bi	-12	-12	-12
Ca	100	132	116
Cd	166	157	162
Ce	-8	18	5
Co	-2	-2	-2
Cr	-4	-4	-4
Cu	2	-1	1
Dy	-1	-1	-1
Eu	-1	-1	-1
Fe	96	93	95
K		-59	-59
La	-2	-2	-2
Li	245	248	247
Mg	81	80	81
Mn	39	37	38
Mo	-2	-2	-2
Na	2049		2049
Nd	8	13	-15
Ni		8	8
P	109	104	107
Pb	-16	-16	-16
S	-16	-16	-16
Si	4606	2825	3716
Sn	-16	-16	-16
Sr	1	2	2
Te	-12	-12	-12
Ti	12	11	12
V	-2	-2	-2
Y	-1	-1	-1
Zn	42	41	42
Zr	24		24
Sample Wt	10.2069	10.1953	
DF	2000	2000	

**CHARACTERIZATION
(CONTINUED)
ICP ANALYSIS**

RWCT - 2.4.3			
Element	Conc.	Conc.	Average
	(KOH Fusion)	(Na2O2 Fusion)	Concentration
	(ppm)	(ppm)	(ppm)
Ag	5	1	3
Al	153	143	148
B	453	453	453
Ba	4	2	3
Be	-1	-1	-1
Bi	-12	-12	-12
Ca	100	132	116
Cd	166	157	162
Ce	-8	18	5
Co	-2	-2	-2
Cr	-4	-4	-4
Cu	2	-1	1
Dy	-1	-1	-1
Eu	-1	-1	-1
Fe	96	93	95
K		-59	-59
La	-2	-2	-2
Li	245	248	247
Mg	81	80	81
Mn	39	37	38
Mo	-2	-2	-2
Na	2049		2049
Nd	8	13	-15
Ni		8	8
P	109	104	107
Pb	-16	-16	-16
S	-16	-16	-16
Si	4606	2825	3716
Sn	-16	-16	-16
Sr	1	2	2
Te	-12	-12	-12
Ti	12	11	12
V	-2	-2	-2
Y	-1	-1	-1
Zn	42	41	42
Zr	24		24
Sample Wt	10.2069	10.1953	
DF	2000	2000	

SIMULANT MAKEUP

ICP ANALYSIS

SIPT3 - 2.3.1					SIPT3 - 2.3.2			
Element	Estimated Det. Limit (PPM)	Conc. (KOH Fusion) (PPM)	Conc. (Na2O2 Fusion) (PPM)	Average Concentration (PPM)	Element	Conc. (KOH Fusion) (PPM)	Conc. (Na2O2 Fusion) (PPM)	Average Concentration (PPM)
Ag	0.005	-2	-2	-2	Ag	3	-2	1
Al	0.03	191	181	186	Al	213	187	200
B	0.01	245	268	257	B	429	388	409
Ba	0.003	2	3	3	Ba	2	3	3
Be	0.003	-1	-1	-1	Be	-1	-1	-1
Bi	0.06	-29	-29	-29	Bi	-29	-29	-29
Ca	0.01	73	-5	73	Ca	121	-5	121
Cd	0.006	266	255	261	Cd	263	240	252
Ce	0.04	-20	-20	-8	Ce	-20	-20	-8
Co	0.01	-5	-5	-5	Co	-5	-5	-5
Cr	0.02	-10	-10	-10	Cr	-10	-10	-10
Cu	0.006	-3	-3	-3	Cu	-3	-3	-3
Dy	0.006	-3	-3	-3	Dy	-3	-3	-3
Eu	0.004	-2	-2	-2	Eu	-2	-2	-2
Fe	0.005	83	113	98	Fe	101	97	99
K	0.3		-147	-147	K		-147	-147
La	0.01	-5	-5	-5	La	-5	-5	-5
Li	0.005	132	150	141	Li	233	212	223
Mg	0.06	52	58	55	Mg	82	65	74
Mn	0.003	61	60	61	Mn	61	56	59
Mo	0.01	-5	-5	-5	Mo	-5	-5	-5
Na	0.05	2053		2053	Na	2245		2245
Nd	0.02	-10	14	2	Nd	-10	11	-12
Ni	0.02		-10	-10	Ni		-10	-10
P	0.08	141	130	136	P	137	212	175
Pb	0.08	-39	-39	-39	Pb	-39	-39	-39
S	0.08	-39	-39	-39	S	-39	-39	-39
Si	0.01	4022	4024	4023	Si	5727	5133	5430
Sn	0.08	-39	-39	-39	Sn	-39	-39	-39
Sr	0.003	-1	3	1	Sr	-1	3	1
Te	0.06	-29	-29	-29	Te	-29	-29	-29
Ti	0.003	9	12	11	Ti	13	12	13
V	0.01	-5	-5	-5	V	-55	-5	-30
Y	0.003	-1	-1	-1	Y	-1	-1	-1
Zn	0.01	209	213	211	Zn	210	213	212
Zr	0.01	10		10	Zr	20		20
Sample Wt		5.0988	5.0999		Sample Wt	5.103	5.1038	
DF		2500	2500		DF	2500	2500	

IC ANALYSIS

SIPT3 - 2.3.1		SIPT3 - 2.3.2		SIPT3-2.3.2
Estimated Det. Limit (PPM)	Conc. (PPM)	Conc. (PPM)	Conc. (PPM)	Conc. (PPM)
Fluoride	0.5	-107	-108	-22
Chloride	0.5	-107	-108	-22
Nitrite	1.0	-214	-217	-43
Nitrate	1.0	6028	6005	5978
Phosphate	1.0	317	334	295
Sulfate	1.0	-214	-217	-43
Oxalate	1.0	783	807	735
Formate	1.0	143	136	139
Water Leach DF		21.43	21.65	21.65
DF		10	10	2

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

SIMULANT MAKEUP BATCH 2

ICP ANALYSES

RWCT - 4.2.1

Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	0.005	171	264	217
Al	0.03	6569	13433	10001
B	0.01	22231	17858	20044
Ba	0.003	82	166	124
Be	0.003	-19	-23	-21
Bi	0.06	-390	-453	-421
Ca	0.01	4619		4619
Cd	0.006	6823	13745	10284
Ce	0.04	-260		-260
Co	0.01	-65	-76	-70
Cr	0.02	-130	-151	-140
Cu	0.006	657	105	381
Dy	0.006	-39	-45	-42
Eu	0.004	-26	-30	-28
Fe	0.005	3237	7095	5166
K	0.3		-2267	-2267
La	0.01	-65	297	-65
Li	0.005	12423	10320	11372
Mg	0.06	3767	4091	3929
Mn	0.003	1610	3160	2385
Mo	0.01	-65	-76	-70
Na	0.05	94933		94933
Nd	0.02	-130	959	-130
Ni	0.02		453	453
P	0.08	4330	8435	6383
Pb	0.08	-519	-604	-562
S	0.08	-519	-604	-562
Si	0.01	222336	239145	230741
Sn	0.08	-519	-604	-562
Sr	0.003	36	154	95
Te	0.06	-390	-453	-421
Ti	0.003	512	707	610
V	0.01	-65	-76	-70
Y	0.003	-19	-23	-21
Zn	0.01	442	553	497
Zr	0.01	571		571

Sample Wt 0.385 0.3309
 DF 2500 2500

RWCT - 4.2.2

Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	185	-33	-33
Al	6677	6045	6361
B	22175	19972	21073
Ba	80	87	84
Be	-20	-20	-20
Bi	-403	-395	-399
Ca	4485		4485
Cd	6993	6432	6713
Ce	-268		-268
Co	-67	-66	-67
Cr	-134	-132	-133
Cu	252	-40	-40
Dy	-40	-40	-40
Eu	-27	-26	-27
Fe	3261	3089	3175
K		-1977	-1977
La	-67	-66	-67
Li	12366	11265	11815
Mg	3737	3425	3581
Mn	1661	1530	1595
Mo	-67	-66	-67
Na	98161		98161
Nd	-134	242	-134
Ni		227	227
P	4506	4031	4269
Pb	-537	-527	-532
S	-537	-527	-532
Si	222271	200667	211469
Sn	-537	-527	-532
Sr	38	67	53
Te	-403	-395	-399
Ti	487	454	471
V	-67	-66	-67
Y	-20	-20	-20
Zn	563	863	713
Zr	579		579

Sample Wt 0.3726 0.3793
 DF 2500 2500

IC ANALYSIS

RWCT - 4.2.1

Anion	Estimated Det. Limit (ppm)	Concentration (ppm)
Fluoride	0.5	0
Chloride	0.5	0
Nitrite	1.0	0
Nitrate	1.0	10600
Phosphate	1.0	452
Sulfate	1.0	0
Oxalate	1.0	688
Formate	1.0	172

Water Leach DF 31.02
 Sample DF 5

RWCT - 4.2.2

Concentration (ppm)
0
0
0
10700
430
0
686
188

Water Leach DF 31.81
 Sample DF 5

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

SIMULANT CHARACTERIZATION

ICP ANALYSIS

RWCT - 4.2.1					RWCT - 4.2.2			
Element	Estimated Det. Limit (PPM)	Conc. (KOH Fusion) (PPM)	Conc. (Na2O2 Fusion) (PPM)	Average Concentration (PPM)	Element	Conc. (KOH Fusion) (PPM)	Conc. (Na2O2 Fusion) (PPM)	Average Concentration (PPM)
Ag	0.005	11	27	-1	Ag	10	14	12
Al	0.03	353	391	372	Al	309	359	334
B	0.01	492	1048	770	B	292	533	413
Ba	0.003	5	6	5	Ba	4	6	5
Be	0.003	-2	-2	-2	Be	-2	-2	-2
Bi	0.06	-41	-40	-40	Bi	-37	-40	-38
Ca	0.01	129	339	129	Ca	95	293	95
Cd	0.006	454	437	446	Cd	412	458	435
Ce	0.04	-27	-27	-8	Ce	-25	-26	-8
Co	0.01	-7	-7	-7	Co	-6	-7	-6
Cr	0.02	-14	-13	-13	Cr	-12	-13	-13
Cu	0.006	-4	-4	-4	Cu	-4	-4	-4
Dy	0.006	-4	-4	-4	Dy	-4	-4	-4
Eu	0.004	-3	-3	-3	Eu	-2	-3	-3
Fe	0.005	191	204	197	Fe	188	197	192
K	0.3		-200	-200	K		-198	-198
La	0.01	-7	-7	-7	La	-6	-7	-6
Li	0.005	262	569	415	Li	155	287	221
Mg	0.06	106	194	150	Mg	75	119	97
Mn	0.003	104	101	102	Mn	97	106	101
Mo	0.01	-7	-7	-7	Mo	-6	-7	-6
Na	0.05	5891		5891	Na	5227		5227
Nd	0.02	-14	34	10	Nd	-12	33	-12
Ni	0.02		14	14	Ni		14	14
P	0.08	254	287	271	P	238	304	271
Pb	0.08	-54	-53	-54	Pb	-50	-53	-51
S	0.08	-54	-53	-54	S	-50	-53	-51
Si	0.01	6520	10913	8716	Si	4575	6814	5695
Sn	0.08	-54	-53	-54	Sn	-50	-53	-51
Sr	0.003	2	6	4	Sr	2	6	4
Te	0.06	-41	-40	-40	Te	-37	-40	-38
Ti	0.003	19	26	23	Ti	16	20	18
V	0.01	-7	-7	-7	V	-6	-7	-6
Y	0.003	-2	-2	-2	Y	-2	-2	-2
Zn	0.01	287	284	286	Zn	263	286	275
Zr	0.01	31		31	Zr	28		28
Sample Wt		3.698	3.7451		Sample Wt	4.0367	3.7925	
DF		2500	2500		DF	2500	2500	

IC ANALYSIS

RWCT - 4.2.1		RWCT - 4.2.2		RWCT - 4.2.3
Estimated Det. Limit (PPM)	Conc. (PPM)	Conc. (PPM)	Conc. (PPM)	Conc. (PPM)
Fluoride	0.5	-78	-80	-79
Chloride	0.5	-78	-80	-79
Nitrite	1.0	-155	-159	-157
Nitrate	1.0	10872	10462	10809
Phosphate	1.0	-155	-159	-157
Sulfate	1.0	-155	-159	-157
Oxalate	1.0	673	653	671
Formate	1.0	177	172	181
Water Leach DF	25.29	24.21	31.45	
DF	5	5	5	

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

**SIMULANT CHARACTERIZATION
(CONTINUED)
ICP ANALYSIS**

RWCT - 4.2.2				RWCT - 4.2.3			
Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)	Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	17	11	14	Ag	15	19	17
Al	414	317	365	Al	458	435	446
B	1474	525	999	B	2132	2019	2076
Ba	5	5	5	Ba	6	6	6
Be	-2	-2	-2	Be	-2	-2	-2
Bi	-43	-42	-42	Bi	-33	-37	-35
Ca	296	255	275	Ca	408	466	437
Cd	423	423	423	Cd	447	392	420
Ce	-29	-28	-28	Ce	-22	-25	-23
Co	-7	-7	-7	Co	-6	-6	-6
Cr	-14	-14	-14	Cr	-11	-12	-12
Cu	-4	-4	-4	Cu	-3	-4	-4
Dy	-4	-4	-4	Dy	-3	-4	-4
Eu	-3	-3	-3	Eu	-2	-2	-2
Fe	154	146	150	Fe	213	198	206
K		-208	-208	K		-187	-187
La	-7	-7	-7	La	-6	-6	-6
Li	770	279	525	Li	1159	1119	1139
Mg	260	112	186	Mg	350	324	337
Mn	87	100	94	Mn	96	87	92
Mo	-7	-7	-7	Mo	-6	-6	-6
Na	7049		7049	Na	7760		7760
Nd	19	42	30	Nd	11	24	18
Ni		-14	-14	Ni		14	14
P	244	233	238	P	233	252	243
Pb	-58	-55	-56	Pb	-44	-50	-47
S	-58	-55	-56	S	-44	-50	-47
Si	14162	6362	10262	Si	16245	18071	17158
Sn	-58	-55	-56	Sn	-44	-50	-47
Sr	3	7	5	Sr	3	5	4
Te	-43	-42	-42	Te	-33	-37	-35
Ti	26	18	22	Ti	39	37	38
V	-7	-7	-7	V	-6	-6	-6
Y	-2	-2	-2	Y	-2	-2	-2
Zn	328	281	304	Zn	240	282	261
Zr	35		35	Zr	39		39
Sample Wt	3.4767	3.6062		Sample Wt	4.5444	4.0129	
DF	2500	2500		DF	2500	2500	

**SIMULANT CHARACTERIZATION
(CONTINUED)
ICP ANALYSIS**

Element	RWCT - 4.2.3		
	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	31	20	25
Al	423	450	436
B	1741	2156	1948
Ba	5	6	6
Be	-2	-2	-2
Bi	-44	-44	-44
Ca	355	560	457
Cd	542	398	470
Ce	-29	-29	-29
Co	-7	-7	-7
Cr	-15	-15	-15
Cu	-4	-4	-4
Dy	-4	-4	-4
Eu	-3	-3	-3
Fe	187	191	189
K		-221	-221
La	-7	-7	-7
Li	924	1192	1058
Mg	300	356	328
Mn	98	91	95
Mo	-7	-7	-7
Na	7629		7629
Nd	-15	41	-15
Ni		20	20
P	267	242	254
Pb	-59	-59	-59
S	-59	-59	-59
Si	16402	19120	17761
Sn	-59	-59	-59
Sr	3	8	5
Te	-44	-44	-44
Ti	30	39	35
V	-7	-7	-7
Y	-2	-2	-2
Zn	333	305	319
Zr	32		32
Sample Wt	3.3945	3.3902	
DF	2500	2500	

SIMULANT CHARACTERIZATION

ICP ANALYSES

RWCT - 7.2.1

Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	0.005	10	2	6
Al	0.03	456	477	467
B	0.01	1395	1543	1469
Ba	0.003	6	7	7
Be	0.003	-1	-1	-1
Bi	0.06	-14	-14	-14
Ca	0.01	296	372	296
Cd	0.006	492	512	502
Ce	0.04	-10	40	-10
Co	0.01	-2	-2	-2
Cr	0.02	-5	-5	-5
Cu	0.006	4	2	3
Dy	0.006	-1	-1	-1
Eu	0.004	-1	-1	-1
Fe	0.005	207	219	213
K	0.3		215	215
La	0.01	-2	4	-2
Li	0.005	762	870	816
Mg	0.06	248	273	261
Mn	0.003	117	120	119
Mo	0.01	3	3	3
Na	0.05	7043		7043
Nd	0.02	13	23	13
Ni	0.02		17	17
P	0.08	254	263	259
Pb	0.08	-19	-19	-19
S	0.08	-19	-19	-19
Si	0.01	13962	15614	14788
Sn	0.08	-19	-19	-19
Sr	0.003	2	4	3
Te	0.06	-14	-14	-14
Ti	0.003	32	35	34
V	0.01	-2	-2	-2
Y	0.003	-1	-1	-1
Zn	0.01	60	52	56
Zr	0.01	38		38

Sample Wt 10.446 10.4315
 DF 2500 2500

RWCT - 7.2.2

Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	11	5	5
Al	385	394	390
B	530	796	663
Ba	7	5	6
Be	-1	-1	-1
Bi	-15	-15	-15
Ca	145	222	145
Cd	481	468	475
Ce	-10	23	-10
Co	-2	-2	-2
Cr	-5	-5	-5
Cu	-1	-1	-1
Dy	-1	-1	-1
Eu	-1	-1	-1
Fe	191	191	191
K		108	108
La	-2	-2	-2
Li	287	450	369
Mg	119	155	137
Mn	118	112	115
Mo	3	-2	1
Na	5904		5904
Nd	11	17	11
Ni	0	13	13
P	263	250	257
Pb	-19	-19	-19
S	-19	-19	-19
Si	7064	9209	8137
Sn	-19	-19	-19
Sr	2	4	3
Te	-15	-15	-15
Ti	22	24	23
V	-2	-2	-2
Y	-1	-1	-1
Zn	52	49	51
Zr	29		29

Sample Wt 10.2639 10.3114
 DF 2500 2500

IC ANALYSIS

RWCT 7.2.1

	Estimated Det. Limit (ppm)	Concentration (ppm)
Fluoride	0.5	106
Chloride	0.5	-102
Nitrite	1.0	-203
Nitrate	1.0	11636
Phosphate	1.0	631
Sulfate	1.0	-203
Oxalate	1.0	669
Formate	1.0	-102

Water Leach DF 20.31
 Sample DF 10

RWCT - 7.2.2

Concentration (ppm)
102
-92
-184
11627
533
-184
673
-92

Water Leach DF 18.31
 Sample DF 10

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

HOMOGENEITY/RESUSPENSION

ICP ANALYSIS

RWCT - 7.3.1					RWCT - 7.3.2				
Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)	Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)	
Ag	0.005	9	11	10	Ag	10	10	10	
Al	0.03	342	444	393	Al	515	393	454	
B	0.01	629	1309	969	B	1995	1003	1499	
Ba	0.003	5	7	6	Ba	9	6	7	
Be	0.003	-2	-2	-2	Be	-1	-1	-1	
Bi	0.06	-45	-44	-44	Bi	-29	-29	-29	
Ca	0.01	148	419	148	Ca	391	293	391	
Cd	0.006	418	490	454	Cd	512	455	483	
Ce	0.04	-30	-29	-29	Ce	-19	-19	-8	
Co	0.01	-7	-7	-7	Co	-5	-5	-5	
Cr	0.02	-15	-15	-15	Cr	-10	-10	-10	
Cu	0.006	-4	-4	-4	Cu	-3	-3	-3	
Dy	0.006	-4	-4	-4	Dy	-3	-3	-3	
Eu	0.004	-3	-3	-3	Eu	-2	-2	-2	
Fe	0.005	192	219	206	Fe	230	194	212	
K	0.3		-218	-218	K		-145	-145	
La	0.01	-7	-7	-7	La	-5	-5	-5	
Li	0.005	336	718	527	Li	1078	553	816	
Mg	0.06	130	236	183	Mg	339	185	262	
Mn	0.003	98	112	105	Mn	117	108	112	
Mo	0.01	-7	-7	-7	Mo	-5	-5	-5	
Na	0.05	5883		5883	Na	8671		8671	
Nd	0.02	-15	26	-15	Nd	14	26	20	
Ni	0.02		15	15	Ni		13	13	
P	0.08	251	318	284	P	288	299	293	
	0.08	-60	-58	-59	Pb	-38	-39	-38	
	0.08	-60	-58	-59	S	-38	-39	-38	
Si	0.01	7293	13297	10295	Si	19074	10430	14752	
Sn	0.08	-60	-58	-59	Sn	-38	-39	-38	
Sr	0.003	2	7	5	Sr	3	5	4	
Te	0.06	-45	-44	-44	Te	-29	-29	-29	
Ti	0.003	20	31	25	Ti	41	26	33	
V	0.01	-7	-7	-7	V	-5	-5	-5	
Y	0.003	-2	-2	-2	Y	-1	-1	-1	
Zn	0.01	308	316	312	Zn	212	228	220	
Zr	0.01	27		27	Zr	39		39	
Sample Wt		3.3456	3.4427		Sample Wt	5.2484	5.188		
DF		2500	2500		DF	2500	2500		

HOMOGENEITY/RESUSPENSION (CONTINUED) ICP ANALYSIS

RWCT - 7.3.2			
Element	Conc.	Conc.	Average
	(KOH Fusion) (ppm)	(Na2O2 Fusion) (ppm)	Concentration (ppm)
Ag	11	12	12
Al	503	391	447
B	1614	582	1098
Ba	6	6	6
Be	-2	-2	-2
Bi	-43	-44	-44
Ca	335	299	317
Cd	497	459	478
Ce	-29	-29	-29
Co	-7	-7	-7
Cr	-14	-15	-15
Cu	-4	-4	-4
Dy	-4	-4	-4
Eu	-3	-3	-3
Fe	216	201	209
K		-220	-220
La	-7	-7	-7
Li	865	315	590
Mg	296	124	210
Mn	114	112	113
Mo	-7	-7	-7
Na	7960		7960
Nd	19	35	27
Ni		16	16
P	283	282	283
Pb	-58	-59	-58
S	-58	-59	-58
Si	16092	7250	11671
Sn	-58	-59	-58
Sr	3	8	5
Te	-43	-44	-44
Ti	36	24	30
V	-7	-7	-7
Y	-2	-2	-2
Zn	320	882	601
Zr	38		38
Sample Wt	3.4689	3.4154	
DF	2500	2500	

**HOMOGENEITY/RESUSPENSION
(CONTINUED)
ICP ANALYSIS**

RWCT - 7.3.3

Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	0.005	8	10	9
Al	0.03	297	397	347
B	0.01	177	832	505
Ba	0.003	4	6	5
Be	0.003	-2	-2	-2
Bi	0.06	-43	-44	-44
Ca	0.01	70	288	70
Cd	0.006	386	476	431
Ce	0.04	-29	-29	-29
Co	0.01	-7	-7	-7
Cr	0.02	-14	-15	-15
Cu	0.006	-4	-4	-4
Dy	0.006	-4	-4	-4
Eu	0.004	-3	-3	-3
Fe	0.005	157	206	182
Cl	0.3		-220	-220
La	0.01	-7	-7	-7
Li	0.005	92	454	273
Mg	0.06	57	154	106
Mn	0.003	94	115	105
Mo	0.01	-7	-7	-7
Na	0.05	4985		4985
Nd	0.02	-14	28	-14
Ni	0.02		53	53
P	0.08	249	334	291
Pb	0.08	-58	-59	-58
S	0.08	-58	-59	-58
Si	0.01	3480	9326	6403
Sn	0.08	-58	-59	-58
Sr	0.003	2	6	4
Te	0.06	-43	-44	-44
Ti	0.003	13	24	19
V	0.01	-7	-7	-7
Y	0.003	-2	-2	-2
Zn	0.01	310	318	314
Zr	0.01	16		16

Sample Wt
DF

3.4721
2500

3.4059
2500

RWCT - 7.3.3

Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	10	10	10
Al	500	419	459
B	1755	789	1272
Ba	6	6	6
Be	-2	-2	-2
Bi	-46	-44	-45
Ca	360	282	360
Cd	484	482	483
Ce	-30	-29	-8
Co	-8	-7	-7
Cr	-15	-15	-15
Cu	-5	-4	-4
Dy	-5	-4	-4
Eu	-3	-3	-3
Fe	212	183	198
K		-219	-219
La	-8	-7	-7
Li	939	430	685
Mg	316	158	237
Mn	112	116	114
Mo	-8	-7	-7
Na	8010		8010
Nd	23	31	27
Ni		-15	-15
P	275	307	291
Pb	-61	-58	-60
S	-61	-58	-60
Si	17192	9168	13180
Sn	-61	-58	-60
Sr	3	6	5
Te	-46	-44	-45
Ti	36	24	30
V	-8	-7	-7
Y	-2	-2	-2
Zn	320	350	335
Zr	38		38

Sample Wt
DF

3.2884
2500

3.4304
2500

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

SETTLING ICP ANALYSES

RWCT - 8.2.1

Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	0.005		242	242
Al	0.03		6765	6765
B	0.01		18179	18179
Ba	0.003		91	91
Be	0.003		-7	-7
Bi	0.06		-141	-141
Ca	0.01		4430	4430
Cd	0.006		7578	7578
Ce	0.04		-94	-94
Co	0.01		-23	-23
Cr	0.02		62	62
Cu	0.006		22	22
Dy	0.006		-14	-14
Eu	0.004		-9	-9
Fe	0.005		3194	3194
K	0.3		-703	-703
La	0.01		34	34
Li	0.005		10268	10268
Mg	0.06		3302	3302
Mn	0.003		1803	1803
Mo	0.01		28	28
Na	0.05		0	0
Nd	0.02		242	242
Ni	0.02		215	215
P	0.08		3749	3749
Pb	0.08		-187	-187
S	0.08		326	326
Si	0.01		164434	164434
Sn	0.08		-187	-187
Sr	0.003		53	53
Te	0.06		-141	-141
Ti	0.003		429	429
V	0.01		-23	-23
Y	0.003		-7	-7
Zn	0.01		1074	1074
Zr	0.01		0	0

Sample Wt
DF

1.0676
2500

RWCT - 8.2.2

Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag		114	114
Al		5776	5776
B		14720	14720
Ba		75	75
Be		-7	-7
Bi		-150	-150
Ca		5477	5477
Cd		6471	6471
Ce		-100	-100
Co		-25	-25
Cr		-50	-50
Cu		27	27
Dy		-15	-15
Eu		-10	-10
Fe		2849	2849
K		-748	-748
La		30	30
Li		8283	8283
Mg		2819	2819
Mn		1545	1545
Mo		-25	-25
Na		0	0
Nd		214	214
Ni		187	187
P		3368	3368
Pb		-199	-199
S		502	502
Si		128677	128677
Sn		-199	-199
Sr		48	48
Te		-150	-150
Ti		371	371
V		-25	-25
Y		-7	-7
Zn		1194	1194
Zr		0	0

Sample Wt
DF

1.0029
2500

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

Note: Not enough sample to run duplicate analyses

SETTLING ICP ANALYSES

RWCT - 8.2.3					RWCT - 8.2.4				
	Estimated	Conc.	Conc.	Average		Conc.	Conc.	Average	
	Det. Limit	(KOH Fusion)	(Na2O2 Fusion)	Concentration		(KOH Fusion)	(Na2O2 Fusion)	Concentration	
Element	(ppm)	(ppm)	(ppm)	(ppm)	Element	(ppm)	(ppm)	(ppm)	
Ag	0.005		177	177	Ag		234	234	
Al	0.03		7534	7534	Al		8472	8472	
B	0.01		20150	20150	B		3703	3703	
Ba	0.003		95	95	Ba		125	125	
Be	0.003		-7	-7	Be		-18	-18	
Bi	0.06		-146	-146	Bi		-351	-351	
Ca	0.01		4945	4945	Ca		3131	3131	
Cd	0.006		8455	8455	Cd		12857	12857	
Ce	0.04		-97	-97	Ce		-234	-234	
Co	0.01		-24	-24	Co		-58	-58	
Cr	0.02		-49	-49	Cr		-117	-117	
Cu	0.006		25	25	Cu		-35	-35	
Dy	0.006		-15	-15	Dy		-35	-35	
Eu	0.004		-10	-10	Eu		-23	-23	
Fe	0.005		3468	3468	Fe		4768	4768	
K	0.3		-731	-731	K		-1754	-1754	
La	0.01		31	31	La		-58	-58	
Li	0.005		11446	11446	Li		2028	2028	
Mg	0.06		3651	3651	Mg		1524	1524	
Mn	0.003		1972	1972	Mn		3251	3251	
Mo	0.01		25	25	Mo		-58	-58	
Na	0.05			0	Na			0	
Nd	0.02		251	251	Nd		386	386	
Ni	0.02		198	198	Ni		315	315	
P	0.08		4139	4139	P		6560	6560	
Pb	0.08		-195	-195	Pb		-468	-468	
S	0.08		325	325	S		-468	-468	
Si	0.01		76387	76387	Si		99743	99743	
Sn	0.08		-195	-195	Sn		-468	-468	
Sr	0.003		58	58	Sr		85	85	
Te	0.06		-146	-146	Te		-351	-351	
Ti	0.003		424	424	Ti		377	377	
V	0.01		-24	-24	V		-58	-58	
Y	0.003		-7	-7	Y		-18	-18	
Zn	0.01		1022	1022	Zn		2519	2519	
Zr	0.01			0	Zr			0	
Sample Wt			1.0257		Sample Wt		0.4276		
DF			2500		DF		2500		

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

Note: Not enough sample to run duplicate analyses

SETTLING **ICP ANALYSES**

RWCT - 8.2.5

Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	0.005		274	274
Al	0.03		11487	11487
B	0.01		3836	3836
Ba	0.003		300	300
Be	0.003		-21	-21
Bi	0.06		-425	-425
Ca	0.01		3952	3952
Cd	0.006		16412	16412
Ce	0.04		-283	-283
Co	0.01		-71	-71
Cr	0.02		-142	-142
Cu	0.006		-43	-43
Dy	0.006		-43	-43
Eu	0.004		-28	-28
Fe	0.005		6122	6122
K	0.3		-2126	-2126
La	0.01		-71	-71
Li	0.005		2299	2299
Mg	0.06		1847	1847
Mn	0.003		4111	4111
Mo	0.01		-71	-71
Na	0.05		0	0
Nd	0.02		376	376
Ni	0.02		366	366
P	0.08		8510	8510
Pb	0.08		-567	-567
S	0.08		-567	-567
Si	0.01		118835	118835
Sn	0.08		-567	-567
Sr	0.003		144	144
Te	0.06		-425	-425
Ti	0.003		497	497
V	0.01		-71	-71
Y	0.003		-21	-21
Zn	0.01		1615	1615
Zr	0.01		0	0

Sample Wt 0.3528
DF 2500

RWCT - 8.2.6

Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag		276	276
Al		11301	11301
B		4200	4200
Ba		145	145
Be		-22	-22
Bi		-433	-433
Ca		3624	3624
Cd		15446	15446
Ce		-289	-289
Co		-72	-72
Cr		-144	-144
Cu		-43	-43
Dy		-43	-43
Eu		-29	-29
Fe		5957	5957
K		-2166	-2166
La		-72	-72
Li		2405	2405
Mg		1864	1864
Mn		3882	3882
Mo		-72	-72
Na		0	0
Nd		426	426
Ni		382	382
P		8008	8008
Pb		-578	-578
S		-578	-578
Si		124495	124495
Sn		-578	-578
Sr		110	110
Te		-433	-433
Ti		495	495
V		-72	-72
Y		-22	-22
Zn		1611	1611
Zr		0	0

Sample Wt 0.3462
DF 2500

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

Note: Not enough sample to run duplicate analyses

SETTLING/HOMOGENEITY/RESUSPENSION **ICP ANALYSES**

RWCT - 8.2.9

Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	0.005		292	292
Al	0.03		9653	9653
B	0.01		3429	3429
Ba	0.003		145	145
Be	0.003		-22	-22
Bi	0.06		-434	-434
Ca	0.01		3634	3634
Cd	0.006		16951	16951
Ce	0.04		-289	-289
Co	0.01		-72	-72
Cr	0.02		-145	-145
Cu	0.006		-43	-43
Dy	0.006		-43	-43
Eu	0.004		-29	-29
Fe	0.005		5762	5762
K	0.3		-2168	-2168
La	0.01		-72	-72
Li	0.005		2076	2076
Mg	0.06		1647	1647
Mn	0.003		4323	4323
Mo	0.01		-72	-72
Na	0.05		0	0
Nd	0.02		409	409
Ni	0.02		371	371
P	0.08		8728	8728
Pb	0.08		-578	-578
S	0.08		-578	-578
Si	0.01		113656	113656
Sn	0.08		-578	-578
Sr	0.003		104	104
Te	0.06		-434	-434
Ti	0.003		438	438
V	0.01		-72	-72
Y	0.003		-22	-22
Zn	0.01		1516	1516
Zr	0.01		0	0

Sample Wt
DF

0.3460
2500

RWCT - 8.5.1

Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag		212	212
Al		8390	8390
B		6571	6571
Ba		129	129
Be		-21	-21
Bi		-427	-427
Ca		3692	3692
Cd		11981	11981
Ce		-284	-284
Co		-71	-71
Cr		-142	-142
Cu		-43	-43
Dy		-43	-43
Eu		-28	-28
Fe		4467	4467
K		-2133	-2133
La		-71	-71
Li		3706	3706
Mg		1780	1780
Mn		2993	2993
Mo		-71	-71
Na		0	0
Nd		244	244
Ni		267	267
P		7104	7104
Pb		-569	-569
S		-569	-569
Si		119312	119312
Sn		-569	-569
Sr		92	92
Te		-427	-427
Ti		399	399
V		-71	-71
Y		-21	-21
Zn		1574	1574
Zr		0	0

Sample Wt
DF

0.3516
2500

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

Not enough sample to run duplicate analyses

HOMOGENEITY/RESUSPENSION **ICP ANALYSES**

RWCT-8.5.2

Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	0.005		222	222
Al	0.03		8747	8747
B	0.01		8047	8047
Ba	0.003		125	125
Be	0.003		-22	-22
Bi	0.06		-433	-433
Ca	0.01		4015	4015
Cd	0.006		12532	12532
Ce	0.04		-288	-288
Co	0.01		-72	-72
Cr	0.02		-144	-144
Cu	0.006		-43	-43
Dy	0.006		-43	-43
Eu	0.004		-29	-29
Fe	0.005		4678	4678
K	0.3		-2163	-2163
La	0.01		-72	-72
Li	0.005		4686	4686
Mg	0.06		2001	2001
Mn	0.003		3105	3105
Mo	0.01		-72	-72
Na	0.05		0	0
Nd	0.02		374	374
Ni	0.02		303	303
P	0.08		7795	7795
Pb	0.08		-577	-577
S	0.08		-577	-577
Si	0.01		132319	132319
Sn	0.08		-577	-577
Sr	0.003		100	100
Te	0.06		-433	-433
Ti	0.003		427	427
V	0.01		-72	-72
Y	0.003		-22	-22
Zn	0.01		1608	1608
Zr	0.01		0	0

Sample Wt 0.3526
DF 2500

RWCT - 8.5.3

Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag		191	191
Al		8544	8544
B		15691	15691
Ba		155	155
Be		-21	-21
Bi		-425	-425
Ca		5138	5138
Cd		10451	10451
Ce		-284	-284
Co		-71	-71
Cr		-142	-142
Cu		-43	-43
Dy		-43	-43
Eu		-28	-28
Fe		4189	4189
K		-2127	-2127
La		-71	-71
Li		8749	8749
Mg		3074	3074
Mn		2528	2528
Mo		-71	-71
Na		0	0
Nd		322	322
Ni		291	291
P		5523	5523
Pb		-567	-567
S		-567	-567
Si		189095	189095
Sn		-567	-567
Sr		96	96
Te		-425	-425
Ti		489	489
V		-71	-71
Y		-21	-21
Zn		1593	1593
Zr		0	0

Sample Wt 0.3417
DF 2500

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

Note: Not enough sample to run duplicate analyses

HOMOGENEITY/RESUSPENSION **ICP ANALYSES**

RWCT - 8.5.4

Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	0.005		235	235
Al	0.03		8516	8516
B	0.01		15284	15284
Ba	0.003		127	127
Be	0.003		-22	-22
Bi	0.06		-439	-439
Ca	0.01		5795	5795
Cd	0.006		10579	10579
Ce	0.04		-293	-293
Co	0.01		-73	-73
Cr	0.02		-146	-146
Cu	0.006		-44	-44
Dy	0.006		-44	-44
Eu	0.004		-29	-29
Fe	0.005		4299	4299
K	0.3		-2195	-2195
La	0.01		-73	-73
Li	0.005		8560	8560
Mg	0.06		3055	3055
Mn	0.003		2550	2550
Mo	0.01		-73	-73
Na	0.05		0	0
Nd	0.02		355	355
Ni	0.02		312	312
P	0.08		5592	5592
Pb	0.08		-585	-585
S	0.08		-585	-585
Si	0.01		187226	187226
Sn	0.08		-585	-585
Sr	0.003		111	111
Te	0.06		-439	-439
Ti	0.003		493	493
V	0.01		-73	-73
Y	0.003		-22	-22
Zn	0.01		923	923
Zr	0.01		0	0

Sample Wt 0.3417
DF 2500

RWCT - 8.5.5

Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag		185	185
Al		7695	7695
B		21163	21163
Ba		545	545
Be		-20	-20
Bi		-409	-409
Ca		6123	6123
Cd		8063	8063
Ce		-273	-273
Co		-68	-68
Cr		-136	-136
Cu		-41	-41
Dy		-41	-41
Eu		-27	-27
Fe		3580	3580
K		-2045	-2045
La		-68	-68
Li		11968	11968
Mg		3761	3761
Mn		1905	1905
Mo		-68	-68
Na		0	0
Nd		296	296
Ni		262	262
P		4576	4576
Pb		-545	-545
S		-545	-545
Si		223419	223419
Sn		-545	-545
Sr		105	105
Te		-409	-409
Ti		519	519
V		-68	-68
Y		-20	-20
Zn		1438	1438
Zr		0	0

Sample Wt 0.3668
DF 2500

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

Not enough sample to run duplicate analyses

HOMOGENEITY/RESUSPENSION **ICP ANALYSES**

RWCT - 8.5.6

Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	0.005		169	169
Al	0.03		7527	7527
B	0.01		21550	21550
Ba	0.003		135	135
Be	0.003		-21	-21
Bi	0.06		-427	-427
Ca	0.01		5913	5913
Cd	0.006		8061	8061
Ce	0.04		-285	-285
Co	0.01		-71	-71
Cr	0.02		-142	-142
Cu	0.006		-43	-43
Dy	0.006		-43	-43
Eu	0.004		-28	-28
Fe	0.005		3596	3596
K	0.3		-2134	-2134
La	0.01		-71	-71
Li	0.005		12258	12258
Mg	0.06		3793	3793
Mn	0.003		1897	1897
Mo	0.01		-71	-71
Na	0.05		0	0
Nd	0.02		265	265
Ni	0.02		273	273
P	0.08		4434	4434
Pb	0.08		-569	-569
S	0.08		-569	-569
Si	0.01		226522	226522
Sn	0.08		-569	-569
Sr	0.003		89	89
Te	0.06		-427	-427
Ti	0.003		517	517
V	0.01		-71	-71
Y	0.003		-21	-21
Zn	0.01		1441	1441
Zr	0.01		0	0

Sample Wt 0.3514
DF 2500

RWCT - 8.5.7

Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag		188	188
Al		7815	7815
B		18283	18283
Ba		134	134
Be		-20	-20
Bi		-409	-409
Ca		5492	5492
Cd		9172	9172
Ce		-273	-273
Co		-68	-68
Cr		-136	-136
Cu		-41	-41
Dy		-41	-41
Eu		-27	-27
Fe		3863	3863
K		-2046	-2046
La		-68	-68
Li		10366	10366
Mg		3431	3431
Mn		2191	2191
Mo		-68	-68
Na		0	0
Nd		329	329
Ni		274	274
P		5204	5204
Pb		-546	-546
S		-546	-546
Si		204173	204173
Sn		-546	-546
Sr		91	91
Te		-409	-409
Ti		494	494
V		-68	-68
Y		-20	-20
Zn		1566	1566
Zr		0	0

Sample Wt 0.3666
DF 2500

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

Not enough sample to run duplicate analyses

HOMOGENEITY/RESUSPENSION **ICP ANALYSES**

RWCT - 8.5.8

Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	0.005		197	197
Al	0.03		7820	7820
B	0.01		20960	20960
Ba	0.003		120	120
Be	0.003		-20	-20
Bi	0.06		-409	-409
Ca	0.01		5843	5843
Cd	0.006		8651	8651
Ce	0.04		-272	-272
Co	0.01		-68	-68
Cr	0.02		-136	-136
Cu	0.006		87	87
Dy	0.006		-41	-41
Eu	0.004		-27	-27
Fe	0.005		3721	3721
K	0.3		-2044	-2044
La	0.01		-68	-68
Li	0.005		11860	11860
Mg	0.06		3818	3818
Mn	0.003		1984	1984
Mo	0.01		-68	-68
Na	0.05		0	0
Nd	0.02		384	384
Ni	0.02		272	272
P	0.08		5181	5181
Pb	0.08		-545	-545
S	0.08		-545	-545
Si	0.01		221185	221185
Sn	0.08		-545	-545
Sr	0.003		89	89
Te	0.06		-409	-409
Ti	0.003		518	518
V	0.01		-68	-68
Y	0.003		-20	-20
Zn	0.01		1635	1635
Zr	0.01		0	0

Sample Wt
DF

0.367
2500

RWCT - 8.5.9

Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag		170	170
Al		8032	8032
B		21238	21238
Ba		224	224
Be		-21	-21
Bi		-423	-423
Ca		5891	5891
Cd		8244	8244
Ce		-282	-282
Co		-71	-71
Cr		-141	-141
Cu		-42	-42
Dy		-42	-42
Eu		-28	-28
Fe		3680	3680
K		-2117	-2117
La		-71	-71
Li		11914	11914
Mg		3859	3859
Mn		1892	1892
Mo		-71	-71
Na		0	0
Nd		371	371
Ni		287	287
P		4402	4402
Pb		-565	-565
S		-565	-565
Si		220356	220356
Sn		-565	-565
Sr		89	89
Te		-423	-423
Ti		524	524
V		-71	-71
Y		-21	-21
Zn		1476	1476
Zr		0	0

Sample Wt
DF

0.3542
2500

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

Not enough sample to run duplicate analyses

HOMOGENEITY/RESUSPENSION **ICP ANALYSES**

RWCT - 8.5.10

Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	0.005		190	190
Al	0.03		7122	7122
B	0.01		20577	20577
Ba	0.003		95	95
Be	0.003		-22	-22
Bi	0.06		-431	-431
Ca	0.01		5893	5893
Cd	0.006		7926	7926
Ce	0.04		-287	-287
Co	0.01		-72	-72
Cr	0.02		-144	-144
Cu	0.006		-43	-43
Dy	0.006		-43	-43
Eu	0.004		-29	-29
Fe	0.005		3375	3375
K	0.3		-2154	-2154
La	0.01		-72	-72
Li	0.005		11567	11567
Mg	0.06		3667	3667
Mn	0.003		1829	1829
Mo	0.01		-72	-72
Na	0.05		0	0
Nd	0.02		282	282
Ni	0.02		268	268
P	0.08		4347	4347
Pb	0.08		-574	-574
S	0.08		-574	-574
Si	0.01		213886	213886
Sn	0.08		-574	-574
Sr	0.003		88	88
Te	0.06		-431	-431
Ti	0.003		481	481
V	0.01		-72	-72
Y	0.003		-22	-22
Zn	0.01		1575	1575
Zr	0.01			0

Sample Wt

0.3482

DF

2500

RWCT - 8.5.11

Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag		198	198
Al		7259	7259
B		21511	21511
Ba		95	95
Be		-22	-22
Bi		-431	-431
Ca		5952	5952
Cd		8056	8056
Ce		-287	-287
Co		-72	-72
Cr		-144	-144
Cu		-43	-43
Dy		-43	-43
Eu		-29	-29
Fe		3408	3408
K		-2154	-2154
La		-72	-72
Li		12313	12313
Mg		3777	3777
Mn		1857	1857
Mo		-72	-72
Na		0	0
Nd		281	281
Ni		276	276
P		4904	4904
Pb		-574	-574
S		-574	-574
Si		220204	220204
Sn		-574	-574
Sr		88	88
Te		-431	-431
Ti		495	495
V		-72	-72
Y		-22	-22
Zn		1539	1539
Zr			0

Sample Wt

0.3482

DF

2500

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

Not enough sample to run duplicate analyses

HOMOGENEITY/RESUSPENSION **ICP ANALYSES**

RWCT - 8.5.12

Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	0.005		194	194
Al	0.03		7289	7289
B	0.01		22856	22856
Ba	0.003		142	142
Be	0.003		-22	-22
Bi	0.06		-436	-436
Ca	0.01		6246	6246
Cd	0.006		7624	7624
Ce	0.04		-291	-291
Co	0.01		-73	-73
Cr	0.02		-145	-145
Cu	0.006		-44	-44
Dy	0.006		-44	-44
Eu	0.004		-29	-29
Fe	0.005		3381	3381
K	0.3		-2180	-2180
La	0.01		-73	-73
Li	0.005		12842	12842
Mg	0.06		4000	4000
Mn	0.003		1792	1792
Mo	0.01		-73	-73
Na	0.05		0	0
Nd	0.02		281	281
Ni	0.02		291	291
P	0.08		3946	3946
Pb	0.08		-581	-581
S	0.08		-581	-581
Si	0.01		230523	230523
Sn	0.08		-581	-581
Sr	0.003		85	85
Te	0.06		-436	-436
Ti	0.003		516	516
V	0.01		-73	-73
Y	0.003		-22	-22
Zn	0.01		1454	1454
Zr	0.01		0	0

Sample Wt

0.344

DF

2500

RWCT - 8.5.13

Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag		208	208
Al		7464	7464
B		21380	21380
Ba		121	121
Be		-21	-21
Bi		-421	-421
Ca		5786	5786
Cd		8291	8291
Ce		-281	-281
Co		-70	-70
Cr		-140	-140
Cu		-42	-42
Dy		-42	-42
Eu		-28	-28
Fe		3519	3519
K		-2104	-2104
La		-70	-70
Li		11918	11918
Mg		3796	3796
Mn		1964	1964
Mo		-70	-70
Na		0	0
Nd		293	293
Ni		271	271
P		4176	4176
Pb		-561	-561
S		-561	-561
Si		224467	224467
Sn		-561	-561
Sr		83	83
Te		-421	-421
Ti		513	513
V		-70	-70
Y		-21	-21
Zn		1470	1470
Zr		0	0

Sample Wt

0.3564

DF

2500

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

Not enough sample to run duplicate analyses

HOMOGENEITY/RESUSPENSION **ICP ANALYSES**

RWCT - 8.5.14

Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	0.005		189	189
Al	0.03		7269	7269
B	0.01		22331	22331
Ba	0.003		109	109
Be	0.003		-21	-21
Bi	0.06		-426	-426
Ca	0.01		6080	6080
Cd	0.006		7922	7922
Ce	0.04		-284	-284
Co	0.01		-71	-71
Cr	0.02		-142	-142
Cu	0.006		-43	-43
Dy	0.006		-43	-43
Eu	0.004		-28	-28
Fe	0.005		3382	3382
K	0.3		-2129	-2129
La	0.01		-71	-71
Li	0.005		12521	12521
Mg	0.06		3900	3900
Mn	0.003		1831	1831
Mo	0.01		-71	-71
Na	0.05		0	0
Nd	0.02		265	265
Ni	0.02		251	251
P	0.08		4297	4297
Pb	0.08		-568	-568
S	0.08		-568	-568
Si	0.01		228492	228492
Sn	0.08		-568	-568
Sr	0.003		87	87
Te	0.06		-426	-426
Ti	0.003		510	510
V	0.01		-71	-71
Y	0.003		-21	-21
Zn	0.01		1505	1505
Zr	0.01		0	0

Sample Wt
DF

0.3522
2500

RWCT - 8.5.15

Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag		199	199
Al		7491	7491
B		22249	22249
Ba		160	160
Be		-20	-20
Bi		-406	-406
Ca		6028	6028
Cd		7876	7876
Ce		-270	-270
Co		-68	-68
Cr		-135	-135
Cu		-41	-41
Dy		-41	-41
Eu		-27	-27
Fe		3464	3464
K		-2028	-2028
La		-68	-68
Li		12574	12574
Mg		3888	3888
Mn		1853	1853
Mo		-68	-68
Na		0	0
Nd		226	226
Ni		267	267
P		3978	3978
Pb		-541	-541
S		-541	-541
Si		229178	229178
Sn		-541	-541
Sr		86	86
Te		-406	-406
Ti		521	521
V		-68	-68
Y		-20	-20
Zn		1429	1429
Zr		0	0

Sample Wt
DF

0.3698
2500

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

Not enough sample to run duplicate analyses

**CHARACTERIZATION
(CONTINUED)
ICP ANALYSIS**

RWCT - 2.4.3			
Element	Conc.	Conc.	Average Concentration
	(KOH Fusion) (ppm)	(Na2O2 Fusion) (ppm)	
Ag	5	1	3
Al	153	143	148
B	453	453	453
Ba	4	2	3
Be	-1	-1	-1
Bi	-12	-12	-12
Ca	100	132	116
Cd	166	157	162
Ce	-8	18	5
Co	-2	-2	-2
Cr	-4	-4	-4
Cu	2	-1	1
Dy	-1	-1	-1
Eu	-1	-1	-1
Fe	96	93	95
K		-59	-59
La	-2	-2	-2
Li	245	248	247
Mg	81	80	81
Mn	39	37	38
Mo	-2	-2	-2
Na	2049		2049
Nd	8	13	-15
Ni		8	8
P	109	104	107
Pb	-16	-16	-16
S	-16	-16	-16
Si	4606	2825	3716
Sn	-16	-16	-16
Sr	1	2	2
Te	-12	-12	-12
Ti	12	11	12
V	-2	-2	-2
Y	-1	-1	-1
Zn	42	41	42
Zr	24		24
Sample Wt	10.2069	10.1953	
DF	2000	2000	

SETTLING **ICP ANALYSES**

RWCT - 8.2.1

Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	0.005		242	242
Al	0.03		6765	6765
B	0.01		18179	18179
Ba	0.003		91	91
Be	0.003		-7	-7
Bi	0.06		-141	-141
Ca	0.01		4430	4430
Cd	0.006		7578	7578
Ce	0.04		-94	-94
Co	0.01		-23	-23
Cr	0.02		62	62
Cu	0.006		22	22
Dy	0.006		-14	-14
Eu	0.004		-9	-9
Fe	0.005		3194	3194
K	0.3		-703	-703
La	0.01		34	34
Li	0.005		10268	10268
Mg	0.06		3302	3302
Mn	0.003		1803	1803
Mo	0.01		28	28
Na	0.05			0
Nd	0.02		242	242
Ni	0.02		215	215
P	0.08		3749	3749
Pb	0.08		-187	-187
S	0.08		326	326
Si	0.01		164434	164434
Sn	0.08		-187	-187
Sr	0.003		53	53
Te	0.06		-141	-141
Ti	0.003		429	429
V	0.01		-23	-23
Y	0.003		-7	-7
Zn	0.01		1074	1074
Zr	0.01			0

Sample Wt 1.0676
DF 2500

RWCT - 8.2.2

Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag		114	114
Al		5776	5776
B		14720	14720
Ba		75	75
Be		-7	-7
Bi		-150	-150
Ca		5477	5477
Cd		6471	6471
Ce		-100	-100
Co		-25	-25
Cr		-50	-50
Cu		27	27
Dy		-15	-15
Eu		-10	-10
Fe		2849	2849
K		-748	-748
La		30	30
Li		8283	8283
Mg		2819	2819
Mn		1545	1545
Mo		-25	-25
Na			0
Nd		214	214
Ni		187	187
P		3368	3368
Pb		-199	-199
S		502	502
Si		128677	128677
Sn		-199	-199
Sr		48	48
Te		-150	-150
Ti		371	371
V		-25	-25
Y		-7	-7
Zn		1194	1194
Zr			0

Sample Wt 1.0029
DF 2500

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

Note: Not enough sample to run duplicate analyses

SIMULANT MAKEUP

PVT-D-K1016

ICP ANALYSIS

RWCT - 10.2.1					RWCT - 10.2.2			
Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)	Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	0.005	5	5	5	Ag	5	4	4
Al	0.03	415	430	422	Al	476	465	470
B	0.01	1377	1327	1352	B	1703	1779	1741
Ba	0.003	5	6	5	Ba	6	6	6
Be	0.003	-1	-1	-1	Be	-1	-1	-1
Bi	0.06	-29	-29	-29	Bi	-29	-29	-29
Ca	0.01	287	356	287	Ca	355	432	355
Cd	0.006	407	434	420	Cd	454	423	439
Ce	0.04	-19	-19	-19	Ce	-19	-19	-8
Co	0.01	-5	-5	-5	Co	-5	-5	-5
Cr	0.02	-10	-10	-10	Cr	-10	-10	-10
Cu	0.006	-3	-3	-3	Cu	-3	-3	-3
Dy	0.006	-3	-3	-3	Dy	-3	-3	-3
Eu	0.004	-2	-2	-2	Eu	-2	-2	-2
Fe	0.005	185	198	191	Fe	209	200	205
K	0.3		-144	-144	K		-143	-143
La	0.01	-5	-5	-5	La	-5	-5	-5
Li	0.005	755	780	767	Li	936	1042	989
Mg	0.06	233	220	226	Mg	289	298	293
Mn	0.003	102	108	105	Mn	111	100	105
Mo	0.01	-5	-5	-5	Mo	-5	-5	-5
Na	0.05	5422		5422	Na	6100		6100
Nd	0.02	-10	-10	-10	Nd	-10	-10	-10
Ni	0.02		16	16	Ni		16	16
P	0.08	228	240	234	P	249	214	231
Pb	0.08	-38	-38	-38	Pb	-38	-38	-38
S	0.08	-38	-38	-38	S	-38	-38	-38
Si	0.01	13406	13633	13519	Si	17236	13074	15155
Sn	0.08	-38	-38	-38	Sn	-38	-38	-38
Sr	0.003	2	9	5	Sr	3	5	0
Te	0.06	-29	-29	-29	Te	-29	-29	-29
Ti	0.003	32	31	31	Ti	47	37	42
V	0.01	-5	-5	-5	V	-5	-5	-5
Y	0.003	-1	-1	-1	Y	-1	-1	-1
Zn	0.01	204	195	204	Zn	199	210	199
Zr	0.01	60		60	Zr	37		37
Sample Wt		5.2165	5.1985		Sample Wt		5.2307	5.2502
DF		2500	2500		DF		2500	2500

IC ANALYSIS

RWCT - 10.2.1			RWCT - 10.2.2	
	Estimated Det. Limit (ppm)	Conc. (ppm)	Conc. (ppm)	
Fluoride	0.5	-107	-140	
Chloride	0.5	-107	-140	
Nitrite	1.0	-215	-280	
Nitrate	1.0	11575	11731	
Phosphate	1.0	578	657	
Sulfate	1.0	-216	-280	
oxalate	1.0	719	682	
ormate	1.0	-108	-140	
Water Leach DF		21.56	28.06	
DF		10.00	10.00	

Note: All values have been corrected for all laboratory weights (Wt) dilution factors (DF)

SIMULANT CHARACTERIZATION

ICP ANALYSIS

RWCT - 10.3.1					RWCT - 10.3.2				
Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)	Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)	
Ag	0.005	4	10	7	Ag	7	6	7	
Al	0.03	242	459	351	Al	501	390	446	
B	0.01	550	1221	886	B	1918	1536	1727	
Ba	0.003	3	7	5	Ba	7	6	7	
Be	0.003	-2	-2	-2	Be	-1	-1	-1	
Bi	0.06	-43	-43	-43	Bi	-28	-29	-29	
Ca	0.01	133	365	133	Ca	383	375	383	
Cd	0.006	262	451	357	Cd	460	355	408	
Co	0.04	-29	-29	-8	Co	-19	-19	-8	
Co	0.01	-7	-7	-7	Co	-5	-5	-5	
Cr	0.02	-14	-14	-14	Cr	-9	-10	-10	
Cu	0.006	-4	-4	-4	Cu	-3	-3	-3	
Dy	0.006	-4	-4	-4	Dy	-3	-3	-3	
Eu	0.004	-3	-3	-3	Eu	-2	-2	-2	
Fe	0.005	114	205	160	Fe	212	175	194	
K	0.3		-216	-216	K		-143	-143	
La	0.01	-7	-7	-7	La	-5	-5	-5	
Li	0.005	290	658	474	Li	1040	839	940	
Mg	0.06	104	225	165	Mg	335	265	300	
Mn	0.003	69	109	89	Mn	108	83	-96	
Mo	0.01	-7	-7	-7	Mo	-5	-5	-5	
Na	0.05	4234		4234	Na	8149		8149	
Nd	0.02	-14	37	12	Nd	14	25	-12	
Ni	0.02		19	19	Ni		13	13	
P	0.08	191	319	255	P	265	231	248	
Pb	0.08	-58	-58	-58	Pb	-38	-38	-38	
S	0.08	-58	-58	-58	S	-38	-38	-38	
Si	0.01	5645	12566	9106	Si	18908	14568	16738	
Sn	0.08	-58	-58	-58	Sn	-38	-38	-38	
Sr	0.003	-2	7	3	Sr	3	4	4	
Te	0.06	-43	-43	-43	Te	-28	-29	-29	
Ti	0.003	16	29	23	Ti	39	31	35	
V	0.01	-7	-7	-7	V	-5	-5	-5	
Y	0.003	-2	-2	-2	Y	-1	-1	-1	
Zn	0.01	295	295	295	Zn	198	222	210	
Zr	0.01	17		17	Zr	31		31	
Sample Wt		3.4628	3.4744		Sample Wt	5.3005	5.2603		
DF		2500	2500		DF	2500	2500		

IC ANALYSIS

RWCT - 10.3.1			RWCT - 10.3.2		RWCT - 10.3.3	
	Estimated Det. Limit (ppm)	Conc. (ppm)	Conc. (ppm)	Conc. (ppm)	Conc. (ppm)	
Fluoride	0.5	-83	-74	-78		
Chloride	0.5	-83	-74	-78		
Nitrite	1.0	-166	-147	-157		
Nitrate	1.0	11579	11522	11442		
Phosphate	1.0	621	620	585		
Sulfate	1.0	-166	-147	-157		
Oxalate	1.0	734	699	684		
Formate	1.0	191	190	209		
each DF		33.29	29.42	31.37		
Sample DF		5	5	5		

Note: All values have been corrected for all-laboratory weights (Wt) and dilution factors (DF)

**SIMULANT CHARACTERIZATION
(CONTINUED)
ICP ANALYSIS**

RWCT - 10.3.3			
Element	Conc.	Conc.	Average
	(KOH Fusion)	(Na2O2 Fusion)	Concentration
	(ppm)	(ppm)	(ppm)
Ag	7	7	7
Al	446	478	462
B	1466	1611	1539
Ba	6	7	7
Be	-2	-2	-2
Bi	-43	-44	-44
Ca	308	446	377
Cd	409	450	430
Ce	-28	-29	-29
Co	-7	-7	-7
Cr	-14	-15	-15
Cu	-4	-4	-4
Dy	-4	-4	-4
Eu	-3	-3	-3
Fe	181	191	186
K		-221	-221
La	-7	-7	-7
Li	789	889	839
Mg	268	282	275
Mn	99	111	105
Mo	-7	-7	-7
Na	6897		6897
Nd	16	32	-15
Ni		-15	-15
P	248	291	270
Pb	-57	-59	-58
S	-57	-59	-58
Si	14783	16065	15424
Sn	-57	-59	-58
Sr	3	7	5
Te	-43	-44	-44
Ti	32	35	34
V	-7	-7	-7
Y	-2	-2	-2
Zn	308	326	317
Zr	30		30
Sample Wt	3.5215	3.3975	
DF	2500	2500	

**SIMULANT CHARACTERIZATION
(CONTINUED)
ICP ANALYSIS**

RWCT - 10.3.2				RWCT -10.3.3			
Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)	Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	8	8	8	Ag	24	7	16
Al	401	459	430	Al	266	373	320
B	1325	1394	1360	B	533	1272	903
Ba	5	7	6	Ba	8	6	7
Be	-2	-2	-2	Be	-1	-1	-1
Bi	-44	-44	-44	Bi	60	-29	16
Ca	281	419	350	Ca	144	322	233
Cd	364	422	393	Cd	148	354	251
Ce	-30	-29	-30	Ce	153	-19	67
Co	-7	-7	-7	Co	16	-5	6
Cr	-15	-15	-15	Cr	20	-10	5
Cu	-4	-4	-4	Cu	16	-3	7
Dy	-4	-4	-4	Dy	19	-3	8
Eu	-3	-3	-3	Eu	5	-2	1
Fe	181	180	181	Fe	83	166	125
K		-219	-219	K		-143	-143
La	-7	-7	-7	La	37	-5	16
Li	711	771	741	Li	293	693	493
Mg	248	260	254	Mg	244	224	234
Mn	89	107	98	Mn	39	87	63
Mo	-7	-7	-7	Mo	11	-5	3
Na	6275		6275	Na	2127		2127
Nd	18	42	30	Nd	190	24	107
Ni		15	15	Ni		14	14
P	224	280	252	P	110	245	178
Pb	-59	-58	-59	Pb	121	-38	42
S	-59	-58	-59	S	-38	-38	-38
Si	13459	14277	13868	Si	4729	12594	8662
Sn	-59	-58	-59	Sn	-38	-38	-38
Sr	3	7	5	Sr	4	4	4
Te	-44	-44	-44	Te	77	-29	24
Ti	29	32	31	Ti	20	27	24
V	-7	-7	-7	V	17	-5	6
Y	-2	-2	-2	Y	5	-1	2
Zn	337	293	315	Zn	73	205	139
Zr	28		28	Zr	32		32
Sample Wt	3.3785	3.4304		Sample Wt	5.2648	5.239	
DF	2500	2500		DF	2500	2500	

EVAPORATOR/CONDENSER

ICP ANALYSIS

Element	Estimated Det. Limit (ppm)	Conc. RWCT 13.1.1 (ppm)	Conc. RWCT 13.1.2 (ppm)	Conc. RWCT 13.1.3 (ppm)	Conc. RWCT 13.3.4 (ppm)	Conc. RWCT 13.1.5 (ppm)	Conc. RWCT 13.1.6 (ppm)	Conc. RWCT 13.1.7 (ppm)	Conc. RWCT 13.1.8 (ppm)	Conc. RWCT 13.1.9 (ppm)
Ag	0.005	15.7	14.5	0.3	0.1	0.1	0.1	0.1	-0.1	0.1
Al	0.03	2.8	3.1	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
B	0.01	3.6	3.5	3.3	3.1	3.1	3.1	3.0	3.1	3.1
Ba	0.003	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Be	0.003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bi	0.06	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
Ca	0.01	220.5	217.4	13.5	1.9	1.2	1.2	1.2	0.3	0.4
Cd	0.006	19.2	18.4	1.3	0.4	0.3	0.3	0.3	0.2	0.2
Ce	0.04	0.6	0.7	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Co	0.01	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Cr	0.02	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
Cu	0.006	0.1	0.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Dy	0.006	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Eu	0.004	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe	0.005	3.2	6.1	0.1	-0.1	0.1	0.1	0.1	0.1	-0.1
K	0.3	7.7	5.5	7.5	5.1	5.2	5.2	3.0	3.3	-3.0
La	0.01	0.2	0.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Li	0.005	0.5	0.3	0.2	0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Mg	0.06	0.6	0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
Mn	0.003	6.2	6.9	0.2	0.1	0.0	0.0	0.0	0.0	0.0
Mo	0.01	-0.1	0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Na	0.05	6.2	4.4	2.7	1.3	0.6	0.5	-0.5	-0.5	0.5
Nd	0.02	1.5	2.3	0.3	0.2	-0.2	0.2	1.9	-0.2	-0.2
Ni	0.02	0.5	0.8	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
P	0.08	1.7	1.6	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8
Pb	0.08	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8
S	0.08	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8
Si	0.01	7.7	9.3	2.8	2.1	1.5	1.4	-0.1	1.2	1.5
Sn	0.08	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	1.1	-0.8	-0.8
Sr	0.003	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Te	0.06	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
Ti	0.003	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0
V	0.01	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Y	0.003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zn	0.01	0.6	0.9	4.4	4.2	4.5	4.3	4.3	3.8	4.0
Zr	0.01	0.6	1.7	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
DF		10	10	10	10	10	10	10	10	10

IC ANALYSIS

	Estimated Det. Limit (ppm)	RWCT - 13.1.1 Conc. (ppm)	RWCT - 13.1.2 Conc. (ppm)	RWCT - 13.1.3 Conc. (ppm)	RWCT - 13.1.4 Conc. (ppm)	RWCT - 13.1.5 Conc. (ppm)	RWCT - 13.1.6 Conc. (ppm)	RWCT - 13.1.7 Conc. (ppm)	RWCT - 13.1.8 Conc. (ppm)	RWCT - 13.1.9 Conc. (ppm)
Fluoride	0.5	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50
Chloride	0.5	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50
Nitrite	1.0	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
Nitrate	1.0	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
Phosphate	1.0	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
Sulfate	1.0	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
Oxalate	1.0	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
Formate	1.0	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50

W---- Leach DF
DF

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

SIMULANT CHARACTERIZATION

ICP ANALYSIS

RWCT - 15.2.17

Element	Estimated Det. Limit (ppm)	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	0.005	11	11	-1
Al	0.03	789	610	700
B	0.01	3074	2024	2549
Ba	0.003	10	9	10
Be	0.003	-2	-2	-2
Bi	0.06	-46	-47	-47
Ca	0.01	624	554	624
Cd	0.006	653	594	624
Ce	0.04	-31	-32	-8
Co	0.01	-8	-8	-8
Cr	0.02	-15	-16	-16
Cu	0.006	5	-5	0
Dy	0.006	-5	-5	-5
Eu	0.004	-3	-3	-3
Fe	0.005	330	280	305
K	0.3		-237	-237
La	0.01	-8	-8	-8
Li	0.005	1659	1108	1384
Mg	0.06	541	355	448
Mn	0.003	146	143	145
Mo	0.01	-8	-8	-8
Na	0.05	11823		11823
Nd	0.02	25	42	34
Ni	0.02		22	22
P	0.08	378	408	393
Pb	0.08	-62	-63	-63
S	0.08	-62	-63	-63
Si	0.01	26803	20262	23533
Sn	0.08	-62	-63	-63
Sr	0.003	4	9	7
Te	0.06	-46	-47	-47
Ti	0.003	62	44	53
V	0.01	-8	-8	-8
Y	0.003	-2	-2	-2
Zn	0.01	316	348	332
Zr	0.01	50		50

Sample Wt 3.2329
DF 2500

3.167
2500

RWCT - 15.2.18

Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	8	10	9
Al	426	644	535
B	1391	2458	1925
Ba	5	9	7
Be	-2	-2	-2
Bi	-47	-48	-48
Ca	295	612	295
Cd	412	581	497
Ce	-31	-32	-8
Co	-8	-8	-8
Cr	-16	-16	-16
Cu	-5	-5	-5
Dy	-5	-5	-5
Eu	-3	-3	-3
Fe	349	282	316
K		-240	-240
La	-8	-8	-8
Li	746	1348	1047
Mg	253	423	338
Mn	98	133	116
Mo	-8	-8	-8
Na	6915		6915
Nd	-16	33	-12
Ni		23	23
P	271	391	331
Pb	-63	-64	-64
S	-63	-64	-64
Si	13388	24441	18915
Sn	-63	-64	-64
Sr	2	8	5
Te	-47	-48	-48
Ti	33	51	42
V	-8	-8	-8
Y	-2	-2	-2
Zn	441	338	390
Zr	25		25

Sample Wt 3.1874
DF 2500

3.1274
2500

IC ANALYSIS

RWCT - 15.2.74

RWCT - 15.2.8

RWCT - 15.2.9

	Estimated Det. Limit (ppm)	Conc. (ppm)	Conc. (ppm)	Conc. (ppm)	
Fluoride	0.5	-100	-113	-113	
Chloride	0.5	-100	-113	-113	
Nitrite	1.0	-200	-226	-226	
Nitrate	1.0	15233	14899	14945	
Phosphate	1.0	1061	718	707	
Sulfate	1.0	-200	-226	-226	
Oxalate	1.0	1049	970	1063	
Formate	1.0	452	497	471	
Leach DF	19.99	Water Leach DF	22.61	Water Leach DF	22.55
Sample DF	10	Sample DF	10	Sample DF	10

Note: All values have been corrected for all laboratory weights (Wt) and dilution factors (DF)

**SIMULANT CHARACTERIZATION
(CONTINUED)
ICP ANALYSIS**

RWCT -15.2.18				RWCT - 15.2.19			
Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)	Element	Conc. (KOH Fusion) (ppm)	Conc. (Na2O2 Fusion) (ppm)	Average Concentration (ppm)
Ag	11	13	12	Ag	9	11	10
Al	570	561	566	Al	698	551	625
B	1590	1677	1634	B	2659	1633	2146
Ba	7	7	7	Ba	9	8	9
Be	-2	-2	-2	Be	-2	-2	-2
Bi	-43	-43	-43	Bi	-47	-48	-48
Ca	345	471	408	Ca	541	458	500
Cd	571	540	556	Cd	638	569	604
Ce	-29	-29	-29	Ce	-31	-32	-32
Co	-7	-7	-7	Co	-8	-8	-8
Cr	-14	-14	-14	Cr	-16	-16	-16
Cu	-4	-4	-4	Cu	-5	-5	-5
Dy	-4	-4	-4	Dy	-5	-5	-5
Eu	-3	-3	-3	Eu	-3	-3	-3
Fe	265	235	250	Fe	312	257	285
K		-214	-214	K		-238	-238
La	-7	-7	-7	La	-8	-8	-8
Li	856	937	897	Li	1435	936	1186
Mg	296	295	296	Mg	467	292	380
Mn	145	132	139	Mn	146	141	144
Mo	-7	-7	-7	Mo	-8	-8	-8
Na	9412		9412	Na	11159		11159
Nd	16	26	21	Nd	21	36	29
Ni		15	15	Ni		22	22
P	350	333	342	P	370	407	389
Pb	-57	-57	-57	Pb	-62	-63	-63
S	-57	-57	-57	S	-62	-63	-63
Si	16585	17348	16967	Si	25835	16297	21066
Sn	-57	-57	-57	Sn	-62	-63	-63
Sr	3	8	6	Sr	4	8	6
Te	-43	-43	-43	Te	-47	-48	-48
Ti	37	38	38	Ti	55	38	47
V	-7	-7	-7	V	-8	-8	-8
Y	-2	-2	-2	Y	-2	-2	-2
Zn	298	317	308	Zn	337	318	328
Zr	40		40	Zr	47		47
Sample Wt	3.488	3.5035		Sample Wt	3.2142	3.1537	
DF	2500	2500		DF	2500	2500	

APPENDIX D

STL Straight Sections

1/2" Straight Section

Avg. Temp. = 38 C

*.

1" Straight Section

Avg. Temp. = 18.1 C

STL Testing: Acceptance Testing with Water

1 1/2" Straight Section

Avg. Temp. = 34.1 C

2" Straight Section

Avg. Temp. = 29.2 C

STL Testing: Acceptance Testing with Water

STL Elbow Sections

1/2" Elbow Section (Remote Seal s)

1/2" Elbow Only (Remote Seal)

Avg. Temp. = 38.1 C, Le/D = 9.5

STL Testing: Acceptance Testing with Water

1" Elbow Section (Remote Seal)

Avg. Temp. = 19.1 C

1" Elbow Only (Remote Seal)

Avg. Temp. = 19.1 C, LeD = 14

STL Testing: Acceptance Testing with Water

1 1/2" Elbow Section (Remote Seal)

Avg. Temp. = 34.1 C

1 1/2" Elbow Only (Remote Seal)

Avg. Temp. = 34.1 C, Le/D = 14

STL Testing: Acceptance Testing with Water

2" El bow Section (Remote Seal)

Avg. Temp. = 29.2 C

2" El bow Only (Remote Seal)

Avg. Temp. = 29.2 C, L/D = 14

STL Testing: Acceptance Testing with Water

STL Testing: Acceptance Testing with Water

Elbow Sections (Water Taps)

1/2" Elbow Section (Water Tap)

Avg. Temp. = 38.1 C, Le/D = 9.5

1/2" Elbow Only (Water Tap)

Avg. Temp. = 38.06 C, Le/D = 9.5

STL Testing: Acceptance Testing with Water

STL Testing: Acceptance Testing with Water

1 1/2" El bow Section (Water Tap)

Avg. Temp. = 34.1 C, Le/D = 14

1 1/2" El bow Only (Water Tap)

Avg. Temp. = 34.1 C, Le/D = 14

STL Testing: Acceptance Testing with Water

2" El bow Section (Water Tap)

Avg. Temp. = 29.2 C, Le/D = 14

2" El bow Only (Water Tap)

Avg. Temp. = 29.2 C, Le/D = 14

STL Testing: Comparison of RWCT Simulant Pressure Drop with Water

3" Straight Section Pressure Drop Comparison

2" Straight Section Pressure Drop Comparison

STL Testing: Comparison of RWCT Simulant Pressure Drop with Water

1 1/2" Straight Section Pressure Drop Comparison

1" Straight Section Pressure Drop Comparison

STL Testing: Comparison of RWCT Simulant Pressure Drop with Water

1/2" Straight Section Pressure Drop Comparison

3" Elbow Section Pressure Drop Comparison (Remote Seal)

STL Testing: Comparison of RWCT Simulant Pressure Drop with Water

.2" Elbow Section (Remote Seal)

2" Elbow Section Pressure Drop Comparison (Remote Seal)

1 1/2" Elbow Section (Remote Seal)

1 1/2" Elbow Section Pressure Drop Comparison (Remote Seal)

STL Testing: Comparison of RWCT Simulant Pressure Drop with Water

1" Elbow Section (Remote Seal)

1" Elbow Section Pressure Drop Comparison (Remote Seal)

1/2" Elbow Section (Remote Seal)

1/2" Elbow Section Pressure Drop Comparison (Remote Seal)

STL Testing: Comparison of RWCT Simulant Pressure Drop with Water

2" Elbow Section (Water Taps)

2" Elbow Section Pressure Drop Comparison (Water Taps)

1 1/2" Elbow Section (Water Taps)

1 1/2" Elbow Section Pressure Drop Comparison (Water Taps)

STL Testing: Comparison of RWCT Simulant Pressure Drop with Water

1" Elbow Section (Water Taps)

1" Elbow Section Pressure Drop Comparison (Water Taps)

1/2" Elbow Section (Water Taps)

1/2" Elbow Section Pressure Drop Comparison (Water Taps)

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CALCULATION WORKSHEET

Calc. No. _____

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Sample Calculation for dP of water flowing through pipe w/
roughness $(\epsilon) = 0.00015$ ft and $\epsilon = .00015$ ft.

1/2" STRAIGHT SECTION:

$$D = 0.622 \text{ in} = .0518 \text{ ft}$$

$$L_{st} = 25 \text{ ft}$$

$$L_{eb} = 11.75 \text{ ft}$$

$$Q_{wg} = 9.09 \text{ gpm}$$

$$dP_{st, meas} = 171.33 \text{ " H}_2\text{O}$$

$$dP_{st, meas} / 25 \text{ ft} = 6.85 \text{ " H}_2\text{O} / \text{ft}$$

$$dP_{eb, meas} = 91.88 \text{ " H}_2\text{O} / \text{ft}$$

$$Q \quad T = 38.9^\circ\text{C} = 312.05 \text{ K}$$

$$\rho_w = 61.97 \text{ lb/ft}^3 \quad (\text{Perry's, Ch. 13})$$

$$\text{Velocity} = 9.09 \frac{\text{gal}}{\text{min}} \times \frac{35.313 \text{ ft}^3}{264.17 \text{ gal}} \times \frac{\text{min}}{60 \text{ sec}} \times \frac{1}{\pi \left(\frac{0.622 \text{ in} \cdot \frac{1 \text{ ft}}{12 \text{ in}} \right)^2} = 9.6 \text{ ft/s}$$

$$\text{Viscosity: } \ln \eta = -2.47E1 + \frac{4.21E3}{312.05 \text{ K}} + (4.53E-2) 312.05 \text{ K} - (3.38E-5) (312.05 \text{ K})^2$$

$$\eta \text{ (cp)} = e^{-0.38266} = 0.682 \text{ cp}$$

from Reid, Prausnitz, Poling;
Properties of Gases & Liquids;
McGraw Hill; pg. 455.

$$Re \# : Re \# = \frac{50.6 Q \rho}{D \mu}$$

from Crane; Flow of Fluids Tech Paper #410;
(Eqn 3-3)

$$Re \# = \frac{(50.6)(9.09 \text{ gpm})(61.97 \text{ lb/ft}^3)}{(0.622 \text{ in})(0.682 \text{ cp})} \quad \begin{matrix} Q = \text{gpm}; \rho = \text{lb/cu. ft.} \\ d = \text{in. diameter}; \mu = \text{visc. (cp)} \end{matrix}$$

$$Re \# = 67,637$$

Calculation of f

Smooth pipe $\epsilon = .00015 \text{ ft}$ commercial
 $\epsilon = 0$ smooth

$$\text{Colebrook Eqn} = \frac{1}{f} = -4 \log \left(\frac{\epsilon}{3.7D} + \frac{1.256}{Re \sqrt{f}} \right)$$

$$f \left(\frac{\epsilon = .00015 \text{ ft}}{Re = 67,637} \right) = .006953 \text{ solved by iteration}$$

$$f (Re = 0, Re = 67,637) = .004887 \text{ solved by iteration}$$

Title Calculation of Expected Pressure Drop for Water Project RWCT / CIPT FCT

Prepared by: G.P. Alving / P.P. 11/13/90

Date 11/13

Reviewed by:

Date

Battelle Pacific Northwest Laboratories	CALCULATION WORKSHEET	Calc. No. _____ Page <u>2</u> of <u>4</u>
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Estimated Pressure Drop per Length ($\Delta P/L$) (from PERRY'S CHEM 5-24 eqn. 5-57)

$$\frac{\Delta P}{L} = \frac{2fv^2}{Dg_c} \times \rho = \frac{(lb/ft^2)}{ft}$$

$$\frac{\Delta P}{L} = \frac{2fv^2}{Dg_c} \times \rho \times \frac{ft^2}{144 in^2} \times \frac{27.7276 in H_2O}{lb/in^2} = in. H_2O/ft.$$

f = friction factor D = diameter = ft ρ = lb/ft^3
 v = $ft/sec.$ g_c = $32.2 ft/sec^2$

for Commercial Sch. 40 pipe: $\epsilon = .00015 ft.$

$$\frac{\Delta P}{L} (f(\epsilon = .00015 ft) = .006953) = \frac{2(.006953)(9.5)^2}{(.622/12)(32.2)} \times 61.97 \times \frac{1}{144} \times 27.7276 = 9.15 \frac{in. H_2O}{ft.}$$

for Smooth Pipes, $\epsilon = 0$

$$\frac{\Delta P}{L} (f(\epsilon = 0) = .004887) = \frac{2(.004887)(9.5)^2}{(.622/12)(32.2)} \times 61.97 \times \frac{1}{144} \times 27.7276 = 6.44 \frac{in. H_2O}{ft.}$$

Experimental $\Delta P/L = 171.32 in. H_2O/25 ft \approx 6.85 in. H_2O/ft.$

with expected for smooth & commercial roughness pipe.

Title <u>Calculation of Expected Pressure Drop for Water</u>	Project <u>RWCT/SIPT/FST</u>
Prepared by: <u>GP Abrigo, LP Abrigo</u>	Date <u>11/3</u> Reviewed by: _____ Date _____

Title Calculation of Expected Pressure Drop for Water

Project RUCI/STL/FST

Prepared by: GP Abingo

Date: 11/3

Reviewed by:

Date:

Calculation of Pressure Drop in Long Radius Elbows:

Pipe Diam. _____

Long Radius Elbows _____

Bend Radius _____

Lo/D _____

Lo/D	0.622	1.049	1.61	2.067	3.068
9.5	1.5	1.5	2.25	1.47	4.5
14	1.43	1.5	2.25	1.45	3
14	1.43	1.5	2.25	1.45	3
14	1.43	1.5	2.25	1.45	3
14	1.43	1.5	2.25	1.45	3

* Perry's GLE HB 6-57, Table 6-15
 ~ Perry's GLE HB 6-57, Table 6-15
 ~ Perry's GLE HB 6-57, Table 6-15

Lo = equiv. length of straight pipe.
 D = diam. of pipe.
 for 1/2" elbow only ΔP:

Lo = 9.5 × (622/12) ft = 492 ft

for ε = 0.00015
 ΔP_{el} = 9.15 × (H₂O) × 492 ft = 4.5 × H₂O

for ε = 0
 ΔP_{el} = 6.85 × (H₂O) × 492 ft = 3.37 × H₂O

To get experimental elbow only ΔP as measured by Remote Seal

ΔP_{el} = ΔP_{el, sec} - L_{el} (ΔP/L)_{straight, exp.}

L_{el} = length of straight section pipe in elbow section (from ΔP transmitter to elbow welds).

(ΔP/L)_{straight, exp.} = measured experimental straight section ΔP/L.

ΔP_{el} = 91.88 H₂O - 11.75 ft (6.85 H₂O) = 11.4 × H₂O

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CALCULATION WORKSHEET

Calc. No. _____

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To convert elbow only pressure drop to L_e/D :

$$L_e/D = \Delta P_{elb} \times \left(\frac{L}{\Delta P} \right)_{\text{straight, db}} \times \frac{1}{D}$$

$$L_e/D = 11.4 \text{ "H}_2\text{O} \times \left(\frac{\text{ft}}{6.85 \text{ "H}_2\text{O}} \right) \times \left(\frac{1}{.622/12 \text{ ft}} \right) = 32$$

Remote seal $L_e/D = 32$ expected ~ 9.5 from Perry's Lit.

→ Radial test w/ water taps instead of remote seal units.

L_e/D with water taps ≈ 5 . Closer to Perry's.

 Title: Calculation of Expected Pressure Drop for Water

Project _____

Prepared by:

GP Abrigo EIP Abrigo

Date

11/3

Reviewed by:

Date

Pacific Northwest Laboratories

ENGINEERING WORKSHEET

Page 1 of 2

Prepared By: GP Abrigo

Date: 2/23/94

Project: RWCT STL

Title/Subject: Temp. Correction

Temperature correction of measured water DPs.

Because water tests were performed at different temperatures than RWCT simulant testing, the water tests were temperature corrected because water viscosity could change as much as 50% due to the temperature difference in the tests.

An example is shown for the temperature correction in a 1/2" pipe.

Assumptions: smooth pipe, $E = 0$ (roughness); (conservative correction) average temps. for both tests were used.

① avg. water temp: 38.06°C $\rightarrow \mu_{\text{water}}^{(38.06)} = 0.70615 \text{ cp}$ calculated water viscosity
 avg. RWCT temp: 49.9°C $\mu_{\text{water}}^{(49.9)} = 0.57052 \text{ cp}$ at temps. using eqn below

$$\ln \mu_{\text{water}} = -2.47 \text{E}1 + \frac{4.21 \text{E}3}{(T^\circ\text{K})} + (4.53 \text{E}-2)(T^\circ\text{K}) - (3.38 \text{E}-5)(T^\circ\text{K})^2$$

from Properties of Gases & Liquids of Reid, Prausnitz, and Poling pg. 455.

② Calculate Re #. from Crane eqn 3-3.

$$\text{Re \#} = \frac{50.6 Q \rho}{d \mu}$$

$Q = \text{gpm} = \text{at each data point}$
 $\rho = \text{density} = 62 \text{ lb/cu. ft.}$
 $d = 0.622"$
 $\mu(38.06); \mu(49.9^\circ\text{C})$

$$\text{Re \#}(38.06) = \frac{50.6 \cdot 9.4 \text{ gpm} \cdot 62 \text{ lb/cu. ft.}}{0.622" \cdot 0.70615 \text{ cp}} = 67,107.91$$

$$\text{Re \#}(49.9^\circ\text{C}) = \frac{50.6 \cdot 9.4 \cdot 62}{0.622 \cdot 0.57052} = 83061.41$$

Calculate f using shortcut formula (non-iterative)
 by Shacham from Chemical Engineering Dec 14, 1981 pgs. 91-93
 by Zarko Glinjić.
 Assume $E=0$ in calculations (smooth pipe)

$$f = \frac{1}{2} \log \left(\frac{2/d}{3.7} - \frac{5.02}{\text{Re \#}} \log \left(\frac{E/d}{3.7} + \frac{14.5}{\text{Re \#}} \right) \right)^{-2}$$

Pacific Northwest Laboratories

ENGINEERING WORKSHEET

Page 2 of 2Prepared By: G.P. AbrigoDate: 2/23/94Project: RWCT STLTitle/Subject: Temp. Correction.

$$\text{Since } \Delta P/L = \frac{2fv^2\rho}{Dg_c}$$

$$\begin{aligned} v &= \text{ft/sec} \\ \rho &= \text{lb/ft}^3 \\ D &= \text{ft} \\ g_c &= 32.2 \end{aligned}$$

The only thing that changes substantially with temperature is μ and therefore f . All other values essentially are the same. (w/ e-o)

The temperature correction is:

$$C = \frac{f(49.9^\circ\text{C}) - f(38.06^\circ\text{C})}{f(38.06^\circ\text{C})} \quad \text{or} \quad \frac{f(\text{RWCT Temp}) - f(\text{water})}{f(\text{water temp})}$$

The water pressure measured in the straight and elbow sections is multiplied by:

$$\Delta P_{\text{corrected}} = \Delta P_{\text{measured}} (1 + C)$$

$\text{H}_2\text{O} \qquad \qquad \text{H}_2\text{O}$

In this case

$$C = \frac{0.001677 - 0.001896}{0.001896} = -0.04473$$

In the calculation spreadsheet, this temp correction is done for each data point for its particular velocity.

This is because the Temp. correction, C , is a function of velocity.

Attached is an excel worksheet with the a/g. temps for the water & RWCT simulant in the various STL tests. It also shows the ~~temp~~ dependence of the correction factor.
 velocity

Calculation of Errors associated w/ L_e/D values for 90° Long Radius Elbows

$$\frac{L_e}{D} = \left(dP_{es} \cdot \frac{L_{sr}}{dP_{sr}} - L_{sr,es} \right) \frac{1}{D}$$

L_e = equiv. lengths of straight section dP , ft.

D = diameter, ft.

dP_{es} = Elbow Section dP , in. H_2O w/ $G_{dP_{es}}$

L_{sr} = Length of straight section, ft.

dP_{sr} = Straight Section dP , in. H_2O w/ $G_{dP_{sr}}$

$L_{sr,es}$ = Length of straight pipe in elbow section (not including elbow), ft.

Find $G_{L_e/D}$

$$G_{L_e/D} = \sqrt{\left\{ \left(\frac{1}{dP_{es}} \left(\frac{L_e}{D} \right) \right) G_{dP_{es}} \right\}^2 + \left\{ \left(\frac{1}{dP_{sr}} \left(\frac{L_e}{D} \right) \right) G_{dP_{sr}} \right\}^2} \quad \text{BKA}$$

$$G_{L_e/D} = \sqrt{\left\{ \left(\frac{1}{dP_{es}} \left(\frac{L_e}{D} \right) \right) G_{dP_{es}} \right\}^2 + \left\{ \left(\frac{1}{dP_{sr}} \left(\frac{L_e}{D} \right) \right) G_{dP_{sr}} \right\}^2}$$

$$\frac{\partial}{\partial P_{es}} \frac{L_e}{D} = \frac{L_{sr}}{D dP_{sr}}$$

$$\frac{\partial}{\partial P_{sr}} \frac{L_e}{D} = -\frac{dP_{es} L_{sr}}{D} \frac{1}{dP_{sr}^2}$$

$$G_{L_e/D} = \sqrt{\left\{ \frac{L_{sr}}{D dP_{sr}} G_{dP_{es}} \right\}^2 + \left\{ -\frac{dP_{es} L_{sr}}{D dP_{sr}^2} G_{dP_{sr}} \right\}^2}$$

Note: $dP_{es} = f(V)$ V = fluid velocity
 are curvefits
 of data
 generated by
 AXUM
 by TRIMETRIX
 $dP_{sr} = f(V)$
 $G_{dP_{es}} = f(V)$
 $G_{dP_{sr}} = f(V)$

Title Calculation of Errors Associated w/ L_e/D

Project Slur, Test Loop

Prepared by: G.P. Abrigo

Date 6/1/94

Reviewed by:

Date

Calculation of error in dP , σ_{dP}

Using AXUM by TRIMETRIX curvefit: $dP = f(Q)$ in H_2O

$$dP = aQ^2 + bQ + c \quad ; Q = \text{volumetric flow, gpm}$$

with standard errors in the coefficients.

σ_a , σ_b , σ_c

To find σ_{dP}

$$\sigma_{dP} = \sqrt{\left(\frac{\partial}{\partial a} dP \sigma_a\right)^2 + \left(\frac{\partial}{\partial b} dP \sigma_b\right)^2 + \left(\frac{\partial}{\partial c} dP \sigma_c\right)^2}$$

$$\sigma_{dP} = \sqrt{(Q^2 \sigma_a)^2 + (Q \sigma_b)^2 + \sigma_c^2}$$

Calculated σ_{dP} for elbow sections σ_{dP_e}
 for straight section σ_{dP_s}

Title Calculation of error for in-line ultrasonic flow Project PVT-D-K1016

Prepared by: J.P. Hargis

Date 3/1/94

Reviewed by: _____

Date _____

APPENDIX E

v3

Test RWCT001		Condenser Heat Transfer Calculations				
Evaporator	Start Time	14:37	14:00	11:57	12:38	13:19
	End Time	15:07	14:30	12:28	13:15	13:51
	Elapsed Time, min	30	30	31	37	32
	Starting Volume, gal	8629	8604	8703	8701	8630
	Ending Volume, gal	8622	8593	8676	8673	8604
	Ave. Process Temp, °F	210.11	210.00	209.70	210.16	209.63
Shell Side	Headspace Pressure, psia	14.249	14.251	14.249	14.248	14.250
	Evaporation Rate, gpm	10.75	9.56	7.57	9.29	9.90
	Process hfg, Btu/lb	971.53	971.60	971.80	971.50	971.84
	Flow, gpm	354.56	354.57	354.75	355.03	354.88
	T _{in} , °F	80.85	80.41	80.19	81.21	80.53
	T _{out} , °F	113.33	109.14	103.45	109.46	109.82
Tube Side	ΔT, °F	32.48	28.74	23.26	28.25	29.29
	P _{in} , psia	44.031	44.011	43.977	44.007	44.031
	P _{out} , psia	37.416	37.392	37.280	37.401	37.430
	ΔP, psi	6.615	6.619	6.697	6.606	6.601
	Condensate Flow (1), gpm	10.75	9.56	7.57	9.29	9.90
	Condensate Flow (2), gpm	10.73	9.33	7.77	9.27	10.03
Heat Transfer	Condensate Temp, °F	103.81	100.39	101.02	101.91	101.23
	Condense Heat, Btu/Hr	5.194E+06	4.617E+06	3.658E+06	4.490E+06	4.783E+06
	Subcool Heat, Btu/Hr	5.683E+05	5.208E+05	4.091E+05	5.003E+05	5.335E+05
	Off-gas Flow, SCFM	NA	NA	43.19	41.54	NA
	Off-gas Flow, ACFM	NA	NA	50.20	49.26	NA
	Off-gas Temp, °F	147.29	140.42	130.88	140.32	141.37
Entrainment	Off-gas Pressure, psia	13.991	14.052	14.111	14.049	14.041
	Pressure Drop, ΔP, psi	0.258	0.200	0.138	0.199	0.209
	ΔT, Cooling Water, °F (3)	29.42	26.14	20.70	25.40	27.07
	Condense LMTD, °F	110.84	113.42	116.29	112.93	112.81
	Subcool LMTD, °F	60.58	57.87	58.72	58.33	58.56
	Weighted Δt, °F	102.45	103.36	105.85	103.24	103.21
Energy Balance	Condenser U, Btu/Hr ft ² °F	124.82	110.32	85.28	107.26	114.31
	v at Off-gas Temp, ft ³ /lb	NA	NA	154.18	121.80	NA
	Calculated H ₂ O, gpm	NA	NA	0.04	0.05	NA
	Actual H ₂ O, gpm	NA	NA	0.00	0.00	NA
	Difference, gpm	NA	NA	-0.04	-0.05	NA
	Total Heat In, Btu/Hr	5.762E+06	5.138E+06	4.067E+06	4.990E+06	5.316E+06
Energy Balance	Total Heat Out, Btu/Hr	5.734E+06	5.076E+06	4.111E+06	4.993E+06	5.175E+06
	% Difference	0.49	1.21	-1.08	-0.05	2.67

1 - Using Instantaneous Flow 2 - Using Totalized Flow 3 - To condense process Spec.Grav. ##

Test RWCT0001		Evaporator Heat Transfer Calculations				
	Start Time	14:37	14:00	11:57	12:38	13:19
	End Time	15:07	14:30	12:28	13:15	13:51
	Elapsed Time, min	30	30	31	37	32
Process	Starting Volume, gal	8629	8604	8703	8701	8630
	Ending Volume, gal	8622	8593	8676	8673	8604
	Level Change (PDI-1002), gp	-0.63	-0.93	0.00	0.15	-7.10
	Level Change (PDI-1003), gp	0.21	-4.48	0.42	0.03	-2.12
	Ave. Level Change, gpm	-0.21	-2.70	0.21	0.09	-4.61
	Ave. Temp, °F	210.11	210.00	209.70	210.16	209.63
	Headspace Pressure, psia	14.25	14.25	14.25	14.25	14.25
	Evaporation, Btu/Hr	5.188E+06	4.611E+06	3.653E+06	4.484E+06	4.775E+06
	Reheat, Btu/Hr	5.683E+05	5.208E+05	4.091E+05	5.003E+05	5.335E+05
	Total Heat, Btu/Hr	5.756E+06	5.132E+06	4.062E+06	4.985E+06	5.309E+06
Condenser	Condensate Flow (1), gpm	10.75	9.56	7.57	9.29	9.90
	Condensate Flow (2), gpm	10.73	9.33	7.77	9.27	10.03
	Evaporation Rate, gpm	10.75	9.56	7.57	9.29	9.90
	Condensate Temp, °F	103.81	100.39	101.02	101.91	101.23
	Off-gas Flow, SCFM	NA	NA	43.19	41.54	NA
Steam	Flow, Lb/Hr	5937.16	5216.49	4254.04	5205.99	5244.41
	Header Pressure, psia	103.03	103.36	103.56	103.14	103.25
	Pin, psia	85.36	73.45	57.83	73.44	72.75
	Tin, °F	328.91	329.17	329.38	329.05	329.10
	Tsat at Pin, °F	316.58	306.18	290.29	306.17	305.53
	Vapor Cp at Tsat, Btu/Lb°F	0.48	0.48	0.48	0.48	0.48
	hfg at Tsat, Btu/Lb	897.93	905.83	917.50	905.83	906.31
	Condensate Pout, psia	64.75	54.51	41.62	54.41	53.68
	Condensate Tout, °F	215.77	214.95	213.93	217.45	213.99
	Coil Pressure Drop, psi	20.61	18.94	16.21	19.03	19.07
	Desuperheat Heat, Btu/Hr	3.527E+04	5.778E+04	8.012E+04	5.739E+04	5.956E+04
	Condense Heat, Btu/Hr	5.331E+06	4.725E+06	3.903E+06	4.716E+06	4.753E+06
	Subcool Heat, Btu/Hr	5.985E+05	4.759E+05	3.249E+05	4.619E+05	4.801E+05
	Total Heat, Btu/Hr	5.965E+06	5.259E+06	4.308E+06	5.235E+06	5.293E+06
Heat Transfer Coefficient	Desuperheat LMTD, °F	112.53	107.27	98.85	107.04	107.25
	Condensation Δt , °F	106.47	96.18	80.59	96.01	95.90
	Subcool LMTD, °F	34.35	30.76	25.90	34.41	29.61
	Weighted Δt , °F	87.97	80.73	69.72	82.99	79.79
	Boiling U, Btu/Hr ft ² °F	197.69	189.91	180.14	183.90	193.38
Agitator	Speed, rpm	85.00	85.00	85.00	45.00	130.00
	Current, Amps	37.87	37.85	37.54	24.69	64.69
	Voltages, Volts	460.00	460.00	460.00	460.00	460.00
	Agitator Pout, KW	15.69	15.67	15.39	3.71	40.07
	Agitator Pout, Btu/Hr	53,541	53,462	52,516	12,650	136,724
Energy Balance	Tank Losses, Btu/Hr	207000	207000	207000	207000	207000
	Total Heat In, Btu/Hr	6.019E+06	5.312E+06	4.361E+06	5.248E+06	5.429E+06
	Total Heat Out, Btu/Hr	5.963E+06	5.339E+06	4.269E+06	5.192E+06	5.516E+06
	% Difference	0.92	-0.50	2.10	1.07	-1.59

1 - Using Instantaneous Flow 2 - Using Totalized Flow

Spec.Grav.

Design Calculations
CALC-SIPT-002, Rev. 0

For
Slurry-Integrated Performance Testing
6/7/93

HB-15 Coil Heat Transfer Coefficients

Prepared By:

Brian Hatchell
Brian Hatchell

6/10/93
Date

Reviewed By:

Michael W. Rube

6/9/93
Date

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1.0 Introduction

The following calculations determine the overall heat transfer coefficients for the coils in the test vessel (HB-15) during transient batch heating, boiling, and transient batch cooling. The overall heat transfer coefficient (U) is the inverse of all resistances between the steam (and cooling water) and the process side. The resistances include:

- 1) Coil side convective heat transfer coefficient
- 2) Fouling factor inside the tube
- 3) Resistance of the tube wall
- 4) Fouling factor outside the tube wall
- 5) Process side heat transfer coefficient

The quantities are calculated for each process condition and combined to calculate the overall predicted heat transfer coefficient during heating, boiling, and cooling. The calculations rely on actual process data for material property evaluation, agitator speed, etc. The calculations assume water as the process liquid, since properties are well defined for water. Following the calculations is a derivation of the actual heat transfer coefficients during water testings.

2.0 Data

Heat Transfer Area:

Cooling Coil Outside Area, A_c :	144.00 ft ²	Ref 1, pg 67
Heating Coils Outside Area, A_h :	343.00 ft ²	Ref 1, pg 67

Coil Properties: 2" SCH 40 Pipe Coil, Hastalloy C-276

Ref 6, Sheet 4

Conductivity, K tube	6.03	Btu/hr ft ² °F	at 125 °F	Per Ref
	6.24	Btu/hr ft ² °F	at 168 °F	7, pg 155
	6.46	Btu/hr ft ² °F	at 212 °F	

Outside Diameter, D_o	2.375 in	=	0.198 ft
Inside Diameter, D_i	2.067 in	=	0.172 ft

Inside Area, $A_i = (\pi/4) * D_i^2 =$	0.0233	ft ²
$\pi =$	3.14159	

Vessel Dimensions

Vessel Inside Diameter, D_j	12.000 ft	Ref. 6
Vessel Paddle Diameter, L	3.000 ft	

3.0 Overall Heat Transfer Coefficient

The overall coil heat transfer coefficient is determined according to the following equations.

$$\frac{1}{U_D} = \frac{1}{h_{io}} + \frac{1}{h_o} + R + f_i + f_o \quad \text{Ref.2 pg 106 (1)}$$

$$h_{io} = h_i \frac{D_i}{D_o} \quad \text{Ref.2 pg 86 (2)}$$

$$R = \frac{2.3 D_o}{2 K_{mbs}} \log \left(\frac{D_o}{D_i} \right) \quad \text{Ref. 2 pg 86 (3)}$$

$$\frac{1}{U_C} = \frac{1}{h_{io}} + \frac{1}{h_o} + R \quad \text{Ref. 2, pg 86 (4)}$$

Where:	h_{io}	=	Tube side heat transfer coefficient based on outside area
	h_i	=	Tube side heat transfer coefficient based on inside area
	f_i	=	Tube side fouling factor
	f_o	=	Vessel side fouling factor
	R	=	Resistance through the tube wall
	h_o	=	Vessel side heat transfer coefficient
	K_{mbs}	=	Tube conductivity
	U_D	=	Overall heat transfer coefficient (dirty)
	U_C	=	Overall heat transfer coefficient (clean)
	D_i	=	Inside diameter of tube
	D_o	=	Outside diameter of tube

The clean heat transfer coefficient (U_C) does not include fouling factors, and thus represents the predicted heat transfer coefficient for a new component. The dirty heat transfer coefficient (U_D) accounts for fouling equivalent to approximately one year of continuous service.

4.0 Heat Transfer Coefficient - Transient Cooling

Cooling water is supplied to the test vessel cooling coils after the completion of the evaporation process to cool the liquid from boiling to 125 °F. The following calculations show the prediction of the heat transfer coefficient between the process liquid and the cooling water. The overall heat transfer coefficient is evaluated using data at three process temperatures: 125°F, 168.5°F, and 212°F.

4.1 Test Conditions - Transient Cooling

Use test data from TST019	Time, Start Cool	3:37:50
5/7/92	Time, End Cool	5:15:50
See SIPT Test Data Log	Elapsed Time	1.63 hrs
	Process Start Temp	207.61 °F
	Process End Temp	125.57 °F
	Water Flow	121.71 gpm
	Water Flow	60,905 lb/hr
	Average Water Inlet Temp	75.52 °F
	Average Water Outlet Temp	115.48 °F
	Process Liquid Weight	44,572 lb

Cooling water temperatures:	Process @ 207.6 °F	Process @ 167.7°F	Process @ 125.6 °F	
Cooling water inlet temp, °F	75.99	73.83	75.22	*
Cooling water outlet temp, °F	143.35	119.21	98.42	*

* Instantaneous cooling water temperatures at the specified process temperature, from TST019.

4.2 Vessel Side Heat Transfer Coefficient - Transient Cooling

For a submerged tube coil subjected to mechanical agitation by a paddle, Reference 2 offers the following correlation for the vessel side heat transfer coefficient:

$$\frac{h_o D_j}{k} = 0.87 \left(\frac{L^2 N \rho}{\mu} \right)^{2/3} \left(\frac{c \mu}{k} \right)^{1/3} \left(\frac{\mu}{\mu_w} \right)^{0.14} \quad \text{Ref. 2, pg. 722} \quad (5)$$

Where :	h_o	=	heat transfer coefficient, Btu/hr - ft ² °F
	D_j	=	vessel diameter, ft
	k	=	process conductivity at bulk temperature, Btu/hr - ft°F
	L	=	blade diameter, ft
	N	=	agitator speed, rev/hr
	ρ	=	process density at bulk temperature, lb/ft ³
	c	=	process specific heat at bulk temperature, Btu/lb°F
	μ	=	process viscosity at bulk temperature, lb/ft - hr
	μ_w	=	process viscosity at wall temperature, lb/ft - hr

Properties of Water at Tb
Ref 5, pg 750

	Process @ 207.6 °F	Process @ 167.7°F	Process @ 125.6 °F	
k	0.393	0.386	0.374	Btu / hr ft F
ρ	59.918	60.875	61.690	lb / ft ³
μ	0.716	0.937	1.339	lb / ft hr
c	1.010	1.000	1.000	Btu / lb F

Agitator Speed N 85.00 rpm 5100.00 rev / hr

For water, $\left(\frac{\mu}{\mu_w}\right)^{0.14} = 1.00$ Approximately, per Ref. 2, pg. 723

	Process @ 207.6 °F	Process @ 167.7°F	Process @ 125.6 °F	
Solve for ho	855.46	779.47	683.02	Btu / hr ft ² F

4.3 Tube Side Heat Transfer Coefficient - Transient Cooling

The film coefficient for fully developed turbulent pipe flow may be found by:

$$Nu = 0.027 Re_d^{0.8} Pr^{1/3} \left(\frac{\mu}{\mu_w}\right)^{0.14} \quad \text{Ref. 4, pg 178} \quad (6)$$

Where:

- Nu = Nusselt Number = $h_i D_i / k$, Ref. 4, pg 182
- Re_d = Reynolds Number
- Pr = Prandlt Number
- μ = process viscosity at bulk temperature
- μ_w = process viscosity at wall temperature
- D_i = Inside diameter of pipe
- k = conductivity of fluid

Representative tube side water temperature
(average inlet and outlet temps provided above)

Process @ 207.6 °F	Process @ 167.7°F	Process @ 125.6 °F
109.67	96.52	86.82

Properties of Water at
average Temp
Ref 5, pg 750

k	0.368	0.362	0.357	Btu / hr ft ² F
ρ	61.945	62.117	62.166	lb / ft ³
μ	1.532	1.724	1.934	lb / ft hr
c	1.000	0.999	0.999	Btu / lb°F
Pr	4.164	4.750	5.419	Prandlt #

Ave. Cooling Water Flow = 121.63 gpm = 975.55 ft³ / hr from TST019
 Mass Flow, MDOT = density*flow = 60430.90 lb / hr Assume constant density
 Flow Speed, $u = (MDOT / \text{density} * A_i) = 41864.19$ ft / hr of water (it changes
 very little)

Calculate Reynold's number:

$$Re_d = \frac{\rho u D_i}{\mu} \quad \text{Ref. 2, pg. 29} \quad (7)$$

	Process @ 207.6 °F	Process @ 167.7°F	Process @ 125.6 °F
Red =	291,614	259,823	231,852

Regions $Re_d < 2300$ Laminar Reference 2, pg. 29
 > 2300 Turbulent

We are well into the turbulent zone.

For Water, $\left(\frac{\mu_B}{\mu_w}\right)^{0.14} = 1.00$ Approximately

$Nu = h D_i / k$ Ref. 4, pg 182

	Process @ 207.6 °F	Process @ 167.7°F	Process @ 125.6 °F	
Nu =	1,023	974	929	
Solve for hi:	hi = 2,183	2,048	1,925	Btu/hrft ² °F

This is based on inside area. All calculations are referenced to outside area.

$h_{io} = (D_i/D_o)*h_i =$

1,900	1,782	1,675	Btu/hrft ² °F
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Ref. 2, pg 105

4.4 Fouling Factors - Transient Cooling

$f_i = 0.001$ City Water, below 125 F Ref.5, pg 425
 $f_o = 0.002$ City Water, above 125 F

4.5 Overall Predicted Heat Transfer Coefficient - Transient Cooling

	Process @ 207.6°F	Process @ 167.7°F	Process @ 125.6°F	
Use Eq. 3 to calculate R	R	0.0021	0.0022	0.0023
Use Eq. 4 to calculate Uc	Uc	261.7	247.3	230.4
Use Eq. 2 to evaluate Ud:	Ud	146.6	142.0	136.2
				Btu/hrft ² °F

4.6 Overall Experimental Heat Transfer Coefficient - Transient Cooling

The following calculations document the actual heat transfer coefficient between the cooling water and the process liquid during the cooling process. A correlation for a coil-in-tank vessel,

nonisothermal cooling medium is used to calculate U, based on actual test conditions

Assumptions: U is constant
 Cooling water flow is constant
 Specific heats are constant
 Heating or cooling medium has a constant inlet temperature
 Agitation produces a uniform batch fluid temperature
 No partial phase changes occur
 Heat loss from the tank are negligible (may not be reasonable at high temperatures)

$$\ln\left(\frac{T_1 - t_1}{T_2 - t_1}\right) = \frac{wc}{MC} \left(\frac{e^{UA/wc} - 1}{e^{UA/wc}} \right) \Theta \quad \text{Ref. 2, pg. 628} \quad (8)$$

Where: t_1 = inlet water temperature
 T_1 = initial process temperature
 T_2 = final process temperature
 Θ = cooling time
 w = water flow
 c = specific heat of cooling water
 M = mass of process liquid
 C = specific heat of process

Use test data from TST019	Time, Start Cool	3:37:50
	Time, End Cool	5:15:50
	Elapsed Time, Θ	1.63 hrs
	Start Temp, T_1	207.61 degF
	End Temp, T_2	125.57 degF
	Water Flow	121.71 gpm
	Water Flow, w	60,905 lb/hr
	Average Water Inlet Temp, t_1	75.52 degF
	Average Water Exit Temp	115.48 degF
	Process Weight, M	44,572 lb

$C(\text{water}) =$	1.00	Btu / lb F	Ref. 5, pg. 750
$c =$	1.00	Btu / lb F	

Equation 8 cannot be used to solve for U directly, so I will iterate on U until the equality is satisfied.

U =	241.35	Btu / hr Ft ² F
UA / wc =	0.57	

Left Hand Side, Eq. 6:	0.9705	√	The equality is satisfied
Right Hand Side, Eq. 6:	0.9705	√	

The instantaneous transient cooling heat transfer coefficient is evaluated below to determine how the coefficient varies with vessel temperature. A small time segment is used for each data point (1 minute), so that the temperature of the cooling water inlet and exit and the vessel process temperature are essentially constant. The same test data is used for the evaluation (TST019). Fourier's law is used to determine the overall heat transfer coefficient. A log-mean temperature difference between the cooling water and the process liquid is used for ΔT .

$$Q = U A \Delta T \text{ Ref 2, pg 86} \quad (9)$$

$$\Delta T = \frac{\Delta t_2 - \Delta t_1}{\ln(\Delta t_2 / \Delta t_1)} \text{ Ref 2, pg 42} \quad (10)$$

Where	Q	=	Heat transfered through coils
	U	=	Instantaneous heat transfer coefficient
	A	=	Cooling coil outside area
	ΔT	=	Log Mean Temperature Difference between Cooling water and process
	Δt_1	=	The higher temperature of the hot fluid (-) the higher temperature of the cold liquid
	Δt_2	=	The lower temperature of the hot fluid (-) the lower temperature of the cold liquid

Q is determined from the cooling water change in temperature, i.e.:

$$Q = \text{MDOT} * C_p \Delta t \quad \begin{array}{l} C_p = \text{specific heat of cooling water} = 1 \text{ Btu / lb } ^\circ\text{F} \\ \Delta t = \text{temperature rise of cooling water} \end{array}$$

Average cooling water temperature throughout cooling process in
 $T(\text{ave, cooling water}) = 95.50 \quad ^\circ\text{F} \quad \text{per TST019}$

Density of water at this temperature = $62.12 \quad \text{lb/ft}^3 \quad \text{Ref. 5, pg 750}$

Weight per gallon = $8.30 \quad \text{lb/gal}$

$$\text{MDOT} = \text{Flow rate GPM} * (8.30 \text{ lb/gal}) * (60 \text{ min/Hr})$$

The transient cooling heat transfer coefficient is plotted versus process temperature in the following graph. The periodic fluxuations are caused by the control limits of the cooling tower. Note that the Q imbedded in the instantaneous heat transfer coefficient is based on the change in enthalpy of the cooling water. It neglects the heat input by the agitator and heat losses from the tank. The overall heat transfer coefficient, which was calculated to be $241 \text{ Bht/Hrft}^2\text{ } ^\circ\text{F}$, is based on the change in enthalpy of the process over time. For this reason, the instantaneous heat transfer coefficient is somewhat different than the overall.

Transient Cooling Heat Transfer Coefficient

A process temperature versus transient cooling heat transfer coefficient was fit through the data.

$$U = mT + b$$

m b
 0.21 238.68

Units of m (Btu/hr ft² °F)/°F

Units of b Btu/hr ft² °F

$$U = mT + b$$

where T = process temperature, °F

	Process @ 207.6°F	Process @ 167.7°F	Process @ 125.6°F	
U	281.4	273.2	264.6	Fitted to the data with a straight line

This is also shown in the previous plot.

4.7 Comparison of Predicted and Actual Heat Transfer Coefficient - Transient Cooling

The predicted, actual overall, and actual instantaneous transient cooling heat transfer coefficients are summarized below.

	Process @ 207.6°F	Process @ 167.7°F	Process @ 125.6°F	Comments
U _c , predicted	261.7	247.3	230.4	Predicted
U _d , predicted	146.6	142.0	136.2	Predicted
U, actual	241.4	241.4	241.4	Actual, overall
U, actual	281.4	273.2	264.6	Instantaneous, using linear curve fit
U, design	70.0	70.0	70.0	Used by Fluor Daniel

The instantaneous heat transfer coefficient is a better indication of heat transfer, since it is based on the actual heat transfer through the coils, and does not include heat losses from the tank and agitator heat input. Since the overall heat transfer coefficient is effected by tank heat loss, it is somewhat lower than the instantaneous heat transfer coefficient. The instantaneous cooling heat transfer coefficient was slightly higher than the predicted clean heat transfer coefficient U_c , which is somewhat surprising, but not alarming considering the accuracy of the correlations. The coils are relatively new and it is expected that the cooling heat transfer coefficient will decrease with time to the dirty value U_d .

5.0 Heat Transfer Coefficient - Transient Heating

Steam flowing through the heating coils is used to heat the process liquid from an initial batch temperature of 125 °F to boiling. The following calculations predict the overall heat transfer coefficient between the steam and the process liquid. The overall heat transfer coefficient is evaluated using data at three process temperatures: 125°F, 168.5°F, and 212°F.

5.1 Test Conditions - Transient Heating

Transient conditions taken from
TST019, 5/7/92

Time, Start Heating	10:06 AM	
Time, End Heating	11:16 AM	
Elapsed Time, hrs	1.17	hrs
Steam Temp	349.86	°F
Steam Pressure	133.67	psia
Steam Tsat	349.47	°F
Slurry Mass	68109.77	lb
Starting Slurry Temp	124.92	°F
Ending Slurry Temp	208.66	°F
Process cp	1.00	Btu/lb°F

I will calculate the transient cooling heat transfer coefficient at the same temperatures as transient cooling: 207.6, 167.7, and 125.6 °F.

5.2 Vessel Side Heat Transfer Coefficient - Transient Heating

The situation is identical to transient cooling. The resulting outside heat transfer coefficients are repeat below.

	Process @ 207.6 °F	Process @ 167.7°F	Process @ 125.6 °F	
Solve for ho	ho	855.46	779.47	683.02 Btu/hr ft ² °F

5.3 Tube Side Heat Transfer Coefficient - Transient Heating

It is customary to adopt a conventional and conservative value for the film coefficient of condensing steam, since it is never controlling, rather than obtain one by calculation.

For air-free steam, a value of 1500 btu/Hr ft²°F will be used (see Ref. 2, page 164).

$$h_{io} = 1500.00 \text{ Btu /Hr Ft}^2\text{°F}$$

5.4 Fouling Factors - Transient Heating

$$f_i = 0.0005 \text{ Steam, non-oil-bearing Ref.5, pg 425}$$

$$f_o = 0.002 \text{ City Water, above 125 F}$$

5.5 Overall Predicted Heat Transfer Coefficient - Transient Heating

	Process @ 207.6°F	Process @ 167.7°F	Process @ 125.6°F	
Use Eq. 3 to calculate R	R	0.0021	0.0022	0.0023
Use Eq. 4 to calculate Uc	Uc	252.5	241.0	226.8 Btu / hr ft ² F
Use Eq. 2 to evaluate Ud:	Ud	154.8	150.4	144.7 Btu / hr ft ² F

5.6 Overall Experimental Heat Transfer Coefficient - Transient Heating

The following calculations determine the actual heat transfer coefficient between the steam and the process liquid during the heating process. A correlation for a coil-in-tank vessel, isothermal heating medium is used to calculate U, based on actual test conditions

Assumptions: U is constant
 Steam flow is constant
 Specific heat of process is constant throughout heating process
 Heating medium has a constant inlet temperature
 Agitation produces a uniform batch fluid temperature
 Isothermal heating medium
 No partial phase changes occur
 Heat loss from the tank are negligible
 Heat due to sub-cooling of the steam condensate is neglected

$$\ln\left(\frac{T_1 - t_1}{T_1 - t_2}\right) = \frac{UA\Theta}{Mc} \quad \text{Ref. 2, pg. 627} \quad (11)$$

Where: T_1 = isothermal medium temperature
 t_1 = initial process temperature
 t_2 = final process temperature
 Θ = heating time
 c = specific heat of process
 M = mass of process liquid
 A = heat transfer area

Using test conditions for heating during TST019:

$T_1 = 349.47 \quad ^\circ\text{F}$
 $t_1 = 124.92 \quad ^\circ\text{F}$
 $t_2 = 208.66 \quad ^\circ\text{F}$
 $c = 1.00 \quad \text{Btu/lb}^\circ\text{F}$
 $M = 68,110$
 Heating time $1.17 \quad \text{hr}$

Solve for U $79.44 \quad \text{Btu/HrFt}^2^\circ\text{F}$

The instantaneous heating heat transfer coefficient is evaluated below to determine how the coefficient varies with vessel temperature. A small time segment is used for each data point (1 minute); so that the temperature of the steam condensate temperature and the vessel process temperature are essentially constant. The same test data is used for the evaluation (TST019). Q is determined from the heat of condensation of the steam, plus any subcooling of the condensate.

$Q = \text{MDOT} * (C_p \Delta t + h_{fg})$ C_p = specific heat of steam condensate = 1 Btu / lb $^\circ\text{F}$
 Δt = temperature drop of condensate
 h_{fg} = heat of vaporization of the steam
 MDOT = mass flow of steam

The transient heating heat transfer coefficient is plotted versus process temperature in the following graph. Note that the Q neglects the heat input by the agitator and heat losses from the tank. The instantaneous heat transfer coefficient is determined from Fourier's Law, $Q = UA\Delta T$, where ΔT is log-mean temperature difference between the steam and the process liquid.

Transient Heating Heat Transfer Coefficient

A process temperature versus transient heating heat transfer coefficient was fit through the data.

$$U = mT + b$$

m b
 0.64 52.15

Units of m (Btu/hr ft² °F)/°F

Units of b Btu/hr ft² °F

$$U = mT + b$$

where T = process temperature, °F

	Process @ 207.6°F	Process @ 167.7°F	Process @ 125.6°F	
U	185.5	159.9	132.8	Fitted to the data with a straight line

This is also shown in the previous plot.

5.7 Comparison of Predicted and Actual Heat Transfer Coefficient - Transient Heating

	Process @ 207.6°F	Process @ 167.7°F	Process @ 125.6°F	Comments
Uc, predicted	252.5	241.0	226.8	Predicted
Ud, predicted	154.8	150.4	144.7	Predicted
U, actual	79.4	79.4	79.4	Actual, overall, using equation 11
U, actual	185.5	159.9	132.8	Actual, using linear curve fit
U, design	120.0	120.0	120.0	Used by Fluor Daniel

The equation used to predict the overall transient heating heat transfer coefficient (Equation 11) appears inadequate for this situation. The primary reason for this is that Equation 11 assumes an isothermal heating medium. Even though the steam condenses at a constant temperature, a large amount of heat is transferred by subcooling the condensate. The result is that Equation 11 severely underpredicts the heat transfer coefficient. The actual heating heat transfer coefficient (using instantaneous values) is only slightly above the predicted dirty (U_d) heat transfer coefficient. The reason for this is that, during water processing, the coils are oversurface, meaning that there is excess surface area for the application. This is supported by the fact that the steam condensate temperature (exit) is only slightly above the process temperature during heat up (see the following plot of steam condensate temperature versus process temperature during heatup), indicating that essentially all available heat is extracted from the steam. Operating the steam coils at higher steam flows would eliminate this situation.

Steam condensate temperature minus process temperature

6.0 Heat Transfer Coefficient - Boiling

Steam flowing through the steam coils is used to evaporate the process liquid. The following calculations predict the overall heat transfer coefficient between the steam and process liquid. Actual test data is used for property evaluation, flow rates, etc. The effect of boiling on the heat transfer coefficient will not be considered. Boiling heat transfer can be divided into different regions of behavior: natural convection, nucleate boiling, transitional boiling, and film boiling (see Reference 3, pg. 387), depending on the amount of heat flux between the liquid and the heat transfer surface. Boiling in the test vessel will occur in the nucleate, transitional, or film boiling regime. In general, boiling increases the heat transfer of a process if the boiling occurs in the nucleate or film boiling regime. During transitional boiling, however, the heat transfer surface is engulfed in a layer of vapor. This layer of vapor acts as insulation and can decrease the heat transfer.

Heat transfer in the tank will be a combination of forced convection by agitation and boiling heat transfer. Due to the complexities involved in calculating a boiling heat transfer coefficient, the effect of boiling will be ignored, and a heat transfer coefficient based only on forced convection will be calculated. The results will be compared to actual test data to validate this simplification.

The situation is therefore identical to transient heating, so the same equations will be used here.

6.1 Test Conditions - Boiling

Using data from TST029	Time Start	11:13	
	Time End	11:43	
	Elapsed Time	30.00	min
	Steam Header Pressure	127.32	psia
	Steam Flow, mdot	5758.48	lb /hr
	Steam Tin	345.11	°F
	Steam Pin	125.78	psia
	Steam Condensate Tout	213.49	°F
	Evaporation Rate:	10.18	gpm
	Average Process Temp	211.08	°F

6.2 Vessel Side Heat Transfer Coefficient - Boiling

Properties of Water at Tb Ref 5, pg 750	Process @ 211.08 °F	
	k	0.393 Btu / hr ft F
	ρ	59.834 lb / ft ³
	μ	0.705 lb / ft hr
	c	1.010 Btu / lb F

Agitator Speed N 85.00 rpm 5100.00 rev / hr

For water, $\left(\frac{\mu}{\mu_w}\right)^{0.14} = 1.00$ approximately

Use Eq. 5 to
solve for h_o

	Process @ 207.6 °F	
h_o	859.58	Btu / hr ft ² F

6.3 Tube Side Heat Transfer Coefficient - Boiling

It is customary to adopt a conventional and conservative value for the film coefficient of condensing steam, since it is never the controlling factor, rather than obtain one by calculation. For air-free steam, a value of 1500 btu/Hr ft²°F will be used (see Ref. 2, page 164).

$$h_{io} = 1500.00 \quad \text{Btu/ Hr Ft}^2\text{°F}$$

6.4 Fouling Factors - Boiling

$$\begin{aligned} f_i &= 0.0005 && \text{Steam, non-oil-bearing} && \text{Ref.5, pg 425} \\ f_o &= 0.002 && \text{City Water, above 125 F} \end{aligned}$$

6.5 Overall Predicted Heat Transfer Coefficient - Boiling

Use Eq. 3 to calculate R
Use Eq. 4 to calculate U_c
Use Eq. 2 to evaluate U_d :

R	0.0021	
U_c	252.8	Btu/hr ft ² °F
U_d	154.9	Btu/hr ft ² °F

6.6 Overall Experimental Heat Transfer Coefficient - Boiling

Fourier's Law will be used to determine the overall heat transfer coefficient between the tube side and the vessel side:

$$Q = U A_h \Delta t \quad \text{Ref. 2, pg. 86} \quad (12)$$

Where: U = boiling overall heat transfer coefficient
 A_h = outside heat transfer area of the coils
 Δt = Log-mean Temperature difference between tube side fluid and process liquid.

Two cases are considered: Case 1: steam enters at saturation temperature
 Case 2: steam enters at a superheated condition

Case 1:

Q is determined from the change in enthalpy of the tube side steam. At maximum evaporation, the steam enters at essentially the saturation temperature. The steam condenses and is subcooled below the saturation temperature. Therefore,

$$Q = q(\text{condense}) + q(\text{subcool})$$

To calculate the weighted temperature difference Δt , it is first necessary to calculate separately the temperature difference between the steam and the vessel liquid (this is constant) and the log-mean temperature difference between the steam condensate and the vessel liquid. These temperature differences are then weighted by the amount of energy transferred in each

phase to determine the overall, weighted temperature difference.

Using data from TST029

Time Start	11:13	
Time End	11:43	
Elapsed Time	30.00	min
Steam Header Pressure	127.32	psia
Steam Flow, mdot	5758.48	lb /hr
Steam Tin	345.11	°F
Steam Pin	125.78	psia
Steam Condensate Tout	213.49	°F
Evaporation Rate:	10.18	gpm
Average Process Temp	211.08	°F

Saturation temperature, $T_s = 344.80$ °F Very close to T_{in}
 Ref.8, pg860 desuperheating ignored

heat of vaporization, $h_{fg} = 875.61$ btu / lb Ref. 8, pg. 861
 (at T_{sat})

$q(\text{cond}) = \dot{m} \cdot h_{fg} = 5.042\text{E}+06$ Btu / hr

$q(\text{subcool}) = \text{mass flow of steam} \cdot \text{temperature drop} = \dot{m} \cdot (T_{sat} - T_{out})$
 $q(\text{subcool}) = 7.561\text{E}+05$ Btu / hr

Total Heat Lost from steam = $Q = 5.798\text{E}+06$ Btu/Hr

Now, calculate temperature difference during condensing and subcooling phases:

Condensation, Δt_c

Hot Fluid		Cold Fluid	Δt
344.80	High	211.08	133.72
344.80	Low	211.08	133.72

$\Delta t_c = 133.72$ °F

$q(\text{cond}) / \Delta t_s = 37706.23$ Btu / hr °F

Sub-cooling, Δt_s

Hot Fluid		Cold Fluid	Δt
344.80	High	211.08	133.72
213.49	Low	211.08	2.41

LMTD = Logarithmic mean temperature difference

$\Delta t_s = \text{LMTD} = (\Delta t(\text{high}) - \Delta t(\text{low})) / \ln (\Delta t(\text{high}) / \Delta t(\text{low}))$

$\Delta t_s = 32.71$ °F

$q(\text{subcool}) / \Delta t_s = 23120.06$ Btu / hr °F

Ref.2, pg. 42

Calculate weighted temperature difference per Reference 2, pg. 291.

$$\Delta t(\text{weighted}) = Q / ((q/\Delta t)_c + (q/\Delta t)_s) \quad \text{Ref. 2, pg. 291}$$

$$= 95.33 \text{ } ^\circ\text{F}$$

Calculate overall heat transfer coefficient using Fourier's Law (Eq. 8):

$$U = Q / A_h \Delta t = 177.3 \text{ Btu / hr ft}^2 \text{ } ^\circ\text{F}$$

For lower evaporation rates, a valve is used to reduce the pressure and flow of the incoming steam. This reduces the saturation temperature of the steam, and results in superheated steam at the inlet. For this situation,

$$Q = q(\text{desuperheat}) + q(\text{condense}) + q(\text{subcool})$$

Using data from TST029

Time Start	14:26	
Time End	14:56	
Elapsed Time	30.00	min
Steam Header Pressure	130.08	psia
Steam Flow, mdot	1429.01	lb /hr
Steam Tin	346.73	°F
Steam Pin	34.37	psia
Steam Condensate Tout	209.30	°F
Evaporation Rate:	2.45	gpm
Average Process Temp	209.80	°F

Saturation temperature, $T_s = 258.17 \text{ } ^\circ\text{F}$
 Ref.8, pg860
 Average of T_s and $T_{in} = 302.45 \text{ } ^\circ\text{F}$

Substantially lower than T_{in}
 desuperheating must be considered

Steam vapor specific heat at $T_{in} = 0.48 \text{ Btu / lb } ^\circ\text{F}$ Ref. 5, pg 735

$$q(\text{desuperheat}) = \dot{m} \cdot c (T_{in} - T_{sat}) = 60,971 \text{ Btu / hr}$$

heat of vaporization, $h_{fg} = 940.07 \text{ btu / lb}$ Ref. 8, pg. 861
 (at T_{sat})

$$q(\text{cond}) = \dot{m} \cdot h_{fg} = 1.343\text{E}+06 \text{ Btu / hr}$$

$$q(\text{subcool}) = \text{mass flow of steam} \cdot \text{temperature drop} = \dot{m}(T_{sat} - T_{out})$$

$$q(\text{subcool}) = 6.984\text{E}+04 \text{ Btu / hr}$$

$$\text{Total Heat Lost from steam} = Q = 1.474\text{E}+06 \text{ Btu/Hr}$$

Now, calculate temperature difference during desuperheating, condensing, and subcooling phases:

Desuperheat, Δt_{sub}

Hot Fluid		Cold Fluid	Δt
346.73	High	209.80	136.92
258.17	Low	209.80	48.37

$$\Delta t_{sub} = \text{LMTD} = 85.10 \text{ } ^\circ\text{F}$$

$$q(\text{desuperheat}) / \Delta t_{sub} = 716.44 \text{ Btu / hr } ^\circ\text{F}$$

Condensation, Δt_c

Hot Fluid		Cold Fluid	Δt
258.17	High	209.80	48.37
258.17	Low	209.80	48.37

$$\Delta t_c = 48.37^\circ\text{F}$$

$$q(\text{cond}) / \Delta t_s = 27774.18 \quad \text{Btu / hr } ^\circ\text{F}$$

Sub-cooling, Δt_s

Hot Fluid		Cold Fluid	Δt
258.17	High	209.00	49.17
209.30	Low	209.00	0.30

$$\Delta t_s = \text{LMTD} = (\Delta t(\text{high}) - \Delta t(\text{low})) / \ln (\Delta t(\text{high}) / \Delta t(\text{low}))$$

Ref.2, pg. 42

$$\Delta t_s = 9.57^\circ\text{F}$$

$$q(\text{subcool}) / \Delta t_s = 7298.65 \quad \text{Btu / hr } ^\circ\text{F}$$

Calculate weighted temperature difference per Reference 2, pg. 291.

$$\Delta t(\text{weighted}) = Q / ((q/\Delta t)_{\text{desuper}} + (q/\Delta t)_c + (q/\Delta t)_s)$$

$$= 41.19^\circ\text{F}$$

Ref. 2, pg. 291

Calculate overall heat transfer coefficient using Fourier's Law (Eq. 8):

$$U = Q / A_h \Delta t = 104.3 \quad \text{Btu / hr ft}^2 \text{ } ^\circ\text{F}$$

6.7 Comparison of Predicted and Actual Heat Transfer Coefficient - Boiling

At 10 gpm evaporation, the following table summarized the boiling heat transfer coefficients:

	R	0.0021	
Predicted	Uc	253	Btu / hr ft ² F
Predicted	Ud	155	Btu / hr ft ² F
Actual	U	177	Btu / hr ft ² F

The actual heat transfer coefficient, is bracketed by the predicted clean and dirty heat transfer coefficient. Note that no boiling effects were considered in the derivation of the predicted heat transfer coefficient. In fact, boiling may actually reduce the heat transfer coefficient. During heating, the actual heat transfer coefficient was 185.5 (at a process temperature of 207.5 °F), which is actually above the boiling heat transfer coefficient calculated here. Possible reasons for this are: 1) vapor binding during the boiling process may reduce the heat transfer coefficient and 2) bubbles formed during boiling at the top of the process liquid may reduce the actual heat transfer area.

7.0 References

- 1) R.L. McKay, et. al., April 21, 1992, Test Plan for Slurry-Integrated Performance Testing (SIPT), Hanford Waste Vitrification Program, Test Plan No. HWVP-91-1.2.2.03.03B, Revision 1, Prepared by Pacific Northwest Laboratory.
- 2) Kern, D.Q., 1950, Process Heat Transfer, Mcgraw-Hill Book Company, New York.
- 3) Lienhard, J.H., 1981, A Heat Transfer Textbook, Prentice-Hall, Inc, New Jersey.
- 4) Holman, J.P., 1972, Heat Transfer, 3rd Edition, Mcgraw-Hill Book Company, New York.
- 5) Welty, J.R., Wicks, C.E., and Wilson, R.E., 1976, Fundamentals of Momentum, Heat, and Mass Transfer, 2nd Edition, John Wiley and Sons, New York.
- 6) Richmond Machine and Fabrication, Inc., HWVP Feed Prep Test Vessel Drawing D-10183.
- 7) 1980, Metals Handbook, 9th Edition, Volume 3, American Society for Metals, Metals Park, Ohio.
- 8) Wark, K., 1977, Thermodynamics, Mcgraw-Hill Book Company, New York.

APPENDIX F

Pacific Northwest Laboratories

ENGINEERING WORKSHEET

Page 1 of 2

Prepared By: JT DAUME Date: 26 MAY Project: RWCT PUMP CHARACTERIZATION
 Subject: _____

TRANSFER PUMP CALCULATIONS

Time: 2/4/94 11:30Flow Rate 166.77 GPM
(GIVEN)

$$\text{VELOCITY} = \left(\frac{\text{GAL}}{\text{MIN}} \right) \frac{1.4805}{60 \text{ S}} \frac{\text{ft}^3}{7.4805 \text{ GAL}} \frac{1}{\frac{1}{4} \left(2.067 \text{ in} + \frac{1 \text{ ft}}{12 \text{ in}} \right)^2} = 15.94 \frac{\text{ft}}{\text{sec}}$$

Speed 1635.36 RPM
(GIVEN)

$$\text{VELOCITY HEAD} = \frac{V^2}{2g} = \frac{(15.94 \frac{\text{ft}}{\text{sec}})^2}{2(32.17 \frac{\text{ft}}{\text{sec}^2})} = 3.95 \text{ FT OF FLUID}$$

Pipe ID = 2.067 in
(GIVEN)

$$\text{REYNOLDS NUMBER} = 123.9 \frac{DV\rho}{\mu} = 123.9 \frac{(2.067 \text{ in})(15.94 \frac{\text{ft}}{\text{sec}})(63.40 \frac{\text{lb}}{\text{ft}^3})}{0.5196 \text{ CP}}$$

CRANE EQN 3-3

$$= 498215.5$$

$$Re/D = \frac{Re}{D(\text{in})} = \frac{498215.5}{(2.067 \text{ in} \frac{1 \text{ ft}}{12 \text{ in}})} = 2892398 \text{ ft}^{-1}$$

$$\text{FRICTION FACTOR} = 4 \times 0.1854 \left(\frac{Re}{D} \right)^{-0.2636} = 0.0147$$

EQN 7.5.3 in Sect. 7

Weight Cells = 49880.74 lbs
(GIVEN)

$$\text{GALLONS} = \frac{(\text{lbs})}{\rho_{\text{fluid}}} (7.4805 \frac{\text{GM}}{\text{ft}^3}) = \frac{49880.74 \text{ lbs}}{63.40 \frac{\text{lb}}{\text{ft}^3}} (7.4805 \frac{\text{GAL}}{\text{ft}^3}) = 5985 \text{ GALS}$$

F.2

Pacific Northwest Laboratories

ENGINEERING WORKSHEET

Page 2 of 2Prepared By: JT DAUME

Date:

Project:

Subject:

$$\text{WATER LEVEL} = \frac{\text{GAL}}{\text{ft}} = \frac{5385.7 \text{ GAL}}{67 \text{ ft}} = 82.90 \text{ IN WATER}$$

McKAY

$$\text{DISTANCE FROM WATER LEVEL TO PUMP CENTERLINE} = \frac{138.25}{\text{GIVEN}} - 82.90 = 55.35 \text{ W.}$$

$$\text{DISTANCE FROM TRANSMITTER TO PUMP CENTERLINE} = \frac{92.00}{\text{GIVEN}} \text{ IN WATER}$$

$$\begin{aligned} \text{PIPE FRICTION LOSS (DISCHARGE)} &= (ff) \left(\frac{45}{D} \right) \times (VEL H_0) + (0.13 + 0.266) \times (VEL H_0) \\ &\quad \begin{array}{c} \text{AMOUNT OF P.P.E BEFORE DISCHARGE TRANS.} \\ \text{K(45)} \quad \text{K(ELBOW)} \quad \text{CRANE A-26-28} \end{array} \\ &= 0.0177 \times \frac{45}{2.067} \times 3.75 \text{ FT} + (.396)(3.75 \text{ FT}) = 2.323 \text{ FT OF FL.} \end{aligned}$$

$$\begin{aligned} \text{PIPE FRICTION LOSS (SUCTION)} &= (ff) \left(\frac{138.25}{D} \right) (VEL H_0) = 0.0177 \left(\frac{138.25}{2.067} \right) (3.75 \text{ FT}) \\ &= 3.351 \text{ FT OF FLUID} \end{aligned}$$

$$\text{DISCHARGE GAUGE READING} = 41.29 \text{ PSI WATER (GIVEN)}$$

$$\begin{aligned} \text{TOTAL HEAD (FT OF WATER)} &= \frac{VEL H_0}{36} + \text{DISCH. GAGE} + 2.303 + \frac{h_{20}}{36} + \frac{\text{TRANS TO CL}}{12} \dots \\ &\dots + \frac{\text{WATER LVL TO CL}}{12} + \frac{h_{23}}{36} \end{aligned}$$

$$\begin{aligned} &= \frac{3.75 \text{ FT}}{1.03} + (41.29 \frac{\text{lb}}{\text{IN}^2}) \left(2.303 \frac{\text{ft}}{\text{PSI}} \right) + \frac{2.323 \text{ FT}}{1.03} + \frac{92.00 \text{ IN}}{12 \frac{\text{IN}}{\text{FT}}} + \frac{55.35 \text{ IN}}{12 \frac{\text{IN}}{\text{FT}}} + \frac{3.351}{1.03} \\ &= 117.89 \text{ FT OF WATER} \end{aligned}$$

$$\text{FLUID TEMP} = 130 \text{ F}$$

$$\text{DENSITY (lb/ft}^3\text{)} = 61.55 \text{ (WATER @ 130F)}$$

$$\text{SPECIFIC GRAV} = 1.03$$

$$\text{ACTUAL DENS} = (1.03)(61.55) = 63.40 \text{ lb/ft}^3$$

$$\text{VISCOSITY} = 0.52 \text{ CP VISC OF H}_2\text{O AT 130F (PENGUS, REID, L)}$$