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Bench Scale Saltcake Dissolution Test Report

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

Fluor Hanford

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EXECUTIVE SUMMARY

A potential scenario for retrieving saltcake from single shell tanks is the "Rainbird® sprinkler" method. Water is distributed evenly across the surface of the saltcake and allowed to percolate by gravity through the waste. The salt dissolves in the water, forming a saturated solution. The saturated liquid is removed by a saltwell pump situated near the bottom of the tank. By this method, there is never a large inventory of liquid in the tank that could pose a threat of leakage. Exploratory laboratory bench-scale tests were completed to evaluate physical and chemical parameters associated with dissolution of a simulated Hanford saltcake waste by this method.

This task was performed for, and in collaboration with, River Protection Project (RPP) Retrieval Engineering, Retrieval System Development. This work was funded by the Tanks Focus Area (EM-50) under Technical Task Plan Number RL09WT22 and satisfies Milestone A.1-3, "Perform Saltcake Dissolution Retrieval Tests".

A saltcake slurry simulant was prepared based on the known composition of tank 241-S-102 waste and was used to conduct two separate tests. One portion was used in a preliminary shallow-bed leaching test in a bed 5.5 cm deep and 29 cm in diameter, and the remainder in a detailed deep-bed test 19 cm deep and 29 cm in diameter.

The initial shallow bed volume was 3.56 liters. 16.1 liters of water were uniformly sprinkled on the shallow bed (4.5 initial bed volumes) at the maximum manually controlled rate the bed could accept without forming a pool. The sprinkled water passed through the bed by gravity to produce 18.9 liters of leachate (5.3 initial bed volumes) in 1455 minutes of testing time. The initial area-specific flow rate achieved was 2.1×10^{-3} cm/min, which accelerated as the bed dissolved and channels formed, to a final rate of approximately 4.9×10^{-2} cm/min. One attempt to repair channels that formed in the shallow bed showed they were re-establishing within 0.7 liters application, and fully re-established within 3.5 liters application. The test removed 95% of the initial bed volume predominantly by dissolution of the solids. A small fraction of the solids was entrained in the leachate.

The deep bed test began with 12.4 liters of bed volume, and the same method of water application was used. No attempt was made to repair any spontaneous channels that formed in this test. 44.2 liters of water (3.6 initial bed volumes) were sprinkled on this bed in 6784 minutes of testing time to produce 53.8 liters of leachate (4.4 initial bed volumes) and remove 94% of the bed volume before termination due to the disappearance of the main soluble layer of bed material at a bed height of 1.1 cm. The initial maximum-absorbable sprinkling rate per unit area was approximately 2.7×10^{-3} cm/min, which accelerated through two separate episodes of channel formation and self-healing to a final constant (area-specific) flow rate of approximately 1.3×10^{-2} cm/min.

Samples of leachate and bed material were occasionally acquired during the deep bed test to follow the dissolution of a few representative chemical constituents. The results show that

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highly soluble minor constituents such as chloride and nitrite were removed by 0.81 initial bed volumes of water. Other, less-soluble minor constituents such as phosphate, sulfate, oxalate and fluoride were made even less soluble early in the test by the presence of the major constituents. Their solubility and removal actually increased as the major constituents themselves were removed, but the minor constituents were not completely removed by the end of the test. The largest constituent, nitrate, was also initially reduced in solubility until 2 initial bed volumes of water had been applied, after which it was almost completely (but not entirely) removed by completion of the test. Since nitrate was expected to be completely removed due to its solubility, the results suggest that equilibrium was not achieved between the nitrate and the leachant over all test stages, and that the nitrate dissolution process was perhaps limited by mass-transfer. Final dissolution efficiencies for the constituents must await forthcoming, more complete chemical analyses.

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1.0 INTRODUCTION

A potential scenario for retrieving saltcake from single shell tanks is the “Rainbird® sprinkler” method. Water is distributed evenly across the surface of the saltcake and allowed to percolate by gravity through the waste. The salt dissolves in the water, forming a saturated solution. The saturated liquid is removed by a saltwell pump situated near the bottom of the tank. By this method, there is never a large inventory of liquid in the tank that could pose a threat of leakage.

There are many variables or factors that can influence the hydrodynamics of this retrieval process. They include saltcake porosity; saltwell pumping rate; salt dissolution chemistry; factors that could promote flow channeling (e.g. tank walls, dry wells, inclusions or discontinuities in the saltcake); method of water distribution; plug formation due to crystal formations or accumulation of insoluble solids. A brief literature search indicates that very little experimental data exist on these aspects of saltcake dissolution (Wiersma 1996, 1997).

The tests reported here were planned (Herting, 2000) to provide preliminary data and information for planning future, scaled-up tests of the sprinkler method.

2.0 TEST OBJECTIVES

The test objectives as formulated in reference (Herting, 2000) are repeated essentially verbatim here.

The test is to provide a first characterization of water flow and salt dissolution through a porous salt simulant bed. More specifically, the test attempts to establish water accumulation and conditions in which steady state liquid addition/removal occurs.

Considering the exploratory nature and limited scope of this test, no attempt was made to establish scaling relationships and predictions to a full size tank. The test should, however, provide useful knowledge and elements necessary for defining and performing such scaled tests in the near future.

The saltcake simulant was placed in a cylindrical polycarbonate container to facilitate visual observation. Water was dripped in a uniform pattern onto the surface of the saltcake, and saturated liquid drained out a screened hole in the bottom of the tank (hence simulating retrieval of a saturated solution through a saltwell screen). The rate of water addition would be adjusted to avoid flooding the saltcake.

The physical and chemical parameters that were measured as a function of time during the test included:

- water addition rate

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- liquid drainage rate
- visual observations of flow patterns
- physical appearance and volume of saltcake
- chemical composition of drained liquid
- polarized light microscopy (PLM) analysis of solids.

In addition, measurements to detect the presence of liquid at various levels within the saltcake were to be considered.

The test was to be run twice – first on a shallow saltcake bed (5 cm bed depth) and then on a deeper bed (25 cm bed depth), both with the same bed diameter of 30 cm. The first five parameters listed above would be varied and measured with the shallow bed, and all six on the deep bed. The purpose of the shallow bed test was to allow:

- a first and qualitative idea of the scaling effect (the height:diameter ratio of the shallow bed approximates a typical single shell tank saltcake bed);
- an opportunity to make any necessary adjustments to the equipment design before committing the large amount of chemicals needed to prepare the deep bed;
- a chance to evaluate the amount of time it takes to saturate the liquid flowing through the bed, based on comparison of the initial effluent from the shallow bed test and the deep bed test.

These original objectives above evolved somewhat as work progressed and preliminary results were obtained. The significant changes to the objectives became:

- The average test vessel diameter was 28.7 cm i.d. after fabrication, rather than the nominal 30cm.
- The vessel floor became a full-diameter screen instead of a localized central screen to permit practical flow rates of leachate through the bed.
- The simulant was manufactured with more water than originally planned in order to make it manageable enough to mix, transfer and settle.
- The planned reconcentration and reuse of the 5 cm bed test materials for inclusion in the subsequent deep bed test was found to require too much time and was not done.
- The larger test began with a bed height of 19 cm instead of the planned 25 cm due to the nonuse of the 5 cm bed test materials, and additional settling of the simulant slurry whose water content was greater than originally planned.

3.0 TEST DESCRIPTION

3.1 Simulant Selection and Composition

The rationale for the simulant recipe is detailed in reference (Herting, 2000) and is repeated essentially verbatim here. The simulant was prepared by a process similar to the way the actual

saltcakes were laid down in the single-shell tanks, through a combination of evaporation and cooling.

Tank S-102 saltcake was selected as the basis for the composition of the simulant in consideration of the following:

- The saltcake in S-102 is representative of a large fraction of Hanford saltcakes.
- S-102 saltcake is essentially the same as the saltcake in tanks S-103 and S-105, which are candidates for the first in-tank retrieval tests.
- S-102 saltcake has been fully characterized through core sampling.

Two core samples were taken from tank S-102 in 1996. Both core samples (core 125 and core 130) contained 11 segments. Segments 2-8 from both cores contained saltcake. The average analytical results for these segments are shown in Table 1.

The first two columns in Table 1 show the concentrations of the components in the S-102 core sample saltcake segments (segments 2-8) as reported in the Tank Characterization Report (Anantatmula 1999). The third column shows the components in the form of their assumed species as they are present in the saltcake. The fourth column gives the analyte weight percent (column 2) adjusted for the species weight by multiplying by the appropriate mole weight ratio. For example, Al is converted to AlO_2^- by multiplying by the factor $[(26.9815 + 2 \times 15.9994) / 26.9815]$.

The simulant composition cannot follow the S-102 composition perfectly, because the mass and charge balances for the simulant are constrained to be 100% and 1.00, respectively. Therefore, some adjustments had to be made. These adjustments are somewhat arbitrary, and any number of combinations could have been used.

Tank BY-106 contains saltcake that is similar to that in S-102, so its composition (last column in Table 1) was used as a guide in making the needed adjustments. Except for Na, no component concentration was raised above the concentration found in BY-106. The Na concentration had to be raised more to bring the charge balance up to 1.00. The final balanced simulant composition matches the S-102 composition for all species except K^+ , Na^+ , F^- , SO_4^{2-} , $\text{C}_2\text{O}_4^{2-}$, CO_3^{2-} , and H_2O , all of which were raised to increase the mass balance to 100%.

The recipe for achieving this composition is attached appears as Appendix A. Minor deviations from the recipe are listed in the procedure section.

Table 1. Core Sample and Simulant Concentrations in Weight Percent.

Analyte	S-102 ^a	Species	S-102 ^b	Simulant	BY-106 ^c
Al	1.10	AlO ₂ ⁻	2.40	2.40	3.50
B	0.05	B(OH) ₃	0.29	0.29	not reported
Ca	0.03	Ca(OH) ₂	0.055	0.055	0.02
Cr	0.19	Cr(OH) ₃	0.38	0.38	0.22
Fe	0.13	Fe ₂ O ₃	0.19	0.19	0.03
K	0.09	K	0.09	0.24	0.24
Na	22.0	Na	22.0	25.54	25.0
Si	0.04	SiO ₂	0.086	0.086	0.04
F ⁻	0.03	F ⁻	0.03	0.62	0.62
Cl ⁻	0.28	Cl ⁻	0.28	0.28	0.16
NO ₂ ⁻	3.06	NO ₂ ⁻	3.06	3.06	2.71
NO ₃ ⁻	45.6	NO ₃ ⁻	45.6	45.6	40.5
PO ₄ ³⁻	0.99	PO ₄ ³⁻	0.99	0.99	0.30
SO ₄ ²⁻	0.60	SO ₄ ²⁻	0.60	1.20	1.20
C ₂ O ₄ ²⁻	0.31	C ₂ O ₄ ²⁻	0.31	1.26	1.26
TIC	0.54	CO ₃ ²⁻	2.70	3.50	7.15
TOC	0.20	CH ₃ COO ⁻	0.45	0.45	0.16
OH ⁻	0.42	OH ⁻	0.42	0.42	1.14
H ₂ O	13.1	H ₂ O	13.1	13.44	14.7
Mass Balance ^d			93.0	100.00	99.0
Charge Balance ^e			0.94	1.000	0.94

^a Tank Characterization Report (Anantatmula 1999, Table B3-8).

^b Analyte concentrations converted to weight of assumed species.

^c BY-106 saltcake composite sample analysis (Herting 1998, Table 8-2).

^d Sum of species weights (should equal 100%; simulant constrained to be 100%)

^e Ratio of cation equivalents to anion equivalents (should equal 1.00; simulant charge balance constrained to be 1.00)

3.2 Apparatus

The testing vessel (Figure 1) was constructed by removing the bottom of a nominal 30 cm diameter polycarbonate tub and gluing it to the bottom of a 30 cm diameter Buchner funnel whose own top had been removed. This provided a transparent vessel with a full-width drain floor. The tub sides had a 2.9° taper giving it a smaller base than top, but it averaged an actual 28.7 cm i.d. over its height. The Buchner floor was lined with a woven plastic painter's filter screen (Figure 2) of approximately 0.5 mm x 0.1 mm mesh to contain the simulant slurry solids. A ruler indexed to the floor of the test bed was attached to the outside of the tub to gauge the heights of slurry material and pooled water in the test vessel.

The sprinkler was constructed by spot-gluing a length of plastic laboratory tubing in a spiral pattern to the inside of the slip-fit lid to the tub, then puncturing the tube in many places using a hypodermic needle (Figure 3.) Water was supplied to the sprinkler by an adjustable-speed peristaltic pump drawing from either a 2-liter graduated cylinder or a graduated 20-

liter carboy in order to track the cumulative volume applied, while the leachate was drained into a similar graduated cylinder or carboy to track the volume leached.

3.3 Procedure

The simulant was manufactured in 22 batches to permit heating each batch, to evaporate excess water and to obtain net weights on a laboratory scale. Minor deviations to the planned procedure (Appendix A) included:

- Discontinuing the additions of the chromium nitrate after 6 batches, because the color it imparted was becoming more intense than any real saltcake,
- Substituting rusted iron filings for Fe_2O_3 after two batches, in amounts calculated to make up the desired iron content, because it is more likely that the iron in real saltcake is in the form of a hydrous oxide rather than a red, refractory oxide such as Fe_2O_3 ,
- Discontinuing the addition of SiO_2 after six batches in deference to the corrosive input of silica from the preparation beakers, and,
- Utilizing combinations of $\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O}$, NaOH , and $\text{Na}_2\text{HPO}_4 \cdot 7\text{H}_2\text{O}$ as needed to achieve the desired phosphate and hydroxide weights using available reagents, since the dodecahydrate was in short supply.

Twenty batches were manufactured and consolidated, and then a portion was taken for the shallow bed test. Deviating again from the plan, the products of the shallow bed test were not reused. Instead, the remaining two batches were manufactured and added to the unused portion and that entire volume was used for the deep bed test.

For each test, the simulant was mixed and the appropriate portion was transferred to the test vessel to settle, drain and/or decant completely before beginning sprinkling operations. A video camera was set to view and record the side of the test vessel and measuring scale for 2 seconds at 10-minute intervals. Sprinkler pump operations quickly evolved into a manually attended, as-needed, on-off duty cycle because even the lowest pump speed setting would generally cause excessive pooling on top of the test bed if left on for very long. Sprinkling was also discontinued each evening and weekend and resumed at the beginning of the next workday.

While testing was in progress, manual observations of the volumes of water applied to the bed, the volumes leached from the bed, the bed height and the pool height were logged on data sheets. Also recorded were the appearance of the bed surface, and indications of channeling.

For the shallow bed test only, an attempt was made to repair channels in the bed when they first appeared. This was to learn whether they could be repaired, because channeling reduces dissolution efficiency. However, channels did quickly redevelop as discussed below, and this operation was not carried out on the deep bed test.

During the deep bed test, samples were thieved from the surface and mid-depth of the bed at 12 drainage intervals for subsequent Polarized Light Microscopy (PLM) analysis of phases.

Concurrently 12 one-liter portions of the leachate were captured, sub-sampled and clarified for analysis of dissolved constituents.

4.0 RESULTS

4.1 Simulant Behavior

The simulant composition as actually produced is provided in Table 2.

Table 2. Simulant Composition.

Reagent	Weight in Simulant (g)	Percent in Simulant
NaNO ₃	20144.96	53.50
H ₂ O	7883.82	20.94
Na ₂ CO ₃	2040.06	5.42
NaAl(OH) ₄	1584.44	4.21
NaNO ₂	1514.70	4.02
Na ₃ PO ₄ ·12H ₂ O	1220.00	3.24
Na ₂ C ₂ O ₄ ·2H ₂ O	803.22	2.13
Na ₂ SO ₄	585.64	1.56
NaOH	452.99	1.20
NaF	452.10	1.20
CH ₃ COONa·3H ₂ O	206.36	0.55
KNO ₃	204.82	0.54
NaCl	152.24	0.40
Cr(NO ₃) ₃ ·9H ₂ O	132.84	0.35
B(OH) ₃	95.70	0.25
Na ₂ HPO ₄ ·7H ₂ O	86.04	0.23
FeOOH	63.43	0.17
Ca(OH) ₂	18.26	0.05
SiO ₂	7.68	0.02
Fe ₂ O ₃	5.70	0.02
Totals	37655.00	100.00

When allowed to settle, the simulant would settle to a dense but uncohesive mass under a clear mother liquor. The solids would segregate into a ~ 1 cm top layer of very fine reddish opaque fines over a coarser, less opaque, less reddish body. This mass could be resuspended to thick slurry with forceful stirring, the force being needed to remix densely packed, uncohesive particles of low voidage with liquor.

When the appropriate amount of mixed slurry was poured into the test vessel, it would resettle into a bed of solids and the excess mother liquor would be allowed to drain out before testing began. The rate of pre-test liquor drainage was considerably faster while the

bed was still loosely packed than the rate of subsequent flows during testing when the bed was tightly packed. This confirms that the drain system offered considerably less resistance to flow than did the beds themselves, and therefore the flows during actual testing were governed mostly by bed resistance.

The shallow bed test portion settled to a 5.5cm high bed (volume 3.6 liter) and a total of 750 mL of pre-test drained liquor before drainage ceased, while the deep bed test portion settled to a 19.1 cm high bed (bed volume 12.4 liter) and 2480 mL of liquor. Both beds, despite being completely drained, maintained complete liquid saturation without any air voids as viewed from the sides and top. Furthermore, when sprinkling operations commenced, each bed quickly responded by draining clear leachate (in less than 6-10 minutes for the shallow bed, and less than 5-20 minutes for the deep bed). This indicated a fairly complete hydraulic connection. When sprinkling was suspended each night or weekend, the drainage would continue for hours but be complete by morning. The deep bed would also noticeably shrink. Each bed would still be saturated, and the response to resumption of sprinkling would be as rapid as the last resumption of sprinkling.

Flow results and chemical analyses discussed below suggest the initial porosity of this settled bed material was on the order of 10%.

4.2 Shallow Bed Test

The raw test data appears in Appendix B. Plots derived from the data appear in Figures 4 and 5. The video did not provide useful information due to poor lighting and width of field.

The slurry initially transferred to the test bed was allowed to settle and drain overnight to a bed height of 5.5 cm (bed volume 3.6 liter) and 750 mL of drained mother liquor. The drainage had ceased by morning, yet capillary action held the bed completely saturated with liquor. Sprinkling at the maximum rate the bed would accept was accomplished by manually observing the buildup of surface water, then stopping the sprinkler pump until the buildup was absorbed. This meant the pump had to be turned on and off frequently, because it would quickly cause water pooling even at its lowest speed setting. Since the bed was always internally saturated with liquid, there could be no observations of pooling at the bottom of the vessel. The sprinkler lid was occasionally rotated to remove any bias in application across the bed surface.

Because testing was suspended at night and over weekends, the applied, pooled, drained and bed volumes were plotted vs. "test time" -- the elapsed time minus the idle intervals. The results can be viewed in Figures 4 and 5. They reveal slight discontinuities in drainage and bed volumes due to drainage and resultant bed shrinkage during the idle period. On the whole, however, the results were sufficiently continuous with test time to warrant interpreting the data in this way. It should be noted that drainage responded within a few minutes to applications, even after extended idle periods.

Also note that more volume drained than was applied. This is primarily due to additional drainage of interstitial liquor as the bed dissolves. Even so, the terminal drainage volume

(18.9 liter) combined with the remaining bed volume (0.2 liter) and the pooled volume (0 liter) was less than the total applied volume (16.1 liter) combined with the initial bed volume (3.6 liter) by -0.56 liter, or -3%. This deficit was reasonable considering the volumes of solution of the constituents, imprecision in volume determinations and possibly, to a small extent, evaporation. The complexity of the simulant makes it impossible to estimate the volume deficit to expect when its constituents are dissolved and diluted. However, it is worth noting that two significant constituents, NaNO_3 and Na_2CO_3 , both produce volume deficits on the order of one or two percent when individually dissolved in water to dilutions comparable to these tests (Weast, 1977).

The acceleration in bed throughput after 790-900 minutes test time shown in Figures 4 and 5 was due to the onset of channel flows in the bed, as evidenced by localized depressions, vortices and bubbling at the top of the bed, accompanied by solids appearing in the leachate. Some of the channeling appeared to occur at the bed wall, as viewed from the side. These were not outright holes that would show through to the screen. 800 minutes corresponded to a bed depth of approximately 4.5 cm. and 1.2 liters of water application. One attempt was made to repair these channels by stirring the immediate vicinity to learn if leachant-wasting channel flows could be repaired, but the repair was only temporary. The channeling began to form again by 4.2 cm bed depth and 2.7 liters application, and was fully re-established by 3.4 cm bed height and 5.6 liters application. The test was terminated when the screen began to show through "valleys" in the test bed. A summary of test data appears in Table 3.

Table 3. Shallow Bed Test Summary Data

Datum	Initial	Final	Ratio to Initial Bed Volume
Bed Diameter cm	28.7	28.7	
Bed Height cm	5.5	0.3	
Bed Volume mL	3558	194	
Bed Remaining mL		194	0.0545
Elapsed Time min	0	7262	
Test Time min	0	1455	
Applied Water mL	0	16100	4.5
Area-Specific Application Rate cm/min	0.0021	0.049	
Drained Leachate (mL)	0	18900	5.3
Volume Deficit mL	0	-564, (-3%)	

4.3 Deep Bed Test

The deep bed test data appears in Appendix C, and Figures 6 and 7 are derived from that data. The slurry not used for the shallow bed test was supplemented with the final two batches, then mixed and poured into the cleaned test vessel. Overnight drainage and decanting yielded 19.1 cm (bed volume 12.4 liters) of drained-but-saturated test bed and 2480 mL of liquor. The bed settled to 1-2 cm of very fine, opaque, redder material on top of a coarser, less opaque, less red mass. This test was also conducted by a manually attended, on-off sprinkler pump control to provide the maximum sprinkling rate the bed would accept without observing excessive pooling, but unlike the previous test, there was no attempt to repair or modify any spontaneous channeling. Also unique to this test was the taking of samples from the bed and leachate for subsequent chemical analysis.

The video record showed that overnight drainage and bed shrinkage would be virtually complete in 8 hours after adjournment, but that slightly more would occur before morning.

Once again, channeling manifested itself in the same ways as in the shallow bed test, except that none of the channeling appeared to be at the bed wall. No attempt was made to repair the channels and all the channels healed themselves in 10 liters or less additional drainage, possibly due to the fines in the bed. In contrast to the shallow bed, the first channeling episode didn't appear until at least 4.5 cm of bed height had disappeared. This gave a greater opportunity for top-layer fines to accumulate, since they appeared to be insoluble. The fines were observed to migrate into a channel or depression, encouraged by the splashing droplets from above. This may have contributed to plugging a channel. Related to this, the excursions in flow rates (Figures 6 and 7) were not as dramatic as with the shallow bed test, and had a more limited duration in comparison to the shallow bed.

Figure 6 indicates the drainage volumes where samples were taken. Samples of the bed were taken separately from the surface and from the bed mid-depth using a small thief, while leachate samples were collected by capturing a liter terminating at the indicated drainage value, then sub-sampling that liter. Thieving was done with a minimum of bed disturbance, and no channeling seemed to occur as a result of the sampling actions.

As sprinkling progressed, the bed surface became very topographically rough on the few-centimeter scale, complete with columnar structures and puddles. The gross slope of the surface also came to tilt several centimeters over the course of testing despite occasional random rotation of the sprinkler lid to reduce bias. Understandably this made the estimates of bed and pool volumes based on a single index scale very crude. Towards the end of the test, the topography and slope returned partially to a less tilted state with grains of white material beginning to appear, but the puddling and slope were still pronounced. Figures 8 and 9 show views of the bed from the side and top after test termination.

The test was terminated when the bottom layer was no longer visible, only the top, fine layer and its acquired white constituent remained. The screen was still fully covered. Possibly upwards of twice the bed volume remained than was estimated by the single index height reading of 1.1 cm, due to the remaining roughness, tilt and mounding taken by the bed

surface, but any attempt to make a correction would only introduce more uncertainty. Figures 8 and 9 may convey some idea of the situation.

A total of perhaps 1.5 liters of bulk solids were settled in the 54 liters of leachate. The final volume deficit of combined drainage and remaining bed volumes over combined applied water and initial bed volumes was 2 liters, or -4%. This was not unreasonable in light of the level of precision in the various volume measurements combined with the volumes of solution of the bed components and perhaps some evaporation of leachate.

The summary data of the deep bed test appears in Table 4.

Table 4. Deep Bed Test Summary Data

Datum	Initial	Final	Ratio to Initial Bed Volume
Bed Diameter cm	28.7	28.7	
Bed Height cm	19.1	1.1	
Bed Volume mL	12356	712	
Bed Remaining mL		712	0.058
Initial Porosity			<0.1*
Elapsed Time min	0	30137	
Test Time min	0	6784	
Applied Water mL	0	44200	3.6
Area-Specific Application Rate cm/min	0.0027	0.013	
Drained Leachate (mL)	0	53.8	4.4
Volume Deficit mL	0	-2065, (-4%)	

*Estimated by Density Change in Leachate

4.4 Deep Bed and Leachate Chemistry

Five of the thirteen samples were submitted for ion chromatography (IC) analysis to yield concentrations for fluoride, chloride, nitrite, nitrate, phosphate, sulfate and oxalate. Also, all of the samples, including one from the pre-test drained mother liquor, had their liquid densities determined. The leachate chemical results are plotted against drained volume in Figures 10, 11 and 12. These analyses did not provide data to track the significant aluminate and carbonate constituents due to budget constraints. However, all the samples have been retained for more complete future analyses.

The density data in Figure 10 show a drop in density from 1.44 to 1.38 g/mL had occurred before 1.3 liters had drained, probably due to at least the partial displacement of retained liquor by the breakthrough of less-concentrated leachant. What followed was a period of roughly constant density of 1.36-1.38 g/mL to about 23 liters, corresponding to the

sodium nitrate, 1.37 g/mL (Perry, 1984). Thereafter the density dropped quickly to a lower residual value of 1.06 g/mL by 35 liters of drainage, and remained there until the test's end. This corresponded to the rapid depletion of nitrate, the major bed constituent, leaving behind less-soluble, minor constituents.

All the chloride and nitrite had apparently been flushed from the bed by 10 liters' drainage. The nitrate however was initially suppressed from dissolving in the liquid phase, and then began to be removed, and finally was significantly depleted in correspondence with the drop in density. The solubilities of fluoride, phosphate, sulfate and oxalate were also suppressed in early samples, but steadily rose to ever-greater concentrations in the leachate throughout the remainder of the test. All these observations were predicted by the plan (Herting, 2000), based on the idea that as the leachant gathers ionic strength by taking up major constituents, the less-soluble constituents reprecipitate in the bed. Later, when the major constituents are removed, these minor constituents become more soluble and hence more mobile.

All the thief samples from the deep test bed were analyzed by Polarized Light Microscopy (PLM) to identify phases present and estimate their relative abundance. PLM analysis can identify sufficiently large crystal phases through a combination of crystal habit, refractive index and light polarization. Figures 13 and 14 are typical of the observations made. The former is from a bed surface sample taken at 1.0 liters water application, while the latter was from a surface sample taken at 6.7 liters application. In these figures, there are two kinds of crystals visible. The brighter easily seen crystals constitute NaNO_3 , while the more ghostly, transparent crystals are $\text{Na}_7\text{F}(\text{PO}_4)_2 \cdot 19\text{H}_2\text{O}$.

The PLM analyses reported that NaNO_3 and the double salt $\text{Na}_7\text{F}(\text{PO}_4)_2 \cdot 19\text{H}_2\text{O}$ were the only two phases positively identified. Other phases were certainly present, but their particle sizes were too small to permit identification. The two identified phases qualitatively constituted most of the mass early in the test, and retreated to the minority by the test's end, but the changes in ratios of relative compositions as a function of drainage were gradual. The double salt's prominence remained throughout the test. Based on qualitative observations, the differences between bed surface and bed interior were subtle, with a slight relative depletion of sodium nitrate at the surface in comparison to the interior.

Table 5. Estimated Dissolution Mass Balance

The calculation of chemical constituent mass balance can only apply to those constituents actually dissolved in the leachate, not to those in the solids that were merely sluiced there by solids entrainment in the leachate.

Nonetheless, one can produce a crude mass balance of the analyzed anions by summing the trapezoidal areas under the plotted points and dividing by the total constituent mass in the initial bed. This summing should further underestimate the true total removal from the bed since there is yet no analysis for either the pre-test interstitial liquor or the last bit of

leachate. The current results are presented in Table 5. Many of the values will increase when future analytical results of all the samples are received.

Constituent	Initial Bed Mass (gm)	Approx. Percent Dissolved
Cl ⁻	66	53 ¹
C ₂ O ₄ ²⁻	296	36 ²
F ⁻	145	58
NO ₂ ⁻	719	49 ¹
NO ₃ ⁻	10597	107
PO ₄ ³⁻	239	39 ²
SO ₄ ²⁻	282	57 ²

¹Substantial fraction may be in initial liquor

²May be high (Used less-than values)

The remaining 6% of the bed at test's end had lost its underlying, granular layer to leave the fines on the top layer, but also some white material. This certainly consists mostly of the remaining mass of minor, poorly soluble simulant constituents, or of compounds derived from them.

5.0 DISCUSSION

The comparison of flow-rates between the two tests indicates the following:

- The flow rates of both the shallow-bed and deep-bed tests were comparable in the early stages of each test, even though bed heights were different (Figure 15; recall that bed heights were at their maxima at the beginning of their respective tests). However the channeling in the shallow bed test overwhelmed the comparability in its later stages (Figures 4 and 5).
- The deep bed's ability to self-heal its channels resulted in final-stage flow rates more or less constant with changes in bed height (Figures 6, 7 and 15).
- The flows were not application-limited -- when the sprinkling rate got too high, the applied water would begin to pool on top of the bed.

One intuitively expects bed flow rate at constant pressure drop to be inversely proportional to bed height, and so a bed 3.5 times as high ought to have 1/3.5 times the flow rate. Recall however that these beds were sprinkled at the maximum absorption rate, and that gravity alone, operating across the bed, is the driving force for flow. To explain these disparate observations, we investigate the possibility that the gravitationally driven flow through the bed could be independent of bed height. In incompressible flow through granular beds:

$$\Delta P = KG^2L$$

where P is pressure, G is area-specific mass flow rate, L is bed height, and K is a constant collecting the porosity, particle size and other bed parameters (Perry, 1984). The steady flow is driven only by gravity across the bed, so the head loss exactly matches the hydrostatic head that would exist at zero flow, (Holland, 1974):

$$\Delta P = \rho g L$$

where ρ is liquid density and g is the gravitational acceleration constant. We also recognize that our area-specific flow rates are volumetric:

$$G = \rho \left(\frac{q}{A} \right)$$

where q represents flow rate and A represents area. Combining these three relations leads to:

$$\left(\frac{q}{A} \right) = \sqrt{\frac{g}{\rho K}} \equiv K'$$

where K' is a new overall constant, and bed height has canceled out entirely.

We do not expect K' to be the same at the start and end of a test, because bed parameters have changed by way of slurry dissolution. However, for both beds at their earliest stages, this explains the comparable rates in terms of comparable bed parameters despite differing bed heights. The constant flow rate as a function of bed height is also explained at the late stages of the deep bed test, albeit with a different K' representing a more depleted, more open matrix. Of course we cannot expect this expression to hold when channels form.

This relation would also be invalid if the capillarity that held liquid in the drained bed were significant. We argue however that once flow has been re-established, the capillarity that holds static liquid in the bed ceases to be supplied by the miniscule bed particles and is replaced through wetting by a much less significant capillarity of the larger painter's screen or Buchner drain holes.

An idea of the deep bed's initial porosity can be inferred from the density data. The initial bed volume of 12.4 liters was in a state of complete saturation, yet had ceased draining before sprinkling operations began. Within 1.28 liters of drainage after sprinkling began, the leachate density had already dropped from the interstitial liquor value, suggesting that liquid other than the retained liquor was already breaking through. This sets an upper bound of approximately 10% on the initial bed porosity, assuming a uniform, non-diffusive flow front through the bed. No doubt the true porosity continually changed as leaching progressed.

The patterns of chemical dissolution implied by the leachate chemistry and PLM data are generally consistent. One can understand why nitrate, phosphate and fluoride were still

appearing in the leachate towards the end because both NaNO_3 and the double salt $\text{Na}_7\text{F}(\text{PO}_4)_2 \cdot 19\text{H}_2\text{O}$ were identified in the corresponding bed samples. The leaching of phosphate, sulfate, fluoride, oxalate and other anions representing less-soluble compounds was clearly being suppressed in the early stages, and later these anions were becoming more soluble. The combined effect of the major, more-soluble slurry constituents such as nitrate, nitrite, hydroxide and carbonate were presumably providing the suppression through their contributions to the leachant's ionic strength until they could be flushed away.

The solubility of nitrate itself appears to have been suppressed in the early stages, presumably due to the initially high ionic strength contributed by other constituents such as carbonate, hydroxide and nitrite, and it was never completely flushed away by 44 liters of water, as it should have been according to equilibrium solubility. Our approximate mass balance on the nitrate is consistent with virtually all the nitrate having been removed, but mass balance based on nitrate analyses is subject to measurement uncertainty. PLM analysis is not, when positive identification is made in the last sample. The results raise questions as to whether leaching is operating at equilibrium with respect to the slurry's largest component.

The nitrite and chloride salts are generally highly soluble and were in lesser amounts than nitrate in the original slurry. A large portion of their masses could well have already been dissolved in the liquor associated with the slurry. Hence, it is plausible that their rapid depletion in the leachate is due to mere displacement of interstitial liquor, and their mass balance accountability would improve substantially if the pre-test drained liquor were to be chemically analyzed.

One can make crude extrapolations of the bed heights and water application data to estimate how much additional water might have been required to remove the beds entirely. For the shallow bed, this extrapolation arrives at 2.5 liter, or 0.7 additional initial bed volumes. For the deep bed, the figure is an additional 17 liters, or 1.4 additional initial bed volumes.

6.0 CONCLUSIONS

The initial shallow bed volume of slurry described in this report was 3.56 liters in a 28.7 cm diameter, drainable tank. 4.5 initial bed volumes of sprinkled water, at the maximum manually controlled, gravity driven rate the bed could accept without forming a pool, managed to remove 95% of the bed volume by dissolution or entrainment and produce 5.3 initial bed volumes of leachate in 1455 minutes of testing time. The initial area-specific flow rate achieved was 2.1×10^{-3} cm/min, which accelerated as the bed dissolved and channels formed, to a final rate of approximately 4.9×10^{-2} cm/min. One attempt to repair channels that formed in the shallow bed showed they would quickly re-establish themselves within 1 initial bed volume of application. The combined ending bed and leachate volumes were 3% less than the combined applied water and initial bed volumes.

The deep bed test was begun with 12.4 liters of bed volume in the 28.7cm drainable tank, and the same method of water application was used. No attempt was made to repair any spontaneous channels that formed in this test. 3.6 initial bed volumes of water were

sprinkled on this bed in 6784 minutes of testing time to produce 4.4 initial bed volumes of leachate and remove 94% of the bed volume before termination. The final volume deficit in this test was -2.1 liters or -4% of the initial bed volume plus applied water volume. The initial maximum-absorbable sprinkling rate per unit area was approximately 2.7×10^{-3} cm/min, which accelerated through two separate episodes of channel formation and self-healing to a final constant (area-specific) flow rate of approximately 1.3×10^{-2} cm/min.

The leaching tended to preferentially remove more-soluble simulant constituents from less-soluble constituents by solubility suppression of the latter. Almost all of the major constituent, nitrate, was removed, while significant fractions of the minor constituents remained in the residual bed volume. The trends in bed volume suggest they would also be removed in less than two additional bed volumes' water application.

7.0 RECOMMENDATIONS

The results of these tests provide an initial basis for the design of scaled tests. The purpose of these tests should be to provide data needed to model the bed behavior in a full-scale tank.

8.0 ACKNOWLEDGEMENTS

J. R. Smith provided able and innovative apparatus fabrication.

K. McDonald and J. K. Watts produced the simulant slurry.

J. R. Smith and J. K. Watts both conducted careful testing.

D. L. Herting provided the slurry preparation procedure and PLM analyses.

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Figure 1. Test Apparatus.

Figure 2. Macrograph of Paint Filter Screen.

Figure 3. Sprinkler Apparatus.

Figure 4. Shallow Bed Volumes.

Figure 5. Shallow Bed Area-Specific Flow Rates.

Figure 6. Deep Bed Volumes.

Figure 7. Deep Bed Area-Specific Flow Rates.

Figure 8. Deep Bed at End of Test -- Side View.

Figure 9. Deep Bed at End of Test -- Top View.

Figure 10. Leachate Density

Figure 11. Leachate High Concentrations.

Figure 12. Leachate Low Concentrations.

Figure 13. Polarized Micrograph of Deep Bed Surface Sample after 1 liter Applied Water.

Figure 14. Polarized Micrograph of Deep Bed Surface Sample after 6.7 Liters Applied Water

Figure 15. Area-Specific Drainage Flow Rates vs. Bed Heights.

APPENDIX A
PROCEDURE FOR PREPARING SIMULATED SALTCAKE

D. L. Herting

Consisting of 9 pages, including the cover page

This document is a "Test Procedure" as defined in the WMH-310 Manual ("Hanford Analytical Laboratory Operating Administration"), Section 1.9, "Laboratory Test Planning", Rev. 2, July 19, 1999. The pages of this document will be affixed to a controlled laboratory notebook for use in the laboratory. Review and approval of the document is required before laboratory work can commence.

The Department of Energy's Tanks Focus Area (EM-50) has approved funding for a project to study dissolution behavior of single shell tank saltcake waste to support long-range waste retrieval programs. The Test Plan that describes the work is HNF-6519, "Test Plan for Simulated Saltcake Retrieval Test", D. L. Herting and J. C. Person, July 17, 2000. This Test Procedure describes the steps for preparing the saltcake simulant that will be used for the testing.

Briefly, the saltcake simulant is prepared by evaporation and cooling of an aqueous salt solution to simulate the method by which saltcakes were laid down in the single shell tanks. Due to the large volume of saltcake required for the tests (3.5 L for the shallow bed test and 18 L for the deep bed test), the simulant is made in many small batches using 2 L glass beakers. The product saltcake is stored and eventually blended in a polycarbonate tank identical to the one that will be used for the tests, except that it has not been fitted with the equipment required for the test measurements. After blending, the saltcake is transferred to the test tank.

This test procedure will not generate any hazardous waste, as all of the chemicals used will be saved for future testing. The waste resulting from the eventual use of the simulated saltcake (that testing being covered under a separate Test Procedure) has been pre-designated. The Waste Stream Fact Sheet and Waste Compatibility Assessment are included in the above-referenced Test Plan.

APPROVAL/REVIEW SIGNATURES:

D. L. Herting, Cognizant Scientist
Process Chemistry

Date

L. L. Lockrem, Manager
Technology Project Management

Date

Preliminary Preparations

Calibrate the polycarbonate receiver tank by marking it with a vertical scale using a permanent marker on the outside of the tank at 1 cm intervals, with a longer hash mark for each 5 cm. Number the 5 cm hash marks starting with zero at the level of the inside bottom of the tank.

Ensure that all of the chemicals shown on the Reagent List are available in the laboratory. Record on the Reagent List any pertinent information from the label of each bottle, e.g., formula weight, manufacturer, purity, hydration state, etc.

Batches #1 - #4 will be combined to make the Shallow Bed saltcake.

The Deep Bed saltcake will be prepared from batches #5 - #22, plus the evaporated product recovered from the Shallow Bed test.

Reagent List

Name	Notes
sodium aluminate, $\text{NaAl}(\text{OH})_4$	
boric acid, $\text{B}(\text{OH})_3$	
calcium hydroxide, $\text{Ca}(\text{OH})_2$	
chromium(III) nitrate, $\text{Cr}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$	
iron(III) oxide, Fe_2O_3	
potassium nitrate, KNO_3	
silicon dioxide, SiO_2	
sodium fluoride, NaF	
sodium chloride, NaCl	
sodium nitrite, NaNO_2	
sodium nitrate, NaNO_3	
sodium phosphate, $\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O} \cdot 0.25\text{NaOH}$	
sodium sulfate, Na_2SO_4	
sodium oxalate, $\text{Na}_2\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$	
sodium carbonate, Na_2CO_3	
sodium acetate, CH_3COONa	
sodium hydroxide, NaOH	

Reagent Checklist

(place check or hash mark after chemical added to beaker,
one mark for each batch)

Formula	Weight, grams	Checkmarks
NaAl(OH)_4	72.02	
NaOH	19.89	
Na_2CO_3	92.73	
$\text{Na}_2\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$	36.51	
$\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O} \cdot 0.25\text{NaOH}$	61.00	
Na_2SO_4	26.62	
NaF	20.55	
NaCl	6.92	
NaNO_2	68.85	
KNO_3	9.31	
CH_3COONa	9.38	
NaNO_3	915.68	
B(OH)_3	4.35	
Ca(OH)_2	0.83	
$\text{Cr(NO}_3)_3 \cdot 9\text{H}_2\text{O}$	22.14	
Fe_2O_3	2.85	
SiO_2	1.28	

Prepare Batch #1 Solution

1. Place a magnetic stirbar in a 2 L glass beaker labeled "Batch 1". Record the tare weight (beaker + stirbar) on the Data Sheet.
2. Fill the beaker about ½ full with deionized water and place the beaker on a stirrer hotplate. Add a thermometer or thermocouple to the water to monitor the temperature. Heat the water to 70-90 °C while stirring.
3. Weigh out the amount of **sodium aluminate, NaAl(OH)₄**, shown on the Reagent Checklist using a weigh boat or small beaker. [Weigh out all chemicals in this procedure to +/- 1% of the value shown in the table.] Gradually add the sodium aluminate to the hot water.

Go on to step 4 as soon as most of the sodium aluminate has dissolved. If too much time elapses before step 4, aluminum hydroxide will begin to precipitate in the beaker.

Caution: Addition of sodium hydroxide in step 5 will cause localized heating of the solution. If the NaOH is added too quickly, this heating could cause localized boiling of the solution, which would result in bumping and splashing of the hot liquid. Add the NaOH slowly enough to prevent localized boiling.

4. Turn off the heater. Slowly and carefully add the amount of **sodium hydroxide, NaOH**, shown in Table 1. The NaOH may be added as solid pellets or as 50% solution. If 50% solution is added, double the weight shown in Table 1.

Note: Add the remainder of the chemicals in the order shown on the next page (steps 5-19). After each addition, stir the solution long enough to allow the solid to dissolve, but do not expect complete dissolution (i.e., solution may remain cloudy.) The last five components (steps 15-19) are not expected to dissolve appreciably, but should be given ample opportunity to disperse uniformly in the slurry. Adjust the heater as necessary to keep the temperature between 50 °C and 90 °C throughout the remainder of the reagent addition (steps 5-19).

If the slurry becomes too thick to allow dissolution of the solids that are expected to dissolve, water may be added, but do not exceed a total volume of ~1900 mL as measured by the markings on the side of the beaker.

5. Add sodium carbonate, Na₂CO₃.
6. Add sodium oxalate, Na₂C₂O₄.

7. Add sodium phosphate dodecahydrate, $\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O}$.
8. Add sodium sulfate, Na_2SO_4 .
9. Add sodium fluoride, NaF .
10. Add sodium chloride, NaCl .
11. Add sodium nitrite, NaNO_2 .
12. Add potassium nitrate, KNO_3 .
13. Add sodium acetate, $\text{NaC}_2\text{H}_3\text{O}_2$.
14. Add sodium nitrate, NaNO_3 .
15. Add boric acid, H_3BO_3 or $\text{B}(\text{OH})_3$.
16. Add calcium hydroxide, $\text{Ca}(\text{OH})_2$.

Caution: Chromium(III) nitrate is an acid, and may react violently with the caustic solution. Dissolve the solid in water as indicated, and add the solution slowly.

17. Dissolve the chromium(III) nitrate nonahydrate, $\text{Cr}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$, in ~50 mL water, and slowly add the solution to the beaker.
18. Add iron(III) oxide, Fe_2O_3 .
19. Add silicon dioxide, SiO_2 .

Proceed to "Evaporation and Cooling" on the next page.

Evaporation and Cooling, Batch #1

The goal of the Evaporation and Cooling portion of the procedure is to produce a saltcake slurry that contains approximately 5-10% supernatant liquid after settling at ambient temperature. The evaporation endpoint volume can be adjusted as necessary to achieve that goal.

20. Adjust the heater to maintain a temperature in Batch #1 slurry of 100 – 120 °C. (Avoid rapid boiling.) Allow the water to evaporate until the total volume of slurry reaches an evaporation endpoint volume of ~1000 mL.

Note: If the slurry becomes too thick to stir before reaching the evaporation endpoint volume, the evaporation may be stopped at that point.

21. Turn off the heater and allow the solution to cool to ambient temperature. Continue stirring, if possible, until the slurry reaches ambient temperature. If the stirrer stops because the slurry becomes too thick, the stirrer may be turned off while the slurry finishes cooling.
22. When the slurry reaches ambient temperature (probably after sitting overnight), turn off the stirrer if it was not turned off in step 21, and allow the slurry to settle for at least one hour. Evaluate whether the goal of 5-10% supernatant liquid by volume has been reached. (Is the volume of supernatant liquid 5% to 10% of the total slurry volume?)

If yes: proceed to step 23.

If $V_{\text{liq}} < 5\%$ of V_{slurry} , add 50 mL deionized water, stir with a stirring rod or spatula, and repeat step 22. (V_{liq} = volume of supernatant liquid; V_{slurry} = volume of total slurry including supernatant liquid.)

If $V_{\text{liq}} > 10\%$ of V_{slurry} , repeat steps 20-22 to evaporate more water.

23. Record the total weight of the beaker + stirbar + slurry on the Data Sheet.
24. Transfer as much of the slurry as is practical from the 2 L beaker to the polycarbonate receiver tank and place the lid on the tank. Rinse the beaker with deionized water, and add the rinsate to the Batch #2 beaker at any step in its preparation after step 14.

Data Sheet

Batch #	Gross Weight, g	Tare Weight, g	Net Batch Weight
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			

Check Weights:

Prepare Batch #2 - #22 Solutions

25. For each succeeding batch, repeat steps 1-24 for preparation of Batch #1 solution including Evaporation and Cooling EXCEPT:

Add rinsate from Batch #1 beaker (see step 24) to Batch #2 at any point after step 14 in Batch #2.

Similarly, add rinsate from Batch #2 beaker to Batch #3 beaker, etc.

Batches #1 - #4 will comprise the Shallow Bed saltcake.

The Deep Bed saltcake will be made from batches #5 - #22 plus the re-evaporated product of the Shallow Bed test.

Re-Evaporation of Shallow Bed Product

After the conclusion of the Shallow Bed test, collect all of the drained liquid fractions not used for chemical analyses plus the material that remains inside the polycarbonate tank. Evaporate the collected material according the instructions and criteria in steps 20-24.

This Concludes the Procedure for Preparing Simulated Saltcake

APPENDIX B

SHALLOW BED TEST DATA

Consisting of 5 pages including cover page

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Elapsed Time min	Testing Time min	Applied mL	Pooled mL	Drained mL	Bed Vol. mL	Bed Height cm	Pooling cm	Bed/Channeling Description	Action/Comment
0	0	0	0	0	3558	5.5		0 2 mm fines on top, moist , no channels	start pump
6	6	0	259	10	3558	5.5	0.4		stop pump
12	12	0	194	25	3558	5.5	0.3		
20	20	0	162	50	3558	5.5	0.25		
28	28	0	129	75	3558	5.5	0.2		
33	33	0	65	90	3558	5.5	0.1		
38	38	0	0	100	3558	5.5	0		
40	40	0	0	100	3558	5.5		0 a little broken on top	start pump
49	49	300	388	139	3493	5.4		0.6 (slight) channel on back outside wall	stop pump
64	64	300	356	180	3493	5.4	0.55		
71	71	300	323	190	3493	5.4	0.5		
81	81	300	323	208	3493	5.4	0.5		
91	91	300	291	225	3493	5.4	0.45		
103	103	300	259	240	3493	5.4	0.4		
111	111	300	259	255	3493	5.4	0.4		
126	126	300	259	270	3493	5.4	0.4		
136	136	300	259	290	3493	5.4	0.4		
145	145	300	226	300	3493	5.4	0.35		
155	155	300	226	310	3493	5.4	0.35		
173	173	300	194	332	3493	5.4	0.3		
186	186	300	162	348	3493	5.4	0.25		
200	200	300	162	360	3493	5.4	0.25		
213	213	300	162	375	3493	5.4	0.25		
275	275	300	129	430	3461	5.35	0.2		
303	303	300	97	440	3461	5.35	0.15		
320	320	300	97	450	3429	5.3	0.15		
330	330	#N/A	97	450	3429	5.3	0.15		Transfer 450 mL from discharge graduate to carboy
338	338	#N/A	0	450	3396	5.25		0 little crack on top + depressed in 2 sq cm area	
340	340	300	#N/A	450	3396	5.25	#N/A		start pump
346	346	350	259	500	3396	5.25	0.4	surface obliterated/smoothed by drops	stop pump
362	362	350	259	545	3396	5.25	0.4	surface obliterated with water	
372	372	350	226	600	3364	5.2	0.35		
415	415	350	129	660	3364	5.2	0.2	some puddling - wet surface	
1293	415	350	0	871	3041	4.7		0 bed drained but saturated, wet 2x2 cm depression under fines in center, one tiny path forming, otherwise very good	
1340	462	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		camera pan, then off
1346	468	350	0	871	3041	4.7			start adding flow
1355	477	600	453	871	3041	4.7	0.7	surface covered	
1361	483	900	518	871	3041	4.7	0.8		stop flow
1381	503	900	518	890	3041	4.7	0.8		
1405	527	900	453	900	3041	4.7	0.7		

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Elapsed Time min	Testing Time min	Applied mL	Pooled mL	Drained mL	Bed Vol. mL	Bed Height cm	Pooling cm	Bed/Channeling Description	Action/Comment
1430	552	900	453	910	3041	4.7	0.7		
1455	577	900	453	918	3041	4.7	0.7		
1485	607	900	453	920	3041	4.7	0.7		
1515	637	900	453	925	3041	4.7	0.7		
1545	667	900	453	930	3041	4.7	0.7		
1575	697	900	453	930	3041	4.7	0.7		
1605	727	900	453	940	3041	4.7	0.7		
1640	762	900	388	1006	3041	4.7	0.6		
1659	781	900	0	1160	3041	4.7		0 breakthrough channeled from back and sides of wall	
1660	782	900	0	#N/A	#N/A	#N/A			start flow
1674	796	1100	647	#N/A	2911	4.5	1		
1681	803	1300	#N/A	1250	2911	4.5	#N/A		Transfer graduate from discharge to carboy
1686	808	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		stop flow
1686	808	1600	970	1270	2911	4.5	1.5		
1695	817	#N/A	#N/A	2000	#N/A	#N/A	#N/A	suddenly broke through	Broke through
1695	817	#N/A	0	2000	#N/A	#N/A	0		Transfer graduate from discharge to carboy
1698	820	#N/A	0	2000	2911	4.5	0		start flow
1698	820	#N/A	#N/A	2000	#N/A	#N/A	#N/A		breakthroughs on walls opposite each other
1703	825	1900	0	2210	2846	4.4		0 bed mostly flat a 3rd hole opening @ the top center/back. a 4th hole top front	
1710	832	2100	0	2490	#N/A	#N/A		0 bed uneven channeling in multiple locations	
1713	835	2100	0	2650	2782	4.3	0		
1736	858	#N/A	#N/A	2750	2782	4.3	#N/A		patched the channel holes. Will restart on Monday
5645	858	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	see drawing sheet 2	Smoothed the surface and added a few drops of moisture to moisten. Smoothed 3 depressions that had developed over the weekend.
5687	900	#N/A	#N/A	2890	#N/A	#N/A	#N/A		
5690	903	2100	0	2890	2717	4.2	0	mostly flat	
5700	913	2600	518	3290	2717	4.2	0.8	covered with water	stopped flow. transferred drain graduate to carboy
5725	938	2600	#N/A	3520	2717	4.2	#N/A	new holes opened up-left wall sigmoidal crevasse & hole in from wall / right side hole in from wall	transferred drain graduate to carboy
5751	964	2900	0	3570	2717	4.2		0 bed smooth channel developed almost immediately at rear	
5772	985	3100	#N/A	4030	2523	3.9	#N/A	bed channeling	
5783	996	3300	259	4320	2458	3.8	0.4	small puddles some channels very large	

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Elapsed Time min	Testing Time min	Applied mL	Pooled mL	Drained mL	Bed Vol. mL	Bed Height cm	Pooling cm	Bed/Channeling Description	Action/Comment
5795	1008	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		stopped for another job
5824	1037	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		restart
5825	1038	4100	0	4960	2264	3.5	0	bad channels	
5833	1046	4200	0	5160	2264	3.5	0		moved drain to big carboy
5885	1098	5600	0	7000	2200	3.4	0	bad channels	
5895	1108	6000	0	7200	2135	3.3	0		
5905	1118	6100	#N/A	7500	2135	3.3	#N/A		stopped pump[?]
5965	1178	8100	518	9000	1941	3	0.8	bed moved and filled in some canyons channels collapsed and plugged enough to pool	rinsate clearing up
5972	1185	8100	323	9000	1941	3	0.5	95% covered by pool	
5980	1193	8200	323	9100	1941	3	0.5	95% covered by pool	equilibrium? pump adj. 1 linewidth
5997	1210	8600	388	9600	1941	3	0.6	98% covered by pool	
6012	1225	9100	388	10000	1941	3	0.6	98% covered by pool no channeling observed	
6025	1238	9300	323	10300	1876	2.9	0.5	100% covered by pool no channeling observed	
6033	1246	9600	194	10800	1876	2.9	0.3	100% covered by pool no channeling observed	
6045	1258	10100	0	11500	1811	2.8	0	95% covered by pool, 0 mm 95% no channeling observed	
6071	1284	10700	#N/A	12900	1423	2.2	#N/A	80% covered by pool	breakthrough
6075	1288	10800	#N/A	13000	1294	2	#N/A	flat, 2 craters, 10% pool 2 channels mid-bed	
6085	1298	11100	194	13300	970	1.5	0.3	mostly flat, 30% pool both channels closed	
6095	1308	11200	259	13700	776	1.2	0.4	mostly flat, 40% pool no channels observed	
6107	1320	11900	194	14000	647	1	0.3	mostly flat, 30% pool no channels observed	
6108	1321	11900	#N/A	14000	647	1	#N/A		shut off flow
7128	1321	11900	0	14100	647	1	0	flat, some pillars	start flow, rinsate settled to lower 1 1/4" of carboy
7132	1325	11900	#N/A	14100	647	1	#N/A		1st water into receiver
7140	1333	12100	#N/A	14200	582	0.9	#N/A	some pillars, some puddling no channels observed	at 5 liters, swapped supply carboy for full 2-l graduate
7160	1353	12440	#N/A	14800	453	0.7	#N/A	1 pillar, some puddling no channels observed	
7168	1361	13100	#N/A	14900	453	0.7	#N/A		inlet parted; lost 40 mL of water
7170	1363	13100	#N/A	#N/A	#N/A	#N/A	#N/A		added 1 l to supply
7175	1368	13260	#N/A	15000	453	0.7	#N/A	flat, pillar fell, some puddling no channels observed	
7188	1381	13480	0	15100	388	0.6	0	some screen showing, no pooling	
7197	1390	13600	#N/A	15200	388	0.6	#N/A		upped flow

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Elapsed Time min	Testing Time min	Applied mL	Pooled mL	Drained mL	Bed Vol. mL	Bed Height cm	Pooling cm	Bed/Channeling Description	Action/Comment
7199	1392	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		lowered flow, [add 1 l to supply?]
7215	1408	14100	#N/A	16500	323	0.5	#N/A		
7241	1434	15600	#N/A	18000	259	0.4	#N/A		
7262	1455	16100	#N/A	18900	194	0.3	#N/A		terminated

APPENDIX C

DEEP BED TEST DATA

Consisting of 13 pages including the cover page

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Elapsed Time min	Testing Time min	Pump rate	Applied mL	Pooled mL	Drained mL	Bed Vol. mL	Height at Bed cm	Height at Pool cm	Bed/Pool/Channeling Description	Action/Comment
0	0	0.00	0	0	0	12356	19.1	19.1	No Pool No flow	
2	2	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		
3	3	0.00	150	129	0	12356	19.1	19.3	Small Pool - 2mm water crept up side	
10	10	0.00	150	129	0	12356	19.1	19.3	Surface peeking through surface	Almost instantly got increased output
13	13	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		
14	14	0.00	250	194	#N/A	12356	19.1	19.4	Small Pool - 3mm Difficult to measure	
20	20	0.00	250	129	24	12356	19.1	19.3		Measured Drainage volume (clear solution)
30	30	0.00	250	129	40	12356	19.1	19.3	Skiff of water on surface ~ 2mm	Measured Drainage volume (clear solution)
40	40	0.00	250	129	53	12356	19.1	19.3	Little Depression ~ 7mm deep x ~ 30 mm long	Measured Drainage volume (clear solution)
55	55	0.00	250	129	82	12356	19.1	19.3	5 erosion "holes" on surface including 2 depressions mentioned above	Measured Drainage volume (clear solution)
75	75	0.00	250	65	110	12356	19.1	19.2	7 erosion holes - includinge depressions afore named	Measured Drainage volume (clear solution)
82	82	1.00	350	65	#N/A	12356	19.1	19.2	erosion on rt side 8 cm x 1 1/2 cm. Left side 7cm x ~ 80 mm	Started pump (1=rate)
83	83	0.00	350	129	120	12356	19.1	19.3	Skiff of water on surface ~ 2mm - (7 depression same)	Stopped pump after 100 mL added - measured clear drainage solution
97	97	0.00	350	129	138	12356	19.1	19.3	Skiff of water on surface ~ 2mm - (7 depression same)	measure clear sol.
115	115	0.00	350	65	160	12356	19.1	19.2	numerous depression on surface	measure clear sol.
140	140	0.00	350	65	200	12356	19.1	19.2	numerous depression on surface	measure clear sol.
155	155	0.00	350	0	220	12356	19.1	19.1	numerous depression on surface	Started pump (1=rate)
156	156	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		Started pump
157	157	0.00	450	129	240	12356	19.1	19.3	numerous depressions under water cap 2 main holes same size	stopped pump took measurements
180	180	0.00	450	129	272	12356	19.1	19.3	numerous depressions under water cap 2 main holes same size	took measurements
200	200	0.00	450	65	300	12356	19.1	19.2	numerous depressions under water cap 2 main holes same size	took measurements
230	230	0.00	450	0	340	12356	19.1	19.1		
230	230	1.00	#N/A	#N/A	#N/A	12356	19.1	#N/A		started pump
231	231	0.00	550	129	350	12356	19.1	19.3	Depressions covered with water	stopped pump took measurements
232	232	0.00	550	#N/A	#N/A	#N/A	#N/A	#N/A		500 mL added to feed
265	265	0.00	550	129	400	12292	19	19.2	surface still covered with water	took measurements
290	290	0.00	550	65	450	12292	19	19.1	surface - skiff of water water - many tiny footprint depressions	took measurements
300	300	1.00	650	#N/A	#N/A	#N/A	#N/A	#N/A		started pump
301	301	0.00	650	194	460	12292	19	19.3	rt. side ~ 10 cm wide/2.5 cm deep leftside (same as before)	stopped pump took measurement
324	324	0.00	650	194	500	12292	19	19.3	surface skiff of water small foot print impression	took measurement
350	350	0.00	650	129	540	12292	19	19.2	surface skiff of water small foot print impression	took measurement clear sol.
365	365	0.00	650	129	560	12292	19	19.2	surface skiff of water small foot print impression	took measurement clear sol.

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Elapsed Time min	Testing Time min	Pump rate	Applied mL	Pooled mL	Drained mL	Bed Vol. mL	Height at Bed cm	Height at Pool cm	Bed/Pool/ Channeling Description	Action/Comment
390	390	0.00	650	65	600	12292	19	19.1	surface skiff of water small foot print impression	took measurement clear sol.
393	393	1.00	750	#N/A	#N/A	#N/A	#N/A	#N/A		start pump
394	394	0.00	750	162	620	12292	19	19.25	surface water skiff no change in 2 deeper depressions-(many small depressions) no change)	stopped pump
410	410	0.00	750	129	640	12292	19	19.2	surface water skiff no change in 2 deeper depressions-(many small depressions) no change)	took measurements clear liquid
1311	410	0.00	750	0	1260	11903	18.4	18.4	many air holes/2 main surface depressions healed over - no standing liq on surface	took measurements - liquid clear
1315	414	0.00	#N/A	0	1260	11903	18.4	18.4		1 liter removed 260 mL in collections graduate left
1321	420	1.00	#N/A	#N/A	1260	#N/A	#N/A	#N/A		took 1 liter for sampling start pump
1323	422	0.00	1000	129	1280	11903	18.4	18.6		sampled bed stopped pump added 500 mL to supply
1355	454	0.00	1000	65	1320	11903	18.4	18.5	slight covering	took measurement
1385	484	0.00	1000	65	1360	11903	18.4	18.5	slight covering	took measurement
1415	514	0.00	1000	0	1400	11903	18.4	18.4	exposed bed top	
1420	519	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		recorded on wrong line pump started 100 mL added
1421	520	0.00	1100	65	1410	11903	18.4	18.5	slight water covering	took measurement
1455	554	0.00	1100	65	1480	11903	18.4	18.5	slight water covering	took measurement
1485	584	0.00	1100	65	1500	11903	18.4	18.5	slight water covering	took measurement
1515	614	0.00	1100	0	1560	11903	18.4	18.4	exposed bed	
1516	615	1.00	1200	#N/A	#N/A	#N/A	#N/A	#N/A		start pump
1517	616	0.00	1200	65	1560	11903	18.4	18.5	slight water covering no change in surface	stop pump take measurement
1550	649	0.00	1200	65	1600	11903	18.4	18.5	slight water covering no change in surface	take measurement
1580	679	0.00	1200	65	1640	11903	18.4	18.5	skiff of water on bed	took measurement
1610	709	0.00	1200	65	1700	11903	18.4	18.5	slight water cover on bed	took measurement
1670	769	0.00	1200	0	1800	11903	18.4	18.4	no cover or water on bed	took measurement
1685	784	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		started pump
1686	785	0.00	1400	65	1810	11839	18.3	18.4	bed slidghtly covered with water	stopped pump took measurement
1715	814	0.00	1400	65	1860	11839	18.3	18.4	bed slidghtly covered with water	took measurement
1745	844	0.00	1400	65	1900	11839	18.3	18.4	peaks out of water rest of bed covered	took measurement
1775	874	0.00	1400	0	1950	11774	18.2	18.2	pooling of water on bed	took measurement
1805	904	0.00	1400	0	1990	11774	18.2	18.2	no water	took measurement
1805	904	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		start pump
1806	905	0.00	1500	65	2000	11774	18.2	18.3	water on bed (covered)	stop pump
1835	934	0.00	1500	0	2040	11774	18.2	18.2	(water puddles)	(added 500 mL to feed supply)
1843	942	0.00	1500	#N/A	2040	#N/A	#N/A	#N/A		500 mL added to feed & 1000mL removed from drainage
1848	947	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		start pump
1850	949	0.00	1600	129	2060	11709	18.1	18.3		stopped pump took measurements
2772	949	0.00	1600	0	2660	11386	17.6	17.6	bed very moist	took measurements
2777	954	1.00	1800	65	2665	11386	17.6	17.7	water cover over bed bed has no holes just "hilled and valleyed" slightly - not smooth	
2793	970	0.00	1800	65	2680	11386	17.6	17.7	water skiff over bed	
2825	1002	0.00	1800	65	2740	11386	17.6	17.7	some of bed peeking through water but mostly covered	
2840	1017	0.00	1800	0	2765	11386	17.6	17.6	pooling of water on bed with peaks	(same) as above
2870	1047	0.00	1800	0	2810	11386	17.6	17.6	less pooling of water on bed with peaks	(same) as above

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Elapsed Time min	Testing Time min	Pump rate	Applied mL	Pooled mL	Drained mL	Bed Vol. mL	Height at Bed cm	Height at Pool cm	Bed/Pool/Channeling Description	Action/Comment
2871	1048	1.00	1800	#N/A	#N/A	#N/A	#N/A	#N/A		start pump
2873	1050	0.00	1950	65	2820	11386	17.6	17.7	water skiff over bed	stopped pump took measurement
2907	1084	0.00	1950	0	2860	11386	17.6	17.6		start pump
2908	1085	1.00	1950	0	2860	11386	17.6	17.6		stopped pump
2909	1086	0.00	2000	129	2870	11256	17.4	17.6	water skiff over bed	(added 500 mL to supply vol)
2940	1117	0.00	2000	65	2970	11256	17.4	17.5		took measurement
2971	1148	0.00	2000	65	2970	11256	17.4	17.5	some bed peaking through	took measurement
3020	1197	0.00	2000	0	3055	11192	17.3	17.3	no pools	took measurement
3023	1200	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		took measurement
3025	1202	0.00	2200	129	3065	11192	17.3	17.5	water over bed	[started pump]
3070	1247	0.00	2200	65	3120	11192	17.3	17.4		took measurement
3071	1248	0.00	2200	65	3120	11192	17.3	17.4		took measurement
										moved 1 liter drainage to large carboy
										took measurement
3105	1282	0.00	2200	65	3200	11192	17.3	17.4	bed covered in skiff of water	took measurement
3135	1312	0.00	2200	65	3250	11127	17.2	17.3	peaks of bed through skiff of water	
3165	1342	0.00	2200	0	3310	11127	17.2	17.2	small wet spot	
3167	1344	1.00	2400	194	3320	11127	17.2	17.5	covered bed	[started pump]
3215	1392	0.00	2400	129	3400	11127	17.2	17.4	skiff of water covering surface	[stopped pump]
3230	1407	0.00	2400	65	3430	11127	17.2	17.3	peaks of bed through skiff of water	
7100	1407	1.00	2400	0	4140	10674	16.5	16.5	surface damp	[started pump]
7102	1409	0.00	2600	65	4140	10674	16.5	16.6	skiff of water covering surface	stopped pump
7115	1422	0.00	2600	0	4150	10674	16.5	16.5	some puddles	sample # SP04 taken
										some solids had filtered through.
										Drainage appears clear now
										500 mL water to supply volume
7140	1447	0.00	2600	65	4200	10610	16.4	16.5	material peeking through	
7160	1467	0.00	2600	0	4270	10610	16.4	16.4	3 x 5mm holes in center	
7161	1468	1.00	2900	453	4290	10351	16	16.7	few peaks exposed	started pump
7162	1469	0.00	2900	453	4290	10351	16	16.7		pump off
7190	1497	0.00	2900	323	4360	10351	16	16.5	lots of peaks	
7220	1527	0.00	2900	259	4460	10351	16	16.4	peaks ghrough skiff of water	
7230	1537	0.00	2900	259	4480	10351	16	16.4	peaks through skiff of water	
7250	1557	0.00	2900	129	4520	10351	16	16.2	peaks through skiff of water	
7264	1571	0.00	2900	65	4590	10351	16	16.1		
7271	1578	1.00	3100	323	4600	10351	16	16.5		[started pump]
7272	1579	0.00	3100	#N/A	#N/A	#N/A	#N/A	#N/A		500 mL added to feed
7320	1627	0.00	3100	65	4770	10351	16	16.1	peaks through skiff of water some pooling	[stopped pump]
7345	1652	0.00	3100	0	4870	10351	16	16	no pooling on surface	
7349	1656	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		(no readings)
7353	1660	0.00	3300	323	4900	10286	15.9	16.4	peaks through skiff of water	[started pump]
7380	1687	0.00	3300	#N/A	5000	#N/A	#N/A	#N/A	erosion at front left edge 4 cm x 4.5 cm (some pooling)	[stopped pump]
										Drained 1 liter added to carboy
										slight reddish drainage deposited into 2L grad.
7400	1707	0.00	3300	0	5100	10286	15.9	15.9	erosion at front left edge 4 cm x 4.5 cm no pooling	slightly pink draining liquid
7405	1712	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		started pump
7410	1717	0.00	3500	259	5140	10286	15.9	16.3	pooling (draining solution clear)	stopped pump
										added 500 mL to feed
7445	1752	0.00	3500	0	5290	10286	15.9	15.9	no pooling (pinkish drainage) holes (shallow ones) on surface	
7446	1753	1.00	3500	#N/A	#N/A	#N/A	#N/A	#N/A		vol 1000 in grad feed

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Elapsed Time min	Testing Time min	Pump rate	Applied mL	Pooled mL	Drained mL	Bed Vol. mL	Height at Bed cm	Height at Pool cm	Bed/Pool/Channeling Description	Action/Comment
7451	1758	0.00	3700	323	5330	10221	15.8	16.3		start pump
7490	1797	0.00	3700	259	5520	10027	15.5	15.9	3 cm deep depression x 10 cm long in south side	stopped pump pinkish drainage
7500	1807	1.00	#N/A	0	#N/A	10027	15.5	15.5	top of bed no standing water except depressions	start pump
7502	1809	0.00	3800	550	5580	9801	15.15	16		stop pump
7520	1827	0.00	3800	65	5660	10027	15.5	15.6	top of bed exposed except some peaks	
7530	1837	1.00	#N/A	#N/A	5700	#N/A	#N/A	#N/A	bed uncovered	start pump
7537	1844	0.00	4000	323	5740	10027	15.5	16	some peaks uncovered	stop pump
7540	1847	0.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		liquid has slight pink/tan color 500 mL added to feed
7550	1857	0.00	4000	259	5830	10027	15.5	15.9	some peaks uncovered	
7580	1887	0.00	4000	0	5980	9963	15.4	15.4	no water on bed small depression started	
7583	1890	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		started pump
7588	1895	0.00	4300	388	6050	9963	15.4	16	skiff of water with peaks through it	stopped pump
7610	1917	0.00	4300	323	6130	9963	15.4	15.9	peaks through some water (tan color liq)	transferred 1 liter from collection grad to carboy
8540	1917	0.00	4300	0	6920	9704	15	15	Dry top - with small crystals - 4 signs of breakthrough see drawings 1 and 2	stronger pink/tan color - more fines
8545	1922	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		pump started
8562	1939	0.00	4800	323	7000	9510	14.7	15.2	top 50% of bed covered	pump stopping
8562	1939	0.00	4800	#N/A	#N/A	#N/A	#N/A	#N/A		500 mL added
8585	1962	0.00	4800	65	7180	9510	14.7	14.8	slight cover of water on bed	
8600	1977	0.00	4800	#N/A	7260	#N/A	#N/A	#N/A		pink/tan color (total of 7 liters to carboy) note: transferred 1 L to carboy
8606	1983	1.00	5000	#N/A	#N/A	#N/A	#N/A	#N/A		start pump
8609	1986	0.00	5000	129	7320	9445	14.6	14.8	bed covered ~ 80% rest in puddles	stopped pump
8640	2017	0.00	5000	0	7480	9445	14.6	14.6	bed exposed water standing in puddles	added 500 mL to feed grad. cyl. (to total 1 Liter feed)
8642	2019	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		start pump
8650	2027	0.00	5300	323	7540	9380	14.5	15	50% covered with water peaks exposed	stop pump (pink water)
8670	2047	0.00	5300	194	7700	9316	14.4	14.7	30% covered with water	
8680	2057	1.00	#N/A	65	7760	9316	14.4	14.5		start pump
8682	2059	0.50	5350	129	7780	9316	14.4	14.6	~30% bed covered	turned speed down to ~0.5 after 50 mL
8690	2067	0.50	5400	129	7840	9316	14.4	14.6		continuing to pump
8695	2072	0.50	5440	194	7880	9316	14.4	14.7		
8707	2084	0.50	5500	194	7960	9316	14.4	14.7		will start sample on next liter
8715	2092	0.50	5550	259	8000	9251	14.3	14.7		started sample SP05
8720	2097	0.50	5600	#N/A	#N/A	#N/A	#N/A	#N/A		added 500 mL to feed
8733	2110	0.50	5680	0	8440	9251	14.3	14.3	breakthrough! water drained sample has	distinct red color
8738	2115	0.50	5690	0	8490	9251	14.3	14.3		water starting to accumulate again but continues to breakthrough
8750	2127	0.50	5740	0	8630	9186	14.2	14.2		
8775	2152	0.50	5970	0	8900	9122	14.1	14.1	no cover just water in puddles, more puddles	liq. draining clear forming - transferred 1 liter to carboy (9 liter total)
8800	2177	0.50	6100	0	9090	8928	13.8	13.8		added 500 mL to feed
8810	2187	0.50	6150	0	9150	8863	13.7	13.7	20% of bottom covered	
8825	2202	0.50	6250	0	9275	8863	13.7	13.7		

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Elapsed Time min	Testing Time min	Pump rate	Applied mL	Pooled mL	Drained mL	Bed Vol. mL	Height at Bed cm	Height at Pool cm	Bed/Pool/Channeling Description	Action/Comment
8840	2217	0.50	6400	0	9470	8345	12.9	12.9		
8860	2237	0.50	6500	65	9610	8151	12.6	12.7		500 mL added to feed
8870	2247	0.50	6550	0	9790	8151	12.6	12.6		
8890	2267	0.50	6700	0	10000	8022	12.4	12.4		sample to SP05 N Book
8891	2268	0.50	#N/A	#N/A	10000	#N/A	#N/A	#N/A		whc-n-596-1 pg 71-76 returned remainder to receiver [i.e., carboy]
8900	2277	0.50	6750	0	10060	8022	12.4	12.4	>20% of bottom covered bed varies from ~11cm to ~15cm sloping upward to rear	
8915	2292	0.50	6870	0	10200	7892	12.2	12.2		
8930	2307	0.50	6980	0	10360	7892	12.2	12.2		
8935	2312	0.50	7000	#N/A	#N/A	#N/A	#N/A	#N/A		500 mL transferred to large jug
8960	2337	0.50	7100	0	10640	7698	11.9	11.9		
8963	2340	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		increased pump speed to 1
8970	2347	1.00	7300	0	10790	7698	11.9	11.9		
8980	2357	1.00	7500	388	10840	7698	11.9	12.5	bed 40% covered	return pump speed to 0.5
8982	2359	0.50	7500	453	10920	7698	11.9	12.6	bed 40% covered	
8990	2367	0.50	7600	518	10980	7698	11.9	12.7		
8992	2369	0.50	#N/A	#N/A	11000	#N/A	#N/A	#N/A		transferred 1 liter to carboy
9010	2387	0.50	7700	0	11580	7634	11.8	11.8	bed drained	
9011	2388	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		pump to 1
9020	2397	1.00	7900	0	11660	7504	11.6	11.6		
9030	2407	0.00	8400	0	12180	7440	11.5	11.5		pump off transferred 1 liter to carboy
9035	2412	0.00	8400	0	12230	7440	11.5	11.5		
9980	2412	0.00	8400	0	12840	7375	11.4	11.4	bed slope low in front with large sink holes see drawing 3	
9988	2420	1.00	#N/A	#N/A	13000	#N/A	#N/A	#N/A	bed slope low in front with large sink holes see drawing 3	started pump
10000	2432	0.00	8700	0	13100	7375	11.4	11.4	sink holes getting larger-water running through (reddish liq.)	stopped pump transferred 1 liter to carboy
10014	2446	0.50	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		started pump
10022	2454	0.50	8800	0	13280	7375	11.4	11.4	water passing through large holes at front of bed (reddish liquid)	pump running at 0.5
10034	2466	0.50	9200	0	13500	7246	11.2	11.2	pooling up over holes in bed tho no water at point of measurement	reddish liquid changed to clear again in collection grad
10040	2472	0.50	9500	129	13580	6922	10.7	10.9	holes are healing over-(raised Mt Zion area at back of bed) liquid pooling at measurement area	
10060	2492	0.00	9800	776	13850	6922	10.7	11.9	solids resettled-water level higher at measuring point (75% water covered). Peaks at back surrounded by water see drawing 4	stopped pump
10078	2510	0.00	9800	776	14000	6922	10.7	11.9	still 75% water covered bed with Zion like peaks at back of bed exposed	transferred 1 liter to carboy (14 liters total)
10100	2532	0.00	9800	323	14260	6922	10.7	11.2	50% water covered bed - Zion peaks at back	Pink liq. in grad -not red
10115	2547	0.00	9800	65	14320	6987	10.8	10.9		bed increased at point of measurement as water level dropped
10129	2561	0.00	9800	0	14430	6987	10.8	10.8	40% water covered bed-peaks at back	pink liq in grad collector
10130	2562	0.50	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		start pump @ 0.5

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Elapsed Time min	Testing Time min	Pump rate	Applied mL	Pooled mL	Drained mL	Bed Vol. mL	Height at Bed cm	Height at Pool cm	Bed/Pool/Channeling Description	Action/Comment
10140	2572	0.00	10150	194	14520	6857	10.6	10.9	50% of bed covered (peaks eroding more)	stopped pump (less out than in)
10159	2591	0.00	10150	65	14630	6857	10.6	10.7	still ~50%+ of bed covered	pink liq in grad.
10171	2603	0.00	10150	0	14700	6857	10.6	10.6	35% of bed covered	pink liq in grad.
10172	2604	0.35	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		start pump slower speed
10189	2621	0.35	10500	194	14860	6793	10.5	10.8	50%+ of bed covered Back still higher but eroding	(liquid pink in grad)
10200	2632	0.00	10500	317	14900	6793	10.5	10.99	50%+ of bed covered Back still higher but eroding	stopped pump less out than in
10220	2652	0.00	10500	259	15000	6793	10.5	10.9	65% of bed cover (Zion Peaks eroding)	pulled 15 liter sample SP06A + DS07 and DS08 bed samples
10235	2667	0.00	10500	65	15090	6793	10.5	10.6	65% of bed covered peaks eroding	
10242	2674	0.35	#N/A	0	#N/A	6793	10.5	10.5		start pump
10265	2697	0.35	10700	323	15290	6793	10.5	11	75% of bed covered still higher at back see drawing 4	(200 in - 200 out) continue pump
10280	2712	0.35	11000	453	15380	6793	10.5	11.2	75% of bed covered still higher at back see drawing 4	more in than out
10283	2715	0.00	11000	518	15400	6793	10.5	11.3	80% of bed covered/water higher part eroding slanted bed	turn off pump
10303	2735	0.00	11000	453	15500	6728	10.4	11.1	80% of bed covered/water higher part eroding	
10325	2757	0.00	11000	259	15620	6728	10.4	10.8	75% bed covered	
10355	2787	0.00	11000	65	15810	6728	10.4	10.5	65% bed covered	
10370	2802	0.00	11000	0	15880	6728	10.4	10.4	65% bed covered	
10370	2802	3.50	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		started pump
10390	2822	3.50	11300	259	16000	6599	10.2	10.6	65% bed covered peaks at back	transferred 1 liter to carboy (16 liter total)
10393	2825	0.00	11400	323	16030	6599	10.2	10.7	65 % bed covered peaks at back	stopped pump
10400	2832	0.00	11400	194	16110	6599	10.2	10.5	65% bed covered peaks at back	
10430	2862	0.00	11400	194	16240	6599	10.2	10.5	65% bed covered peaks at back	
11438	2862	0.00	11400	0	17290	6340	9.8	9.8	bed high (front 5cm back 15cm) sinkhole and depression over front 70%	transfer 1 liter to carboy
11457	2881	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		turn on pump rate of 1
11492	2916	0.50	12300	323	17510	6081	9.4	9.9	80% of bed covered higher peaks eroding	truned pump rate down to 0.5
11500	2924	0.50	12400	453	17560	6081	9.4	10.1		
11508	2932	0.35	12500	582	17620	6081	9.4	10.3		stopped pump
11540	2964	0.50	12500	323	17840	6016	9.3	9.8		
11543	2967	0.50	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		start pump
11555	2979	0.00	12600	453	17940	5887	9.1	9.8	75% of bed covered	stop pump
11565	2989	0.00	12600	0	18600	5822	9	9		breakthrough
11568	2992	0.50	#N/A	#N/A	18600	#N/A	#N/A	#N/A		1 liter to carboy start pump
11593	3017	0.50	13000	0	18980	5822	9	9	7.3 water at pool 6.8 bed height	
11597	3021	0.50	#N/A	#N/A	19000	#N/A	#N/A	#N/A		transferred 1 liter to carboy started samp col.
11608	3032	0.00	13200	0	19060	5628	8.7	8.7	50% of bed covered	stop pump
11630	3054	0.00	13200	0	19200	5628	8.7	8.7	35% of bed covered	
11650	3074	0.00	13200	0	19300	5628	8.7	8.7	30% of bed covered	
11665	3089	0.00	13200	0	19360	5628	8.7	8.7	30% of bed covered	
11693	3117	0.00	13200	0	19470	5628	8.7	8.7	15% of bed covered	
11695	3119	0.50	13200	0	19480	5628	8.7	8.7	15% of bed covered	start pump
11710	3134	0.00	13300	0	19545	5564	8.6	8.6	35-40% of bed covered (terrain same as above)	stopped pump
11730	3154	0.00	13300	0	19630	5564	8.6	8.6	20-25% of bed covered	
11730	3154	0.50	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		start pump
11745	3169	0.50	13500	0	19710	5564	8.6	8.6	30-35% of bed covered	
11770	3194	0.50	13700	65	19850	5434	8.4	8.5	60-65% covered bed	light p
11780	3204	0.50	13800	65	19910	5369	8.3	8.4	60-65% covered bed	

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Elapsed Time min	Testing Time min	Pump rate	Applied mL	Pooled mL	Drained mL	Bed Vol. mL	Height at Bed cm	Height at Pool cm	Bed/Pool/Channeling Description	Action/Comment
11795	3219	0.50	14200	388	20000	5305	8.2	8.8	85-90% covered bed peaks reduced down greatly over 1/2 have crumbled to bed level	sample very clear
11810	3234	0.50	14300	453	20040	5305	8.2	8.9	90% covered bed	
11840	3264	0.50	14400	518	20280	5240	8.1	8.9	90% covered bed	light pink liquid
11865	3289	0.50	14500	518	20430	5175	8	8.8	90% covered bed	light pink liquid
11890	3314	0.50	14600	518	20600	5175	8	8.8	90% covered bed peaks collapsing	
11915	3339	0.50	14700	518	20760	5175	8	8.8	60% of peaks collapsed	
11930	3354	0.00	14700	518	20810	5175	8	8.8	90% covered bed	shut off pump pink solution
17185	3354	0.00	14700	0	22400	4464	6.9	6.9	moist after weekend	left for 3 days
17190	3359	1.00	14700	0	22400	4464	6.9	6.9		start pump 2 liter
17200	3369	0.50	15000	0	22420	4464	6.9	6.9	50% bed covered	transferred to carboy
17215	3384	0.50	15200	0	22460	4464	6.9	6.9	70-80% covered bed soaking very well	slowed pump to 0.5
17240	3409	0.50	15400	0	22550	4464	6.9	6.9	80-90% covered	throughput starting to increase
17270	3439	0.50	15500	0	22660	4464	6.9	6.9	80-90% bed covered still peaks (back edge eroding) (rt-side)	
17305	3474	0.50	15600	0	22790	4464	6.9	6.9	80-90% bed covered still peaks (back edge eroding) (rt-side)	
17345	3514	0.50	15750	65	22960	4464	6.9	7	85-90% of bed covered water pooling more than outgo	
17353	3522	0.00	15775	129	22980	4464	6.9	7.1	90% of bed covered	attempted to slow pump and it stopped
17354	3523	0.00	15775	129	22980	4464	6.9	7.1	90% of bed covered (no breakthrough)	pump shut off
17360	3529	0.00	15775	129	23000	4464	6.9	7.1		transferred 1 liter to carboy- pink liq.
17380	3549	0.00	15775	65	23090	4464	6.9	7	85% of bed covered	
17400	3569	0.50	15775	0	23140	4464	6.9	6.9	~85% of bed cover	started pump
17415	3584	0.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		pump died (loose connection)
17425	3594	0.50	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		restarted
17430	3599	0.50	16200	129	23260	4399	6.8	7	90-95% of bed covered	trouble adjusting speed of pump (too fast)
17440	3609	0.00	16500	388	23300	4399	6.8	7.4	90-95% of bed covered	stopped pump
17460	3629	0.00	16500	323	23340	4399	6.8	7.3		see page 73 of notebook.
17480	3649	0.00	16500	259	23380	4399	6.8	7.2	90%-95% of bed covered but liquid is dropping nicely	Readjusted tubing in pump
17510	3679	0.00	16500	129	23500	4399	6.8	7	85-90% of bed covered	[drainage] amount not adjusted for ~70 mL removed [for John's Sample]
17524	3693	0.50	16500	0	23560	4399	6.8	6.8	85-90% of bed covered	started pump
17554	3723	0.50	16500	0	23680	4399	6.8	6.8	85-90% of bed covered	(very slow pump)
17570	3739	0.50	16500	0	23840	4399	6.8	6.8	85-90% of bed covered	
17605	3774	0.50	16500	0	23880	4399	6.8	6.8	85-90% of bed covered	
17630	3799	0.50	16600	0	23960	4334	6.7	6.7	80% of bed covered	
17645	3814	0.50	16600	0	24000	4334	6.7	6.7	70%-80% bed covered	1 liter transferred to carboy 24 liter total
17660	3829	0.00	16600	0	24060	4334	6.7	6.7	70-80% of bed covered	stopped pump for day
17680	3849	0.00	16600	0	24130	4334	6.7	6.7	60-70% of bed covered	stopped pump for day
18616	3849	0.00	16600	0	24660	4076	6.3	6.3	bed moist	
18620	3853	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		start pump
18655	3888	0.50	17000	0	24740	4076	6.3	6.3	80% of bed covered	(slowed pump down to 0.5 rate)
18685	3918	0.50	17300	0	24850	4076	6.3	6.3	90% of bed covered	
18715	3948	0.50	17400	0	24860	4076	6.3	6.3	90% of bed covered	

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Elapsed Time min	Testing Time min	Pump rate	Applied mL	Pooled mL	Drained mL	Bed Vol. mL	Height at Bed cm	Height at Pool cm	Bed/Pool/Channeling Description	Action/Comment
18730	3963	0.00	17500	0	25000	4076	6.3	6.3	90 % of bed covered	(stopped pump to sample)
18735	3968	0.50	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		restart pump
18742	3975	0.50	17500	0	25100	4076	6.3	6.3	90% of bed covered	
18775	4008	0.50	17600	0	25620	4076	6.3	6.3	30% of bed covered breakthrough (small one)	reddish collection sol.
18810	4043	0.50	17900	0	25880	4076	6.3	6.3	10% of bed covered	(getting darker pink solution)
18820	4053	0.50	18000	0	26040	4011	6.2	6.2		transferred 1 liter to carboy
18850	4083	0.50	18300	0	26300	4011	6.2	6.2	70% of bed covered	solution running clear
18870	4103	0.50	18500	0	26380	3946	6.1	6.1	80-85% of bed covered	solution running clear
18900	4133	0.50	18700	0	26720	3882	6	6	80-85% of bed covered	solution running clear
18930	4163	0.50	18800	0	27000	3882	6	6	40% of bed covered	color draining clear solution
18955	4188	0.50	19000	0	27100	3817	5.9	5.9	70% of bed covered	clearish solution
18985	4218	0.50	19300	0	27220	3817	5.9	5.9	90% of bed covered	clearish solution
19010	4243	0.50	19500	0	27660	3623	5.6	5.6	20% of bed covered tiny breakthrough	reddish collection solution
19030	4263	0.50	19600	0	27725	3623	5.6	5.6	75% of bed covered	running "clear" for collection now
19045	4278	0.50	19700	129	27800	3170	4.9	5.1	90% of bed covered	flattening out of bed noted
19070	4303	0.50	19800	65	28100	3105	4.8	4.9	10% of bed covered	1 liter to carboy
19100	4333	0.50	20400	0	28600	3105	4.8	4.8	<10% of bed covered	
19115	4348	0.50	20600	0	29000	3105	4.8	4.8	<10% of bed covered	pump off (transferred 1 liter)
20090	4348	0.00	20600	0	29260	3041	4.7	4.7	Bed looks fairly level all area (no peaks) direr on top some white salting on surface	started pump turned pump down
20105	4363	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	small breakthrough occurred (sinkhole in center)	
20108	4366	0.50	20900	0	29320	3041	4.7	4.7	75% bed covered by water water still breaking through small hole	reddish solution collection
20125	4383	0.50	21100	0	29500	3041	4.7	4.7	only 40% of bed covered now	still reddish drips
20140	4398	0.50	21300	0	29640	3041	4.7	4.7	only 10% of bed covered	still reddish drips
20170	4428	0.50	21500	0	29820	2976	4.6	4.6	~10-15% of bed covered	still reddish drips (still hole in center)
20195	4453	0.50	21600	0	30000	2976	4.6	4.6	~5% of bed covered	still reddish drips
20196	4454	0.00	21600	0	30000	2976	4.6	4.6	10% bed coverage	stopped pump
20219	4477	0.50	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		sampled
										transferred 1 liter to carboy after later taking sample
20220	4478	0.50	21600	0	30190	2911	4.5	4.5	5% bed coverage more holes opening on bed - more breakthroughs	started pump
20230	4488	0.50	21700	0	30300	2911	4.5	4.5	5% bed coverage more holes opening in bed	
20240	4498	0.50	22000	0	30590	2782	4.3	4.3		0% continuing breakthrough red collection
20250	4508	0.50	22300	0	30800	2717	4.2	4.2		0%
20260	4518	0.00	22500	0	31000	2717	4.2	4.2		stopped pump added water to feed carboy (to 15 liter)
										(transferred 1 liter to carboy) *note 2 liters of breakthrough liq. collecte at this point
20280	4538	0.00	22500	#N/A	#N/A	#N/A	#N/A	#N/A		transferred 1 liter to carboy conferred

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Elapsed Time min	Testing Time min	Pump rate	Applied mL	Pooled mL	Drained mL	Bed Vol. mL	Height at Bed cm	Height at Pool cm	Bed/Pool/Channeling Description	Action/Comment
										with chemist
20295	4553	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		inform to continuing to add water a good rate started pump (15000 total feed)
20305	4563	1.00	22700	65	31240	2588	4	4.1	bed is covered 45% still breakthrough but holes filling	
20315	4573	0.50	23000	65	31460	2588	4	4.1	bed 45% covered still breakthrough	
20330	4588	0.50	23300	0	31890	2588	4	4	bed 25% covered still breakthrough color of drop	
20338	4596	0.00	23500	0	32000	2588	4	4	bed 10% covered	stopped pump transferred 1 liter to carboy start pump
20340	4598	0.50	23500	0	32100	2588	4	4	bed 10% covered	
20350	4608	0.50	23600	65	32300	2588	4	4.1	bed 40% covered still breakthrough	
20360	4618	0.50	23700	0	32500	2588	4	4	bed 30% covered still breakthrough	
20376	4634	0.50	24000	0	32780	2523	3.9	3.9	puddling ~ 20-25% no visible holes- (puddled)	
20385	4643	1.00	24400	65	33000	2523	3.9	4	pooling at ~40% of bed covered	increased pump speed to ~1
20395	4653	1.00	24600	65	33280	2523	3.9	4	40% bed channel near center of bed	1 liter added to carboy collected sample
20411	4669	1.00	25300	0	34000	2523	3.9	3.9	45-60% . channel near center of bed Hoodoos on surface white grains on top of bed	
20421	4679	1.00	25700	65	34620	2523	3.9	4	45-60% . channel hole near center of bed	
20432	4690	0.00	26200	65	35000	2523	3.9	4		pump turned off
20433	4691	0.00	26200	0	35015	2523	3.9	3.9	no water on bed	sampled take 1 liter (35 liter) off and sample
20445	4703	0.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	no water on bed	start pump
20446	4704	1.00	26200	65	35100	2523	3.9	4	70% of bed covered 2 holes new old one healed over	
20455	4713	0.00	26550	194	35300	2458	3.8	4.1	90% coverage from pool - only one hole	pump off
20459	4717	0.50	26550	0	35470	2458	3.8	3.8	pool gone	pump on at 0.5 rate
20470	4728	0.50	26700	0	35650	2458	3.8	3.8	70% bed coverage new channel hole open rest closed	
20485	4743	0.50	27000	65	35880	2458	3.8	3.9	80% bed coverage	
20497	4755	0.50	27200	65	36000	2458	3.8	3.9	80% bed coverage	
20505	4763	0.50	27400	65	36140	2458	3.8	3.9	85% (1 hole still (chan) bed & water out)	transferred 1 liter to carboy (36 liters)
20520	4778	0.50	27500	65	36440	2458	3.8	3.9	85% (1 hole still (chan) bed & water out)	
20535	4793	0.50	28000	323	36580	2458	3.8	4.3	90% Note hole not leaking	slowed pump a bit
20545	4803	0.50	28000	259	36660	2458	3.8	4.2	90% of bed covered no holes or swirls visible	
20555	4813	0.50	28100	129	36880	2458	3.8	4	90% of bed covered no holes or swirls visible solution appears clearer (hole mending finally?)	
20570	4828	0.50	28200	0	37280	2458	3.8	3.8	75% of bed covered	
20571	4829	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		stopped pump for day
21500	4829	0.00	28200	0	37280	2329	3.6	3.6	mid sized depression center-front from yesterday moist surface salted with white	breakthrough
21515	4844	1.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	No evidence of breakthrough this am - running clear	started pump slowed pump to 0.5 at 7:50
21520	4849	0.50	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		slowed pump to 0.5 at 7:50
21530	4859	0.50	28400	129	37320	2329	3.6	3.8		
21560	4889	0.50	28600	194	37400	2329	3.6	3.9		slowed pump again at 8:35
21565	4894	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		slowed pump again at 8:35
21590	4919	0.00	28700	129	37500	2329	3.6	3.8		pump off

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Elapsed Time min	Testing Time min	Pump rate	Applied mL	Pooled mL	Drained mL	Bed Vol. mL	Height at Bed cm	Height at Pool cm	Bed/Pool/Channeling Description	Action/Comment
21600	4929	0.50	28700	259	37780	2005	3.1	3.5	small breakthrough	pump on
21620	4949	0.50	28800	194	37860	2005	3.1	3.4		
21650	4979	0.50	29100	65	38240	1941	3	3.1		1 liter transferred to carboy
21680	5009	0.50	29500	0	38580	1941	3	3		
21710	5039	0.50	29600	0	38760	1941	3	3		
21740	5069	0.50	30000	259	38960	1811	2.8	3.2	70% of bed covered	
21746	5075	0.50	30000	388	39000	1811	2.8	3.4	75% of bed covered	mended clearer solution
21770	5099	0.50	30200	323	39180	1811	2.8	3.3	75% of bed covered	reduced speed slightly
21810	5139	0.50	30500	194	39530	1811	2.8	3.1	60% of bed covered	solution dripping clear in color
21831	5160	0.50	30600	194	39640	1811	2.8	3.1	60% of bed covered	more color (pink) in solution
21860	5189	0.50	30700	453	39740	1811	2.8	3.5	80% of bed covered	clear solutions again (samples at 40 liters)
21880	5209	0.50	30800	129	40000	1811	2.8	3	50% of bed covered	more color (pink) in solution
21890	5219	0.50	31100	0	40180	1811	2.8	2.8	50% of bed covered	sample "soupy " at 2 cm depth
21920	5249	0.50	31300	323	40300	1747	2.7	3.2	70% of bed covered	still pumping at low 0.5 rate (slowed more)
21950	5279	0.50	31400	259	40420	1747	2.7	3.1	75% of bed covered	still pumping at low 0.5 rate (slowed more) pumping clearer sol.
21980	5309	0.50	31500	323	40520	1682	2.6	3.1	85% of bed covered	pumping clearer sol.
21985	5314	0.00	31500	388	40540	1682	2.6	3.2	85% of bed covered	shut off pump for the day
22940	5314	0.00	31500	0	40800	1553	2.4	2.4		
22941	5315	0.50	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		start pump
22970	5344	0.50	31600	0	40880	1553	2.4	2.4		
23000	5374	0.50	31700	0	41000	1553	2.4	2.4		Transfer 1 liter to carboy
23001	5375	1.00	#N/A	#N/A	41000	#N/A	#N/A	#N/A		increased speed
23015	5389	0.50	32000	65	41220	1553	2.4	2.5	20% of bed slightly covered	slowed back down
23045	5419	0.50	32300	388	41390	1553	2.4	3	60% of bed covered	slowed slightly
23075	5449	0.50	32500	453	41460	1553	2.4	3.1	80% covered	slowed pump again
23120	5494	0.50	32600	65	41860	1553	2.4	2.5	20% covered	added 10 L to feed
23150	5524	0.50	32700	518	42140	1423	2.2	3	30% covered with water	transferred 1 liter to carboy
23195	5569	0.50	33300	388	42620	1164	1.8	2.4	10% covered	
23210	5584	0.50	33400	388	42700	1164	1.8	2.4	10% covered	
23285	5659	0.50	34400	453	43720	1164	1.8	2.5		1 liter transferred to carboy
23300	5674	0.50	34600	518	43940	1164	1.8	2.6	50% covered	slowed pump
23305	5679	0.50	34600	518	44000	1164	1.8	2.6	50% covered	1 liter to carboy
23320	5694	0.50	34700	453	44200	1164	1.8	2.5	50% covered	collecting 1 liter sample
23330	5704	0.50	34800	388	44310	1164	1.8	2.4	50% covered	
23360	5734	0.50	35200	388	44580	1164	1.8	2.4	50% covered	
23390	5764	0.00	35500	518	45000	1164	1.8	2.6	50% covered	made samples
27260	5764	0.00	35500	0	45300	1035	1.6	1.6	0% covered	stopped pump
27265	5769	0.50	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		start pump
27290	5794	0.50	35600	129	45340	1035	1.6	1.8	10% covered	
27306	5810	0.50	35700	65	45460	1035	1.6	1.7	5% covered bed	1 small breakthrough hole (reddish solution)
27320	5824	0.50	35700	129	45540	1035	1.6	1.8	10% covered	1 hole covered in water but 2 new holes opened up
27335	5839	0.50	35800	129	45640	1035	1.6	1.8	20 of bed covered	no holes visible or water filled
27350	5854	0.50	36000	65	45760	1035	1.6	1.7	10% of bed covered	2 holes opened at back of bed

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Elapsed Time min	Testing Time min	Pump rate	Applied mL	Pooled mL	Drained mL	Bed Vol. mL	Height at Bed cm	Height at Pool cm	Bed/Pool/ Channeling Description	Action/Comment
27370	5874	0.50	36100	0	45890	1035	1.6	1.6	5 % of bed covered 1 hole opened at back of bed	
27395	5899	0.50	36300	0	46000	1035	1.6	1.6	5% of bed covered	transferred 1 lite to carboy (total 46000)
27425	5929	0.50	36500	0	46220	1035	1.6	1.6	10 % of bed covered 1 hole at back side	
27455	5959	0.50	36800	0	46430	1035	1.6	1.6	10% bed covered no holes visible	
27490	5994	0.50	37000	0	46720	1035	1.6	1.6	10% bed covered no holes visible	
27515	6019	0.50	37200	0	46900	1035	1.6	1.6	5-10% bed covered no holes visible	
27533	6037	0.50	37300	0	47000	1035	1.6	1.6	5-10% bed covered	transferred 1 liter to carboy (47000)
27575	6079	0.50	37500	0	47310	1035	1.6	1.6	5-10% bed covered	
27590	6094	0.50	37700	0	47520	1035	1.6	1.6	5-10% bed covered	a few small open holes
27620	6124	0.50	38100	194	47720	970	1.5	1.8	25% of bed covered water covers holes	
27650	6154	0.50	38500	65	48200	970	1.5	1.6	35% of bed covered	transferred 1 liter to carboy (48000)
27655	6159	0.50	38500	65	48200	970	1.5	1.6	25% of bed covered water covers holes	
27680	6184	0.50	38700	0	48480	970	1.5	1.5	20% of bed covered	
27710	6214	0.50	39200	65	48940	906	1.4	1.5	25% of bed covered	
27725	6229	0.50	39500	65	48990	906	1.4	1.5	25% of bed covered	
27730	6234	0.50	39500	65	49000	906	1.4	1.5	25% of bed covered	transferred 1 liter to carboy
27740	6244	0.50	39600	65	49260	906	1.4	1.5	20% of bed covered small hole'	
27755	6259	0.00	39700	65	49320	906	1.4	1.5	20% of bed covered	shhut off pump for night
28695	6259	0.00	39700	0	49400	841	1.3	1.3	no water on bed	
28700	6264	0.50	39700	0	49400	841	1.3	1.3		started pump
28730	6294	0.50	39900	0	49540	841	1.3	1.3	10% of bed covered	
28760	6324	0.50	40200	0	49820	841	1.3	1.3	5% of bed covered	
28783	6347	0.50	40500	0	50000	841	1.3	1.3		
28784	6348	0.00	40500	0	50000	841	1.3	1.3		stopped pump and took samples
										transferred 1 liter (50000 total)
28792	6356	0.50	40500	0	50050	841	1.3	1.3		start pump
28820	6384	0.50	40700	0	50360	841	1.3	1.3	10% of bed covered	
28850	6414	0.50	41000	0	50600	841	1.3	1.3	20% of bed covered	
28880	6444	0.50	41200	0	50860	841	1.3	1.3	30% of bed covered	
28904	6468	0.50	41500	0	51030	841	1.3	1.3	30% of bed covered	transferred 1 liter to carboy (51000)
28905	6469	0.50	41500	0	51030	776	1.2	1.2	30% of bed covered	
28940	6504	0.50	41900	0	51370	776	1.2	1.2	35% of bed covered	
28945	6509	0.50	42000	0	51450	776	1.2	1.2		added 6 liters to feed
28945	6509	0.50	42000	0	51450	776	1.2	1.2	30% of bed covered	
28970	6534	0.50	42300	0	51680	776	1.2	1.2	40% of bed covered	
29000	6564	0.50	42500	0	51920	776	1.2	1.2	40% of bed covered	
29027	6591	0.50	42600	129	52120	712	1.1	1.3		transferred 1 liter to carboy
29032	6596	0.50	42600	#N/A	52120	#N/A	#N/A	#N/A		
29081	6645	0.50	43200	0	52600	712	1.1	1.1	~30% coverage by water surface very uneven and mounded in center - real volume ~2x(height measurement x pi/4 x diameter^2) "Two layer" bed gone i.e. bottom stratum gone bed appears to consist of only one layer	
29120	6684	0.50	43500	129	52900	712	1.1	1.3	~50% of bed covered "Two layer" bed gone i.e. bottom stratum gone bed appears to consist of only one layer	
29163	6727	0.50	43700	65	53220	712	1.1	1.2	~50% of bed covered "Two layer" bed gone i.e. bottom stratum gone bed appears to consist of only one layer	transferred 1 liter to carboy
29220	6784	0.00	44200	0	53690	712	1.1	1.1	~40% of bed covered	pump off for the

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Elapsed Time min	Testing Time min	Pump rate	Applied mL	Pooled mL	Drained mL	Bed Vol. mL	Height at Bed cm	Height at Pool cm	Bed/Pool/ Channeling Description	Action/Comment
30137	6784	0.00	44200	0	53780	712	1.1	1.1	bed surface drained	evening