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Key Words:
Tank 25
Draining
Saltcake
Simulation
Interstitial Liquid

Retention:
Permanent

MODEL RESULTS OF THE DRAINING OF TANK 25 INTERSTIAL LIQUID (U)

C. D. Barnes
G. P. Flach

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ADC &
Reviewing
Official: M. K. Harris, Manager
(Name and Title)

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REPORT DATE FEBRUARY 14, 2005

Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

Prepared for the U.S. Department of Energy
Under Contract Number DEAC09-96-SR18500

SAVANNAH RIVER NATIONAL LABORATORY

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SRNL
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REVIEWS AND APPROVALS

2/10/05
C. Daniel Barnes, Co-author, Environmental Restoration Technology Section — Date

2/10/05
Greg P. Flach, Co-author, Environmental Restoration Technology Section — Date

2/10/05
Mary K. Harris, Level 4 Manager, Environmental Restoration Technology Section — Date

2/11/05
Stephen J. Strohmeier, Salt Engineering — Date

2/14/05
Eloy Saldivar, Level 4 Manager, Salt Engineering — Date

2-11-05
Renee H. Spires, Level 3 Manager, Salt Engineering — Date

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LIST OF ACRONYMS AND ABBREVIATIONS

ACRONYMS

FACT	Subsurface Flow and Contaminant Transport – Modeling Software
OLI/ESP	OLI Environmental Software Package
SRNL	Savannah River National Laboratory
STOMP	Subsurface Transport Over Multiple Phases – Modeling Software

ABBREVIATIONS

C	Centigrade
cP	centipoise
ft	feet
g	gram
gal	gallon
gpm	gallons per minute
L	liter
hr	hour
m	meter
s	second
temp	temperature

1.0 EXECUTIVE SUMMARY

SRNL was tasked to simulate the draining of interstitial liquid from Tank 25 saltcake which is scheduled to take place in 2005. The salt processing plan baseline[1] identifies a target of 135,000 gallons of interstitial liquid to be removed from Tank 25. Due to the uncertainty of the Tank 25 material properties and conditions, several cases were modeled varying the saltcake and interstitial liquid properties. The cases present a wide range of performance. The nominal baseline, case 1, removed the 135,000 gallons in approximately 1,030 hours of pump operation. The cases with optimal drain characteristics (high intrinsic permeability, high temp.) drain the 135,000 gallons in less time. Those with less favorable drain conditions did not approach the 135,000 gallons in a reasonable amount of time. Common to all cases unable to achieve the target volume was the low temperature at which they were run, 30^{o}C (the lowest modeled), though there were additional contributing factors. A summary of the results are shown in Table 1.

Table 1. Summary of Tank 25 Drain Model Results

Case	Time (hrs.)	Volume Removed (gal.)	Volume Remaining (gal.)	Pump Rate (at given time, gpm)	Time to Drain 135k gals. (hrs)
1 (nominal)	500	126,816	211,626	1.05	1,030
	1030	135,535	202,907	intermittent	
2	500	103,567	234,875	1.16	NA (>1,500)
	1500	120,476	217,967	Intermittent	
3	500	134,391	204,051	0.98	550
	836	139,761	198,681	intermittent	
4	450	74,505	263,937	0.98	NA (»1,530)
	1530	89,564	248,878	intermittent	
5	500	180,963	157,479	1.31	180
6	500	95,273	186,762	1.01	NA (»500)
7	500	144,107	303,675	1.11	385

2.0 INTRODUCTION

The draining of liquid from Tank 25 is scheduled to begin in summer of 2005, similar to that completed in 2003 for Tank 41[2]. To assist in the planning of this operation the draining of the interstitial liquid from the Tank 25 saltcake was modeled using the groundwater simulation package STOMP[3] which was recently modified by SRNL to allow inclusion of the physical property correlations of the liquid being modeled[4]. This enhanced code was used to simulate the draining of Tank 25 interstitial liquid under a variety of conditions using density and viscosity correlations for the Tank 25 supernate developed as part of this task using OLI/ESP 6.7.

Cases were run for what were estimated to be the nominal and bounding tank conditions in order to predict the volume of liquid removed as a function of time. Initial data collected from the actual draining operation can be compared to the simulation results to determine which case best represents the tank conditions and, therefore, provides the best estimate of the time required to remove a target volume of interstitial liquid. This report describes the results of the modeling tasks completed as directed by the Technical Task Request SP-TTR-2004-00024[5], and is organized as follows:

The model conditions and the general assumptions applied to it are explained in Section 3.1 along with the determination of the bounding conditions. The simulation results are given in Section 3.2 and include pump rates, liquid volumes, and relative saturations as a function of time. The results of the nominal case are compared with those of the FACT[6] groundwater modeling package as a method of validation. These results are shown in Appendix A as is the data used to validate OLI/ESP.

3.0 DISCUSSION

3.1 MODEL CONDITIONS AND ASSUMPTIONS.

Data collected during the draining of Tank 41 in the fall of 2002 and spring of 2003 was used to characterize the saltcake in the tank[7]. A major assumption used in this work is that the physical properties of the Tank 25 saltcake are similar to those of Tank 41. Among the parameters used to characterize the saltcake are its intrinsic permeability and porosity, which were estimated for the Tank 41 saltcake to be $3.51 \times 10^{-11} m^2$ and 0.30[7], respectively. These values were applied to the Tank 25 saltcake for the nominal case (and most other cases as well). In all cases the height of the saltcake was assumed to be 316 inches.

An initial (and maximum) pump rate of 20 gpm was used in all cases. This rate was maintained until the target liquid height in the well was achieved which, for the nominal case, was 2ft from the tank bottom. Once at the target height the pump rate was adjusted (slowed) to maintain that height in the well.

The surface area of the well wall was equivalent to that of a 14 inch diameter well, though the geometry of the model well was rectangular instead of a cylindrical; this was not considered to have a significant effect. The supernate above the level of the saltcake was not considered here since the current plan is to remove the free supernate with the existing transfer jet in a separate operation. Some small amount of free supernate may remain after removal by the transfer jet. This volume was not considered in the model and may add a small amount of time to the drain operation. The times predicted in the model are only for removal of the interstitial liquid from the saltcake

3.1.1 Calculation of Nominal and Bounding Conditions.

A total of seven cases were run at various conditions which are listed in Table 2. The nominal (50^{o}C) and bounding temperatures (30 – 60^{o}C) were based on historical data and conditions that would safely expedite the draining of the tank. The nominal well level was 2 feet above the tank floor, which is the assumed pump suction elevation. The only deviations to this were cases 4 and 5, which were set to 1ft. and 5 ft., respectively. Bounding values for the intrinsic permeability of the saltcake were based on the variables used in its calculation – the hydraulic conductivity and the liquid density and viscosity.

The hydraulic conductivity characterizes the liquid flow through the saltcake and is a function of the intrinsic permeability - a property of the saltcake alone - and the fluid density and viscosity. The intrinsic permeability of the Tank 41 saltcake was calculated to be $3.51x10^{-11}m^2$ based on a hydraulic conductivity of 150 inches/day [7] and a density and viscosity of the interstitial liquid of 1378g/L and 10.8cP, respectively, as predicted by OLI/ESP at a temperature of 28^{o}C (the average temperature over the Tank 41 draining operation). Because of the variation in temperature, possible heterogeneity of the saltcake, etc., a simulated (idealized) drain curve based on a particular value for the hydraulic conductivity will match certain portions of the actual data better than others, while an alternate hydraulic conductivity will perform better elsewhere. The range of hydraulic conductivity values which, overall, remained relatively close to the actual drain curve (the

Table 2. Simulation Conditions for each Case

Case	Temperature (^{o}C)	Intrinsic Permeability (m^2)	Porosity	Well Height (ft)	Liquid Retention Curve
1 (nominal)	50	$3.51x10^{-11}$	0.30	2	Sandy Loam
2	30	$3.51x10^{-11}$	0.30	2	Sandy Loam
3	60	$3.51x10^{-11}$	0.30	2	Sandy Loam
4	30	$2.5x10^{-11}$	0.30	5	Sandy Loam
5	60	$5.0x10^{-11}$	0.30	1	Sandy Loam
6	30	$3.51x10^{-11}$	0.25	2	Loamy Sand
7	60	$3.51x10^{-11}$	0.40	2	Loam

simulated well did not go dry nor remain consistently above that of the actual data) was between 120 – 180 inches/day. In addition, the temperature readings taken while draining Tank 41 ranged from ~25 – 31°C, with corresponding density/viscosity ranges of 1.38(+) – 1.38g/cm^3 and 12.2 - 9.54cP, respectively. From these ranges for hydraulic conductivity and liquid density and viscosity, a conservative value for the saltcake intrinsic permeability was calculated to be 2.5x10^{-11}m^2 (26 Darcy at 50°C) and 5.0x10^{-11}m^2 (52 Darcy at 50°C) was calculated as an optimistic value.

Two additional simulation cases were requested using different combinations of the liquid retention curve and saltcake porosity, accounting for possible differences between the Tank 41 and 25 saltcake pore geometry, porosities, and/or differences in the surface tension between the interstitial liquids of the two tanks. The liquid retention curve gives the relative saturation of the porous media as a function of pressure. For example, the relative saturation of a medium having a small pore size and a high liquid surface tension would be higher than that for a system of large pore size and low liquid surface tension at the same pressure (assuming at least one system is below 100% saturation). The form of retention curve used in the models was the van Genuchten equation[8] which is given as:

$$\frac{S_w - S_{wr}}{1 - S_{wr}} = \left[1 + \left(-a\Psi\right)^b\right]^{-\left(1-\frac{1}{b}\right)}, \qquad (1)$$

where S_w is the relative saturation, S_{wr} is the residual (or minimum) saturation, Ψ is the capillary suction head, and a and b are the parameters given in Table 3. An estimate of the appropriate combination of the saltcake porosity and liquid retention curve corresponding to the volume of liquid removed from the Tank 41 saltcake was done in earlier work[7] and determined to be the Sandy Loam retention curve at a 0.30 porosity. These were later confirmed using data from a gamma probe to estimate the amount of liquid in the saltcake as a function of height[9].

Table 3. van Genuchten Liquid Retention Curve Parameters

Retention Curve Type	**S_{wr}**	**a** (1/m)	**ß**
Sandy Loam (nominal)	0.101	2.69	1.45
Loam	0.153	1.12	1.48
Loamy Sand	0.126	3.47	1.74

In other work (J. Josephs - 2003), the surface tension of a 6.5M Na simulant (Hanford Tank 271-AN107) was measured to be only about 10% greater than that of pure water. Therefore, it is believed that the difference in surface tensions between the comparatively similar interstitial liquids of Tanks 41 and 25 (neither contain surfactants) is negligible within the context of this work, and that these variations about the nominal porosity and liquid retention curve essentially express variations in the saltcake alone. The choice of bounding parameter pairs about the nominal values was arbitrary, and selected to result in ±10% of the actual Tank 41 drained liquid volume. A porosity of 0.25 with a liquid retention curve corresponding to that of Loamy Sand gave a volume ~10% less than the actual drained volume, while a porosity of 0.40 with a Loam liquid retention curve resulted in a volume ~10% greater.

3.2 SIMULATION RESULTS

The simulation results of the seven cases are shown in the following sets of plots, a summary of the results is given in Table 1. Figures 1-7 plot the pump rate and the volume of interstitial liquid removed as a function of time (note that the scales of the plots occasionally differ between cases), Figure 1 represents the nominal case. The plots are labeled with the temperature, intrinsic permeability (IP), the liquid retention curve used when it is different than Sandy Loam, and the porosity when it is different than 0.30. The spikes on some of the pump rate curves are due to the simulation's attempt to instantaneously achieve the well level set point the moment the pump is turned on following an idle period. The duration of the spikes are generally on the order of a few seconds and have a negligible contribution to the total volume removed. Figure 8 is a collection of each of the volume curves from the previous plots. Figure 9 shows the estimated volumes of interstitial liquid remaining as a function of time. Figures 10-16 plot the change in the well level with time. The initial portion of the curves, where most of the change takes place, are expanded and included as insets in these figures. Figures 17-30 show two snap-shots of the saltcake relative saturation for each case at 100 and 500 hours.

Cases 1, 3, 5, and 7 were able to achieve the target volume of 135,000 gal. within a reasonable amount of time. Cases 5 and 7 are the most optimistic cases and were able to achieve the target volume before the pump reached the minimum rate of 1 gpm, that is, the total flow of interstitial liquid to the well remained above 1 gpm. Cases 1 and 3 were able to achieve the target volume, but not before the pump reached its minimum rate. Once the pump rate fell below ~1 gpm (i.e. total liquid flow to the well fell below 1 gpm), the pump was turned off for a period of time to allow the well to fill. The pump was then turned on for a given period during which it could operate at or above the minimum rate. The pump was operated in this intermittent fashion until the target volume was achieved. The efficiency of liquid removal was greatly diminished during this portion of the operation, resulting in a significant amount of the total drain time being used to retrieve a relatively small portion of the 135k gal. Even when the pump could be run continuously the efficiency of the operation quickly diminished over time. In nominal case (case 1) for example, 90% of the target volume was retrieved in only 34% of the total time needed to achieve the target (441 hrs. to retrieve 90% of the volume, 1,030 hrs to retrieve the target volume of 135k gal.). Case 3 was not as severe, but still significant, retrieving 90% of the target in 60% of the total time (327 hrs. to retrieve 90% of the target volume, 550 hrs. to retrieve the target volume of 135k gal.).

Cases 2, 4, and 6 did not achieve the target volume within the time of the simulations, which was slightly more than two months for cases 2 and 4. Plots of the liquid removal rate (Figures 2, 4, and 6) indicate that the target volume cannot be achieved within a reasonable amount of time. All three cases were run at 30^{o}C. While the temperature effect on liquid viscosity is very important, it is not possible to determine quantitatively how the liquid removal rate is affected by each factor over the range investigated here. The selection of simulation scenarios was driven by defining nominal and bounding cases, as opposed to a parametric study. The cases 4, and 6 had additional factors (low intrinsic permeability, low porosity) contributing to the low volume removal. However, a comparison of cases 1-3 (Figures 1-3), which are identical except for temperature, demonstrates the dramatic effect temperature can have on the liquid removal rate.

Figure 1. Case 1, IP: 3.51x10^{-11}m^2, Temp: 50^{o}C

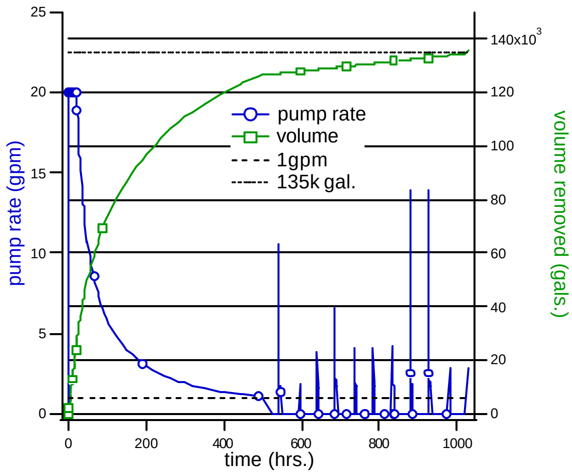


Figure 2 . Case 2, IP: 3.51x10^{-11}m^2, Temp: 30^{o}C

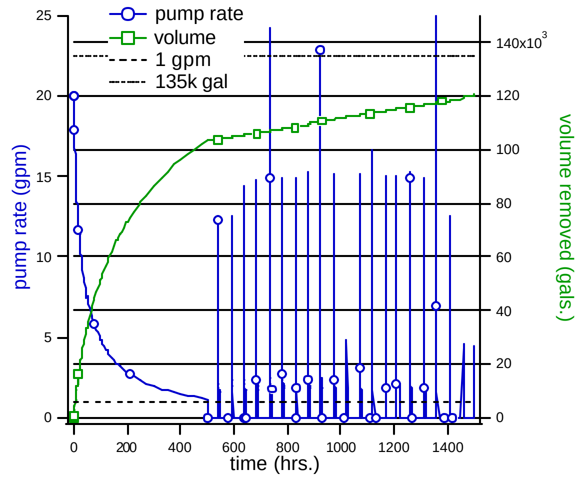


Figure 3. Case 3, IP: 3.51x10^{-11}m^2, Temp: 60^{o}C

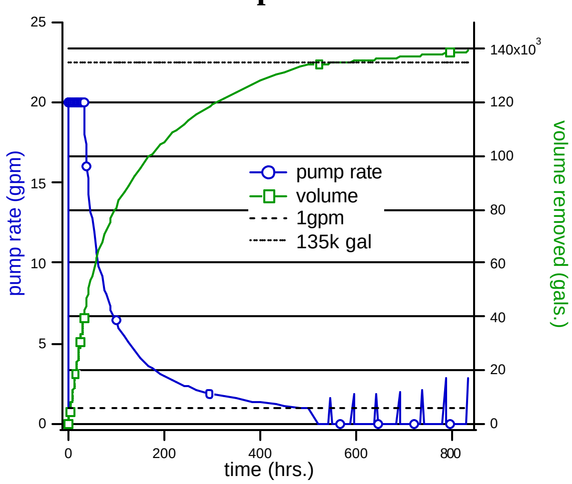


Figure 4. Case 4, IP: 2.5x10^{-11}m^2, Temp: 30^{o}C

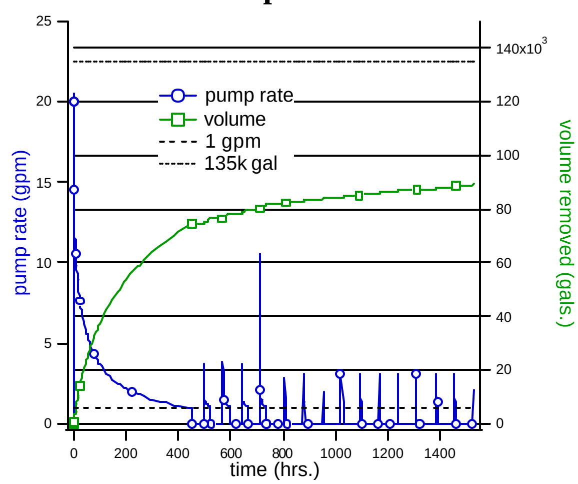


Figure 5. Case 5, IP: 5.0x10^{-11}m^2, Temp: 60^{o}C

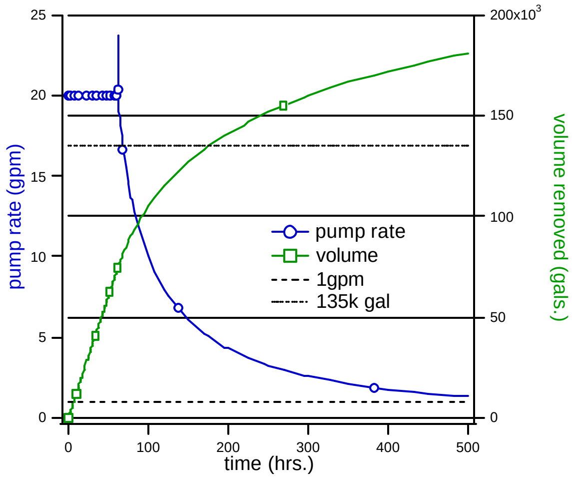


Figure 6. Case 6, Loamy Sand, Porosity: 0.25, IP: 3.5x10^{-11}m^2, Temp: 30^{o}C

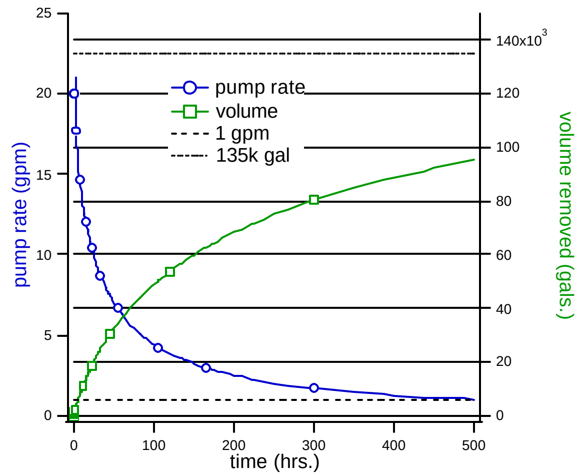


Figure 7. Case 7, Loam, Porosity: 0.40, IP: 3.5x10^{-11}m^2, Temp: 60^{o}C

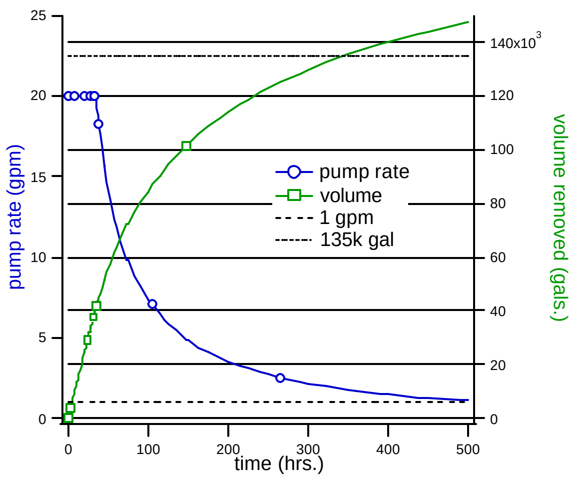


Figure 8. Volume of Interstitial Liquid Removed

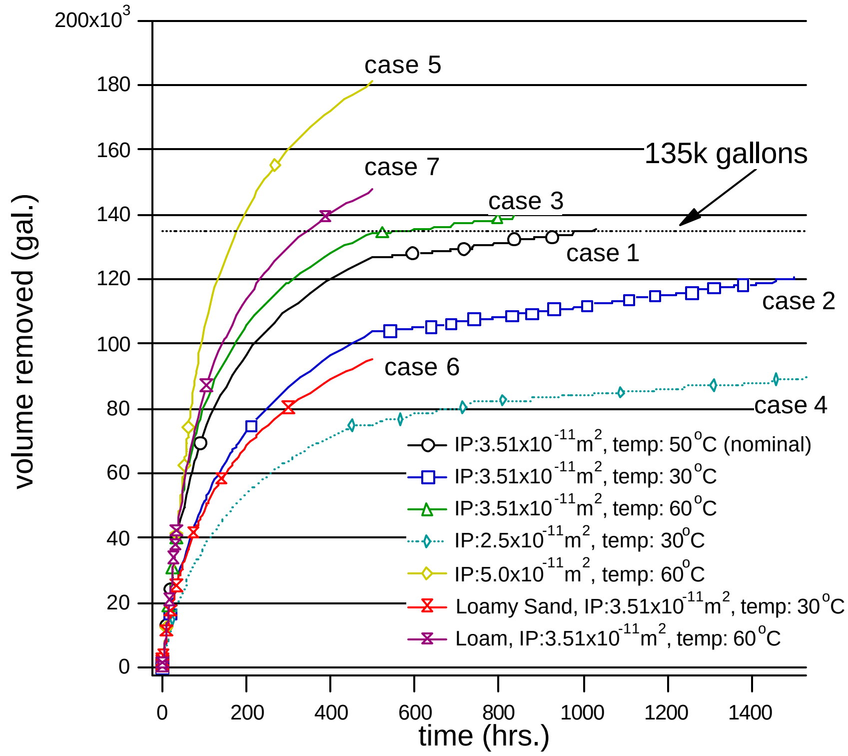


Figure 9. Volume of Interstitial Liquid Remaining

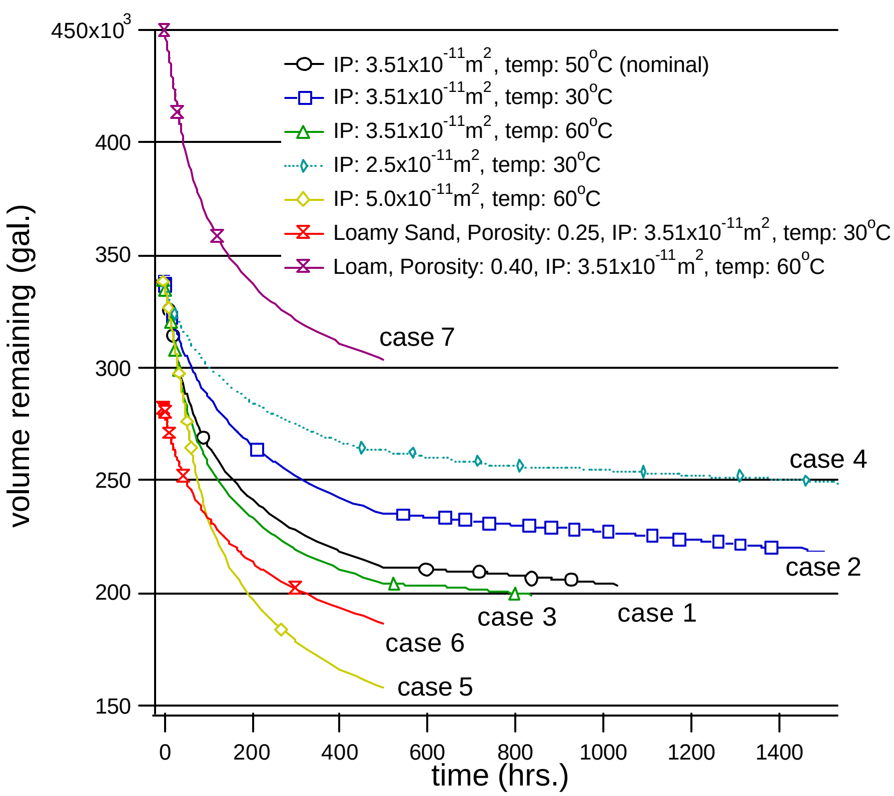


Figure 10. Case 1 – Well Level

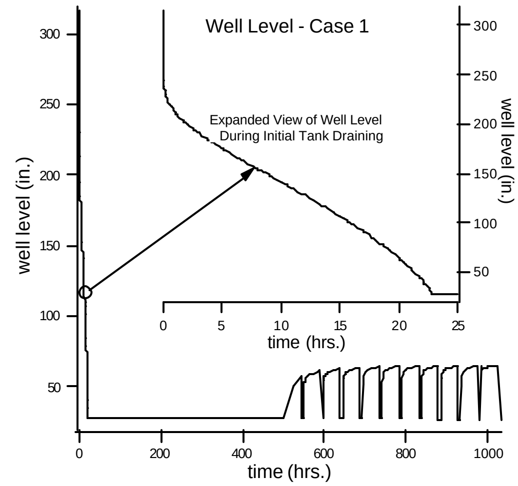


Figure 11. Case 2 – Well Level

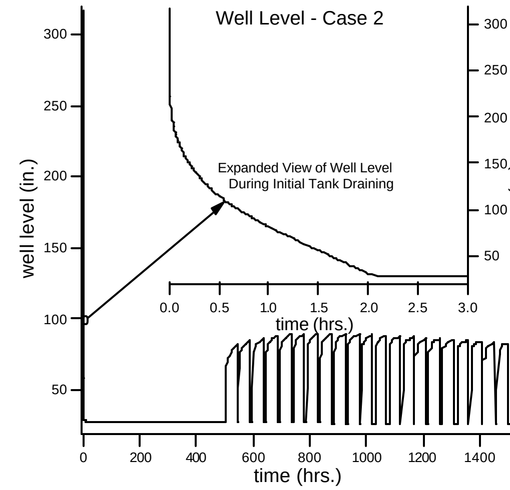


Figure 12. Case 3 – Well Level

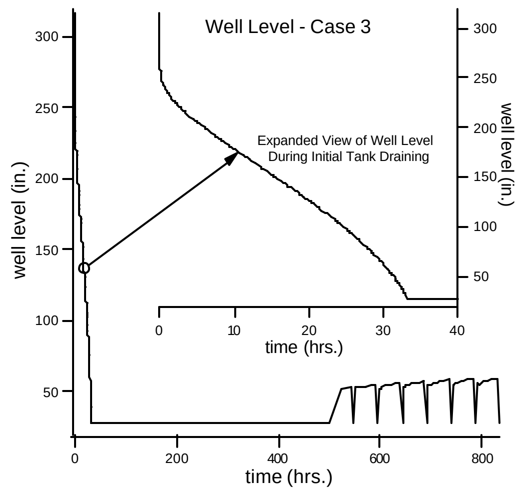


Figure 13. Case 4 – Well Level

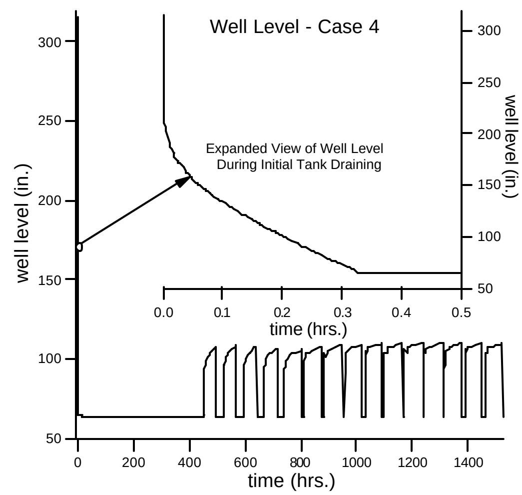


Figure 14. Case 5 – Well Level

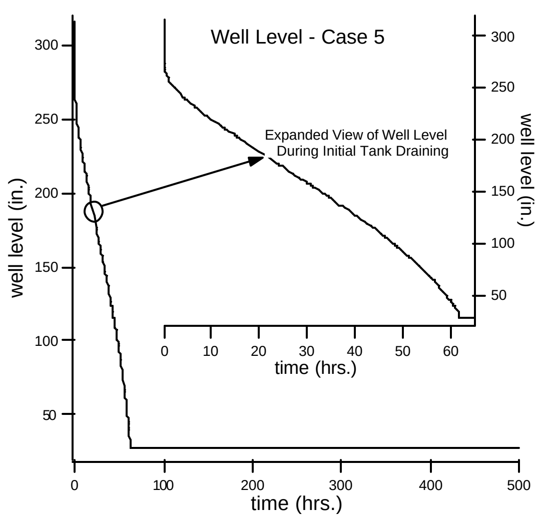


Figure 15. Case 6 – Well Level

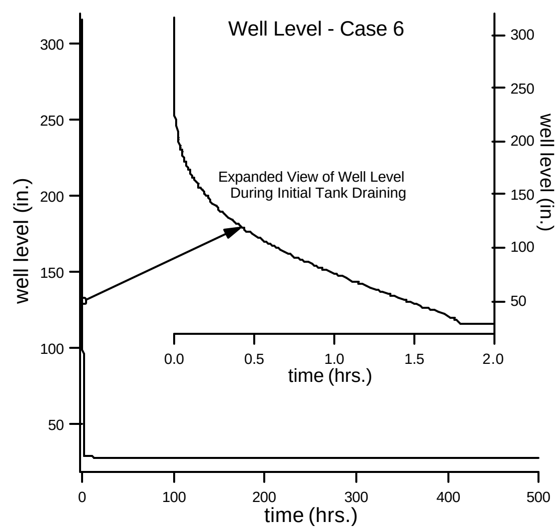


Figure 16. Case 7 – Well Level

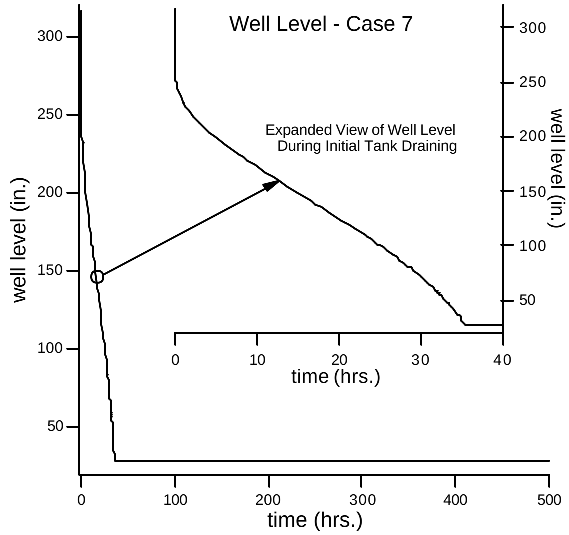


Figure 17. Case 1 Saturation, 100hrs.

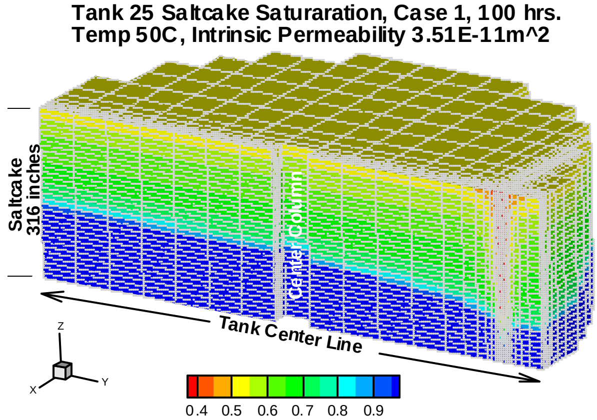


Figure 18. Case 1 Saturation, 500hrs.

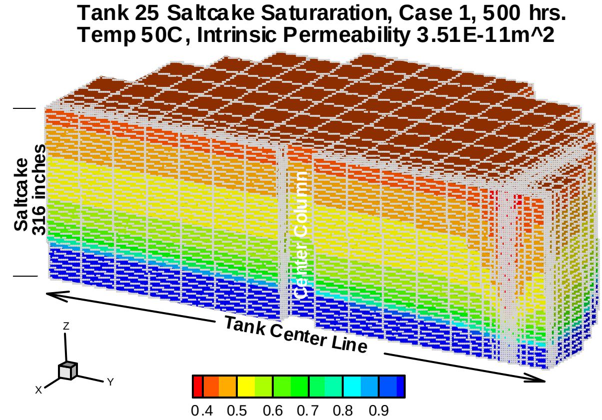


Figure 19. Case 2 Saturation, 100hrs.

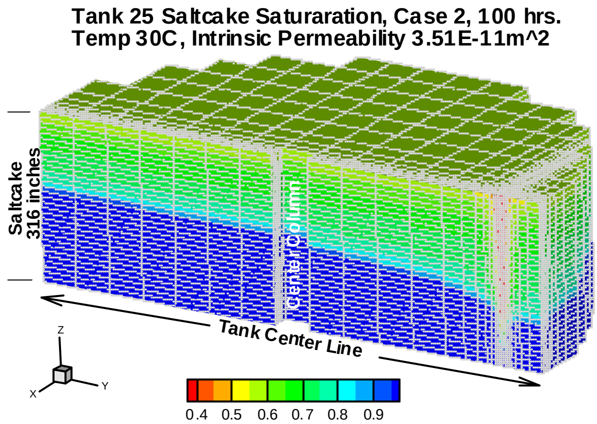


Figure 20. Case 2 Saturation, 500hrs.

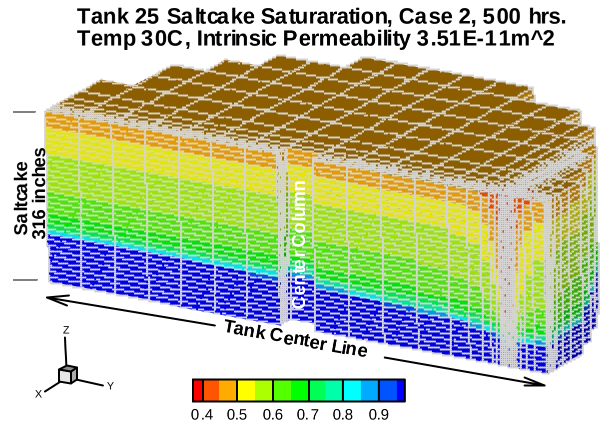


Figure 21. Case 3 Saturation, 100hrs.

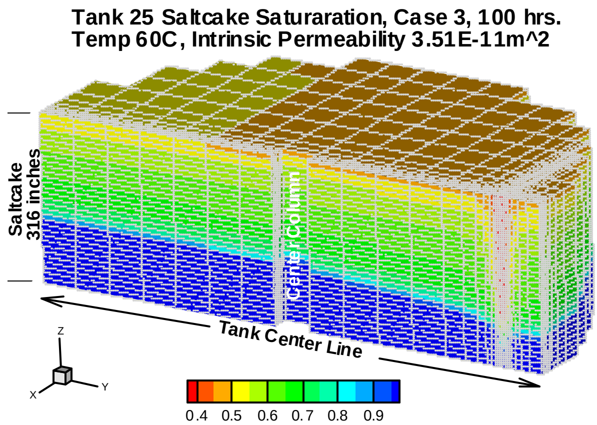


Figure 22. Case 3 Saturation, 500hrs.

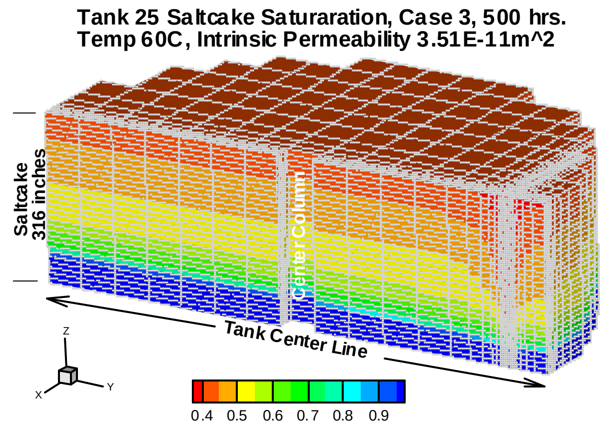


Figure 23. Case 4 Saturation, 100hrs.

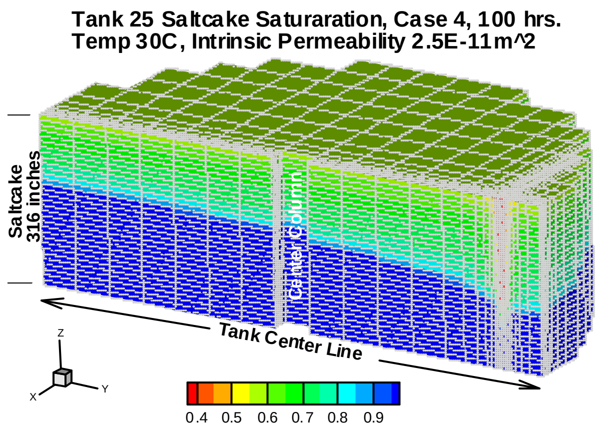


Figure 24. Case 4 Saturation, 500hrs.

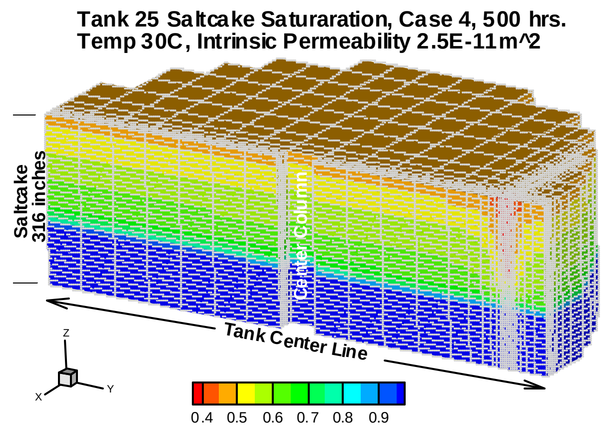


Figure 25. Case 5 Saturation, 100hrs.

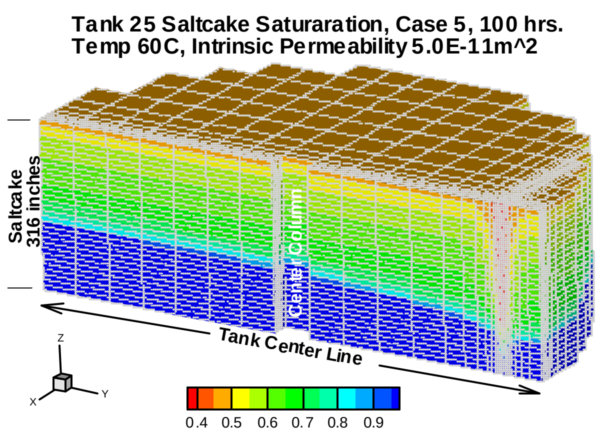


Figure 26. Case 5 Saturation, 500hrs.

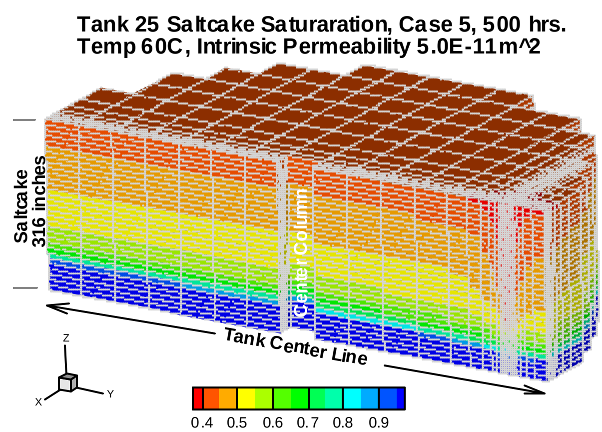


Figure 27. Case 6 Saturation, 100hrs.

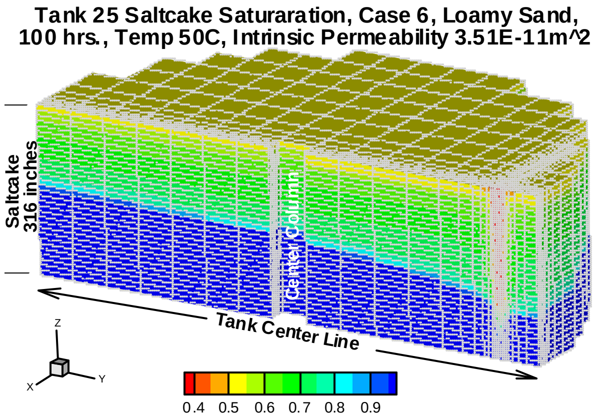


Figure 28. Case 6 Saturation, 500hrs.

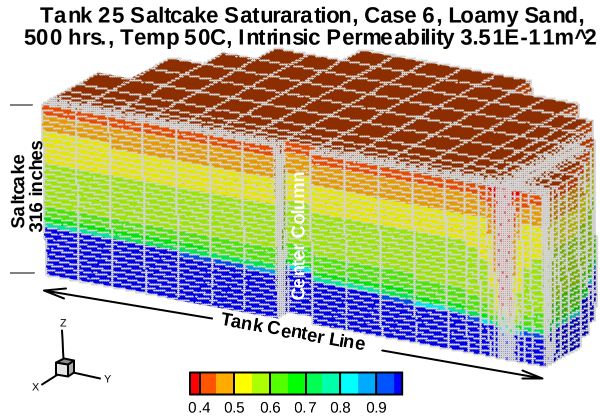


Figure 29. Case 7 Saturation, 100hrs.

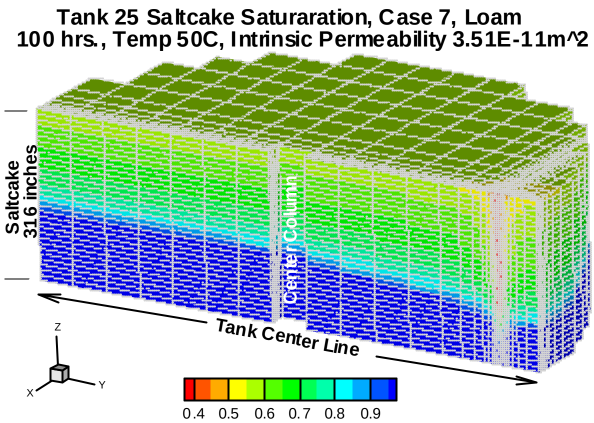
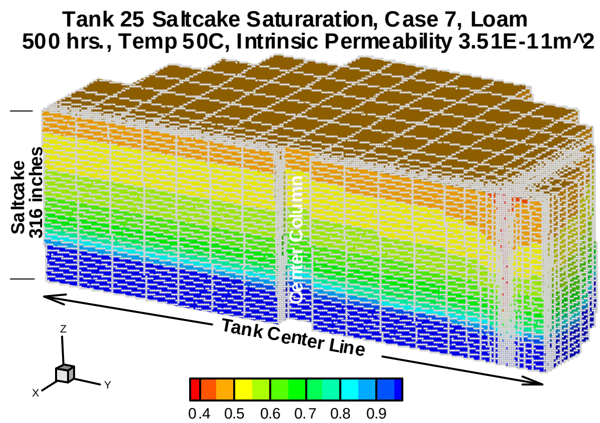


Figure 30. Case 7 Saturation, 500hrs.



SUMMARY

The simulation results indicate that it is possible to drain the target volume of 135,000 gals. of interstitial liquid from the Tank 25 saltcake in a reasonable amount of time under the nominal conditions. The scenarios investigated included variations in the interstitial liquid temperature, salt cake intrinsic permeability, saltcake porosity, and the liquid retention which were used to define nominal and bounding cases. Four of the seven simulation cases were successful at achieving the target volume. The three exceptions were run at the lowest temperature modeled, 30^{o}C, of which two had additional factors contributing to the low volume of liquid removal (low, intrinsic permeability, low porosity).

Initial data collected during the actual draining operation of Tank 25 can be compared to the simulation results to determine which scenario best matches the actual tank conditions. The results of that scenario can then used to predict if/when the drain operation will be completed. This is dependent on being able to maintain a pump rate of 20 gpm until the target well level is reached, then maintaining that level. Any comparison between the simulation and actual conditions would be invalid if, during the actual draining of Tank 25, the pump rate differs significantly from that of the simulation. However, additional simulations could be run using the actual pump rate to determine which case agrees most closely with the observed well level and, in doing so, provides the best representation of the tank conditions.

4.0 REFERENCES

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APPENDIX A. STOMP SIMULATION MODEL AND OLI/ESP VALIDATION

The simulation results of case 1 were compared to those of a similar simulation done for the same case using FACT[6] and are shown Figure 31 and Figure 32. This was done as a method of validation of the STOMP simulation input (the form of input between the packages is very different). This is also a validation of the STOMP code, though this was done in previous work[4]. The slight offset in total volume removed is due to the somewhat different initial pump rates applied to the two simulations. In the FACT simulation, the well level was brought down at a constant rate until it reached the target level of 2 ft., unlike the STOMP simulation where a pump rate of 20 gpm was maintained until the target well level was reached. This resulted in a lower average pump rate during the initial part of FACT simulation and, therefore, a correspondingly lower total liquid volume removed. The pump rates come to excellent agreement following this initial portion of the simulations, at which point the volume curves are qualitatively identical.

Figure 31. Interstitial Liquid Volume Removed, FACT vs. STOMP

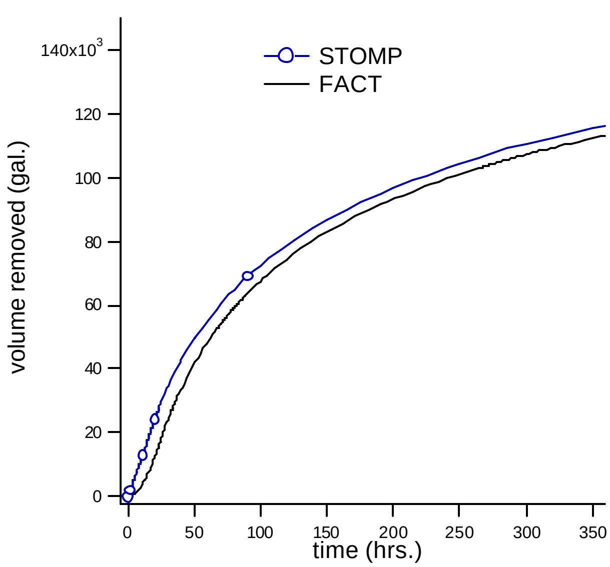
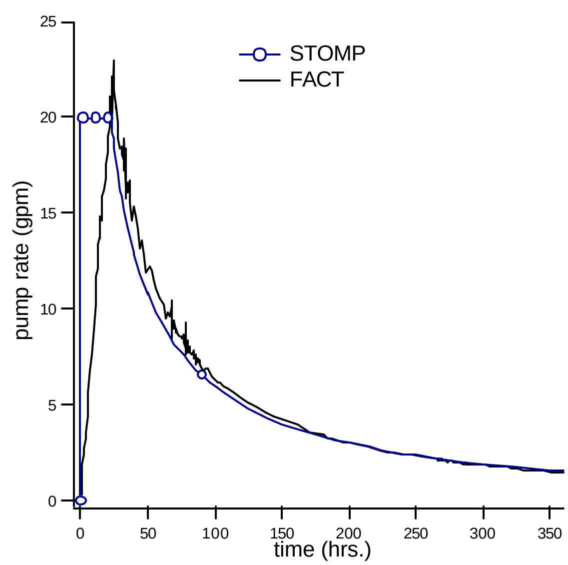


Figure 32. Pump Rate FACT vs. STOMP



Correlations describing the density and viscosity of the supernate of Tanks 25 and 41 as a function of temperature were developed using OLI/ESP 6.7 based on analytical data of the supernate for each of the tanks. The correlations were linear fits of the OLI/ESP predictions with an R^2 of >0.98. The density and viscosity of a Tank 41 simulant[10] at 25°C were measured to be 12.3 cP and 1.39 g/cm^3, respectively, and are in excellent agreement with the correlation values of 12.2 cP and 1.38g/cm^3. No viscosity data is available for Tanks 41 or 25, however. OLI/ESP values for a simple NaOH – H_2O system over a range of concentrations are compared to published values[11] in Figure 33 as an additional method of validation.

Figure 33. Density and Viscosity of NaOH – H_20 System at 20^oC
Comparison of CRC and OLI/ESP Values