Atlantic Richfield Hanford Company
Richland, Washington 99352

RHO-CD-80

EVALUATION OF THE 241-S-111 SALT WELL
JET PUMP PROTOTYPE

D. R. DIXON

MASTER

PREPARED FOR THE U.S. ENERGY RESEARCH AND DEVELOPMENT
ADMINISTRATION UNDER CONTRACT E (45-1) 2130

PRELIMINARY REPORT

THIS REPORT CONTAINS INFORMATION OF A PRELIMINARY NATURE. IT IS SUBJECT TO REVISION OR CORRECTION AND THEREFORE DOES NOT REPRESENT A FINAL REPORT. IT WAS PREPARED PRIMARILY FOR INTERNAL USE WITHIN THE ATLANTIC RICHFIELD HANFORD COMPANY. ANY EXPRESSED VIEWS AND OPINIONS ARE THOSE OF THE AUTHOR AND NOT NECESSARILY OF THE COMPANY.

NOTICE

THIS REPORT WAS PREPARED AS AN ACCOUNT OF WORK SPONSORED BY THE UNITED STATES GOVERNMENT. NEITHER THE UNITED STATES NOR THE UNITED STATES ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION, NOR ANY OF THEIR EMPLOYEES, NOR ANY OF THEIR CONTRACTORS, SUBCONTRACTORS, OR THEIR EMPLOYEES, MAKES ANY WARRANTY, EXPRESS OR IMPLIED, OR ASSUMES ANY LEGAL LIABILITY OR RESPONSIBILITY FOR THE ACCURACY, COMPLETENESS OR USEFULNESS OR ANY INFORMATION, APPARATUS, PRODUCT OR PROCESS DISCLOSED, OR REPRESENTS THAT ITS USE WOULD NOT INFRINGE PRIVATELY OWNED RIGHTS.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

UNCLASSIFIED

RHO-CD-80

1

EVALUATION OF THE 241-S-111 SALT WELL
JET PUMP PROTOTYPE

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

D. R. Dixon

Waste Processing and Development Team
Waste Engineering Unit
Process Engineering Department
Research and Engineering Function

September 1, 1977

APPROVED BY:

Date

Operated for Energy Research and Development Administration
by Rockwell Hanford Operations under Contract EY-77-C-06-1030

24B

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

TABLE OF CONTENTSEVALUATION OF THE 241-S-111
SALT WELL JET PUMP PROTOTYPE

	<u>Page</u>
I. INTRODUCTION	5
II. SUMMARY	5
III. DISCUSSION	6
A. EQUIPMENT	6
B. OPERATING PROBLEMS	7
C. COMPARISON OF DATA WITH FLOW MODEL	9
1. BASIC THEORY	9
2. SALT CAKE/INTERSTITIAL LIQUOR PHYSICAL PARAMETERS	10
3. PUMPING TIME	10
IV. REFERENCES	11
V. APPENDIX	23

LIST OF TABLES

	<u>Page No.</u>
I MAIN EQUIPMENT	12
II OPERATING PROBLEMS	13
III MONTHLY PRODUCTION	14
IV POROSITY CALCULATIONS	15
V RECOVERY DATA	16
A1 LIQUID REMAINING	25

LIST OF FIGURES

	<u>Page No.</u>
I PUMPED WELL DETAILS	17
II JET ASSEMBLY	18
III EQUIPMENT LOCATION	19
IV RECOVERY CURVE	20
V EQUILIBRIUM FLOW RATE	21
VI FLOW RATE DATA	22
A1 PUMPING TIME	26

EVALUATION OF THE 241-S-111 SALT WELL JET PUMP PROTOTYPE

INTRODUCTION

In order to minimize the potential for leakage of liquid radioactive waste stored in underground tanks, the waste is being concentrated to a slurry. Concentration takes place in the evaporator-crystallizer units (242-A and 242-S) and the bottoms are routed to underground storage tanks where the solids are allowed to settle. After the surface liquid is removed, the remaining liquid in the salt cake (termed interstitial liquor) is pumped using a salt well to collect the drainable liquid. The interstitial liquor may undergo further concentration and/or be stored in double-shell tanks.

Deep well turbine (P-10) pumps are used to pump the salt wells until the flow rate of interstitial liquor into the well is less than the minimum pumping rate of the pump. Once this happens, a pump capable of pumping at lower flow rates is needed to continue removing liquor. The recirculating jet pump system in Tank 241-S-111 was installed to accomplish this purpose. This document is presented to:

- o Document the results of the first year of operation by the instrumented jet pump system.
- o Describe the equipment installed, operational problems encountered with the equipment and some solutions found effective for these operational difficulties.
- o Calculate and compare the results with the idealized model.

SUMMARY

The jet pump system installed in Tank 241-S-111 has operated for five months since installation in January 1976. When the pump failed in January 1977, 247,000 gallons of liquor had been pumped with a final pumping rate of 0.5 - 0.6 GPM ($\sim$ 800 GPD). It is estimated that the tank has 126,300 gallons remaining of which 76,200 gallons is drainable (the remaining is held by capillary forces). With the present jet pump design, an estimated pumping rate of .05 GPM would be the minimum that could be achieved. An additional 220 days of continuous pumping is predicted to reach this minimum rate.

Several operating problems have hampered production from the jet pump system. Pumping was stopped for seven months (May to December 1976) due to the strike and low priority following the strike. The dip tube bubblers, used for liquid level measurement, became plugged with solids when submerged in the liquid. A periodic steam purge was applied to help dissolve these solids and keep the tubes open. It was found that the

tubes should be purged as soon as they are installed. An electrical interlock system in S and SX farms will shut down all pumps if any raw water supply is used. The purpose of the interlock system is to prevent the backflow of radioactive liquid. Numerous shutdowns of the 111-S jet pump have resulted from this action, therefore, this interlock system needs to be eliminated for future jet pump installations. Repairs on the jet pump system after January 1977 were delayed due to crane availability. The needed maintenance was finished in June 1977, but pumping could not be resumed because the routing to the receiver tank is used to pump evaporator feet for currency.

A mathematical model based on the Darcy radial flow equation has been developed to predict the in-flow rate of liquor to a salt well. Using the data from 111-S, the empirical constant necessary to use this equation was determined. This constant, defined as the ratio of the salt cake permeability to the liquor viscosity (k/μ), ranged from 0.3 to 1.0 Darcy/centipoise. Assuming that the sludge does not allow liquid to flow through it, the k/μ ratio was found to be 0.8. The porosity of the salt cake was found to be .30, which agrees with previous estimates.

DISCUSSION

A. EQUIPMENT

The recirculating jet pump system (Figure I) is capable of operating continuously even though the flow of interstitial liquor into the salt well may be very slow (< 0.05 GPM). The pump circulates liquid until the liquid level in the well rises above a predetermined set point. When this set point is reached, the control valve (DOV) on the discharge side of the pump opens and allows liquid to be pumped out. The control valve is adjusted automatically to maintain a constant well level, thus keeping the pump-out rate equal to the in-flow rate of liquid into the well. When the system operates properly, the well level is kept low to achieve the maximum pump-out rate, while maintained sufficient liquid cover over the pump suction to prevent drawing in air. The main equipment is listed in Table I.

Three dip tube bubblers are located in the pumped well to measure the weight factor and specific gravity. The liquid level can be determined from this data. The first dip tube is located near the bottom of the well, the second is ten inches above that and the third is twenty feet above the first. The specific gravity is calculated by measuring the difference in pressure between the bottom two tubes, both being below the liquid surface. Knowing the specific gravity, the liquid level can be determined by measuring the pressure difference between the bottom and top (reference) tubes. The top tube is located above the liquid surface. The control valve is adjusted according to the pressure differential. A pair of dip tubes is located in each of the observation wells to measure the weight factor.

Liquid is drawn into the pumping system by means of the jet assembly at the bottom of the recirculation loop (Figure II). Liquid is pumped through the pressure reducing nozzle creating a suction which draws liquid in from the well. The check valve at the bottom prevents any back flow of liquid into the well during pump priming.

For measuring the flow of liquid out of the tank, a one-inch Fischer and Porter magnetic flowmeter was installed. The range of this flowmeter as specified by the manufacturer (2.2 - 70 GPM) was greater than the average pump-out rate of the jet pump. Testing of the 1/4 inch and 1/2 inch flowmeters though, showed that they were accurate at lower flow rates than the manufacturer indicated. A 1/4 inch Fischer and Porter flowmeter has since been installed. The S and SX farm jet pump systems will be equipped with 1/2 inch Foxboro magnetic flowmeters.

The control valve for regulating the flow of liquid to the receiver tank is Research Controls 1/2-inch, Model B-380. The valve trim controls how far the valve is open at different flow rates. Presently, G linear trim is used at 111-S which is only open a small part of the way at low flow rates (25 percent open at 0.3 GPM). For better control at low flow rates, future jet pump systems will have E equal percentage trim which is open further at these flow rates (52 percent open at 0.3 GPM).

B. OPERATING PROBLEMS

The recirculating jet pump system was installed in Tank 111-S during January 1976. Since startup on February 1, 1976, the pump ran approximately 50 percent of the time (excluding work stoppage time) until the pump seal failed on January 24, 1977. The work stoppage resulted in shutting the jet pump system down from April 29 to November 13. A summary of the operating problems are given in Table II.

The interstitial liquor which drains into the well is mainly a saturated solution of sodium nitrate which may form crystals on objects coming in contact with it. Solids have caused pluggage of the dip tubes, well screen and control valve resulting in several operating problems. If the dip tubes become plugged, there is no measure of the liquid level in the well. A plugged well screen prevents liquid from entering the well resulting in a lower pump-out rate. Hot water has been used to dissolve the solids in the dip tubes and flush the well screen. This is not always successful and rodding of the dip tubes has been attempted when hot water failed. When the dip tubes were first installed purging equipment was not available and all four tubes below the liquid level became plugged. The upper (SpG) tube in the pumped well was cleared by rodding before operation began and was used to estimate the liquid level, by assuming a specific gravity. The pump occasionally lost prime due to incorrect liquid level readings from this dip tube. The dip tubes in observation well I (Figure III) were cleared in January 1977 near the end of operation while the other tubes were never able to be opened. In the future, dip tubes below the liquid level should be replaceable and be purged with steam continuously to prevent blockage.

The 111-S jet pump is electrically interlocked with other pumps in the 241-S Tank Farm. If the raw water supply is used to prime a pump, all other pumps in this system will be automatically shutdown to prevent a potential back flow of radioactive liquid into the raw water supply. Numerous shutdowns of the jet pump have resulted from this action. A pressure switch in the raw water line initiates this shutdown. When more jet pumps are installed, continued use of this interlock system would not be practical. A simple alternative to this problem would be to install a back flow preventer in the raw water line.

The electrical interlock system has made pump priming difficult. Before the pump is started, the recirculation loop must be filled with raw water, and after priming the raw water line has to be depressurized before the interlock system will allow the pump to start. Over a period of time, solids can build up on the foot valve, preventing it from closing all the way and allowing some of the water in the recirculation loop to escape. By the time the raw water line is depressurized, enough water can leak out to prevent the pump from starting. It is possible that some pump seal failures are due to the numerous attempts to restart the pump without sufficient water. By eliminating the interlock system, pump priming could be easier and required less often.

Several new pieces of equipment were evaluated during the testing of the jet pump system. In addition to measuring the well liquid level by means of the dip tubes, a pressure transducer manufactured by Setra Systems was used. This transducer failed after only 3-1/2 months of use and the readings showed large discrepancies from that of the dip tubes. The transducer seal had failed allowing liquid inside the unit and solids covered the pressure sensing head. The use of the pressure transducer has been discontinued. Two methods were used to measure the flow of liquid to the receiver tank. The first device was an ultrasonic flowmeter made by Controlotron Corporation which simply clamped over the existing pipe. The clampitron failed after only two months of operation and tended to show more liquid being pumped than the FIC gauge in the receiver tank indicated. A one-inch Fischer and Porter magnetic flowmeter was installed with the former turbine pump and operated the entire time the jet pump system was working. This flowmeter was larger than desired and measured fewer gallons pumped than the FIC gauge did for most of the operating time. A comparison of the magnetic flowmeter and FIC gauge is shown in Table IV with the porosity calculations.

Since the jet pump shutdown on January 24, repairs have been made to make the system operable again. Repairs include:

- o unplug, decontaminate pump pit drain
- o steam lance pumped well
- o changed pump
- o changed DOV
- o changed manual recirculation valve
- o removed pressure transducer
- o pressure tested process line
- o installed new dip tubes
- o changed magnetic flowmeter (1/4 inch)
- o replaced pump case
- o replaced DOV bypass valve
- o installed new flexible jumper

The system has not been restarted because the pump-out routing to the receiver tank (107-S) is being used to pump evaporation feed. The new dip tubes have become plugged since installation and will need to be replaced. Flushing of the pumped well is needed because solids have been found in the well.

C. COMPARISON OF DATA WITH FLOW MODEL

In order to evaluate the effectiveness of the jet pump system, data has been collected for comparison with the theoretical model. During operation this data was used to adjust operating parameters. Changes in the weight factor within the pumped well were recorded on a strip chart recorder. When the pump is shutdown, the rise in weight factor as a function of time would be shown on the recorder. A typical recovery curve after a pump shutdown is shown in Figure IV. Weight factor data from the observation wells was not taken because the dip tubes could not be unplugged. Monthly production data as recorded by the magnetic flowmeter is shown in Table III.

1. Basic Theory

A mathematical model has been developed which describes the fluid flow in salt cake (reference 1). This model is based on the Darcy radial flow model assuming homogeneous properties throughout the salt cake. For a centrally located salt well under pseudo steady state conditions, the equation simplifies to:

$$q = 0.044 \frac{K}{\mu} \gamma \frac{(h_e^2 - h_w^2)}{\ln \frac{r_e}{r_w}} \quad \text{Equation 1}$$

Where:

- q = flow rate in gallons per minute
- k = permeability in Darcies
- γ = fluid specific gravity
- μ = viscosity in centipoise
- h_e = height of fluid at point e in feet
- r_e = distance radially from the center of the well to point e, in feet.
- h_w, r_w = height of fluid and radial distance for the salt well, in feet.

Point e is usually taken as the tank wall.

The solid lines in Figure V show the predicted in-flow rate to a salt well versus the equilibrium pressure head for various cake permeabilities and fluid viscosities. The constants used in these calculations were:

$$\begin{aligned} \gamma &= 1.44 \\ r_e &= 37.5 \text{ ft.} \\ r_w &= .42 \text{ ft.} \end{aligned}$$

2. Salt Cake/Interstitial Liquor Physical Parameters

In order to use the flow model equation to predict the in-flow rate to a salt well, the physical characteristics of the salt cake and interstitial liquor must be determined. Experimental measurements on actual and synthetic liquors have been made to determine the viscosity and specific gravity. These parameters will vary with concentration and temperature. Determining the salt cake permeability is more difficult because the viscosity and density of the liquor that will be in contact with the cake must be known at the tank temperature. To estimate the interstitial liquor remaining in the salt cake, the porosity or void volume of the cake needs to be calculated.

The porosity of the salt cake in Tank 111-S was calculated in two different ways in Table IV. Method A assumes that the liquid removed from the tank is measured accurately by the magnetic flowmeter. The liquid transferred is calculated by measuring the increased liquid level in the receiver tank 107-S for method B. A porosity of .30 was found for the last month of operation by the second method. This agrees with other estimates of the porosity (reference 3). Using this value for the porosity, the total interstitial liquor remaining in the tank is estimated to be 126,300 gallons (Table A1).

The flow rate of liquid into the salt well versus the average pressure head is plotted in Figure V. The recovery data (Table V) is plotted twice, once with the liquid heights referenced to the tank bottom (Case 1) and the second time referencing them to the top of the sludge layer (Case 2), 4-2/3 feet above the tank bottom. This is done because the sludge is assumed to be homogeneous, without cracks or pockets of liquid, and theoretically should not allow liquid to flow through it. Assuming an average specific gravity of 1.44 for the liquor, the ratio of the cake permeability to the liquor viscosity (K/μ) is computed using Equation 1. The K/μ ratio was found to range from 0.3 to 1.0 Darcy/centipoise with an average of about .4 for Case 1 and .8 for Case 2. A record of the in-flow rate over the last six weeks of operation is shown in Figure VI. The solid line indicates the flow rate calculated from the flow model equation using $K/\mu = .8$. When pumping stopped in late January, the in-flow rate was between .5 and .6 GPM.

3. Pumping Time

As the height of liquid in the salt cake decreases, the in-flow to the salt well will decrease as shown in Figure V. With the present control valve and magnetic flowmeter, a flow rate of about .05 GPM would be the minimum that could be attained. Equipment may be developed which would allow pumping at lower flow rates. However, the quantity of liquid removed at these low rates is small in comparison to the total amount of liquid removed from the tank and takes a considerable amount of time (Figure A1). Approximately 220 days of continuous pumping will be required to reach an in-flow rate of .05 GPM and 70,000 gallons of liquid will remain in the tank. Only 20,000 gallons of this liquid is drainable, the rest is held by capillary action. Pumping times to attain various liquid levels are calculated in the Appendix.

REFERENCES

1. ARH-C-6 (unclassified), September 30, 1975, L. L. Handy, Consultant, "Flow Properties of Salt Cake for Interstitial Liquid Removal/Immobilization Development Program"
2. ARH-CD-545 (unclassified), January 15, 1976, W. P. Metz, "A Topical Report on Interstitial Liquid Removal from Hanford Salt Cakes"
3. ARH-ST-129 (unclassified), November 1975, D. M. Strachan, "Permeability, Capillarity, and Pore Volume of Synthetic Hanford Salt Cake"
4. Drawing, H-2-69892, "Jet Pump Installation 241-S-11A"
5. Drawing, H-2-38434, "10 Inch Salt Well Casing for 241-S-11A"
6. Drawing, H-2-69816, "Jet Assembly and Check Valve"

TABLE I

MAIN EQUIPMENT

1. 1-1/2 HP Goulds Model 3642 centrifugal pump.
2. One ten-inch diameter salt well with a four-foot four-inch well screen.
3. Two three-inch diameter observation wells with three foot well screens.
4. Dip tubes for measuring weight factor and specific gravity. The tubes are made of 3/8 inch pipe.
5. Jet Assembly for drawing the liquor into the pump (Figure II)
6. One-inch Fischer and Porter Magnetic Flowmeter Model 10D1418A.
7. 1/2-inch B-380 Research Controls Control Valve with G linear trim.

TABLE II

OPERATING PROBLEMS

<u>Operating Problems</u>	<u>Solutions/Recommendations</u>
1. Pump seal failure	Replace pump; revise priming system
2. Control valve leaking	Replace/repair
3. Plugged dip tubes	Steam purge; replaceable tubes
4. Shutdowns due to interlock system when flushing other pumps.	Eliminate interlock system
5. Solids in pumped well (well screen)	Flush with hot water
6. Plugged control valve	Cleaned by steam purge
7. Difficult to prime pump	Eliminate interlock system
8. Leaking jumper, pump breakage	Installed flexible jumper
9. Oversized magnetic flowmeter (1")	1/4-inch flowmeter installed

TABLE III

MONTHLY PRODUCTION

<u>Month</u>	Magnetic Flowmeter <u>Start</u>	Reading <u>Finish</u>	Days* Pumping <u>Attempted</u>	Gallons <u>Pumped</u>	Flow* Rate (GPM)
February 76	71200	144206	21	73006	2.41
March 76	144206	204422	18	60216	2.32
April 76	204422	255224	25	50802	1.41
Work Stoppage					
November 76	255224	267225	9	12001	0.93
December 76	267225	298523	17	31298	1.28
January 77	298523	317974	<u>20</u>	<u>19451</u>	0.68
Total Operation			110	246774	

*Estimate

TABLE IV
POROSITY CALCULATIONS

Date	Liquid Lev. (Dip Tubes)	Total Volume	Liquid Pumped	Liquid Lev. (FIC)	Liquid Received	Porosity	
	Δh_l (ft) 111-S	ΔV_t (gal) 111-S	ΔG_m (gal) Mag. Flow	Δh_l (ft) 107-S	ΔG_F (gal) 107-S FIC	Method A $\theta_A = \frac{\Delta G_m}{\Delta V_t}$	Method B $\theta_E = \frac{\Delta G_F}{\Delta V_t}$
12/26 to 12/31	$\frac{14.64}{14.06} > 0.58$	19166	5172	.175	5783	.270	.302
12/31 to 1/5	$\frac{14.06}{13.14} > 0.92$	30402	6202	.217	7160	.204	.236
1/5 to 1/8	$\frac{13.14}{12.9} > 0.24$	7931	2544	.100	3305	.321	.417
1/12 to 1/14	$\frac{12.9}{12.78} > 0.12$	3965	2415	.083	2754	.609	.695
1/14 to 1/20	$\frac{17.78}{11.98} > 0.80$	26437	5486	.233	7711	.208	.292
Totals (12/26 to 1/20)	2.66	87901	21819	.808	26712	.248	.304

TABLE V

RECOVERY DATA

<u>Date</u>	<u>Liquid Level* (ft)</u>		<u>Flow Rate (GPM)</u>
	<u>Before Shutdown</u>	<u>Following Recovery</u>	<u>(Before Shutdown)</u>
December 26, 1976	7.7	14.6	.88
December 31, 1976	4.1	14.1	.91
January 5, 1977	4.1	13.1	.98
January 8, 1977	4.1	12.9	.85
January 14, 1977	5.3	12.8	.80
January 20, 1977	5.3	12.0	.49

* Measured from tank bottom at the center

FIGURE I
PUMPED WELL DETAILS

1. Check Valve
2. Reducer
3. Jet Body
4. Jet Nozzle
5. Jet Tube

FIGURE II JET ASSEMBLY

FIGURE III EQUIPMENT LOCATION*

1. Pumped Well (WF III)
2. Observation Wells
 - a. WF I
 - b. WF II
3. FIC Gauges
4. Sludge measuring tapes
5. Thermocouple tree
6. Ventilation

* Measurements Approximate

FIGURE IV RECOVERY CURVE

FIGURE V EQUILIBRIUM FLOW RATE

(k/μ) γ = 1.44

FIGURE VI FLOW RATE DATA

APPENDIX

Several assumptions are made in the following calculations. In determining the in-flow rate to the salt well, the liquid heights are referenced to the top of the sludge layer, assuming that the sludge has a low permeability and is homogeneous. A capillary rise of one foot is assumed for the salt cake (reference 2), and the sludge is estimated to be 4 2/3 feet thick with a porosity of 0.3. The nondrainable interstitial liquor would be contained in the sludge and held in the first foot of salt cake due to capillary forces. The results of these calculations are shown in Table A1 and Figure A1.

h_s = sludge thickness (ft)

h_l = total height of liquid above tank bottom (ft)

h_c = capillary rise in salt cake (ft)

V_g = volume of liquid in tank (gallons)

ϕ = porosity

V_d = volume of dished tank bottom

Liquid Remaining

$h_e = 12.36$ ft 2/18/77 from dip tube bubbler

$h_l = h_e + h_c = 12.36 + 1.0 = 13.36$

$V_g = \phi [(h_l - 1.0) \pi r_e^2 + V_d]$

$V_g = .3 [(13.36 - 1.0) \pi (37.5)^2 (7.48 \text{ gal/ft}^3) + 12,500]$

$V_g = 126,283$ gallons

In-Flow Rate

From Figure V line 2

$\sqrt{h_e^2 - h_w^2} = 2.0$ ft. @ $q = .047$ GPM

$h_w = 0$ at top of sludge layer

$h_e = 2.0$ ft.

$V_g = 69,880$ gallons

Non-Drainable Liquid

$h_l = h_s + h_c = 4.67 + 1.0 = 5.67$

$V_g = 50,050$

Pumping Time

From reference 1

$$t = \frac{.365 \phi r_e^2 \mu \ln \frac{r_e}{r_w}}{K_Y} \left[\frac{1}{h} - \frac{1}{h_i} \right]$$

 h_i = height above sludge layer at $t = 0$ h = height above sludge layer at any time t .

$$\phi = .30$$

$$r_e = 37.5 \text{ ft}$$

$$r_w = .42 \text{ ft.}$$

$$\gamma = 1.44$$

$$h_i = 7.7 \text{ ft}$$

$$k/\mu = 0.80 \text{ from Figure V}$$

$$t = \frac{.365 (.3)(37.5)^2 \ln \left(\frac{37.5}{.42} \right)}{(.80)(1.44)} \left[\frac{1}{h} - \frac{1}{7.7} \right]$$

$$t = (600.41) \left[\frac{1}{h} - .13 \right] \text{ days}$$

TABLE A1

LIQUID REMAINING

<u>Liquid Height Above Sludge (ft)</u>	<u>Time (days)</u>	<u>Flow Rate (GPM)</u>	<u>Liquid Remaining In Tank (gal)</u>	<u>Drainable Liquid (gal)</u>
7.7	0	.67	126,280	76,230
7.0	7.8	.56	119,450	69,400
6.0	22.1	.41	109,530	59,480
5.0	42.1	.28	99,620	49,570
4.0	72.1	.18	89,700	39,650
3.0	122.1	.104	79,790	29,740
2.0	222.2	.047	69,880	19,830
1.3	383.9	.02	62,940	12,890
1.0	522.4	.012	59,960	9,910
0.9	589.1	.01	58,970	8,920

FIGURE AT PUMPING TIME