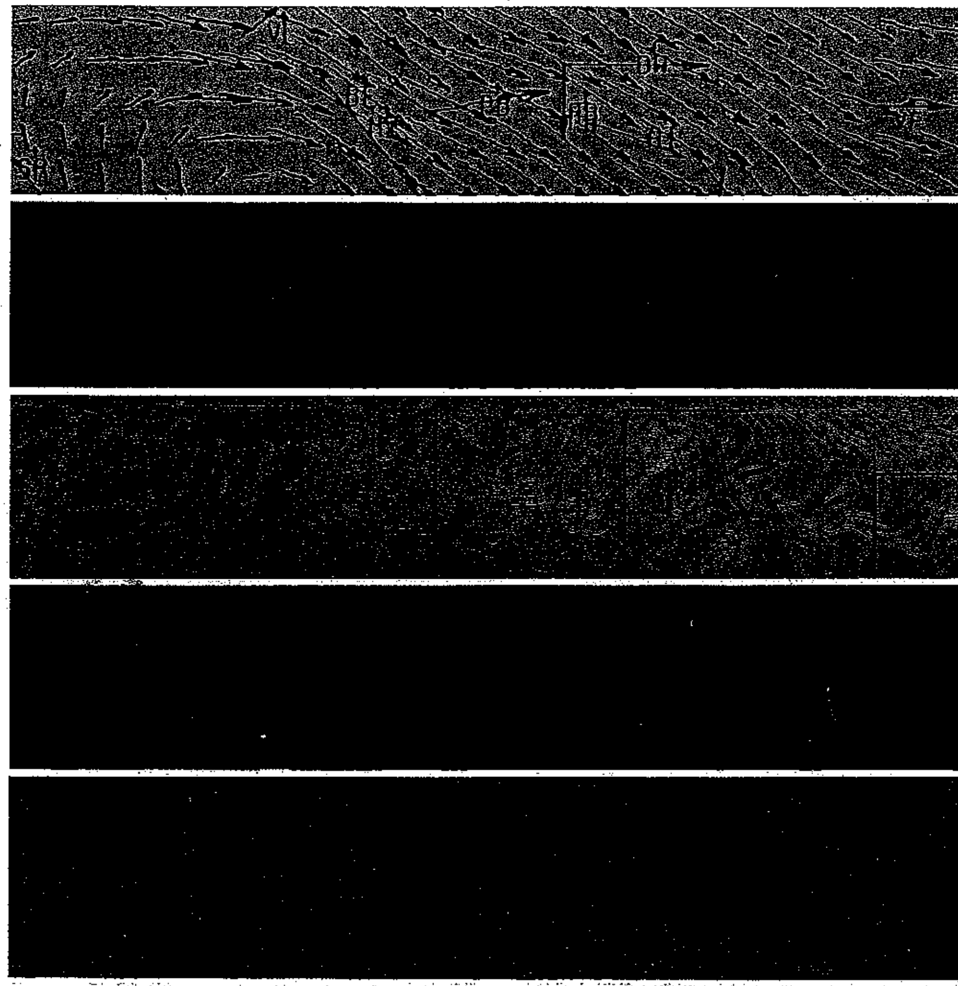

FINAL REPORT
PERMEABILITY TESTS
CHEVRON GULF REFINERY
PHILADELPHIA, PENNSYLVANIA

General Refinery

SEPTEMBER 4, 1987

Dames & Moore

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DAMES & MOORE A PROFESSIONAL LIMITED PARTNERSHIP
4620 STREET ROAD, TREVOSE, PENNSYLVANIA 19047 (215) 364-7910

September 4, 1987

Chevron Gulf Refinery
30th and Penrose Streets
Philadelphia, PA 19101

Attention: Mr. Frank Hannigan

Re: Final Report
Permeability Tests
Chevron Gulf Refinery
Philadelphia, Pennsylvania

Dear Mr. Hannigan:

With this letter, we are submitting three copies of the referenced report. Dames & Moore appreciated the opportunity to prepare this report for Chevron Gulf and we look forward to working with you again in the near future.

Very truly yours,

DAMES & MOORE
A Professional Limited Partnership

Michael J. Hess

Michael J. Hess, P.E.
Lead Consultant

David Wagner

David Wagner
Project Manager

DKC/DW:jw

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CONTENTS

1.0 INTRODUCTION

Dames & Moore is pleased to present to Chevron Gulf this report which contains the field procedures, observations, calculations and results of the three double-ring infiltrometer tests performed in the soil adjacent to five above ground storage tanks. These tanks, labeled 317, 1004, 1005, 1086, and 1087, are located on Chevron Gulf's Main Plant in Philadelphia, Pennsylvania and contain slop oil and spent caustics.

This study was performed in accordance with our proposal dated September 2, 1987.

1.1 OBJECTIVE

The objective of this study was to determine the permeability of soil surrounding the referenced tanks.

1.2 SCOPE OF WORK

In order to achieve the objective, these tasks were performed:

Task 1 - Three double-ring infiltrometer tests designated as Test A (Tank 1086 and 1087 both of which contain spent caustics), Test B (Tank 1004 and 1005 both of which contain slop oil) and Test C (Tank 317 which contains slop oil);

Task 2 - Data Analysis; and

Task 3 - Report Preparation.

2.0 FIELD PROCEDURES

A double-ring infiltrometer was installed at each of the three referenced areas. The tests were conducted on the least granular, most cohesive soil layer encountered above the ground water table.

A 24 1/4-inch I.D., fiberglass cylinder, 22 inches long was driven 3 to 6 inches into the soil and leveled. A second cylinder, with a 12-inch I.D., 22-inch high, and made of steel was placed in the center of the first ring, driven 1-1/2 to 2 inches into the soil and leveled. Both rings were then keyed into the soil with a tamp.

The inner ring and the annular space between the rings was then filled to a height of 6 inches above the soil surface with the test permeant. The permeant used for each test was taken from the tank of concern for that area.

Initial fluid level readings were taken for both the inner ring and the annular space. Additional fluid level readings were taken at 15 minute intervals. If little change occurred, reading intervals were increased to one hour and then to 24 hours. After each reading in which a drawdown was recorded, permeant was added to the rings to bring the fluid back up to the initial level. The volume of permeant added after each reading was recorded. The tests were continued for a period of three days for test A and B, and 2 days for Test C.

Data recorded in the field is presented in Appendix

3.0 OBSERVATIONS

TEST A

- The test was conducted in an area enclosed by a concrete wall containing tanks 1086 and 1087.

- The soil at the ground surface was a clayey silt with traces of sand, gravel, brick, glass and shells. It was dark brown and moist.

- The ground water table was at 11-1/2" below the surface.

- There was some ponding on the surface due to recent rains. The area within the concrete wall is several feet lower than the surrounding ground. This area usually drains to a surface drain which had been closed.

- Because the soil was uniform from the ground surface to the ground water level, the test was conducted at the surface.

- The permeant for the test was spent caustic taken from tank 1087.

- Heavy rains on the night of August 31, 1987 created excessive ponding around the test cylinders and made it difficult to determine any change in ground water level.

TEST B

COULDN'T CONDUCT THE TEST BECAUSE OF RAIN

- WRONG The test was conducted in an area enclosed by a compacted earth dike.

- The ground surface at the site of Test B was covered with 1 to 1-1/2 inches of gravel, underlain by silty sand. At 8± inches, the soil changed to a silty clay with little sand, gravel and brick fill.

- The water table was encountered at 11 inches below the surface.

- The test was conducted on the clayey soil 8 inches below the surface.

- The permeant for the tests was slop oil taken from tank 1005. The density of the oil is 26.3 and the viscosity at 100°C is 6.61 centistokes or 47.5 SUV.

- Leaking of the permeant was detected around the outer ring after the first hour reading. This leak was sealed by additional tamping.

- Heavy rains on the night of 8-31 caused the ground water table to rise to within two inches of the ground surface.

- On the morning and afternoon of 9-1 an increase in the permeant level was detected in both the inner cylinder and the annular space. Over the next two days, the level in the annular space decreased while the level in the inner cylinder remained constant and above the initial level.

TEST C

- o The soil at the site of Test C was a silty sand with little gravel fill, brown in color and oily.

- o The ground water table was encountered at 10 inches below the surface on August 31, 1987.

- o The permeant used was slop oil taken from tank 320 because 317 was empty at the time.

- o At the time of the initial filling of the cylinders on September 1, 1987, the ground water table was at 3-1/2 inches below the surface.

- o On the first day of the test, water with a slight sheen began to collect around the outside of the outer ring. As the ground water level decreased over the next days, this water dispersed.

- o The fluid initially used to fill the cylinders was a watery oil. A more viscous fluid was used to refill the cylinders after each reading. Both fluids were taken from tank 320.

4.0 ANALYTICAL PROCEDURES AND RESULTS

The data for the inner ring for Tests A and C were converted to elapsed time in minutes and cumulative volume in milliliters (see Appendix calculation sheets 1 and 3, respectively). It was not possible to analyze the Test B data as no trend was established.

The volume vs. time data for Tests A and C were then plotted on a trial and error basis so as to determine the approximate equation of the curve in each case. Examples of these plots are shown on Figures 1, 2, and 3.

For Test A (at Tanks 1086 and 1087), the closest fitting relationship was found from a log-log plot of volume (V) infiltrated vs. time (t) (see Figure 1). In this case, the regression equation was:

$$\log V = 0.8494 + 0.6152 (\log t) \qquad (1)$$

As shown on page 1 of the calculation sheets, this equation was used to obtain the derivative of V with respect to t (dV/dt). This was then converted to an expression for dh/dt, where h is the head above the bottom of the ring at any time t, by using the conversion factor of 729.68 sq. cm. (113.1 sq in.) as the area within the inner ring. The final equation for dh/dt, which is the instantaneous infiltration rate, is

$$dh/dt = (5.9606 \times 10^{-3})t^{-0.3848} \qquad (2)$$

By using this equation for arbitrary values of elapsed time, the dh/dt, or the instantaneous infiltration rates were computed, as shown on page 2 of the calculation sheets. Then, these values were plotted on Figure 4.

A similar procedure was used with the Test C data. However, as shown on Figure 2, no really close fit could be obtained. The best fit was a plot of volume infiltrated vs. the log of the elapsed time. The regression equation is equation (5) on page 3 of the calculation sheets. In an attempt to get a better fit, the last two data points were omitted and the resulting data were plotted. The results are shown on Figure 3.

10-7

In this case, a reasonably good fit was obtained in the plot of volume vs. the log of elapsed time. Data based on equation (7) of the calculation sheets (for all the Test C data) are shown on page 5 of the calculation sheets and have been plotted on Figure 4.

Figure 4 shows that the infiltration rates were much lower for Test A than for Test C. In neither case had the tests been conducted long enough that equilibrium conditions were attained. The lengths of the tests were limited due to the imposed time constraints.

Test C particularly, shows a significantly declining infiltration rate at the time the test was terminated. This was most likely due to the notable increase in viscosity of the permeant obtained from tank 320 as the test progressed. The infiltration rate seems to have "leveled out" better in the case of Test A.

Soil physics theory indicates that the long-term infiltration rate of an insitu soil body may closely approach the soils saturated vertical hydraulic conductivity value (K_v). Thus, an upper estimate for the K_v of the soil tested at Tanks 1086 and 1087 (Test A) would be 3×10^{-6} cm/sec.

In the case of Test C near Tank 317, it is harder to provide a reasonable estimate as it appears that near steady-state conditions had not yet been established. Based on the available data, we will have to say that an upper estimate for the K_v value at Tank 317 is 2×10^{-5} cm/sec.

As previously mentioned, it was not possible to determine permeability characteristics of the soil in Test B from the field data obtained.

As noted in the observations, permeant levels within the inner cylinder rose after the rainfall on the night of August 31 and remained constant at that elevation for the remainder of the test. This was possibly due to an increase in the ground water table to a level above the soil surface at the bottom of the cylinder. The test was conducted on a soil surface 8" below the existing ground. The water table was observed to be within 2 to 3 inches of the existing ground on the morning of September 1.

It is important to note that the permeability (hydraulic conductivity) values obtained in these tests refer to the fluid that was used for the test. To convert to K_v values appropriate for normal-quality water, use the equation:

$$K_w = K_s \; (u_s/u_w) \; (P_w/P_s)$$

Where, K_w is the permeability with pure water; K_s, is the permeability with the solution used; u_w is the viscosity of pure water at the field temperature; u_s is the viscosity of the solution used; P_w is the density of pure water; and P_s is the density of the solution used.

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APPENDIX

Field Data and Calculations

FIELD DATA

FILE Chevron
SUBJECT Double Ring Infiltrometer
SHEET 1 OF 3

TEST A

Test Fluid Spent Caustic

Ring	ID (in)	OD (in)	ID Area (in^2)	OD Area (in^2)	Depth Driven into ground (in)
Inner	12.0	12.75	113.1	127.7	2.0"
Outer	24.25	N/A	461.9	N/A	6.0"

Annular Space → 334.2 in^2

Test conducted at existing ground surface

Date	Real Time	Time Interval	Elapsed Time	Inner Ring: Depth to Fluid (in)	Inner Ring: Vol. Fluid Added (in^3)	Inner Ring: Σ Vol. Fluid Added (in^3)	Inner Ring: Infil. Rate (in/hr)	Annular Space: Depth to Fluid (in)	Annular Space: Vol Fluid Added (in^3)	Annular Space: Σ Vol. Fluid Added (in^3)	Annular Space: Infill Rate (in/hr)	Combined: Vol. Fluid Added (in^3)	Combined: Σ Vol Fluid Added (in^3)	Combined: Infil Rate (in/hr)
(1) 8/31/87	13:25	—	—	12.50	—	—	—	10.38	—	—	—	—	—	—
	13:40	0:15	0:15	12.50	0	0	—	10.38	0	0	—	0	0	—
	15:00	1:20	1:35	12.56	6.8	6.8		10.44	20.0	20.0	-	26.8	26.8	
9/1/87	8:48	17:48	19:23	12.75	28.3	35.1		10.63	83.6	103.6		111.9	138.7	
	13:30	4:42	24:05	12.56	6.8	41.9		10.44	20.0	123.6		26.8	165.5	
(3) 9/2/87	11:45	22:15	46:20	12.62	13.6	55.5		10.50	40.0	163.6		53.6	219.1	
(4) 9/3/87	9:35	21:50	68:10	12.59	10.2	65.7		10.43	16.7	180.3		26.9	246.0	

(1) G.W.L = 11 ½" below ground surface
(2) G.W.L = 5" " " "
(3) G.W.L = 7 ½" " " "
(4) G.W.L = 9 ½" " " "

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FIELD DATA

FILE CHEVRON
SUBJECT Double Ring Infiltrometer
SHEET 2 OF 3

TEST B

TEST FLUID SLOP OIL

RING	ID (IN)	OD (IN)	ID AREA (in²)	OD AREA (in²)	DEPTH Driven into ground (in)
INNER	12.0	12.75	113.1	127.7	1.25"
OUTER	24.25	N/A	461.9	N/A	3.0"

ANNULAR SPACE → 334.2 in²

TEST CONDUCTED 8" BELOW EXISTING GROUND

	REAL TIME	TIME INTERVAL	ELAPSED TIME	INNER RING: DEPTH TO FLUID (IN)	INNER RING: VOL. FLUID ADDED (IN³)	INNER RING: Σ VOL. FLUID ADDED (IN³)	INNER RING: INFILL. RATE (IN/HR)	ANNULAR SPACE: DEPTH TO FLUID (IN)	ANNULAR SPACE: VOL FLUID ADDED (IN³)	ANNULAR SPACE: Σ VOL. FLUID ADDED (IN³)	ANNULAR SPACE: INFILL RATE (IN/HR)	COMBINED: VOL. FLUID ADDED (IN³)	COMBINED: Σ VOL FLUID ADDED (IN³)	COMBINED: INFILL RATE (IN/HR)
① 8/31/87	11:25	—	—	—	—	—	—	—	—	—	—	—	—	—
	11:40	0:15	0:15	14.25	0	0	—	13.75	0	0	—	0	0	—
	13:40	2:00	2:15	14.39	15.9	15.9		13.92	75.6	75.6		91.5	91.5	
*	15:15	1:35	3:50	14.25	0	15.9		13.75	0	75.6		0	91.5	
9/1/87	9:10	17:55	21:45	14.25	0	15.9		12.87	0	75.6		0	91.5	
	13:40	4:30	26:15	13.94	0	15.9		12.87	0	75.6		0	91.5	
③ 9/2/87	11:30	21:50	48:05	13.94	0	15.9		13.69	0	75.6		0	91.5	
④ 9/3/87	9:15	21:45	69:50	13.94	0	15.9		14.13	127.0	202.6		127.0	218.5	

① G.W.L. = 11" below ground surface

② G.W.L. = 2" " " "

③ G.W.L. = 7½" " " "

④ G.W.L. = 8½" " " "

* Heavy rains occured on the night of the 31st

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FILE Chevron
SUBJECT Double Ring Infiltrometers
SHEET 3 OF 3

FIELD DATA

TEST C

TEST FLUID Slop Oil

Ring	ID (in)	OD (in)	ID Area (in²)	OD Area (in²)	Depth Driven into ground (in)
Inner	12.0	12.75	113.1	127.7	1.5"
Outer	24.25	N/A	461.9	N/A	3.0"

Annular Space → 334.2 in²

Test conducted @ existing ground surface.

Date	Real Time	Time Interval	Elapsed Time	Inner Ring: Depth to Fluid (in)	Inner Ring: Vol. Fluid Added (in³)	Inner Ring: Σ Vol. Fluid Added (in³)	Inner Ring: Infil. Rate (in/hr)	Annular Space: Depth to Fluid (in)	Annular Space: Vol Fluid Added (in³)	Annular Space: Σ Vol. Fluid Added (in³)	Annular Space: Infill Rate (in/hr)	Combined: Vol. Fluid Added (in³)	Combined: Σ Vol Fluid Added (in³)	Combined: Infil. Rate (in/hr)
① 9/1/87	9:55	–	–	15.19	–	–	–	13.19	–	–	–	–	–	–
	10:10	:15	:15	16.75	176.4	176.4		13.75	188.0	188.0		364.4	364.4	
	10:40	:30	:45	17.38	247.4	423.8		14.0	270.7	458.7		518.1	882.5	
	10:55	:15	1:00	15.81	70.7	494.5		13.50	103.6	562.3		174.3	1056.8	
	11:10	:15	1:15	15.63	49.5	544.0		13.44	82.7	645.0		132.2	1189.0	
	11:25	:15	1:30	15.50	41.5	585.6		13.50	103.6	748.6		145.1	1334.1	
	11:40	:15	1:45	15.43	27.1	612.7		13.44	82.7	831.3		109.8	1443.9	
	11:55	:15	2:00	15.38	21.5	634.2		13.44	82.7	914.0		104.2	1548.1	
	12:55	1:00	3:00	15.56	42.1	676.3		14.19	334.2	1248.2		376.3	1924.4	
② 9/2	12:00	23:05	26:05	16.63	162.9	839.2		15.50	772.0	2020.2		934.9	2859.3	
③ 9/3	9:45	21:45	47:50	15.5	35.1	874.3		13.50	103.6	2123.9		138.7	2998.0	

① G.W.L. = 3½" below ground surface
② G.W.L. = 4½" " " "
③ G.W.L. = 4½" " " "

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Test A - at Tanks 1086 + 1087

Elapsed Time (min)	Cumulative Volume thru Inner Ring (ml.) [16.387 ml = 1 in^3]
95	111.4
1,163	575.18
1,445	686.6
2,780	909.5
4,090	1,076.6

From the graphs, we see that plot of Log (Volume) vs Log (t) gives the best-fitting line:

$$\log(V) = 0.8494 + 0.6152 \log t \qquad (1)$$

$$\log(V) = \log(7.0697) + \log t^{0.6152}$$

$$\log(V) = \log[7.0697\, t^{0.6152}]$$

$$V = 7.0697\, t^{0.6152} \qquad (2)$$

$$\frac{dV}{dt} = (7.0697)(0.6152)\, t^{-0.3848} \qquad (3)$$

$$= 4.3493\, t^{-0.3848}$$

To convert $\frac{dV}{dt}$ to $\frac{dh}{dt}$, where h is depth of infiltrating water in cm

$$h\,(cm) = V(ml)/113.1\,in^2 = V(ml)/729.68\,cm^2$$

$$V = 729.68\,h$$

$$dV = 729.68\,dh$$

$$\therefore\ 729.68\frac{dh}{dt} = 4.3493\, t^{-0.3848}$$

$$\boxed{\frac{dh}{dt} = 5.9606\times10^{-3}\, t^{-0.3848}} \qquad (4)$$

TEST A - Tanks 1086 + 1087

COMPUTED INSTANTANEOUS INFILTRATION RATES
BASED ON EQUATION (4)

Elapsed Time (min)	Instantaneous Infiltration Rate (cm/sec)
50	2.2×10^{-5}
100	1.7×10^{-5}
200	1.3×10^{-5}
500	9.1×10^{-6}
1000	7.0×10^{-6}
2000	5.3×10^{-6}
3000	4.6×10^{-6}
4000	4.1×10^{-6}
5000	3.7×10^{-6}
7000	3.3×10^{-6}
10000	2.9×10^{-6}

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TEST C - at Tank 317

Elapsed Time (min)	Cumulative Volume thru Inner Ring (in ml.)
15	2,891
45	6,945
60	8,103
75	8,915
90	9,596
105	10,040
120	10,393
180	11,082
1,565	13,752
2,870	14,327

(1) Using all the data, it is seen that the best fit, although not very good, at that, is from the plot of Cumulative Volume vs. the logrithm of time.

$$V = 9.9557 + 4474.19 \log(t) \quad (5)$$

$$\frac{dV}{dt} = \frac{4474.19}{t} \quad (6)$$

$$729.68 \frac{dh}{dt} = \frac{4474.19}{t}$$

$$\boxed{\frac{dh}{dt} = \frac{6.1317}{t}} \quad (7)$$

(2) A better fit is obtained by omitting the last two data points (for elapsed times of 1,565 + 2,870 minutes)
Here, the equation is $V = -6146.07 + 7919.24 \log(t)$

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TEST C – at Tank 317

$$\frac{dV}{dt} = \frac{7919.24}{t} \qquad (8)$$

$$\boxed{\frac{dh}{dt} = \frac{7919.24}{729.68}\left(\frac{1}{t}\right) = \frac{10.853}{t}} \qquad (9)$$

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TEST C - TANK 317

COMPUTED INSTANTANEOUS INFILTRATION RATES

BASED ON EQUATION (7)

Elapsed Time (min)	Instantaneous Infiltration Rate (cm/sec)
10	1.0×10^{-2}
20	5.1×10^{-3}
50	2.0×10^{-3}
100	1.0×10^{-3}
200	5.1×10^{-4}
500	2.0×10^{-4}
1000	1.0×10^{-4}
2000	5.1×10^{-5}
3000	3.4×10^{-5}
4000	2.5×10^{-5}

BASED ON EQUATION (9) [early data]

Elapsed Time (min)	Instantaneous Infiltration Rate (cm/sec)
5	3.6×10^{-2}
10	1.8×10^{-2}
20	9.0×10^{-3}
50	3.6×10^{-3}
100	1.8×10^{-3}
200	9.0×10^{-4}
500	3.6×10^{-4}

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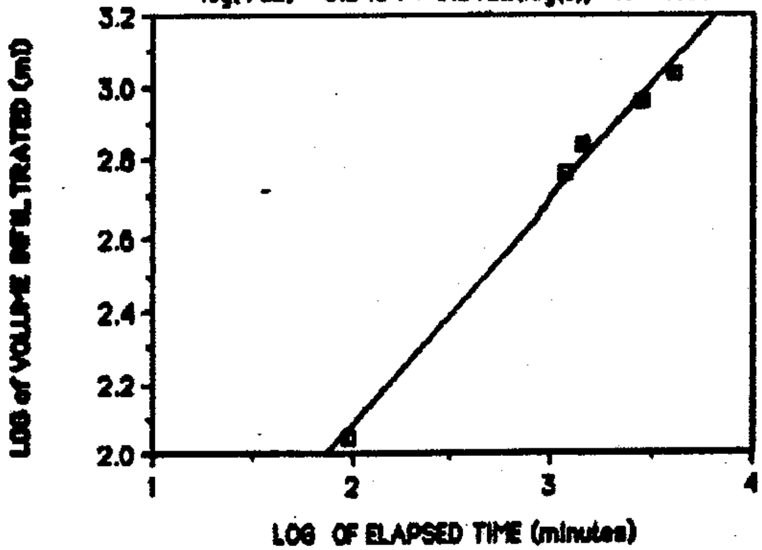
PLOT OF INFILTRATION DATA AT TANKS 1086 AND 1087

$\log(VOL) = 0.8494 + 0.6152(\log(t))$; $R = 1.00$



PLOT OF INFILTRATION DATA AT TANKS 1086 AND 1087

$VOL = -1051.7066 + 564.7322(\log t)$; $R = 0.98$

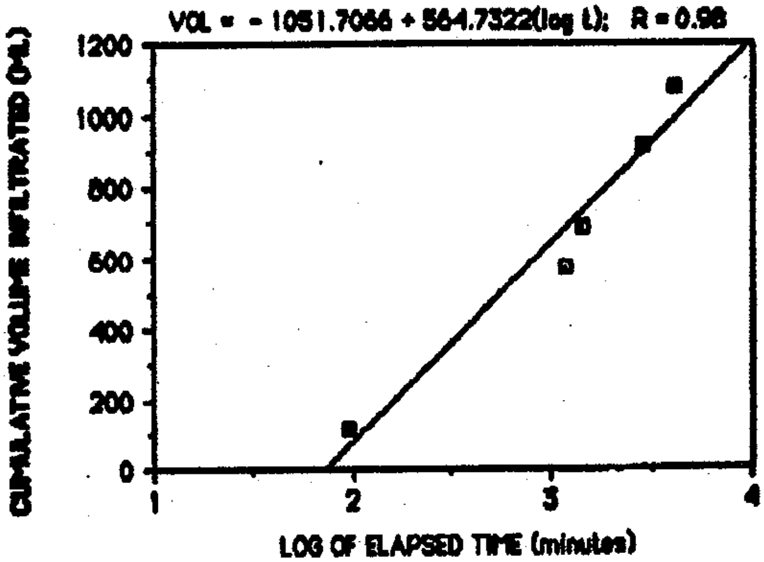


FIGURE 1
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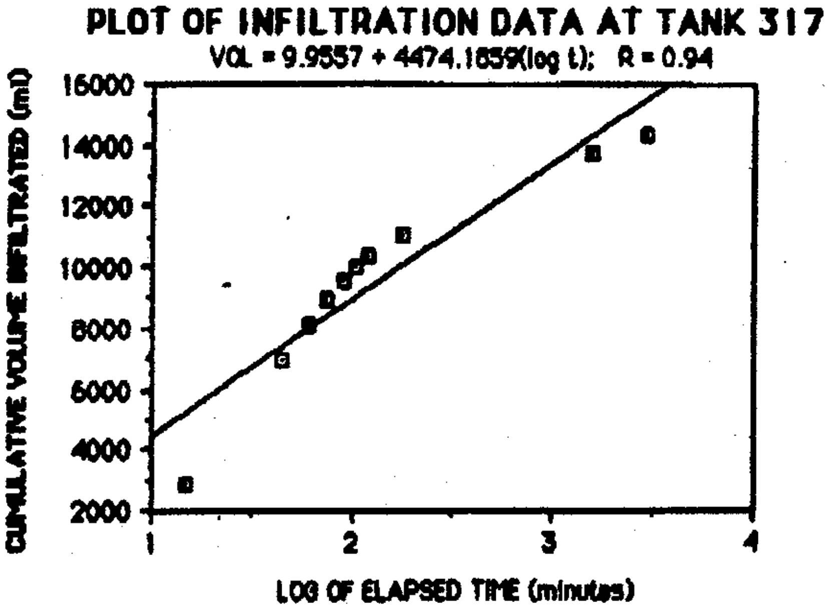

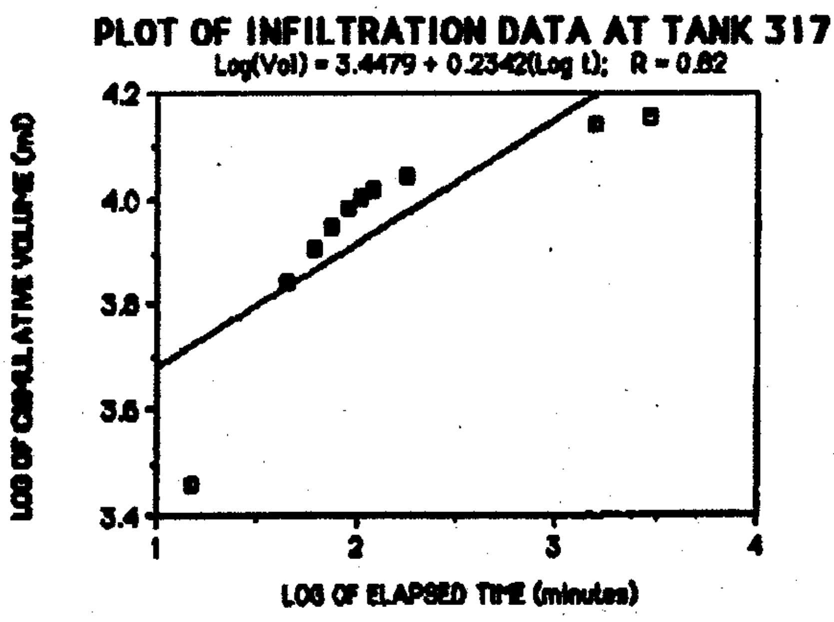

FIGURE 2
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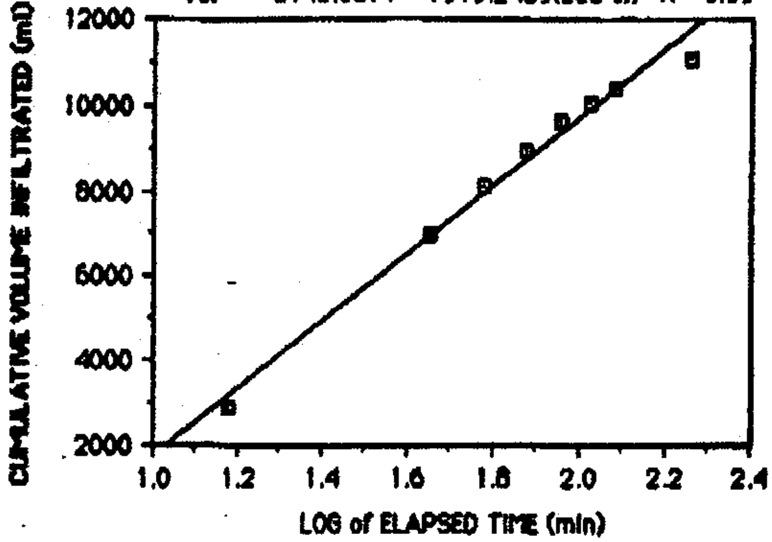
PLOT OF INFILTRATION DATA (PORTION) AT TANK 317

Vol = - 6146.0671 + 7919.2439(LOG t); R = 0.99



PLOT OF INFILTRATION DATA (PARTIAL) AT TANK 317

Log(V) = 2.8745 + 0.5552(log t); R = 0.96

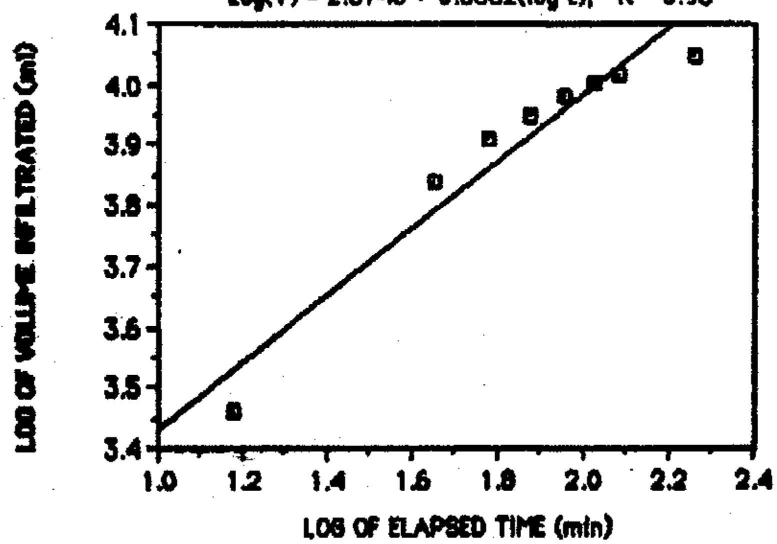


FIGURE 3
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PLOT OF INSTANTANEOUS INFILTRATION RATE VS. TIME

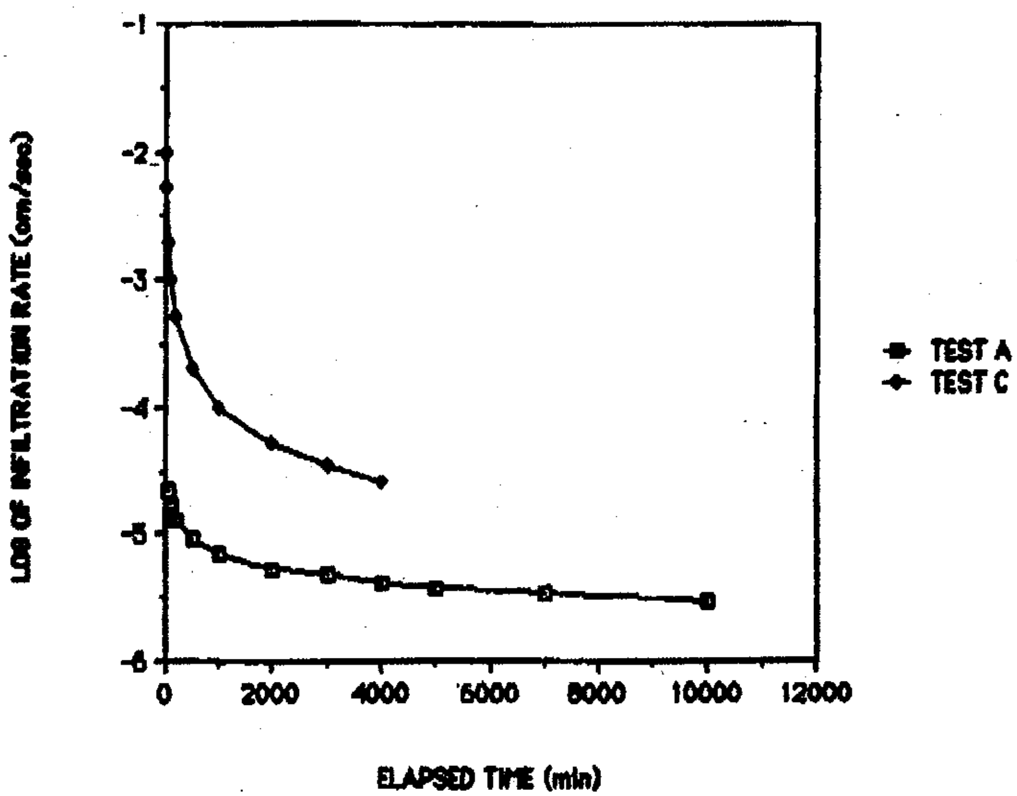

FIGURE 4

Dames & Moore