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Velocity and Gravity Effects In Relative Permeability Measurements

By

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This study could not have been completed without the help of a number of people.

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Thanks must also go to our parents, without whose encouragement and support, we never would have gotten this far. **And** to Cliffy Beal, her patience, love and encouragement was an immeasurable contribution to this work.

Dr. H. J. Ramey Jr., our faculty advisor, provided the direction and inspiration necessary to carry out this study.

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ABSTRACT

There have been several studies on the effects of gravity and flowrate on laboratory relative permeability measurements. Most of these studies have concentrated on the effect of these parameters on the flooding front. Miller's (1983) data showed that the influence of of these and other variables are not understood. The study found that the calculated recovery at breakthrough was different than the observed recovery at breakthrough. The calculated recovery at breakthrough was based on theory derived from Buckley-Leverett piston-like displacement. This study attempted to determine how gravity or core positioning and flowrate of the displacing fluid might be used to achieve a stable flooding front.

A relative permeameter with unsteady-state flow was used for the apparatus. The core material was an unconsolidated silica sand. The core was 2 in. in diameter and 20 in. long. The fluids were refined white mineral oil and salt water. All measurements were done at room temperature.

This study found that gravity had no significant effect on the difference between calculated and observed recovery at breakthrough. It also observed that an increase in flowrate would increase the flooding front instabilities. Therefore as flowrate decreased the calculated and observed breakthrough approach a single value.

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Section 1: INTRODUCTION

The recovery of crude oil from a reservoir frequently involves more than one phase through the porous media. Since Darcy's Law was formulated for the **flow** of a single phase through a porous media, a modification must be made for the flow of multiple phases. It is here that the concept of relative or effective permeability **is** introduced. ***Relative permeability*** is the ratio of the permeability of a phase in two phase flow to the permeability of the single-phase flow. If a petroleum engineer understands the concept of relative permeability and the factors which influence its behavior, he could use this knowledge to attain maximum recovery in a reservoir.

In the past, there have been several experiments conducted on relative permeability. However, results derived from such studies often differed. Though research may have been carefully done, experimental procedures accurately and scientifically conducted, and reproducibility very high, there are still several variables (such as gravity effects and velocity effects).

The study that was investigated was that of Miller (1983). Miller explored the effect of temperature on relative permeability and found that relative permeability remained unaffected by temperature. His approach was to use a simple, well-known porous media and fluid system to determine the effect of elevated temperatures on relative permeability. His experiments were conducted using a dynamic displacement relative permeameter. Miller modified the apparatus from the original design and construction by Jeffers (1981). Though his results were reproducible, Miller saw a water breakthrough consistently earlier than that predicted by Buckley-Leverett theory.

It is thought that, due to the size of the core used (2" in diameter, 24" in length), that gravity may have had an effect on the front such that a Buckley-Leverett displacement through the core was not attained. In this case, the equations used by Miller to predict actual breakthrough would then not apply. To test this hypothesis, an unconsolidated core was first prepared in the same manner in which Miller prepared his. Then a series of runs, both with the core in a horizontal position and in a vertical position, was conducted. Assuming all else constant, any difference in results between the two runs could be attributed to some type of gravity effect on the front in the horizontal core.

The rate of fluid flow through the core was another variable that could potentially have an effect on the displacing front during a flood. A flow rate of higher velocity might have rendered any capillary forces at the front negligible, but might induce an instability in the front (viscous fingering) that would not be in keeping with the Buckley-Leverett model. With the core in the vertical position, the velocity was varied such that some type of relationship could be deduced.

The apparatus used in this study was the same as that used by Miller. The only modification to the apparatus was the construction of a vertical core holder.

The only change in the procedure used by Miller was that this study was conducted at room temperature only. Since early breakthrough was observed at all temperatures, room temperature was selected for ease.

The data observed in this investigation will be analyzed by the software developed by Miller based on the techniques of Welge (1952) and Johnson, Bossler, and Naumann (1959). Details on the apparatus, procedure, and data analysis are given later in the report.

Section 2 : Literature Review

A great deal of analysis has been done in the area of two phase relative permeability. There have been studies on the effects of pore geometry, wettability, viscosity, velocity, interfacial tension, capillary forces, saturation history, and temperature. This section gives a brief synopsis and discussion of the studies relative to this report.

The two most common methods of measuring relative permeability are steady state and unsteady state displacement. The steady state test involves simultaneously flowing two phases (i.e. oil and water) through a homogenous core. The pressure differential is measured and the relative permeability measured. This method only gives a single point on the relative permeability curve once equilibrium of the two fluid saturations has been reached.

The dynamic displacement or unsteady state test involves injecting a fluid into a core with little or no connate saturation of that fluid with the intent to displace the mobile portion of a second fluid. Due to its simplicity and speed, the unsteady state system was chosen for this study. Osoba et. al. (1951), Richardson & & (1952), Owens et. al. (1956), and Richardson (1957) studied the differences in relative permeability measured by the two methods. They found little or no discrepancy between the methods.

Welge (1952), using Buckley-Leverett displacement theory, produced the necessary basis to enable one to calculate relative permeability ratios. Assuming that relative permeability is solely a function of saturation, Welge developed the following relationships in order to calculate the relative permeability ratio:

$$f_o = \frac{\overline{S}_d - S_{d2}}{W_i} \tag{2.1}$$

and

$$f_o = \frac{1}{\frac{k_{rw}}{k_{ro}} \frac{\mu_o}{\mu_w} + 1} \tag{2.2}$$

where:

f_o = fractional volume of oil flowing from core outlet

$\overline{S}_d$ = average saturation of displacing fluid

S_{d2} = saturation of displacing fluid at the core outlet

W_i = cumulative pore volumes of the displacing fluid injected

k_{ro}, k_{rd} = relative permeabilities of oil and the displacing fluid

μ_o, μ_d = viscosity of oil and displacing fluid

Johnson, Bossler, and Naumann (1959) expanding, on Welge's work, produced the necessary mathematical equations to determine individual relative permeabilities from unsteady state displacement data. The equation which follows was also based on non-capillary Buckley Leverett frontal displacement theory:

$$f_o = k_{ro} \frac{d\left[\frac{1}{W_i I_r}\right]}{d\left[\frac{1}{W_i}\right]} \tag{2.3}$$

where:

I_r = relative injectivity, $(q/\Delta p)/(q/\Delta p)_{initial}$

q = total volumetric flowrate

Δp = differential pressure across the core

Jones and Roszelle (1978) continued this investigation into the calculation of relative permeability from unsteady state displacement data. Jones and Roszelle presented a graphical technique which makes the relative permeability calculation much more simple and accurate than the previous method. **A** complete discussion of this method may be found in the U.S. Department of Energy report by Sufi & d (1982).

In 1958, there were two studies relevant to this one. One study was conducted by Sanberg, Gournay, and Sippel. This study used the "dynamic flow technique" to determine the effects of fluid flow rate and viscosity on relative permeability. Radio-tracers were used for the detection of fluid saturation and saturation gradients. Flowrates were varied from 2.5 to 140.6 ml/hr and oil viscosities from .398 to **1.683** cp. The values of relative permeability for both phases were found to increase and asymptotically approach a constant value as the flow rate increased. The change in relative permeability was explained by boundary effects because there was no change in the relative permeability when the rate was high enough to completely saturate the core. The study also concluded that the relative permeability was independent of the non-wetting phase viscosity.

The other report in 1958 was written by Kyte and Rapoport. This study provided a comprehensive picture of waterflood behavior in water-wet media. Included in this paper was an extensive discussion of boundary effects. Kyte and Rapoport found that outlet end effects decrease with an increase in length of the core, fluid flow rate, and fluid viscosities. The report also found that inlet end effects were more prevalent for short cores, high water injection rates, and high oil-water viscosity ratios. These inlet effects caused localized water injection and therefore a distortion of the linear flood front (fingering). Kyte and Rapoport developed a scaling factor:

$$\textit{scaling factor} = Lv\mu_w \tag{2.4}$$

where:

L = length of the core, cm

v = velocity, cm/min

For this scaling factor there are values suffuciently great to insure stablized flooding conditions.

Abrams (1975) studied the influence of fluid viscosity, interfacial tension, and flow velocity on residual oil saturation (S_{or}). This study found that strongly water-wet cores (cos θ= 1) could be described in terms of Moore and Slobod dimensionless group expanded to include viscosity effects:

$$\left[\frac{v\mu_w}{\sigma_{o-w}}\right]\left(\frac{\mu_w}{\mu_o}\right)^{0.4} \tag{2.5}$$

where:

σ = oil-water interfacial tension, dynes/cm

After studying six different sandstones and one limestone, Abrams concluded that as the dimensionless group increased residual oil saturation decreased.

When a fluid displaces a more viscous immiscible fluid, the displacement front may become unstable and viscous fingering begins. Peters and Flock (1981) presented a dimensionless group which would predict the onset of viscous instabilities in porous media (for water displacing oil):

$$I_{sc} = \frac{(M-1)(v-v_c)\mu_w d^2}{C^* \sigma k_{wor}} \tag{2.6}$$

where:

$$v_c = \frac{k_{wor}(\rho_w - \rho_o) g \cos\alpha}{\mu_w (M-1)} \tag{2.7}$$

and

$$M = \frac{k_{wor}\mu_o}{k_{oiw}\mu_w} \tag{2.8}$$

where:

d = core diameter, ft

C^* = wettability number, dimensionless

σ = oil-water interfacial tension, dyne/cm

k_{wor} = permeability to water at residual oil saturation, darcy

v = constant superficial velocity, ft/s

v_c = characteristic velocity, ft/s

ρ_w, ρ_o = water and oil density, g/cm^3

g = gravatational aceleration, ft/s^2

α = angle core make to the vertical

M = end point mobility ratio, dimensionless

k_{oiw} = permeability to oil at connate water saturation, Darcy

Figure 2.1 shows that this dimensionless group has a critical value of 13.56. Peters and Flock showed that above this critical value, the finger wavelength will be short, resulting in the accornadation of numerous fingers by the core.

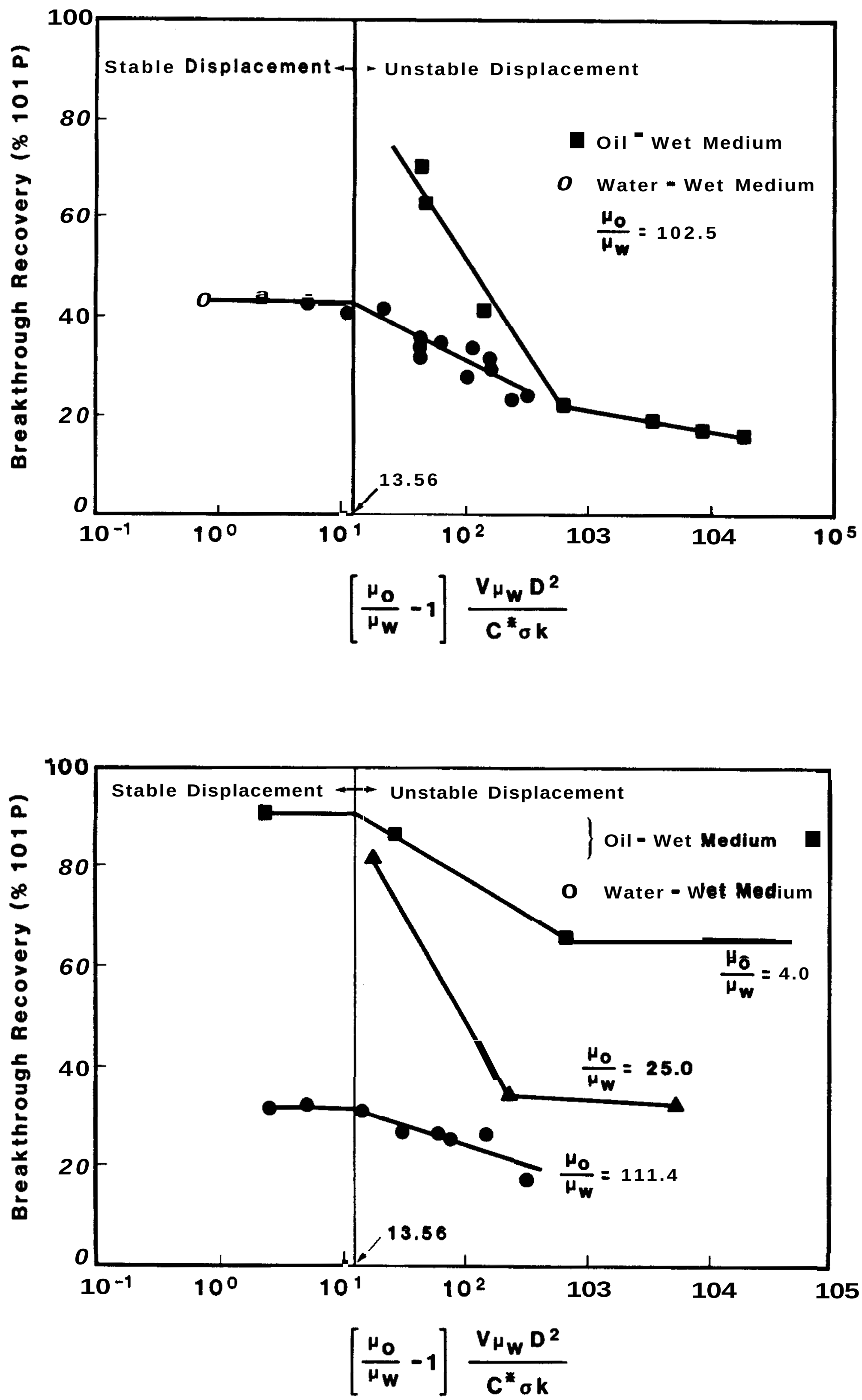

Figure 2.1 Recovery Data from Peters and Rock (1981)

Section 3 : Problem Statement

As pointed out in the literature review, there have been several studies involving relative permeability. The most recent reports have concentrated on the effect of temperature on relative permeability. The conclusions of these studies were contradictory; some concluded that temperature did effect relative permeability and others concluded that temperature had no effect on relative permeability. The purpose of this study was to determine why these discrepancies exist in the literature and suggest methods for achieving consistent results.

In order to eliminate many inconsistencies in measurement of relative permeabilities, a simple system was needed *so* that all results could be repeated. Miller (1983) proved that the apparatus was able to repeat measurements accurately.

There were two phenomena in Miller's dissertation which warranted futher investigation. The first, which is presented in Fig. 3.1, was an increase in the oil permeability at irreducible water saturation as flow through the core was stopped and started. The change in the oil permeability became greater as the temperature was increased. The second phenomena, which is presented in Fig. 3.2, is the difference between calculated or inferred breakthrough and actual breakthrough. Since the inferred breakthrough was calculated using Buckley-Leverett displacement theory, this difference might be attributed to a smearing in the flooding front. Therefore, this study concentrated on the flooding front. A flooding front which approaches piston-like displacement should eliminate such factors as fingering and gravity underride and therefore contribute to repeatable or consistent results. The two factors on which this study focused were gravity and velocity. These two parameters were varied in order to determine

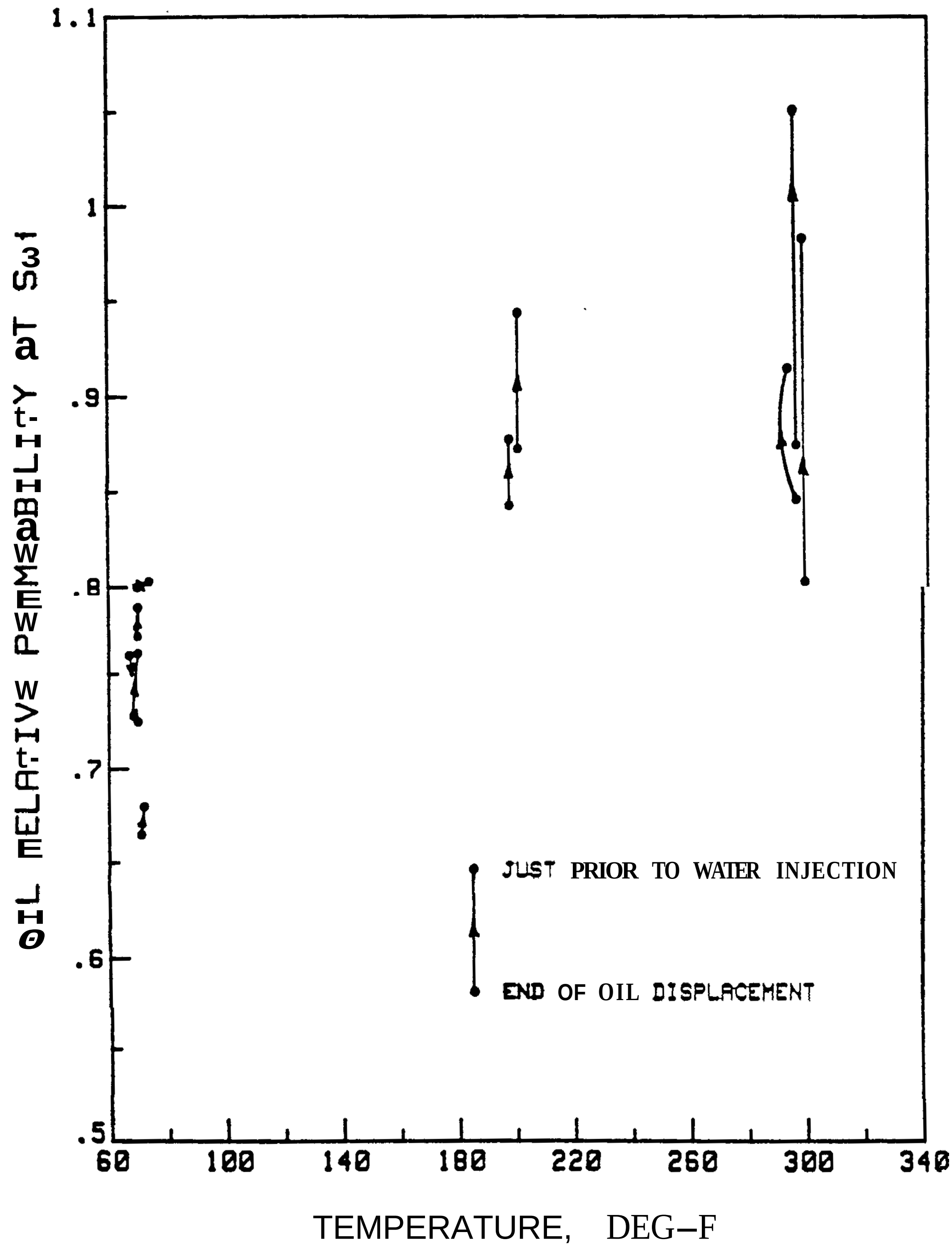

Figure 3.1 Oil Relative Permeabilities at Irreducible Water Saturation vs. Temperature (from Miller (1983))

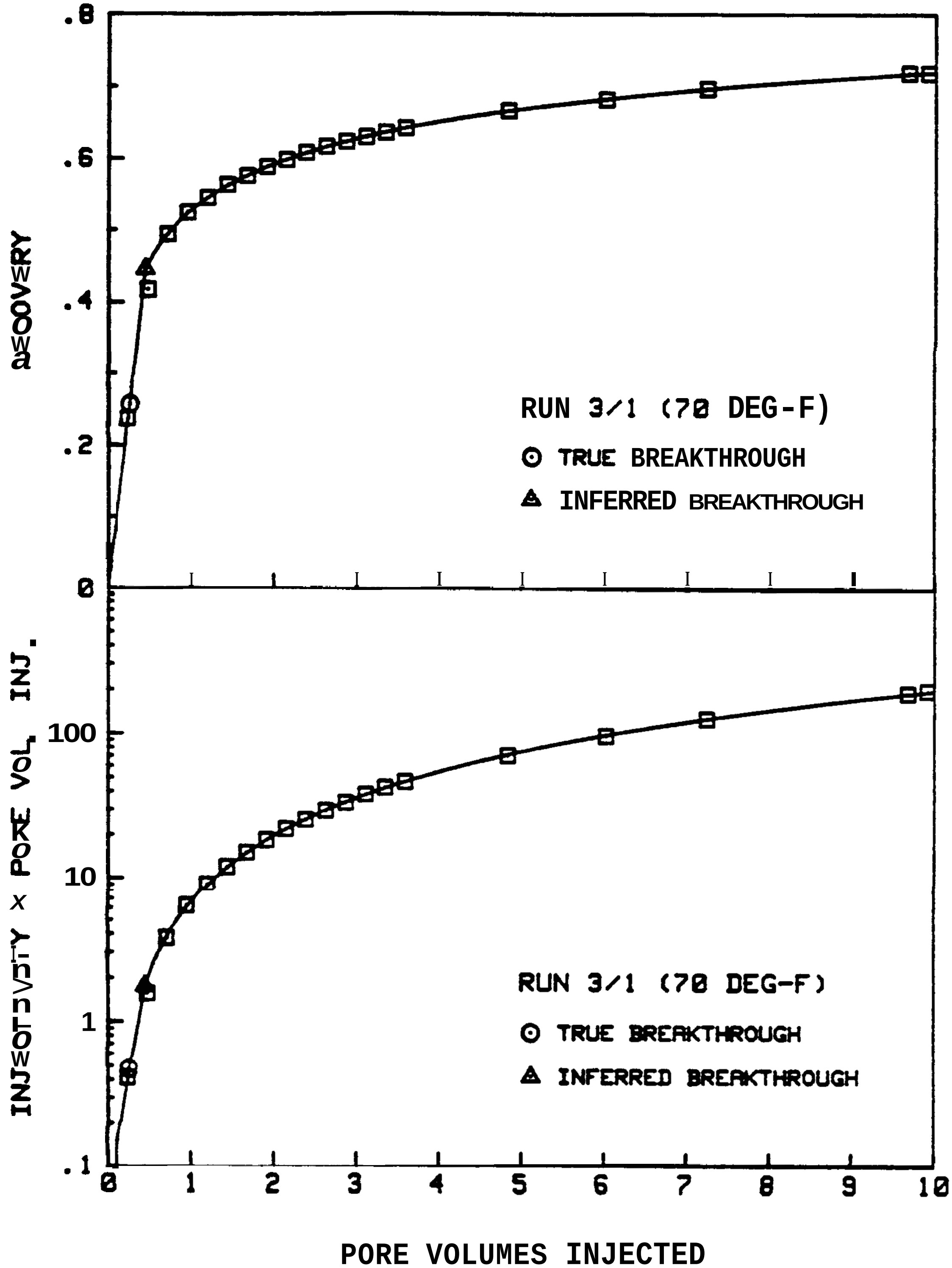

Figure 3.2 **Recovery** *and Injectivity* **X Pore** *Volumes Injected vs. Pore Volumes Injected (from Miller (1983))*

how they might be used to obtain piston-like displacement found in Buckley-Leverett theory. If one could achieve a consistent flooding front, such factors as recovery at breakthrough would become more stable and the variance in relative permeability could be attributed to other elements (i.e. temperature).

Section 4 : APPARATUS AND MATERIALS

Experiments were conducted using a relative permeameter with salt water and a mineral oil in an unconsolidated sandstone core. This section briefly describes the apparatus and the materials used to obtain the relevent data. A detailed description of the apparatus and materials are presented in Appendix A and C respectively.

4.1 Apparatus

The original construction of the apparatus was done by Jeffers (1981) for "dynamic displacement experiments on large scale cores at elevated temperatures". Many components which were incorporated into the construction of the apparatus were used by Casse (1979), Counsil (1979), and Sageev (1981) in their experimental work. Miller (1983) also conducted experimental work on the apparatus after making a few modifications. Detailed diagrams and explanations of the apparatus may be found in Appendix A. Also included in Appendix A is a discussion and diagram of the core in the horizontal and vertical position (the only modification made to the apparatus).

The core holder contains six pieces :

1. inner sleeve
2. outer sleeve
3. traveling end plug
4. fixed end plug
5. 2 caps

The inner sleeve contained an unconsolidated sand, which had been carefully sifted and packed. Screens were attached to both plugs to prevent sand from flowing out the downstream end of the core, and the plugs were grooved to insure that an uniform flow was injected and retrieved throughout the cross- section of the core. The outer sleeve and the caps provided a seal for a 500psi confining pressure.

The injection system used one pump with an accumulator to dampen the pulsing action of the pump. When injecting oil into the core, the pump flowed oil from a reservoir through a filter, a needle valve, a capillary tube flowmeter, **and** finally to the core. The needle valve controlled the flow rate. When injecting water into the core, the pump flowed oil through the needle valve, capillary tube flowmeter, and into a water vessel. The oil displaced the water out of the vessel and into the core after it is passed through a filter. By measuring the pressure drop across the flowmeter, the instantenous and average flowrate was measured.

The effluent measurement system consisted of a glass tube separator, a pressure regulator, and a dozen graduated graduated cylinders. The glass tube separator allowed a visual measurement of the displaced fluid. The pressure regulator provided a constant pressure at the downstream end of the core. The graduated cylinders measured the total fluid produced. To insure accuracy in the separator measurements, the seperator was calibrated after each run, and cleaned after several runs.

The pressure measurement system consisted of diaphragm-type pressure transducers which would measure the pressure drop across the core. The transducer was equiped with a three-way valve so that it could be zeroed before each run. **A** similar transducer system was used for the capillary tube flowmeter. Both pressures were recorded on a strip chart.

4.2 Fluids

Oil and salt water were chosen as the two fluids in this study because this combination allowed a comparison of the results to previous reports. Blandol, a refined white mineral oil, has a viscosity of 30 cp, and a density of .847 g/cc a 70°F. The salt water was distilled water combined with **2%** sodium chloride. The salt water solution has a viscosity of 1.03 cp and a density of .853 g/cc at 70°F. All of the appropiate viscosity and density versus temperature correlations are presented in Appendix C.

Section 5 : PROCEDURES AND DATA ANALYSIS

This section describes a stepwise procedure (previously presented in Miller (1983)) for making a diplacement run. Also included are a discussion of the core preperation and loading, and the method of data analysis. A more thorough presention may be found in Appendix B and D respectively.

5.1 Core Material and Preparation

The core material was composed of an Ottawa silica sand. Before packing the core, the sand was sieved and recombined in predetermined proportions. Then the sand mixture was washed and oven dried. This process not only provided homogeneity within a core, but also from one core to another. With pneumatic vibrators strapped to the inner sleeve, the dry sand was packed.

After assembling the end plugs and the outer sleeve, the entire core holder was mounted in the air bath and confining pressure applied. The core was then evacuated to less than 50 μTorr vacuum and filled with salt water. System connections were made and lines bled of air in preparation for displacement runs.

5.2 Displacement Runs

Before displacing the salt water out of the core with oil, the absolute permeability of the core was determined. To measure the absolute permeability, all pressure transducers were zeroed and water was pumped through the core.

The differential pressure drop across the core was recorded on a strip chart. Flowrate was measured with a graduated cylinder and a stopwatch. This procedure was repeated until the absolute permeability varied only 1.5%.

Having arrived at an absolute permeability, oil was flooded through the core until irreducible water saturation was achieved. When two pore volumes of oil were injected, the water production was undectable therefore the oil flood was halted.

After making all of the necessary preparations for the waterflood, including zeroing the pressure transducers, oil injection was resumed until a steady flowrate and pressure drop were obtained. Then two valve were switched to simultaneously change from a oilflood to a waterflood and to change from measuring water production to oil production in the effluent seperator. Once the waterflood had begun, the cumulative water injected, cumulative oil produced, volumetric flowrate, inlet and oulet temperatures, and differential pressure drop across the core, and flowmeter were measured and recorded. After ten pore volumes of water were injected, oil production was negligible. The seperator was then calibrated order to determine the oil production. This procedure was repeated using the same core for two horizontal floods and six vertical floods (flowing up the core). The vertical floods followed the horizontal floods.

The flowrate for the horizontal floods was approximately 40 cc/min and the flowrate for the vertical floods ranged from 7.3 cc/min to 70 cc/min. The flowrates described were the flowrates of the displacing fluid at breakthrough. These flowrates provided a pressure drop across the core which was greater than 5 psi and less than 150 psi. These flowrates also met the criteria of Rapoport and Leas (1953) scaling factor ($Lv\mu_w$) to achieve a stablized flooding front.

The multiple floods done on the same core at horizontal and vertical positions and at various flowrates, allowed not only establishment of reproducibility, but also an evaluation of the effects of the two parameters.

5.3 Data Analysis

In the literature survey, it was discussed that relative permeability vs. saturation could be determined from displacement experiments based on techniques of Welge (1952) and Johnson, Bossler, and Naumann (1959). In summary these techniques are based on the following three equations:

$$f_o = \frac{\overline{S}_d - S_{d2}}{W_i} \tag{5.1}$$

$$f_o = \frac{1}{\frac{k_{rw}}{k_{ro}} \frac{\mu_o}{\mu_w} + 1} \tag{5.2}$$

$$\frac{f_o}{k_{ro}} = \frac{d\left[\frac{1}{W_i \, I_r}\right]}{d\left[\frac{1}{W_i}\right]} \tag{5.3}$$

where:

f_o = fractional volume of oil flowing from core outlet

$\overline{S}_d$ = average saturation of displacing fluid

S_{d2} = saturation of displacing fluid at the core outlet

W_i = cumulative pore volumes of the displacing fluid injected

k_{ro}, k_{rd} = relative permeabilities of oil and the displacing fluid

μ_o, μ_d = viscosity of oil and displacing fluid

I_r = relative injectivity, $(q/\Delta p)/(q/\Delta p)_{initial}$

q = total volumetric flowrate

Δp = differential pressure across the core

Jones and Roszelle (1978) derived a graphical approach which determined f_o by drawing tangents to the experimental N_p vs. W_i curve and finding $(S_{w2}-S_{wi})$ at the corresponding intercept $W_i=0$. They also used the following modified form of **Eq.** 4.3 to determine f_o/k_{ro} as the intercept on an experimental $1/I_r$ vs. W_i curve:

$$\frac{f_o}{k_{ro}} = -W_i \frac{d\left[\frac{1}{I_r}\right]}{d\left[W_i\right]} + \frac{1}{I_r} \tag{5.4}$$

Since differentiating experimental data graphically is an inaccurate process, Miller (1983) developed the following curve fit equations:

Recovery:

$$N_p = a_0 + a_1[ln(W_i)] + a_2[ln(W_i)]^2 + a_3[ln(W_i)]^3 + \cdot \tag{5.5}$$

Injectivity:

$$I_r = b_0 + b_1[ln(W_i)] + b_2[ln(W_i)]^2 + b_3[ln(W_i)]^3 + \tag{5.6}$$

And finally:

$$ln(W_i I_r) = b_0 + b_1[ln(W_i)] + b_2[ln(W_i)]^2 \qquad (5.7)$$

Miller (1983) found that **Eq.** 5.7 gave excellent matches of the $(W_i I_r)$ data at all temperatures, and with the second order N_p vs. ln(W_i) data match, yielded well- behaved relative permeability curves at all temperatures. The usual scatter was removed by curved matching the raw data.

The first recovery and injectivity points immediately after breakthrough were disregarded. Rapid changes in both saturation and flowing volume fractions occur at breakthrough because capillary pressure, gravity effects, and viscous fingering cause the saturation front to be smeared unlike Buckley-Leverett displacement. Therefore the first point after breakthrough was not representative of the trend of the data. Appendix E gives an example of experimental data and the corresponding curve fit for the recovery vs. pore volumes injected and the $(W_i I_r)$ vs. pore volumes injected curves.

Jones and Roszelle (1978) recommended using graphs of recovery and injectivity vs. the reciprocal of pore volumes injected at large values of pore volumes injected. This procedure allows more accurate tangents to be drawn, since at large injected volumes, both recovery and injectivity tend to flatten. Again, examples of this can be seen in Appendix E.

Relative permeabilities were calculated in this study using the absolute permeability of the core to water as the base (recommended by Miller (1983)).

Appendix F describes a computer program written to analyze the displacement data. The program was written by Miller (1983) in BASIC for the 9845B desk-top minicomputer. In addition to performing the calculations, the program utilizes the plotting capabilities of the minicomputer to generate graphs of:

a) recovery and injectivity x pore volumes injected vs. pore volumes injected and the reciprocal of pore volumes injected

b) logarithm of the water-oil permeability ratio vs. water saturation

c) individual water and oil relative permeabilities vs. water saturation

SECTION 6 : RESULTS, CONCLUSIONS, AND RECOMENDATIONS

6.1 Results

Just as was found in Miller's (1983) study using the same apparatus, the results from this experiment have been reproducible. The relative permeability overlay presented in figure 6.1 shows the reproducibility of this study. The graph of recovery versus pore volumes injected were so reproducible that it was difficult to determine which curve was which when overlayed. In Run 1/2 the early time behavior of the recovery curve was higher than subsequent waterfloods. This was attributed to hystersis. Again reproducibility was cornfirrned by the fact that a consistent irreducible water saturation was attained at the end of each flood (Table 6.1).

Run	S_{wi}
Horizontal 1/3	.109
Horizontal 1/5	.109
Vertical 1/7	.104
Vertical 1/9	.096
Vertical 1/11	.097

Table 6.1 Irreducible Water Saturation Data

Having determined that the apparatus yielded consistent results, any difference in the results was attributed to an alteration in a chosen parameter (i.e. core position and velocity of the displacing fluid).

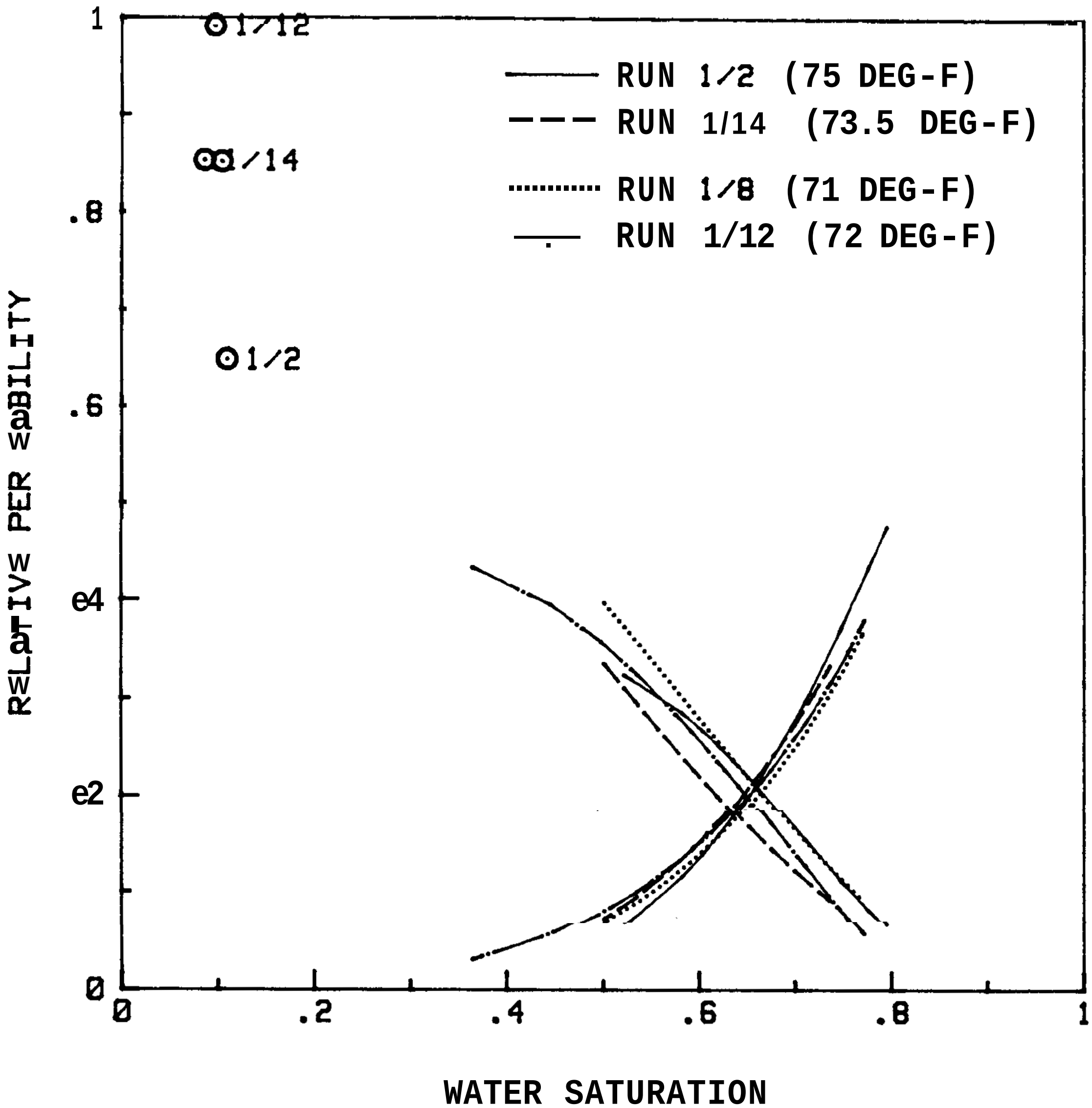

Figure 6.1 Relative *Permeabilities* vs. Water *Saturation (Overplotted)*

Comparing vertical run 1/8 and horizontal run 1/4, produced the following results: the difference between calculated and actual recovery at breakthrough was slightly less for the vertical run than for the horizontal run. Though run 1/8 was run at a higher velocity, it was later determined that this would increase the difference between actual and calculated recovery, yet the difference was still less than that of run 1/4. Also, a plot of recovery versus pore volumes injected showed that run 1/8 had a more uniform displacement front (i.e. higher recovery throughout the diplacement).

With the core in the vertical position, the displacing fluid flowrate was altered. The changes in the flooding front was then examined for the various displacments. The following table and figure show that as the flowrate at breakthrough decreased the difference between the actual and calculated breakthrough decreased.

Breakthrough Velocity (cc/min)	Actual Recovery at Breakthrough (PV's injected)	Calculated Recovery at Breakthrough (PV's injected)	Differencebetween Actual and Calculated (PV's injected)
7.28	0.382	0.471	0.089
25.72	0.327	0.476	0.149
54.02	0.257	0.459	0.202
63.10	0.248	0.469	0.221
71.05	0.208	**0.390**	0.190

Table 6.2 Breakthrough Recovery Data

This fact indicated that for this system the lower, the flowrate, the closer the flooding front approached Buckley-Leverett piston displacement. A comparis-

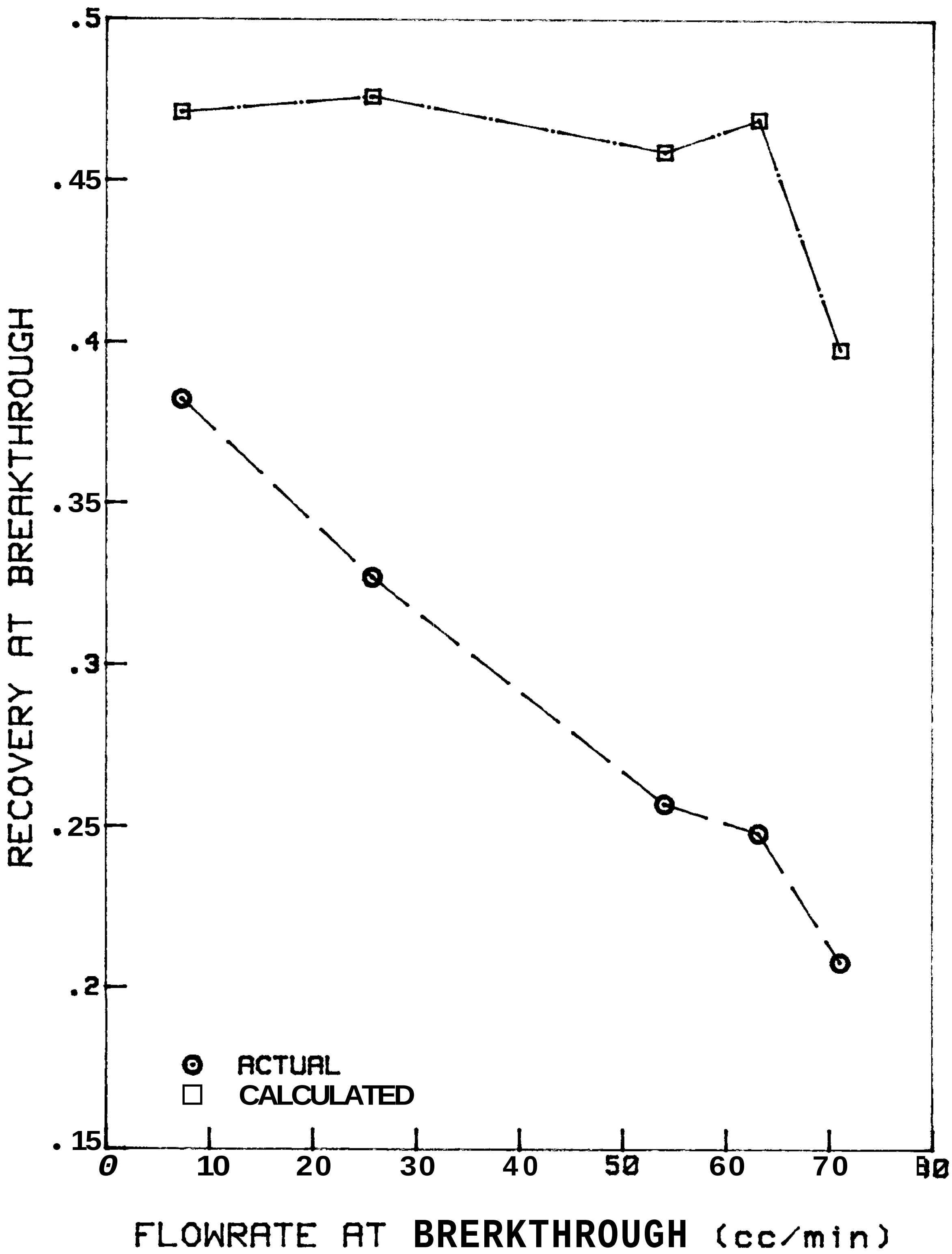

figure 6.2 Recovery at Breakthrough vs. Displacement Velocity

on between figure 6.2 and figure 2.1 indicated that the experiment was experiencing viscous fingering (Peters and Flock (1981)). Peters and Flock experienced viscous fingering when $I_{sc} > 13.56$. For this experiment the dimensionless instability number $I_{sc} > 3000$, confirming that it was above the critical value. Kyte and Rapoport's (1958) critical value for stablized flooding was $L\mu_w v > 6$. The scaling factor for this experiment was $L\mu_w v > 70$.

6.2 Conclusions

1. The apparatus has been constructed so that it can reproduce all results.

2. Gravity had no significant effect on the flooding front in this study

3. For this system velocity must be considered. It had a significant effect on the flooding front.

4. The flooding front was affected by Peters and Flock (1981) instabilities or viscous fingering, not Kyte and Rapoport (1958) instabilities.

6.3 Recommendations

1. Decrease the oil viscosity, core diameter, and flowrate. These are the variables in the Peters and Flock dimensionless instability number which may be changed for this apparatus. A decrease in these variables would produce a decrease in the dimensionless instability number in order that a stable flooding front can be achieved.

2. Miller (1983) checked for outlet effects in the apparatus by inserting a hypodermic neddle two inches into the outlet end of the core. This showed that the pressure drop across the last two inches of the core was normal, given the pressure gradient of the core. This report recommends that the inlet end effects be checked in the same manner. Due to the viscosity differences, the water may not be uniformly injected into the core.

3. Use smaller graduated cylinders prior to breakthrough to obtain more complete data before breakthrough occurs.

NOMENCLATURE

A = cross-sectional area, cm^2

calib = seperator calibration, cc/cm

C^* = wettability number, dimensionless

cSt = kinematic viscosity, cSt

dp/dx = pressure gradient, atm/cm

d = core diameter, cm

D = downstream dead volume, cc

ΣDv = cumulative volume of displacing fluid produced from separator, cc

k = absolute permeability, darcies

k_i = effective permeability to phase i, darcies

k_{ro} = relative permeability to oil, dimensionless

k_{rw} = relative permeability to water, dimensionless

f_d = fractional flow of displaced phase, dimensionless

f_o = fractional flow of oil, dimensionless

f_w = fractional flow of water, dimensionless

h_d = initial dynamic separator level, em

h_o = level of outlet tube in separator, cm

Ah = difference between initial static and dynamic separator levels, cm

I_r = relative injectivity, $(q / \Delta p) / (q / \Delta p)_{initial}$

I_{sc} = viscous instability number, dimensionless

L = length of core, cm

L_m = length of traveling end plug extended from end plug guide, cm

N_c = capillary number, dimensionless

N_p = cumulative pore volumes of oil recovered, dimensionless

Δp = differential pressure across core, psi

p_c = capillary pressure, dynes/cm

Pv = core pore volume, cc

q = total volumetric flowrate, cc/min

q_i = volumetric flowrate of phase i, cc/sec

r = radius, cm

Sep = cumulative separator (produced) volume, cc

$\bar{S}_o$ = average oil saturation, dimensionless

$\bar{S}_w$ = average water saturation, dimensionless

S_{w2} = water saturation at core outlet, dimensionless

S_{wi} = irreducible water saturation, dimensionless

$\bar{S}_{wf}$ = average water saturation after oil displacement, dimensionless

t = time, min

U = upstream dead volume, cc

v = flux velocity (q/A), cm/min

v_b = average seperator bubble velocity, cm/min

v_p = total displaced fluid produced, cm/min

μ_i = viscosity of phase i, cp

μ_o = oil viscosity, cp

μ_w = water viscosity, cp

η = ratio of 2% NaCl solution viscosity to distilled water viscosity, dimensionless

ρ_{wc} = water density at core temperature, g/cc

ρ_{oc} = oil density at core temperature, g/cc

ρ_{we} = water density at effluent temperature, g/cc

ρ_{oe} = oil density at effluent temperature, g/cc

σ = interfacial tension, dynes/cm

θ = contact angle, degrees

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Appendix A : APPARATUS DETAILS

A. 1 Main Flow System

A schematic of the main flow system is shown in figures A.1. The horizontal core holder was placed in a Napco Model 430 temperature controlled bath, though the oven was not used in this study. The vertical core holder was located between the oven and the control panel. Approximately 40 ft. of 1/8 in. 316-stainless steel tubing was used for the water line and approximately 30 ft. for the oil line.

A Valco Model 3P three-way valve was used to switch between oil and water injection. The valve was constructed to withstand 400 psig at 175 degrees centigrade (350 degrees Fahrenheit). An extension to the handle was constructed such that it might be turned from outside the oven (near the control panel).

Outside the airbath, a 3.5 in. long, 0.10 in. I.D., 0.364 in. O.D. sight glass was used to observe produced fluids. This also made possible a visual determination and confirmation of breakthrough. The glass tube was mounted in 3/8 in. swagelok fittings with teflon ferrules, and then tested to 400 psig with nitrogen.

A Whitey three-way switching ball valve was inserted downstream to direct produced fluids either to the effluent measurement system, or to a bypass line. If the handle was placed in the central (shut-off) position core pressure was maintained.

Four Type J thermocouples were used to monitor the temperaturee during runs. The thermocouples were connected to a Leeds and Northrop Speedomax W 24-point temperature recorder as follows:

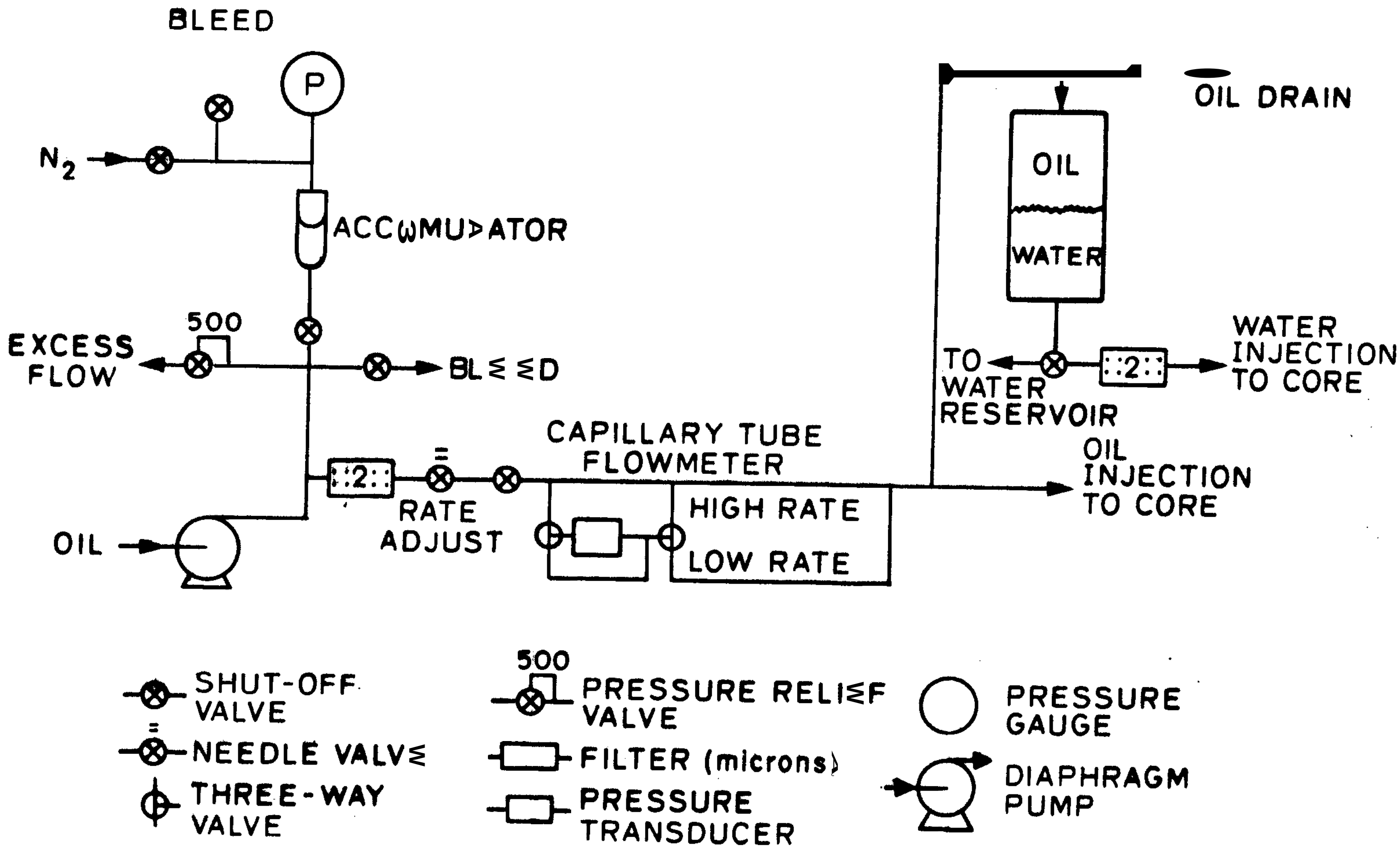


Figure A.1 Schematic of the Main Flow System (after Miller (1983))

Location	Channel No.
Downstream Flowline	7
Upstream Flowline	8
Core Holder Inner Sleeve	10
Room Temperature	11

Table A.1 Thermocouple Locations

A.2 Injection System

A schematic of the injection system is shown in figure A.3. Both water and oil was injected by a Milton Roy Model R-121A controlled volume pump. During an oil flood, oil was injected directly into the core. During a waterflood, however, water was displaced by oil from a one-gallon, teflon-lined, 304-stainless steel pressure vessel into the core. The salt-water was deoxygenated by saturating it with nitrogen prior to injection.

The injection rate was held constant during each run by using an excess flow loop with a 500 psig pressure relief valve. Injection rates were controlled by adjusting pump volume and a needle valve downstream of the pump. Excess flow was kept to a minimum by performing minor adjustments to the pump volume.

The pressure drop across the core always was less than 150 psig, yet the pressure upstream of the needle valve was regulated at 500 psig. Therefore, there is a large pressure drop across the needle valve and at the 100 psig pressure regulator at the effluent measurement system. Subsequently, if the pressure drop across the core changes greatly, the flow rate would change only slightly.

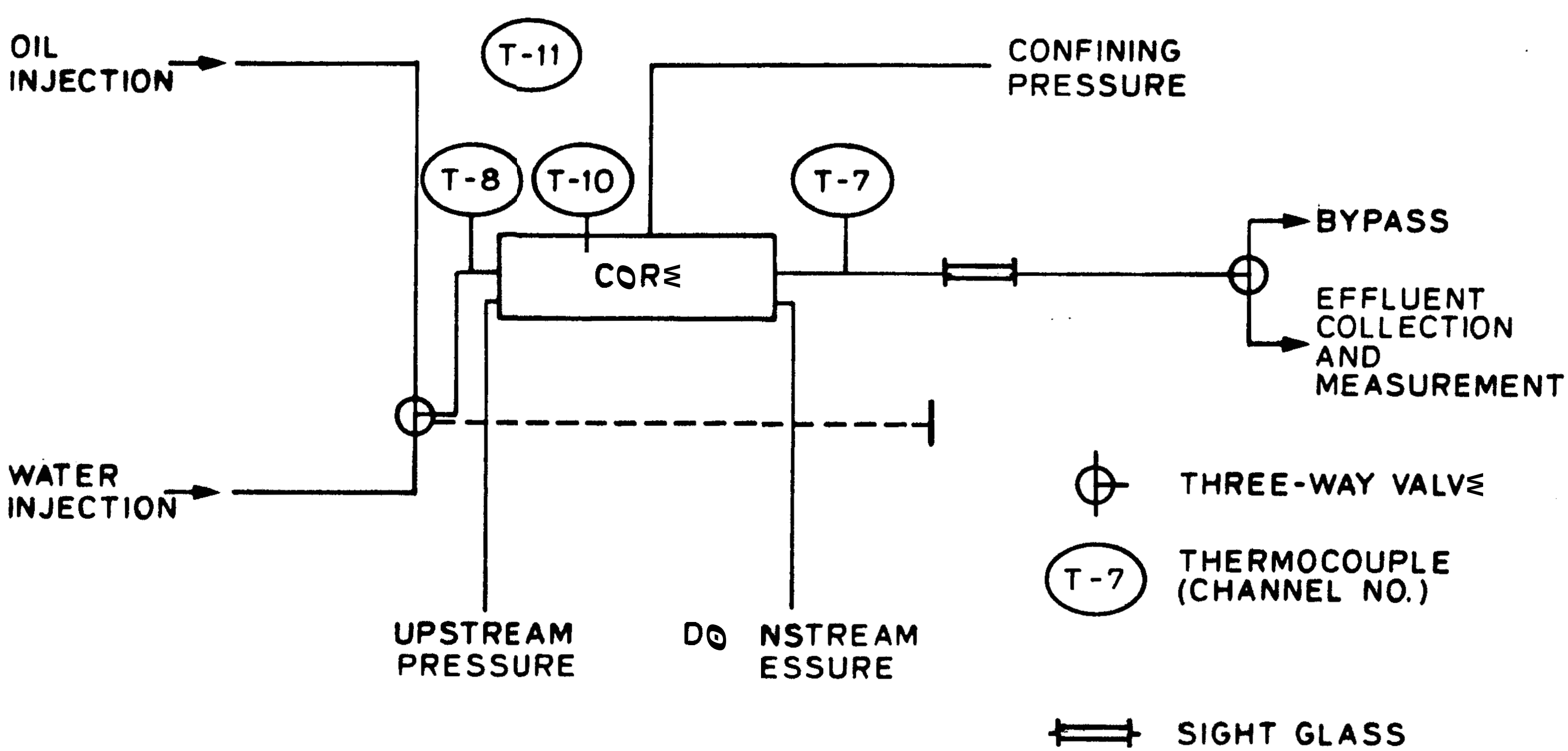


Figure A.2 Schematic of the Injection System – Horizontal Core (after Miller (1983))

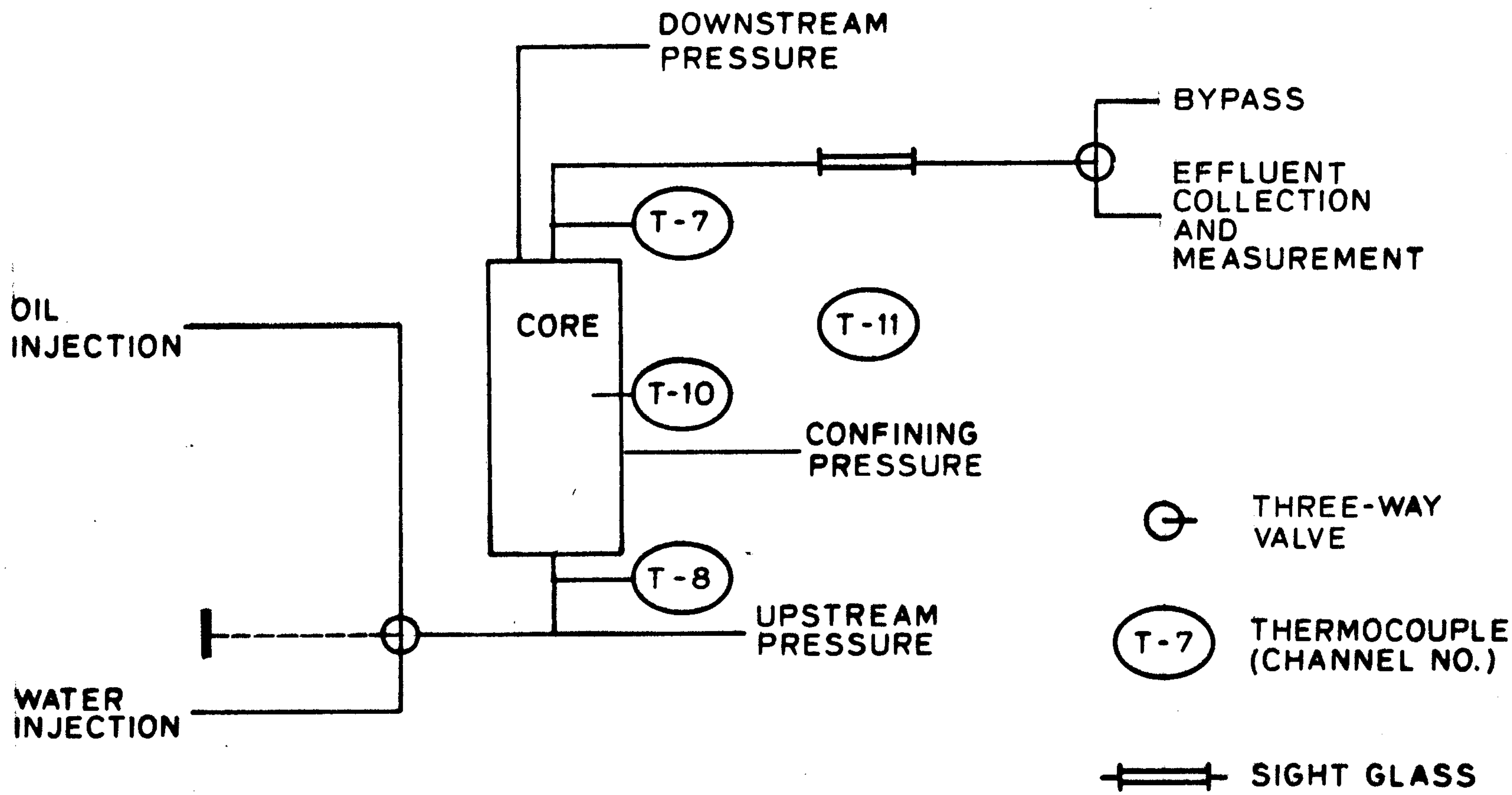


Figure A.3 Schematic of the Injection System -- Vertical Core

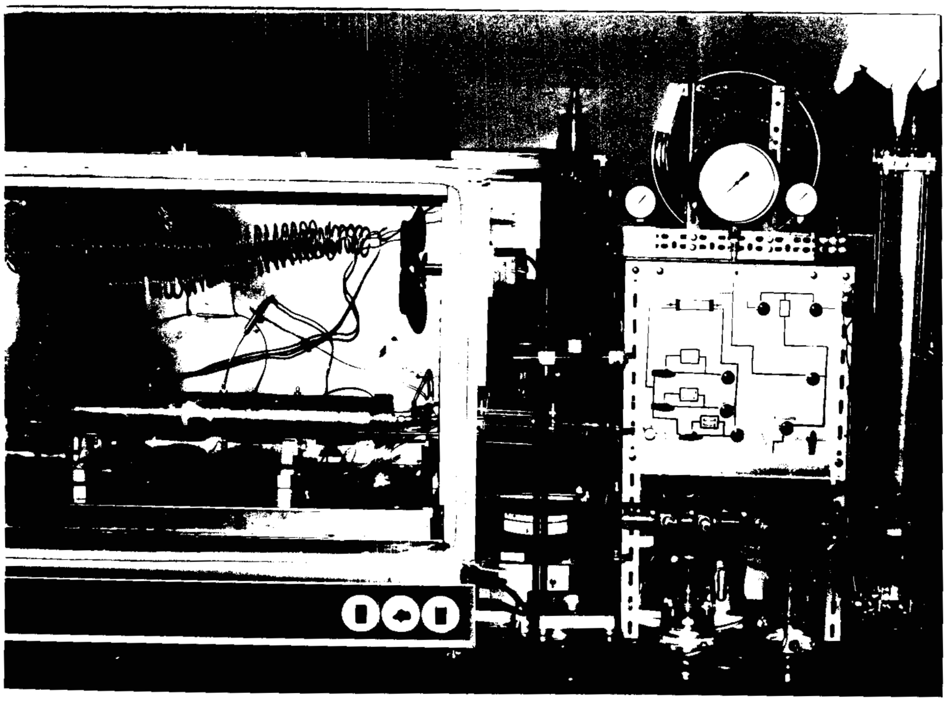


Figure A.4 Photograph of the Apparatus -- Horizontal Core

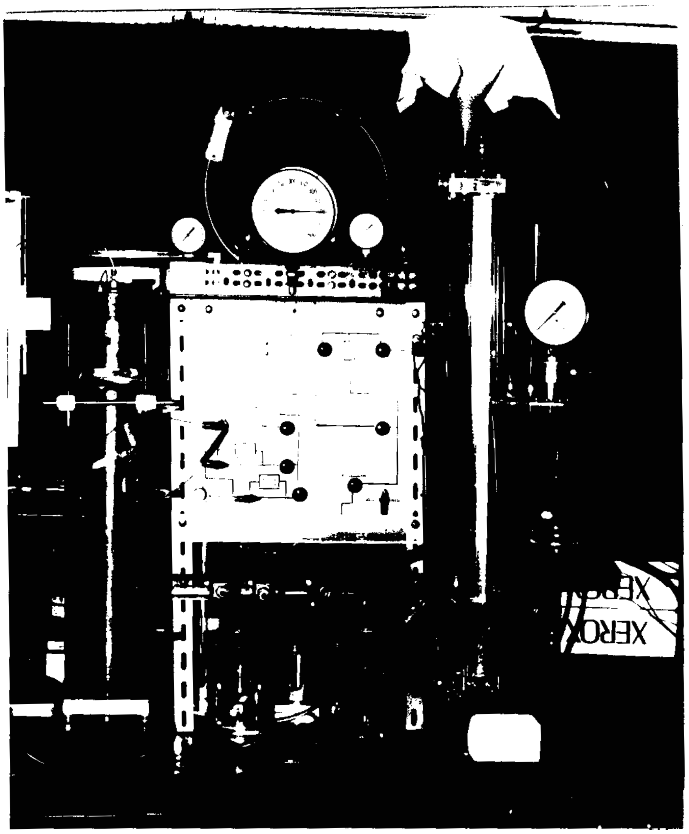


Figure A.5 Photograph of the Apparatus -- Vertical Core

A nitrogen charged Greerolator Model 20-30TMR-S-1/2 WS accumulator was used to dampen pressure pulsations from the pump. The accumulator was charged with a high pressure nitrogen cylinder until it reached the 500 psig relief pressure. Between the accumulator and the large pressure drop across the needle valve, pressure pulsations in the core were eliminated.

A capillary tube flowmeter was used to determine injection rates. The flowmeter consisted of approximately 4 ft. of 0.085 in. I.D., 0.125 in. O.D. 316-stainless steel. A Celesco KP-15 pressure transducer with a 5 psi plate was connected across the flowmeter to measure the flowing pressure differential. A three-way valve was also connected so as to zero the transducer. A Celesco Model CD25A transducer indicator was connected to the pressure transducer, and the pressure drop was recorded on a Soltec Model 1243 three-pen strip-chart recorder.

A.3 Effluent Measurement System

A glass tube separator, which allowed visual observation of the oil-water interface level was the major component in the effluent measurement system (shown in figure A.4). The glass tube, 1 in. I.D., 1.25 in. O.D., 32 in. in length, was mounted in machined recesses in two aluminum blocks. Sealing was accomplished by glueing a rubber o-ring to each end of the tube, then tightening the blocks to the tube ends with 4 threaded steel rods. A graduated scale affixed along the side of the tube allows a visual measurement of the change in the oil/water interface level.

All produced fluids enter through a 0.125 in. 316-stainless steel tube inserted approximately 2 cm. above the bottom of the separator. A three-way valve

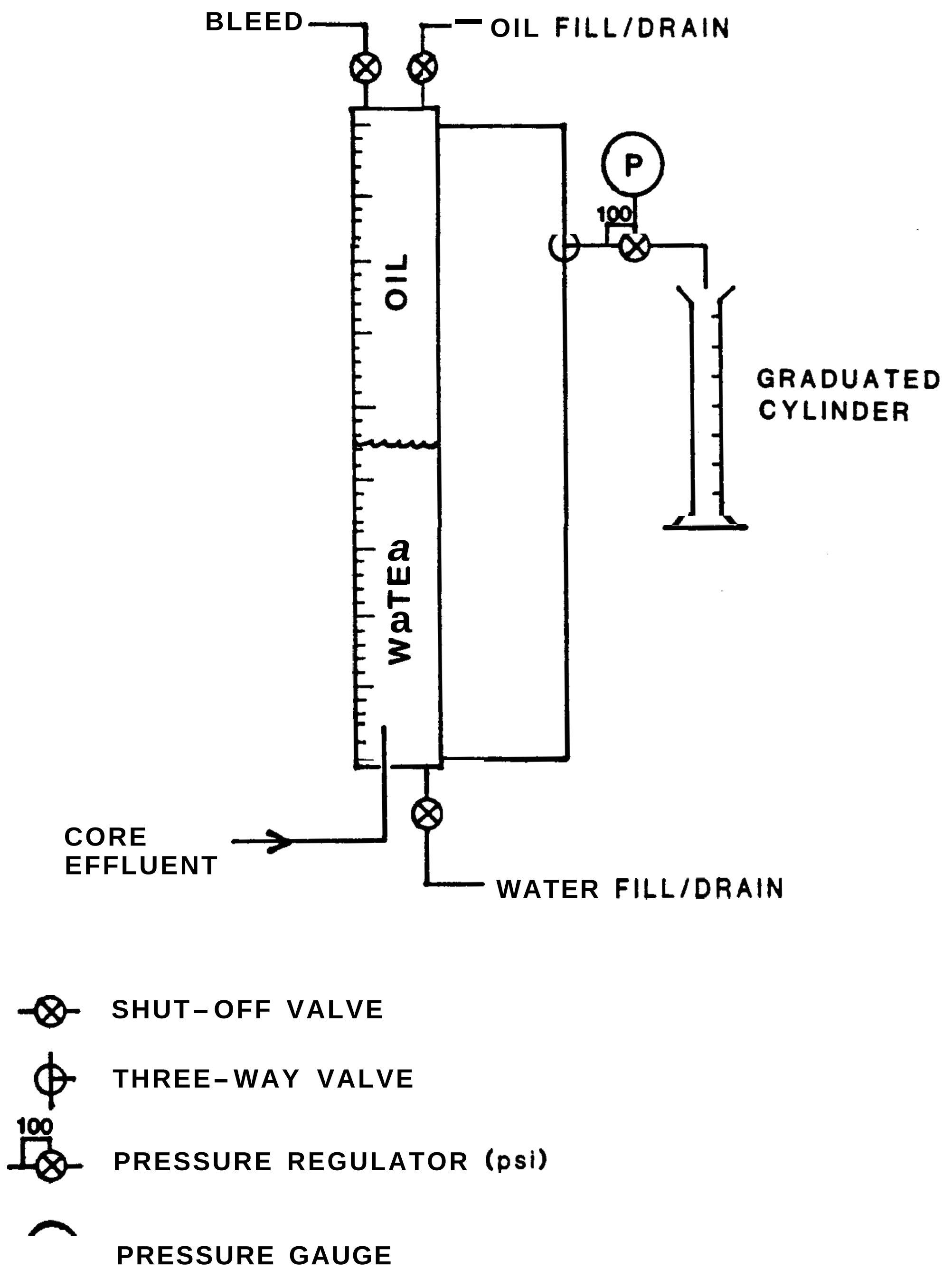
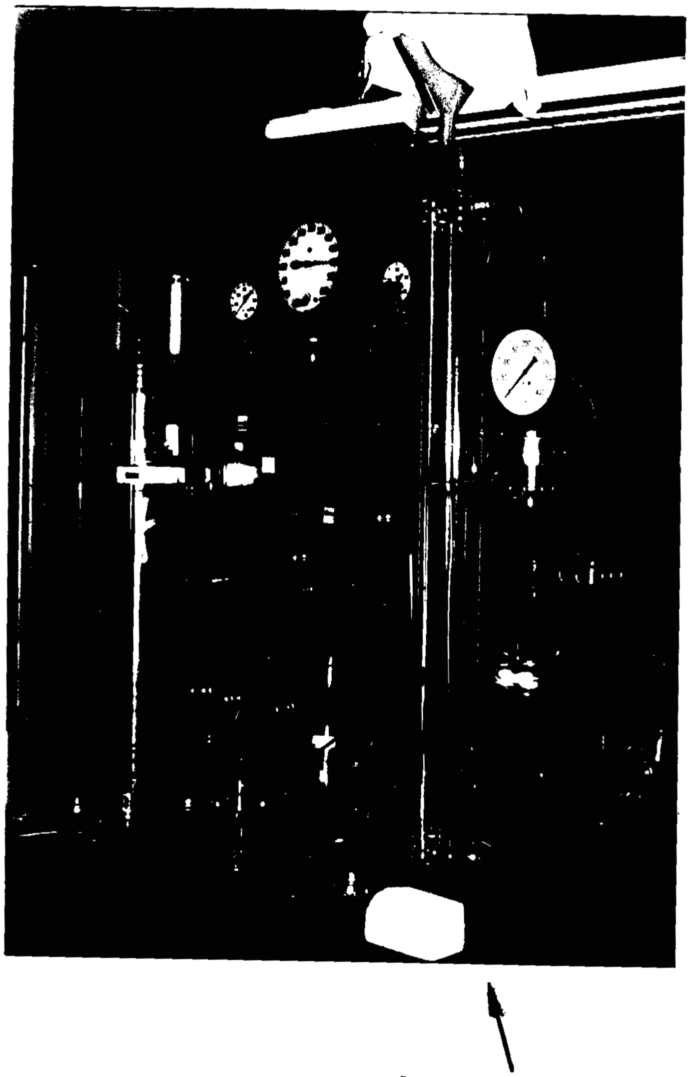


figure A.6 Schematic of the Effluent Measurement System (from ***Miller*** *(1983))*



glass separator tube

Figure A.7 Photograph of the Effluent Measurement System was connected to the top and bottom of the separator, allowing either oil or water to overflow, thus enabling the system to measure either produced oil or produced water. The system pressure was regulated by a Grove Mity-Mite Model SD-90-W air dome type pressure regulator. The body of the regulator was 316-stainless steel, with a Viton diaphram capable of controlling pressures of 25 to 400 psig. The regulator was charged with nitrogen through a Grove loading tee. The total volume of displacing fluid flowing from the separator was collected and measured in graduated cylinders. The separator was calibrated at the end of each run to account for fluids sticking to the sides of the glass. A reservoir of oil and water connected to the separator with Tygon tubing were used to displace fluids for calibration.

A.4 Pressure Measurement System

A bank of three Celesco KP-15 diaphram-type pressure transducers were used to monitor the pressure drop across the core (see figure A.4). A 25, a 100, and a 500 psi pressure plate was used in each of the three transducers. A Celesco Model CD-25A or CD-10C de nodulator/indicator was connected to the three transducers, and the output was recorded on a Soltec Model 1243 three-pen strip-chart recorder. A three-way switching valve was connected to each transducer to enable zeroing.

Pressure guages to monitor internal core pressure were fastened to the upstream and downstream pressure taps. Valves were also attached to bleed the lines of air prior to connecting a fresh core.

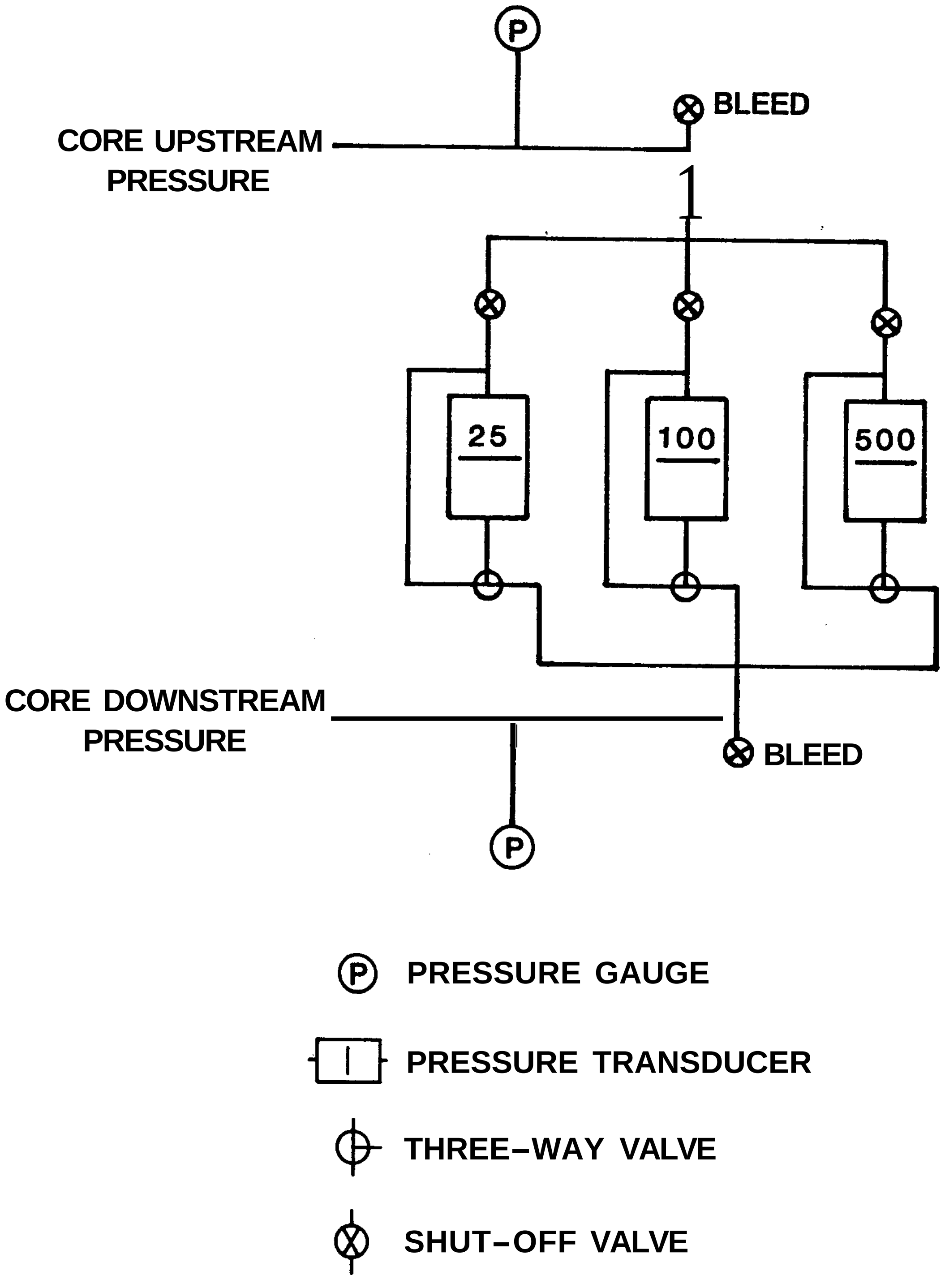


Figure A.8 Schematic of the Pressure Measurement System (after Miller (1983))

A5 Confining Pressure System

A high pressure nitrogen cylinder was used to apply a confining pressure through a 400 cc pressure vessel (figure A.6) to the distilled water confining fluid in the core holder. The confining fluid enveloped the inner sleeve and was maintained at 500 psig. Due to the low compressibility of distilled water, leaks in the confining pressure system were detected and repaired.

A6 Core Holder

The core holder used in this study (figure **A.7)** was originally constructed by Counsil (1979), and later modified by Jeffers (1981) and Miller (1983). Dimensions of the core holder and inner sleeve are given in figures A.8 and A.9. The outer sleeve of the core holder was constructed from 304-stainless steel, 3.5 in. O.D., 2.62 in. I.D., and 26 in. in length. The I.D. of each end was machined to 2.65 in. to accept O-ring seals on the end of the end plug assemblies. The body was threaded on each end for brass retaining caps. Brass was used because it reduces thread siezure problems.

The inner sleeve used to contain the unconsolidated sand-pack was made from 316-stainless steel mechanical grade tubing 2 in. I.D., 2.25 O.D., and 23.05 in. in length. Like the outer sleeve, each end of the inner sleeve was machined (2.02 in. I.D.) to accept O-ring seals on the end plugs. The average I.D. of the inner sleeve was accurately measured by filling the empty sleeve with distilled water from the fixed end plug to a small distance from the opposite end. The result was an average I.D. of 5.044 cm. (1.986 in.)

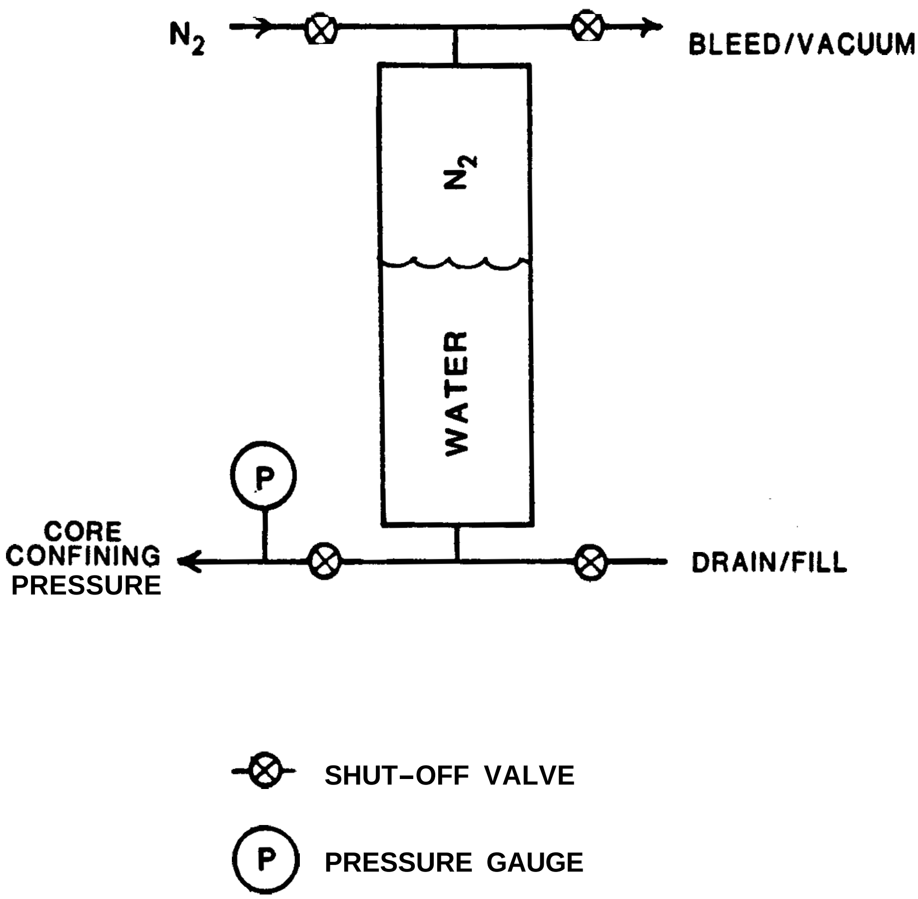


figure A.9 Schematic of the Confining Pressure System (om Miller (1383))

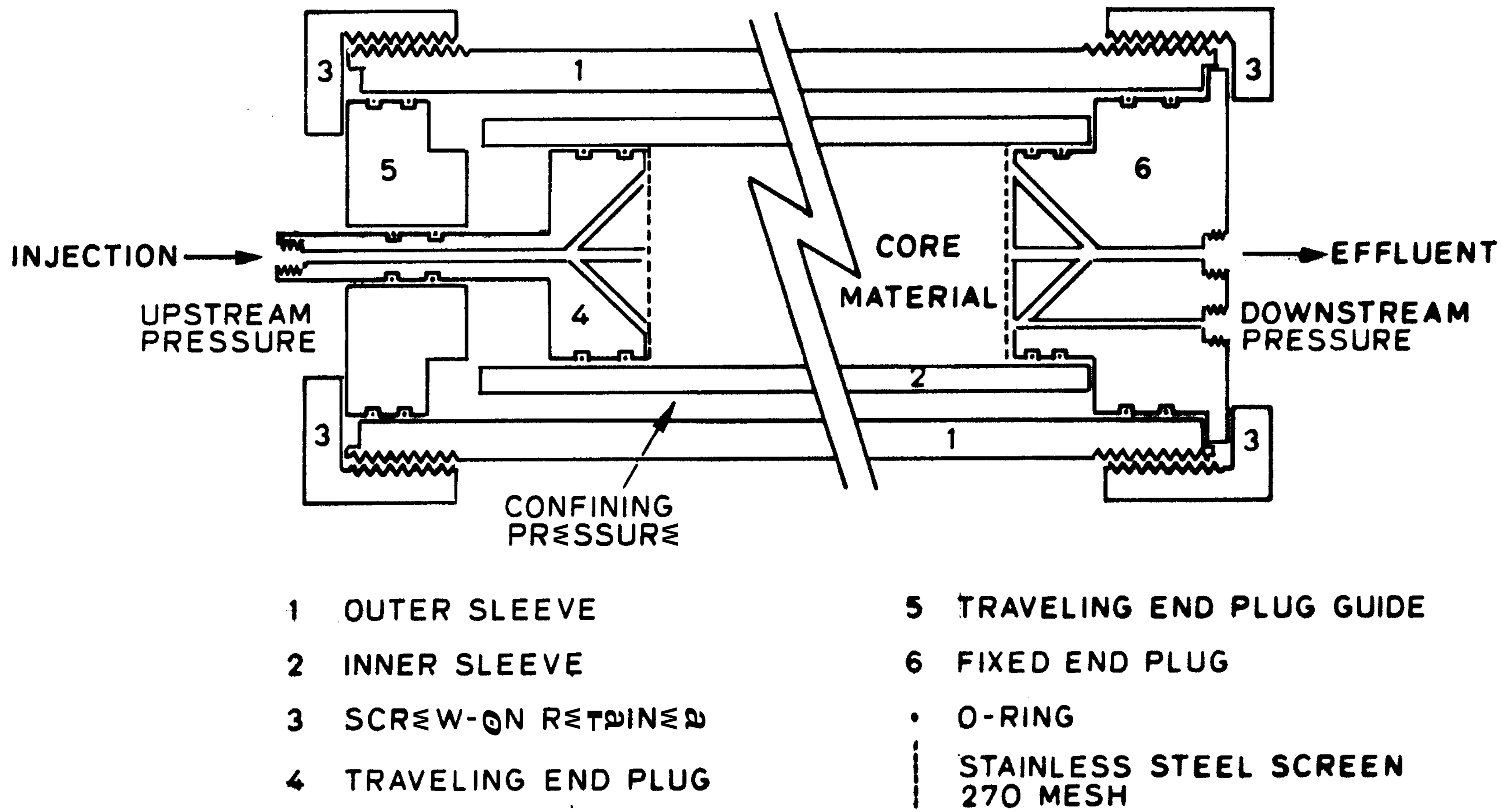


Figure A.10 Schematic of the Core Holder (after Miller (1983))

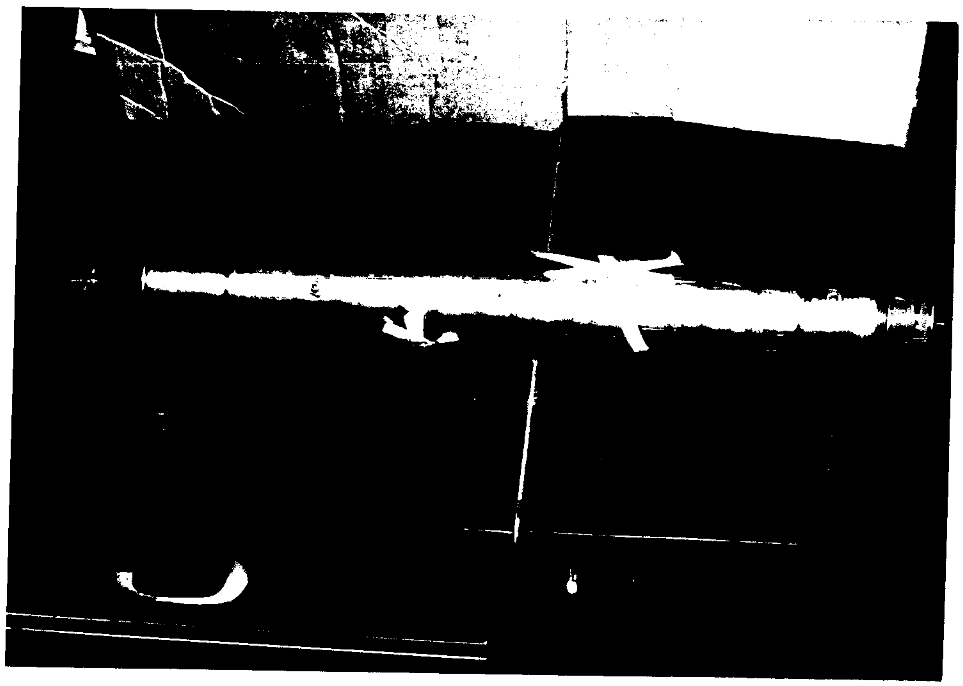


Figure A.11 Photograph of the Core Holder

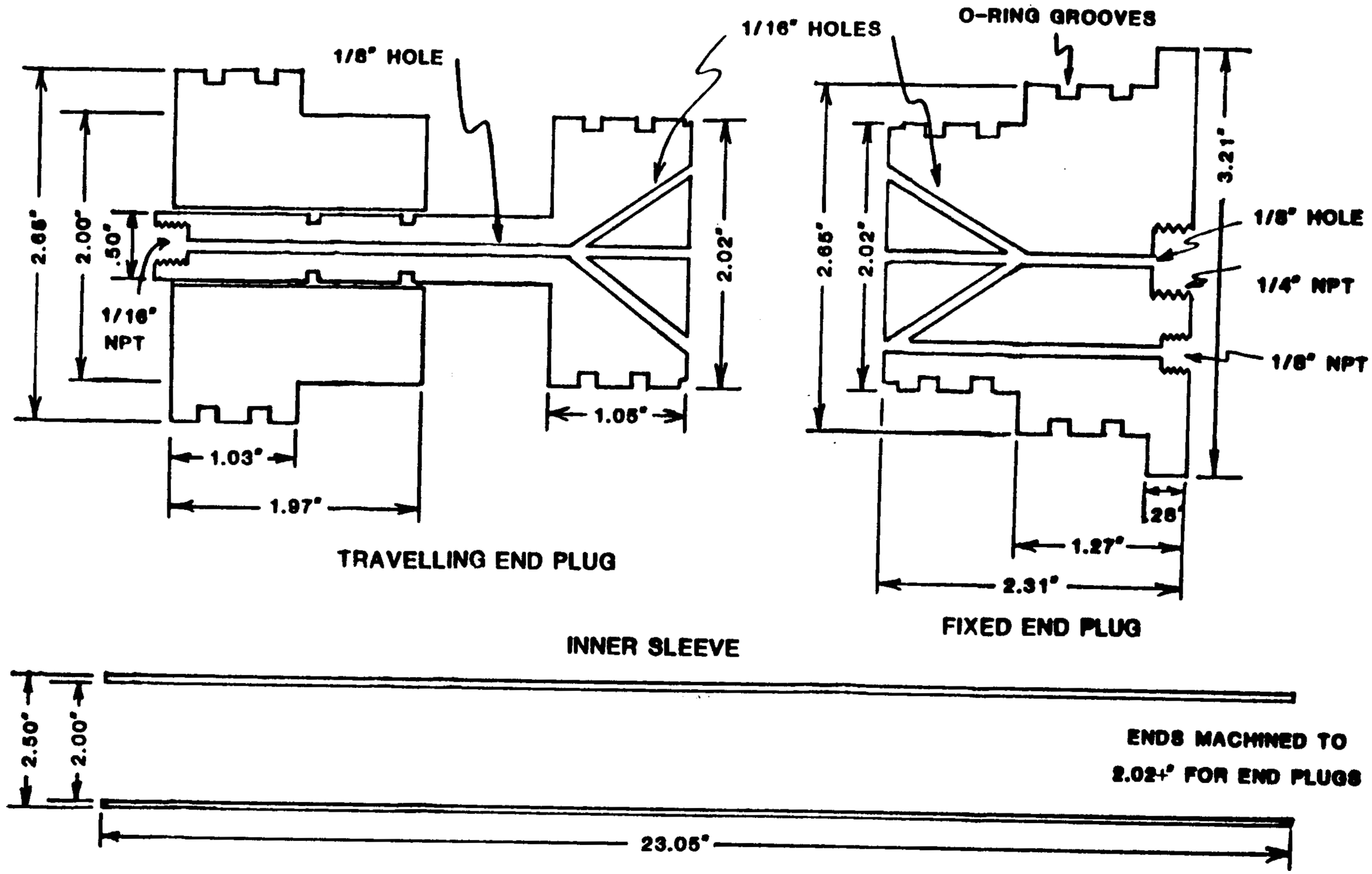


Figure A.12 Dimensions of the Core Holder Inner Sleeve and End Plugs (after Miller (1983))

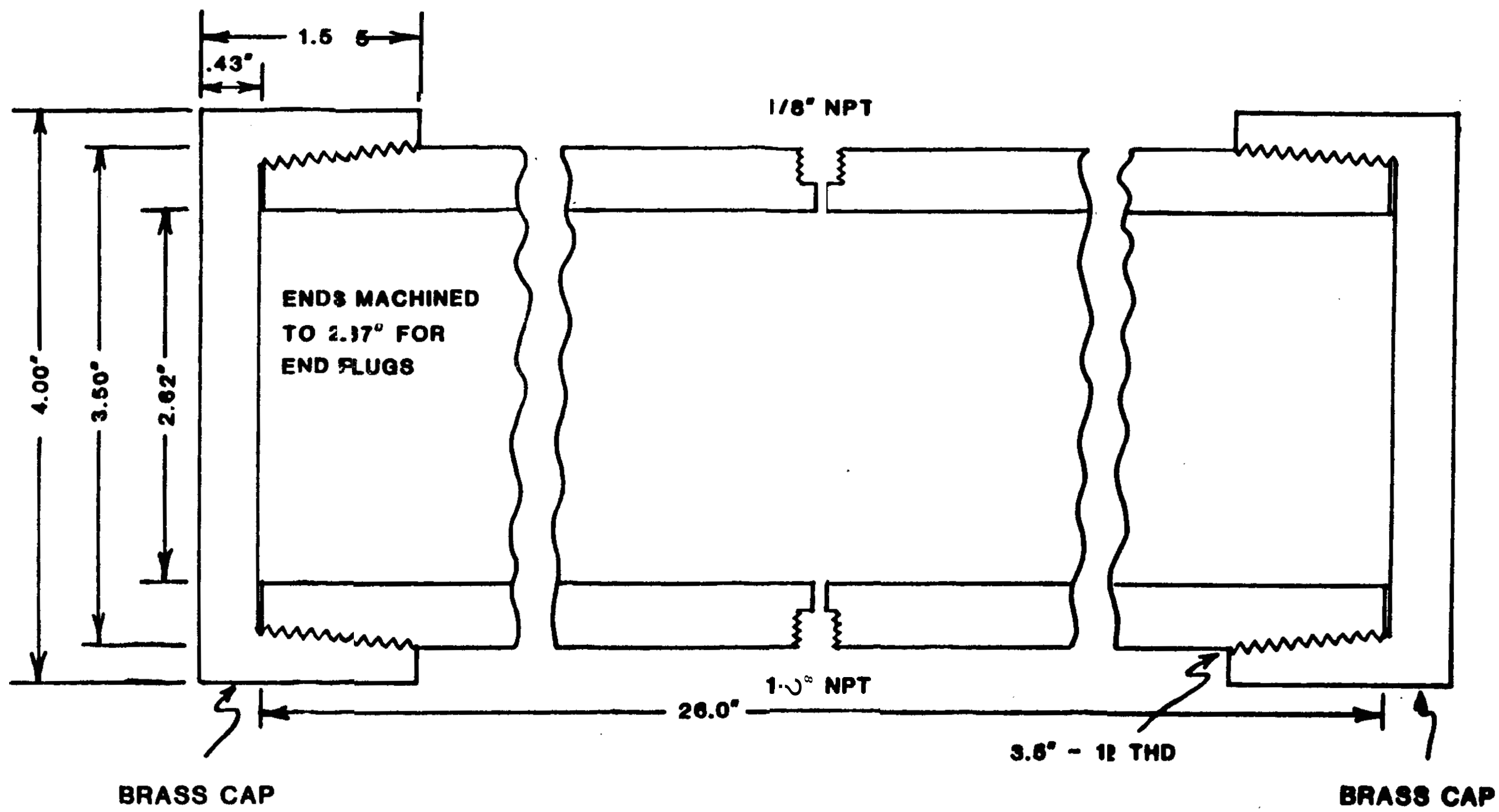


Figure A.13 Dimensions of the Core Holder Outer Shell and Components (from Miller (1983))

A confining force was applied uniaxially along the sand-pack by a free-traveling end plug. A fixed end plug was placed on the opposite end. Both plugs were constructed of 316-stainless steel. In each plug, one central hole, and six radiating holes were drilled to distribute flow across the core face. To aid in this distribution, concentric circular and radiating linear grooves were milled on the face of each plug. Each plug was then covered with 270 mesh screen to retain the sand.

Pressure taps were inserted at both upstream and downstream locations. A hole was drilled directly through the fixed end plug for the downstream pressure tap. Serving as the upstream pressure tap, a 1/16 in., 316-stainless steel tube was inserted into the main flow channel in the traveling end plug.

The core holder dimensions were measured to allow an accurate determination of core length and diameter. Miller found the following from the core holder dimensions:

$$L = L_m + 19.90 \text{ in. } (50.55 \text{ cm.})$$

where:

L = length of core L_m = length of traveling end plug external from the end plug guide.

Dead volumes in the system were also measured and taken into consideration in data analysis. The upstream dead volume (between the three-way valve and the core face) was measured by attaching the traveling plug to the injection system and alternately flowing oil and water through it. The oil and water displaced from the dead volumed was measured several times in a graduated cylinder. The total dead volume was measured by clamping the end plugs together in a rubber sleeve, attaching them to the injection and effluent systems,

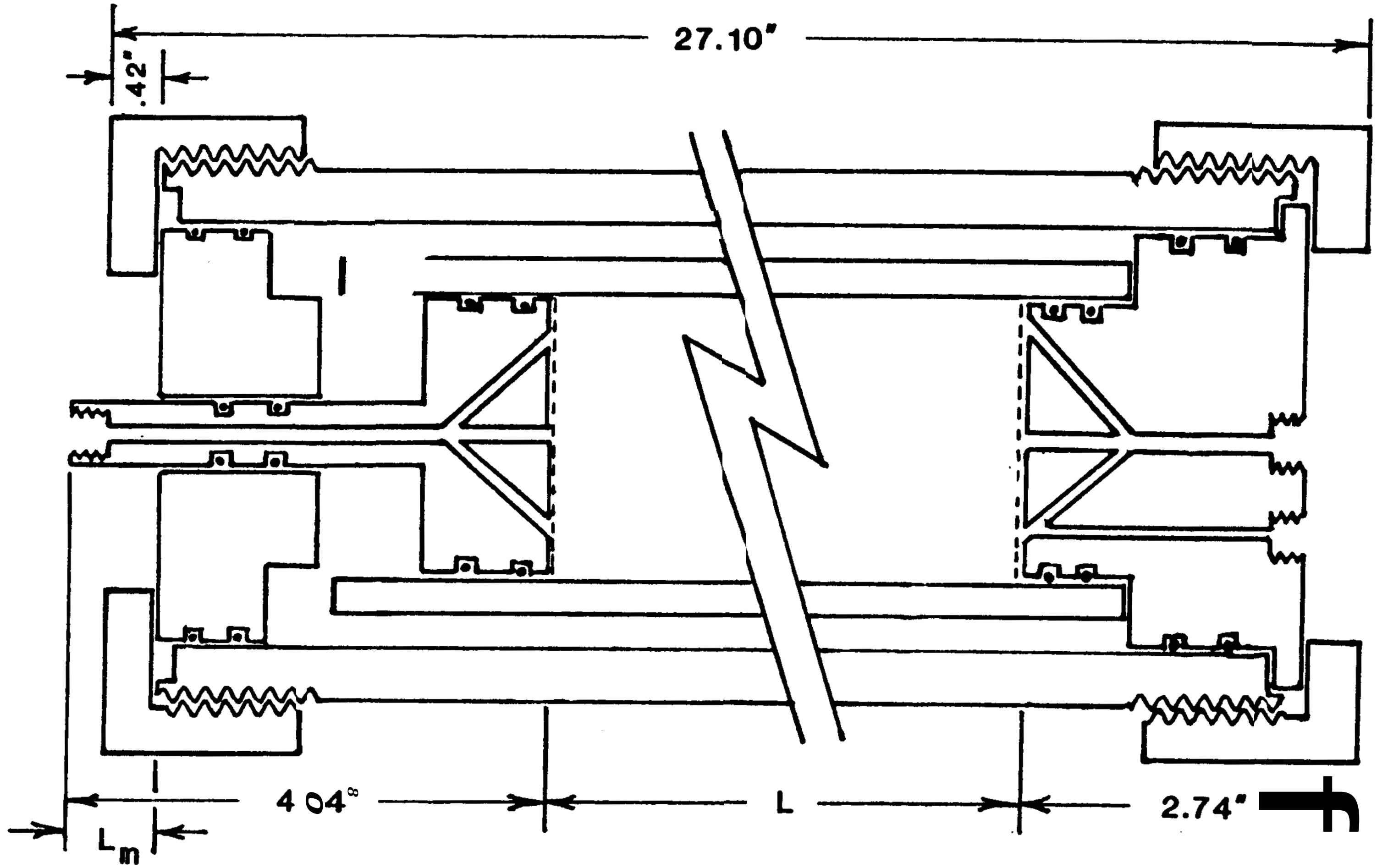


Figure A.14 Core Holder Dimensions for Determining the Length of the Unconsolidated Sand Pack (after Miller (1983)) and alternately flowing oil and water through the system (just as above). The total dead volume was then measured in the glass tube separator. The upstream dead volume was found to be 2.2 *cc*, and the downstream dead volume was measured at 3.0 *cc*.

Appendix B : PROCEDURE DETAILS

The procedures used in this study were virtually identical to those published by Miller (1983) in his PhD dissertation at Stanford Univerity. For the purpose of completeness, those procedures have been included:

The following sections describe the procedures used for core preparation, salt water treatment, oil and water displacement runs, and separator calibration.

B.1 Unconsolidated Sand Preparation and Core Packing

Sand for the unconsolidated sand packs was prepared from industrial quality F-140 Ottawa silica sand. The sand was sieved using a W. S. Tyler Ro-Tap Testing Sieve Shaker. A double stack of W. S. Tyler U.S.A. Standard Testing Sieves were used in the following sequence (top down): 80-, 100-, 120-, 140-, 170-, and 200-mesh and pan.

Approximately 50cc (70 g) of sand was placed in each stack and sieved for at least 10 minutes (recommended procedure by W. S. Tyler Co.). Sand on the 80 and 100 mesh screens and the pan was discarded. After enough sand was sieved, approximately 2000 g of total sand were recombined according to the following percentages:

U.S.A. Standard Sieve Mesh	Percent
100 - 120	25
120 - 140	35
140 - 170	25
170 - 200	15

Table B.1 Sieve Analysis of Unconsolidated Sand Packs

The sand was mixed by shaking in a sealed container and then thoroughly washed with tap water. Washing was done by shaking a sand and tap water mixture in a sealed jar and then pouring off the dirty water after the sand had settled. This procedure was repeated several times until the water was clear (usually around 10 or more times). The sand was then placed on an aluminum pan and oven dried for a few hours.

Sand was packed in the inner sleeve dry. The fixed end plug was first inserted into the sleeve and the assembly placed upright on a wood block. A pneumatic vibrator was strapped to the sleeve with a strap clamp. A plastic insert containing several wide mesh screens was placed in the top of the sleeve to distribute sand as it was poured. With the vibrator running, sand was poured into the sleeve in batches of approximately 200 cc {usually six batches in all). The sand was carefully weighed to determine the porosity (using core dimensions and quartz sand density of 2.65 g/cc). Sand was poured to approximately **4** cm from the top of the sleeve to allow proper plug travel.

The outer shell was then placed over the inner sleeve and the traveling end plug with guide inserted into the open end of the inner sleeve. The entire assembly was placed in a vise and the retaining caps tightly screwed on with strap wrenches.

The core assembly was placed in the air bath and connected downstream to a shut-off valve and then to a vacuum pump teed to a McLeod vacuum guage. Upstream, the core was connected to a shut-off valve and then to a water reservoir on top of the air bath. Care was taken to remove all air from the line between the water reservoir and the shut-off valve. Pressure taps were sealed with Swagelok caps.

The confining pressure system was then purged of all water and connected to the core holder. The inner sleeve thermocouple was connected to the outer shell and 500 psig nitrogen confining pressure applied. The valve between the core and the confining pressure vessel was closed and the vessel bled to atmospheric pressure. The vessel was filled with distilled water using a vacuum and then repressurized with nitrogen. While slowly bleeding nitrogen from the thermocouple connection (to maintain confining pressure), water was displaced from the pressure vessel to fill the core holder.

With the water valve to the core closed and the vacuum valve open,the core was evacuated to less than 50 microTorr. This usually required several hours, or overnight. The vacuum valve **was** then closed and the water valve opened to saturate the core with water.

After being certain the injection valve was switched to "waterflood" and filled to the end with water, the injection line was connected to the core. The pressure taps and downstream line were then connected and the pump started. While pumping a few pore volumes of water to ensure complete saturation, the pressure tap lines were bled.

After the injection rate and differential pressure stabilized, the absolute permeability of the pack to water was measured several times using a graduated cylinder and a stopwatch to determine flowrates. Measurements were usually repeatable to within 0.5%.

The core was now ready for oil displacement to establish irreducible water saturation.

B.2 Salt Water Treatment

Sixteen liters of distilled water were placed in a 5 gal Pyrex bottle. Nitrogen was blown into the water through fish tank air stones to reduce the oxygen concentration in the water and to remove oxygen from the air space in the bottle ...[to minimize corrosion problems]. In 2 liters of heated distilled water, 367 g of NaCl ...was added and stirred...This solution was poured into the pyrex bottle. Nitrogen bubbling was continued for a short time to mix the solution thoroughly.

Approximately 1 gal of water at a time was loaded into the salt water pressure vessel. The Pyrex bottle was sealed between loadings to prevent oxygen contamination of the air space above the water.

B.3 Oil Displacement Runs

At the beginning of a set of displacement runs, the effluent separator was usually dismantled and thoroughly cleaned. The separator was then filled with water from the bottom and oil from the top, being certain to remove air bubbles from the end caps and the lines to the three-way switching valve. Prior to starting an oil displacement run, the oil/water level was positioned near the bottom of the separator.

For displacing the core to irreducible water saturation, the following procedure is recommended:

1. Be certain [water] vessel is filled with [salt water]...

2. With both the injection and effluent switching valves set to "waterflood", start the pump briefly to bring the system to 100 psig. This is done by adjusting the nitrogen charge in the pressure regulator (usually to around 125 psig).

3. Measure the separator level.

4. Start the pump, zero the appropriate transducer(s), and begin to record core differential pressure and the flowmeter reading on the strip-chart recorder. A chart speed of 30 cm/hr was used for most runs.

5. Wait for the rate and differential pressure to stabilize.

6. Switch both the injection and effluent switching valves to "oilflood" simultaneously. Immediately begin measuring effluent oil production in a graduated cylinder (usually 100 ml) while simultaneously starting the stopwatch. Record the differential pressure and flowmeter readings just prior to initiation of oil injection (may be done later).

7. When the graduated cylinder is nearly full, do the following simultaneously:

a) Read separator level.

b) Change graduated cylinder.

c) Depress "lap" button on the stopwatch to get an elapsed time reading while letting the internal clock continue to run.

Immediately depress the "mark" button on the strip-chart recorder to indicate the point at which the data was taken.

0. Record:

a) elapsed time (hr, min, sec) - then restart stopwatch by again pressing "lap" button.

b) separator level (cm)

c) volume of oil in graduated cylinder (cc)

d) differential pressure (psi)

e) flowmeter reading at "mark"

f) average flowmeter reading from previous "mark"

Data d), e), and f) may be recorded any time, since they are permanently recorded.

9. Repeat steps 7 and 8 to the end of the run. Large volume graduated cylinders were generally used after breakthrough, reverting to a 100 ml cylinder at the end to determine an accurate end-point flowrate. Approximately 2 pore volumes of oil were injected to establish irreducible water saturation.

10. Zero transducers, then shut off the pump. Isolate the core with the shut-off valve upstream of the flowmeter and with the switching valve just upstream of the separator (by turning the three-way valve to a neutral shut-off position).

11. Record the final separator level with the pump off. Levels taken with oil flowing are slightly in error, due to the volume of oil in bubbles traveling up the water column.

12. Record the flowmeter reading and differential pressure at oil breakthrough.

13. Bleed the pressure regulator nitrogen charge to bring the separator to atmospheric pressure. Turn the effluent switching valve to neutral. Calibrate the separator (see Appendix B.5).

14. Place the water reservoir on top of the air bath and the oil reservoir on the laboratory bench. Displace oil from the separator to the oil reservoir, until the oil-water interface is near the top of the separator. Close the valves to the reservoirs.

15. Turn the effluent switching valve to "oilflood". Repressurize the pressure regulator nitrogen charge to the previous level.

16. Slowly turn the switching valve upstream of the separator to "flood"... If necessary, proceed to Step 17 with the switching valve in neutral (shut-off). Turn the valve quickly to "flood" when the core pressure begins to rise.

17. Open the shut-off valve upstream of the flowmeter and start the pump to bring the system to full pressure. The system is now ready for a water displacement run.

B.4 Water Displacement Runs

1. With both the injection and effluent switching valves set to "oilflood", start the pump briefly to bring the system to 100 psig. This is done by adjusting the nitrogen charge in the pressure regulator (usually around 125 psig).

2. Measure the static separator level.

3. Start the pump, zero the appropriate transducer(s), and record core differential pressure and the flowmeter reading on the strip-chart recorder. A chart speed of 30 cm/hr was used for most runs.

4. Record the dynamic separator level. The difference between this level and the static level is the amount of oil traveling in bubbles up the water column. Corrections for this effect are discussed in Appendix .

5. Wait for the rate and differential pressure to stabilize.

6. Switch both the injection and effluent valves to "waterflood" simultaneously. Immediately begin measuring effluent water production in a graduated cylinder (usually 100 ml) while simultaneously starting the stopwatch. Record the differential pressure and flowmeter readings just prior to initiation of water injection (may be done later).

7. When the graduated cylinder is nearly full, do the following simultaneously:

   a) Read separator level.

b) Change graduated cylinder.

c) Depress "lap" button on the stopwatch to get an elapsed time reading while letting the internal clock continue to run.

Immediately depress the "mark" button on the strip-chart recorder to indicate the point data was taken.

8. Record:

a) elapsed time (hr, min, sec) - then restart stopwatch by again pressing "lap" button.

b) separator level (cm)

c) volume of water in graduated cylinder (cc)

d) differential pressure {psi)

e) flowmeter reading at "mark"

f) average flowmeter reading from previous "mark"

Data d), e), and f) may be recorded at any time, since they are permanently recorded.

9. Repeat Steps 7 and 8 to the end of the run. Watch for water breakthrough in the sight glass to help pick the breakthrough point on the strip-chart recorder. Large volume graduated cylinders were generally used when oil fractional flows became small, reverting to a 100 ml cylinder at the end to determine an accurate end-point flowrate. Up to [8] pore volumes were injected ...[during each waterflood]...

10. Zero all transducers, then shut off the pump. Isolate the core with the valve upstream of the flowmeter and with the switching valve just upstream of the separator (by turning the three-way valve to a neutral shut-off position).

11. Record the final separator level.

12. Record the flowmeter reading and differential pressure at water breakthrough. Breakthrough is sometimes difficult to establish. Visual observation with the sight glass will give a general idea of breakthrough time.

13. Bleed the pressure regulator nitrogen charge to bring the separator to atmospheric pressure. Turn the effluent switching valve to neutral. Calibrate the separator (see Appendix B.5).

14. Place the oil reservoir on top of the air bath and the water reservoir on the laboratory bench. Displace water from the

separator to the water reservoir until the oil-water interface is near the bottom of the separator. Close the valves to the reservoirs.

15. Turn the effluent switching valve to "waterflood"... Bleed the core pressure by turning the valve upstream of the separator to "flood"...

16. Repressurize the pressure regulator nitrogen charge to its previous level.

17. Slowly turn the switching valve upstream of the separator to "flood"... If necessary, proceed to Step 18 with the switching valve in neutral (shut-off). Turn the valve quickly to "flood" when the core pressure begins to rise.

18. Open the shut-off valve upstream of the flowmeter and start the pump to bring the system to full pressure. The system is now ready... [for an oilflood].

B.5 Separator Calibration

The separator calibration procedure entails displacing the produced oil or water from the separator into graduated cylinders and measuring the corresponding change in separator level . This was found to give accurate and repeatable measurements of produced volumes for material balance purposes:

1. Place the appropriate reservoir on top of the air bath to displace the desired fluid from the separator. Set the effluent switching valve to the neutral shut-off position, and open the valve to the reservoir.

2. To be sure lines are liquid filled, displace a small amount of produced fluid by turning the effluent switching valve briefly to the appropriate setting ("oilflood" to measure oil, "waterflood" for water). Record the separator level.

3. Place a graduated cylinder (usually 100 ml) under the pressure regulator and turn the effluent switching valve to fill the cylinder with produced fluid.

4. Turn the switching valve to neutral and. record the new separator level. Estimate the level if large changes occur in the meniscus shape. A meniscus correction of .17 cm was measured as the difference between a perfectly flat meniscus and the bottom of a fully-developed meniscus when the tube is clean. Record the volume of fluid in the graduated cylinder.

5. Repeat Steps **3** and **4** until the separator level is near that at the beginning of the run.

6. Total produced volume is measured as the total measured in the graduated cylinders plus or minus corrections for differences between the the beginning and ending calibration levels and the beginning and ending run beginning and ending calibration levels and the beginning and ending run levels.

Appendix C : FLUID PROPERTIES AND CORE DATA

This appendix contains information on the density and viscosity of the salt water and the white mineral oil (Btandol), as well as specific properties of the unconsolidated sandstone core used in this study.

C.1 Salt Water Density

The density of a 2% NaCl aqueous solution over a range of temperatures was obtained from the International Critical Tables (1928), **V.3, p.** 79 (see table C. 1).

Temperture (degrees, C)	Density (g/cc)
0	1.01509
10	1.01442
20	1.01246
25	1.01112
30	1.00957
40	1.00593
50	1.00161
60	0.9967
80	0.9852
100	0.9719

Table C.1 Density of 2% NaCl Solution vs. Temperature

The software designed by Miller (1983) to analyze data obtained from the relative permeameter could accept data from either distilled water runs or 2% NaCl solution runs. He found that the ratio of the density of a 2% NaCl solution to the density of distilled water was between 1.0137 to 1.0143 for temperatures from 20° C to 100° C. Since the density ratio was constant, distilled water data could be used to generate the curve-fit for salt water runs. Though this study uses only salt water, distilled water may have been run with no additional calculating or curve-fitting.

The distilled water data from 70° F to 300° F was curve-fit with the following equation:

$$\ln (\rho_w) = a_0 + a_1 T + a_2 T^2 \qquad (C.1)$$

where:

ρ_w = distilled water density, g/cc

T = temperature, degrees F

$a_0 = 6.52014 \times 10^{-3}$

$a_1 = -4.34333 \times 10^{-5}$

$a_2 = -8.78134 \times 10^{-7}$

Equation C.1 matches the distilled water data (shown in table C.2) within a maximum error of ±0.08%.

Temperature (degrees, F)	Specific Volume at 115 psia (cu.ft./lbm)
60	0.01603
70	0.01604
00	0.01607
90	0.01609
100	0.01612
110	0.01616
120	0.01620
130	0.01624
140	0.01629
150	0.01634
160	0.01639
170	0.01645
180	0.01650
190	0.01657
200	0.01663

Table C.2 Distilled Water Specific Volume vs. Temperature

C.2 Salt Water Viscosity

Data on the viscosity of a 2% NaCl solution over a range of temperatures is given in the International Critical Tables (1928), V.5, p. 15. This data is in the form of the parameter η, which is the ratio of the NaCl solution viscosity to the viscosity of distilled water. Table C.3 shows values of η over the given temperature range.

Temperature (degrees, C)	Ratio of 2% NaCl Solution Viscosity to Distilled Water Viscosity, η
1%	1.028
25	1.032
40	1.037
60	1.042
80	1.043
100	1.045

Table C.3 Ratio of 2% NaCl Solution Viscosity to Distilled Water Viscosity vs. Temperature

Since these experiments were conducted at room temperature, a value for η of 1.030 was selected. This value was found to be satisfactory for the range of ambient temperatures encountered during this study.

C.3 Oil Density

Blandol density was calculated by Miller (1983) for a range of temperatures. The measured data is shown in Table C.4.

Temperature (degrees, F)	Blandol Density (g/cc)
84.9	0.8415
101.7	0.8346
124.7	0.8264
149.4	0.0176
174.6	0.8085

Table C.4 Measured Blandol Density *vs.* ***Temperature***

Chu and Cameron (1963) analyzed pressure-volume-temperature behavior for a large number of mineral oils and found that all exhibited a constant thermal expansion coefficient for a temperature range of 32° F to 400° F. Also, the American Petroleum Institute's (APT) recommended procedure for correcting oil gravities for temperature [Frick (1962)] is based on constant thermal coefficients. Therefore, since a constant thermal coefficient is assumed for this oil, the following equation was used to curve-fit the data and extrapolate from 84.9° F to room temperature:

$$\ln(\rho_o) = c_0 + c_1 T \qquad \text{(C.2)}$$

where:

ρ_o = oil density, g/cc

T = temperature, degrees F

$c_0 = -1.3539 \times 10^{-1}$

$c_1 = -4.42405 \times 10^{-4}$

This equation matches the data within a maximum error of ±0.05%. The thermal expansion coefficient was found to be approximately $4.4 \times 10^{-4}/^{\circ}F$. This corresponds to the thermal expansion coefficients for oils near 35° API gravity given by Frick:

Range of API Gravity (at 60 degrees F)	Thermal Expansion Coefficient, /°F
15.0-34.9	4.0×10^{-4}
35.0-50.9	5.0×10^{-4}

Table C.5 API Recommended Thermal Expansion Coefficients for Oils Near 35° API Gravity

The gravity of Blandol is 35° API at 60° F. Using the correlation given by Chu and Cameron for thermal expansion coefficients versus oil viscosity, a thermal expansion coefficient of 4.3×10^{-4} was predicted. Again, this indicates that the measured thermal expansion coefficient is reasonable.

C.4 Oil Viscosity

The viscosity of Blandol vs. temperature was carefully measured by Miller over a range of 100° F to 175° F (see table C.5). Miller had difficulty obtaining accurate data below this range because of problems in maintaining a uniform and constant temperature at low temperature differentials.

C.5 Core Data

Type	Length (cm)	Diameter (cm)	Pore Volume (cc)	Porosity (%)	Permeability (darcies)
Ottawa	51.46	5.044	405.5	38.88	6.412

Table C.7 Core Data

Temperature (degrees, F)	Viscosity (cp)
100	15.30
125	9.74
150	6.70
175	4.80

Table C.6 Measured Blandol Viscosity us. Temperature

By graphing kinematic viscosity versus temperature on a Standard Viscosity-Temperature Chart (published by the American Society for Testing Materials), a straight line should result (see figure C.1). The correlating equation [Wright (1969)] for this chart is shown below:

$$\log \log(cSt + 0.6) = A - B \log(T) \qquad \text{(C.3)}$$

where:

cSt = kinematic viscosity, centistokes

T = temperature

A = 9.8863

B = 3.5587

The equation was accurate to within ±0.6%.

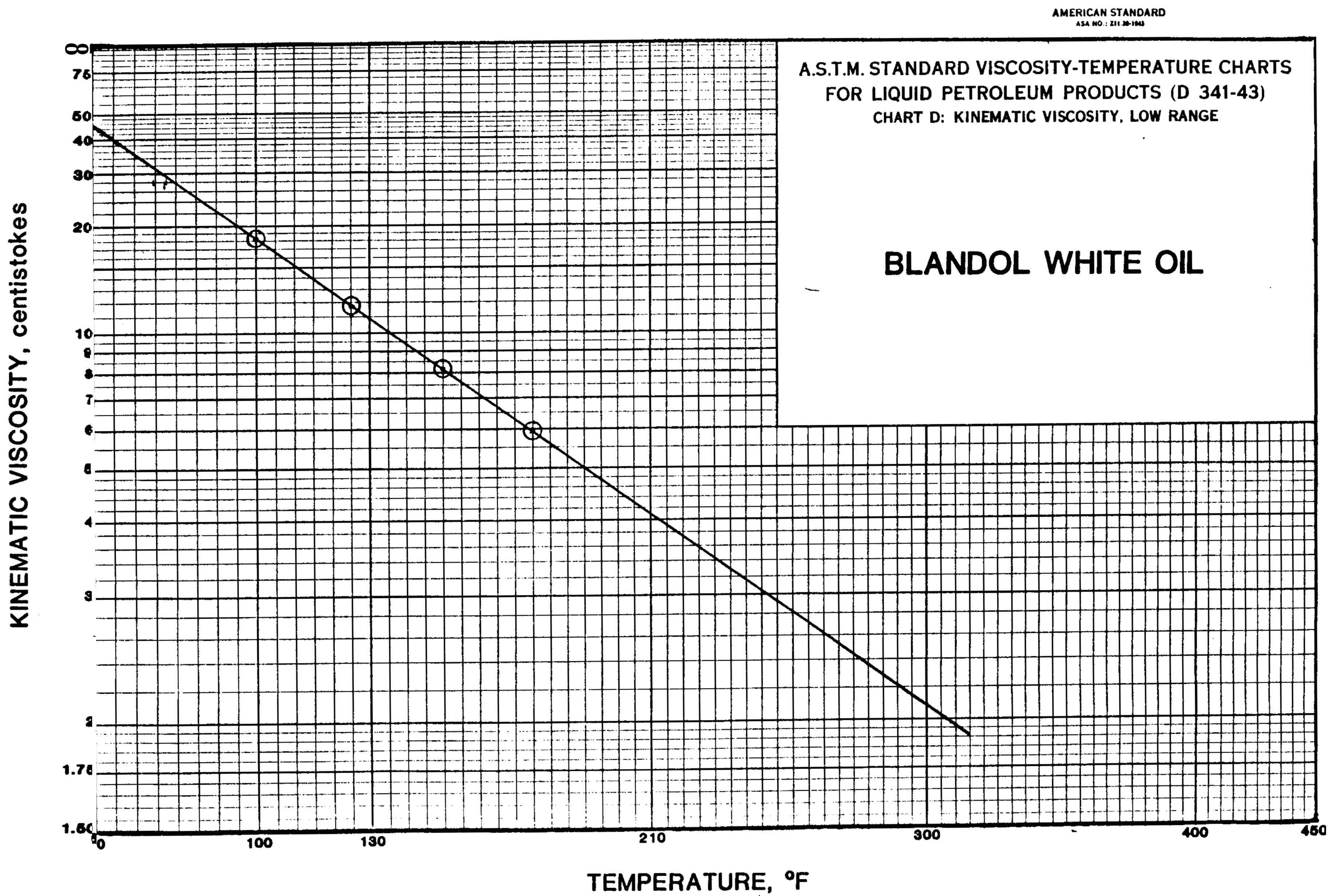


Figure C.1 Standard Viscosity-Temperature Chart

Appendix D : DATA ANALYSIS DETAILS

The data analysis methods used in this study were patterned from Miller (1983). For the purpose of completeness, the following information was taken directly from Miller's PhD dissertation at Stanford, 1983:

The following raw data were measured from the displacement experiments (symbols in parentheses are used in equations in this section):

a) cumulative separator (produced) volume (Sep), cc

b) cumulative volume of displacing fluid produced from the separator (ΣDv), cc

c) core differential pressure (Ap), psi

d) flowmeter readings – at data point
– average from previous data point

In addition, the following data are also needed to determine recovery and injectivity vs. pore volumes injected:

e) core pore volume (Pv), cc

f) dead volume, cc – downstream (D)
– upstream (U)

g) core and effluent temperatures, degrees F

h) oil and water densities vs. temperature

D. 1 Dead Volume and Temperature Corrections

Corrections for dead volumes and density changes with temperature were made with the following mass balance calculations. The calculations are for a water displacement run. The same calculations were made for oil displacement, with fluids reversed.

Water:

$$Initial + In - Out = Final$$

$$S_{wi}\ Pv\ \rho_{wc}$$
$$+\ (W_i\ Pv\ + U)\ \rho_{wc}$$
$$-\ (\Sigma Dv\ -\ Sep)\ \rho_{we}$$

$$\overline{}$$

$$(\overline{S}_w\ Pv\ +\ U\ +\ D\ f_w)\ \rho_{wc} \qquad \text{(D.1)}$$

Oil:

$$Initial + In - Out = Final$$

$$[(1 - S_{wi})Pv\ +\ U\ +\ D]\ \rho_{oc}$$
$$0$$
$$-Sep\ \rho_{oe}$$

$$\overline{}$$

$$[(1 - \overline{S}_w)Pv\ +\ D(1 - f_w)]\ \rho_{oc} \qquad \text{(D.2)}$$

where:

S_{wi} = initial core water saturation

$\overline{S}_w$ = average core water saturation

ρ_{wc}, ρ_{oc} = water and oil densities at core temperature

ρ_{we}, ρ_{oe} = water and oil densities at effluent (room) temperature

W_i = pore volumes water injected

f_w = fractional flow of water at outlet

Equations D.1 and D.2 assume that both dead volumes were initially oil-filled and at core temperature (the amount of downstream dead volume at room temperature was small). Also, the relative amounts of oil and water in the downstream dead volume were estimated by the current water fractional flow.

From Eqns. D.1 and D.2, we can derive:

$$\overline{S}_w - S_{wi} = W_i - [(\Sigma Dv\ -\ Sep)\ (\rho_{we} / \rho_{wc}) - D\ f_w]\ /\ Pv \qquad \text{(D.3)}$$

and,

$$\overline{S}_w - S_{wi} = [Sep(\rho_{oe} / \rho_{oc}) - U - D\ f_w]\ /\ Pv \qquad \text{(D.4)}$$

Solving for W_i,

$$W_i = [Sep\,(\frac{\rho_{oa}}{\rho_{oc}} - \frac{\rho_{we}}{\rho_{wc}}) - U + \Sigma Dv\,\frac{\rho_{we}}{\rho_{wc}}] \,/\, Pv \qquad (D.5)$$

Since pore volumes of oil recovered, $N_p = \overline{S}_w - S_{wi}$, Eqns. **D.4** and **D.5** yeild the N_p vs. W_i relationship. Total volumetric flowrate and core differential pressure were used directly with Eqn. D.5 to generate the ***injectivity** us.* ***pore volumes injected*** data.

D.2 Separator Corrections

Two items were considered to determine accurate data from the separator -- the separator calibration (cc/cm), and a correction for the volume of produced fluid in the bubbles traveling up the water column to the oil-water interface.

The separator calibration section of the computer program used for data analysis {Appendix E) applies calibration information between each data point to compute the incremental produced volume. The method assumes that the average calibration between separator calibration levels (see Appendix B.) holds for the entire interval. The calculation uses a weighted-average calibration when two measured data levels straddle a calibration level.

Correction for "bubbles" is made by calculating an effective bubble velocity based on the initial static and dynamic separator Levels:

$$v_b = \frac{q\,(h_d - h_o)}{\Delta h\,(calib)} \qquad (D.6)$$

where:

v_b = average bubble velocity, cm/min

q = total volumetric flowrate, cc/min

h_d = initial dynamic separator level, cm

h_o = level of outlet tube in separator, cm

Ah = difference between initial static and dynamic separator levels, cm

calib = separator calibration, cc/cm

The bubble velocity was assumed to remain constant for any oil-water level in the separator. Thus the following correction was added to the separator volume to consider the amount of oil in the bubbles.

$$Correction = q\ f_o\ \frac{(h - h_o)}{v_b} \qquad (D.7)$$

where:

f_o = fractional flow of oil (in bubbles)

h = separator level, cm

D.3 Flowrate Calculations

The average volumetric flowrate between measurement points was calculated as $\Delta W_i/\Delta t$, where ΔW_i was calculated by the procedure in Appendix D.1. Separator corrections were made using a flowrate calculated from the uncorrected (for bubbles) separator volumes. The fractional flowing volume of displaced phase was also calculated using uncorrected separator data and was estimated by:

$$f_d = 1 - \frac{N_{p_{i+1}} - N_{p_{i-1}}}{W_{i_{i+1}} - W_{i_{i-1}}} \qquad (D.8)$$

where:

f_d = flowing fraction of displaced phase

Instantaneous flowrates were determined from the capillary tube flowmeter. The average flowrate between measurement points and the average flowmeter reading were used to calculate a flowmeter calibration. This calibration was applied to the flowmeter reading at the measurement point ("mark" on the strip-chart) to determine the instantaneous flowrate. The flowmeter was thus calibrated continuously throughout a run.

D.4 Breakthrough Calculations

Breakthrough times were estimated by visual observation of fluids in the sight glass, combined with the strip-chart records. Differential pressures and flowmeter readings at breakthrough were read from the strip-chart. Pore volumes injected at breakthrough were calculated as that of the measurement before breakthrough, plus the average flowrate multiplied by the elapsed time. Recovery at breakthrough was assumed to be equal to pore volumes injected.

Breakthrough flowrate was calculated using the flowmeter calibration between the data points before and after breakthrough.

D.5 Curve Fitting and Relative Permeability Calculations

Recovery and injectivity data were curve fit by least squares methods using the following equations:

$$N_p = a_0 + a_1[ln(W_i)] + a_2[ln(W_i)]^2 \tag{D.9}$$

$$ln(W_i I_r) = b_0 + b_1[ln(W_i)] + b_2[ln(W_i)]^2 \tag{D.10}$$

The data point immediately after breakthrough was disregarded in both calculations. This point appeared to have considerable error because of rapid saturation and flowing volume changes immediately after breakthrough. Differential pressure data sometimes changed unexplicably near the end of certain runs. When this occurred, the questionable injectivity data was ignored. All recovery data was always used.

Relative permeabilities were calculated from the Welge (1952) and Johnson, Bossler, and Naumann (1959) equations:

$$f_o = \frac{d(N_p)}{d(W_i)} = [a_1 + 2a_2 ln(W_i)] \,/\, W_i \tag{D. 11}$$

$$\begin{aligned} S_{w2} &= S_{wi} + N_p - f_o W_i \\ &= S_{wi} + (a_0 - a_1) + (a_1 - 2a_2) ln(W_i) + a_2[ln(W_i)]^2 \end{aligned} \tag{D.12}$$

$$k_{rw} / k_{ro} = (1/f_o - 1)(\mu_w / \mu_o) \tag{D.13}$$

$$\frac{f_o}{k_{ro}} = \frac{d\left[\frac{1}{I_r W_i}\right]}{d\left[\frac{1}{W_i}\right]}$$

$$= \frac{d[ln(W_i I_r)]}{d[W_i]} \frac{W_i}{I_r}$$

$$= \frac{b_1 + 2b_2[ln(W_i)]\ W_i}{exp[b_0 + b_1 ln(W_i) + b_2[ln(W_i)]^2]} \qquad \text{(D. 14)}$$

Equation D. 14 calculates the relative permeabilities relative to oil permeability at irreducible water saturation (the relative injectivity base is the injectivity just prior to initiation of water injection). Relative permeabilities were normalized to absolute permeability using the calculated effective oil Permeability at irreducible water saturation.

Appendix E: DISPLACEMENT DATA AND PLOTS

This appendix contains the oil and water displacement data and calculations from computer program DSPCLC (see Appendix F). Also included are relative permeability and permeability ratio curves, as well as recovery and injectivity plots, for the waterfloods; and graphs of the recovery and injectivity for the oilfloods.

E.1 Displacement Data. Calculations and Graphs

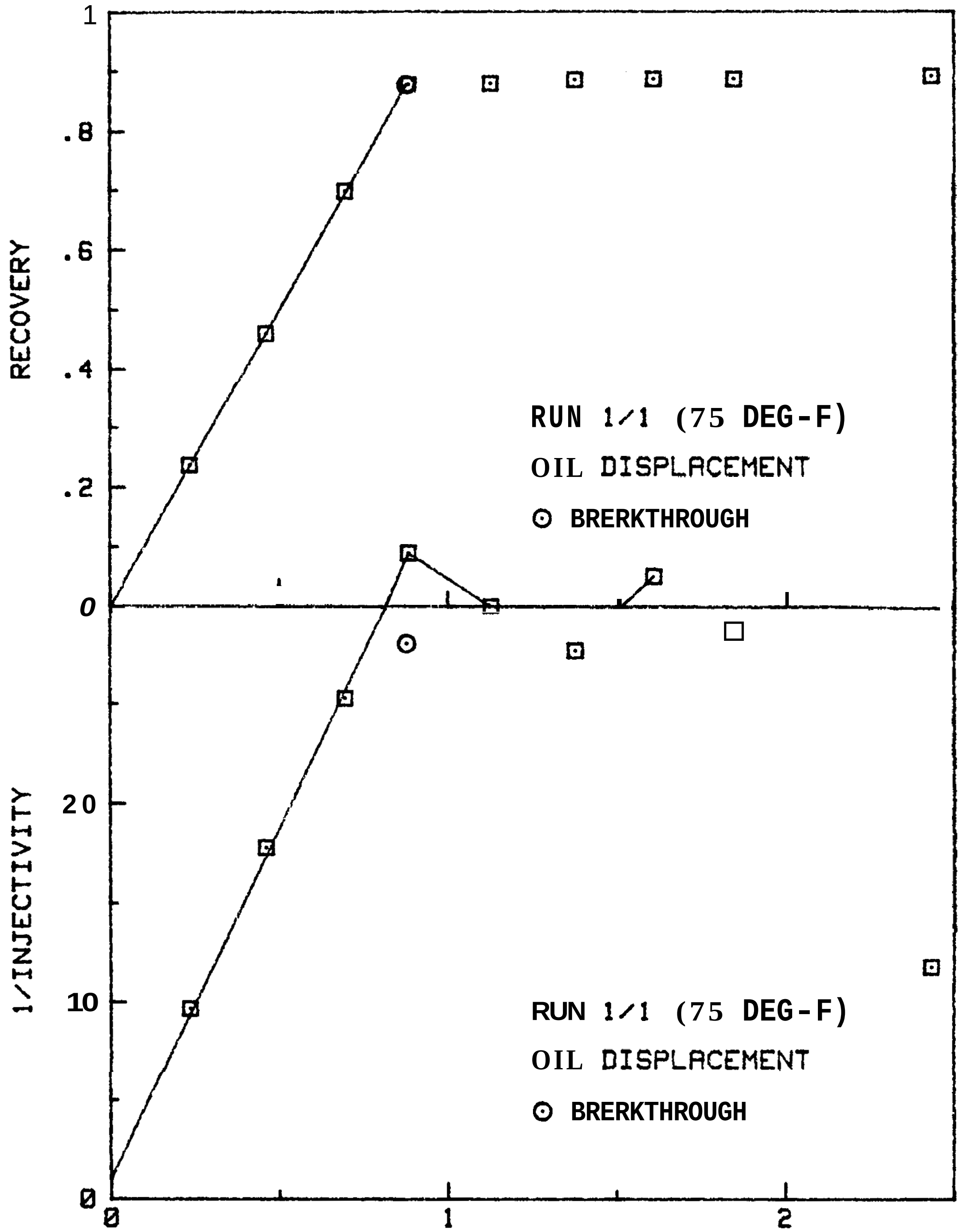
DISPLACEMENT EXPERIMENT CALCULATIONS

PORE VOLUME	390.8 cc	DATE	3/27/84
CORE LENGTH	51.46 cm	CORE/RUN	1/1
CORE DIAMETER	5.044 cm	DISPLACEMENT	OIL-Salt W
DEAD VOL'S: U	2.2 cc	CORE TEMPERATURE	75.0 F
D	3.0 cc	OUTLET TEMPERATURE	75.0 F
SEPARATOR OUTLET	82.72 cm	WATER VISCOSITY	.944 cp
BUBBLE VELOCITY	15.87 cm/sec	OIL VISCOSITY	26.38 cp
ABSOLUTE PERM	6.412 darcies	VISCOSITY RATIO	27.96
INIT SAT - OIL	0.0 %	WATER DENSITY RATIO	1.0000
FINAL SAT - WATER	10.9 %	OIL DENSITY RATIO	1.0000

		SEPARATOR		D-VOL		FLOWRATE						
	TIME	HEIGHT	CALIB	INJ	D-P	CHART			cc			
	(min)	(cm)	(cc/cm)	(cc)	(psi)	AVG	@t	CAL	min	PVi	Rec	1/Inj
ST		72.00										
0	0.00	71.90	4.93	0.0	4.75	1.38	1.38	31.5	43.5	0.000	.000	1.00
1	2.32	53.00	4.93	94.0	40.20	1.29	1.21	31.5	38.1	.235	.237	9.65
2	4.68	35.50	4.96	88.0	69.80	1.18	1.14	31.5	35.9	.460	.461	17.79
3	7.32	17.00	5.00	91.6	92.60	1.11	1.07	31.3	33.5	.694	.699	25.28
BT	9.45				108.60		1.02	34.7	35.4	.877	.877	28.07
4	9.53	2.50	5.00	73.9	105.40	.96	.85	34.7	29.5	.884	.877	32.69
5	12.60	1.90	5.00	94.8	101.40	.84	.84	36.8	30.9	1.126	.879	30.03
6	15.55	1.40	5.00	97.5	100.40	.84	.84	39.3	33.1	1.376	.885	27.81
7	18.70	1.30	5.00	91.3	100.00	.84	.84	34.5	29.8	1.609	.886	31.59
8	21.65	1.30	5.00	93.0	99.20	.84	.84	37.5	31.5	1.847	.886	28.81
9	24.65	.90	5.00	228.7	98.80	.85	.85	89.7	76.2	2.432	.891	11.86

Krw - INITIAL = .850
Kro - FINAL =2.003

Table E.1 Oil Displacement Calculations -- Run 1/1



PORE VOLUMES INJECTED

Figure E.1 Recovery and 1/Injectivity vs. Pore Volumes Injected – Run 1/1

DISPLACEMENT EXPERIMENT CALCULATIONS

FORE VOLUME	390.8 cc	DATE	3/27/84
CORE LENGTH	51.46 cm	CORE/RUN	1/2
CORE DIAMETER	5.044 cm	DISPLACEMENT	Salt Y-OIL
DEAD VOL'S: U	2.2 cc	CORE TEMPERATURE	75.0 F
D	3.0 cc	OUTLET TEMPERATURE	75.0 F
SEPARATOR OUTLET	82.72 cm	WATER VISCOSITY	.944 cp
BUBBLE VELOCITY	44.83 cm/sec	OIL VISCOSITY	26.38 cp
ABSOLUTE PERM	6.412 darcies	VISCOSITY RATIO	27.96
INIT SAT - WATER	10.9 5	WATER DENSITY RATIO	1.0000
FINAL SAT - OIL	15.7 %	OIL DENSITY RATIO	1.0000

	TIME (min)	SEPARATOR HEIGHT (cm)	SEPARATOR CALIB (cc/cm)	D-VOL INJ (cc)	D-P (psi)	FLOWRATE CHART AVG	FLOWRATE CHART @t	FLOWRATE CAL	FLOWRATE cc/min	PVi	Rec	Inj
ST		7.40										
0	0.00	7.20	5.00	0.0	130.00	.84	.84	38.7	32.5	0.000	.000	1.00
1	2.23	25.10	5.00	90.0	75.60	.95	1.06	38.7	41.0	.225	.223	2.17
BT	2.66				62.00		1.08	38.7	41.8	.271	.271	2.70
2	4.42	42.50	5.00	93.0	45.80	1.10	1.13	38.7	43.8	.463	.442	3.82
3	6.55	49.60	4.93	99.0	29.00	1.16	1.18	40.0	47.2	.716	.527	6.51
4	10.53	52.80	4.93	183.0	20.80	1.19	1.19	38.6	45.9	1.184	.566	8.83
5	12.38	53.90	4.93	95.0	18.80	1.19	1.19	43.2	51.4	1.427	.580	10.92
6	14.32	55.20	4.93	91.5	17.00	1.19	1.18	39.8	46.9	1.661	.597	11.03
7	16.40	56.30	4.93	98.0	16.00	1.18	1.18	39.9	47.0	1.912	.610	11.75
8	18.27	57.20	4.93	90.0	14.80	1.18	1.17	40.9	47.8	2.143	.622	12.91
9	20.22	58.10	4.93	95.0	14.00	1.18	1.18	41.3	48.7	2.386	.633	13.91
10	34.25	62.00	4.93	667.0	10.80	1.17	1.16	40.6	47.1	4.092	.682	17.44
11	50.12	64.20	4.93	790.0	9.40	1.15	1.14	43.3	49.4	6.114	.710	20.99
12	51.12	64.40	4.93	50.0	8.60	1.14	1.14	43.9	50.0	6.242	.712	23.24
13	77.50	65.20	4.93	999.0	7.80	1.13	1.13	33.5	37.9	8.798	.722	19.40
14	104.62	66.10	4.93	999.0	7.00	1.12	1.12	32.9	36.8	11.354	.734	21.03

CURVE FITS	c0	C1	c2	%E-MAX	%E-AVG
Recovery	5.5292E-01	9.9645E-02	-9.2229E-03	1.6	.7
Inj. X Pore Vol. Inj.	2.0942E+00	1.7496E+00	-1.4137E-01	14.2	4.6

	PVi	R-ACT	R-CALC	R-%E	I*P-ACT	I*P-CALC	I*P-%E	Sw	Krw	Kro	Kw/Ko
								.109	0.000	.649	0.000
BT		.271	.473		.73	2.03					
3	.716	.527	.519	1.6	4.66	4.45	4.4	.522	.067	.324	.206
4	1.184	.566	.570	.5	10.45	10.87	4.0	.582	.115	.286	.403
5	1.427	.580	.587	1.2	15.58	14.86	4.6	.603	.137	.267	.513
6	1.661	.597	.601	.8	18.33	19.03	3.8	.620	.157	.252	.622
7	1.912	.610	.614	.5	22.47	23.78	5.8	.635	.176	.236	.744
8	2.143	.622	.623	.3	27.66	28.37	2.6	.647	.192	.224	.860
9	2.386	.633	.633	.1	33.18	33.40	.7	.658	.209	.212	.985
10	4.092	.682	.675	1.0	71.36	72.15	1.1	.710	.298	.153	1.951
11	6.114	.710	.703	.9	128.30	121.32	5.4	.746	.368	.113	3.265
12	6.242	.712	.704	1.1	145.04	124.46	14.2	.748	.372	.111	3.354
13	8.798	.722	.726	.5	170.70	186.82	9.4	.775	.432	.082	5.250
14	11.354	.734	.741	.9	238.83	247.25	3.5	.795	.474	.064	7.371

Table E.2 Water Displacement Calculations - Run 1/2

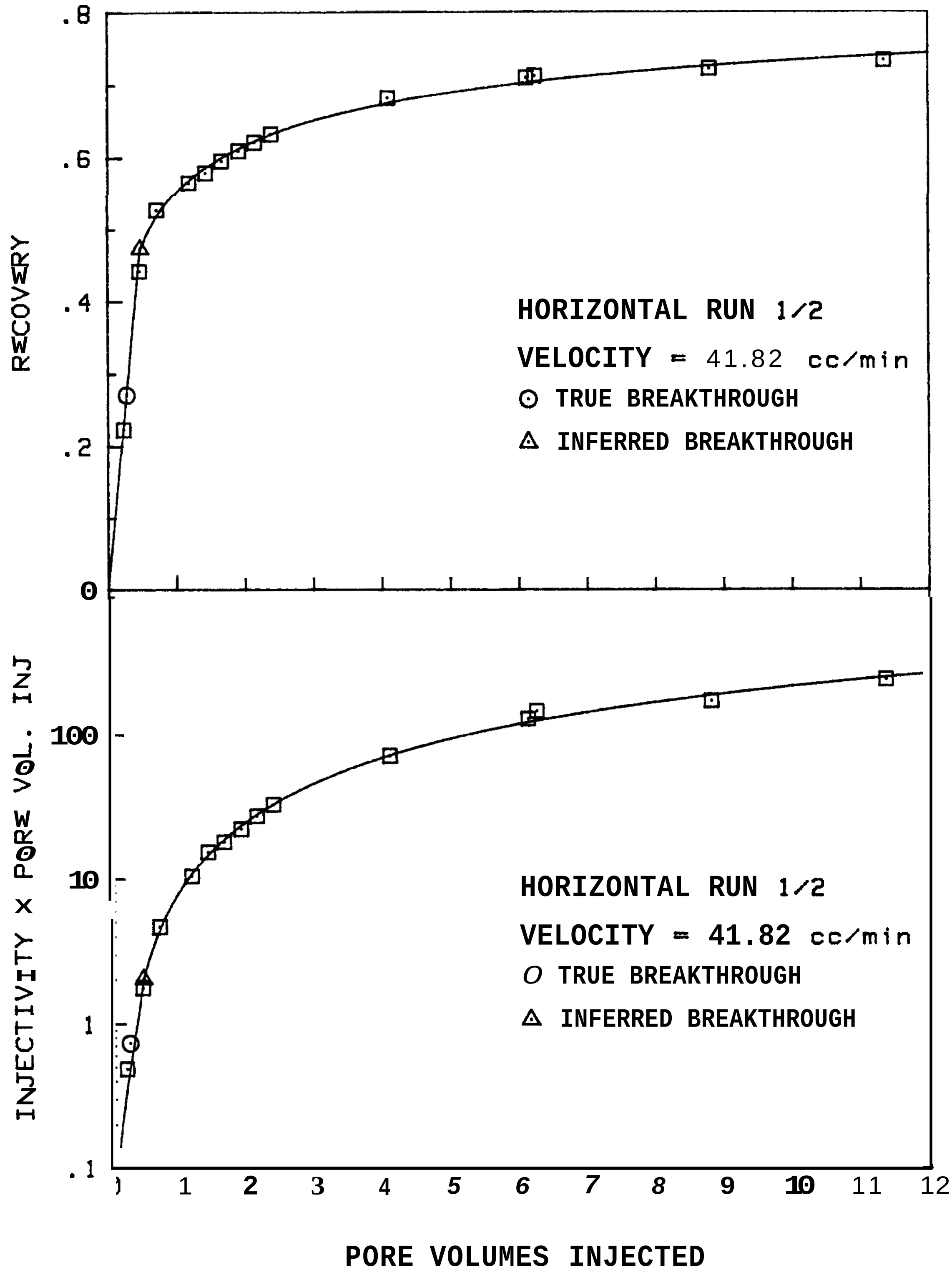


Figure E.2 Recovery and Injectavity x Pore Volumes Injected vs. Pore Volumes Injected -- Run 1/2

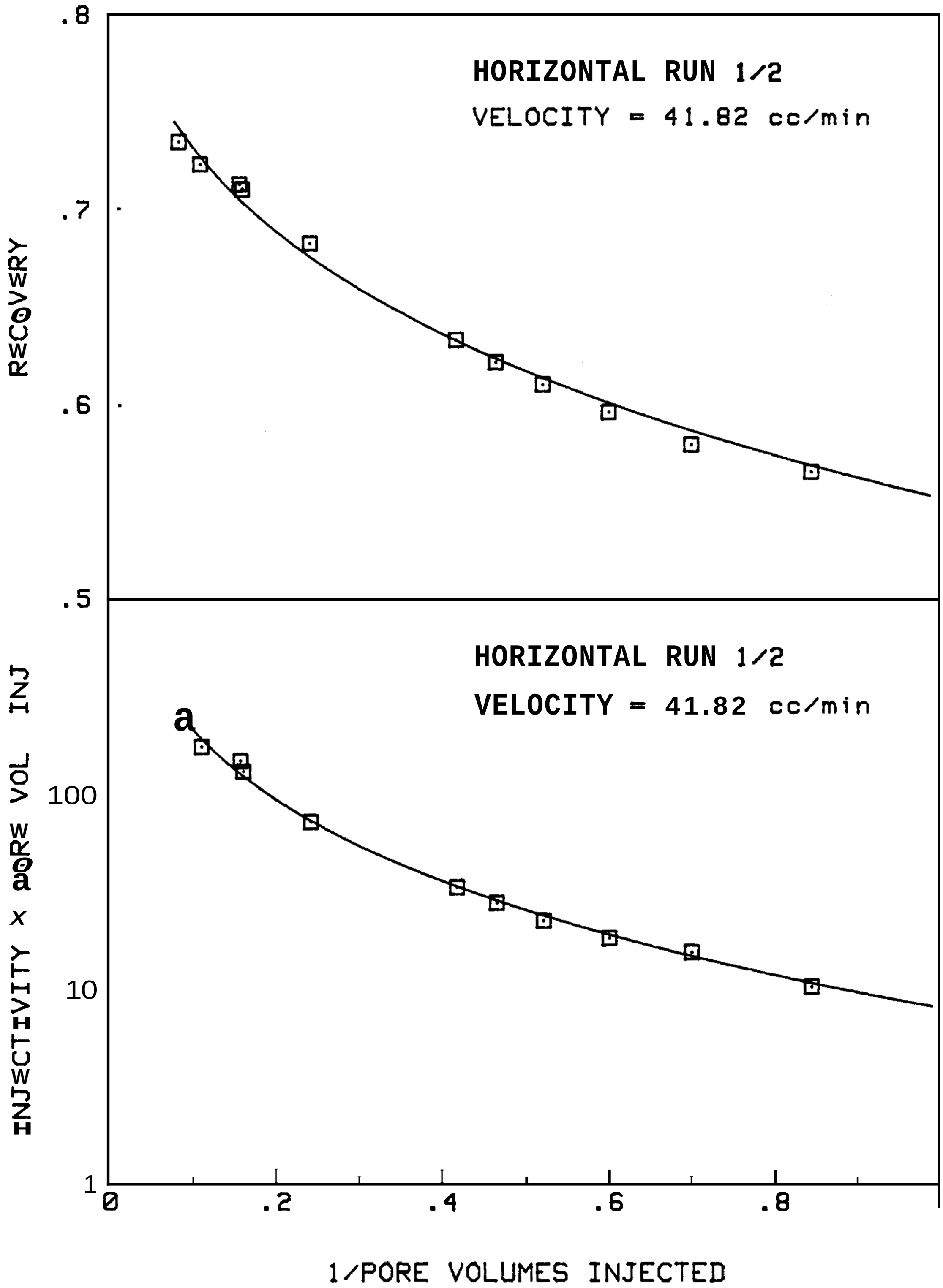


Figure E.3 Recovery and Injectivity x Pore Volumes Injected vs. 1/Pore Volumes Injected – Run 1/2

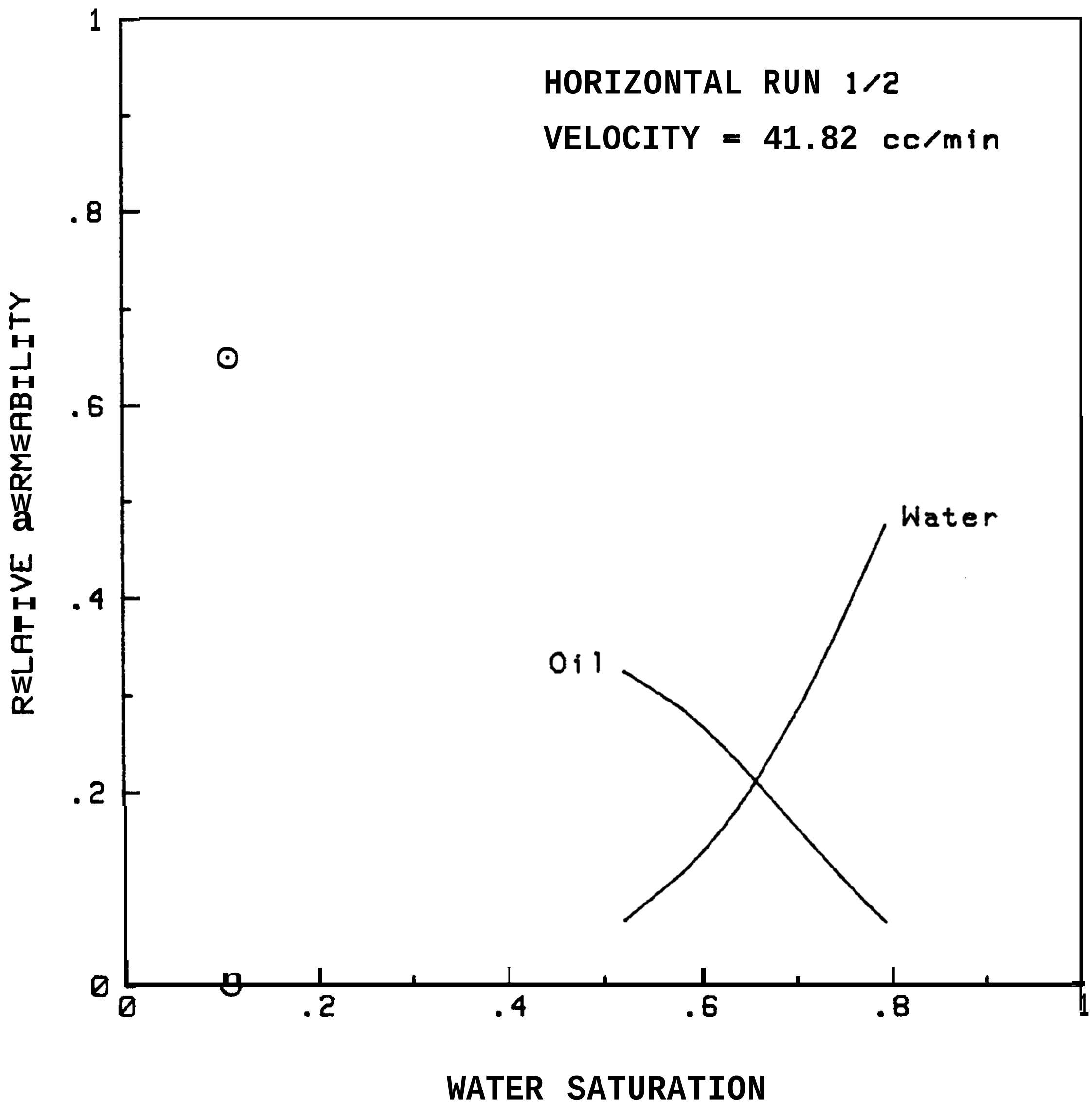


Figure E.4 ***Relative Permeabilities vs. Water Saturation*** *– Run 1/2*

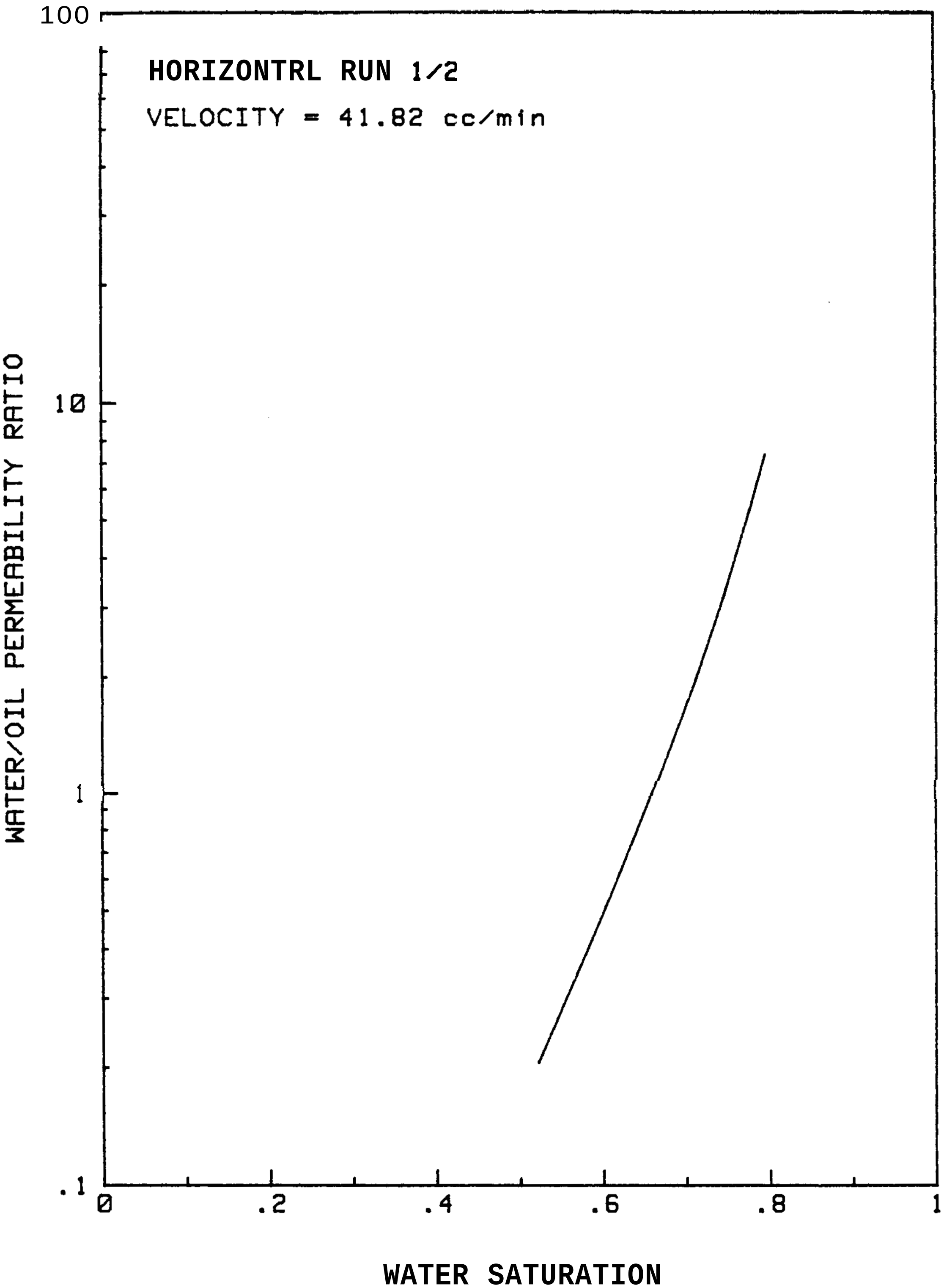


Figure E.5 Relative Permeability Ratio vs. Water Saturation – Run 1/2

DISPLACEMENT EXPERIMENT CALCULRTIONS

PORE VOLUME	390.8 cc	DATE	3/28/84
CORE LENGTH	51.46 cm	CORE/RUN	1/3
CORE DIAMETER	5.044 cm	DISPLACEMENT	OIL-Salt W
DEAD VOL'S: U	2.2 cc	CORE TEMPERATURE	74.0 F
D	3.0 cc	OUTLET TEMPERATURE	74.0 F
SEPARATOR OUTLET	82.72 cm	WATER VISCOSITY	.956 cp
BUBBLE VELOCITY	4.56 cm/sec	OIL VISCOSITY	27.03 cp
ABSOLUTE PERM	6.412 darcies	VISCOSITY RATIO	28.27
INIT SAT - OIL	15.7 %	WATER DENSITY RATIO	1.0000
FINAL SAT - WATER	10.9 %	OIL DENSITY RATIO	1.0000

	TIME (min)	SEPARATOR HEIGHT (cm)	SEPARATOR CALIB (cc/cm)	D-QOL INJ (cc)	D-P (psi)	FLOWRATE CHART AQG	FLOWRATE CHART @t	FLOWRATE CHART CAL	FLOWRATE cc/min	PVi	Rec	1/Inj
ST		79.80										
0	0.00	79.90	4.93	0.0	24.20	1.19	1.19	34.0	40.5	0.000	.000	1.00
1	2.68	57.00	4.93	112.3	56.50	1.04	.99	34.0	33.7	.282	.290	2.81
2	5.52	38.70	4.94	91.5	84.70	.95	.92	34.0	31.3	.516	.525	4.53
BT	7.96				102.50		.87	33.1	28.8	.698	.698	5.95
3	8.65	22.50	5.00	91.3	101.00	.88	.84	33.1	27.8	.749	.723	6.07
4	12.15	22.00	5.00	98.5	100.50	.85	.85	33.1	28.1	1.001	.720	5.97
5	15.42	21.80	5.00	92.0	100.00	.85	.85	33.1	28.2	1.237	.723	5.94
6	19.38	21.30	5.00	111.9	99.60	.85	.85	33.2	28.2	1.523	.729	5.90
7	22.62	21.10	5.00	92.0	99.60	.85	.85	33.5	28.5	1.759	.731	5.85
8	25.87	20.90	5.00	93.1	99.60	.85	.86	33.7	29.0	1.997	.734	5.74
9	29.08	20.90	0.00	93.2	99.60	.86	.86	33.7	29.0	2.235	.734	5.75

Krw - INITIAL = .157
Kro - FINAL = .773

Table E.3 Oil Displacement Calculations -- Run 1/3

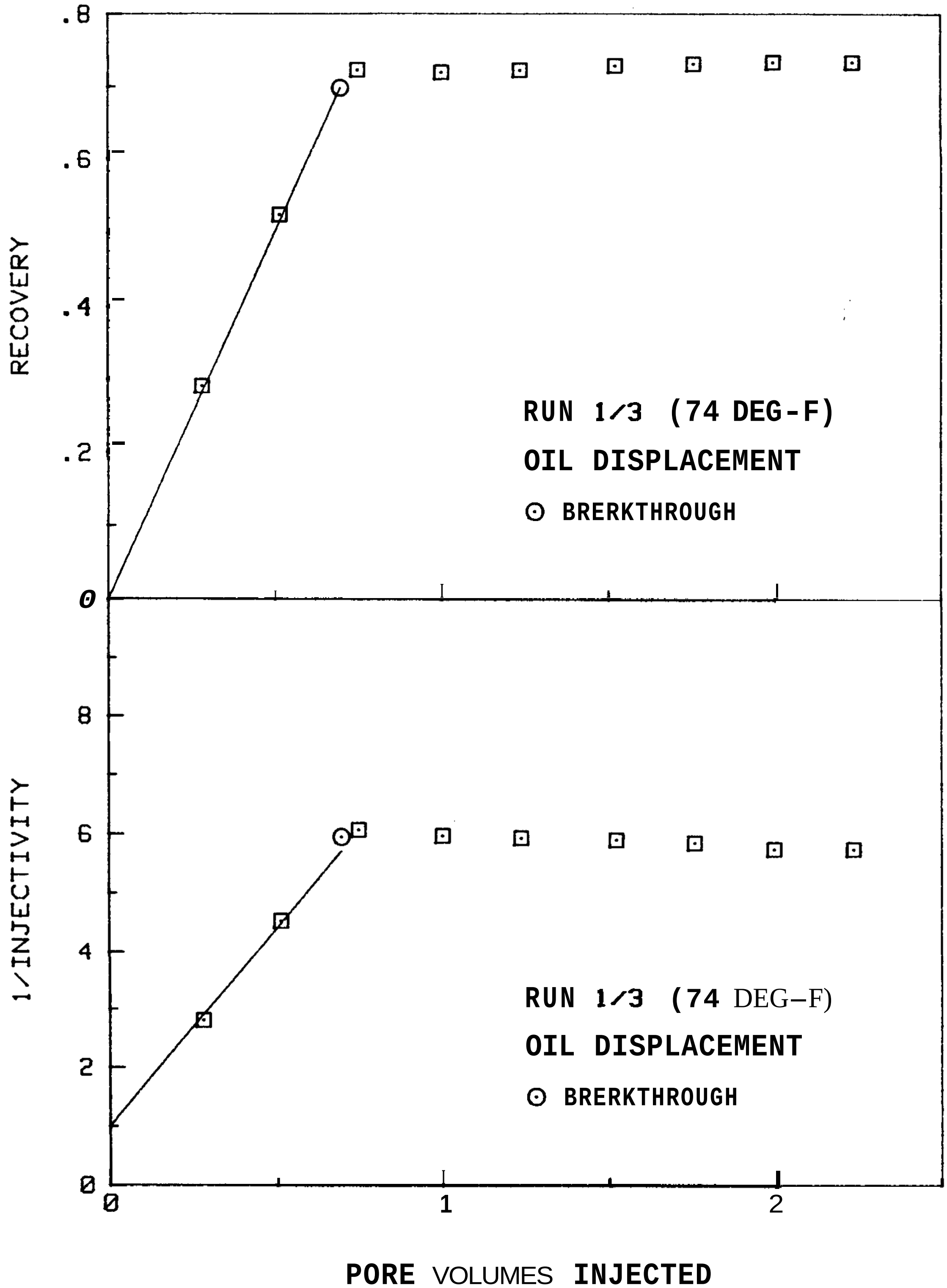


figure E.6 Recovery and 1/Injectivity vs. Pore Volumes Injected - Run 1/3

DISPLACEMENT EXPERIMENT CALCULATIONS

PORE VOLUME	390.8 cc	DATE	3/28/84
CORE LENGTH	51.46 cm	CORE/RUN	1/4
CORE DIAMETER	5.044 cm	DISPLACEMENT	Salt W-OIL
DEAD VOL'S: U	2.2 cc	CORE TEMPERATURE	75.0 F
D	3.0 cc	OUTLET TEMPERATURE	75.0 F
SEPARATOR OUTLET	82.72 cm	WATER VISCOSITY	.944 cp
BUBBLE VELOCITY	7.98 cm/sec	OIL VISCOSITY	26.38 cp
ABSOLUTE PERM	6.412 darcies	VISCOSITY RATIO	27.96
INIT SAT - WATER	10.9 %	WATER DENSITY RATIO	1.0000
FINAL SAT - OIL	18.0 %	OIL DENSITY RATIO	1.0000

	TIME	SEPARATOR HEIGHT	SEPARATOR CALIB	D-VOL INJ	D-P	FLOWRATE CHART AVG	FLOWRATE CHART @t	FLOWRATE CHART CAL	FLOWRATE cc/min	PVi	Rec	Inj
	(min)	(cm)	(cc/cm)	(cc)	(psi)							
ST		12.50										
0	0.00	11.50	5.00	0.0	131.00	.91	.91	37.5	34.1	0.000	,000	1.00
BT	2.05				86.00		1.13	37.5	42.4	.205	.205	1.89
1	2.42	30.90	5.00	96.5	79.00	1.08	1.14	37.5	42.7	.241	.239	2.08
2	4.83	47.30	4.98	106.0	43.00	1.17	1.18	37.5	44.2	.513	.439	3.95
3	6.98	53.20	4.93	98.0	28.00	1.18	1.18	38.6	45.6	.763	.509	6.25
4	9.33	55.70	4.93	100.1	22.50	1.17	1.16	36.4	42.2	1.019	.538	7.21
5	11.32	57.30	4.93	92.0	20.00	1.15	1.15	40.3	46.4	1.255	.559	8.91
6	13.82	59.90	4.93	105.8	16.50	1.14	1.13	37.1	41.9	1.526	.591	9.76
7	16.35	60.10	4.93	110.5	14.50	1.13	1.12	38.6	43.2	1.808	.593	11.45
8	18.53	61.10	4.93	92.5	13.50	1.11	1.11	38.2	42.4	2.045	.606	12.05
9	20.75	62.00	4.93	93.0	12.50	1.10	1.10	38.1	42.0	2.283	,617	12.89
10	23.03	62.70	4.93	95.9	11.80	1.10	1.09	38.2	41.6	2.528	.626	13.54
11	37.88	66.10	4.93	614.0	9.30	1.08	1.07	38.3	41.0	4.100	.669	16.91
12	52.15	68.10	4.93	621.0	10.00	1.10	1.23	39.6	48.7	5.689	.694	18.69
13	63.63	69.40	4.93	585.0	9.30	1.23	1.24	41.4	51.4	7.186	.710	21.21
14	65.45	69.50	4.93	94.1	9.00	1.24	1.23	41.8	51.4	7.426	.711	21.92

CURVE FITS	c0	C1	c2	%E-MAX	%E-AVG
Recovery	5.3299E-01	1.1818E-01	-1.4897E-02	1.8	.7
Inj. X Pore Vol. Inj.	1.9920E+00	1.7866E+00	-1.2833E-01	6.1	2.2

	PVi	R-ACT	R-CALC	R-%E	I*P-ACT	I*P-CALC	I*P-%E	Sw	Krw	Kro	Kw/Ko
								.109	0.000	,676	0.000
BT		.205	.419		.39	1.41					
2	.513	.439	.447	1.8	2.02	2.10	3.6	.418	.037	.381	.097
3	.763	.509	.500	1.7	4.77	4.48	6.1	.483	.064	.354	.181
4	1.019	.538	.535	.6	7.35	7.59	3.2	.527	.089	.326	.274
5	1.255	.559	.559	.1	11.18	10.92	2.3	.557	.111	.302	.367
6	1.526	.591	.580	1.8	14.89	15.24	2.3	.584	.134	,278	.481
7	1.808	.593	.598	.8	20.70	20.19	2.5	.606	.156	,257	.608
8	2.045	.606	.610	.7	24.64	24.64	.0	.622	.173	.241	.719
9	2.283	.617	.620	.5	29.42	29.35	.2	.636	.189	.226	.837
10	2.528	.626	.630	.6	34.24	34.43	.5	.648	.205	.213	.963
11	4.100	.669	.670	.2	69.34	70.62	1.8	.703	.287	.152	1.890
12	5.689	.694	.693	.0	106.32	111.07	4.5	.736	.348	.115	3.029
13	7.186	.710	.708	.3	152.37	150.85	1.0	.758	.393	.092	4.289
14	7.426	,711	.710	.2	162.80	157.33	3.4	.761	.399	.089	4.509

Table E.4 Water Displacement Calculations – Run 1/4

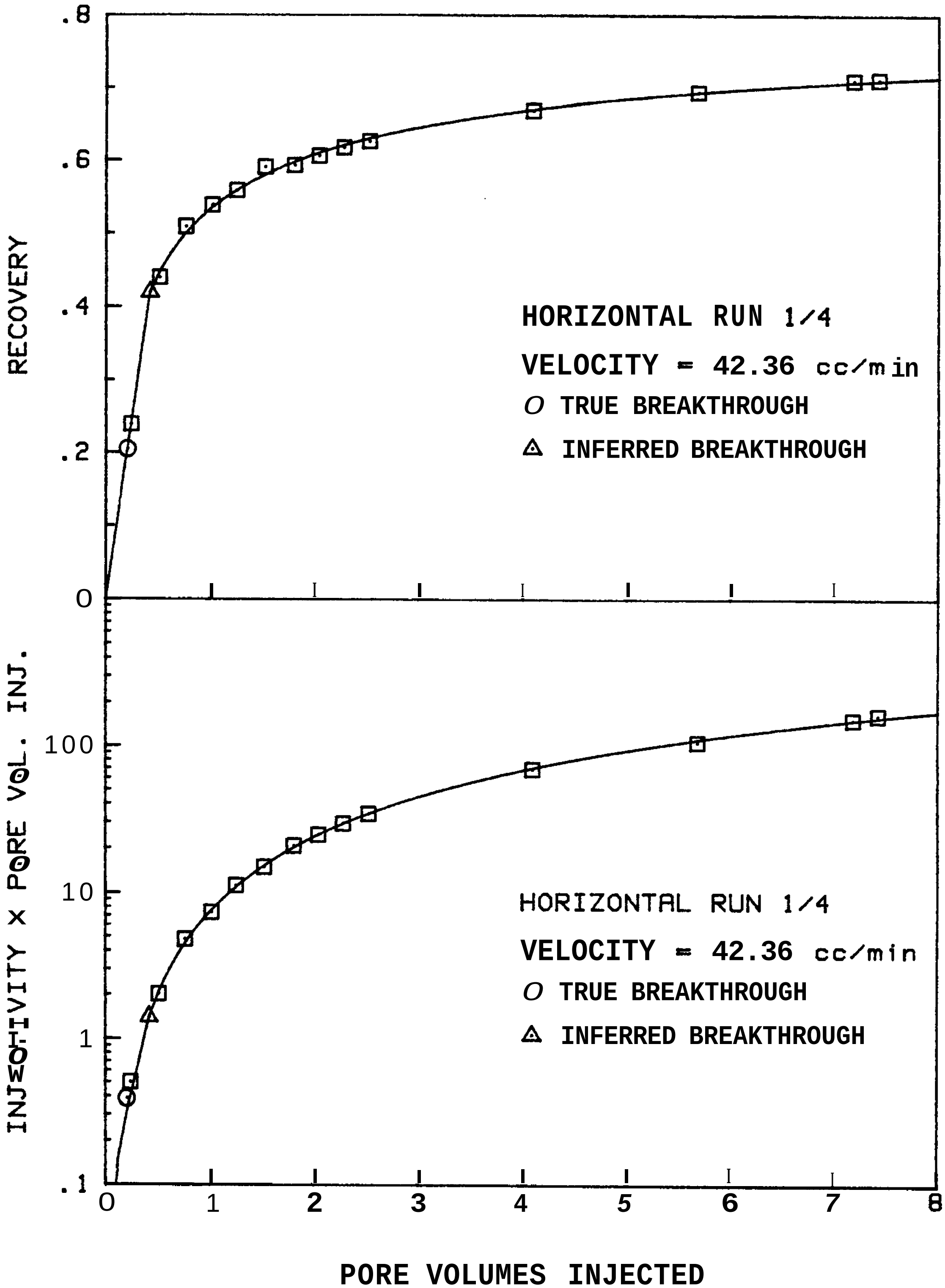


figure E.7 Recovery and Injectivity x Pare Valumes Injected vs. Pore Volumes Injected -- Run 1/4

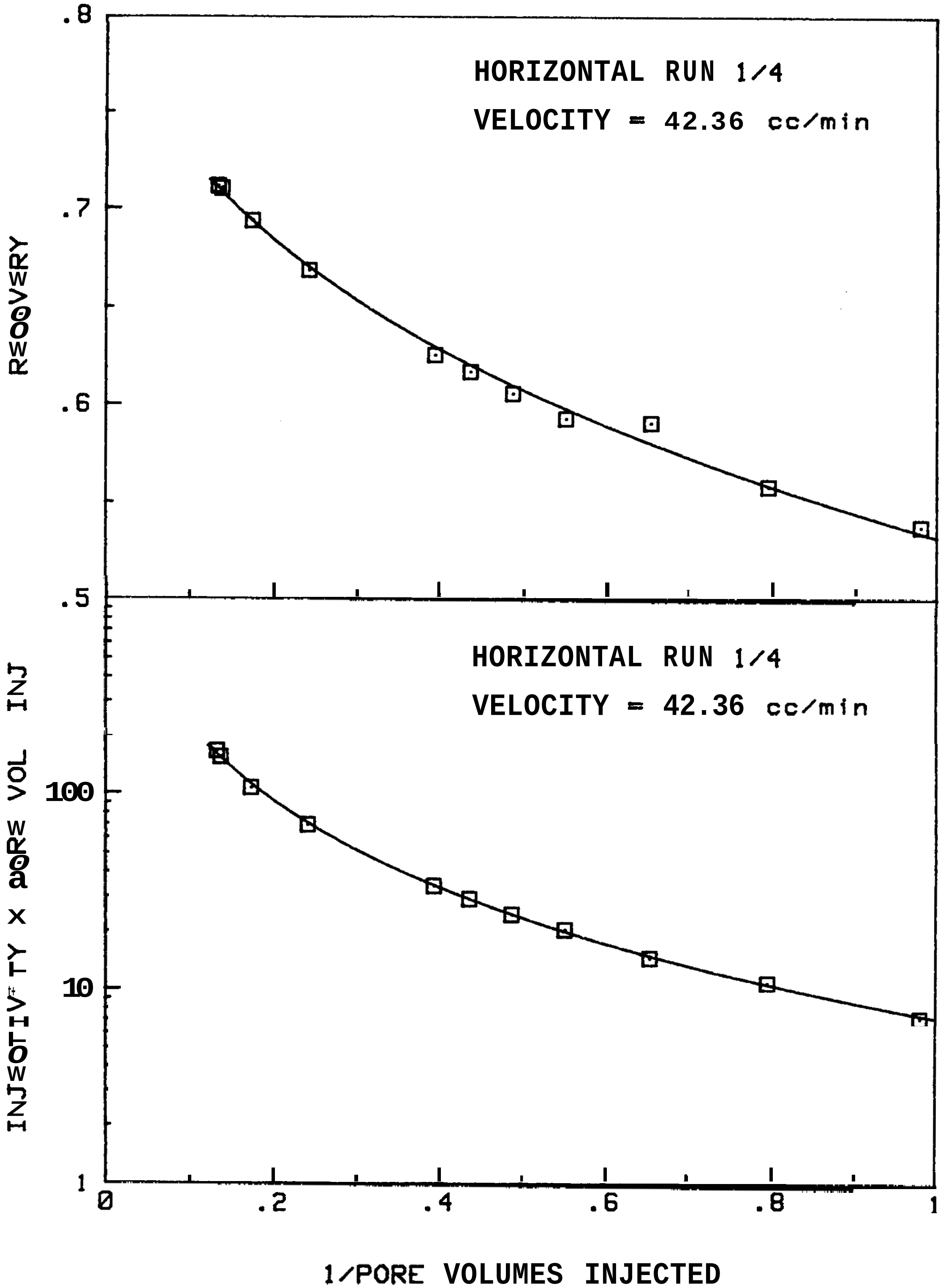


Figure E.8 Recovery and Injectivity **x Pore** *Volumes Injected us.*
*1/****Pore*** *Volumes Injected – Run 1/4*

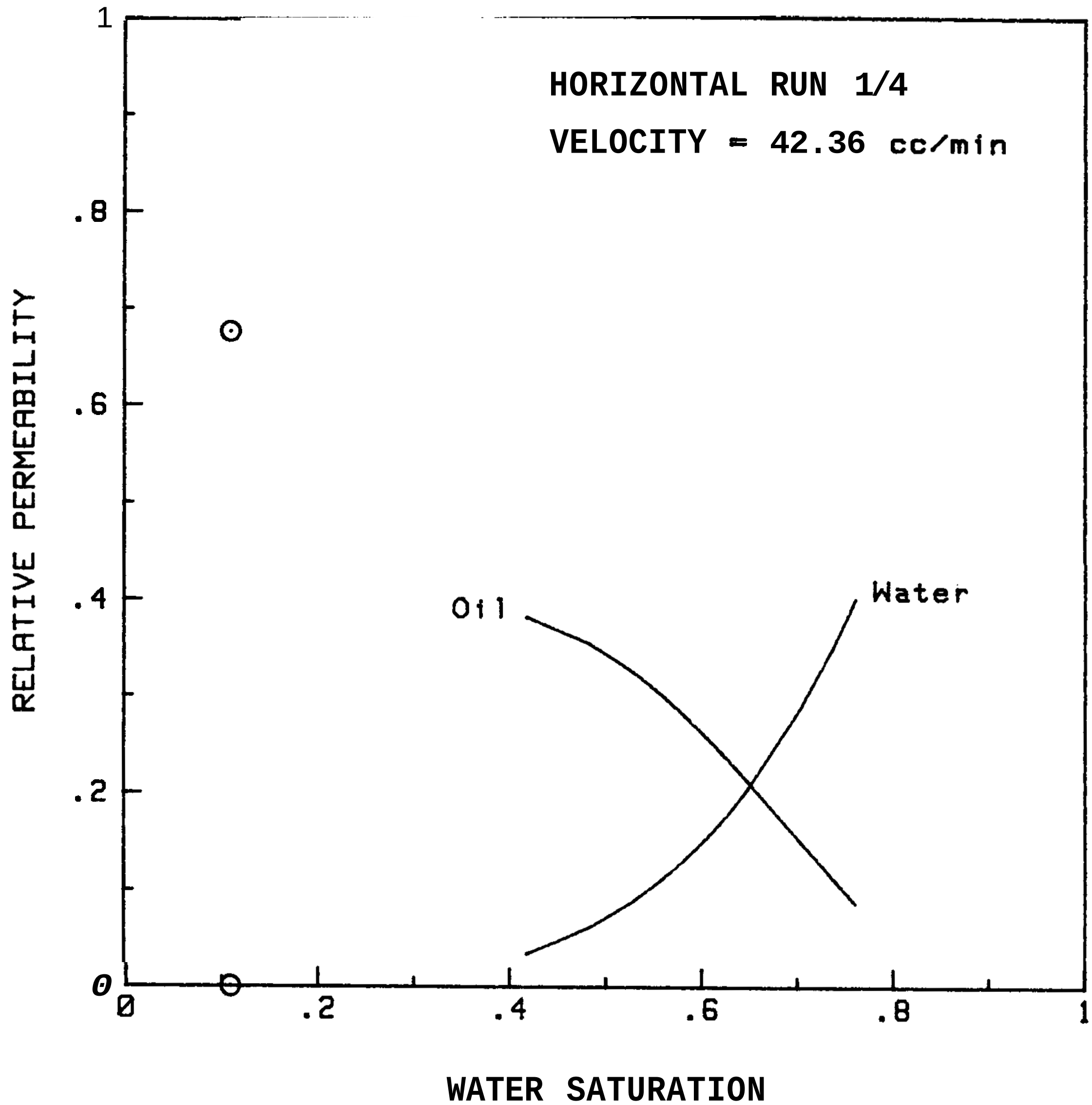


Figure E.9 Relative Permeabilities vs. Water Saturation -- Run 1/4

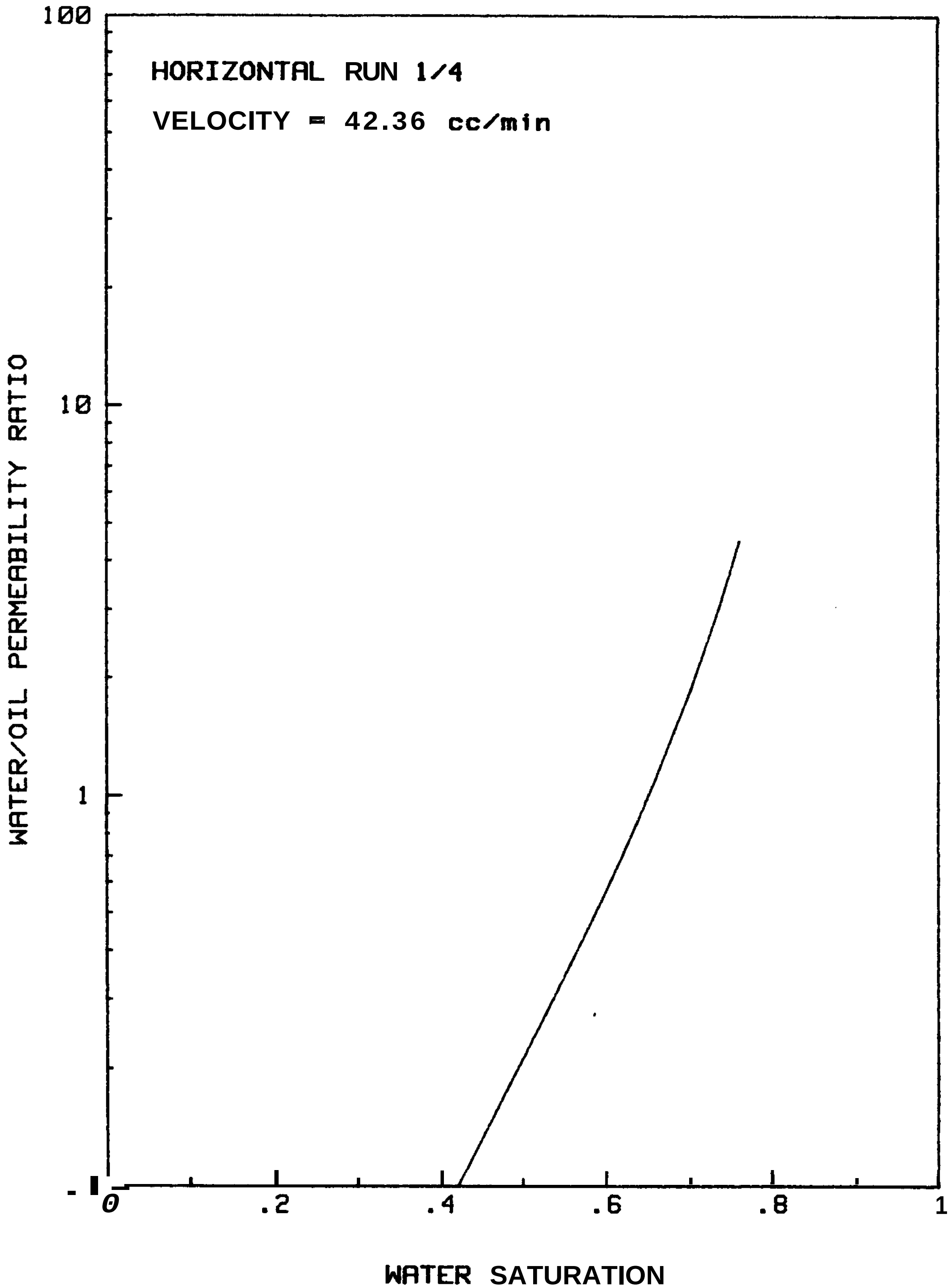


Figure E.10 Relative Permeability Ratio vs. Water Saturation -- Run 1/4

DISPLRCEMENT EXPERIMENT CALCULATIONS

PORE VOLUME	390.8 cc	DATE	4-2-84
CORE LENGTH	51.46 cm	CORE/RUN	17
CORE DIAMETER	5.044 cm	DISPLACEMENT	OIL-Salt W
DEAD VOL'S: U	2.2 cc	CORE TENPERATURE	70.0 F
D	3.0 cc	OUTLET TEMPERATURE	70.0 F
SEPARATOR OUTLET	82.72 cm	WATER VISCOSITY	1.008 cp
BUBBLE VELOCITY	9.17 cm/sec	OIL VISCOSITY	29.81 cp
ABSOLUTE PERM	6.412 darcies	VISCOSITY RATIO	29.57
INIT SRT - OIL	17.2 %	WATER DENSITY RATIO	1.0000
FINAL SAT - WATER	10.4 %	OIL DENSITY RATIO	1.0000

	TINE (min)	SEPARATOR HEIGHT (cm)	SEPARATOR CALIB (cc/cm)	D-VOL INJ (cc)	D-P (psi)	FLOWRRTE CHART AVG	FLOWRRTE CHART @t	FLOWRRTE CAL	FLOWRRTE cc/min	PVi	Rec	1/Inj
ST		69.20										
0	0.00	69.50	4.93	0.0	14.00	2.25	2.25	28.5	64.1	0.000	.000	1.00
1	1.97	51.20	4.93	92.0	59.00	1.71	1.53	28.5	43.4	.230	.228	6.22
2	4.25	32.40	4.97	93.0	105.00	1.43	1.35	28.5	38.5	.468	.469	12.50
3	6.70	14.60	5.00	88.1	127.00	1.27	1.20	28.3	34.0	.693	.691	17.11
BT	6.70				127.00		1.20	28.7	34.4	.693	.693	16.88
4	9.50	12.00	5.00	92.4	127.00	1.15	1.15	28.7	33.0	.930	.715	17.62
5	12.33	11.70	5.00	94.0	127.00	1.15	1.15	28.8	33.2	1.170	.718	17.52
6	15.08	11.50	5.00	92.0	127.00	1.15	1.16	29.1	33.7	1.406	.721	17.23
7	17.82	11.20	5.00	90.7	127.00	1.15	1.15	28.9	33.2	1.638	.724	17.52
8	20.62	11.20	5.00	95.0	127.00	1.15	1.16	29.5	34.2	1.881	.724	16.99
9	23.37	11.20	0.00	94.0	127.00	1.16	1.16	29.5	34.2	2.121	.724	17.01

Krw - INITIAL = .454
Kro - FINAL = .789

*Table **E.5** Oil Displacement Calculations – **Run** 1/7*

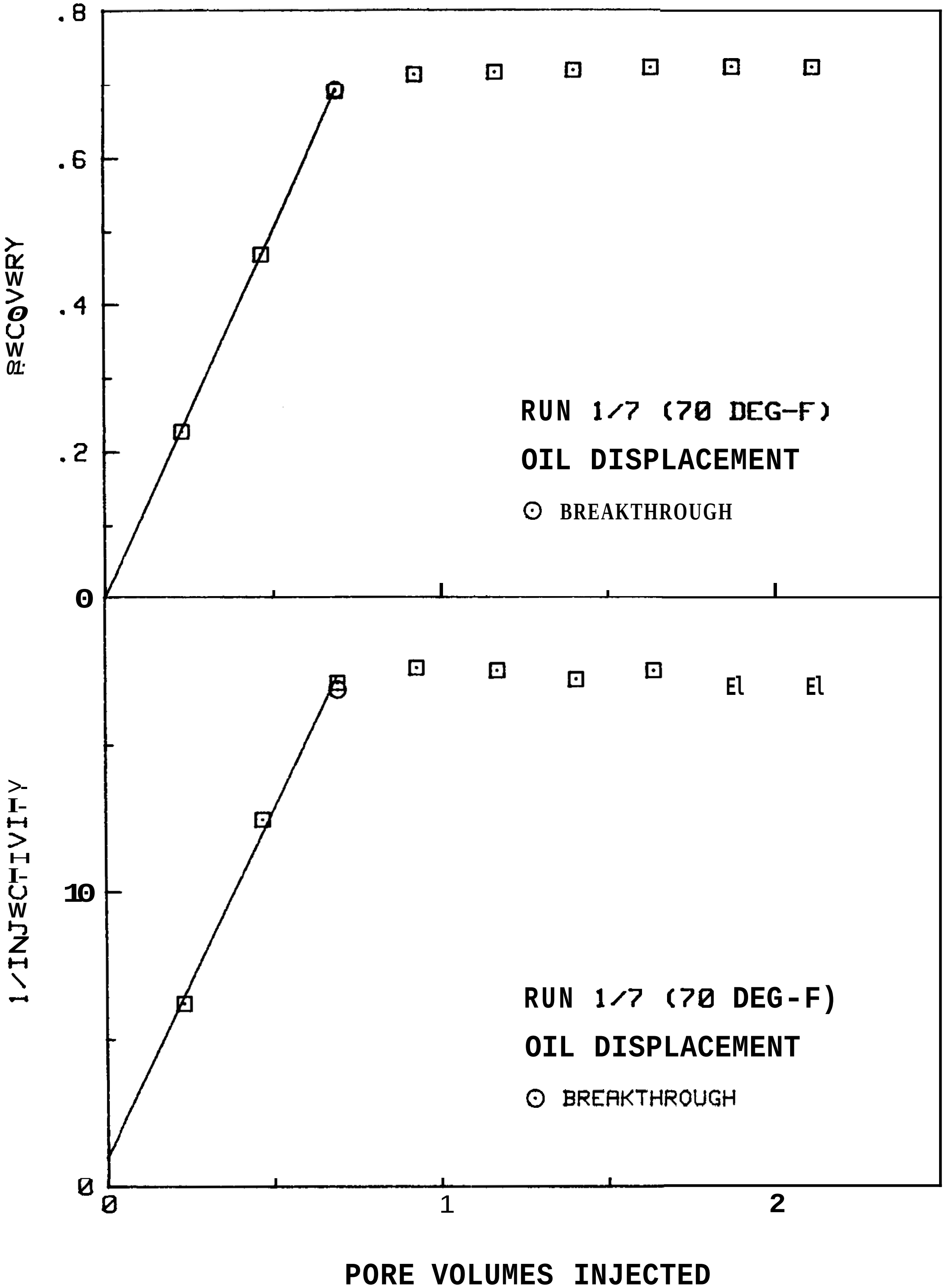


Figure E.11 Recovery and 1/Injectivity vs. Pore Volumes Injected -- Run 1/7

DISPLACEMENT EXPERIMENT CALCULATIONS

PORE VOLUME	390.8 cc	DATE	4-2-84
CORE LENGTH	51.46 cm	CORE/RUN	1/8
CORE DIAMETER	5.044 cm	DISPLACEMENT	Salt W-OIL
DEAD VOL'S: U	2.2 cc	CORE TEMPERATURE	71.0 F
D	3.0 cc	OUTLET TEMPERATURE	71.0 F
SEPARATOR OUTLET	82.72 cm	WATER VISCOSITY	.995 cp
BUBBLE VELOCITY	12.95 cm/sec	OIL VISCOSITY	29.08 cp
ABSOLUTE PERM	6.412 darcies	VISCOSITY RATIO	29.23
INIT SAT - WATER	10.4 L	WATER DENSITY RRTIO	1.0000
FINAL SAT - OIL	16.4 %	OIL DENSITY RATIO	1.0000

		SEPARATOR		D-VOL		FLOWRATE						
						CHART			cc			
	TIME (min)	HEIGHT (cm)	CALIB (cc/cm)	INJ (cc)	D-P (psi)	AVG	@t	CAL	min	PVi	Rec	Inj
ST		11.90										
0	0.00	11.20	5.00	0.0	127.00	1.12	1.12	33.8	37.8	0.000	.000	1.00
1	1.97	29.20	5.00	93.5	109.00	1.40	1.55	33.8	52.3	.234	.223	1.61
BT	2.13				99.00		1.60	33.8	54.0	.257	.257	1.83
2	3.60	44.60	4.99	93.2	70.00	1.69	1.83	33.8	61.6	.472	.414	2.96
3	5.07	52.80	4.93	96.2	47.00	1.90	1.98	34.5	68.2	.718	.512	4.87
4	6.45	55.90	4.93	94.0	39.00	2.00	2.03	34.0	68.8	.959	.549	5.92
5	7.78	57.70	4.93	93.0	34.00	2.04	2.05	34.2	70.1	1.197	.571	6.92
6	9.10	59.10	4.93	92.5	31.00	2.05	2.06	34.3	70.6	1.433	.589	7.65
7	10.42	60.20	4.93	92.5	28.00	2.06	2.07	34.1	70.6	1.670	.602	8.47
8	11.73	61.30	4.93	93.4	26.50	2.08	2.08	34.1	70.9	1.909	.616	8.99
9	13.03	62.20	4.93	92.9	25.00	2.08	2.08	34.4	71.5	2.147	.627	9.60
10	14.37	63.05	4.93	96.5	23.50	2.08	2.09	34.8	72.7	2.394	.638	10.39
11	15.70	63.80	4.93	94.3	22.50	2.10	2.10	33.7	70.7	2.635	.647	10.56
12	16.98	64.40	4.93	92.1	21.50	2.10	2.10	34.2	71.8	2.871	.655	11.21
13	23.42	66.85	4.93	461.0	18.50	2.10	2.10	34.1	71.7	4.050	.686	13.01
14	29.58	68.40	4.93	453.0	17.00	2.10	2.10	35.0	73.5	5.210	.705	14.51
15	35.63	69.50	4.93	444.0	16.00	2.09	2.08	35.1	73.0	6.346	,719	15.33
16	42.20	70.30	4.93	483.0	14.50	2.06	2.03	35.7	72.3	7.582	.729	16.75
17	43.53	70.50	4.93	99.4	14.50	2.03	2.03	36.7	74.4	7.836	.732	17.22

CURVE FITS	C0	C1	c2	LE-MAX	%E-AVG
Recovery	5.5079E-01	1.0950E-01	-1.0287E-02	.5	.2
Inj. X Pore Vol. Inj.	1.8117E+00	1.6513E+00	-7.6861E-02	2.3	.8

	PVi	R-ACT	R-CALC	R-%E	I*P-ACT	I*P-CALC	I*P-%E	Sw	Krw	Kro	Kw/Ko
								.104	0.000	.852	0.000
BT		.257	.459		.47	1.62					
3	.718	.512	.513	.2	3.50	3.51	.4	.501	.070	.396	.177
4	.959	.549	.546	.5	5.68	5.71	.5	.540	.093	.352	.263
5	1.197	.571	.570	.2	8.29	8.21	.9	.568	.112	.318	.353
6	1.433	.589	.589	.1	10.96	10.98	.2	.591	.130	.291	.446
7	1.670	.602	.604	.3	14.14	13.99	1.1	.609	.146	.269	.543
8	1.909	.616	.617	.2	17.16	17.24	.5	.625	.161	.250	.645
9	2.147	.627	.628	.2	20.61	20.67	.3	.639	.175	.234	.749
10	2.394	.638	.639	.1	24.88	24.40	1.9	.651	.188	.219	.860
11	2.635	.647	.647	.0	27.82	28.21	1.4	.662	.201	.206	.972
12	2.871	.655	.655	.0	32.18	32.06	.4	.671	.212	.195	1.084
13	4.050	.686	.684	.3	52.69	53.05	.7	.707	.260	.155	1.682
14	5.210	.705	.704	.2	75.60	75.78	.2	.732	.299	.129	2.325
15	6.346	.719	.718	.1	97.28	99.54	2.3	.751	.330	.110	3.002
16	7.582	.729	.730	.2	126.97	126.65	.3	.767	.360	.095	3.790
17	7.836	.732	.733	.1	134.97	132.36	1.9	.769	.366	.092	3.958

Table E.6 Water Displacement Calculations – Run 1/8

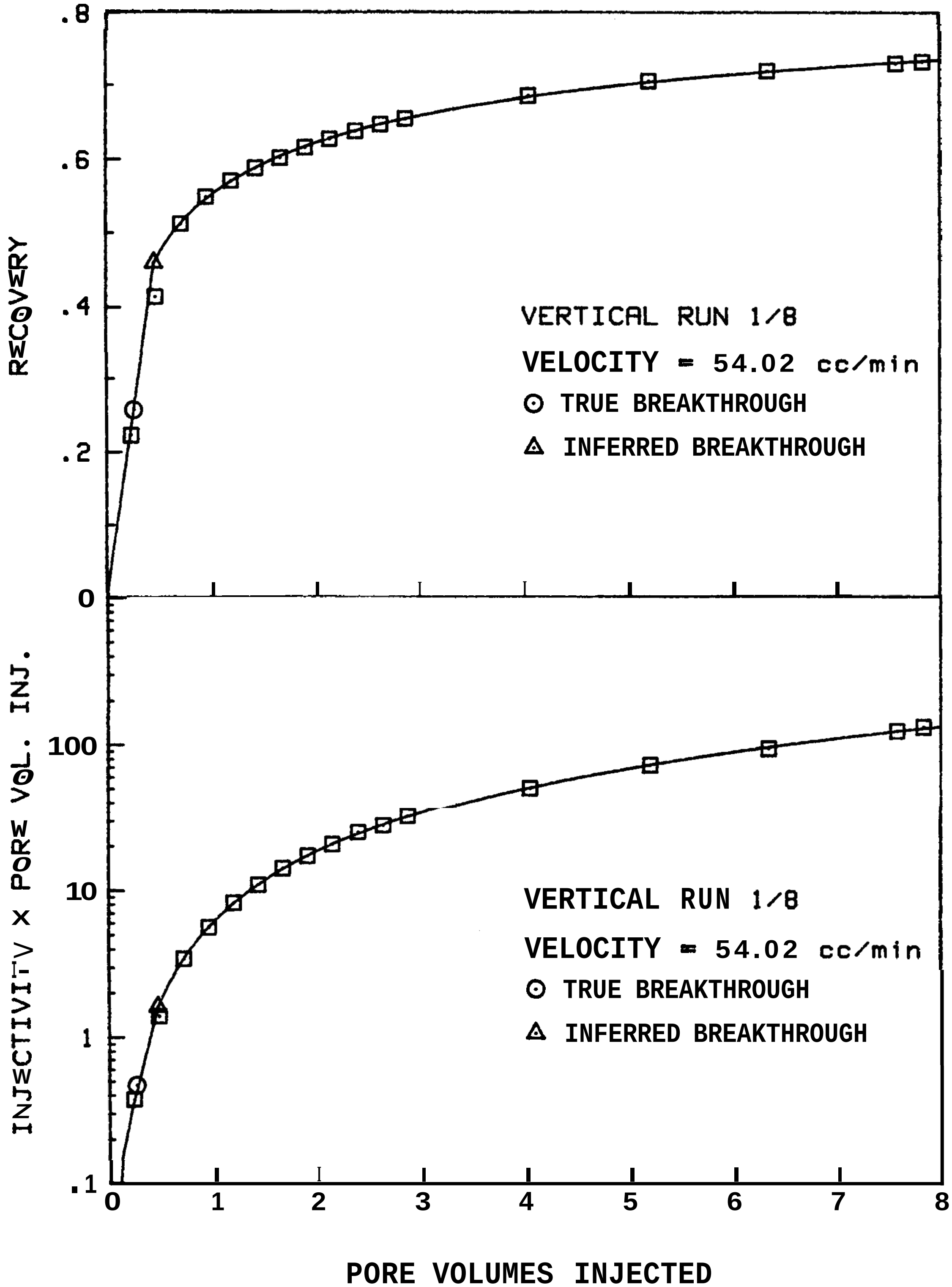


figure E.12 Recovery and Injectivity x Pore Volumes Injected us. Pare Volumes Injected -- Run 1/8

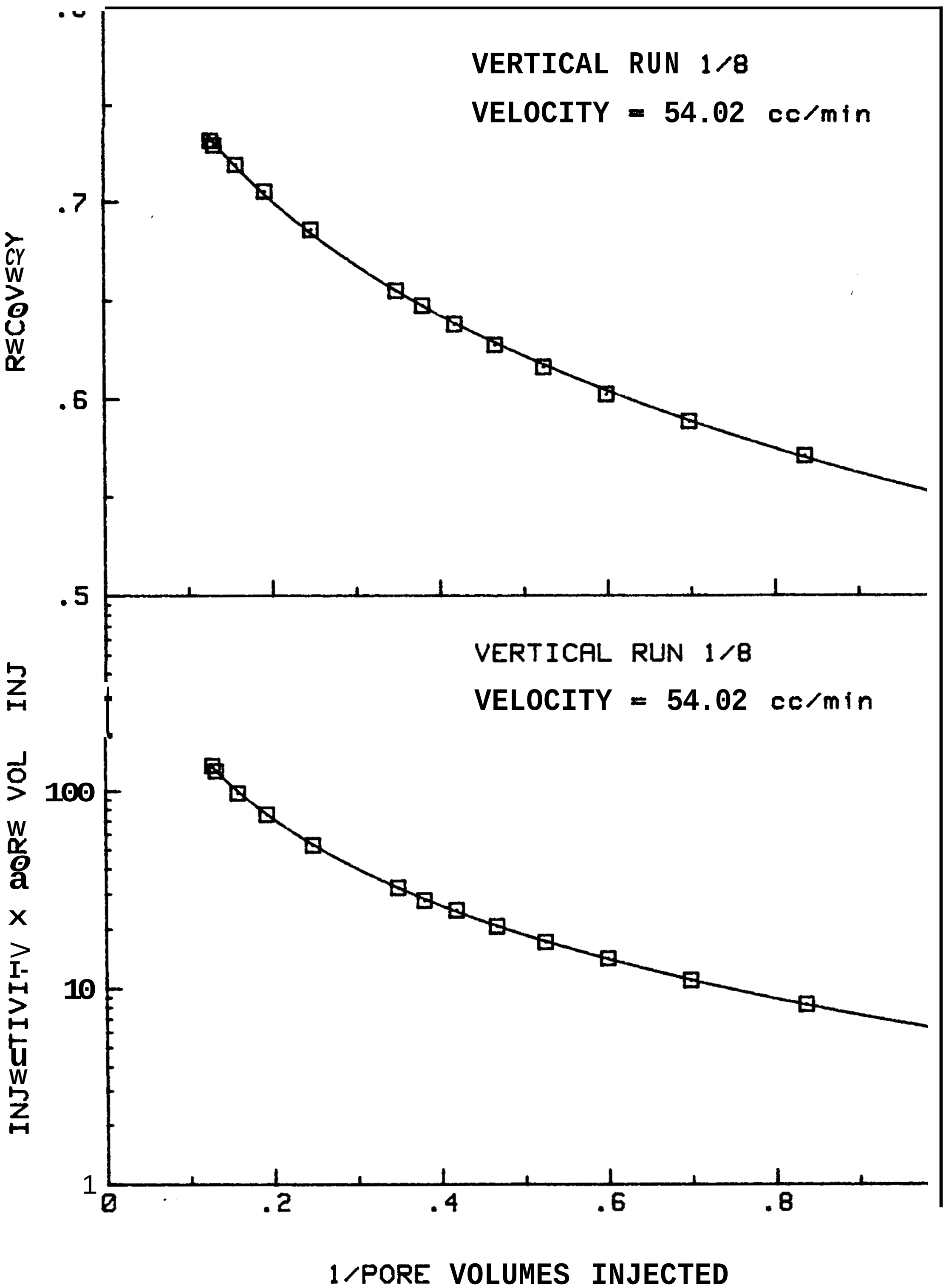


Figure E.13 Recovery and Injectivity x Pore Volumes Injected vs. 1/Pore Volumes Injected – Run 1/8

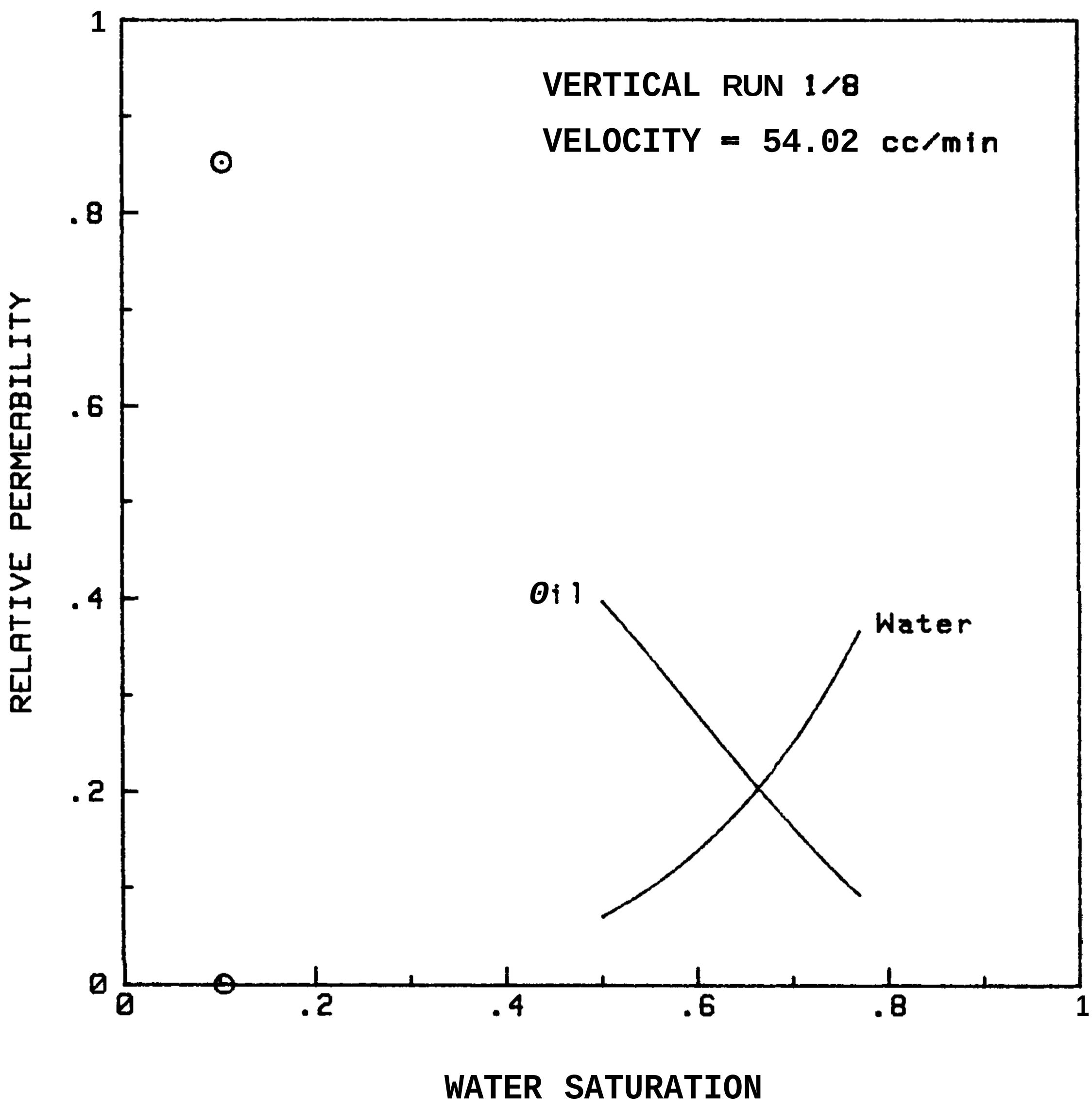


Figure E.14 Relative Permeabilities vs. Water Saturation – Run 1/8

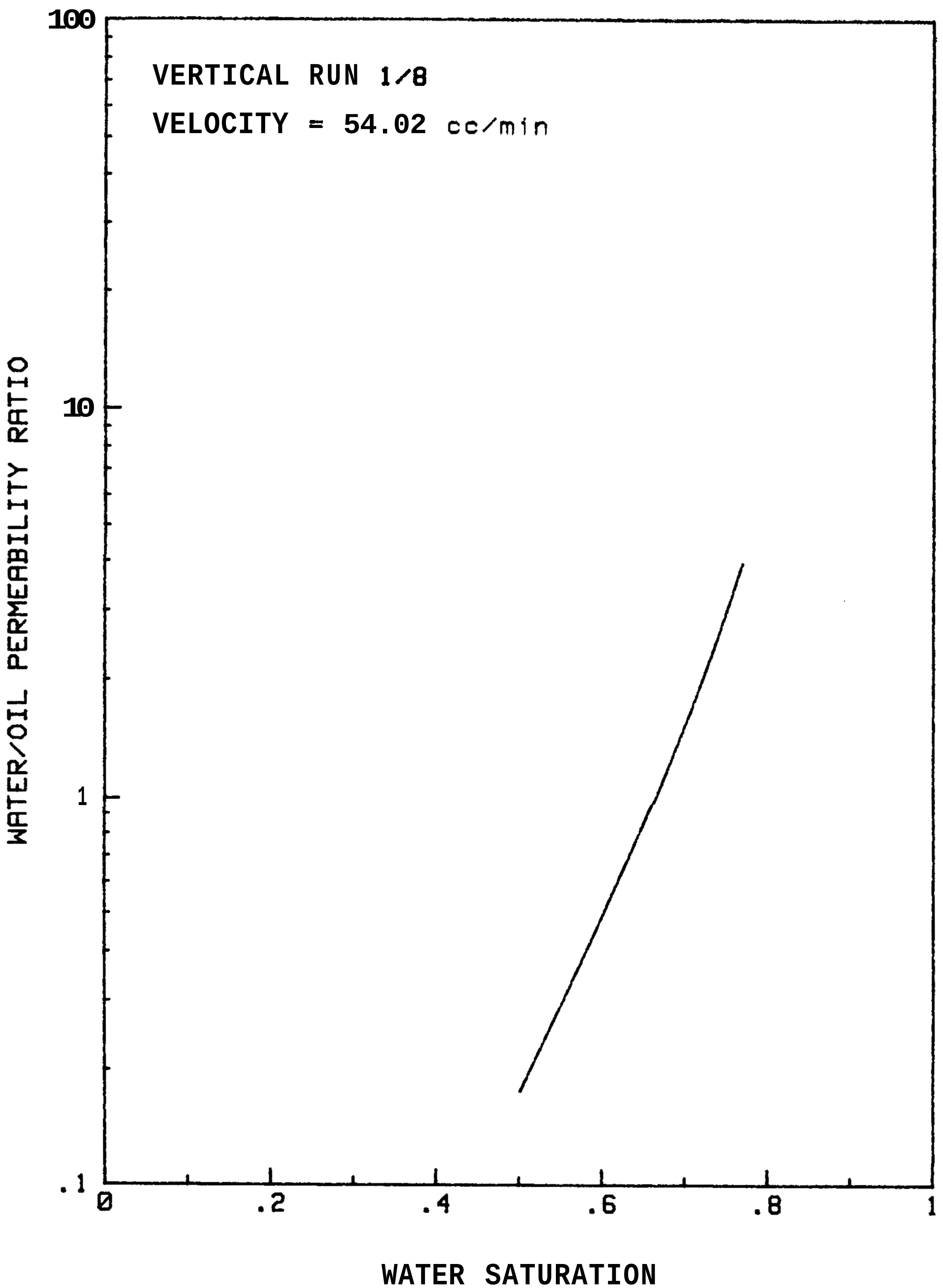


Figure E.15 Relative Permeability Ratio vs. Water Saturation -- Run 1/8

DISPLACEMENT EXPERIMENT CALCULATIONS

PORE VOLUME	390.8 cc	DATE	4/3/84
CORE LENGTH	51.46 cm	CORE/RUN	1/9
CORE DIAMETER	5.044 cm	DISPLACEMENT	OIL-Salt W
DEAD VOL'S: U	2.2 cc	CORE TEMPERATURE	73.0 F
D	3.0 cc	OUTLET TEMPERATURE	76.0 F
SEPARATOR OUTLET	82.72 cm	WATER VISCOSITY	.969 cp
BUBBLE VELOCITY	10.08 cm/sec	OIL VISCOSITY	27.69 cp
ABSOLUTE PERM	6.412 darcies	VISCOSITY RATIO	28.58
INIT SAT - OIL	16.4 %	WATER DENSITY RATIO	,9995
FINAL SAT - WATER	9.6 %	OIL DENSITY RATIO	.9987

		SEPARATOR		D-VOL		FLOWRATE						
						CHART						
	TIME (min)	HEIGHT (cm)	CALIB (cc/cm)	INJ (cc)	D-P (psi)	AVG	@t	CAL	cc/min	PVi	Rec	1/Inj
ST		71.00										
0	0.00	71.20	4.99	0.0	11.00	1.72	1.72	31.1	53.5	0.000	.000	1.00
1	2.25	52.30	4.99	94.5	32.00	1.38	1.26	31.1	39.2	.236	.238	3.97
2	4.77	33.40	4.96	94.0	92.00	1.20	1.15	31.1	35.8	.476	.480	12.51
BT	7.49				123.00		1.05	30.4	31.9	.709	.709	18.77
3	7.55	14.70	4.95	93.0	121.00	1.10	1.05	30.4	31.9	.714	.711	18.46
4	10.60	12.80	5.11	94.6	117.00	1.02	1.02	30.4	31.0	.956	.728	18.37
5	13.58	12.40	5.11	93.0	115.00	1.02	1.02	30.5	31.1	1.194	.732	17.97
6	16.60	12.20	5.11	94.0	114.50	1.02	1.02	30.5	31.1	1.434	.735	17.90
7	19.52	11.90	5.11	92.6	115.00	1.03	1.04	30.8	31.9	1.671	.739	17.56
8	22.40	11.80	5.11	92.9	115.00	1.04	1.03	31.1	32.0	1.908	.740	17.47
9	25.28	11.80	0.00	92.5	114.50	1.03	1.04	31.1	32.3	2.144	.740	17.22

Krw - INITIAL = ,464
Kro - FINAL = .770

Table E.7 Oil Dispalcement **Calculations -- Run** *1/9*

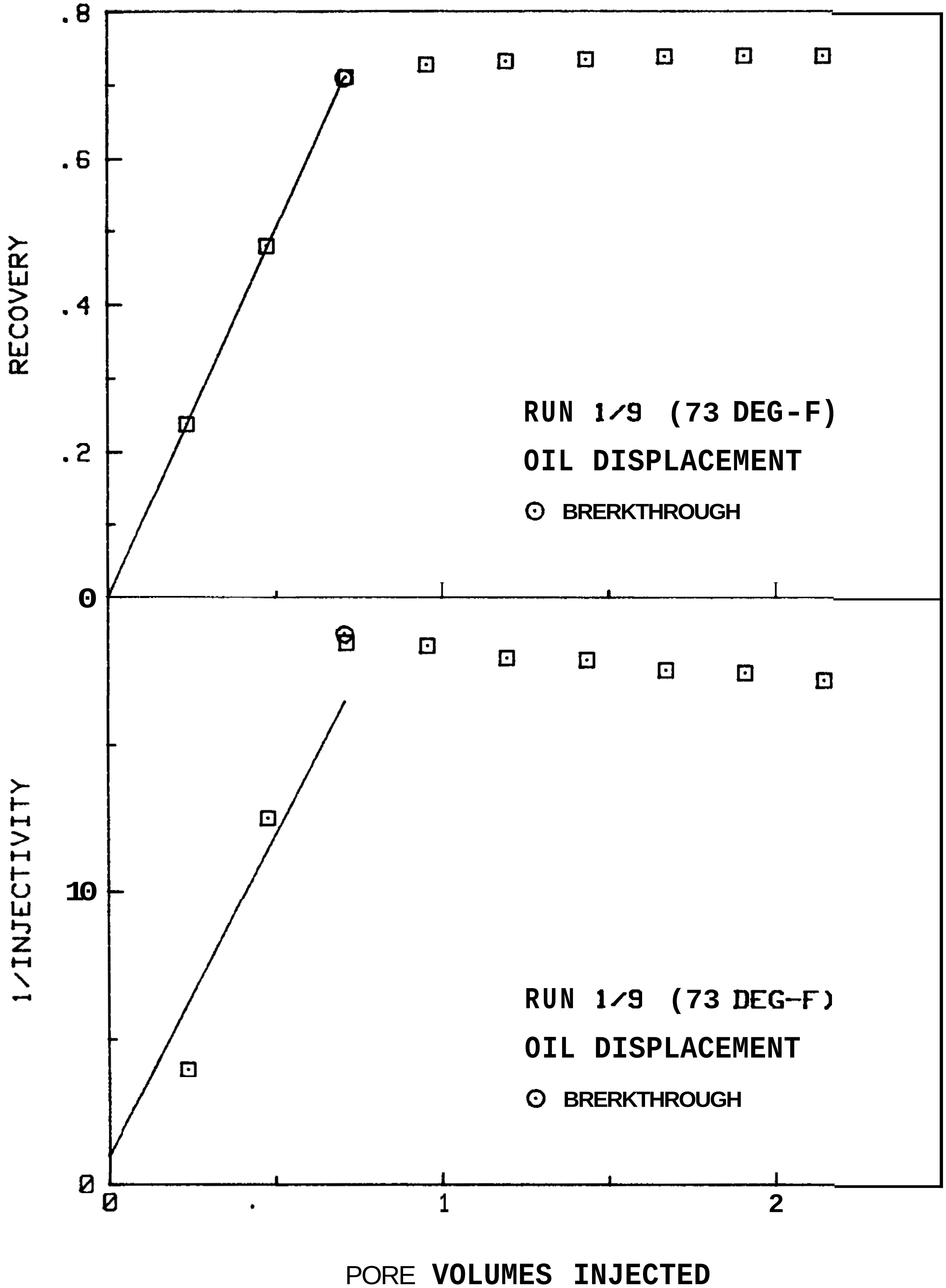


figure E.16 Recovery and 1/Injectivity vs. Pore Volumes Injected – Run 1/9

DISPLACEMENT EXPERIMENT CALCULATIONS

PORE VOLUME	390.8 cc	DATE	4-3-84
CORE LENGTH	51.46 cm	CORE/RUN	1/10
CORE DIAMETER	5.044 cm	DISPLACEMENT	Srlt W-OIL
DEAD VOL'S: U	2.2 cc	CORE TEMPERATURE	76.0 F
D	3.0 cc	OUTLET TEMPERATURE	76.0 F
SEPARATOR OUTLET	82.72 cm	WATER VISCOSITY	.932 cp
BUBBLE VELOCITY	15.61 cm/sec	OIL VISCOSITY	25.76 cp
ABSOLUTE PERM	6.412 darcies	VISCOSITY RATIO	27.66
INIT SAT - WATER	9.6 %	WATER DENSITY RATIO	1.0000
FINAL SAT - OIL	16.9 %	OIL DENSITY RATIO	1.0000

		SEPARATOR		D-VOL		FLOWRATE						
	TIME	HEIGHT	CALIB	INJ	D-P	CHART			cc			
	(min)	(cm)	(cc/cm)	(cc)	(psi)	AVG	@t	CAL	min	PVi	Rec	Inj
ST		12.40										
0	0.00	11.80	5.01	0.0	109.00	.96	.96	35.5	34.0	0.000	.000	1.00
1	1.68	29.50	5.01	93.9	108.00	1.35	1.50	35.5	53.2	.235	.220	1.58
BT	1.77				106.00		1.78	35.5	63.1	.248	.248	1.91
2	3.35	46.60	4.93	96.9	67.00	1.64	1.77	35.5	62.7	.483	.430	3.00
3	4.82	54.00	4.97	90.0	34.00	1.70	1.39	36.1	50.2	.713	.518	4.73
4	6.93	56.50	4.99	90.6	23.00	1.21	1.12	35.4	39.6	.945	.549	5.52
5	9.27	58.30	4.99	95.7	20.00	1.12	1.13	36.6	41.4	1.190	.571	6.63
6	11.58	59.80	4.99	96.0	18.00	1.13	1.13	36.7	41.4	1.435	.590	7.37
7	13.90	61.00	4.99	96.1	16.50	1.14	1.13	36.4	41.1	1.681	.605	7.98
8	16.25	62.10	4.99	97.6	15.00	1.14	1.14	36.4	41.5	1.931	.619	8.87
9	18.52	63.00	4.98	95.1	14.50	1.14	1.15	36.8	42.3	2.174	.631	9.35
10	20.80	63.80	4.98	96.2	14.00	1.15	1.15	36.6	42.1	2.420	.641	9.64
11	23.10	64.50	4.98	97.2	13.00	1.15	1.15	36.7	42.3	2.669	.650	10.41
12	25.37	65.15	4.98	96.9	12.50	1.15	1.15	37.2	42.7	2.917	.658	10.95
13	32.87	67.50	4.98	453.0	11.50	1.15	1.16	52.5	60.9	4.076	.688	16.97
14	46.63	69.20	4.98	474.0	10.00	1.16	1.15	29.7	34.1	5.289	.710	10.93
15	56.88	70.30	4.98	460.0	9.50	1.16	1.16	38.7	44.9	6.466	.724	15.13
16	66.83	71.10	4.98	456.0	9.00	1.16	1.15	39.5	45.4	7.633	.734	16.17
17	68.93	71.20	4.98	94.0	9.00	1.15	1.15	38.9	44.8	7.874	.735	15.93

CURVE FITS		c0	C1	c2	~~%E-MAX~~	~~%E-AVG~~
Recovery		5.5401E-01	1.0563E-01	-8.2241E-03	.3	.1
Inj. X Pore Vol.	Inj.	1.7700E+00	1.6942E+00	-1.0305E-01	28.2	4.5

	~~PVi~~	~~R-ACT~~	~~R-CALC~~	R-%E	I*P-ACT	I*P-CALC	I*P-%E	Sw	Krw	Kro	Kw/Ko
								.096	0.000	.791	0.000
BT		.248	.469		.47	1.54					
3	.713	.518	.517	.2	3.37	3.27	2.9	.502	.063	.321	.196
4	.945	.549	.548	.1	5.21	5.33	2.3	.537	.084	.295	.284
5	1.190	.571	.572	.2	7.88	7.85	.4	.565	.104	.272	.382
6	1.435	.590	.591	.2	10.58	10.68	1.0	.587	.122	.253	.484
7	1.681	.605	.607	.2	13.42	13.77	2.6	.606	.139	.236	.590
8	1.931	.619	.620	.1	17.12	17.12	.0	.621	.155	.221	.700
9	2.174	.631	.631	.1	20.33	20.57	1.2	.634	.169	.208	.811
10	2.420	.641	.641	.0	23.33	24.22	3.8	.646	.182	.197	.925
11	2.669	.650	.650	.0	27.79	28.05	.9	.656	.195	.187	1.042
12	2.917	.658	.658	.1	31.95	32.00	.1	.666	.207	.178	1.162
13	4.076	.688	.686	.3	69.16	51.78	25.1	.700	.254	.145	1.750
14	5.289	.710	.707	.3	57.82	74.14	28.2	.725	.293	.121	2.408
15	6.466	.724	.723	.1	97.83	96.86	1.0	.744	.324	.105	3.084
16	7.633	.734	.735	.1	123.41	120.02	2.8	.759	.349	.092	3.787
17	7.874	.735	.737	.3	125.42	124.85	.5	.761	.354	.090	3.935

***Table** E,8 Water Dispalcement Calculations – Run 1/10*

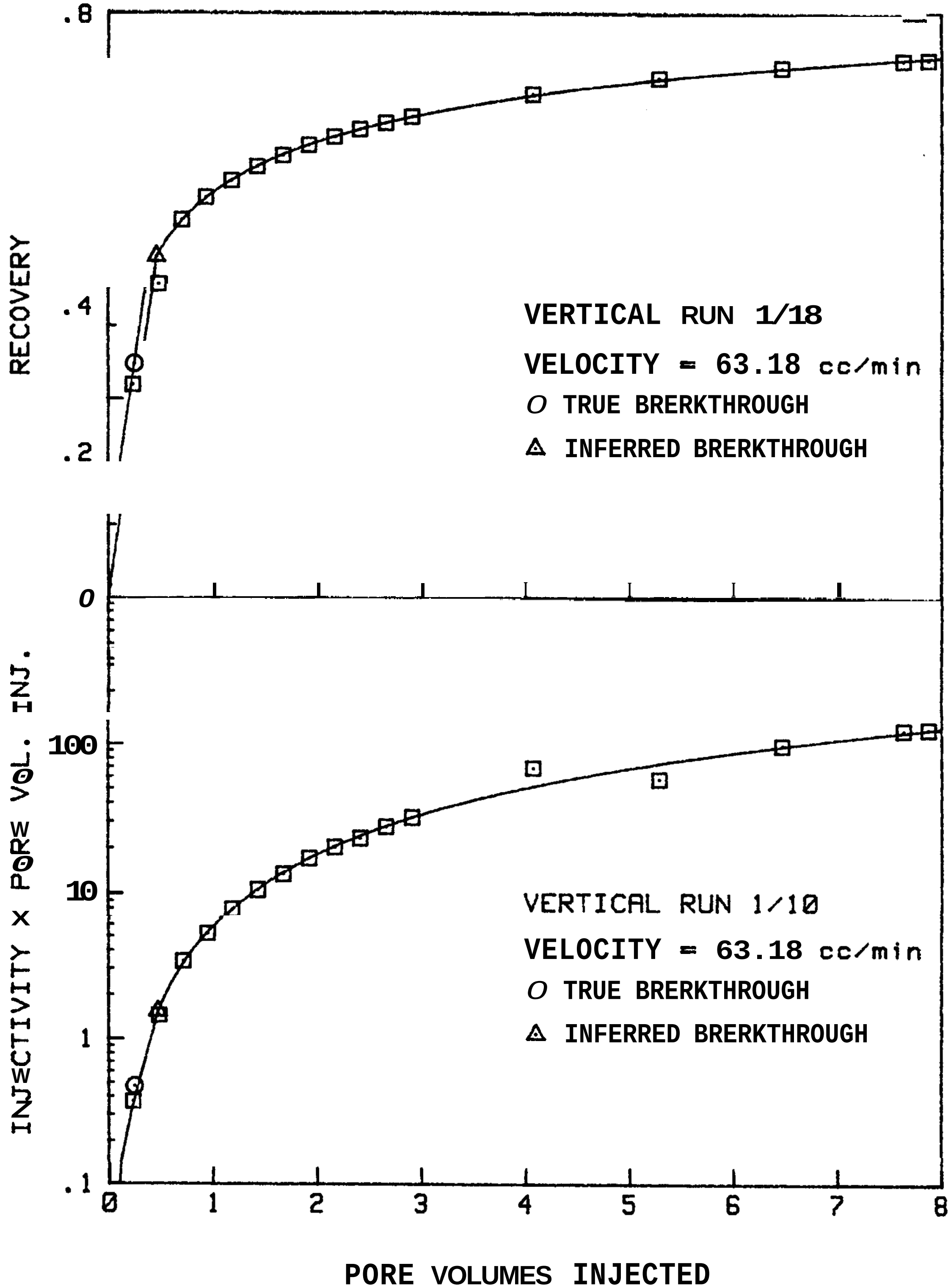


Figure E.17 Recovery and Injectivity x Pore Volumes Injected vs. Pore Volumes Injected – Run 1/10

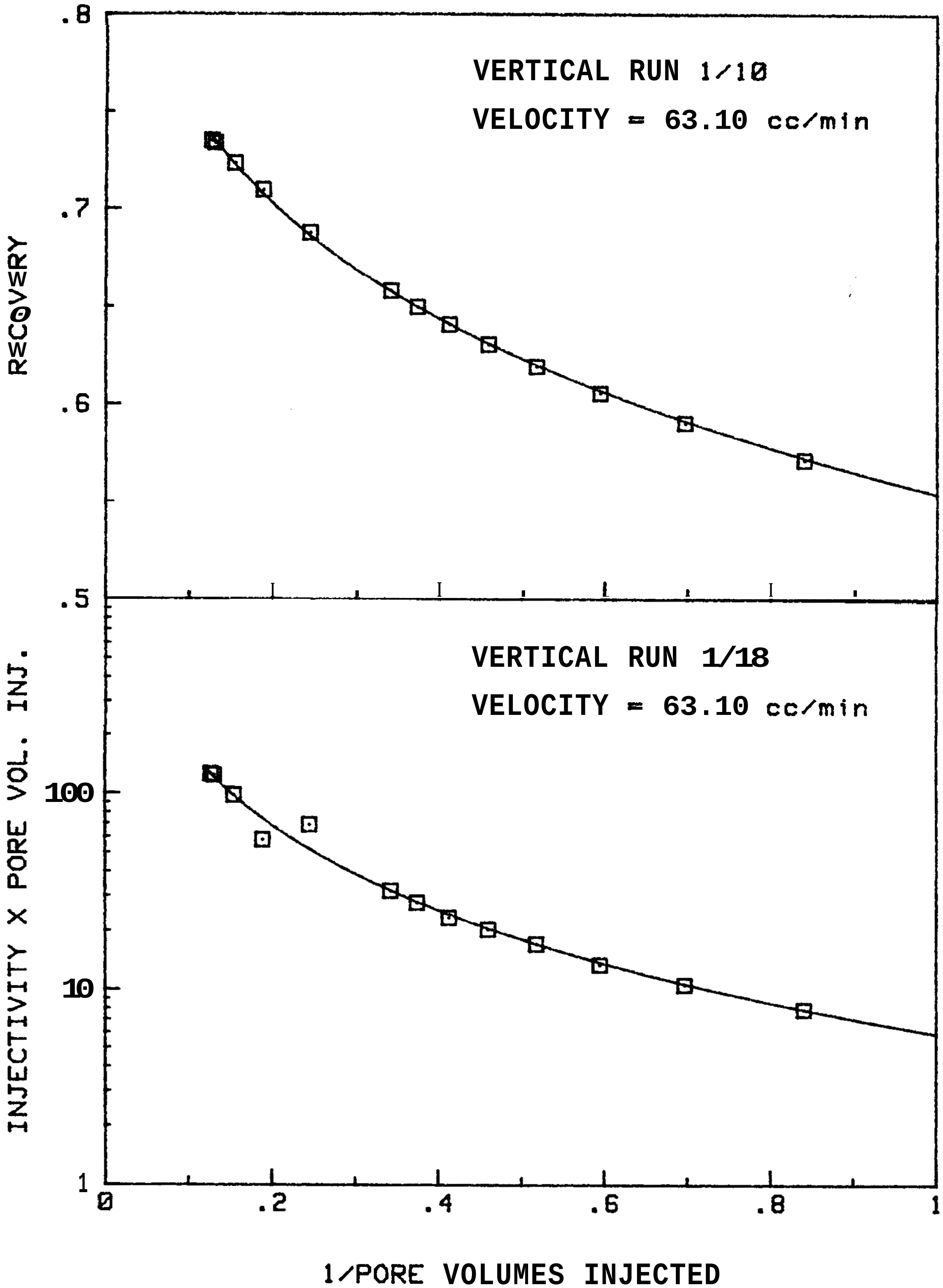


Figure E.18 Recovery and Injectivity x Pare Volumes Injected vs. 1/Pore Valumes Injected – Run 1/10

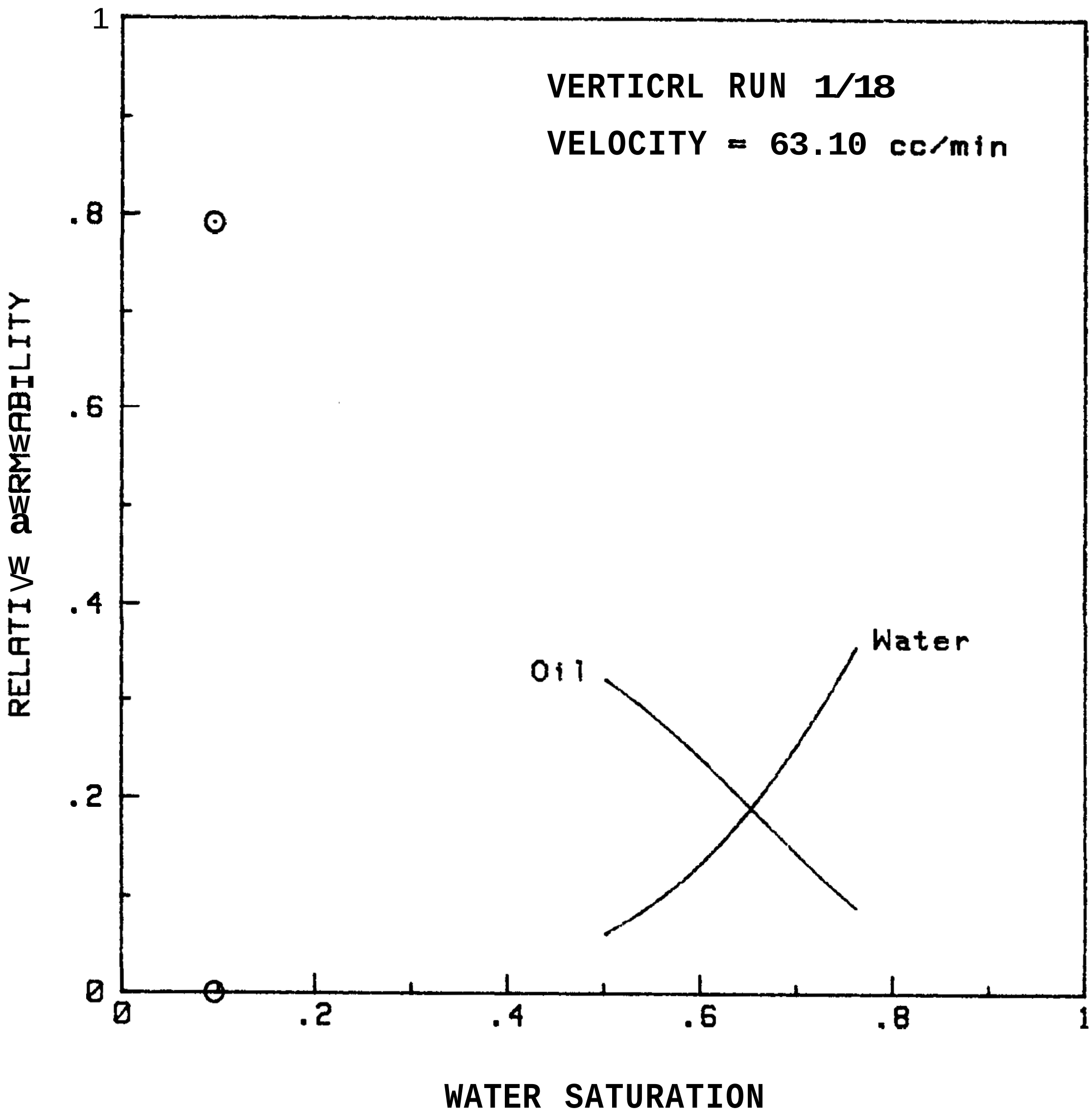


Figure E.19 Relative ***Permeabilities*** *vs. Water Saturation -- Run 1/10*

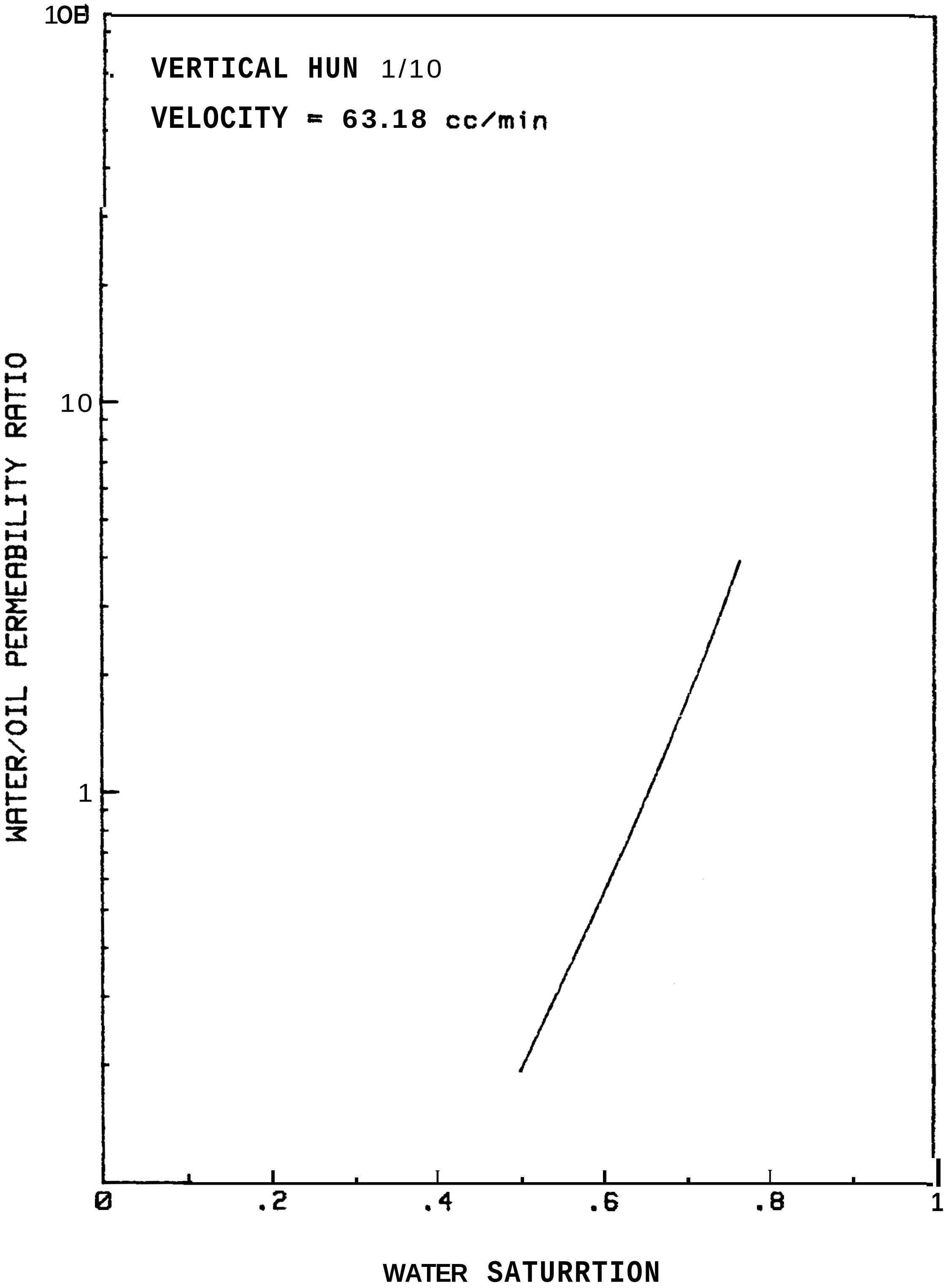


Figure E.20 Relative Permeability Ratio vs. Water Saturation – Run 1/10

DISPLACEMENT EXPERIMENT CALCULATIONS

PORE VOLUME	390.8 cc	DATE	4-6-84
CORE LENGTH	51.46 cm	CORE/RUN	1/11
CORE DIAMETER	5.044 cm	DISPLACEMENT	OIL-Salt W
DEAD VOL'S: U	2.2 cc	CORE TEMPERATURE	76.0 F
D	3.0 cc	OUTLET TEMPERATURE	76.0 F
SEPARATOR OUTLET	82.72 cm	WATER VISCOSITY	.932 cp
BUBBLE VELOCITY	18.05 cm/sec	OIL VISCOSITY	25.76 cp
ABSOLUTE PERM	6.412 darcies	VISCOSITY RATIO	27.66
INIT SAT - OIL	16.9 %	WATER DENSITY RATIO	1.0000
FINAL SAT - WATER	9.7 %	OIL DENSITY RATIO	1.0000

	TINE (min)	SEPARATOR HEIGHT (cm)	SEPARATOR CALIB (cc/cm)	D-VOL INJ (cc)	D-P (psi)	FLOWRATE CHART AVG	FLOWRATE CHART @t	FLOWRATE CHART CAL	FLOWRATE cc/min	PVi	Rec	1/Inj
ST		72.50										
0	0.00	72.60	5.00	0.0	11.50	1.80	1.80	30.4	54.7	0.000	.000	1.00
1	2.13	53.90	5.00	93.2	33.00	1.47	1.35	30.4	41.0	.233	.235	3.83
2	4.55	35.30	5.00	94.0	92.50	1.28	1.22	30.4	37.1	.473	.474	11.87
3	7.20	16.70	4.96	92.9	124.00	1.17	1.12	30.0	33.6	.711	.706	17.58
BT	7.20				124.00		1.12	30.5	34.1	.711	.711	17.28
4	10.12	14.70	4.95	95.1	118.50	1.07	1.07	30.5	32.6	.954	.725	17.29
5	13.05	14.50	4.95	96.0	117.00	1.07	1.07	30.6	32.7	1.200	.727	17.00
6	15.93	14.20	4.95	94.9	116.00	1.07	1.07	30.8	32.9	1.443	.730	16.76
7	18.80	14.10	4.95	95.0	116.00	1.07	1.07	31.0	33.1	1.686	.732	16.65
8	21.70	13.90	4.95	96.2	115.50	1.07	1.07	31.0	33.2	1.932	.734	16.56
9	24.62	13.90	0.00	98.0	115.50	1.07	1.07	31.4	33.6	2.183	.734	16.35

Krw - INITIAL = .436
Kro - FINAL = .737

Table E,9 Oil Dispalcement Calculations – Run 1/11

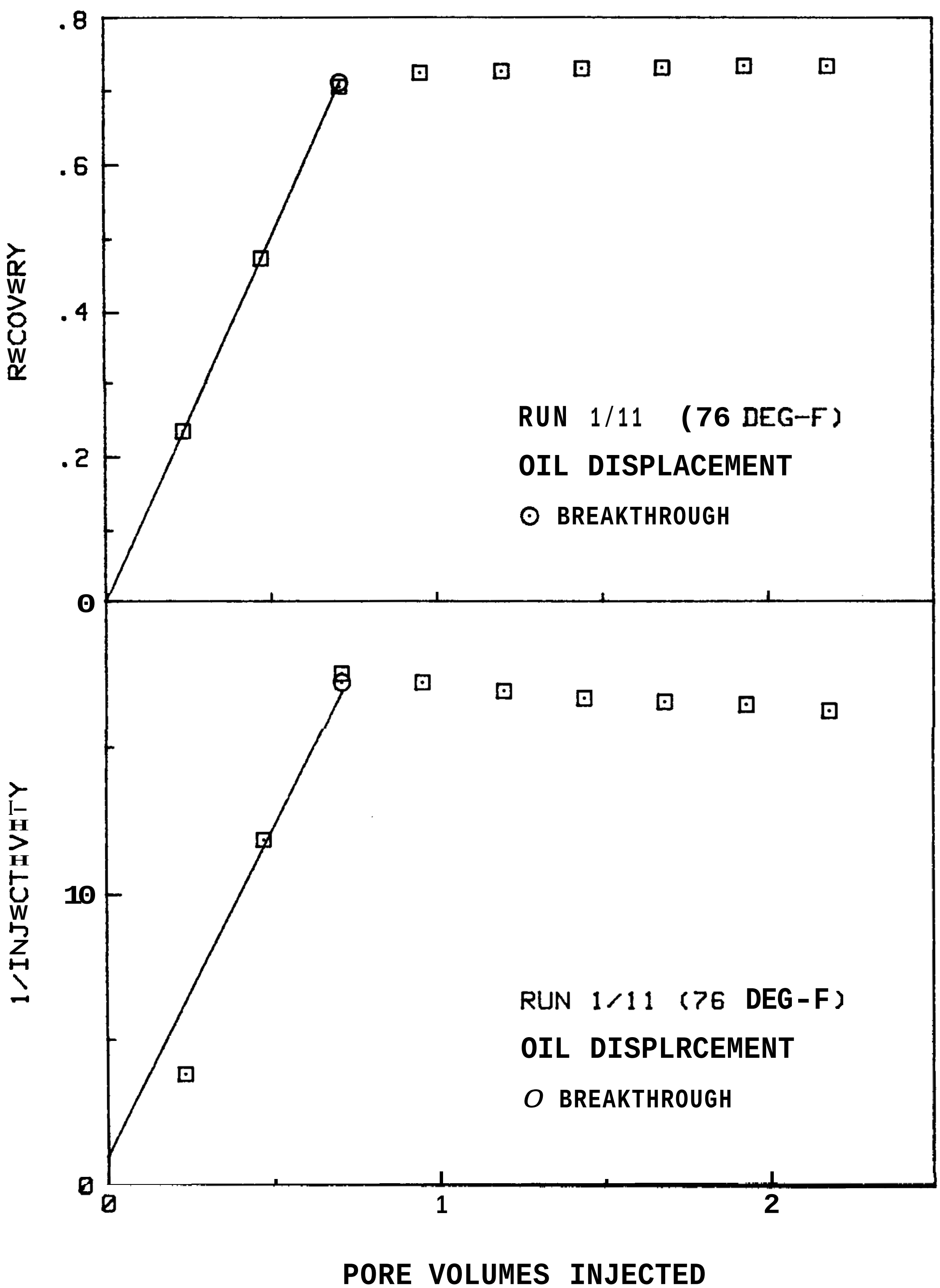


Figure E.21 Recovery and 1/Injectivity vs. Pore Volumes Injected – Run 1/11

DISPLACEMENT EXPERIMENT CALCULATIONS

PORE VOLUME	390.8 cc	DATE	4-9-84
CORE LEHGTH	51.46 cm	CORE/RUN	1/12
CORE DIAMETER	5.044 cm	DISPLACEMENT	Salt W-OIL
DEAD VOL'S: U	2.2 cc	CORE TEMPERATURE	72.0 F
D	3.0 cc	OUTLET TEMPERATURE	72.0 F
SEPARATOR OUTLET	82.72 cm	WATER VISCOSITY	.981 cp
BUBBLE VELOCITY	12.83 cm/sec	OIL VISCOSITY	28.37 cp
ABSOLUTE PERM	6.412 darcies	VISCOSITY RATIO	28.91
INIT SAT - WATER	9.7 %	WATER DENSITY RATIO	1.0000
FINAL SAT - OIL	18.5 %	OIL DENSITY RATIO	1.0000

		SEPARATOR		D-VOL		FLOWRATE						
	TIME	HEIGHT	CALIB	INJ	D-P	CHART			cc			
	~~(min)~~	~~(cm)~~	~~(cc/cm)~~	~~(cc)~~	(psi)	AVG	Qt	CAL	min	PVi	Rec	Inj
ST		9.[illegible]										
0	0.00	8.80	4.97	0.0	127.50	1.53	1.53	29.6	45.3	0.000	.000	1.00
BT	1.30				127.30		2.40	29.6	71.0	.208	.208	1.57
1	1.48	27.90	4.97	94.8	127.30	2.10	2.45	29.6	72.5	.237	.236	1.60
2	2.63	42.90	4.96	94.3	105.00	2.77	3.10	29.6	91.8	.478	.419	2.46
3	3.60	49.50	4.97	96.0	76.00	3.27	3.38	30.4	102.7	.724	.497	3.80
4	4.52	52.90	5.00	96.0	61.50	3.46	3.54	30.3	107.1	.970	.539	4.90
5	5.40	54.90	5.00	95.9	54.00	3.56	3.59	30.5	109.5	1.215	.563	5.71
6	6.40	56.80	5.00	110.7	48.00	3.61	3.63	30.7	111.3	1.498	.587	6.53
7	7.27	57.90	4.98	95.8	44.50	3.64	3.66	30.4	111.1	1.743	.601	7.03
8	8.12	58.90	4.95	95.5	41.00	3.67	3.67	30.6	112.4	1.988	.613	7.71
9	8.93	59.70	4.95	92.1	39.00	3.68	3.68	30.6	112.8	2.223	.623	8.14
10	9.77	60.50	4.95	93.5	37.30	3.69	3.69	30.4	112.2	2.463	.633	8.47
11	10.60	61.10	4.95	95.2	35.50	3.70	3.70	30.9	114.2	2.706	.641	9.06
12	11.43	61.70	4.95	95.2	34.60	3.71	3.71	30.8	114.2	2.950	.649	9.29
13	12.27	62.20	4.95	94.0	33.00	3.71	3.71	30.4	112.8	3.190	.655	9.62
14	16.17	64.00	4.95	447.0	29.80	3.72	3.72	30.8	114.6	4.334	.677	10.83
15	20.35	65.40	4.95	484.0	27.20	3.73	3.75	31.0	116.3	5.573	.695	12.04
16	24.37	66.40	4.95	473.0	26.00	3.75	3.74	31.4	117.4	6.783	.708	12.72
17	28.25	67.00	4.95	459.0	25.50	3.74	3.73	31.6	117.9	7.958	.715	13.01
18	29.08	67.20	4.95	99.1	25.00	3.73	3.73	31.9	118.9	8.211	.718	13.39

CURVE FITS	c0	C1	c2	~~%E-MAX~~	~~%E-AVG~~
Recovery	5.3536E-01	1.2983E-01	-2.1145E-02	2.1	.5
Inj. X Pore Vol. Inj.	1.5779E+00	1.7659E+00	-1.3888E-01	3.8	1.4

	PVi	R-ACT	R-CALC	R-%E	I*P-ACT	I*P-CALC	I*P-%E	Sw	Krw	Kro	Kw/Ko
								.097	0.000	.991	0.000
BT		.208	.398		.33	.84					
2	.478	.419	.428	2.1	1.18	1.22	3.8	.364	.029	.432	,068
3	.724	.497	.491	1.2	2.75	2.70	1.9	.445	.055	.395	.140
4	.970	.539	.531	1.3	4.76	4.59	3.5	.497	.079	.358	,221
5	1.215	.563	.560	.6	6.93	6.80	2.0	.535	.101	.324	.311
6	1.498	.587	.584	.5	9.78	9.67	1.1	.569	.124	.291	.425
7	1.743	.601	.601	.0	12.26	12.39	1.0	.592	.142	.267	.533
8	1.988	.613	.615	.2	15.33	15.26	.5	.611	.159	.245	.648
9	2.223	.623	.626	.3	18.10	18.18	.4	.627	.174	.227	.766
10	2.463	.633	.635	.3	20.85	21.25	1.9	.640	.188	.210	.894
11	2.706	.641	.644	.4	24.52	24.49	.1	.653	.202	.195	1.833
12	2.950	.649	.651	.4	27.42	27.82	1.5	.664	.214	.182	1.179
13	3.190	.655	.658	.4	30.70	31.18	1.6	.674	.226	.170	1.332
14	4.334	.677	.680	.4	46.93	47.89	2.1	.709	.275	,126	2.177
15	5.573	.695	.696	.1	67.08	66.80	.4	.736	.316	.095	3.337
16	6.783	.708	.706	.2	86.25	85.59	.8	.755	.348	.073	4.768
17	7.958	.715	.714	.2	103.55	103.87	.3	.769	.374	.058	6.503
18	8.211	.718	.715	.4	109.95	107.80	2.0	.771	.379	.055	6.931

Table E,10 Water Displacement Calculations – Run 1/12

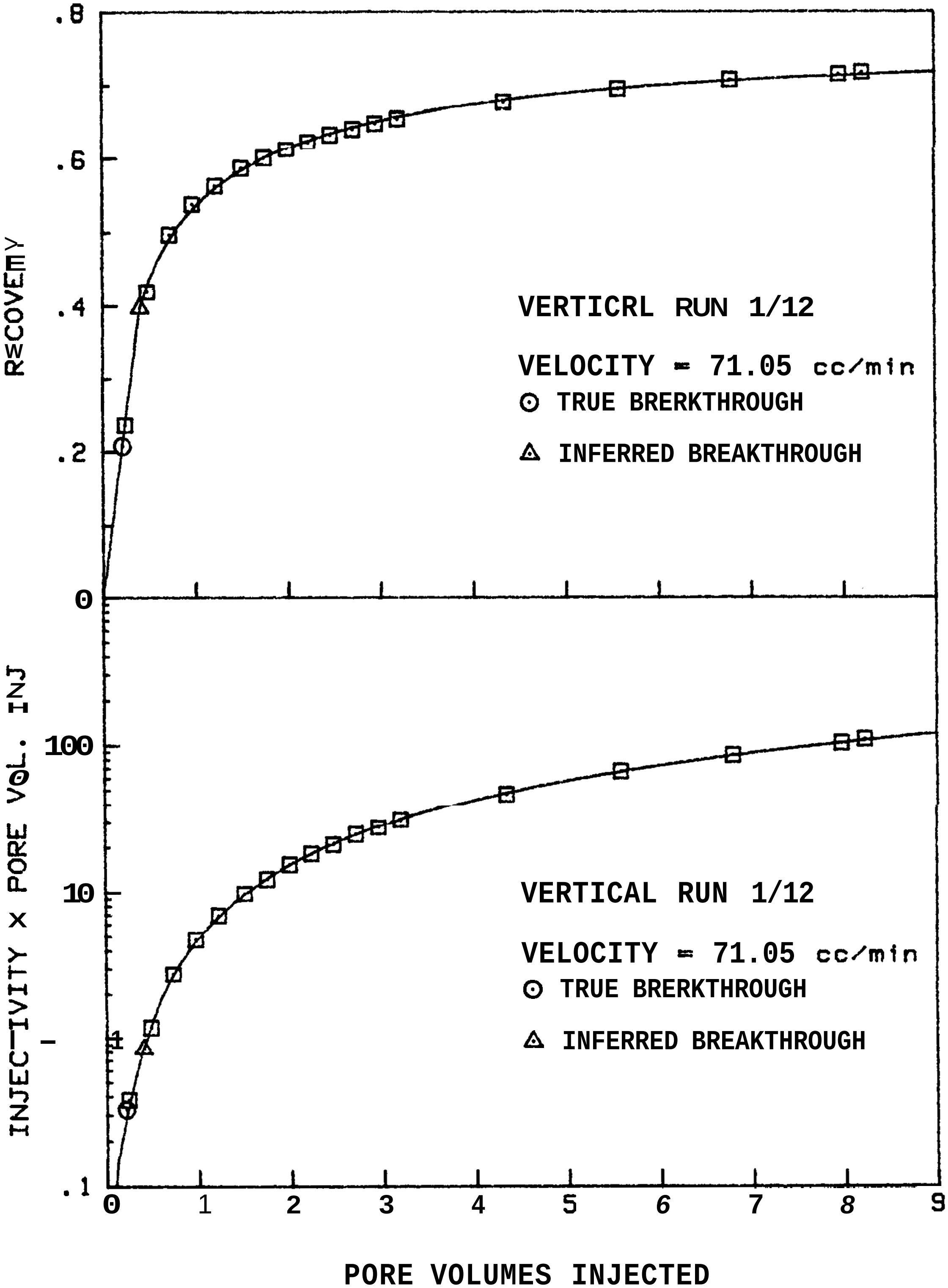


figure E.22 Recovery **and Injectivity** *x* Pare **Volumes Injected** *vs.*
Pare ***Volumes Injected*** – ***Run 1/12***

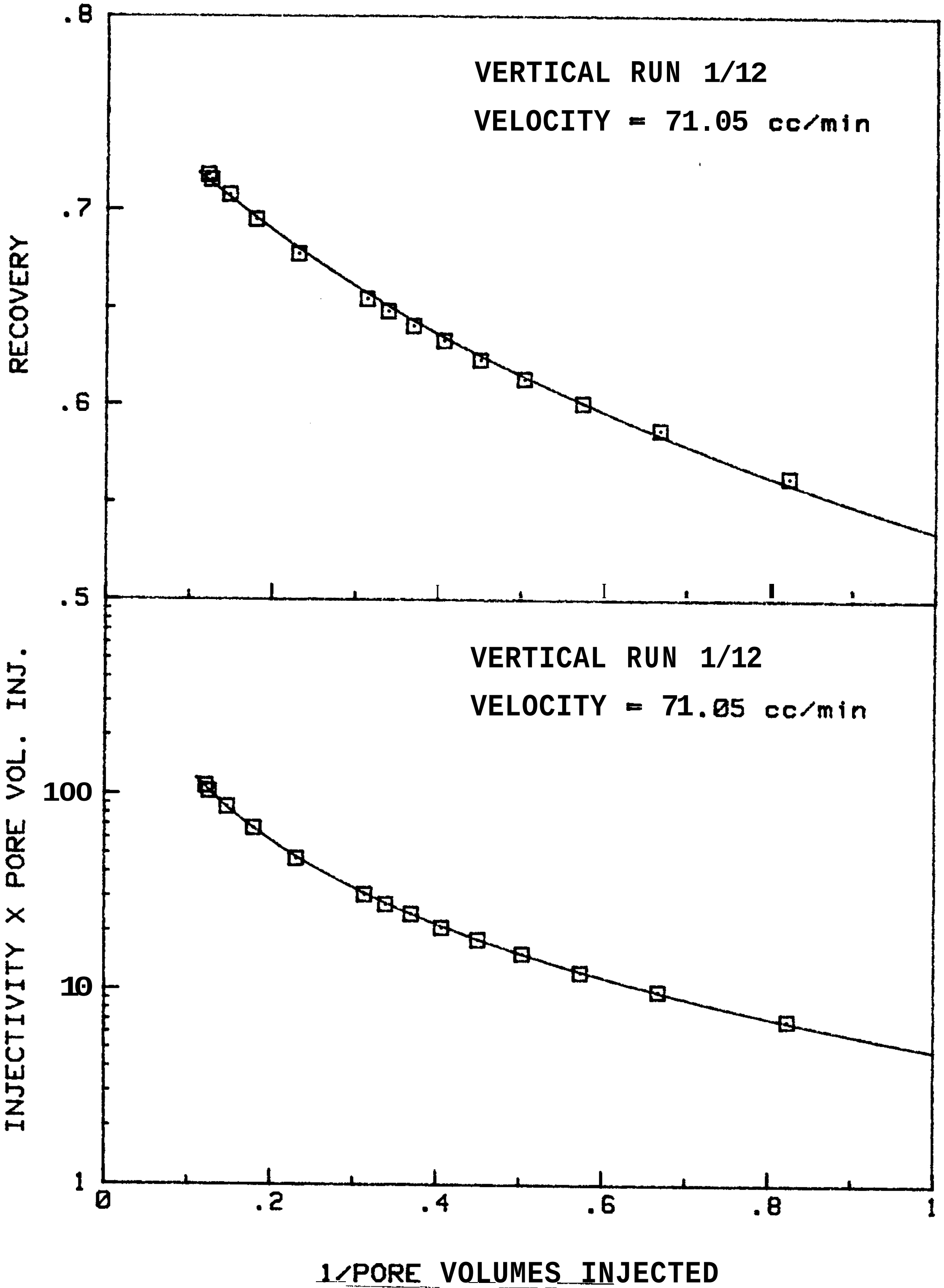


figure E.23 Recovery and Injectivity x Pore Volumes Injected vs. 1/Pore Volumes Injected -- Run 1/12

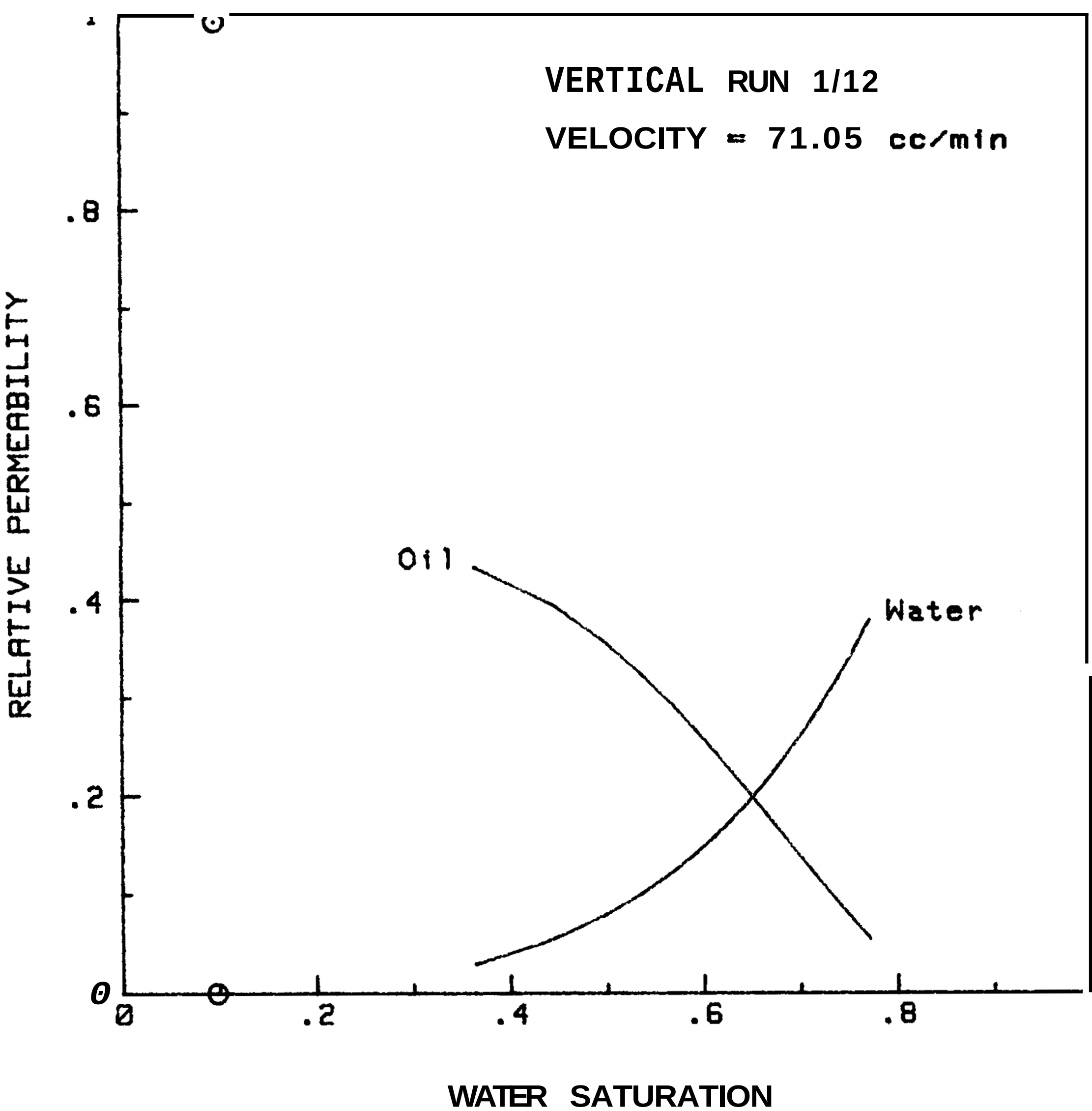


figure E.24 Relative Permeabilities vs. Water Saturation – Run 1/12

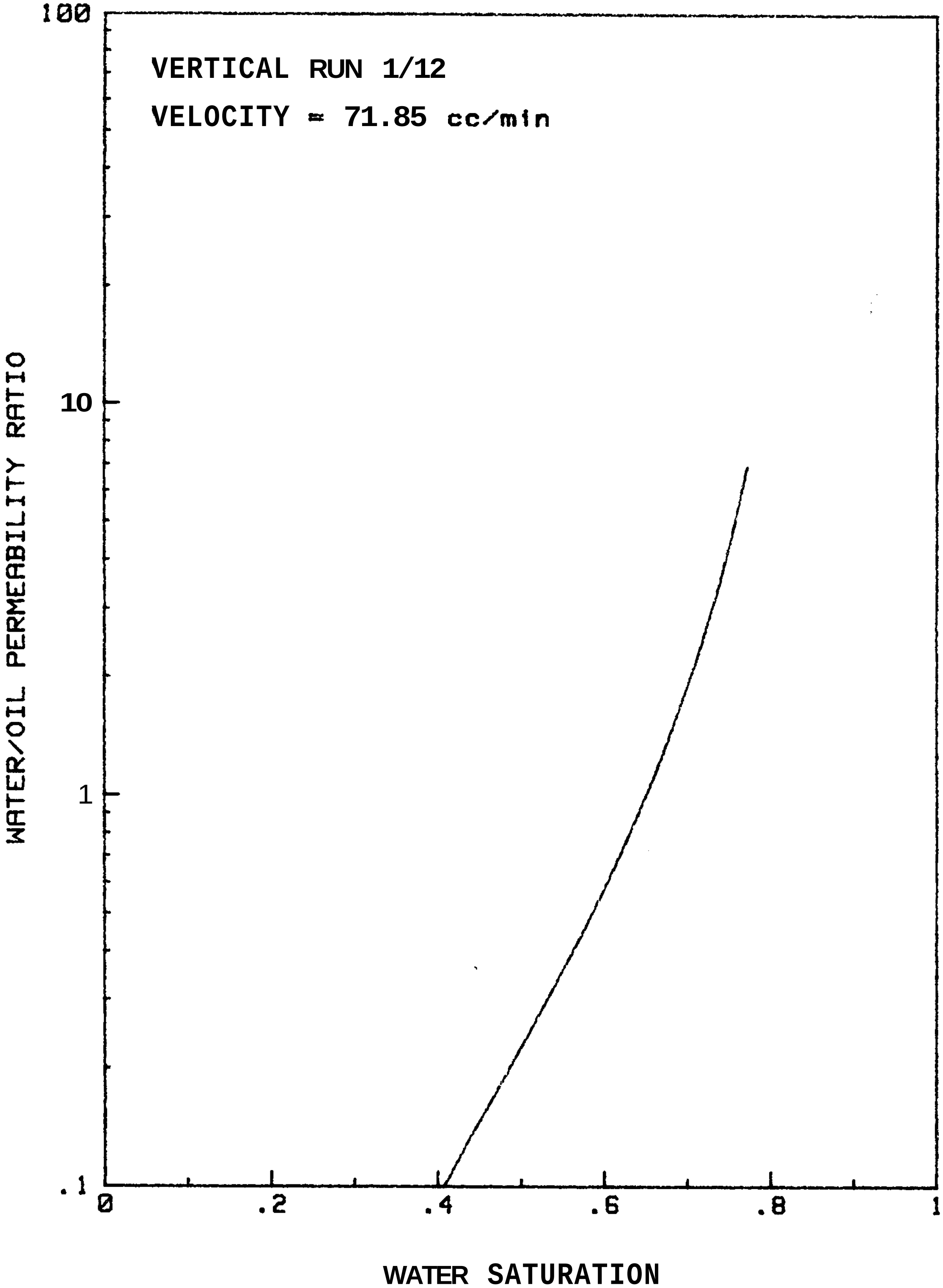


*Figure **E.25** Relative Permeability Ratio vs. Water Saturation – Run 1/12*

DISPLACEMENT EXPERIMENT CALCULATIONS

PORE VOLUME	390.8 cc	DATE	4-9-84
CORE LENGTH	51.46 cm	CORE/RUN	1/13
CORE DIAMETER	5.044 cm	DISPLRCEMENT	OIL-Salt W
DEAD VOL'S: U	2.2 cc	CORE TEMPERATURE	74.0 F
D	3.0 cc	OUTLET TEMPERATURE	74.0 F
SEPARATOR OUTLET	82.72 cm	WATER VISCOSITY	.956 cp
BUBBLE VELOCITY	10.41 cm/sec	OIL VISCOSITY	27.03 cp
ABSOLUTE PERM	6.412 darcies	VISCOSITY RATIO	28.27
INIT SAT - OIL	18.5 %	WRTER DENSITY RATIO	1.0000
FINRL SAT - WATER	8.6 %	OIL DENSITY RATIO	1.0000

	TIME (min)	SEPARATOR HEIGHT (cm)	SEPARATOR CALIB (cc/cm)	D-VOL INJ (cc)	D-P <psi>	FLOWRATE CHART AVG	FLOWRATE CHART @t	FLOWRATE CAL	cc/min	PVi	Rec	1/Inj
ST		75.20										
0	0.00	75.30	5.00	0.0	9.00	1.37	1.37	30.8	42.2	0.000	.000	1.00
1	2.78	55.60	5.00	98.3	45.50	1.15	1.07	30.8	33.0	.246	.249	6.47
2	5.87	36.10	5.00	97.9	80.00	1.03	.98	30.8	30.2	.496	.500	12.43
BT	8.51				102.50		.93	30.3	28.2	.691	.691	17.05
3	9.17	18.90	5.00	95.1	101.00	.95	.91	30.3	27.6	.740	.714	17.17
4	12.57	17.90	4.28	93.2	98.50	.90	.90	30.5	27.4	.978	.718	16.86
5	16.10	17.40	4.95	98.0	98.00	.90	.90	30.8	27.7	1.229	.725	16.58
6	19.70	17.20	4.95	100.0	97.00	.90	.90	30.9	27.8	1.485	.727	16.39
7	23.10	17.00	4.95	94.3	96.50	.90	.90	30.8	27.7	1.726	.729	16.33
8	26.53	17.00	4.95	95.3	96.50	.90	.90	30.8	27.8	1.970	.729	16.31
9	29.90	17.00	0.00	94.7	97.00	.90	.90	31.3	28.1	2.212	.729	16.18

Krw - INITIAL = .441
Kro - FINRL = .771

Table E.11 Oil Displacement Calculations -- Run 1/13

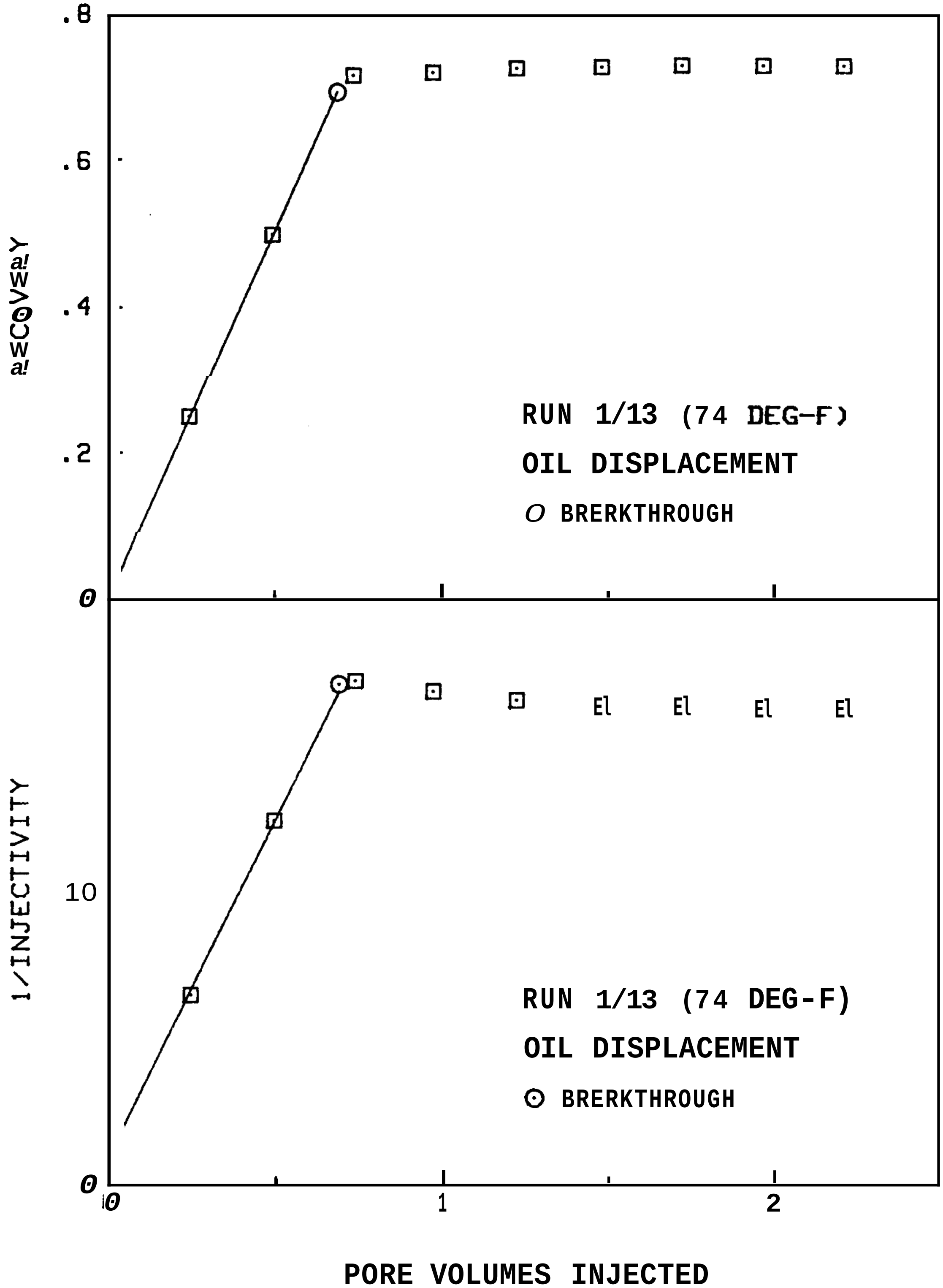


Figure E.26 Recovery and 1/Injectivity vs. Pore Volumes Injected – Run 1/13

DISPLACEMENT EXPERIMENT CALCULATIONS

PORE VOLUME	390.8 cc	DATE	4/10/84
CORE LENGTH	51.46 cm	CORE/RUN	1/14
CORE DIAMETER	5.044 cm	DISPLACEMENT	Salt W-OIL
DEAD VOL'S: U	2.2 cc	CORE TEMPERATURE	73.5 F
D	3.0 cc	OUTLET TEMPERATURE	73.5 F
SEPARATOR OUTLET	82.72 cm	WATER VISCOSITY	.962 cp
BUBBLE VELOCITY	3.55 cm/sec	OIL VISCOSITY	27.35 cp
ABSOLUTE PERM	6.412 darcies	VISCOSITY RATIO	28.43
INIT SAT - WATER	8.6 %	WATER DENSITY RATIO	1.0000
FINAL SAT - OIL	18.9 %	OIL DENSITY RRTIO	1.0000

	TIME (min)	SEPARATOR HEIGHT (cm)	SEPARATOR CALIB (cc/cm)	D-VOL INJ (cc)	D-P (psi)	FLOWRATE CHART AVG	FLOWRATE CHART @t	FLOWRATE CHART CAL	FLOWRATE cc/min	PVi	Rec	Inj
ST		13.00										
0	0.00	12.50	4.96	0.0	24.00	.23	.23	33.1	7.6	0.000	.000	1.00
1	13.30	31.70	4.96	95.6	15.50	.22	.22	33.1	7.3	.239	.235	1.48
BT	21.00				10.50		.22	33.1	7.3	.382	.382	2.19
2	26.37	48.70	4.97	95.1	7.SO	.22	.22	33.1	7.3	.482	.446	3.06
3	39.23	54.40	5.00	94.2	5.00	.22	.22	33.3	7.3	.723	.515	4.62
4	52.52	56.80	5.00	98.2	4.20	.22	.22	33.6	7.4	.975	.545	5.55
5	65.38	58.50	4.97	96.1	3.60	.23	.23	32.5	7.5	1.221	.566	6.54
6	80.35	60.05	4.95	111.1	3.20	.23	.23	32.3	7.4	1.505	.586	7.32
7	93.47	61.10	4.95	96.1	3.00	.22	.22	33.3	7.3	1.751	.599	7.70
8	106.75	62.10	4.95	96.6	2.80	.22	.22	33.1	7.3	1.998	.611	8.19
9	118.25	62.80	4.95	91.3	2.80	.22	.22	36.1	7.9	2.232	.620	8.94
10	130.00	63.60	4.95	93.4	2.70	.22	.22	36.1	7.9	2.471	.630	9.29
11	141.53	64.20	4.95	92.0	2.60	.22	.22	36.3	8.0	2.706	.638	9.68
12	153.52	64.90	4.95	96.0	2.6.0	.23	.23	35.6	8.0	2.952	.647	9.72
13	208.68	67.10	4.95	448.0	2.10	.23	.22	36.1	7.9	4.098	.674	11.93
14	264.98	68.70	4.95	448.0	1.90	.22	.22	36.2	8.0	5.244	.695	13.21
15	327.20	70.00	4.95	490.0	1.80	.21	.21	37.5	7.9	6.498	.711	13.80
16	385.18	70.95	4.95	467.0	1.70	.22	.22	36.6	8.1	7.693	.723	14.94
17	397.00	71.10	4.95	95.6	1.70	.22	.22	36.8	8.1	7.938	.725	15.01

CURVE FITS	C0	C1	c2	%E-MAX	%E-AVG
Recovery	5.4689E-01	9.6894E-02	-5.0460E-03	.2	.1
Inj. X Pore Vol. Inj.	1.7371E+00	1.5984E+00	-6.1789E-02	3.9	1.3

	PVi	R-ACT	R-CALC	R-YE	I*P-ACT	I*P-CALC	I*P-%E	Sw	Krw	Kro	Kw/Ko
								.086	0.000	.853	0.000
BT		.382	.471		.84	1.65					
3	.723	.515	.515	.0	3.34	3.36	.7	.501	.073	.335	.219
4	.975	.545	.544	.1	5.41	5.45	.8	.533	.094	.297	.318
5	1.221	.566	.566	.0	7.99	7.79	2.4	.557	.112	.269	.417
6	1.505	.586	.586	.0	11.01	10.81	1.9	.579	.131	.244	,535
7	1.751	.599	.600	.1	13.49	13.64	1.1	.594	.145	.226	,640
8	1.998	.611	.612	.0	16.37	16.67	1.9	.608	.158	.212	.747
9	2.232	.620	.621	.2	19.96	19.70	1.3	.619	.170	.200	,849
10	2.471	.630	.630	.0	22.94	22.93	.1	.629	.181	.189	.955
11	2.706	.638	.638	.1	26.19	26.23	.2	.637	.191	.180	1.061
12	2.952	.647	.646	.1	28.69	29.81	3.9	.646	.201	.171	1.173
13	4.098	.674	.674	.1	48.87	47.88	2.0	.677	.241	.141	1.709
14	5.244	.695	.694	.2	69.28	67.78	2.2	.699	.274	.121	2.266
15	6.498	.711	.711	.1	89.68	91.12	1.6	.719	.304	.105	2.895
16	7.693	.723	.724	.1	114.96	114.57	.3	.733	.329	.094	3.512
17	7.938	.725	.726	.1	119.15	119.50	.3	.736	.333	.092	3.640

Table E.12 Water Displacement Calculations – Run 1/14

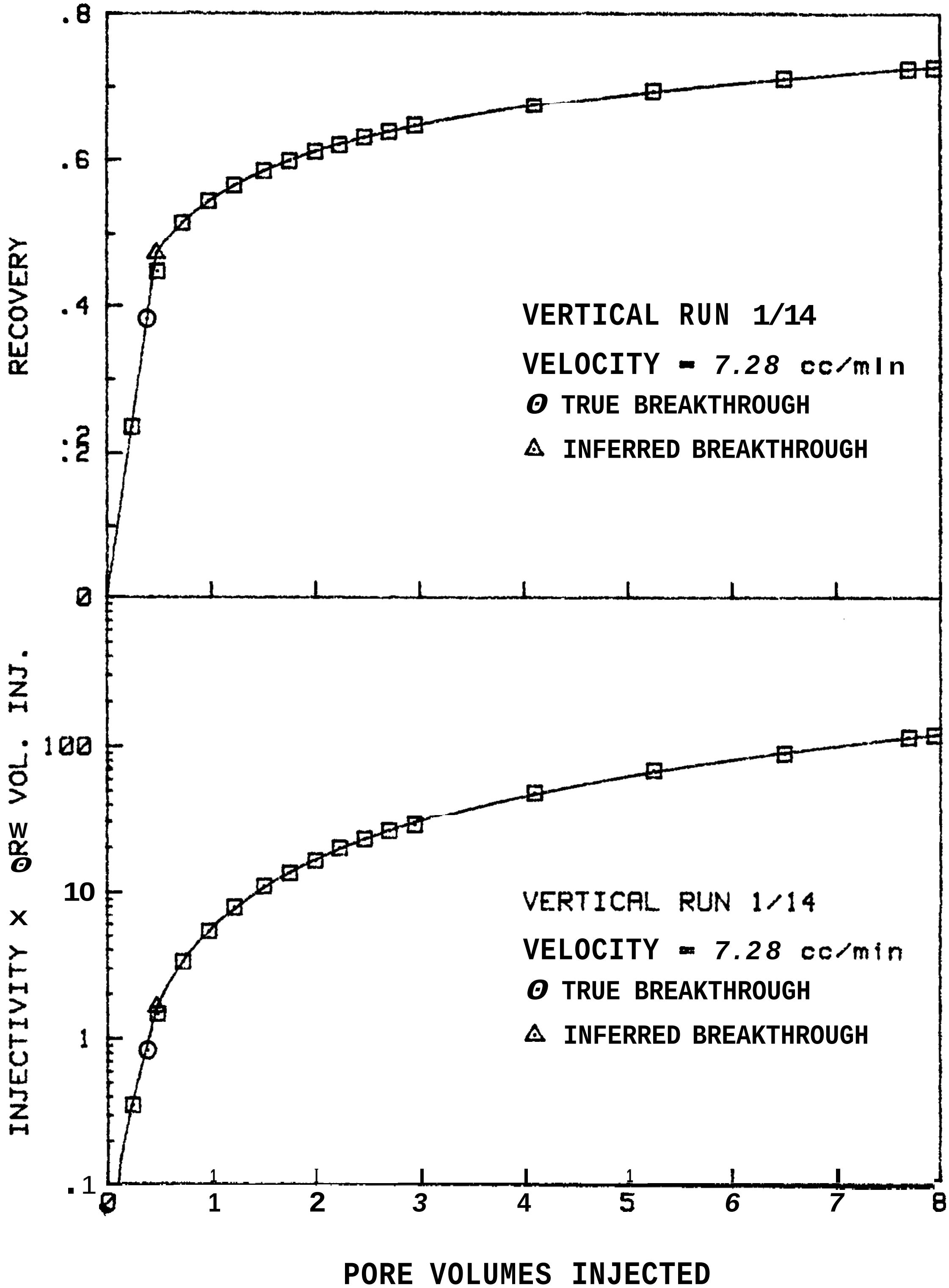


Figure E.27 Recovery and Injectivity x Pore Volumes Injected vs. Pare Volumes Injected – Run 1/14

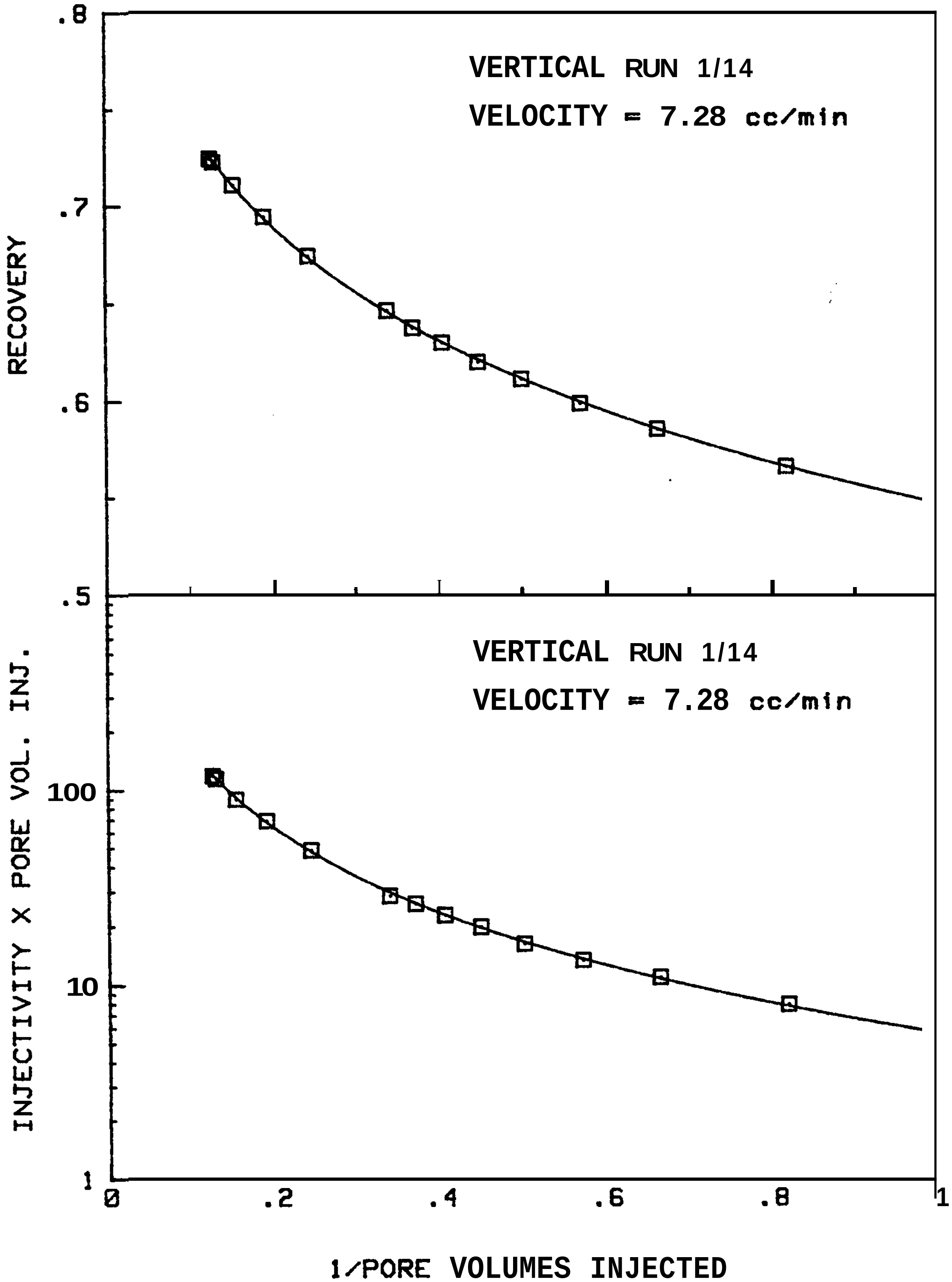


figure E.28 Recovery and Injectavity x Pore Volumes Injected vs. 1/Pore Volumes Injected – Run 1/14

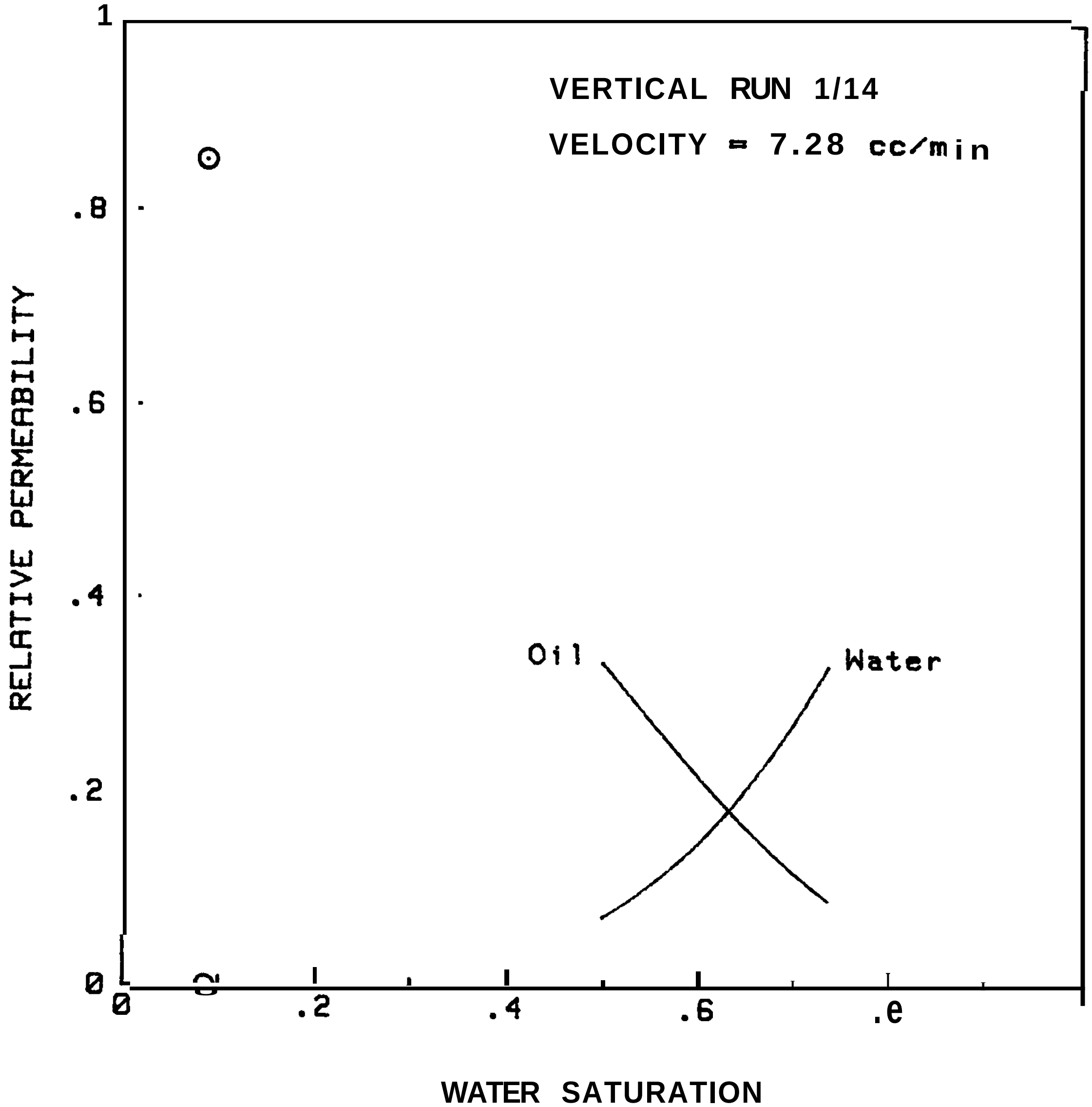


*Figure E.29 Relative Permeabilities vs. Water Saturation -- Run **1/14***

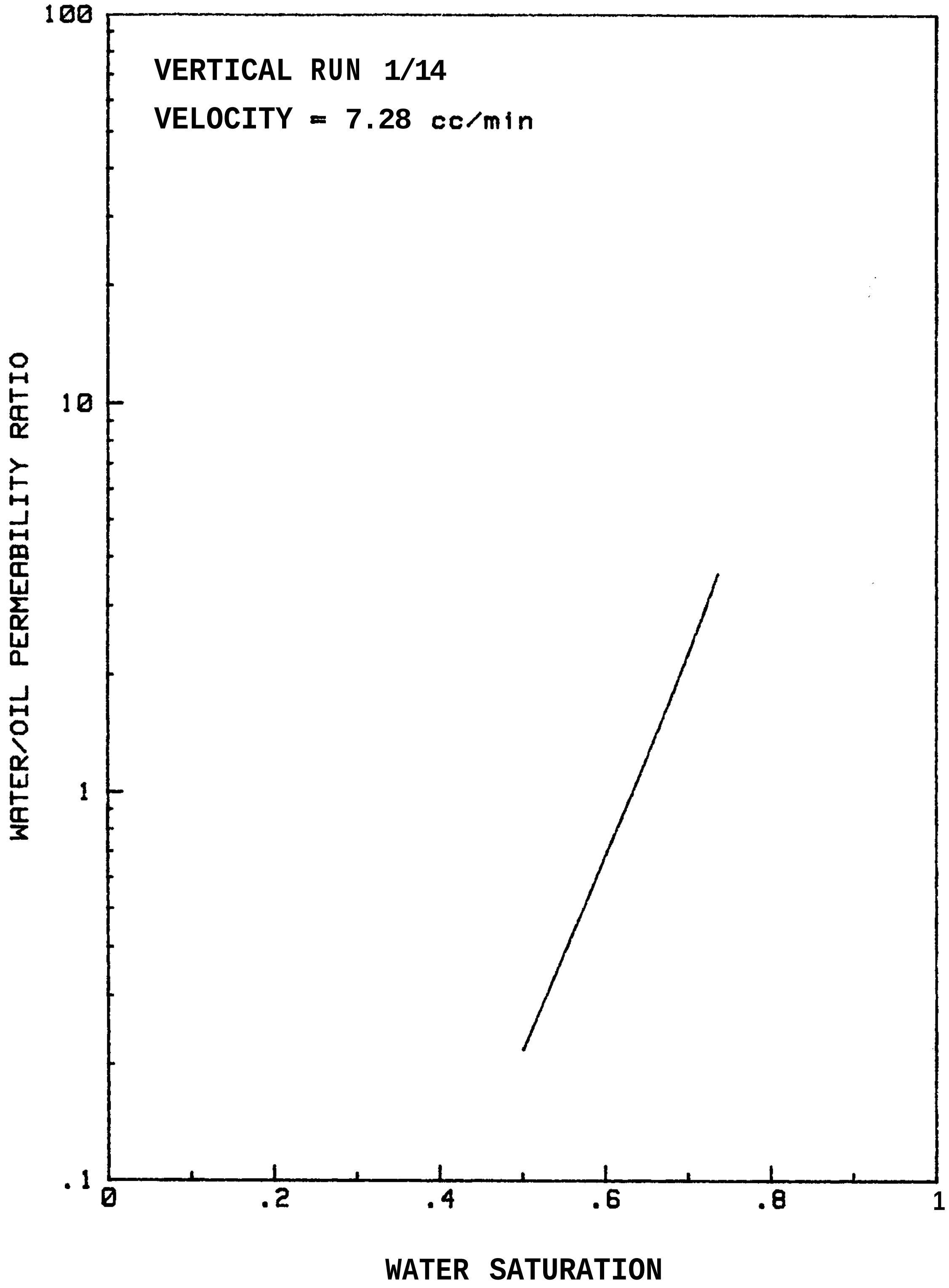


figure E.30 Relative Permeability Ratio vs. Water Saturation – Run 1/14

DISPLACEMENT EXPERIMENT CALCULATIONS

PORE VOLUME	390.8 cc	DATE	4/15/84
CORE LENGTH	51.46 cm	CORE/RUN	1/15
CORE DIAMETER	5.044 cm	DISPLACEMENT	OIL-Salt W
DEAD VOL'S: U	2.2 cc	CORE TEMPERATURE	73.5 F
D	3.0 cc	OUTLET TEMPERATURE	75.0 F
SEPARATOR OUTLET	82.72 cm	WATER VISCOSITY	.962 cp
BUBBLE VELOCITY	20.30 cm/sec	OIL VISCOSITY	27.35 cp
ABSOLUTE PERM	6.412 darcies	VISCOSITY RATIO	28.43
INIT SAT - OIL	18.9 %	WATER DENSITY RATIO	.9997
FINAL SAT - WATER	6.5 %	OIL DENSITY RATIO	.9993

		SEPARATOR		D-VOL		FLOWRATE						
	TIME	HEIGHT	CALIB	INJ	D-P	CHART			cc			
	(min)	(cm)	(cc/cm)	(cc)	(psi)	AVG	@t	CAL	min	PVi	Rec	1/Inj
ST		72.20										
0	0.00	72.30	4.94	0.0	11.20	1.78	1.78	33.6	59.8	0.000	.000	1.00
1	1.98	53.00	4.94	93.9	56.00	1.46	1.34	33.6	45.0	.235	.240	6.64
2	4.23	33.90	4.94	96.0	97.00	1.27	1.20	33.6	40.3	.480	.482	12.85
BT	6.48				127.00		1.10	33.3	36.7	.699	.699	18.49
3	6.73	14.70	4.96	95.0	123.50	1.14	1.07	33.3	35.7	.723	.721	18.49
4	9.43	13.50	4.98	95.7	121.50	1.07	1.07	33.1	35.4	.968	.730	18.31
5	12.10	13.00	4.98	95.3	119.50	1.07	1.07	33.4	35.7	1.212	.736	17.86
6	14.77	12.70	4.98	96.0	118.50	1.07	1.07	33.6	36.0	1.457	.740	17.58
7	17.65	12.45	4.98	105.2	119.00	1.07	1.07	34.1	36.5	1.726	.743	17.42
8	20.22	12.25	4.98	93.8	118.00	1.07	1.07	34.1	36.5	1.966	.745	'17.25
9	22.82	12.20	4.98	95.1	117.50	1.07	1.07	34.2	36.6	2.209	.746	17.16

Krw - INITIAL = .505
Kro - FINAL = .837

Table E.13 Oil Displacement Calculations – Run 1/15

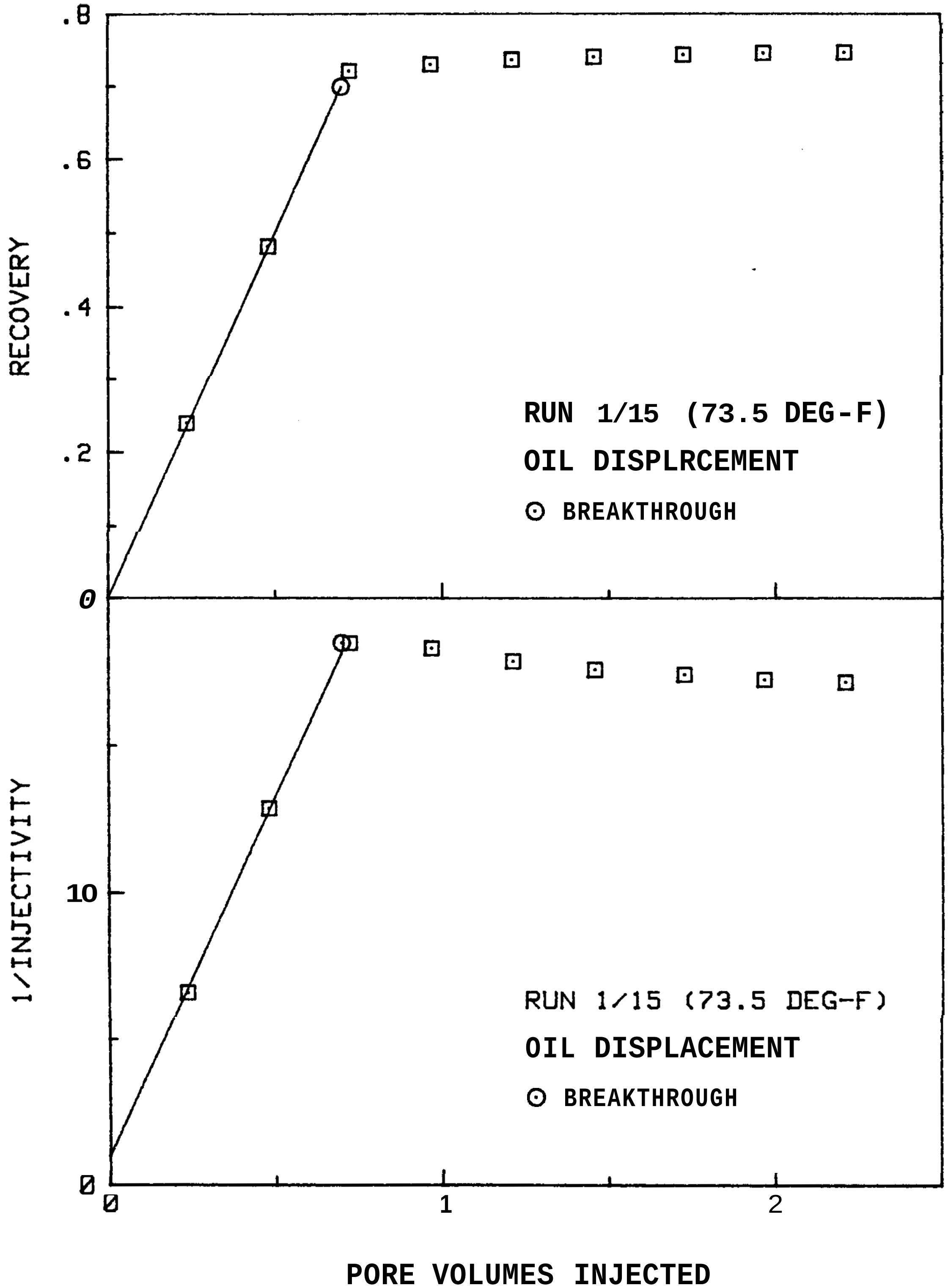


figure E.31 Recovery and 1/Injectivity vs. Pore Volumes Injected – Run 1/15

DISPLACEMENT EXPERIMENT CALCULATIONS

PORE VOLUME	390.8 cc	DATE	4/15/84
CORE LENGTH	51.46 cm	CORE/RUN	1/16
CORE DIAMETER	5.044 cm	DISPLACEMENT	Salt W-OIL
DEAD VOL'S: U	2.2 cc	CORE TEMPERATURE	74.0 F
D	3.0 cc	OUTLET TEMPERATURE	74.0 F
SEPARATOR OUTLET	82.72 cm	WATER VISCOSITY	.956 cp
BUBBLE VELOCITY	10.69 cm/sec	OIL VISCOSITY	27.03 cp
ABSOLUTE PERM	6.412 darcies	VISCOSITY RATIO	28.27
INIT SAT - WATER	6.5 %	WATER DENSITY RATIO	1.0000
FINAL SAT - OIL	19.8 %	OIL DENSITY RATIO	1.0000

	TIME (min)	SEPARATOR HEIGHT (cm)	SEPARATOR CALIB (cc/cm)	D-VOL INJ (cc)	D-P (psi)	FLOWRATE CHART AVG	FLOWRATE CHART @t	FLOWRATE CHART CAL	FLOWRATE cc/min	PVi	Rec	Inj
ST		13.00										
0	0.00	12.50	4.96	0.0	65.00	.60	.60	38.4	23.0	0.000	.000	1.00
1	3.58	30.40	4.96	87.9	50.00	.65	.66	38.4	25.3	.219	.219	1.43
BT	5.18				38.50		.67	38.4	25.7	.327	.327	1.89
2	7.33	47.10	4.98	98.6	28.00	.69	.70	38.4	26.9	.472	.427	2.71
3	10.82	55.00	4.97	97.6	17.00	.71	.72	39.5	28.4	.721	.524	4.72
4	14.23	57.70	4.96	96.9	14.00	.73	.73	38.9	28.4	.969	.556	5.72
5	17.63	59.60	4.96	97.9	12.50	.74	.74	38.9	28.8	1.220	.580	6.50
6	21.03	61.00	4.96	99.2	11.50	.74	.75	39.4	29.6	1.474	.598	7.26
7	24.37	62.20	4.96	97.9	10.50	.75	.75	39.2	29.4	1.724	.613	7.89
8	27.68	63.20	4.97	97.0	9.50	.75	.75	39.0	29.2	1.972	.626	8.69
9	31.45	64.15	4.98	110.8	9.00	.75	.75	39.2	29.4	2.256	.638	9.22
10	34.68	64.90	4.98	96.4	9.00	.75	.75	39.8	29.8	2.503	.647	9.35
11	37.87	65.60	4.98	95.4	8.50	.75	.75	40.0	30.0	2.747	.656	9.95
12	41.15	66.20	4.98	99.0	8.00	.75	.75	40.2	30.2	3.000	.664	10.64
13	56.90	68.40	4.98	478.0	7.50	.75	.75	40.5	30.3	4.223	.692	11.42
14	72.32	70.00	4.98	478.0	6.50	.75	.75	41.3	31.0	5.446	.712	13.46
15	87.32	71.10	4.98	463.0	6.00	.75	.75	41.2	30.9	6.631	.726	14.52
16	102.18	71.90	4.98	473.0	6.00	.75	.75	42.4	31.8	7.841	.736	14.97
17	105.13	72.00	4.98	94.5	6.00	.75	.75	42.7	32.0	8.083	.737	15.07

CURVE FITS	C0	C1	C2	%E-MAX	%E-AVG
Recovery	5.5907E-01	1.0471E-01	-9.0309E-03	.2	.1
Inj. X Pore Vol. Inj.	1.7598E+00	1.6074E+00	-7.1213E-02	5.3	1.3

	PVi	R-ACT	R-CALC	R-%E	I*P-ACT	I*P-CALC	I*P-%E	SW	Krw	Kro	Kw/Ko
								,065	0.000	.942	0.000
BT		.327	.476		.62	1.70					
3	.721	.524	.524	.0	3.40	3.41	.3	.478	.081	.413	.195
4	.969	.556	,556	.1	5.54	5.53	.3	.516	.105	,362	.290
5	1.220	.580	.580	.1	7.93	7.98	.6	.543	.127	.323	.391
6	1.474	.598	.598	.1	10.69	10.72	.3	,566	.146	.293	.498
7	1.724	.613	.613	.1	13.61	13.66	.3	.584	.163	.268	.608
8	1.972	.626	.626	.1	17.14	16.76	2.2	.599	.179	.248	.719
9	2.256	.638	.638	.1	20.81	20.50	1.5	.613	.195	.229	.851
10	2.503	.647	.648	.1	23.40	23.91	2.2	.624	.208	.215	,969
11	2.747	.656	.656	.0	27.33	27.42	.3	.634	.220	.202	1.088
12	3.000	.664	.663	.0	31.91	31.18	2.3	.643	.232	.191	1.215
13	4.223	.692	.691	.0	48.23	50.79	5.3	.677	.280	.151	1.863
14	5.446	.712	.711	.2	73.32	72.22	1.5	.701	.319	.124	2.565
15	6.631	.726	.725	.1	96.28	94.24	2.1	.719	.350	.106	3.290
16	7.841	.736	.736	.1	117.35	117.70	.3	.734	.377	.093	4.073
17	8.083	.737	.738	.2	121.80	122.49	.6	.736	.382	.090	4.235

Table E.14 Water Displacement Calculations - Run 1/16

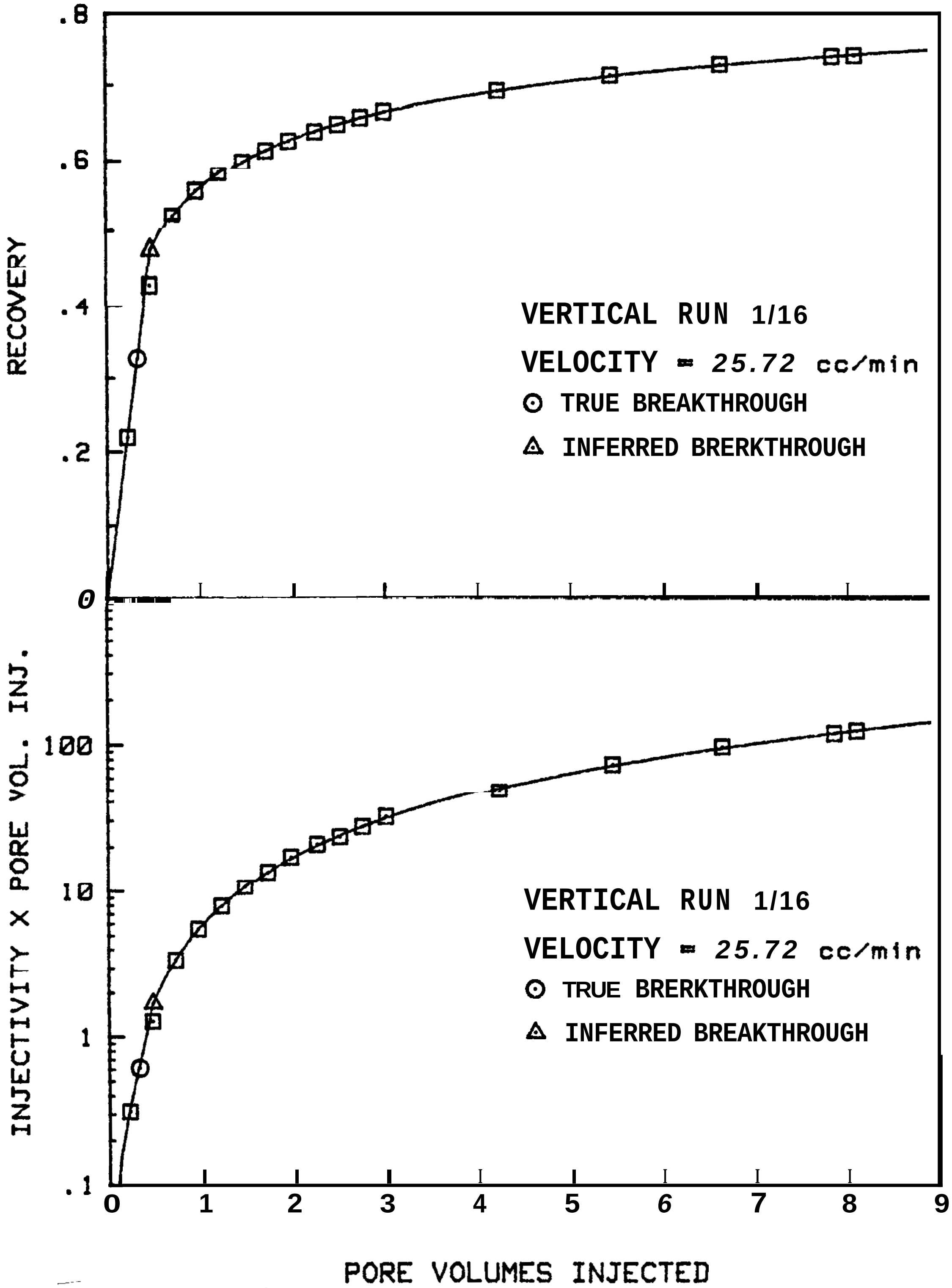


figure E.32 Recovery and Injectivity x Pore Volumes Injected vs. Pore Volumes Injected -- Run 1/16

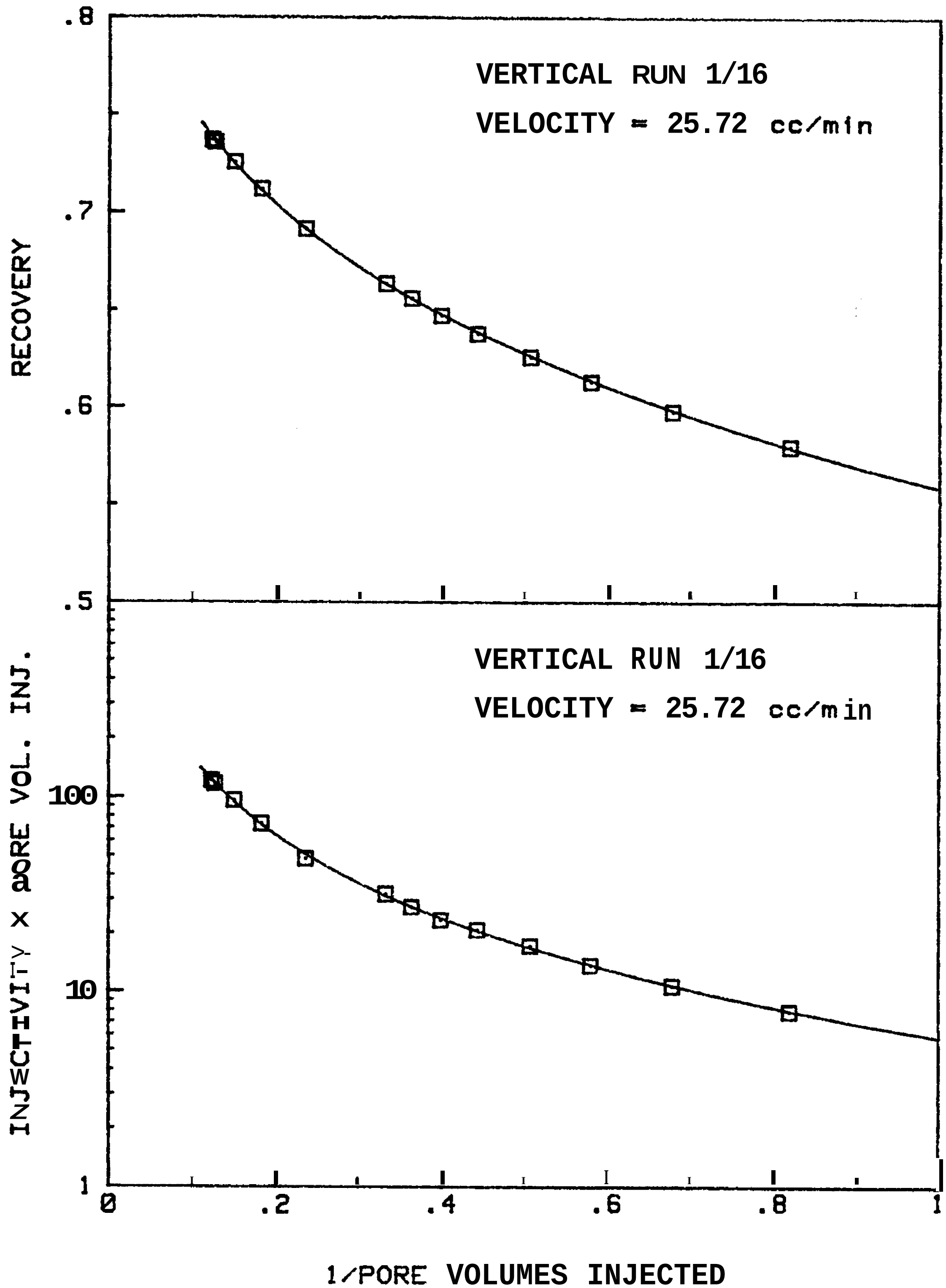


Figure E.33 Recovery *and Injectivity* x Pore *Volumes Injected* vs.
1/Pore *Volumes Injected – Run* 1/16

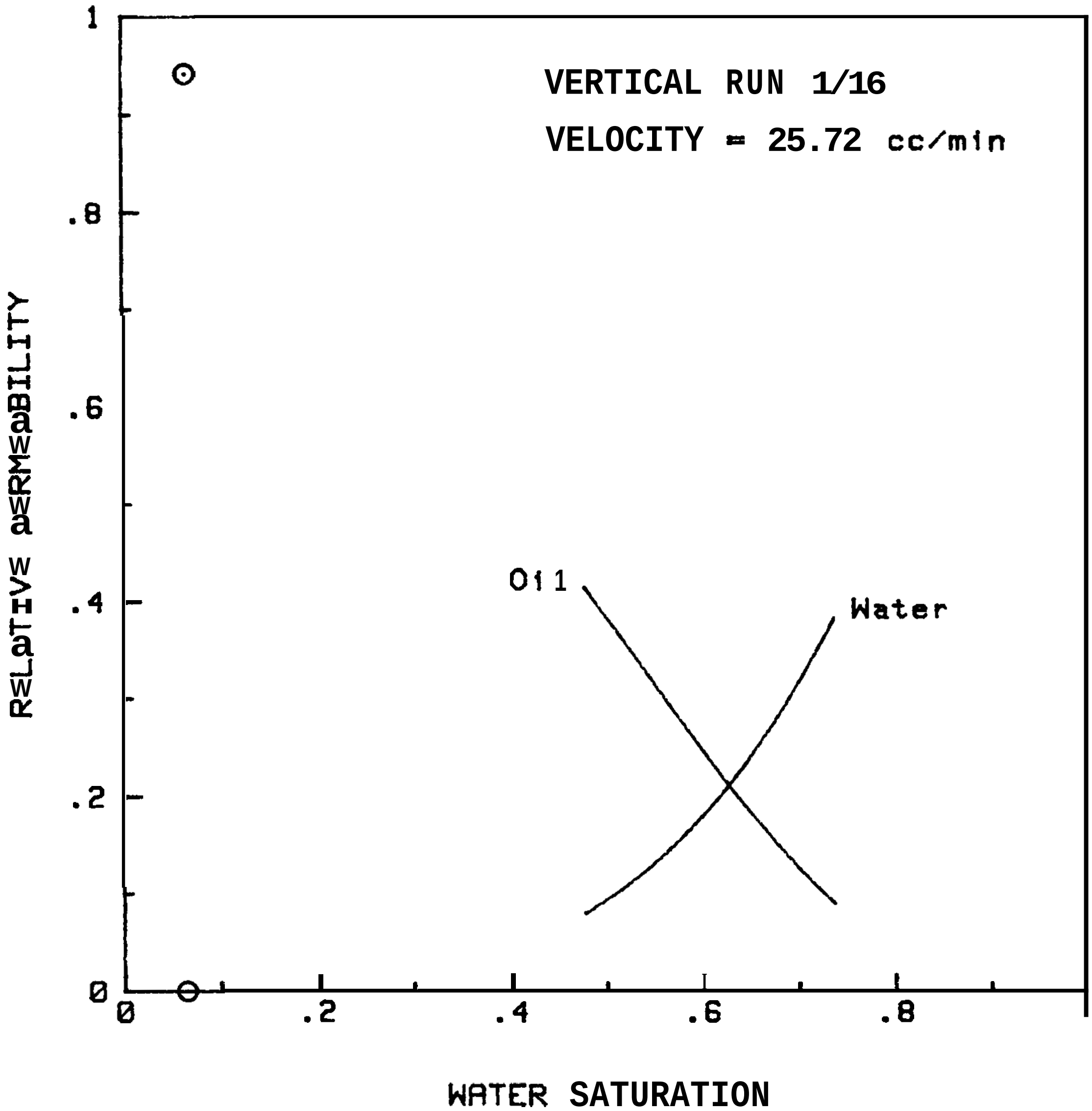


figure E.34 Relative Permeabilities vs. Water Saturation – Run 1/16

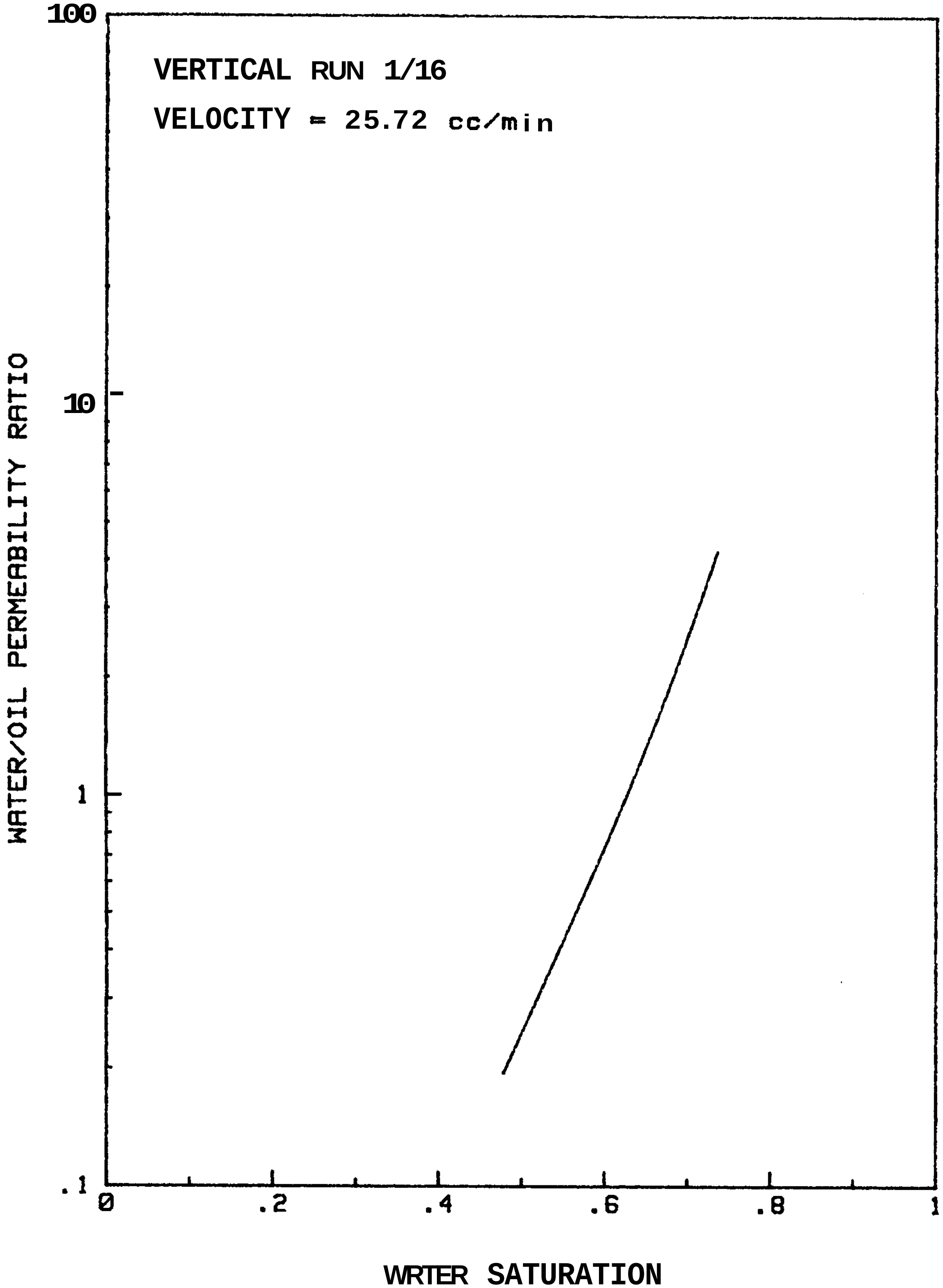


Figure E.35 Relative Permeability Ratio vs. Water Saturation – Run 1/16

Appendix F: COMPUTER PROGRAM (DSPCLC)

DSPCLC is a program written in BASIC by Miller (1983). A few labelling changes were made to better suit this study. The program was run on a Hewlett-Packard 9845B mini-computer. From the raw displacement data, recovery and relative injectivity versus pore volumes injected are calculated. The program also will generate a curve fit for the recovery and injectivity data, and calculate relative permeability relationships. Hard copy graphs can then be generated on a Hewlett-Packard 9872B plotter.

F.1 Flow Chart

PROGRAM DSPCLC

"DATA: MANUAL ENTRY (M) OR FROM TAPE (T) ?"

M

(✱) "DATE ?"

"DISPLACING **FLUID** (O/W) ?"

"CORE TEMP **(D-F)** ?"

"OUTLET TEMP (D-F) ?"

"PORE VOLUME **(cc) ?"**

"CORE LENGTH **(cm) ?"**

"CORE DIAMETER **(cm) ?"**

"ABSOLUTE PERMEABILITY **(darcies) ?"**

"DEAD VOLUMES **(cc): U,D ?"**

"SEPARATOR OUTLET HEIGHT ***(cm)*** ?"

"INITIAL SATURATION *(X)* ?"

"INITIAL STATIC SEPARATOR HEIGHT (cm) ?"

"INITIAL DYNAMIC SEPARATOR HEIGHT ***(cm)*** ?"

"INITIAL D-PRESSURE **(psi) ?"**

'*INITIAL FLOWMETER READING ?"

"BREAKTHROUGH TIME **(Note:** ENTER IN FRACTIONAL MINUTES) ?"

"BREAKTHROUGH D-PRESSURE **(psi) ?"**

"BREAKTHROUGH FLOWMETER READING ?"

T

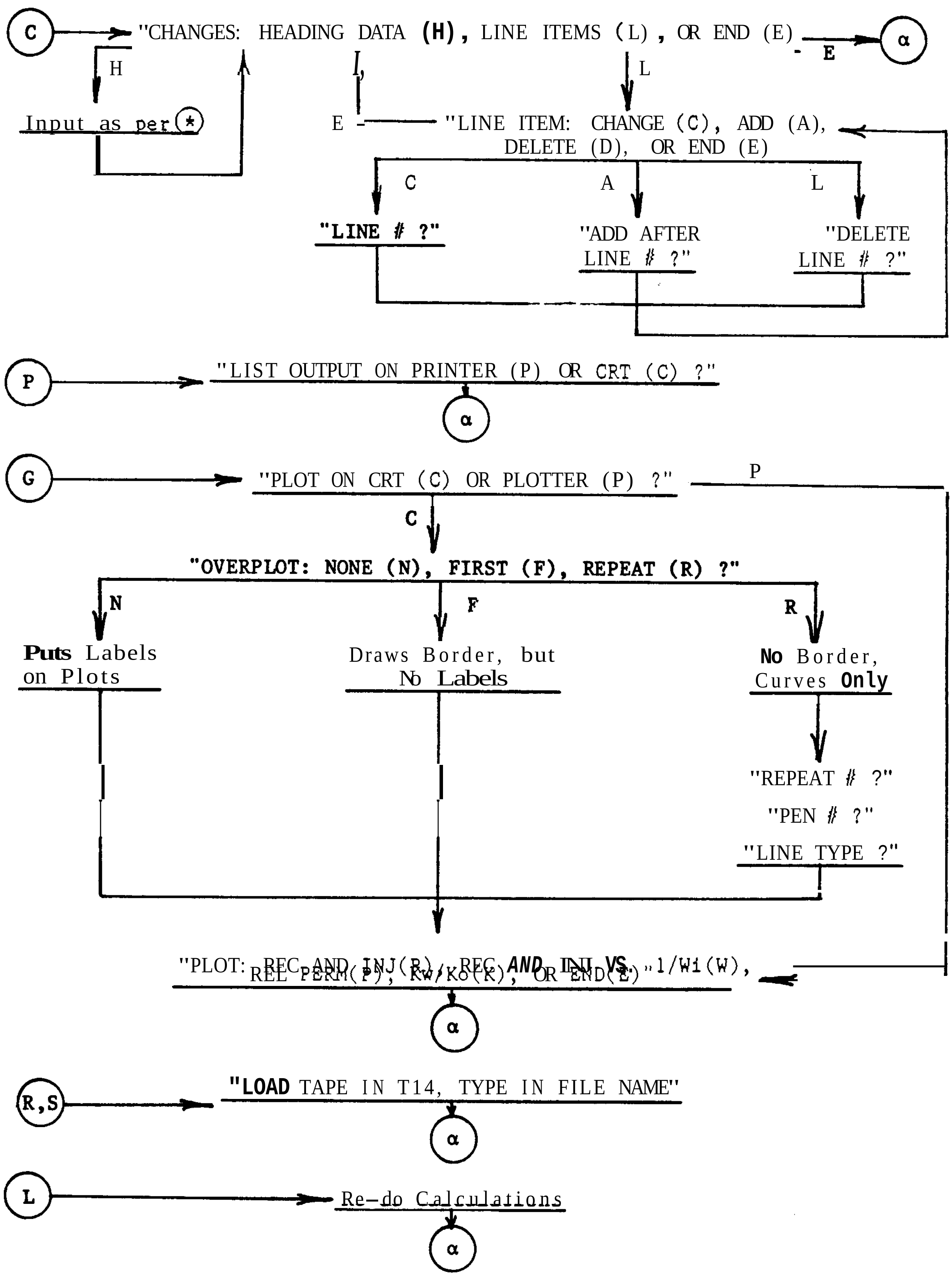
"LOAD TAPE IN T14, TYPE IN FILE **NAME"**

"SEPARATOR CALIBRATION DATA: HEIGHT **(cm)**, D-VOL **(cc)** [NEG. HEIGHT TO END] ?"

"TIME(HR,MIN.SEC),SEP-H(cm),D-VOL INJ(cc), D-PRESS(psi),FLWMTR AVE, FLWMTR @ t ?"

(α) — **"CHANGES(C), PRINT(P), PLOT(G), STORE(S), RE-STORE(R), RE-CALC(L), OR END(E) ?"** — E → **stop**

(C) **(P)** **(G)** **(S,R)** **(L)**


C
"CHANGES: HEADING DATA (H), LINE ITEMS (L), OR END (E)
E
α
H
L
Input as per (*)
E
"LINE ITEM: CHANGE (C), ADD (A), DELETE (D), OR END (E)
C
A
L
"LINE # ?"
"ADD AFTER LINE # ?"
"DELETE LINE # ?"
P
"LIST OUTPUT ON PRINTER (P) OR CRT (C) ?"
α
G
"PLOT ON CRT (C) OR PLOTTER (P) ?"
P
C
"OVERPLOT: NONE (N), FIRST (F), REPEAT (R) ?"
N
F
R
Puts Labels on Plots
Draws Border, but No Labels
No Border, Curves Only
"REPEAT # ?"
"PEN # ?"
"LINE TYPE ?"
"PLOT: REC AND INJ(R), REC AND INJ VS. 1/Wi(W), REL PERM(P), Kw/Ko(K), OR END(E)
α
R,S
"LOAD TAPE IN T14, TYPE IN FILE NAME"
α
L
Re-do Calculations
α

F.2 A Listing of the Computer Program - DSPCLC

```
10    ! PROGRAM DSPCLC
20    DIM Date$[10],Fluid$[10],Fld$[5],Fldd$[5],Core$[10],Ic$[1],Id$[1],If1$[6],
If$[1],Ia$[1],Ii$[1],Iwtyp$[1],Wat$[6]
30    DIM Time(100),Tim(100),Seph(100),Tbcal(100),Op(100),Cop(100),Delv(100),Fma
vg(100),Fmt(100),Fmc(100),Dp(100),Q(100),Wi(100),Rec(100),Inj(100)
40    DIM Hs(7),Dvs(7),Hsc(7),Dvsc(7),Tbsc(7),Pctr(100),Pctp(100)
50    DIM S(100),Krw(100),Kro(100),Kwko(100),Drr(2),Drp(2),Ar(2,2),Ap(2,2),Ai(2,
2),Br(2),Bp(2)
60    COM Cr(2),Cp(2)
70    INTEGER N,Nsc
80    !           PAPER TYPE (1 = 8.5x11, 2 = 11x12.5)
90    Paper=2
100   !           PEN FOR BORDER
110   Pb=1
120   !           BASE RELATIVE PERMEABILITY (0=Absolute, 1=Ko@Swi)
130   Ibs=0
140   !           PLOTTING SPEED
150   Spd=10
160   Ltype=1
170   DEG
180   Del=2
190   Nv=2
200   Flag=0
210   PRINTER IS 16
220   PRINT PAGE
230   INPUT "DATA: MANUAL ENTRY (M) OR FROM TAPE (T) ?",Id$
240   IF Id$="T" THEN GOSUB Tape
250   IF Id$="M" THEN GOSUB Man
260   INPUT "CHANGES(C), PRINT(P), PLOT(G), STORE(S), RE-STORE(R), RE-CALC(L), O
R END(E) ?",Id$
270   IF Id$="E" THEN STOP
280   IF Id$="C" THEN GOSUB Chg
290   IF Id$="P" THEN GOSUB Prnt
300   IF Id$="G" THEN GOSUB Plot
310   IF Id$="S" THEN GOSUB Str
320   IF Id$="R" THEN GOSUB Rrtr
330   IF Id$="L" THEN GOSUB Calc
340   GOTO 260
350   ! ******************************* INPUT NEW DATA ***********************
360 Man:  GOSUB 380
370   GOTO 710
380   INPUT "DATE ?",Date$
390   INPUT "CORE/RUN ?",Core$
400   INPUT "DISPLACING FLUID (O/W) ?",If$
410   INPUT "WATER TYPE (D=DISTILLED, S=SALT) ?",Iwtyp$
420   INPUT "CORE TEMP (D-F) ?",Tc
430   INPUT "OUTLET TEMP (D-F) ?",Te
440   INPUT "PORE VOLUME (cc) ?",Pv
450   INPUT "CORE LENGTH (cm) ?",Lc
460   INPUT "CORE DIAMETER (cm) ?",Dc
470   INPUT "ABSOLUTE PERMEABILITY (darcies) ?",Kabs
480   INPUT "DEAD VOLUMES (cc): U,D ?",U,D
490   INPUT "SEPARATOR OUTLET HEIGHT (cm) ?",Ho
500   INPUT "INITIAL SATURATION (%) ?",Sati
510   INPUT "INITIAL STATIC SEPARATOR HEIGHT (cm) ?",Seps
520   INPUT "INITIAL DYNAMIC SEPARATOR HEIGHT (cm) ?",Seph(0)
530   INPUT "INITIAL D-PRESSURE (psi) ?",Dp(0)
540   INPUT "INITIAL FLOWMETER READING ?",Fmt(0)
550   INPUT "BREAKTHROUGH TIME (Note: ENTER IN FRACTIONAL MINUTES) ?",Tbt
560   INPUT "BREAKTHROUGH D-PRESSURE (psi) ?",Dpbt
570   INPUT "BREAKTHROUGH FLOWMETER READING ?",Fmbt
580   PRINTER IS 16
590   PRINT USING 600
600   IMAGE 6X,"Hs",5X,"Dvs"/
610   FOR I=0 TO 6
620   INPUT "SEPARATOR CALIBRATION DATA: HEIGHT (cm), D-VOL (cc) (NEG. HEIGHT T
```

```
0 END] ?",Hs(I),Dvs(I)
630   IF Hs(I)<0 THEN 690
640   PRINT USING "D,2X,3D.2D,2X,3D.D";I,Hs(I),Dvs(I)
650   NEXT I
660   PRINT "MAX NUMBER (6) OF CALIBRATION DATA REACHED"
670   BEEP
680   I=6
690   Nsc=I-1
700   RETURN
710   PRINT "       Time   Seph   Delv     Dp   Fmavg    Fmt"
720   PRINT USING "4X,4D.2D,2X,2D.2D,8X,3D.3D,9X,D.3D";Time(0),Seph(0),Dp(0),Fmt
(0)
730   N=0
740   FOR I=1 TO 100
750   INPUT "TIME(HR,MIN.SEC),SEP-H(cm),D-VOL INJ(cc),D-PRESS(psi),FLWMTR AVG,FL
WMTR @ t,?",Time(I),Seph(I),Delv(I),Dp(I),Fmavg(I),Fmt(I)
760   IF Time(I)<0 THEN 840
770   N=N+1
780   PRINT USING 790;I,Time(I),Seph(I),Delv(I),Dp(I),Fmavg(I),Fmt(I)
790   IMAGE 2D,2X,4D.2D,2X,2D.2D,2X,3D.D,X,3D.3D,2X,D.3D,2X,D.3D
800   BEEP
810   NEXT I
820   PRINT "MORE THAN 100 DATA POINTS"
830   BEEP
840   RETURN
850   ! *********************** CHANGES **************************************
860 Chg:  INPUT "CHANGES: HERDING DATA (H), LINE ITEMS (L), OR END (E) ?",Id$
870   IF Id$="E" THEN 1250
880   IF Id$="L" THEN 910
890   GOSUB 380
900   GOTO 860
910   INPUT "LINE ITEM: CHANGE (C), ADD (A), DELETE (D), OR END (E) ?",Id$
920   IF Id$="E" THEN 860
930   IF Id$="C" THEN 960
940   IF Id$="A" THEN 1000
950   IF Id$="D" THEN 1140
960   INPUT "LINE I) ?",I
970   INPUT "TIME,SEP-H,D-VOL,D-PRESS,FLOWMTR-AVG,FLOWMTR@t",Time(I),Seph(I),Del
v(I),Dp(I),Fmavg(I),Fmt(I)
980   PRINT USING 790;I,Time(I),Seph(I),Delv(I),Dp(I),Fmavg(I),Fmt(I)
990   GOTO 910
1000  INPUT "ADD AFTER LINE # ?",Iadd
1010  N=N+1
1020  FOR I=N TO Iadd+2 STEP -1
1030  Time(I)=Time(I-1)
1040  Seph(I)=Seph(I-1)
1050  Delv(I)=Delv(I-1)
1060  Dp(I)=Dp(I-1)
1070  Fmavg(I)=Fmavg(I-1)
1060  Fmt(I)=Fmt(I-1)
1090  NEXT I
1100  I=Iadd+1
1110  INPUT "TIME,SEP-H,D-VOL,D-PRESS,FLOWMTR-AVG,FLOWMTR@t",Time(I),Seph(I),Del
v(I),Dp(I),Fmavg(I),Fmt(I)
1120  PRINT USING 790;I,Time(I),Seph(I),Delv(I),Dp(I),Fmavg(I),Fmt(I)
1130  GOTO 910
1140  INPUT "DELETE LINE # ?",Idel
1150  FOR I=Idel TO N-1
1160  Time(I)=Time(I+1)
1170  Seph(I)=Seph(I+1)
1180  Delv(I)=Delv(I+1)
1190  Dp(I)=Dp(I+1)
1200  Fmavg(I)=Fmavg(I+1)
1210  Fmt(I)=Fmt(I+1)
1220  NEXT I
1230  N=N-1
```

```
1240  GOTO 910
1250  Flag=0
1260  RETURN
1270  ! ********************** STORE DATA ON TAPE ******************************
1280 Str: ON ERROR GOTO El
1290  INPUT "LOAD TAPE IN T14, TYPE IN FILE NAME",Ifl$
1300  CREATE Ifl$&":T14",6+N,56
1310  GOSUB Rstr
1320  OFF ERROR
1330  RETURN
1340 El: BEEP
1350  DISP "NAME UNACCEPTABLE ----- ";
1360  GOTO 1290
1370 Rstr: ASSIGN #1 TO Ifl$&":T14"
1380  PRINT #1;Date$,Core$,If$,N,Nsc,Dpbt
1390  PRINT #1;Tc,Te,Pv,Lc,Dc,Tbt,Fmbt
1400  PRINT #1;Ho,Kabs,U,D,Seps,Sati,Iwtyp$
1410  PRINT #1;Hs(*)
1420  PRINT #1;Dvs(*)
1430  FOR I=0 TO N
1440  PRINT #1;Time(I),Seph(I),Delv(I),Dp(I),Fmavg(I),Fmt(I)
1450  NEXT I
1460  PRINT #1;END
1470  ASSIGN #1 TO *
1480  RETURN
1490  ! ****************** READ DATA FROM TAPE **********************
1500 Tape: INPUT "LOAD TAPE IN T14. TYPE IN FILE NAME",Ifl$
1510  ASSIGN #1 TO Ifl$&":T14"
1520  READ #1;Date$,Core$,If$,N,Nsc,Dpbt
1530  READ #1;Tc,Te,Pv,Lc,Dc,Tbt,Fmbt
1540  READ #1;Ho,Kabs,U,D,Seps,Sati,Iwtyp$
1550  READ #1;Hs(*)
1560  READ #1;Dvs(*)
1570  FOR I=0 TO N
1580  READ #1;Time(I),Seph(I),Delv(I),Dp(I),Fmavg(I),Fmt(I)
1590  NEXT I
1600  RETURN
1610  ! ************************** CALCULATIONS ****************************
1620 Calc: Ck=4*Lc/(PI*Dc*Dc*4.0827)
1630  Iwt=1
1640  Wat$="Dist W"
1650  IF Iwtyp$="D" THEN 1680
1660  Iwt=2
1670  Wat$="Salt W"
1680  CALL Watp(Tc,Rhow,Muw,Iwt)
1690  CALL Oilp(Tc,Rhoo,Muo)
1700  CALL Watp(Te,Rhowe,M,Iwt)
1710  CALL Oilp(Te,Rhooe,M)
1720  Drw=Rhowe/Rhow
1730  Dro=Rhooe/Rhoo
1740  Mur=Muo/Muw
1750  IF If$="O" THEN 1810
1760  Fld$="WATER"
1770  Fluid$=Wat$&"-OIL"
1780  Drd=Drw
1790  Dre=Dro
1800  GOTO 1850
1810  Fluid$="OIL-"&Wat$
1820  Fld$="OIL"
1830  Drd=Dro
1840  Dre=Drw
1850  Time(0)=0
1860  Fmavg(0)=Fmt(0)
1870  Delv(0)=0
1880  Tim(0)=0
1890  Cop(0)=0
```

```
1900  Wi(0)=0
1910  Rec(0)=0
1920  Inj(0)=1
1930  !                      SEPARATOR CALIBRATION
1940  Op(0)=0
1950  FOR I=1 TO N
1960  Op(I)=ABS(Seph(I)-Seps)
1970  NEXT I
1980  IF Hs(Nsc)-Seps>20 THEN 2100
1990  Sign=1
2000  IF Seps>Hs(1) THEN Sign=-1
2010  FOR I=0 TO Nsc-1
2020  Hsc(Nsc-I)=Sign*(Hs(I)-Seps)
2030  Tbsc(Nsc-I)=Dvs(I+1)/ABS(Hs(I)-Hs(I+1))
2040  NEXT I
2050  IF Nsc>1 THEN 2080
2060  Hsc(1)=Sign*(Hs(0)-Seps)
2070  Tbsc(1)=Dvs(1)/ABS(Hs(0)-Hs(1))
2080  Hsc(0)=Sign*(Hs(Nsc)-Seps)
2090  GOTO 2150
2100  FOR I=1 TO Nsc
2110  Hsc(I)=Hs(I)-Seps
2120  Tbsc(I)=Dvs(I)/ABS(Hs(I)-Hs(I-1))
2130  NEXT I
2140  Hsc(0)=Hs(0)-Seps
2150  Tbsc(0)=Tbsc(1)
2160  FOR I=1 TO Nrc
2170  IF Hsc(I)>0 THEN 2190
2180  NEXT I
2190  Is=I-1
2200  IF Nsc=1 THEN Is=0
2210  Hsc(Is)=0
2220  FOR I=Nsc-1 TO 0 STEP -1
2230  IF Hsc(I)<Op(N) THEN 2250
2240  NEXT I
2250  If=I+1
2260  Hsc(If)=Op(N)
2270  J=1
2280  FOR I=Is+1 TO If
2290  IF Op(J)>Hsc(I) THEN 2340
2300  Tbcal(J)=Tbsc(I)
2310  J=J+1
2320  IF J<=N THEN 2290
2330  J=N
2340  Dop=(Hsc(I)-Op(J-1))*Tbsc(I)
2350  FOR K=I+1 TO If
2360  IF Hsc(K)>Op(J) THEN 2400
2370  Dop=Dop+(Hsc(K)-Hsc(K-1))*Tbsc(K)
2380  NEXT K
2390  GOTO 2410
2400  Dop=Dop+(Op(J)-Hsc(K-1))*Tbsc(K)
2410  IF Op(J)=Op(J-1) THEN Op(J-1)=Op(J)-.00001
2420  Tbcal(J)=Dop/(Op(J)-Op(J-1))
2430  I=K-1
2440  J=J+1
2450  NEXT I
2460  Tbcal(0)=Tbcal(1)
2470  !                                BUBBLE CORRECTION
2480  Qo=Fmt(0)*Delv(1)/FNTcon(Time(1))/Fmavg(1)
2490  Vbi=1/(Qo*ABS(Seph(0)-Ho))*ABS(Seph(0)-Seps)*Tbcal(0)
2500  !
2510  Sdv=0
2520  Ni=N
2530  FOR I=1 TO N
2540  Tim(I)=FNTcon(Time(I))
2550  Dt=Tim(I)-Tim(I-1)
```

```
2560 Sdv=Sdv+Delv(I)
2570 Cop(I)=Cop(I-1)+(Op(I)-Op(I-1))*Tbcal(I)
2580 Wi(I)=(Cop(I)*(Dre-Drd)-U+Sdv*Drd)/Pv
2590 Qavg=(Wi(I)-Wi(I-1))*Pv/Dt
2600 Fmc(I)=Qavg/Fmavg(I)
2610 Q(I)=Fmt(I)*Fmc(I)
2620 NEXT I
2630 Fmc(1)=Fmc(2)
2640 Q(1)=Fmc(1)*Fmt(1)
2650 Fmc(0)=Fmc(1)
2660 Q(0)=Fmc(0)*Fmt(0)
2670 Inji=Q(0)/Dp(0)
2680 FOR I=1 TO N
2690 IF Dp(I)>0 THEN 2730
2700 Dp(I)=-.0001
2710 Inj(I)=-.0001
2720 GOTO 2740
2730 Inj(I)=Q(I)/Dp(I)/Inji
2740 Qdqt=1
2750 IF I<N THEN Qdqt=1-(Cop(I+1)-Cop(I-1))*Dre/(Wi(I+1)-Wi(I-1))/Pv
2760 Cop(I)=Cop(I)+(1-Qdqt)*Q(I)*ABS(Seph(I)-Ho)*Vbi
2770 Rec(I)=(Cop(I)*Dre-U-D*Qdqt)/Pv
2780 NEXT I
2790 FOR I=1 TO N
2800 IF Tim(I)>Tbt THEN 2820
2810 NEXT I
2820 Isabt=I
2830 Isc=Isabt+1
2840 Fmcbt=Fmc(I)
2850 Qbt=Fmbt*Fmcbt
2860 Wibt=Wi(I-1)+(Wi(I)-Wi(I-1))*(Tbt-Tim(I-1))/(Tim(I)-Tim(I-1))
2870 Recbt=Wibt
2880 Injbt=Qbt/Dpbt/Inji
2890 Satf=(1-Rec(N))*100-Sati
2900 IF If$="O" THEN 3490
2910 !                                    CURVE FIT CALCULATIONS
2920 MAT Cr=ZER
2930 MAT Cp=ZER
2940 MAT Br=ZER
2950 MAT Bp=ZER
2960 MAT Ar=ZER
2970 MAT Ap=ZER
2980 FOR I=Isc TO N
2990 FOR K=0 TO Nu
3000 Drr(K)=LOG(Wi(I))^K
3010 Drp(K)=LOG(Wi(I))^K
3020 Br(K)=Br(K)+Rec(I)*Drr(K)
3030 IF Inj(I)>0 THEN Bp(K)=Bp(K)+LOG(Wi(I)*Inj(I))*Drp(K)
3040 NEXT K
3050 FOR K=0 TO Nu
3060 FOR L=K TO Nu
3070 Ar(K,L)=Ar(K,L)+Drr(K)*Drr(L)
3080 IF Inj(I)>0 THEN Ap(K,L)=Ap(K,L)+Drp(K)*Drp(L)
3090 NEXT L
3100 NEXT K
3110 NEXT I
3120 FOR K=0 TO Nu
3130 FOR L=K+1 TO Nu
3140 Ar(L,K)=Ar(K,L)
3150 Ap(L,K)=Ap(K,L)
3160 NEXT L
3170 NEXT K
3180 HAT Ai=INV(Ar)
3190 MAT Cr=Ai*Br
3200 MAT Ai=INV(Ap)
3210 MAT Cp-Ai*Bp
```

```
3220  Pctmr=0
3230  Pctmp-0
3240  Spctr=0
3250  spctp=0
3260  FOR I=Isc TO N
3270  Rc=FNFr(Wi(I),1)
3280  Pctr(I)=ABS(Rc-Rec(I))*100/Rec(I)
3290  Spctr=Spctr+Pctr(I)
3300  IF Pctr(I)<Pctmr THEN 3340
3310  Pctmr=Pctr(I)
3320  Imr=I
3330  Rm=Rc
3340  IF Inj(I)<0 THEN 3450
3350  Ni=I
3360  Injc=Wi(I)*FNFi(Wi(I),1)
3370  Winjc=Wi(I)*Inj(I)
3380  Pctp(I)=ABS(Injc-Winjc)*100/Winjc
3390  Spctp=Spctp+Pctp(I)
3400  IF Pctp(I)<Pctmp THEN 3460
3410  Pctmp=Pctp(I)
3420  Imp=I
3430  Injm=Injc
3440  GOTO 3460
3450  Pctp(I)=-.001
3460  NEXT I
3470  Pctar=Spctr/(N-Isabt+1)
3480  Pctap=Spctp/(Ni-Isabt+1)
3490  IF If$="O" THEN 3530
3500  Ko=Ck*Q(0)*Muo/Dp(0)
3510  Kw=Ck*Q(Ni)*Muw/Dp(Ni)
3520  GOTO 3550
3530  Kw=Ck*Q(0)*Muw/Dp(0)
3540  Ko=Ck*Q(Ni)*Muo/Dp(Ni)
3550  Kroswi=1
3560  IF Ibs=0 THEN Kroswi=Ko/Kabs
3570  IF If$="O" THEN 3800
3580  FOR I=Isc TO N                    ! REL PERM CALCS
3590  W=Wi(I)
3600  R=FNFr(W,1)
3610  Fo=FNFr(W,2)
3620  IF Fo>0 THEN 3680
3630  Kwko(I)=9999.999
3640  S(I)=-.999
3650  Kro(I)=0
3660  Krw(I)=1
3670  GOTO 3790
3680  Kwko(I)=(1/Fo-1)/Mur
3690  S(I)=Sati/100+R-Fo*W
3700  IF Inj(I)>0 THEN 3740
3710  Kro(I)=-.0001
3720  Krw(I)=-.0001
3730  GOTO 3780
3740  Ir=FNFi(W,1)
3750  Dirdw=FNFi(W,2)
3760  Kro(I)=Fo/Dirdw*Kroswi
3770  Krw(I)=Kwko(I)*Kro(I)
3780  IF Kwko(I)>=10000 THEN Kwko(I)=9999.999
3790  NEXT I
3800  Wbt=Wibt
3810  IF If$="O" THEN 3900
3820  Wbtl=.5
3830  FOR I=1 TO 20
3840  Wbt=FNFr(Wbtl,1)
3850  IF ABS(Wbt-Wbtl)<.0001 THEN 3880
3860  Wbtl=Wbt
3870  NEXT I
```

```
3880  Inbt=FNFi(Wbt,1)
3890  GOTO 4020
3900  Sx=0
3910  Sx2=0
3920  Sxy=0
3930  IF Isabt>1 THEN 3960
3940  Inbt=Wbt
3950  GOTO 4020
3960  FOR I=1 TO Isabt-1
3970  Sx=Sx+Wi(I)
3980  Sx2=Sx2+Wi(I)^2
3990  Sxy=Sxy+Wi(I)/Inj(I)
4000  NEXT I
4010  Inbt=(Sxy-Sx)/Sx2*Wbt+1
4020  Flag=1
4030  RETURN
4040  ! ************************* PRINT OUTPUT ********************************
4050 Prnt:  INPUT "LIST OUTPUT ON PRINTER (P) OR CRT (C) ?",Ic$
4060  PRINTER IS 16
4070  IF Ic$="P" THEN PRINTER IS 0
4080  IF Flag=0 THEN GOSUB Calc
4090  PRINT USING 4100
4100  IMAGE 23X,"DISPLACEMENT EXPERIMENT CALCULATIONS"/
4110  PRINT USING 4120;Pv,Date$
4120  IMAGE "PORE VOLUME",7X,3D.D," cc",23X,"DATE",17X,10A
4130  PRINT USING 4140;Lc,Core$  .
4140  IMAGE "CORE LENGTH",7X,2D.2D," cm",23X,"CORE/RUN",13X,10A
4150  PRINT USING 4160;Dc,Fluid$
4160  IMAGE "CORE DIAMETER",5X,D.3D," cm",23X,"DISPLACEMENT     ",5X,10A
4170  PRINT USING 4180;U,Tc
4180  IMAGE "DEAD VOL'S:   U",6X,2D.D," cc",23X,"CORE TEMPERATURE",5X,3D.D," F"
4190  PRINT USING 4200;D,Te
4200  IMAGE 12X,"D",6X,2D.D," cc",23X,"OUTLET TEMPERATURE",3X,3D.D," F"
4210  PRINT USING 4220;Ho,Muw
4220  IMAGE "SEPARATOR OUTLET  ",2D.2D," cm",23X,"WATER VISCOSITY",6X,D.3D," cp"
4230  Vb=0
4240  IF Vbi<>0 THEN Vb=1/Vbi
4250  PRINT USING 4260;Vb/60,Muo
4260  IMAGE "BUBBLE VELOCITY",3X,2D.2D," cm/sec",19X,"OIL VISCOSITY",8X,2D.2D,"
cp"
4270  PRINT USING 4280;Kabs,Mur
4280  IMAGE "ABSOLUTE PERM",5X,D.3D," darcies",18X,"VISCOSITY RATIO",6X,2D.2D
4290  PRINT USING 4300;Fld$,Sati,Drw
4300  IMAGE "INIT SAT  - ",5A,  2X,2D.D," %",24X,"WATER DENSITY RATIO ",D.4D
4310  Fldd$="OIL"
4320  IF If$="O" THEN Fldd$="WATER"
4330  PRINT USING 4340;Fldd$,Satf,Dro
4340  IMAGE "FINAL SAT - ",5A,  2X,2D.D," %",24X,"OIL DENSITY RATIO",3X,D.4D/
4350  !
4360  PRINT USING 4370
4370  IMAGE 10X,"    SEPARATOR   "," D-VOL",8X,"        FLOWRRTE        " ,X
4380  PRINT USING 4390
4390  IMAGE 5X,"TIME HEIGHT  CALIB   INJ    D-P  ","     CHART      ",3X," cc"
4400  IF If$="O" THEN PRINT USING 4410
4410  IMAGE 3X," (min)  (cm)  (cc/cm)  (cc)  (psi)  AVG   @t  CAL
   min |   PVi   Rec 1/Inj",X,"|"
4420  IF If$="W" THEN PRINT USING 4430
4430  IMAGE 3X," (min)  (cm)  (cc/cm)  (cc)  (psi)  AVG   @t  CAL
   min |   PVi   Rec  Inj ",X,"|"
4440  PRINT USING 4450;Seps
4450  IMAGE "ST",9X,2D.2D,43X,"|",19X,"|"
4460  FOR I=0 TO Isabt-1 .
4470  In=Inj(I)
4480  IF If$="O" THEN In=1/In
4490  PRINT USING 4500;I,Tim(I),Seph(I),Tbcal(I),Delv(I),Dp(I),Fmavg(I),Fmt(I),F
mc(I),Q(I),Wi(I),Rec(I),In
```

```
4500  IMAGE 2D,X,3D.2D,2X,2D.2D,3X,D.2D,2X,3D.D,X,3D.2D,X,D.2D,X,D.2D,X,2D.D,2X,
2D.D,X,"|",X,2D.3D,X,.3D,X,2D.2D,X,"|"
4510  NEXT I
4520  In=Injbt
4530  IF If$="O" THEN In=1/In
4540  PRINT USING 4550;Tbt ,Dpbt ,Fmbt ,Fmcbt ,Qbt ,Wibt ,Recbt ,In
4550  IMAGE "BT",X,3D.2D,22X,3D.2D,6X,D.2D,X,2D.D,2X,2D.D,X,"|",X,2D.3D,X,.3D,X,
2D.2D,X,"|"
4560  FOR J=Isabt TO N
4570  In=Inj(J)
4580  IF If$="O" THEN In=1/In
4590  PRINT USING 4500;J,Tim(J),Seph(J),Tbcal(J),Delv(J),Dp(J),Fmavg(J),Fmt(J),F
mc(J),Q(J),Wi(J),Rec(J),In
4600  NEXT J
4610  IF If$="O" THEN 4830
4620  PRINT USING 4630
4630  IMAGE /"_____CURVE FITS_____",4X,"_____C0_____",2X,"_____C1_____",2X,"_
____C2_____",3X,"%E-MAX",X,"%E-AVG"
4640  PRINT USING 4650;"Recovery",Cr(*),Pctmr,Pctar
4650  IMAGE 21A,2X,3(MD.4DE,X),3X,2D.D,2X,2D.D
4660  PRINT USING 4650;"Inj. X Pore Vol. Inj.",Cp(*),Pctmp,Pctap
4670  PRINT USING 4680
4680  IMAGE /3X,"__PVi__ R-ACT R-CALC R-%E I*P-ACT I*P-CALC I*P-%E"
, 4X,"_Sw_",2X,"_Krw",2X,"_Kro",4X,"Kw/Ko"
4690  PRINT USING 4700;Sati/100,0,Krorwi,0
4700  IMAGE 55X, .3D,1X,D.3D,X,D.3D,4X,D.3D
4710  PRINT USING 4720;Wibt,Wbt,Wibt*Injbt,Wbt*Inbt
4720  IMAGE "BT",7X,D.3D,2X,D.3D,7X,3D.2D,2X,3D.2D
4730  FOR I=Isc TO N
4740  Rc=FNFr(Wi(I),1)
4750  Injc=Wi(I)*FNFi(Wi(I),1)
4760  IF Inj(I)<0 THEN Injc=-.0001
4770  In=Wi(I)*Inj(I)
4780  IF In<0 THEN In=-.0001
4790  PRINT USING 4800;I,Wi(I),Rec(I),Rc,Pctr(I),In,Injc,Pctp(I),ABS(S(I)),Krw(I
),Kro(I),Kwko(I)
4800  IMAGE 2D,X,2D.3D,X,.3D,3X,.3D,X,2D.D,2X,3D.2D,2X,3D.2D,4X,2D.D, 5X,.3D,X,D
.3D,X,D.3D,X,4D.3D
4810  NEXT I
4820  RETURN
4830  PRINT USING 4840;Kw/Kabs,Ko/Kabs
4846  IMAGE /"Krw - INITIAL =",D.3D/"Kro - FINAL   =",D.3D
4850  RETURN
4860  ! ************************ PLOTS *******************************************
4870 Plot: IF Flag=0 THEN GOSUB Calc
4880  INPUT "PLOT-ON CRT (C) OR PLOTTER (P) ?",Ic$
4890  Ia$="N"
4900  Pen=1
4910  IF Ic$="P" THEN 4970
4920  PLOTTER IS 13,"GRAPHICS"
4930  LIMIT 0,184.47,0,149.8
4940  Loct=97
4950  LOCATE 11,RATIO*100-3,11,97
4960  GOTO 5170
4970  PLOTTER IS "9872A"
4980  IF If$="W" THEN 5020
4990  Ia$="N"
5000  Id$="R"
5010  GOTO 5140
5020  INPUT "OVERPLOT: NONE (N), FIRST (F), REPEAT (R) ?",Ia$
5030  Pen=1
5040  Ltype=1
5050  Sz1=1
5060  Rep=1
5070  IF Ia$<>"R" THEN 5140
5080  INPUT "REPEAT # ?",Rep
```

```
5090  INPUT "PEN # ?",Pen
5100  INPUT "LINE TYPE ?",Ltype
5110  IF Ltype=6 THEN Szl=4
5120  IF Ltype=3 THEN Szl=.5
5130  IF Ltype=5 THEN Szl=2
5140  PRINTER IS 7,5
5150  PRINT "VS "&VAL$(Spd)
5160  PRINTER IS 16
5170  Wf=INT(Wi(N))+1
5180  Wfi=INT(Wi(Ni))+1
5190  IF If$="O" THEN Wf=INT(Wi(N)*2+1)/2
5200  Rf=INT(Rec(N)*5+1)/5
5210  Injm=MAX(INT(LGT(Inj(Ni)*Wi(Ni))+1),2)
5220  IF If$="O" THEN Injm=INT(1/Injbt/10+1)*10
5230  IF If$="O" THEN GOSUB Rec
5240  INPUT "PLOT: REC AND INJ(R), REC AND INJ VS. 1/Wi(W), REL PERM(P), Kw/Ko(K
), OR END(E)",Id$
5250  IF Id$="E" THEN 5320
5260  IF Id$="R" THEN GOSUB Rpc
5270  IF If$="O" THEN 5240
5280  IF Id$="W" THEN GOSUB Recwi
5290  IF Id$="P" THEN GOSUB Rel
5306  IF Id$="K" THEN GOSUB Kwko
5310  GOTO 5240
5320  GCLEAR
5330  EXIT GRAPHICS
5340  RETURN
5350  ! ************************ SET PLOT LIMITS ***************************
5360 V:  IF Ic$="C" THEN 5540
5370  Hp=8.5
5380  Vp=11
5390  Lm=1.5
5400  Rm=1
5410  Tm=1
5420  Bm-2
5430  IF Paper=1 THEN 5500
5440  Hp=11
5450  Vp=12.4
5460  Lm=2.3
5470  Rm=1.2
5480  Tm=1.2
5490  Bm=1.05
5500  GOSUB Lim
5510  Loct=100/RATIO-3
5520  LOCATE 11,97,11,Loct
5530  RETURN
5540  GRAPHICS
5550  Loct=97
5560  LOCATE 11,97,11,97
5570  RETURN
5580 Lim: Add=MIN((Hp-Lm-Rm)*25.4,(Vp-Tm-Bm)*25.4)/100
5590  LIMIT Lm*25.4-12-Add,(Hp-Rm)*25.4-12+3*Add,Bm*25.4-6-Add,(Vp-Tm)*25.4-6+3*
Add
5600  RETURN
5610  ! ************************** LOG SCALE ***********************************
5620 Logscl:  LDIR 0
5630  LORG 8
5640  CSIZE 3
5650  FOR Yex=Ks TO Kf-1
5660  MOVE Xs,Yex
5670  LABEL 10^Yex
5680  FOR Inc=2 TO 9
5690  MOVE Xs,LGT(Inc*10^Yex)
5700  SETGU
5710  RPLOT .5,0,-1
5720  SETUU
```

```
5730  NEXT Inc
5740  NEXT Yex
5750  RETURN
5760  ! *************************** RUN LABELS ****************************
5770 Lblrt:   LORG 3
5780  SETCU
5790  RPLOT -5,-5,-2
5800  SETUU
5810  CSIZE 3
5820  LABEL "HORIZONTAL RUN "&Core$
5830  GOSUB Lblv
5840  RETURN
5850 Lbllt:   LORG 3
5860  SETGU
5870  RPLOT 5,-5,-2
5880  SETUU
5890  CSIZE 3
5900  LABEL "HORIZONTAL RUN "&Core$
5910  GOSUB Lblu
5920  RETURN
5930 Lblrb:   LORG 3
5940  SETGU
5950  CSIZE 3
5960  LABEL "HORIZONTAL RUN "&Core$
5970  GOSUB Lblu
5971  SETGU
5980  IF If$="W" THEN 6010
5990  IPLOT 0,-2,-2
6000  LABEL "OIL DISPLACEMENT"
6010  IPLOT Del/2,-2,-2
6020  CALL Plsym(Del,2)
6030  SETGU
6040  RPLOT 3,0,-2
6050  LORG 2
6060  CSIZE 2.5
6070  Bthru$="TRUE BREAKTHROUGH"
6080  IF If$="O" THEN Bthru$="BREAKTHROUGH"
6090  LABEL Bthru$
6100  IF If$="O" THEN 6160
6110  IPLOT -3,-2,-2
6120  CALL Plsym(Del,3)
6130  SETGU
6140  RPLOT 3,0,-2
6150  LABEL "INFERRED BREAKTHROUGH"
6160  SETUU
6170  RETURN
6180 Lblv:   SETGU
6190  IPLOT 0,-2,-2
6200  SETUU
6201  FIXED 2
6210  LABEL "VELOCITY = "&VAL$(Qbt)&" cc/min"
6211  STANDARD
6212  SETUU
6220  RETURN
6230  ! ********************** RECOVERY AND INJECTIVITY PLOTS *****************
6240 Rcc:  GOSUB V
6250  PEN 1
6260  PEN Pb
6270  FRAME
6280  PEN 1
6290  LOCATE 11,97,(Loct+11)/2,Loct
6300  SCALE 0,Wf,0,Rf
6310  IF If$="W" THEN 6340
6320  AXES .5,.1,0,0,2,2,3
6330  GOTO 6350
6340  AXES 1,.1,0,0,1,2,3
```

```
6350  CALL Label(0,Wf,-1,0,Rf,.2,"","RECOVERY")
6360  MOVE 0,0
6370  IF If$="W" THEN 6400
6380  DRAW Wibt, Recbt
6390  GOTO 6490
6400  DRAW Wbt ,Wbt
6410  CALL Plsym(Del,3)
6420  IF If$="O" THEN 6480
6430  FOR W=Wbt TO Wf STEP .1
6440  R=FNFr(W,1)
6450  DRAW W,R
6460  NEXT W
6470  DRAW Wf,FNFr(Wf,1)
6480  MOVE Wibt,Rtcbt
6490  CALL Plsym(Del,2)
6500  FOR I=1 TO N
6510  MOVE Wi(I),Rec(I)
6520  CALL Plsym(Del,1)
6530  NEXT I
6540  MOVE Wf/2,Rf/2
6550  GOSUB Lblrb
6560  LOCATE 11,97,11,(Loct+11)/2          ! INJECTIVITY PLOT
6570  IF If$="W" THEN 6760
6580  SCALE 0,Wf,0,Injm                    ! OILFLOOD
6590  IF Injm<=10 THEN 6630
6600  AXES .5,5,0,0,2,2,3
6610  CALL Label(0,Wf,1,0,Injm,-10,"PORE VOLUMES INJECTED","1/INJECTIVITY")
6620  GOTO 6650
6630  AXES .5,1,0,0,2,2,3
6640  CALL Label(0,Wf,1,0,Injm,-2,"PORE VOLUMES INJECTED","1/INJECTIVITY")
6650  MOVE 0,1
6660  DRAW Wbt,Inbt
6670  MOVE Wibt,1/Injbt
6680  CALL Plsym(Del,2)
6690  FOR I=1 TO Ni
6700  MOVE Wi(I),1/Inj(I)
6710  CALL Plsym(Del,1)
6720  NEXT I
6730  MOVE Wf/2,Injm/2
6740  GOTO 7030
6750  GOTO 6970
6760  SCALE 0,Wf,-1,Injm                   ! WATERFLOOD
6770  AXES 1,1,0,-1,1,1,3
6780  Ks=-1
6790  Kf=Injm
6800  Xs=0
6810  GOSUB Logscl
6820  CALL Label(0,Wf,1,-1,Injm,-99,"PORE VOLUMES INJECTED","INJECTIVITY X PORE
VOL. INJ.")
6830  FOR W=.02 TO Wbt STEP .1
6840  Injp=1/(1+W*(1/Inbt-1)/Wbt)
6850  IF W=.02 THEN MOVE W,LGT(Injp*W)
6860  DRAW W,LGT(Injp*W)
6870  NEXT W
6880  DRAW Wbt,LGT(Inbt*Wbt)
6890  CALL Plsym(Del,3)
6960  FOR W=Wbt TO Wfi STEP .1
6910  Ir=FNFi(W,1)*W
6920  DRAW W,LGT(Ir)
6930  NEXT W
6940  DRAW Wfi,LGT(FNFi(Wfi,1)*Wfi)
6950  MOVE Wibt,LGT(Injbt*Wibt)
6960  CALL Plsym(Del,2)
6970  FOR I=1 TO Ni
6980  Ir=Inj(I)*Wi(I)
6990  MOVE Wi(I),LGT(Ir)
```

```
7000  CALL Plsym(Del,1)
7010  NEXT I
7020  MOVE Wf/2,(Injm+1)/2-1
7030  GOSUB Lblrb
7040  PEN 0
7050  PAUSE
7060  GCLEAR
7070  RETURN
7080  ! ******************** RECOVERY AND INJECTIVITY VS. 1/Wi ****************
7090 Recwi:  GOSUB V
7100  PEN Pb
7110  Rsp=INT(FNFr(1,1)*10)/10
7120  FRAME
7130  PEN 1
7140  LOCATE 11,97,(Loct+11)/2,Loct
7150  SCALE 0,1,Rsp,Rf
7160  AXES .1,.05,0,Rsp,2,2,3
7170  CALL Label(0,1,-999,Rsp,Rf,.1,"","RECOVERY")
7180  MOVE 1/Wf,FNFr(Wf,1)
7190  FOR Winv=1/Wf TO 1 STEP .02
7200  DRAW Winv,FNFr(1/Winv,1)
7210  NEXT Winv
7220  DRAW 1,FNFr(1,1)
7230  FOR I=1 TO N
7240  IF Wi(I)<1 THEN 7270
7250  MOVE 1/Wi(I),Rec(I)
7260  CALL Plsym(Del,1)
7270  NEXT I
7280  MOVE .5,Rf
7290  GOSUB Lblrt
7300                                     ! INJECTIVITY
7310  LOCATE 11,97,11,(Loct+11)/2
7320  SCALE 0,1,0,Injm
7330  AXES .1,1,0,0,2,1,3
7340  Ks=0
7350  Kf=Injm
7360  Xs=0
7370  GOSUB Logscl
7380  CALL Label(0,1,.2,0,Injm,-999,"1/PORE VOLUMES INJECTED","INJECTIVITY X POR
E VOL. INJ.")
7390  MOVE 1/Wfi,LGT(FNFi(Wfi,1)*Wfi)
7400  FOR Winv=1/Wfi TO 1 STEP .02
7410  Ir=LGT(FNFi(1/Winv,1)/Winv)
7420  DRAW Winv,Ir
7430  NEXT Winv
7440  DRAW 1,LGT(FNFi(1,1))
7450  FOR I=1 TO Ni
7460  IF Wi(I)<1 THEN 7490
7470  MOVE 1/Wi(I),LGT(Inj(I)*Wi(I))
7480  CALL Plsym(Del,1)
7490  NEXT I
7500  MOVE .5,Injm
7510  GOSUB Lblrt
7520  PEN 0
7530  PAUSE
7540  GCLEAR
7550  RETURN
7560  ! *************************** REL PERMS ************************
7570 Rel: IF Ic$="C" THEN 7730
7580  Hp=8.5
7590  Vp=11
7600  Lm-1.5
7610  Rm=1
7620  Tm=2
7630  Bm=3
7640  IF Paper=1 THEN 7710
```

```
7650 Hp=11
7660 Vp=12.5
7670 Lm=2.3
7680 Rm=1.2
7690 Tm=1.95
7700 Bm=3.05
7710 GOSUB Lim
7720 GOTO 7740
7730 GRAPHICS
7740 Loct=97
7750 LOCATE 11,97,11,Loct
7760 SCALE 0,1,0,1
7770 IF Ia$="R" THEN 7870
7780 PEN Pb
7790 FRAME
7800 PEN 1
7810 AXES .1,.1,0,0,2,2,3
7820 CALL Label(0,1,.2,0,1,.2, "WATER SATURATION","RELATIVE PERMEABILITY")
7830 IF Ia$="F" THEN 7870
7840 MOVE .5,1
7850 GOSUB Lblrt
7860 GOTO 7990
7870 LORG 2
7880 PEN Pen
7890 MOVE .4,1
7900 SETGU
7910 IPLOT 0,-5*Rep,-2
7920 LINE TYPE Ltype,Szl
7930 IPLOT 8,0,-1
7940 IPLOT 2,0,-2
7950 CSIZE 3
7960 LINE TYPE 1
7970 LABEL "RUN "&Core$&" ("&VAL$(Tc)&" DEG-F)"
7980 SETUU
7990 MOVE Sati/100,MIN(1,Kroswi)
8000 CALL Plsym(Del,2)
8010 LINE TYPE Ltype,Szl
8020 Iss=Isc
8030 MOVE S(Iss),Kro(Iss)
8040 IF Ia$<>"N" THEN 8130
8050 CSIZE 3
8060 LORG 7
8070 RPLOT -.02,0,-2
8080 LABEL "Oil"
8090 MOVE Sati/100,0
8100 CALL Plsym(Del,2)
8110 LINE TYPE Ltype,Szl
8120 MOVE S(Iss),Kro(Iss)
8130 FOR I=Iss+1 TO Ni
8140 IF S(I)<0 THEN 8160
8150 DRAW S(I),Kro(I)
8160 NEXT I
8170 MOVE S(Iss),Krw(Iss)
8180 FOR I=Iss+1 TO Ni
8190 IF S(I)<0 THEN 8210
8200 DRAW S(I),Krw(I)
8210 NEXT I
8220 LINE TYPE 1
8230 IF Ia$<>"N" THEN 8280
8240 LORG 1
8250 RPLOT .02,0,-2
8260 LABEL "Water"
8270 GOTO 8320
8280 IF Ibs=1 THEN 8320
8290 MOVE Sati/100+.02,MIN(Kroswi,1)
8300 LORG 2
```

```
8310  LABEL Core$
8320  PEN 0
8330  PAUSE
8340  GCLEAR
8350  RETURN
8360  ! **************************** Kw/Ko PLOT ***************************
8370 Kwko:  GOSUB V
8380  Ks=-1
8390  Kf=2
8400  Xs=0
8410  PEN Pen
8420  SCALE Xs,1,Ks,Kf
8430  IF Ia$="R" THEN 8560
8440  PEN Pb
8450  FRAME
8460  PEN 1
8470  AXES .1,1,Xs,Ks,2,1,3
8480  GOSUB Logrcl
8490  MOVE Xs,Kf
8500  LABEL 10^Kf
8510  CALL Label(Xs,1,.2,Ks,Kf,-999,"WATER SATURATION","WATER/OIL PERMEABILITY R
ATIO")
8520  IF Ia$="F" THEN 8560
8530  MOVE 0,Kf
8540  GOSUB Lbllt
8550  GOTO 8680
8560  LORG 2
8570  MOVE O,Kf
8580  SETCU
8590  IPLOT 5,-5*Rep,-2
8600  PEN Pen
8610  LINE TYPE Ltype,Szl
8620  IPLOT 8,0,-1
8630  IPLOT 2,0,-2
8640  CSIZE 3
8650  LINE TYPE 1
8660  LABEL "RUN "&Core$&" ("&VAL$(Tc)&" DEG-F)"
8670  SETUU
8680  LINE TYPE Ltype,Szl
8690  MOVE S(Isc).LGT(Kwko(Isc))
8700  FOR I=Isc TO N
8710  IF S(I)<0 THEN 8730
8720  DRAW S(I),LGT(Kwko(I))
8730  NEXT I
8740  LINE TYPE 1
8750  PEN 0
8760  PAUSE
8770  GCLEAR
8780  RETURN
8790  ! *************************** SUBROUTINES ****************************
8800  !
8810  ! *********************** WATER PROPERTIES ****************************
8820  SUB Watp(T,Rhow,Muw,I)
8830  Rhow=EXP(6.52014E-3-4.34333E-5*T-8.78134E-7*T*T)
8840  Muw=EXP(EXP(1.3926+3.0841E-1*LOG(T)-5.7139E-2*LOG(T)*LOG(T)))/208.9
8850  IF I=1 THEN 8900
8860  Rhow=Rhow*1.0137
8870  M=1.03
8880  IF T>150 THEN M=1.045
8890  Muw=Muw*M
8900  SUBEND
8910  ! ************************* OIL PROPERTIES *************************
8920  SUB Oilp(T,Rhoo,Muo)
8930  Rhoo=EXP(-.13539-4.42405E-4*T)
8940  Tr=T+460
8950  Nu=10^(10^(9.8863-3.5587*LGT(Tr)))-.6
```

```
8960 Muo=Nu*Rhoo
8970 SUBEND
8980 ! *********************** TIME CONVERSION ************************
8990 DEF FNTcon(Time)
9000 Ti=Time/100
9010 Hr=INT(Ti)
9020 Min=INT(FRACT(Ti)*100)
9030 Sec=FRACT(Time)
9040 RETURN Hr*60+Min+Sec/.6
9050 FNEND
9060 END
9070 ! ********************PLOT SYMBOLS ********************************
9080 SUB Plsym(Del,Sym)
9090 DEG
9100 SETGU
9110 D=Del/2
9120 RPLOT 0,0,-1
9130 ON Sym GOTO 9170,9140,9250
9140 Nsds=20
9150 D=D/1.2
9160 GOTO 9180
9170 Nsds=4
9180 PDIR -135
9190 RPLOT D,0,-2
9200 FOR Dir=-135 TO 225 STEP 360/Nsds
9210 PDIR Dir
9220 RPLOT D,0,-1
9230 NEXT Dir
9240 GOTO 9310
9250 PDIR -30
9260 RPLOT D,0,-2
9270 FOR Dir=-30 TO 330 STEP 120
9280 PDIR Dir
9290 RPLOT D,0,-1
9300 NEXT Dir
9310 RPLOT 0,0,-2
9320 PDIR 0
9330 SETUU
9340 SUBEND
9350 ! ****************************** RECOVERY FUNCTION **********************
9360 DEF FNFr(X,I)
9370 COM Cr(2),Cp(2)
9380 X1=LOG(X)
9390 ON I GOTO 9400,9420
9400 F=Cr(0)+Cr(1)*X1+Cr(2)*X1^2   ! FUNCTION
9410 RETURN F
9420 Fp=(Cr(1)+2*Cr(2)*X1)/X       ! DERIVITIVE
9430 RETURN Fp
9440 FNEND
9450 ! *************************** INJECTIVITY FUNCTION **********************
9460 DEF FNFi<X,I)
9470 COM Cr(2),Cp(2)
9480 X1=LOG(X)
9490 Ex=EXP(Cp(0)+Cp(1)*X1+Cp(2)*X1^2)
9500 ON I GOTO 9510,9530
9510 F=Ex/X                                    ! FUNCTION
9520 RETURN F
9530 Fp=X*(Cp(1)+2*Cp(2)*X1)/Ex      ! DERIVITIVE
9540 RETURN Fp
9550 FNEND
9560 ! *************************** LABELLING SUBROUTINE ******************
9570 SUB Label(Xs,Xf,Xstep,Ys,Yf,Ystep,Xlbl$,Ylbl$)
9580 DEG
9590 STANDARD
9600 LDIR 0
9610 CSIZE 3
```

```
9620 IF Xstep<0 THEN 9720
9630 LORG 6
9640 FOR X=Xs TO Xf STEP Xstep
9650 MOVE X,Ys
9660 SETGU
9670 RPLOT 0,-1,-2
9680 SETUU
9690 LABEL X
9700 NEXT X
9710 Dy=0
9720 Dy=0
9730 IF Ystep<=-99 THEN 9820
9740 IF Ystep>=0 THEN 9770
9750 Dy=Ystep
9760 Ystep=-Ystep
9770 LORG 8
9780 FOR Y=Ys TO Yf+Dy STEP Ystep
9790 MOVE Xs,Y
9800 LABEL Y
9810 NEXT Y
9820 CSIZE 3                                ! LABELS
9830 IF X1bl$="" THEN 9900
9840 LORG 4
9850 MOVE (Xs+Xf)/2,Ys
9860 SETGU
9870 RPLOT 0,-10,-2
9880 SETUU
9890 LABEL X1bl$
9900 LDIR 90
9910 LORG 6
9920 MOVE Xs,(Ys+Yf)/2
9930 SETGU
9940 RPLOT -10,0,-2
9950 SETUU
9960 LABEL Y1bl$
9970 LDIR 0
9980 SUBEND
```