ER-2836

THE DESIGN AND CALIBRATION OF A KLINKENBERG PERMEAMETER

Richard F. McClure

ER-2836

A thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Engineering (Petroleum Engineering).

Golden, Colorado

Date April 23, 1986

Signed: Richard McClure

Richard F. McClure

Approved: Ramona M Graves

Dr. Ramona M. Graves
(Co-Advisor)

Date April 23, 1986

Craig W. Van Kirk

Dr. Craig W. Van Kirk
Head, Department of
Petroleum Engineering

ABSTRACT

The measurement of core sample permeability is critical to the design of production facilities and to the economic evaluation of hydrocarbon accumulations. Since hydrocarbons are being produced from reservoirs with lower permeabilities than ever before, accurate measurement of these permeabilities is of increasing importance.

Many formations have reactive clays or other properties which make determining permeability using a liquid difficult and uncertain. Measuring permeability with a gas is also difficult, due to gas slippage within the core and gas flow measuring devices.

This report presents a modification of Klinkenberg's[1] steady-state method of determining permeability. The Klinkenberg permeameter presently located in the Petroleum Engineering Department at the Colorado School of Mines, was modified by adding a second stage regulator to the upstream side of the core and by constructing a gas bubble meter to accurately measure the flow of gas through the core sample.

The resulting data from the gas permeameter have been compared with appropriate standards of the petroleum industry, (unsteady-state permeameter, Marathon Oil Co.). The data were used to demonstrate accuracy and

repeatability using four gases, four cores and three differential pressures.

An undergraduate experiment which demonstrates the "Klinkenberg Effect" was developed for use with the newly modified equipment. Proposals for future modification and practical uses of this equipment are included.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES

LIST OF TABLES

LIST OF TABLES

ACKNOWLEDGEMENTS

The author thanks Mr. Charles Aldrich, and Dr. Ramona Graves, Professors of Petroleum Engineering, at the Colorado School of Mines, for their guidance and encouragement in researching this project.

He also thanks the members of the committee, Dr. Fred Poettmann and Dr. B.J. Mitchell, for their interest and criticism.

Dr. Stan Jones of Marathon Research generously provided the permeameter used in testing the rocks and in verifying the conclusions.

The very generous financial support of The Department of Energy and Shell Oil through Dr. Craig Van Kirk, Professor and Head of the Petroleum Engineering Department, facilitated this project.

Mr. Bill Robbins greatly assisted in preparing the instrumentation.

I. INTRODUCTION

The engineer designing methodologies to produce hydrocarbon accumulations should understand the significance of permeability and be able to accurately determine it. Reactive clays and low viscosity reservoir fluids can make obtaining liquid permeability difficult. Using water of different salinities can alter the initial reservoir permeability and low viscosity fluids lead to long tests. These problems can be circumvented by measuring gas permeability at various pressures. Because gas slippage occurs within the rock, these are not direct measurements of true or liquid permeability. Gas permeability data extrapolation to infinite pressure enables prediction of liquid permeability without direct measurement and tedious testing.

Gas permeability of porous media is a linear function of reciprocal mean pressure (Figure 1). This relation can be described by the following equation,

$$K_a = K_l \left(1 + \frac{b}{\bar{P}}\right) \qquad (1)$$

where:

K_a = Apparent or gas permeability,

K_l = Absolute or liquid permeability,

b = Constant (slope of the lines),

$\bar{P}$ = Mean pressure within the core.

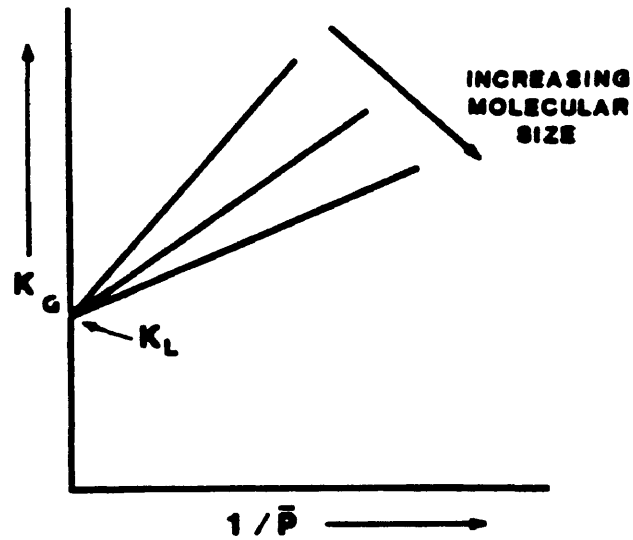


Figure 1

Klinkenberg Effect (After Klinkenberg[1])

The constant "b" is a function of the porous medium, temperature and the molecular size of the gas being used.

There are two methods for measuring gas permeability: the steady-state method and the unsteady-state method. The steady-state method (dp/dt = 0) was used in these experiments. The method is accurate but slower and more inconvenient than the unsteady-state method in which dp/dt is not constant. When a digital computer is used in the unsteady-state method, gas permeabilities may be determined easily and with the same accuracy as the steady-state method.

Gas slippage, commonly called the Klinkenberg Effect, could not be accurately measured with consistency using the laboratory equipment in the Petroleum Engineering Department at the Colorado School of Mines. This report discusses the modification and calibration of a steady-state gas permeability measuring device whose operation is based on gas slippage theory (Klinkenberg Effect).

The investigation proceeded in the following manner. Through the use of gas bubble meters and digital pressure transducers, reproducible measurements were obtained.

1. A device for the accurate measurement of gas permeability was constructed.
2. Gas permeability measurements were made on four reservoir cores.
3. The data were analyzed for accuracy and reproducibility.
4. An undergraduate laboratory experiment which demonstrates the Klinkenberg Effect was developed.
5. The data was checked with a commercial unsteady-state Klinkenberg apparatus for accuracy.

II. LITERATURE REVIEW

The History of Permeability Measurement

The rediscovery of Darcy's Law in the early 1930's made it possible to predict the behavior of oil wells and other more complicated petroleum systems. Before this concept could be applied, it was necessary to measure permeability of the porous medium. Samples were gathered, and initial permeabilities determined by means of a flow test where reservoir crude oil, kerosene or salt water brines were transmitted through the cores at differing flow rates. Flow rates and appropriate pressures were recorded.

The measurement time required when using reservoir crude oil, kerosene and salt water is much greater than the time required when using a gas. Foreign liquids placed in contact with the rock can react with the rock changing the original flow properties. Waters of differing salinities can cause clay swelling. Cores had to be cleaned between each test, to restore initial flow properties. For these reasons, it became accepted practice to use nitrogen or an inert gas, such as helium, as a testing fluid.

Measured permeability to gas was higher than that obtained by flowing a single phase liquid through the core sample. Gas slippage causes the discrepancy between the two methods for determining permeability.

تعارض ، تناقض

The History of Gas Permeability Measurement

In 1941, Klinkenberg[1] showed that gas permeability depends on the nature of the gas, and approximates a linear function of reciprocal mean pressure. He explained this effect by considering the phenomenon of slip, which is related to the mean free path of the molecules.

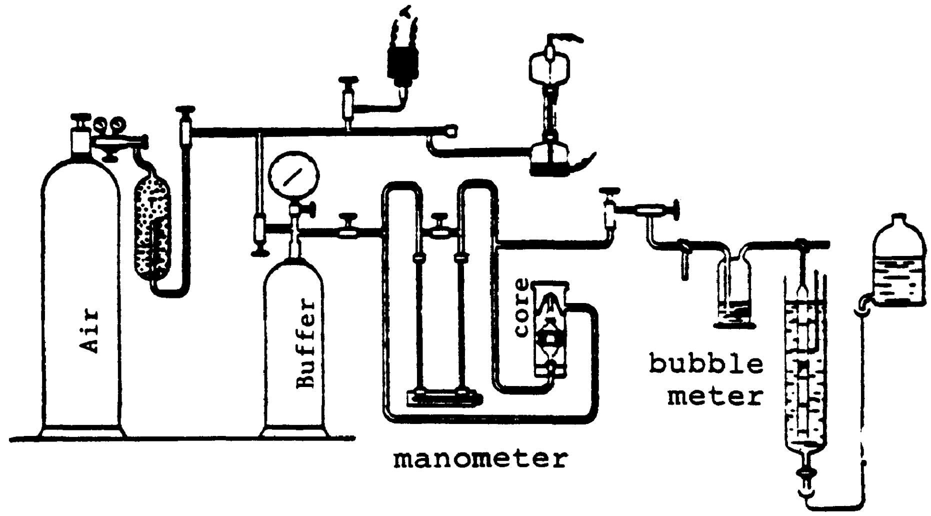
The mean free path of a gas is defined as the average distance between molecular collisions. As the size of a pore throat approaches the mean free path of a gas molecule, the component of velocity parallel to the wall becomes large when compared to the component of velocity perpendicular to the wall. A gas under very high pressure acts much like a liquid, since the additional pressure, forces the gas molecules closer together.

When measured gas permeability is plotted versus reciprocal mean pressure, and the data is extrapolated to infinite pressure, the intercept is equivalent to the liquid permeability of the specific porous medium. This extrapolated permeability is equal to the measured liquid permeability at one hundred per cent saturation.

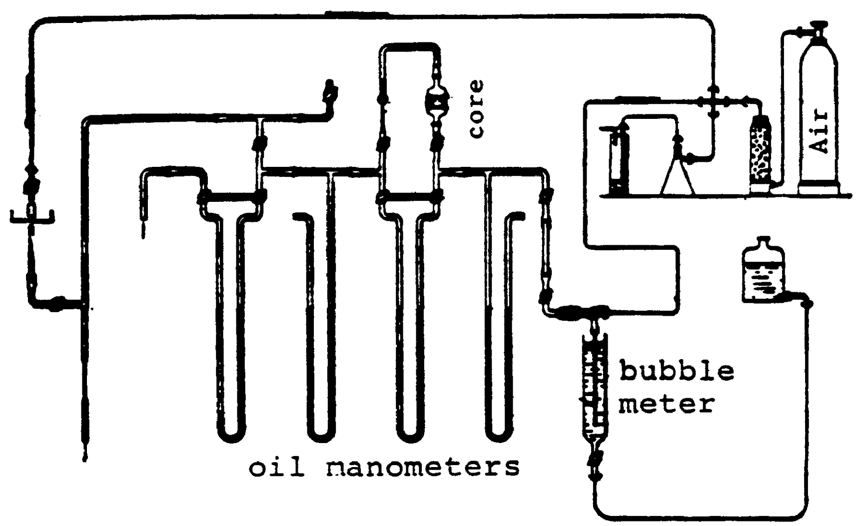
Since digital computers were not available to Klinkenberg[1], his experimental apparatus used the steady-state method for gathering data. His reported experimental values concerning extrapolated liquid permeabilities ranged from 2.4 millidarcies to 200 millidarcies. Klinkenberg[1] was able to measure a difference in pressures across the core as small as 0.00361 psi. His flow rate was measured by counting bubbles passing through a liquid, and collecting the gas (Figure 2).

In 1972, Jones[2] devised an unsteady-state method of measuring gas permeability. With the assistance of a digital computer, he was able to quickly and accurately measure Klinkenberg permeabilities, Klinkenberg slip factors, and Forchheimer[3] "turbulence" factors (ß) in cores. He stated in a personal communication[4] that his method has nearly replaced all steady-state gas permeability determinations in his own laboratory.

Jones' permeameter (Figure 3) uses an electronically controlled throttle valve on the inlet side of the core through which small amounts of gas are allowed to flow through the porous medium. The volumetric flow rate is determined by applying the real gas equation to the inlet reservoir of gas and then calculating the residual gas in the pressure vessel. All pressures upstream from the core are measured with digital transducers. The data are analyzed by a computer as taken.



PERMEABILITY APPARATUS FOR HIGH PRESSURES



PERMEABILITY APPARATUS FOR LOW PRESSURES

Figure 2

Klinkenberg's Permeameter (After Klinkenberg[1])

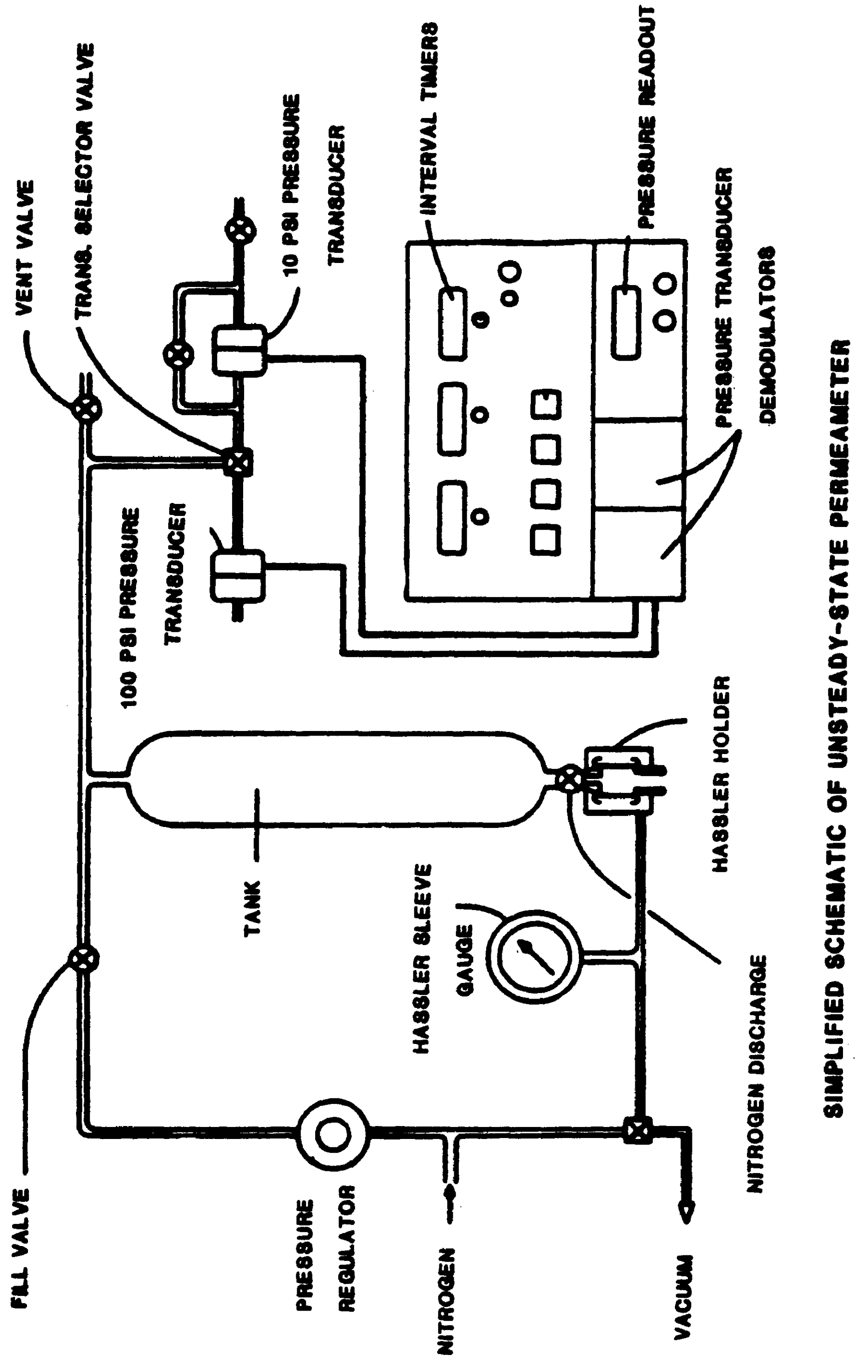


Figure 3

Jones' Permeameter (After Jones[2])

In 1981, Jennings, Carroll, and Raible[5], presented a paper to the Society of Petroleum Engineers in which they discussed gas permeability measurments as a function of confining pressure. Their model assumed that rock pore spaces communicate through micro-fractures. Jennings, et al.[5] related core permeability to confining pressure by measuring the change in electrical conductivity through the core. They extrapolated liquid permeabilities from 20 microdarcies to 200 microdarcies, and results were consistent with their ideas concerning micro-fractures in porous media.

In 1983, Freeman and Bush[6] developed an unsteady-state apparatus for measuring Klinkenberg permeabilities. Their apparatus (Figure 4) was similar to that of Jones[2], except that Freeman and Bush[6] measured the amount of gas which flowed through the core and collected in an outlet reservoir on the downstream side of the core. Freeman and Bush[6] and Jones[2] measured pressures with electronic transducers. Digital computers enabled them to analyze data immediately. Freeman and Bush[6] stated that the rapidity of their testing allowed many more data to be generated in a very short time for use in well-completion applications. They did much of their experimental work

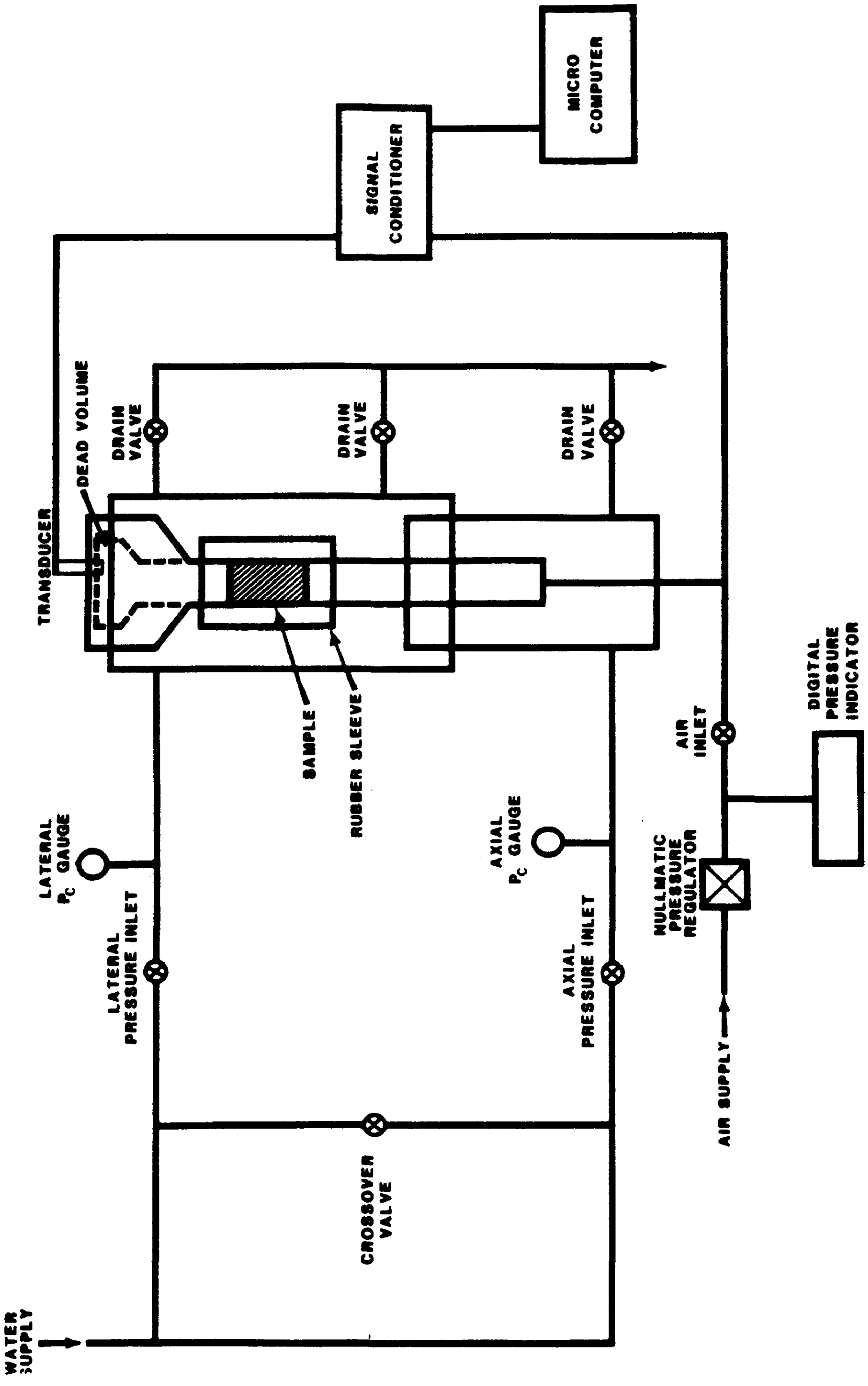


Figure 4

Freeman's Permeameter (After Freeman and Bush[6]) with cores in which the degree of water saturation was varied to simulate changing reservoir conditions. They believed that their rapid, low flow rate, unsteady-state gas permeability test caused very little water saturation change during testing.

In a 1984 paper, Wei, Morrow, and Brower[7] reported to the Society of Petroleum Engineers that they had measured the gas permeability of cores while simultaneously varying the confining pressure and the temperature of the flowing gas. They found that permeability varied inversely with confining pressure, but were unable to demonstrate a significant relationship between permeability and temperature variation. They also published data on the flow of brines at elevated temperature and confining pressure through the cores; their findings were the same.

Visco-Inertial Flow (Forchheimer Effect)

Forchheimer[3] (1914) observed that Darcy's Law failed at high rates of flow. He showed empirically that flow through porous media could be described over a much wider range of flow rates by means of the following quadratic equation:

$$v + \beta \, |v| v = - \frac{K}{\mu} \frac{dP}{dX} \tag{2}$$

where:

v = Velocity,

β = Forchheimer beta factor (turbulence factor),

μ = Viscosity,

dP = Differential pressure,

dX = Differential length.

Forchheimer's findings received little attention until 1951, when Green and Duwez[8] applied it in practical terms.

$$- \frac{dP}{dL} = \alpha \mu_1 Q_1 + \beta \rho_1 Q_1{}^2 \qquad (3)$$

where:

P = Pressure,

L = Length,

α = Inverse of absolute permeability,

Q_1 = Volumetric liquid flow rate per unit area,

ρ_1 = Liquid density,

μ_1 = Liquid viscosity.

Forchheimer[3] and Green and Duwez[8] performed their work on the flow of liquids through porous media, and it was not until 1953 that Cornell and Katz[9] applied the equation to horizontal linear gas flow.

In 1965, Dranchuk and Sadiq[10] published a paper in the Journal of Canadian Petroleum Technology which reported the beginning of their investigation into gas slippage and visco-inertial flow. They experimented with cores in which the traditional Klinkenberg plot of permeability versus reciprocal mean pressure deviated from a straight line at high flow rates. The downward deviation in the traditional Klinkenberg plot is caused by the Forchheimer Effect or visco-inertial flow, commonly but erroneously called turbulence.

A plot of inlet pressure squared minus outlet pressure squared versus flow rate, on log-log paper can be used to delineate the viscous and visco-inertial flow regions (Figure 5). High flow rates are defined as being in the visco-inertial flow region and low flow rates are defined as those being in the viscous flow region.

Integrating Forchheimer's original equation and assuming a constant temperature (T), and viscosity (μ), Cornell and Katz[9] in the early 1950's developed the following equation for linear horizontal gas flow.

$$\frac{(P_1^2 - P_2^2)\,\bar{P}\,A\,T_r}{L\,\bar{Z}\,T\,\mu_g P_r\,Q_r} = \alpha + \frac{\beta\,Q_r\,\rho_g}{A\,\mu_g} \qquad (4)$$

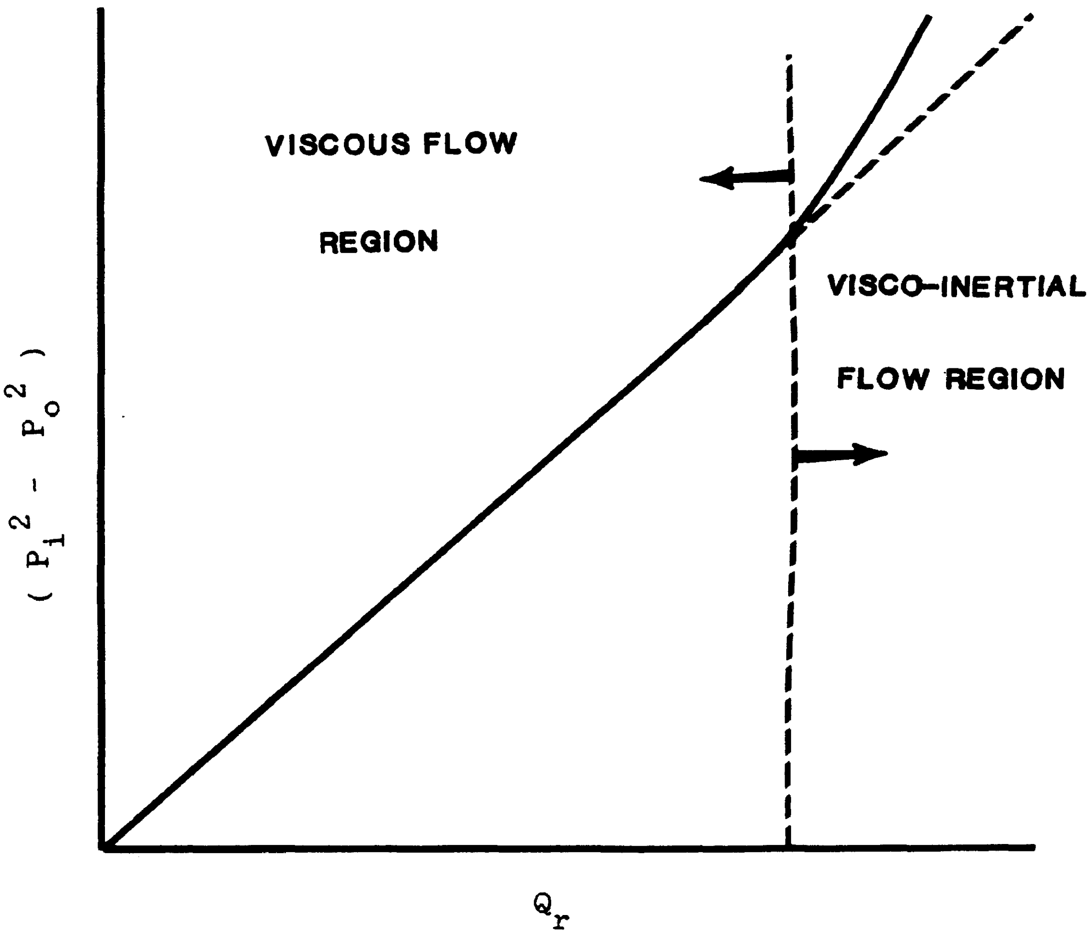


Figure 5

Flow Regime Plot (After Dranchuck and Sadiq[10])

where:

P_1 = Inlet pressure,

P_2 = Outlet pressure,

$\bar{P}$ = Mean pressure of the gas,

ρ_g = Density of the test gas,

T_r = Room temperature,

μ_g = Gas viscosity,

P_r = Room pressure (atmospheric),

$\bar{Z}$ = Mean gas compressibility factor,

A = Cross sectional area of the core,

T = Mean flowing temperature,

Q_r = Gas flow rate at room conditions.

Cornell and Katz[9] primarily used their equation to evaluate the Forchheimer beta factor (β), the coefficient of the squared term in the Green and Duwez[8] quadratic equation. Their equation resulted in an intercept which proved to be the inverse of true liquid permeability (α).

Dranchuk and Sadiq[10] used the traditional Klinkenberg plotting technique and the plotting technique proposed by Cornell and Katz[9] to evaluate several sets of flow data. The results showed that the permeabilities obtained by the two methods invariably differed, with the extrapolated

Klinkenberg permeability always being lower. Both methods depart from linearity. In the case of the Klinkenberg plot, the departure was attributed to the increased flow rate and the indication of visco-inertial flow; while in the case of the Cornell-Katz[9] plot, the departure occurred at low flow rates and was due to slippage at the gas-solid interface.

When the size of the capillary approaches the mean free path of the molecules, the component of the velocity vector parallel to the wall is large compared to the component perpendicular to the wall. Therefore, gases flow through a capillary more rapidly than is predicted by Poiseuille's or Darcy's Law. Laminar flow theory assumes zero fluid velocity at the gas-solid interface, with shear taking place within the fluid. With gases, the individual molecules are in motion and provide a contribution to the velocity effect whenever the mean free path approaches the dimensions of the capillary.

Dranchuk and Kolada[11] showed that if

$$\alpha = \frac{1}{K_1\left(1 + \frac{b}{\bar{P}}\right)} \tag{5}$$

was substituted into the Cornell-Katz Equation[9] (Equation

4), gas slippage and visco-inertial flow could be satisfactorily handled simultaneously. The resulting equation was presented by Casse and Ramey[12]:

$$\frac{\left(1 + \frac{b}{\bar{P}}\right)\left(P_1^2 - P_2^2\right) \bar{P} \, A \, T_r}{L \, \bar{Z} \, T \, \mu_g P_r \, Q_r} = \frac{1}{K} + \frac{\beta \rho_g Q_r \left(1 + \frac{b}{\bar{P}}\right)}{A \, \mu_g} \tag{6}$$

which is of the form Y = 1/K + (ß)X. This is the equation of a straight line with intercept (1/K) and slope (ß).

The straight line portion of the Klinkenberg plot is used to calculate (b). Without the slope of the Klinkenberg plot the determination of (ß) would be an interative solution.

III. DERIVATION OF THE KLINKENBERG EFFECT

Dr. Klinkenberg[1] published (1941) the following derivation which addressed the correction of gas slippage in low permeability rocks. This has become known as the "Klinkenberg Effect".

Consider flow through porous media having "n" capillaries of radius "r". The volume of liquid flowing through the porous media during a unit of time is determined by applying Poiseuille's Equation:

$$\frac{V}{t} = \frac{n \, \pi \, r^4 (P_1 - P_2)}{8 \, L \, \mu_1} \tag{7}$$

where:

- V = Volume,
- t = Time,
- n = Number of capillaries per face,
- r = Radius of the capillaries,
- P_1 = Pressure on the inlet side of the core,
- P_2 = Pressure on the outlet side of the core,
- L = Length of the core,
- μ_1 = Liquid viscosity.

Assuming Darcian flow through the porous media, the cross sectional area is made equivalent to the total area of the capillaries, and the flow equation is expressed by,

$$\frac{V}{t} = \frac{n \pi r^2 K_1 (P_1 - P_2)}{L \mu_1} \tag{8}$$

where:

K_1 = Absolute or liquid permeability.

Substituting equation (7) into equation (8):

$$K_1 = \frac{r^2}{8} \quad . \tag{9}$$

For a gas, consider slippage of the part that is in contact with the wall of it's container. Using Poiseuille's Law as described by Klinkenberg[1] to take into account the slip of the gas at the wall,

$$Q_r = \frac{T_r n \pi r^4 (P_1 - P_2) \bar{P} (1 + \frac{4c\bar{\lambda}}{r})}{P_r T 8 \mu_g L} \tag{10}$$

where:

T = Temperature of the flowing gas,

T_r = Room temperature,

P_r = Room pressure (atmospheric),

Q_r = Gas flow rate at room conditions rate,

$\bar{P}$ = Mean pressure,

c = Proportionality constant,

$\bar{\lambda}$ = Mean free path at the mean pressure.

Substituting equation (9) into equation (10), we have:

$$Q_r = \frac{T_r K_1 n \pi r^2}{P_r T \mu_g L} (P_1 - P_2) \bar{P} \left(1 + \frac{4c\bar{\lambda}}{r}\right) . \quad (11)$$

Darcy's Law uses the cross sectional area of the porous medium which is analogous to the total area of all the capillaries in the Poiseuille's equation, for flow through a capillary. Using this analogy for flow areas, and that the gas deviation factor (Z) is very nearly equal to one, the equation for Darcian gas flow through porous media becomes;

$$Q_r = \frac{T_r K_a n \pi r^2}{P_r T 2 \mu_g L} (P_1^2 - P_2^2) \quad (12)$$

where:

K_a = Apparent or gas permeability.

The pressure term can be factored and so this form of Darcy's Law becomes,

$$Q_r = \frac{T_r \; K_a \; n \; \pi \; r^2}{P_r \; T \quad \mu_g \; L} \quad (P_1 - P_2) \; \bar{P} \tag{13}$$

By substitution of equation (11) into equation (13):

$$K_a = K_1 \left(1 + \frac{4c\bar{\lambda}}{r} \right) . \tag{14}$$

Because the mean free path of the gas is inversely proportional to the pressure, the following relation can be written:

$$\frac{4c\bar{\lambda}}{r} = \frac{b}{\bar{P}} \tag{15}$$

where:

b = A proportionality constant.

Substituting equation (15) into equation (14):

$$K_a = K_l \left(1 + \frac{b}{\bar{P}}\right). \tag{16}$$

This equation relates the apparent gas permeability to the liquid permeability of a porous system to gas,

where:

$$\bar{P} = \frac{P_1 + P_2}{2}$$

is the mean pressure in the core.

For the calculations presented in this report apparent permeability was calculated using the formula obtained from Darcy's Law, as presented by Aldrich[13];

$$\frac{\mu_g}{K_a A}\, dX = -\int_0^L \frac{P_x dP}{P_r Q_r} \tag{17}$$

where:

A = Cross section area,

P_x = Pressure at any point within the core,

P_r = Room pressure (atmospheric),

Q_r = Gas flow rate at room conditions.

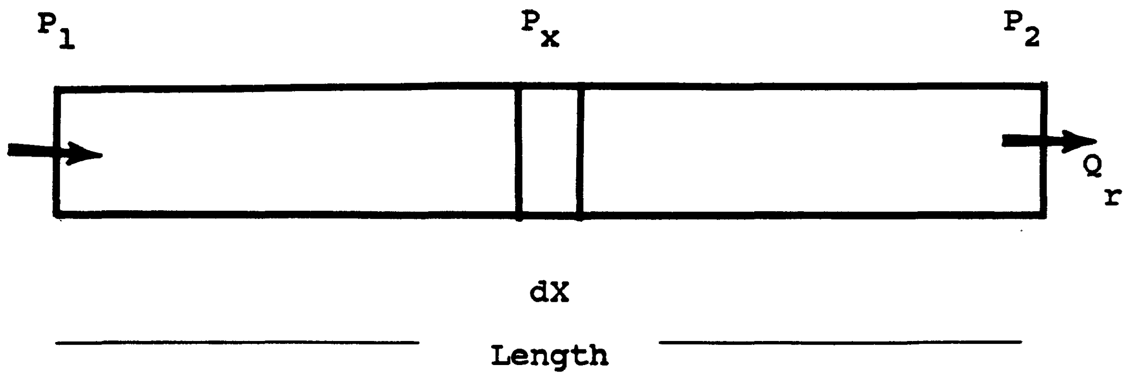


Figure 6

Differential Pressure Element Within the Core

Integrating along the length of the core and using the following boundary conditions;

When

$x = 0$ $\quad P_x = P_1$ $\quad$ Inlet Conditions

$x = L$ $\quad P_x = P_2$ $\quad$ Outlet Conditions

We obtain:

$$\frac{\mu_g L}{K_a A} = \frac{P_1^2 - P_2^2}{2 P_r Q_r} . \tag{18}$$

Solving for K_a;

$$K_a = \frac{P_r Q_r 2 \mu_g L}{(P_1^2 - P_2^2) A} \tag{19}$$

and substituting in the mean pressure within the core,

$$\bar{P} = \frac{P_1 + P_2}{2} \tag{20}$$

Equation (19) becomes,

$$K_a = \frac{P_r Q_r \mu_g L}{(P_1 - P_2) \bar{P} A} . \tag{21}$$

Equations (19) and (20) are used to generate the Klinkenberg plots presented in this report.

IV. EXPERIMENTAL PROCEDURE

A test core was cleaned with toluene in a Soxhlex extractor and dried in a retort (200 °C) to remove any water or toluene trapped in the pores. The core was placed in the rubber sleeved core holder. The permeability of the core to carbon dioxide, nitrogen, helium and hydrogen was measured starting with an inlet pressure of 20 psia and increasing in 15 psi increments to 90 psia. The differential pressure was held constant across the core at 5, 10 and 15 psi, for each inlet pressure. Before the differential pressure was increased the data was repeated twice to verify reproducibility. All laboratory data and calculated data are recorded in Appendix B.

The results for this experimental procedure were verified by using a Ruska liquid permeameter to measure the liquid permeability. The permeability of cores #4828, #4847, #4850 was tested for accuracy using the unsteady-state method of Jones[4] (1972), at Marathon Research Center, Littleton, Colorado.

V. EXPERIMENTAL APPARATUS

The steady-state apparatus as designed by Charles Aldrich[13] is similar in concept to Klinkenbergs'[1]. This equipment accumulates data slowly and tediously (Figure 7). The apparatus as designed is not capable of measuring gas permeabilities when the water saturation is changing. It is also incapable of controlling or measuring confining pressure. It does however incorporate digital pressure recording techniques and a gas bubble meter to measure flow rate. The purpose of this thesis was to find and correct any errors in the original gas permeameter.

Core Holder

The core holder consists of a rubber sleeve around the core which is placed in a steel jack. Since the core holder has no means of controlling or measuring the triaxial stress, these conditions could not be evaluated in this report (Figure 8).

Pressure Measurement

This graduate research cannot improve upon Klinkenberg's technique of determining permeability, for his method is very accurate. However, in order to more

SCHEMATIC OF APPARATUS

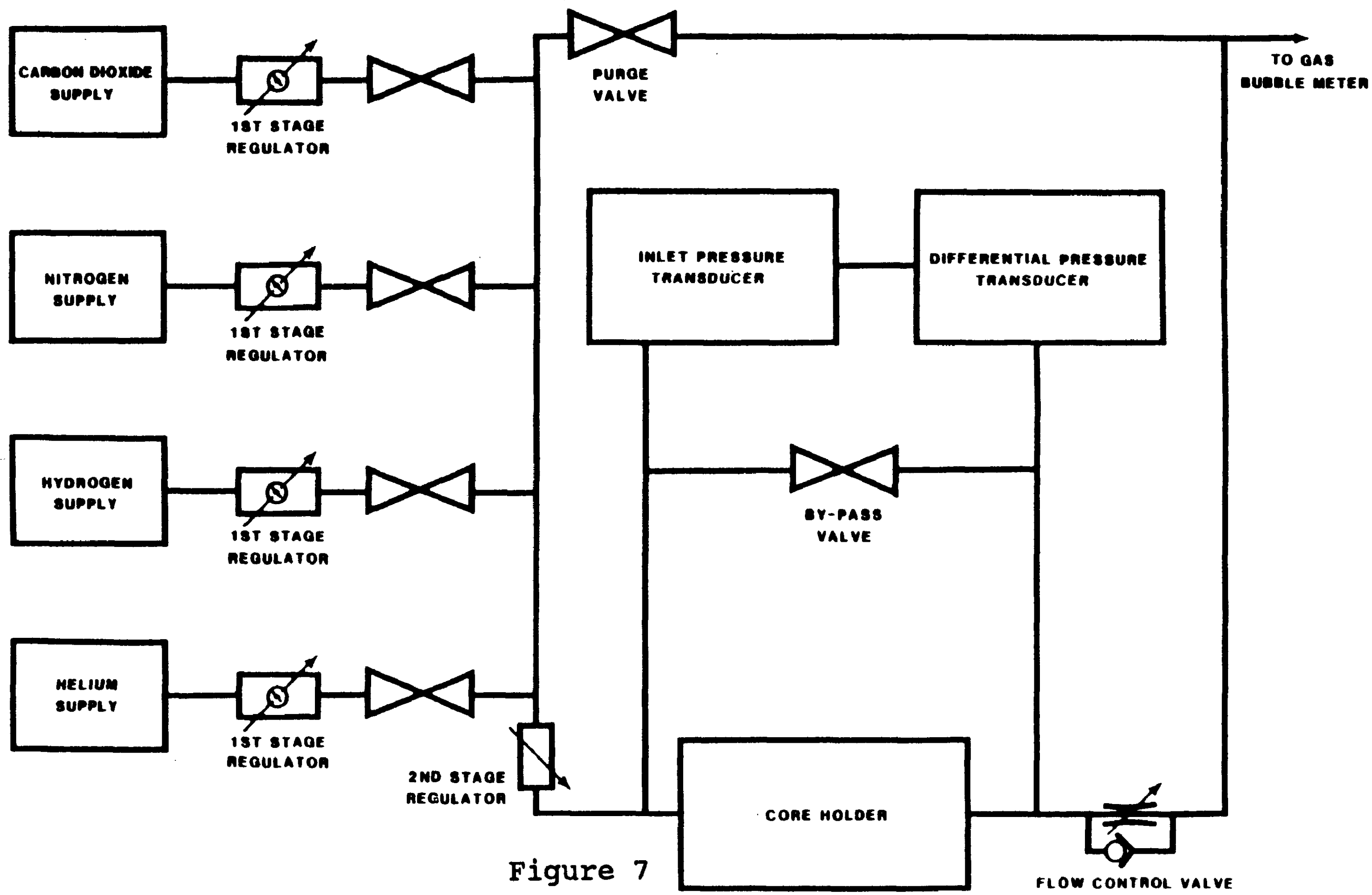


Figure 7

A Modified Klinkenberg Permeameter (After Alrich[13])

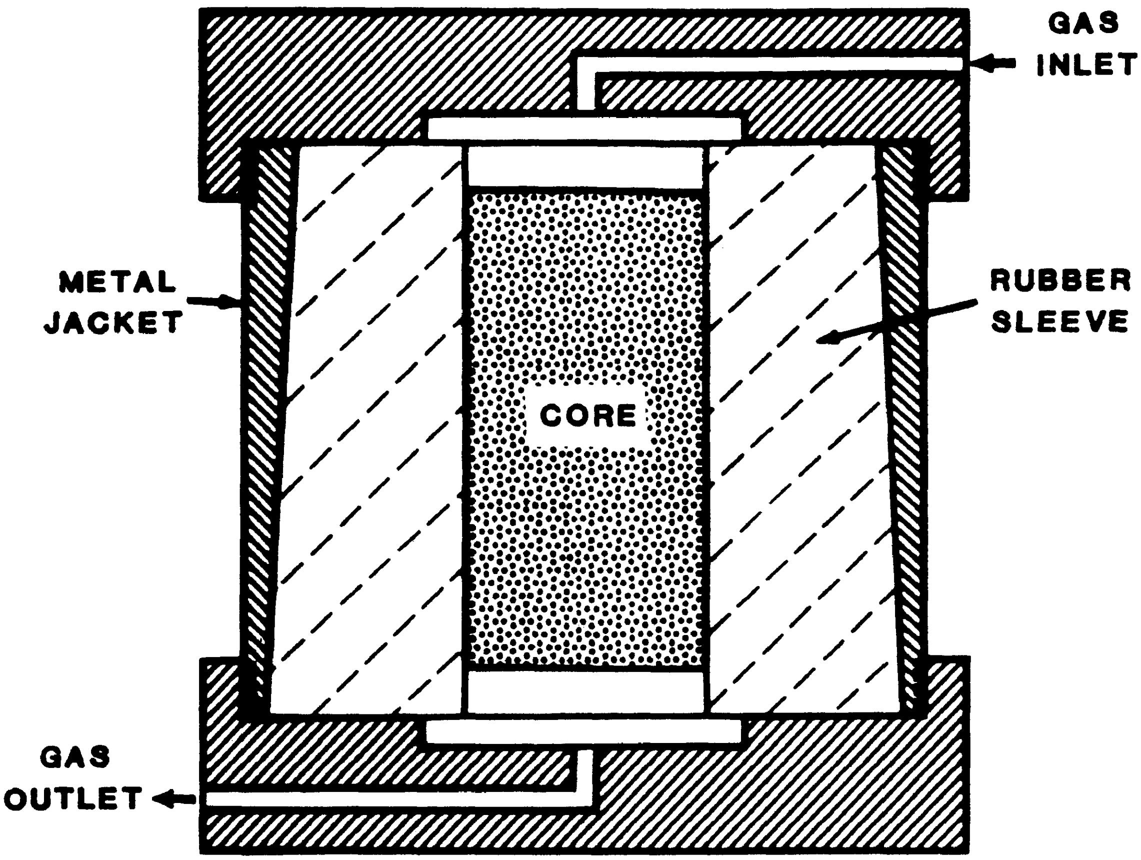


Figure 8

Core Holder

efficiently measure the pressure as well as gas flow rate, this apparatus differs from the previous equipment through utilization of pressure transducers and a gas bubble meter.

Digital pressure transducers having a resolution of 0.1 psi were placed in such a manner that differential pressure and upstream pressure could be recorded. Experimentation with this configuration did not seem to improve the repeatability of the results.

It was found by repeated measurements that the repeatability was more sensitive to differential pressure than inlet pressure. The differential transducer was replaced with another having a resolution of 0.01 psi to improve results.

Gas Flow Rate Measurements

Suspecting an error in the measurement of the flow rate through the core, it was found that the wet test meter was being used outside the range of its accuracy. The wet test meter was replaced with a vertical gas rotometer. Calibration charts provided by the manufacturer were used to convert the vertical height readings of the ball in the rotometer to gas flow rates through the core. The experiments were repeated, and the data improved slightly.

In an attempt to further improve the data a gas bubble meter replaced the rotometer. The gas bubble meter works by placing a soap bubble in the middle of a gas stream and timing its movement through a known volume. The level of the soap in the bottom of the bubble meter is raised until the liquid interferes with the gas stream and a bubble forms. The gas bubble meter measures the flow by timing the movement of a soap bubble vertically through a glass burette (Figure 9). The gas bubble meter in combination with the pressure transducers solved the problem of gathering repeatable data, to demonstrated the Klinkenberg Effect.

Gas Viscosity

Previous laboratory work performed by undergraduates using this apparatus used gas viscosity charts of unknown origin. Gas viscosities for this experiment were obtained from the Handbook of Chemistry and Physics[14] (1978) and were plotted for the temperature range, zero to one hundred degrees centigrade (Figure 10 - Figure 13).

Since pressure has very little effect on viscosity within the pressure range of this equipment (0 - 100 psia), it can be considered negligible. However, temperature is important and within this temperature range, the rate of change of viscosity with temperature is a constant. A

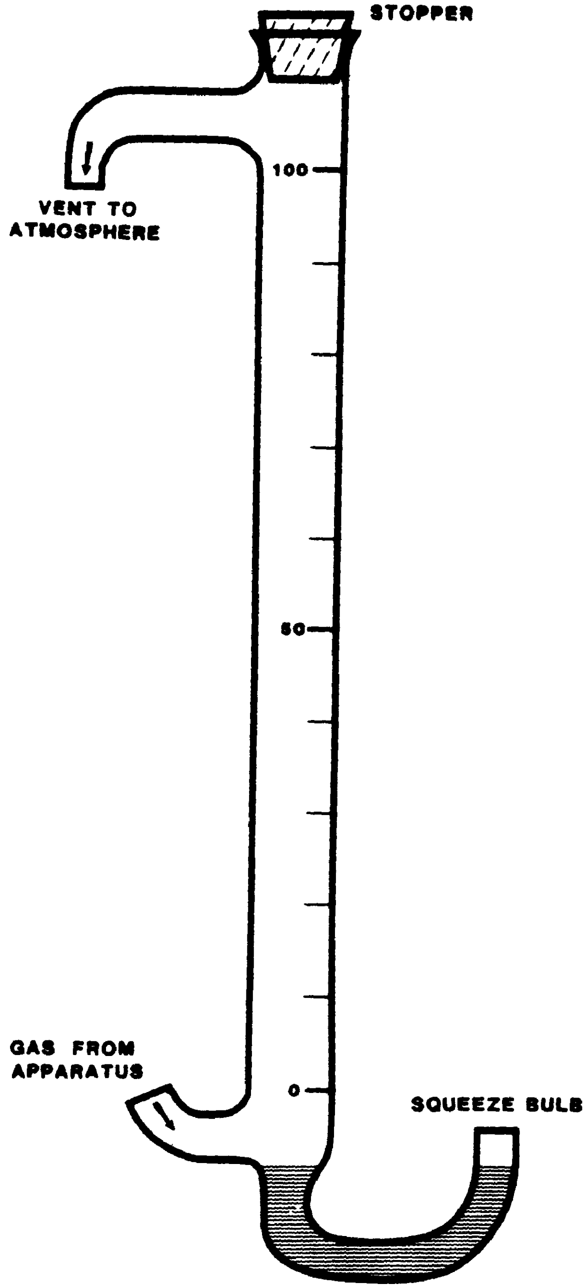


Figure 9

Gas Bubble Meter

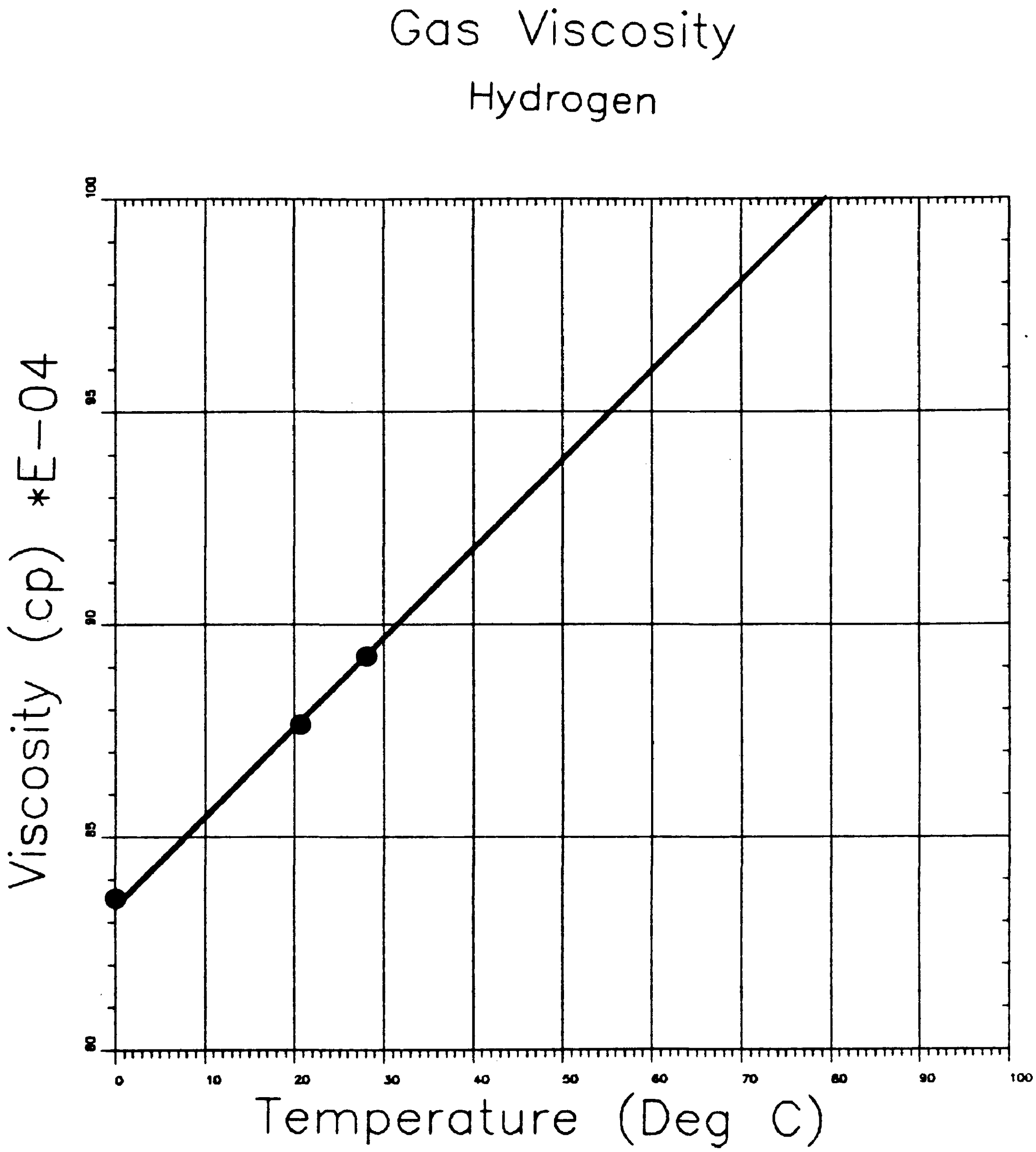


Figure 10

The Viscosity of Hydrogen Gas[14]

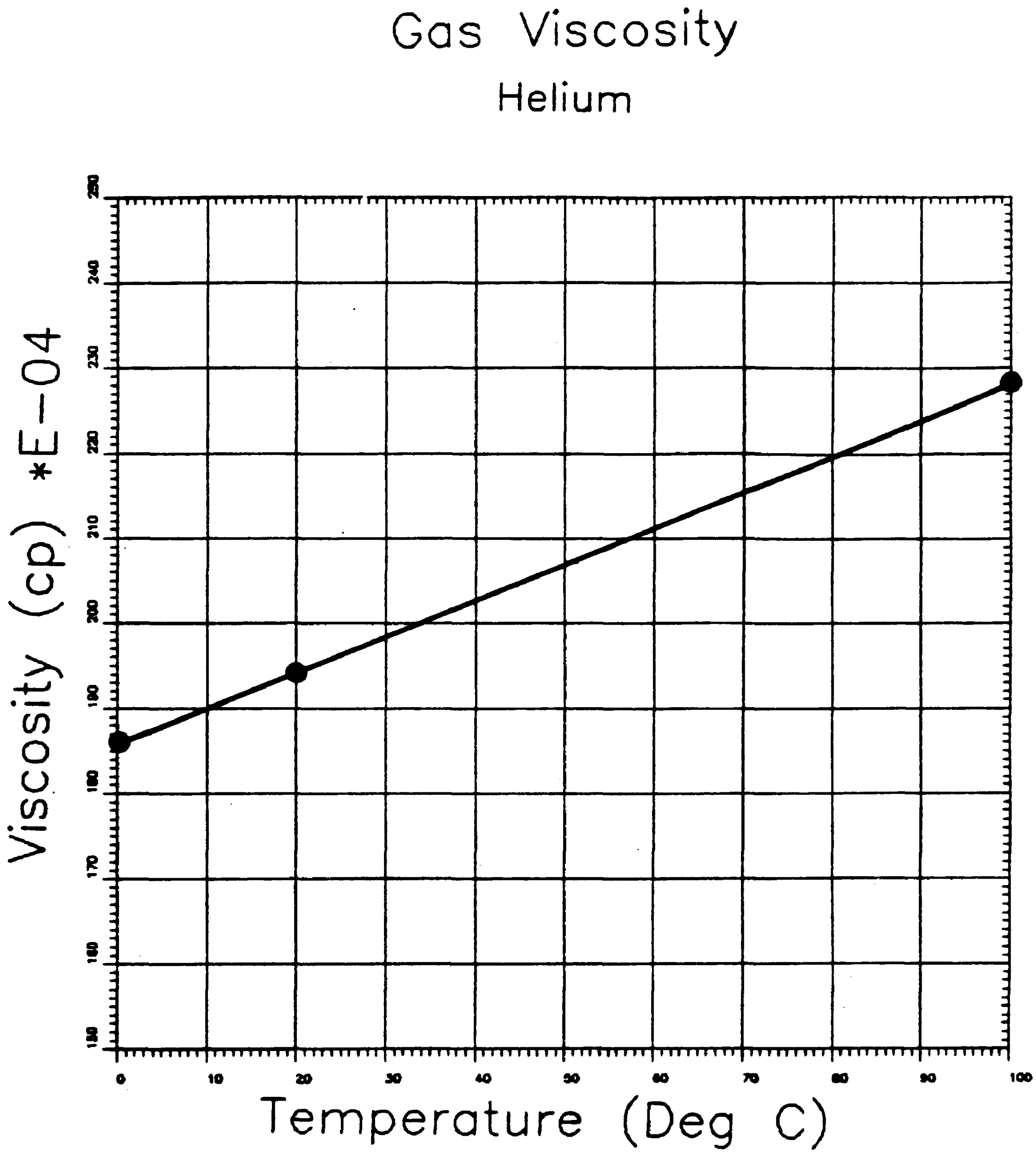


Figure 11

The Viscosity of Helium Gas[14]

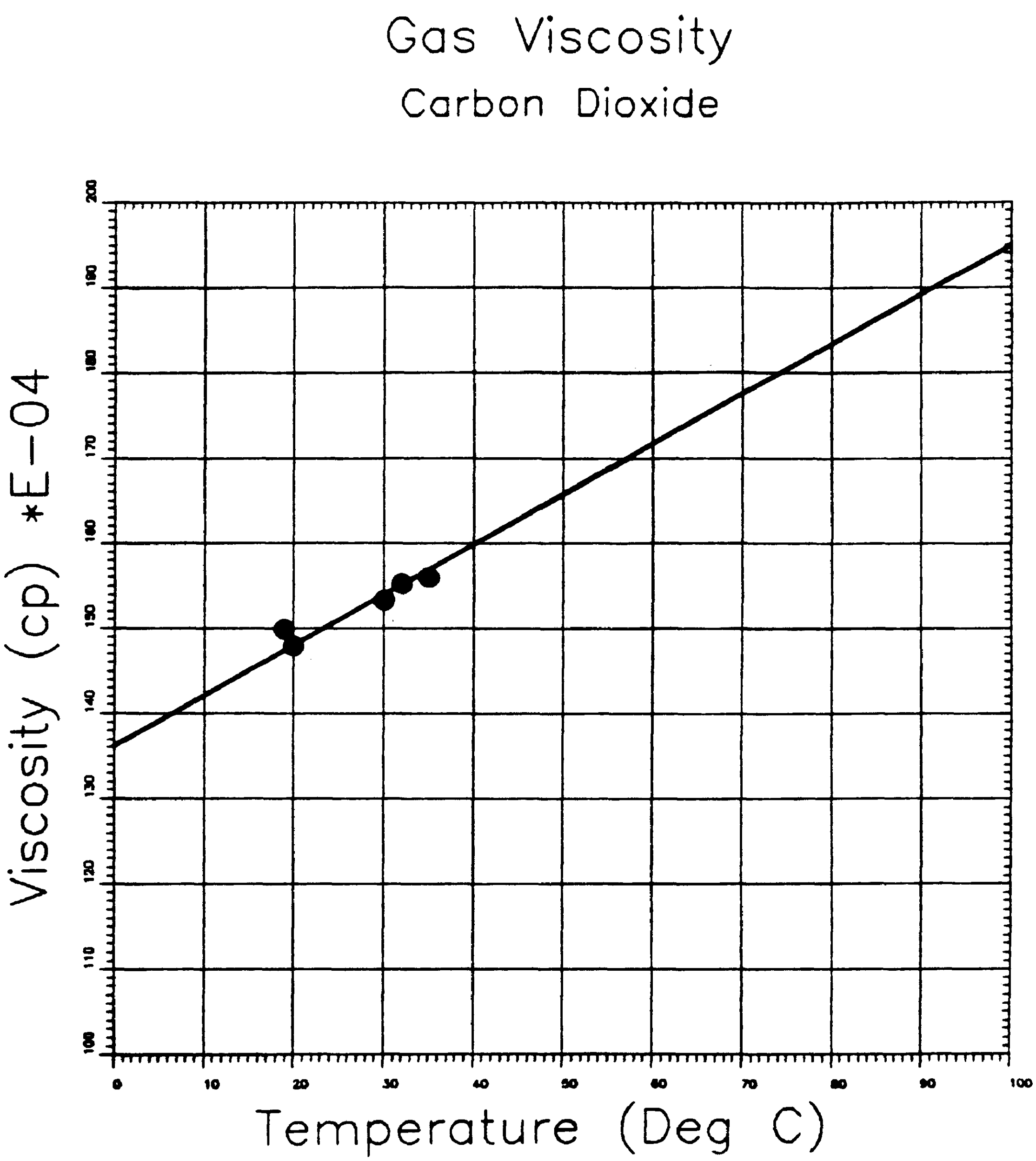


Figure 12

The Viscosity of Carbon Dioxide Gas[14]

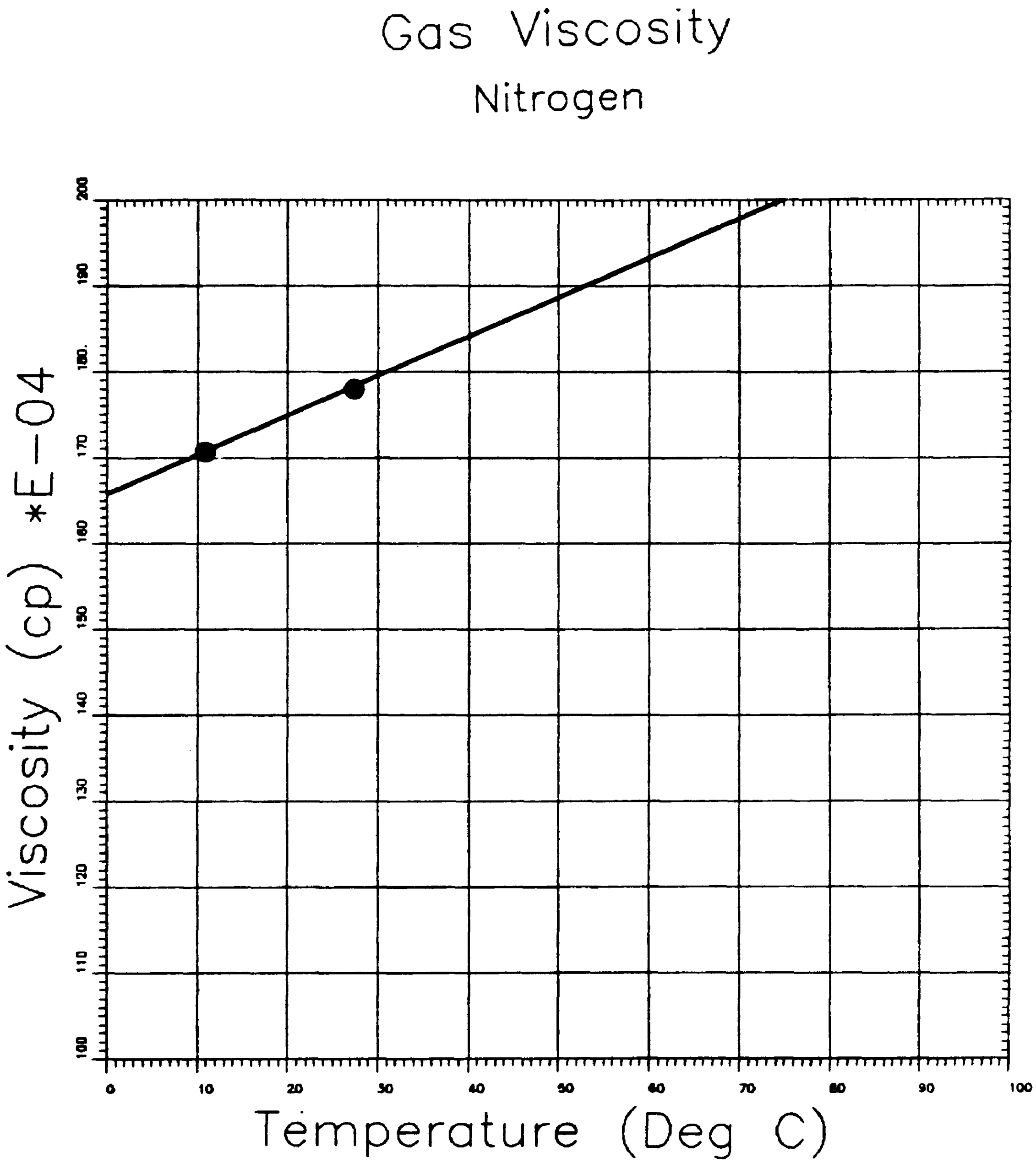


Figure 13

The Viscosity of Nitrogen Gas[14]

least square fit of the data generated the gas viscosity correlations presented in Table 1. Figure 14 gives a plot of liquid heptane viscosity which was used to verify extrapolated liquid permeabilities.

Summary

The data obtained in this experiment was improved through the use of digital pressure transducers, gas bubble meters, and new viscosity correlations. These improvements corrected problems that were present in the previous equipment. Since the apparatus could not measure confining pressures or vary temperatures, these features were not investigated. Also, as stated earlier it was not possible to vary water saturation during the testing. This is not an oversight on the part of the investigator, since the apparatus was designed primarily to be a tool for use by undergraduate students to promote their understanding of gas slippage and the Klinkenberg Effect.

GAS VISCOSITY CORRELATIONS AS A FUNCTION OF TEMPERATURE

Nitrogen Gas Viscosity

$$(\mu) = 0.0000448 * T + 0.0165$$

Carbon Dioxide Gas Viscosity

$$(\mu) = 0.0000500 * T + 0.0138$$

Helium Gas Viscosity

$$(\mu) = 0.0000405 * T + 0.0186$$

Hydrogen Gas Viscosity

$$(\mu) = 0.0000216 * T + 0.0083$$

NOTE: All temperatures are expressed in degrees centigrade and all viscosities are expressed in centipoise. The effect of pressure on viscosity within the pressure range of this equipment (0 - 100 psia) is negligible.

Table 1

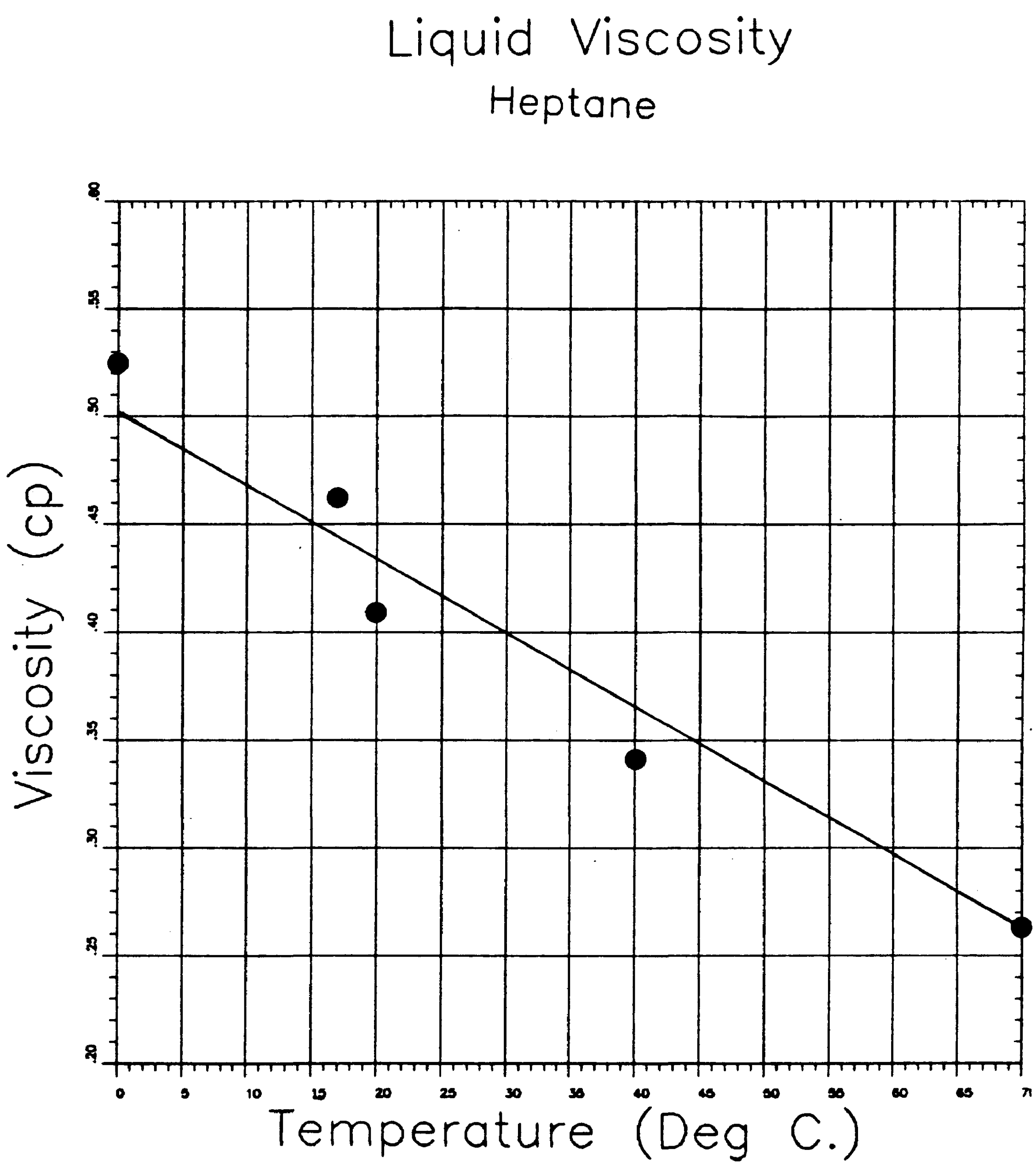


Figure 14

Heptane Liquid Viscosity[14]

VI. VERIFICATION OF RESULTS

The data taken for this experiment was divided into two groups: Data to show repeatability (Figures B1 - B9) (Table B1 - B36) and data to show accuracy (Figures B10 - B12) (Table B37 - B42).

The first data was gathered on Core #1 and repeated three times for verification of equipment repeatability. The data extrapolated consistently to the same liquid permeability. The extrapolated liquid permeabilities, which are presented in Table 2 and Table 4, were calculated by averaging the intercepts for each of the four gases. Results of these runs for a differential pressures of 5 psi, 10 psi and 15 psi are presented in (Figures B1- Figures B9).

The second group of data tested the accuracy of the device. The plots for these cores do not converge as well as the plots from the first sample. Due to high permeabilities, flow rate had to be kept within the limits of the bubble meter, therefore differential pressure was kept to a minimum. When the differential pressure is low, the inaccuracy in the transducer is magnified. This causes the calculated gas permeability data to scatter. This was verified by comparison with unsteady-state results obtained from a local laboratory (Marathon Oil Co., Littleton, Co.).

LIQUID PERMEABILITY DATA (EXTRAPOLATED)

Delta P = 5 psi

Gas	Apparent Liquid Permeabilities Run 1	Run 2	Run 3
Hydrogen	4.71	4.74	4.75
Helium	4.81	4.78	4.75
Nitrogen	4.71	4.68	4.62
Carbon Dioxide	4.78	4.85	4.91

Delta P = 10 psi

Gas	Apparent Liquid Permeabilities Run 1	Run 2	Run 3
Hydrogen	4.73	4.81	4.70
Helium	4.86	4.85	4.91
Nitrogen	4.65	4.66	4.68
Carbon Dioxide	4.75	4.77	4.94

Delta P = 15 psi

Gas	Apparent Liquid Permeabilities Run 1	Run 2	Run 3
Hydrogen	4.81	4.74	4.66
Helium	4.96	4.96	4.88
Nitrogen	4.63	4.63	4.56
Carbon Dioxide	4.54	4.83	4.57

Table 2

Core #1 was stolen before data taken on it could be verified.

The test plugs were cut from six inch diameter whole cores. The cores came from a well drilled in the Huntsman Gas Storage Project operated by KN Energy in Nebraska. These cores are from the top of the J-Sand. Initial core properties were measured and compiled in Table 3.

The results of the unsteady-state method extrapolated liquid permeabilities are presented in Table 4 along with the steady-state values of extrapolated liquid permeability. The percentage difference between liquid and unsteady-state and between steady-state and unsteady-state measurements are provided.

Actual values for liquid permeability were measured using heptane. Liquid heptane was used to prevent any possible interaction with clays. The results of liquid permeability measurements using heptane are also presented in Table 4.

CORE PROPERTIES #4828, #4847, #4850

<u>Core # 4828</u>

Depth	=	4828	Feet
Length	=	2.997	Centimeters
Diameter	=	2.543	Centimeters
Porosity	=	15.210	Percent
Pore Volume	=	2.315	Cubic Centimeters

<u>Core # 4847</u>

Depth	=	4847	Feet
Length	=	2.908	Centimeters
Diameter	=	2.548	Centimeters
Porosity	=	15.541	Percent
Pore Volume	=	2.304	Cubic Centimeters

<u>Core # 4850</u>

Depth	=	4850	Feet
Length	=	2.845	Centimeters
Diameter	=	2.545	Centimeters
Porosity	=	16.783	Percent
Pore Volume	=	2.429	Cubic Centimeters

Table 3

UNSTEADY-STATE AND STEADY-STATE PERMEAMETER DATA

Core #	Steady-State Permeability Experimental (md)	Unsteady-State Permeability Marathon Oil Co. (md)	Liquid Permeability Experimental (md)	Liquid % Deviation From Unsteady -State Permeability	Steady-State % Deviation From Unsteady -State Permeability
4828	1.044	0.577	0.692	19.93	80.85
4847	59.045	60.312	54.836	-9.08	-2.10
4850	130.500	122.004	106.638	-12.59	6.96

Table 4

VII. CONCLUSIONS

Comparison of data obtained from this steady-state instrument with that obtained from a commercial unsteady-state permeameter indicates that the modified instrument demonstrates the "Klinkenberg Effect" satisfactorily. The large percentage differences between the unsteady-state results and the liquid permeability results are due to the unmeasurable triaxial stress which is applied to the core in this experiment. Gray, Fatt, and Bergamini[15] (Figure 15) show that the permeability of a core decreases exponentially with increasing triaxial stress, until an asymptotic value is reached. Marathon's laboratory used a Hassler type core holder in which 1000 psi of triaxial stress was applied to all core plugs during the measurements of gas permeability.

The permeabilities reported here show that this steady-state instrument is able to provide repeatable results on cores in which the extrapolated permeabilities are less than 20 md. When the permeability is below 25 millidarcies the error in the pressure transducers and gas bubble meter is minimized. Comparison of this data with data from a unsteady-state permeameter (Jones' permeameter, Marathon Oil Company[4]) indicate that this steady-state

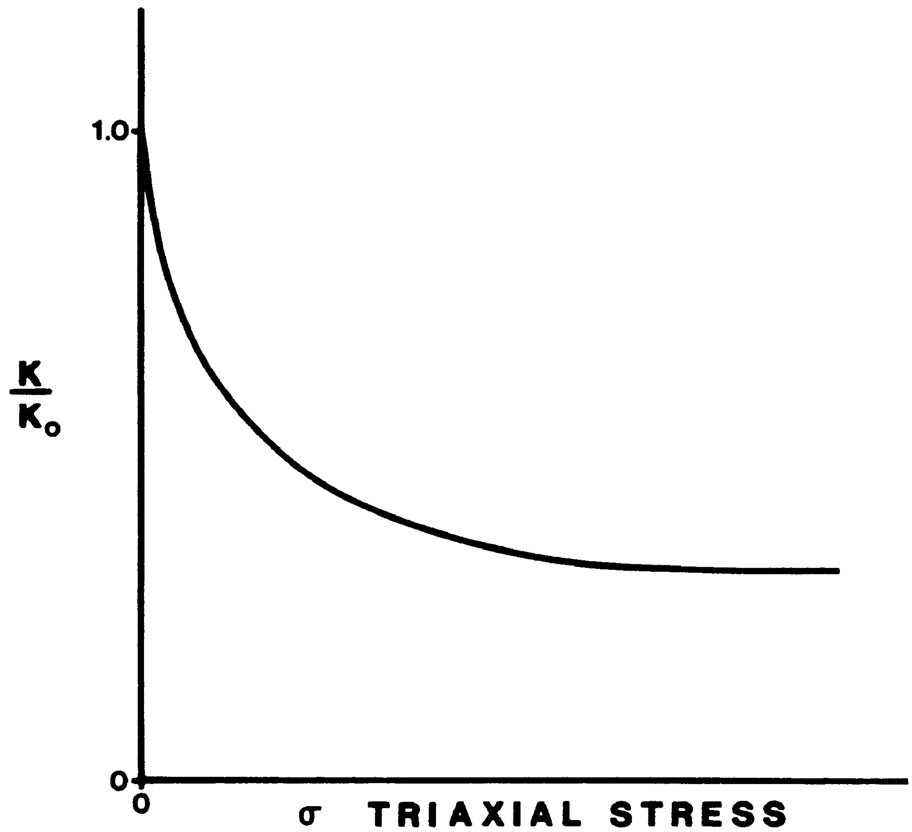


Figure 15

Permeability vs Triaxial Stress (After Gray, et al.[15])

permeameter gives accurate results which demonstrate the Klinkenberg Effect.

The inaccuracies of the pressure transducers, the inability to measure the temperature with a thermocouple, and the inability to measure or control triaxial stress explain the small variations in data scatter at low values of pressure. With higher permeability rocks, the flow rate must be kept low enough to minimize any error in timing the soap bubbles. The differential pressure will also be small because of the high permeability. At low values of differential pressure the error in this pressure $\Delta p = p_i - p_o$ measurement produces a large percentage error in the $p_o = p_i - \Delta p$ calculation of mean pressure within $\bar{p} = \frac{p_i + p_o}{2}$ the core. Thus the Klinkenberg plots become erratic (Figure B10 - B12). The plots of core #4847 and #4850 demonstrate this effect.

VIII. RECOMMENDATIONS

This research indicates areas where further investigations should be performed. It has been shown that the steady-state gas permeameter, as modified in this experiment, can measure gas permeabilities at low values of liquid permeability (less than 25 millidarcies).

Additional investigations to demonstrate the influences of temperature variation, triaxial stress variation and changing liquid saturation need to be made in an effort to simulate reservoir conditions.

This investigator indicates a first priority need for a Hassler type core holder which would be capable of applying carefully controlled and variable levels of triaxial stress to a core. A water or light oil manometer to measure small pressure differences across the core is also needed.

It is recommended that the instrument used in this research be kept available for use in the undergraduate laboratory. An undergraduate laboratory experiment is included in Appendix A.

The data obtained are certainly more reproducible than with the previous equipment. This investigator recommends that students use nitrogen, carbon dioxide and helium. Hydrogen is not recommended for safety reasons. It is recommended that this equipment be used with rocks having a liquid permeability less than 25 millidarcies. The low permeability allows the differential pressure to be high, reducing error associated with the accuracy of the differential transducer. The low permeability (low flow rate) allows soap bubbles to be accurately timed. An optimum range for this apparatus, as shown from the experimental data, is to have an extrapolated liquid permeability between 3 and 25 millidarcies and to have the differential pressure across the core near 15 psi.

NOMENCLATURE

A = Cross sectional area of core

b = Proportionality constant

c = Proportionality constant

K = Permeability

K_l = Equivalent liquid or absolute permeability

K_a = Apparent or gas permeability

K_o = Permeability at zero confining pressure

L = Length of the core

n = Number of capillaries

P = Pressure

P_1 = Inlet pressure

P_2 = Outlet pressure

$\overline{P}$ = Mean pressure within the core

P_r = Room pressure (atmospheric)

P_x = Pressure at any point within the core

Q_l = Volumetric liquid flow rate per unit area

Q_r = Gas flow rate at room conditions

r = Radius of a capillary

t = Time

T = Temperature

T_r = Room temperature

v = Velocity

V = Volume

NOMENCLATURE

X = Distance from the edge of a core

$\bar{Z}$ = Mean gas deviation factor

α = The inverse of absolute permeability

β = Forchheimer beta factor (turbulence factor)

μ = Viscosity

μ_g = Gas viscosity

μ_l = Liquid viscosity

ρ = Density

ρ_g = Gas density

ρ_l = Liquid density

$\bar{\lambda}$ = Mean free path of the molecules

REFERENCES CITED

1. Klinkenberg, L.J., 1941, "The Permeability of Porous Media to Liquids and Gases": API Drilling and Production Practices, p. 200-213.

2. Jones, S.C., 1972, "A Rapid Accurate Unsteady-State Klinkenberg Permeameter": Society of Petroleum Engineers Journal, October, p. 383-397.

3. Forchheimer, P., 1914, "Hydraulik": Chapter 15, Sections 116-118; Leipzig and Berlin, Druck und Verlag von B.G. Teubner.

4. Jones, S.C., 1985, Private Communication, Marathon Research Center.

5. Jennings, J.B., Carroll, H.B., and Raible, C.J., 1981, "The Relationship of Permeability to Confining Pressure in Low Permeability Rock": SPE 9870, presented at the 1981 SPE/DOE Low Permeability Symposium, Denver, Co, May 27-29.

6. Freeman, D.L. and Bush, D.C., 1983, "Low-Permeability Laboratory Measurements by Nonsteady-State and Conventional Methods": Society of Petroleum Engineers Journal, December, p.928-936.

7. Wei, K.K., Morrow, N.R.,and Brower, K.R., 1984, "The Effect of Fluid, Confining Pressure, and Temperature on Absolute Permeabilities of Low-Permeability Sandstones": SPE 13093, presented at the 1984 SPE Technical Conference, Houston, TX, September 16-19.

8. Green, L., Jr. and Duwez, P., 1951, "Fluid Flow Through Porous Metals": Transactions of the American Society of Mechanical Engineers, Vol.18, p.39.

9. Cornell, D. and Katz, D.L., 1953, "Flow of Gases Through Consolidated Porous Media": Industrial and Engineering Chemistry, Vol.45, p. 2145.

10. Dranchuck, P.M. and Sadiq S., 1965, "The Interpretation of Permeability Measurements": The Journal of Canadian Petroleum Technology, Vol. 4, No. 3, p.132.

11. Dranchuck, P.M. and Kolada L.J., 1967, "Interpretation of Steady Linear Visco-Inertial Gas Flow Data": Presented at 18th Annual Technical Meeting of the Petroleum Society of Canada, May 24-26.

12. Casse, F.J. and Ramey, H.J., 1979, "The Effect of Temperature and Confining Pressure on Single-Phase Flow in Consolidated Rocks": Journal of Petroleum Technology, August, p. 1051-1059.

13. Aldrich, C.S., 1985, "Lab Manual, Petroleum Engineering 312, Drilling Fluids and Rock Properties": Colorado School of Mines.

14. CRC Handbook of Chemistry and Physics, 59th Edition, Ed. R.C. Weast, CRC Press, 1978.

15. Gray, D.H.,Fatt, I., and Bergamini, G., 1963, "The Effect of Stress on Permeability of Sandstone Cores": Society of Petroleum Engineers Journal, June, p. 95-100.

Appendix A

UNDERGRADUATE LABORATORY EXPERIMENT

KLINKENBERG EXPERIMENT - The effect of gas slippage on permeability measurements.

Introduction

The purpose of this experiment is to demonstrate the effect that gas slippage has on the determination of gas measured permeability of a core sample. Often the value of liquid permeability is difficult to obtain because of the presence of reactive clays or low viscosity liquid hydrocarbons. Both of these problems can be circumvented by measuring a reservoir's permeability to a gas at various pressures. The extrapolation of this gas data enables the prediction of liquid permeability without direct and tedious testing of the core. Gas measurements eliminate most errors and diminish chances of others.

Gas slippage is related closely to the mean free path of the molecules. The mean free path of a gas is defined as the distance between average molecular collisions. The measured gas permeability is plotted versus the reciprocal mean pressure. A gas acts much like a liquid under very high pressure. When the data for gas permeability is extrapolated to infinite pressure, the intercept yields a permeability constant which is a unique characteristic of the specific porous medium.

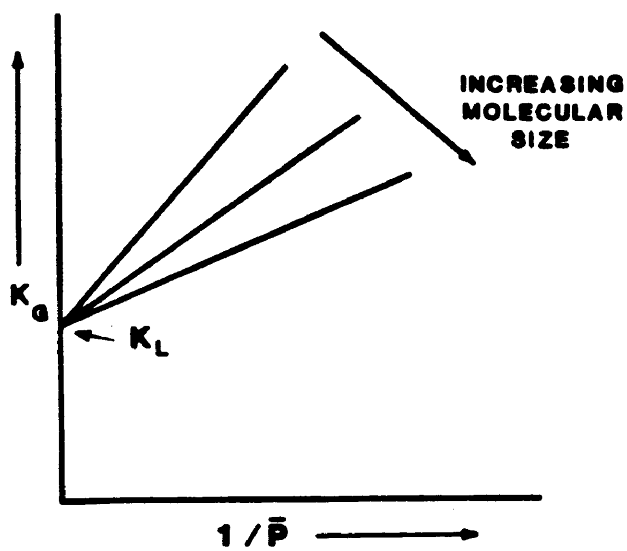


Figure A1

Klinkenberg Effect (After Klinkenberg[1])

Theory

Given Darcy's Law;

$$Q_x = \frac{K_a\ A}{\mu_g} (-dP/dX) \tag{A1}$$

where:

Q_x = Flow rate (cc/sec),

K_a = Apparent or gas permeability (darcies),

μ_g = Viscosity (cp),

A = Cross sectional area (cm^2),

dP = Differential pressure (abs.atm),

dX = Differential length (cm).

Knowing the continuity equation must apply over a closed system.

$$\frac{P_i V_i}{Z_i T_i} = \frac{P_o V_o}{Z_o T_o} \tag{A2}$$

where:

P = Pressure,

V = Volume,

Z = Gas deviation factor,

T = Temperature,

i = subscript signifying inlet conditions,

o = subscript signifying outlet conditions.

Dividing both sides of equation (A2) by time (t) and substituting ($Q = V / t$) in for flow rate;

$$\frac{P_x Q_x}{Z_x T_x} = \frac{P_r Q_r}{Z_r T_r} \qquad \text{(A3)}$$

where:

r = subscript signifying meter or room conditions,

x = subscript signifying conditions at any point within the core

t = time.

A simplifying assumption that Z is constant can be made since at low pressures the Z factor of these gases is approximately equal to one. Another simplifying assumption that temperature is constant, can be made since a low pressure drop across the core cause a negligible Joule-Thompson Effect which would cool the gas. However the temperature of the gas is critical for calculating gas viscosity.

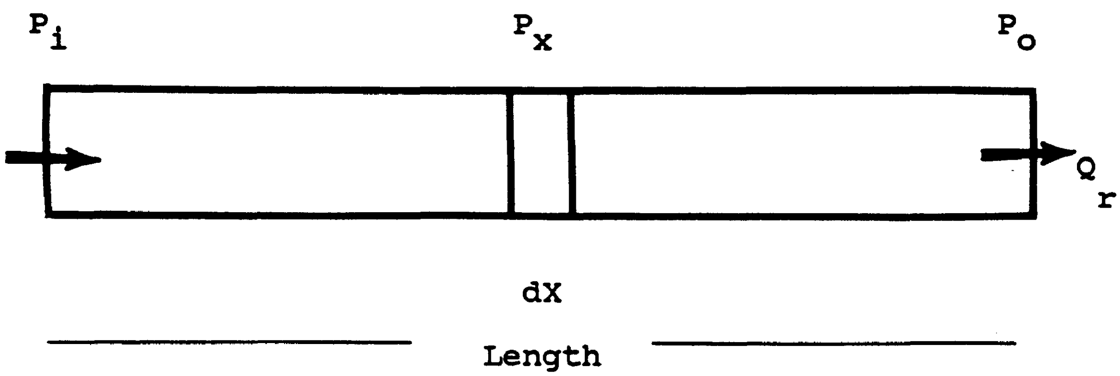


Figure A2

Differential Pressure Element Within the Core

Solving Equation (A3) for Q_x, and substituting into Equation (A1) the following is obtained;

$$\frac{\mu_g}{K_a A}\, dX = -\int_{o}^{L} \frac{P_x\, dP}{P_r Q_r} \qquad \text{(A4)}$$

Integrating along the length of the core and noting the following boundary conditions:

when:

$x = 0$	$P_x = P_i$	Inlet Conditions
$x = L$	$P_x = P_o$	Outlet Conditions

We obtain:

$$\frac{\mu_g L}{K_a A} = \frac{P_i^2 - P_o^2}{2\, P_r Q_r} \tag{A5}$$

where:

L = Length of the core.

Solving for permeability, equation (A5) becomes:

$$K_a = \frac{P_r\, Q_r\, 2\, \mu_g\, L}{(P_i^2 - P_o^2)\, A} \tag{A6}$$

by substituting in the mean pressure within the core,

$$\bar{P} = \frac{P_i + P_o}{2} \tag{A7}$$

Equation (A6) becomes,

room press.

$$K_a = \frac{P_r\, Q_r\, \mu_g\, L}{(P_i - P_o)\, \bar{P}\, A} . \tag{A8}$$

For Laminar Flow.

The equations we have just derived are based upon Darcy's Law and therefore are only valid for laminar flow.

The velocity profile for a liquid within a capillary is of parabolic shape and the laminar flow assumption requires the velocity at the wall to be zero. Klinkenberg conducted experiments on cores in which he measured permeabilities to gas that were much higher than were measured with Newtonian liquids. As the size of the pore throat approaches the mean free path of the gas, (distance between average molecular collisions), the component of velocity which is parallel to the wall is large compared to the component of velocity perpendicular to the wall. He attributed this to the slippage of the gas molecules at the wall contact. He theorized that if the molecules could be forced close enough together, using a high enough pressure similar to the molecules in a liquid, the observed permeabilities would equal liquid permeability measurements.

In this experiment, the distances between the molecules in a gas will be varied in one of two ways. First, when the pressure of the gas in increased, the molecules will be pushed closer together; and if the pressure is decreased, the molecules will separate from one another. When the mean pressure in a core increases the number of molecules per unit volume of a gas is increased, and the gas will act more like a liquid, wherein the velocity of the molecules perpendicular to the wall approaches zero. This is a manifestation of the shortened distances between the molecules, the mean free path of the gas.

Secondly, the size of the molecules can be varied by using gases of different molecular weights. Since the size of the molecules in a gas vary directly with the molecular weight of the gas, molecules being of larger size have shorter distances between them. Therefore the gas will act more like a liquid with these shorter distances.

Procedure

1. Record the barometric pressure and the laboratory room temperature on your data sheet. Obtain a sample core, either from your lab instructor or use your own, if it has a permeability to liquid in the range of three to ten millidarcies. Record the length and diameter of the core on your data sheet.
2. Compare Figure A2 through Figure A4 with the apparatus you are using and familiarize yourself with the locations of all valves and gauges. Close the three supply valves. Open the purge valve and the by-pass valve. Open the flow control valve located on the outlet side of the core. Turn on the power. DO NOT touch the toggle switches that are located on the front of the individual pressure transducers. The toggle

switch should be in the up position. If it is not, ask the lab instructor for assistance. Place the core in the holder and tighten the jacket snugly, with your fingers; loosen the jacket one half turn to prevent galling.

3. Open the main valve on the nitrogen bottle. Observe the pressure at the first stage regulator. Set this pressure initially to 20 psig. Open slowly the supply valve for the nitrogen gas. Close the purge valve after a small amount of gas has been allowed to purge the inlet side of the apparatus. After closing the purge valve, you must regulate the inlet pressure exactly to the desired pressure by manipulating the second stage regulator. The inlet pressure transducer should now read approximately 32 psia. The differential pressure transducer should read zero since the by-pass valve is still open.
4. Ascertain that the gas bubble meter is attached to the apparatus as shown in Figure A4. If necessary, add enough soap solution to the gas bubble meter to bring the level to a point just below the level of the gas inlet port on the side of the meter. Close the flow control valve. Close slowly the by-pass valve. The differential pressure transducer should read less than

0.1 psi. Note: If any time during the experiment the differential pressure transducer reads more than 20 psi, there will be irreversible damage to the transducer. Slowly, open the flow control valve to increase the pressure on the differential transducer. Increase the flow until the desired differential pressure is reached. The adjustment of the flow control valve requires meticulous care if the results are to be satisfactory.

5. The apparatus and your core should now equilibrate. Depending upon the permeability of the sample, this will require from two to six minutes. During this equilibrating period the inlet and differential pressures should have stabilized, shows no change. The differential pressure should be 15 psi. This will give the best possible results. Continue to adjust the inlet regulator and the flow control valve until the pressure transducers read the same values for at least one minute. Once the apparatus and your core are in equilibrium, flow measurements can be made with the gas bubble meter.

6. Block the end of the rubber hose containing the soap solution with one of your hands, and with the other hand squeeze the rubber hose; this action will raise

the level of the soap solution above the gas inlet port on the side of the meter. Practice this maneuver until you can produce a single bubble which will float upward through the meter and travel completely to the top without bursting. Wetting the inside of the meter with soap solution may be required if the bubble is to travel the entire length of the tube without bursting. Record the elapsed time for a single bubble to travel the distance between the etched marks on the side of the tube. The numbers that are etched on the side are in units of cubic centimeters. Since you know the volume of the tube and the time that it takes the bubble to travel a known distance, you can calculate the volumetric flow rate through the core at room temperature and barometric pressure.

7. Record the readings of inlet pressure from the transducer, differential pressure from the transducer, and the five separate time intervals from the bubble meter.
8. Open the by-pass valve. The differential pressure transducer should read zero. Close the flow control valve. Increase the pressure on the first stage regulator an additional 15 - 20 psi. Return to step 4 and adjust the second stage regulator so that it reads

15 - 20 psi above the previous reading, and record a new set of data. Five data points are necessary for each gas at inlet pressures between 32 and 90 psia. Remember that the differential pressure must remain constant (the same value), throughout this experiment.

9. To change gas, open the by-pass valve and close the flow control valve. Close the valve on the supply bottle and turn the handle on the regulator counter clockwise until the pressure on both gauges of the individual supply bottle read zero. Open the purge valve slowly and allow the gas on the inlet side of the core to vent through the meter. If the purge valve is opened too quickly, the surge of gas through the meter will force the soap solution out of the meter. If this happens contact the laboratory instructor. Open the flow control valve and allow any trapped gas on the outlet side of the core to vent. Close the flow control valve. Close the supply valve from the previous gas. Slowly open the valve on the bottle containing the new gas, while observing the regulator pressure gauge on the bottle. Open slowly the supply valve for the new gas. Adjust the first stage regulator so that the inlet pressure is approximately 10 psig. Repeat this experimental procedure for all three

gases. Be certain that you allow all of the new gas to pass through the core and through the meter, since a mixture of gases will affect the results of this experiment adversely.

10. Be sure that the valves on all gas bottles are closed. Turn off the power off at the apparatus. Do not turn off the toggle switches on the transducers. Remove the core and return it to the laboratory instructor if it is not your own.

SCHEMATIC OF APPARATUS

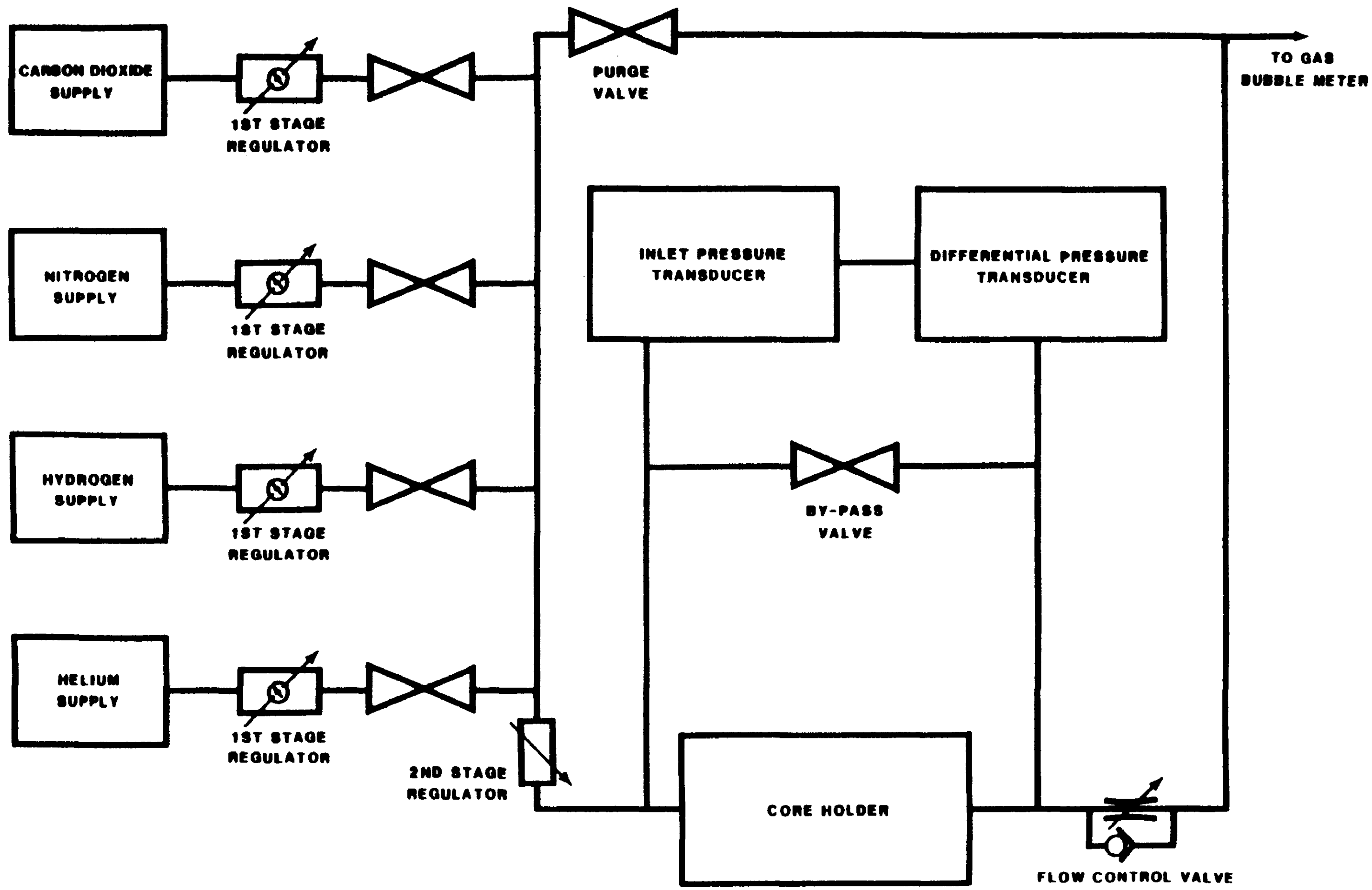


Figure A3

A Modified Klinkenberg Permeameter (After Aldrich[13])

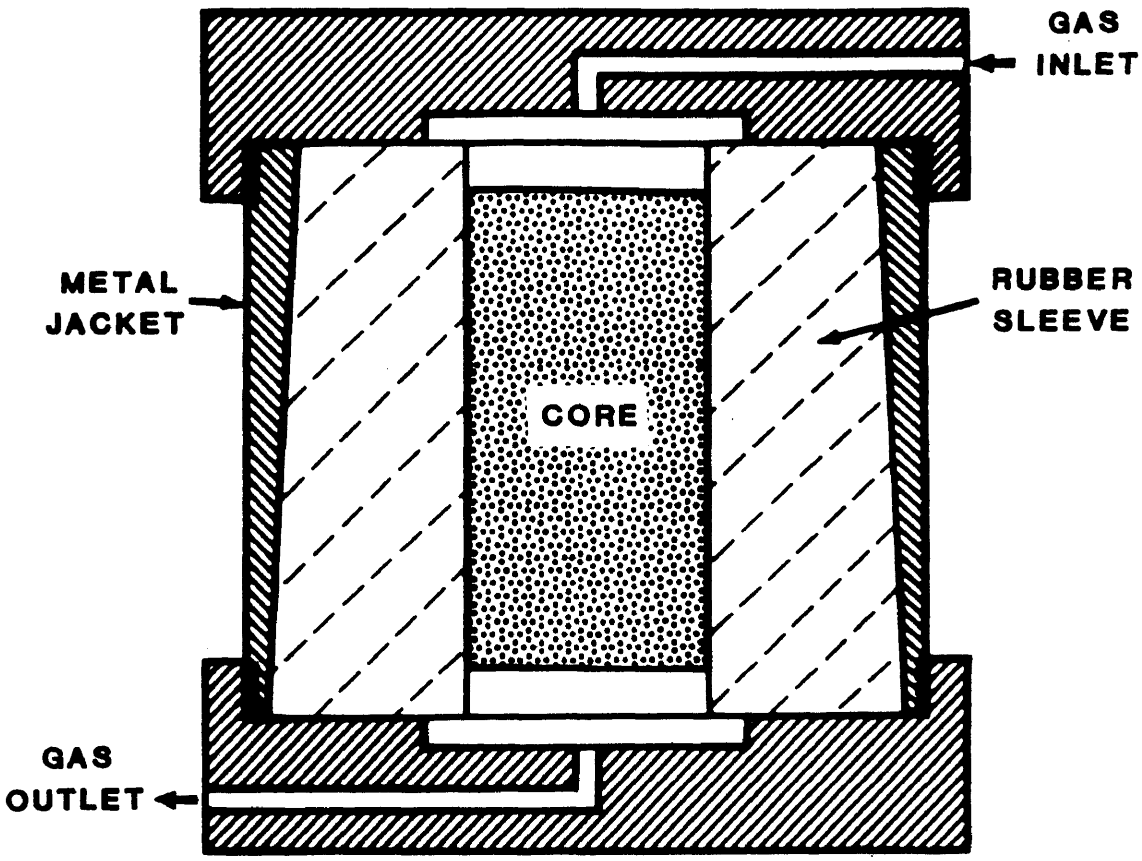


Figure A4

Core Holder

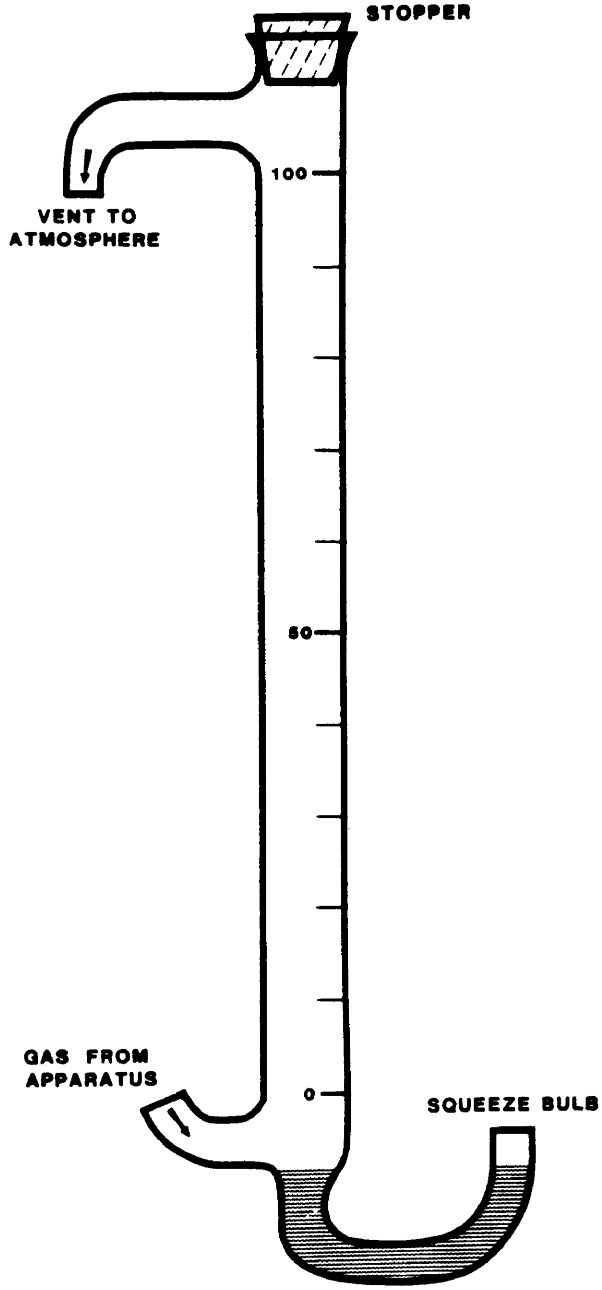


Figure A5

Gas Bubble Meter

REPORT

1. Calculate the observed permeability, and the mean pressure for each data point. Remember that all pressures are expressed in absolute atmospheres and all flow rates are expressed in cubic centimeters per second.
2. Plot all data on regular graph paper as permeability versus reciprocal mean pressure. Draw a straight line though each set of data and extrapolate the line to a reciprocal mean pressure of zero, which corresponds to an infinite mean pressure within the core. Do the points of your plot follow this straight line? From the points of intersection on the Y-axis and your plotted straight lines, make the best estimate of liquid permeability of this core, and compare this estimate with results obtained from previous laboratory experiments. This comparison will allow you to make a conclusion concerning the reliability of your experiment.

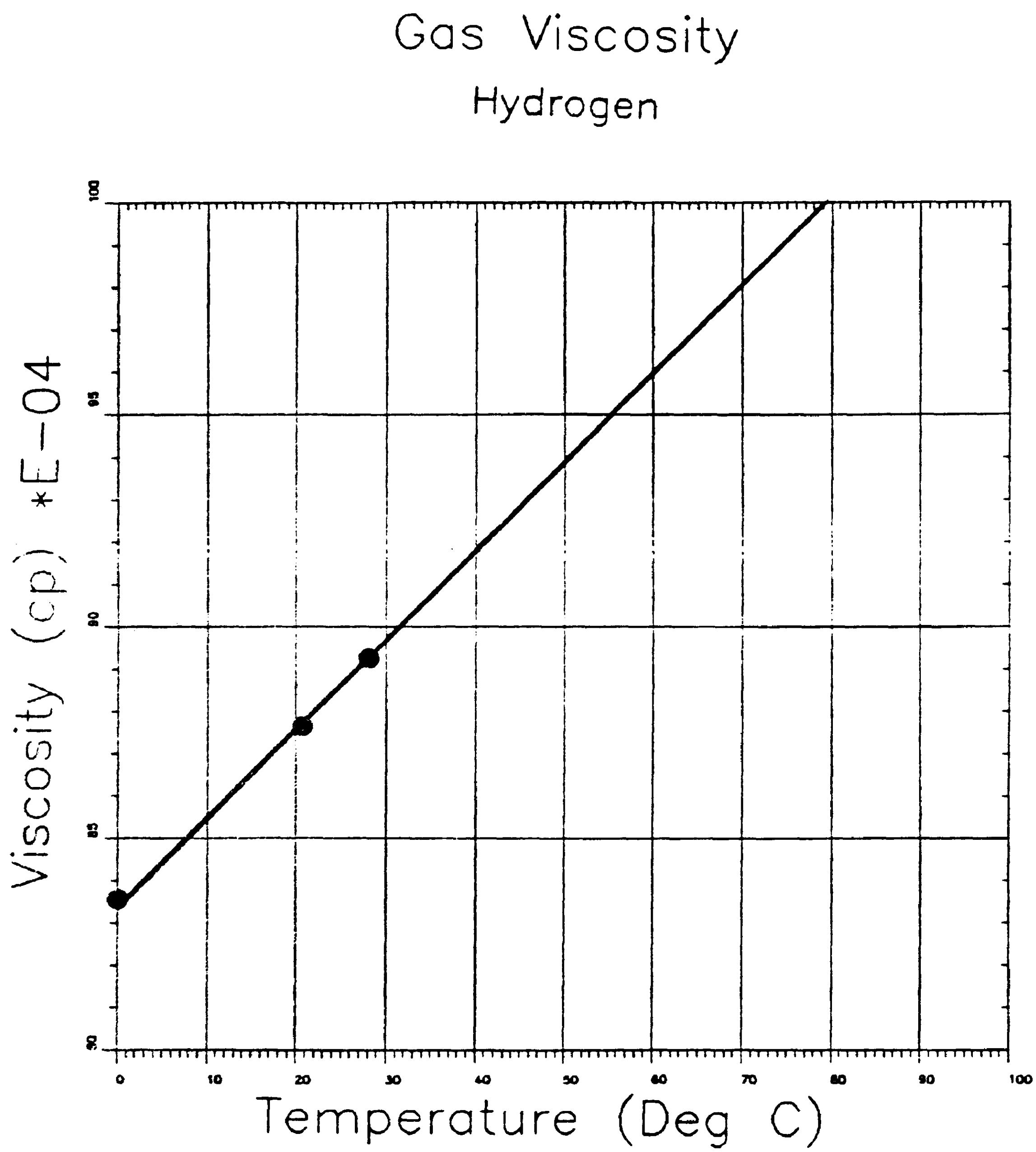


Figure A6

The Viscosity of Hydrogen Gas[14]

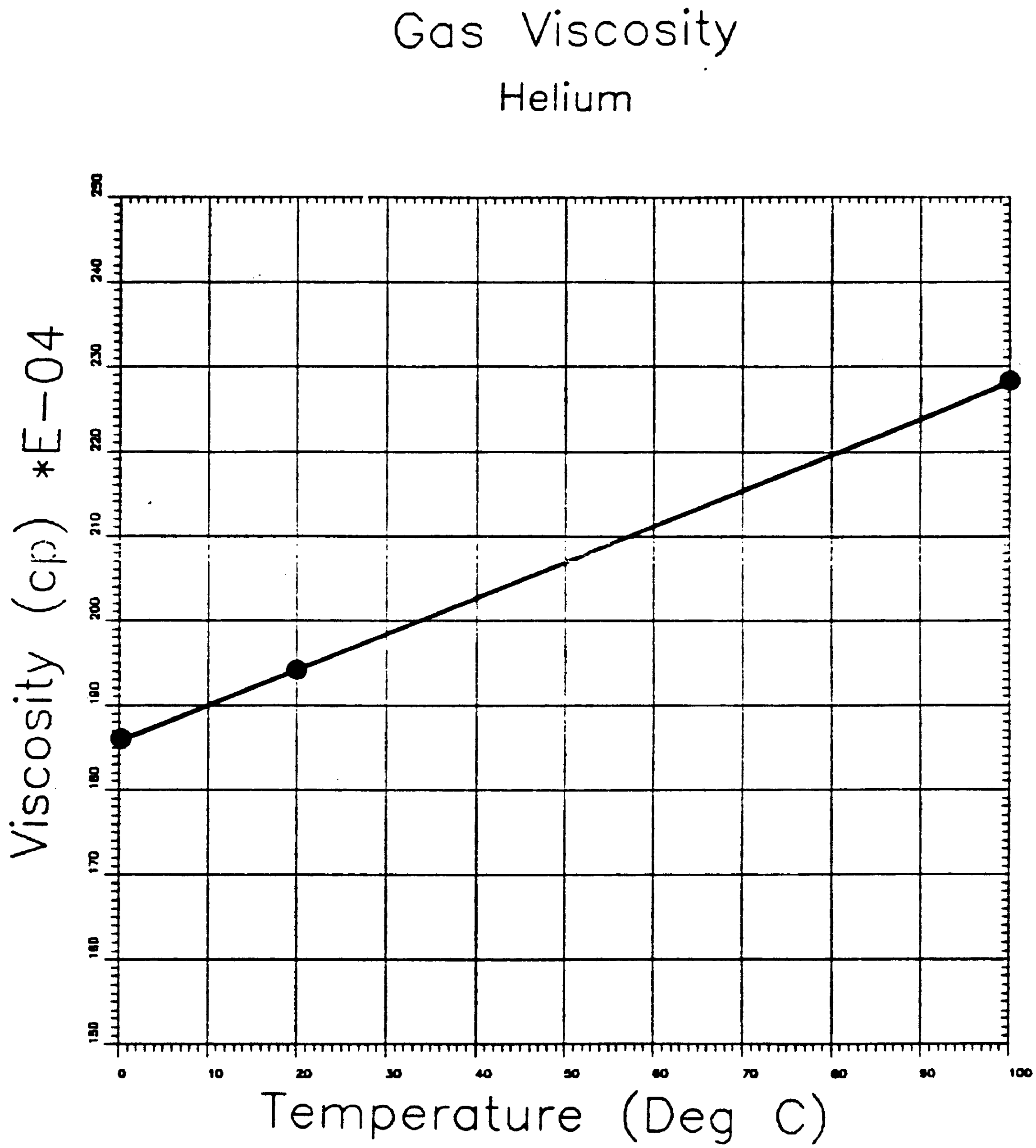


Figure A7

The Viscosity of Helium Gas[14]

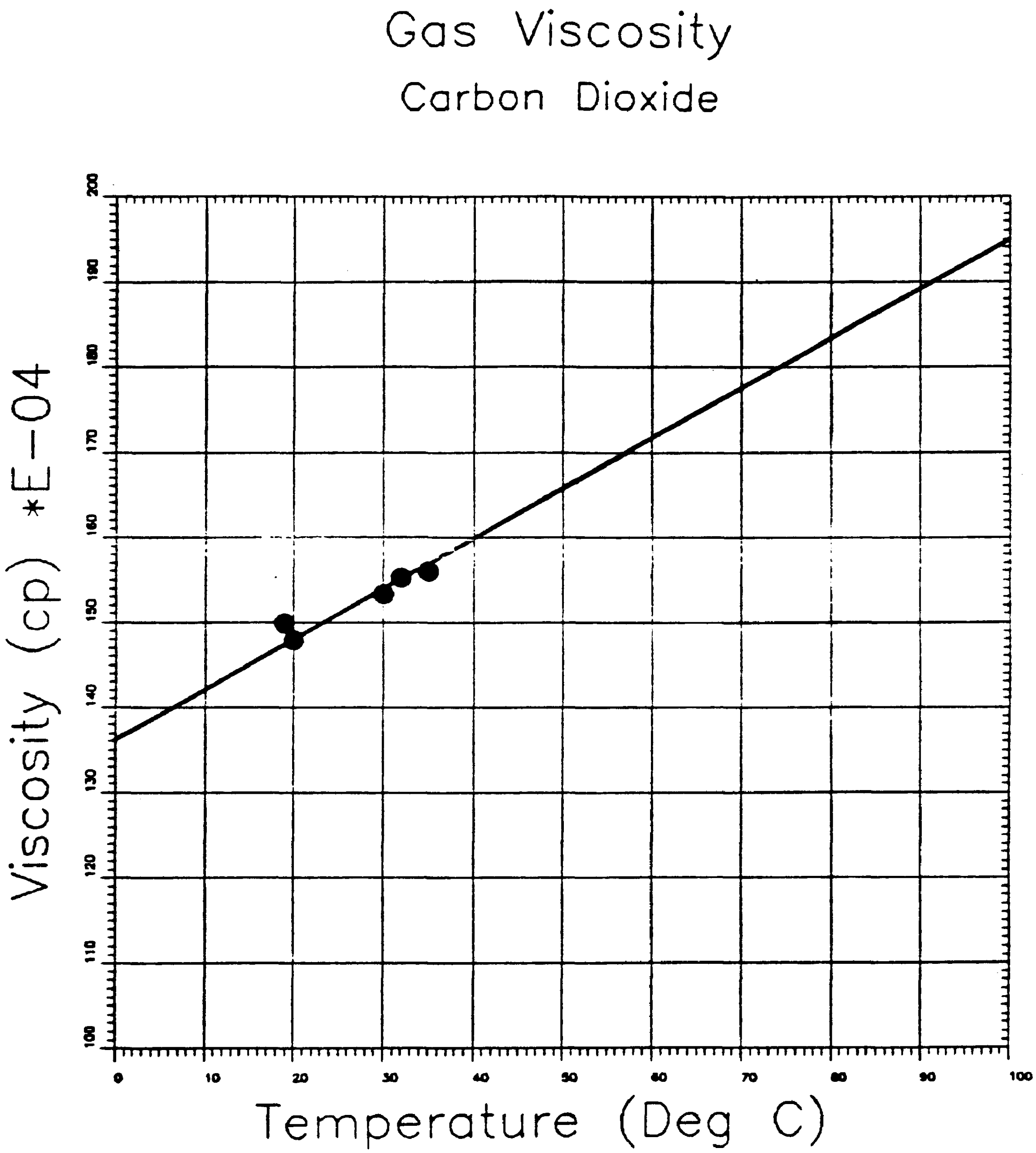


Figure A8

The Viscosity of Carbon Dioxide Gas[14]

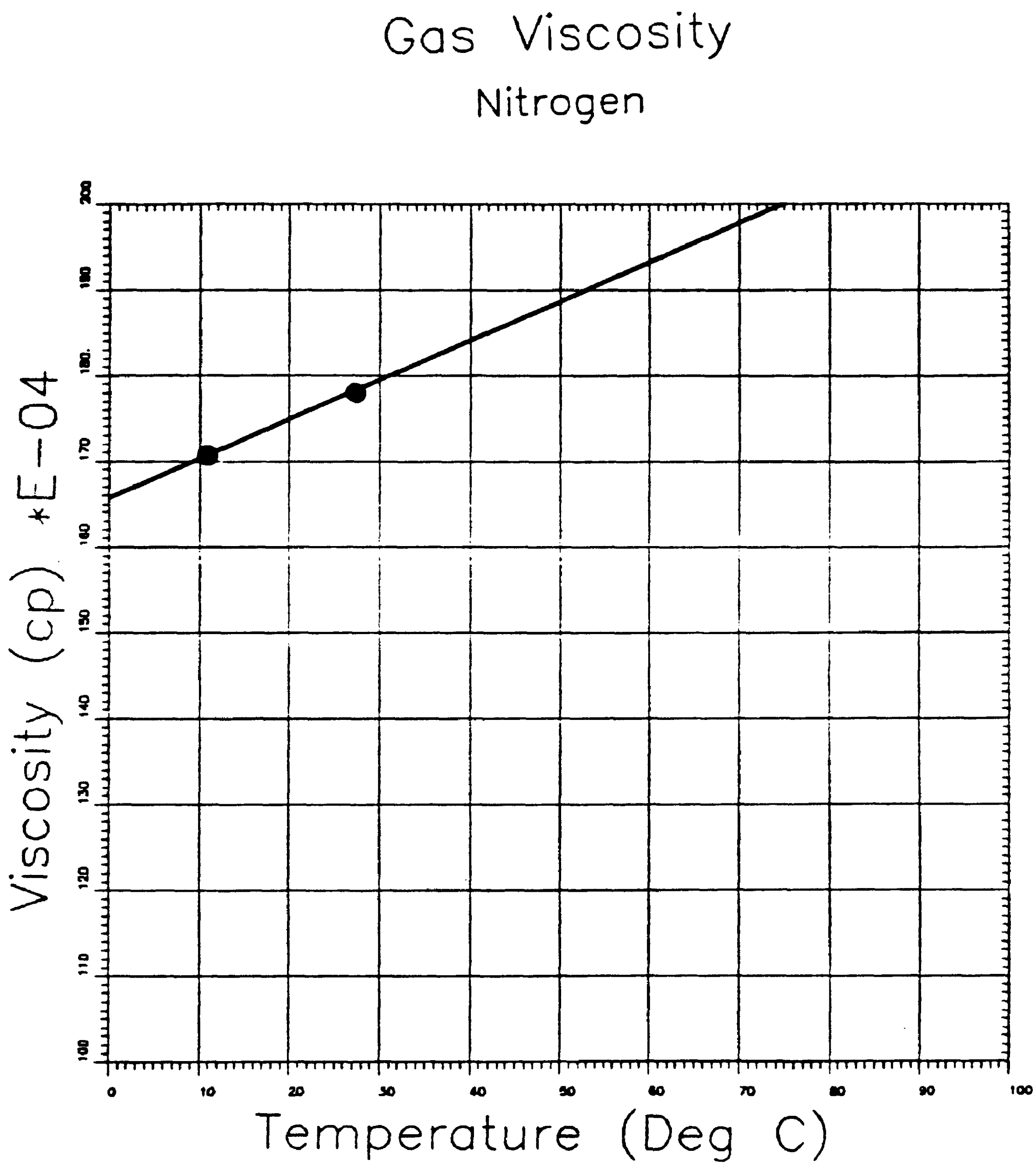


Figure A9

The Viscosity of Nitrogen Gas[14]

GAS VISCOSITY CORRELATIONS AS A FUNCTION OF TEMPERATURE

Nitrogen Gas Viscosity

$$(\mu) = 0.000044848 * T + 0.0165 \quad \text{(A13)}$$

Carbon Dioxide Gas Viscosity

$$(\mu) = 0.000050000 * T + 0.0138 \quad \text{(A14)}$$

Helium Gas Viscosity

$$(\mu) = 0.000040500 * T + 0.0186 \quad \text{(A15)}$$

Hydrogen Gas Viscosity

$$(\mu) = 0.000021600 * T + 0.0083 \quad \text{(A16)}$$

NOTE: All temperatures are expressed in degrees centigrade and all viscosities are expressed in centipoise. The effect of pressure on viscosity within the pressure range of this equipment (0 - 100) psia is negligible.

μ = .0195922

(1) = 25/474 * .0195922 * .8151 ... 3.25 / 2.805 * 1.523 ... = 1.886 md

(2) = 25/734 * .019 ... / 2.805 * .3374 * 3.18 = .8534 md

Table A1

NOMENCLATURE

A = Cross sectional area of core

K = Permeability

K_a = Apparent or gas permeability

L = Length of the core

P = Pressure

P_i = Inlet pressure

P_o = Outlet pressure

$\overline{P}$ = Mean pressure within the core

P_r = Room pressure (atmospheric)

P_x = Pressure at any point within the core

Q_r = Gas flow rate at room conditions

Q_x = Volumetric flow rate at any point within the core

T_r = Temperature of the room

V = Volume

X = Distance from the edge of a core

$\overline{Z}$ = Mean gas deviation factor

μ_g = Gas viscosity

Name: ____________________
Partner: ____________________
Section: ____________________
Date: ____________________

DATA SHEET
SHEET 1

KLINKENBERG EXPERIMENT

Core ID. ______________ Length __________ Dia. ________
Barometric Pressure ________ in. Hg. Room Temp. __________

Test #1 Nitrogen Gas

Inlet Pressure	Diff Pressure	Time #1	Time #2	Time #3	Time #4	Time #5	Meter Vol.	Temp °C

Test #2 Carbon Dioxide Gas

Inlet Pressure	Diff Pressure	Time #1	Time #2	Time #3	Time #4	Time #5	Meter Vol.	Temp °C

Name: ______________________
Partner: ______________________
Section: ______________________
Date: ______________________

DATA SHEET
SHEET 2

KLINKENBERG EXPERIMENT

Core ID. ______________ Length __________ Dia. ______
Barometric Pressure ________ in. Hg. Room Temp. __________

Test #3 Helium Gas

Inlet Pressure	Diff Pressure	Time #1	Time #2	Time #3	Time #4	Time #5	Meter Vol.	Temp °C

Test #4 Hydrogen Gas

Inlet Pressure	Diff Pressure	Time #1	Time #2	Time #3	Time #4	Time #5	Meter Vol.	Temp °C

Name: ____________________
Partner: ____________________
Section: ____________________
Date: ____________________

DATA REDUCTION
SHEET 1

KLINKENBERG EXPERIMENT

Barometric Pressure __________ Atmospheres

Core Length __________ Centimeters

Core Area __________ Square Centimeters

Test #1 Nitrogen Gas

Inlet Pressure (Atm.Abs.)	Outlet Pressure (Atm.Abs.)	Average Time (sec)	Flow Rate (cc/sec)	Perm. (md)	$1/\overline{P}$ (1/atm)

Name: ______________________
Partner: ______________________
Section: ______________________
Date: ______________________

DATA REDUCTION
SHEET 2

KLINKENBERG EXPERIMENT

Barometric Pressure ________ Atmospheres

Core Length ________ Centimeters

Core Area ________ Square Centimeters

<u>Test #2 Carbon Dioxide Gas</u>

Inlet Pressure (Atm.Abs.)	Outlet Pressure (Atm.Abs.)	Average Time (sec)	Flow Rate (cc/sec)	Perm. (md)	$1/\overline{P}$ (1/atm)

Name: ______________________
Partner: ______________________
Section: ______________________
Date: ______________________

DATA REDUCTION
SHEET 3

KLINKENBERG EXPERIMENT

Barometric Pressure __________ Atmospheres

Core Length __________ Centimeters

Core Area __________ Square Centimeters

Test #3 Helium Gas

Inlet Pressure (Atm.Abs.)	Outlet Pressure (Atm.Abs.)	Average Time (sec)	Flow Rate (cc/sec)	Perm. (md)	$1/\overline{P}$ (1/atm)

Name: ______________________
Partner: ______________________
Section: ______________________
Date: ______________________

DATA REDUCTION
SHEET 4

KLINKENBERG EXPERIMENT

Barometric Pressure __________ Atmospheres

Core Length __________ Centimeters

Core Area __________ Square Centimeters

<u>Test #4 Hydrogen Gas</u>

Inlet Pressure (Atm.Abs.)	Outlet Pressure (Atm.Abs.)	Average Time (sec)	Flow Rate (cc/sec)	Perm. (md)	$1/\overline{P}$ (1/atm)

Appendix B

Experimental Data

Delta P = 5 psi **RUN #1**

Calculated Data

Core ID **#1**

Length 3.25 cm. **Diameter** 1.89 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Helium>						
20.00	5.00	25.00	0.01961	0.155	7.158	0.8400
25.00	5.00	25.00	0.01961	0.191	6.854	0.6533
30.00	5.02	25.40	0.01963	0.222	6.492	0.5347
35.00	4.99	25.40	0.01963	0.251	6.251	0.4522
40.00	5.02	26.00	0.01965	0.282	6.061	0.3921
45.00	4.99	26.00	0.01965	0.311	5.922	0.3458
50.00	5.03	26.00	0.01965	0.342	5.792	0.3096
55.00	4.99	26.00	0.01965	0.374	5.775	0.2800
60.00	5.03	26.20	0.01966	0.402	5.621	0.2557
65.00	5.01	26.80	0.01969	0.430	5.558	0.2352
70.00	5.00	27.00	0.01969	0.459	5.510	0.2178
75.00	5.00	27.00	0.01969	0.487	5.438	0.2028
80.00	4.98	27.00	0.01969	0.514	5.393	0.1897
85.00	4.96	27.00	0.01969	0.540	5.346	0.1781
90.00	5.01	27.20	0.01970	0.578	5.345	0.1680
<Hydrogen>						
20.00	4.97	24.00	0.00883	0.302	6.310	0.8393
25.00	5.02	25.00	0.00885	0.375	6.053	0.6536
30.00	4.99	25.00	0.00885	0.440	5.839	0.5344
35.00	4.97	25.00	0.00885	0.505	5.694	0.4521
40.00	5.04	25.20	0.00886	0.578	5.571	0.3922
45.00	4.98	25.60	0.00887	0.636	5.481	0.3458
50.00	5.01	25.60	0.00887	0.705	5.404	0.3095
55.00	5.04	25.80	0.00887	0.775	5.343	0.2801
60.00	5.01	26.00	0.00887	0.831	5.263	0.2557
65.00	4.99	26.00	0.00887	0.896	5.242	0.2352
70.00	5.03	26.00	0.00887	0.967	5.200	0.2178
75.00	5.03	26.00	0.00887	1.031	5.159	0.2028
80.00	5.00	26.20	0.00888	1.090	5.138	0.1897
85.00	4.98	26.20	0.00888	1.149	5.107	0.1782
90.00	5.01	26.40	0.00888	1.220	5.086	0.1680

50 ... .155 cc/sec

22.12

$\frac{P_1+P_2}{2} = \bar{P}$

$\bar{P} = \frac{20+(20-5)}{2} / 14.7$

Table B1

$$\frac{Q\,\mu\,.\,L\,.\,P'}{A(P'^2-P_0^2)\,\bar{P}}$$

$$= \frac{(.155)(.01961)*3.25*.8\ldots}{2.8*1.19*.34}$$

$\bar{P} = \frac{P'+P_0}{2}$

Delta P = 5 psi

RUN #1
Laboratory Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Helium>							
24.59	50.00	323.34	322.19	321.98	321.56	321.52	322.12
24.59	50.00	262.08	261.79	261.63	261.61	261.17	261.66
24.59	50.00	225.50	225.32	225.36	225.36	225.35	225.38
24.59	50.00	199.23	199.25	199.16	199.00	199.08	199.14
24.59	50.00	177.46	177.35	177.28	177.05	177.01	177.23
24.59	50.00	161.11	160.92	161.04	160.87	160.87	160.96
24.59	50.00	146.29	146.18	145.92	146.19	146.07	146.13
24.59	50.00	125.66	135.76	135.42	135.48	135.69	133.60
24.59	50.00	124.43	124.44	124.36	124.47	124.49	124.44
24.59	50.00	116.35	116.44	116.34	116.49	116.21	116.37
24.59	50.00	109.03	108.91	108.87	108.92	108.97	108.94
24.59	50.00	102.59	102.96	102.57	102.79	102.91	102.76
24.59	50.00	97.36	97.29	97.24	97.23	97.41	97.31
24.59	50.00	92.67	92.50	92.32	92.44	92.95	92.58
24.59	50.00	84.05	87.14	87.08	87.06	87.14	86.49
<Hydrogen>							
24.58	50.00	165.34	165.41	165.31	165.26	165.29	165.32
24.58	50.00	133.28	133.18	133.12	133.23	133.19	133.20
24.58	50.00	113.59	113.60	113.59	113.58	113.52	113.58
24.58	50.00	99.01	98.90	98.98	98.88	98.86	98.93
24.58	50.00	86.55	86.62	86.52	86.46	86.50	86.53
24.58	50.00	78.62	78.62	78.56	78.52	78.50	78.56
24.58	50.00	70.90	70.90	70.91	70.89	70.87	70.89
24.58	50.00	64.57	64.57	64.50	64.54	64.50	64.54
24.58	50.00	59.99	59.98	60.01	61.01	59.96	60.19
24.58	50.00	55.88	55.89	55.76	55.73	55.76	55.80
24.58	50.00	51.69	51.70	51.73	51.69	51.67	51.70
24.58	50.00	48.52	48.48	48.57	48.48	48.52	48.51
24.58	50.00	45.89	45.85	45.87	45.87	45.80	45.86
24.58	50.00	43.47	43.52	43.47	43.52	43.52	43.50
24.58	50.00	41.02	40.98	41.03	40.92	40.90	40.97

Table B2

Delta P - 5 psi

RUN #1
Calculated Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Carbon Dioxide>						
20.00	5.04	23.20	0.01496	0.151	5.283	0.8410
25.00	5.00	24.00	0.01500	0.190	5.224	0.6533
30.00	5.00	24.00	0.01500	0.229	5.149	0.5345
35.00	5.01	24.20	0.01501	0.269	5.098	0.4524
40.00	4.98	24.40	0.01502	0.306	5.066	0.3919
45.00	4.96	24.40	0.01502	0.344	5.043	0.3457
50.00	5.03	24.80	0.01504	0.387	5.017	0.3096
55.00	4.99	25.00	0.01505	0.422	4.995	0.2800
60.00	4.98	25.00	0.01505	0.461	4.987	0.2556
65.00	5.03	25.00	0.01505	0.507	4.998	0.2353
70.00	5.03	25.00	0.01505	0.542	4.948	0.2178
75.00	5.01	25.20	0.01506	0.579	4.939	0.2028
80.00	5.04	25.20	0.01506	0.621	4.933	0.1897
85.00	5.01	25.40	0.01507	0.655	4.919	0.1782
90.00	4.98	25.40	0.01507	0.689	4.906	0.1680
<Nitrogen>						
20.00	4.98	26.00	0.01775	0.140	5.884	0.8395
25.00	4.99	26.20	0.01776	0.174	5.653	0.6532
30.00	4.98	27.00	0.01780	0.206	5.498	0.5344
35.00	5.01	27.20	0.01781	0.240	5.395	0.4524
40.00	5.01	27.60	0.01782	0.272	5.302	0.3921
45.00	4.98	27.80	0.01783	0.302	5.229	0.3458
50.00	4.98	28.00	0.01784	0.333	5.165	0.3094
55.00	5.00	29.00	0.01789	0.368	5.156	0.2800
60.00	5.02	29.00	0.01789	0.400	5.102	0.2557
65.00	4.97	29.00	0.01789	0.428	5.066	0.2351
70.00	5.00	29.00	0.01789	0.461	5.023	0.2178
75.00	4.99	29.20	0.01790	0.492	5.008	0.2027
80.00	4.97	29.20	0.01790	0.517	4.943	0.1896
85.00	4.99	29.00	0.01789	0.548	4.902	0.1782
90.00	4.96	28.80	0.01788	0.577	4.887	0.1680

Table B3

Delta P = 5 psi

RUN #1
Laboratory Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Carbon Dioxide>							
24.61	50.00	331.27	331.36	330.70	330.59	330.60	330.90
24.61	50.00	263.08	262.80	262.61	262.70	262.60	262.76
24.61	50.00	218.21	218.31	218.02	218.03	217.96	218.11
24.61	50.00	186.49	186.25	186.22	186.04	186.03	186.21
24.61	50.00	163.52	163.35	163.40	163.50	163.29	163.41
24.61	50.00	145.48	145.52	145.31	145.31	145.31	145.39
24.61	50.00	129.26	129.34	129.15	129.20	129.05	129.20
24.61	50.00	118.51	118.34	118.35	118.49	118.29	118.40
24.61	50.00	108.52	108.47	108.46	108.50	108.50	108.49
24.61	50.00	98.71	98.60	98.68	98.61	98.57	98.63
24.61	50.00	92.36	92.39	92.12	92.19	92.22	92.26
24.61	50.00	86.47	86.51	86.38	86.43	86.33	86.42
24.61	50.00	80.49	80.45	80.56	80.43	80.50	80.49
24.61	50.00	76.31	76.29	76.22	76.41	76.31	76.31
24.61	50.00	72.56	72.54	72.57	72.57	72.55	72.56
<Nitrogen>							
24.60	50.00	356.05	356.05	355.94	356.14	356.15	356.07
24.60	50.00	287.94	287.96	287.96	287.89	287.74	287.90
24.60	50.00	243.18	243.29	243.29	242.99	242.99	243.15
24.60	50.00	208.57	208.56	208.58	208.56	208.75	208.60
24.60	50.00	184.22	184.15	184.15	184.16	184.02	184.14
24.60	50.00	165.92	165.69	165.69	165.87	165.78	165.79
24.60	50.00	150.35	150.29	150.29	150.02	150.19	150.23
24.60	50.00	135.92	135.91	135.91	136.07	136.16	135.99
24.60	50.00	125.03	125.04	125.04	124.84	125.03	125.00
24.60	50.00	116.96	116.80	116.80	117.17	116.95	116.94
24.60	50.00	108.64	108.52	108.52	108.60	108.58	108.57
24.60	50.00	101.64	101.56	101.56	101.71	101.70	101.63
24.60	50.00	96.64	96.72	96.72	96.75	96.66	96.70
24.60	50.00	91.26	91.16	91.16	91.21	91.20	91.20
24.60	50.00	86.72	86.70	86.70	86.76	86.69	86.71

Table B4

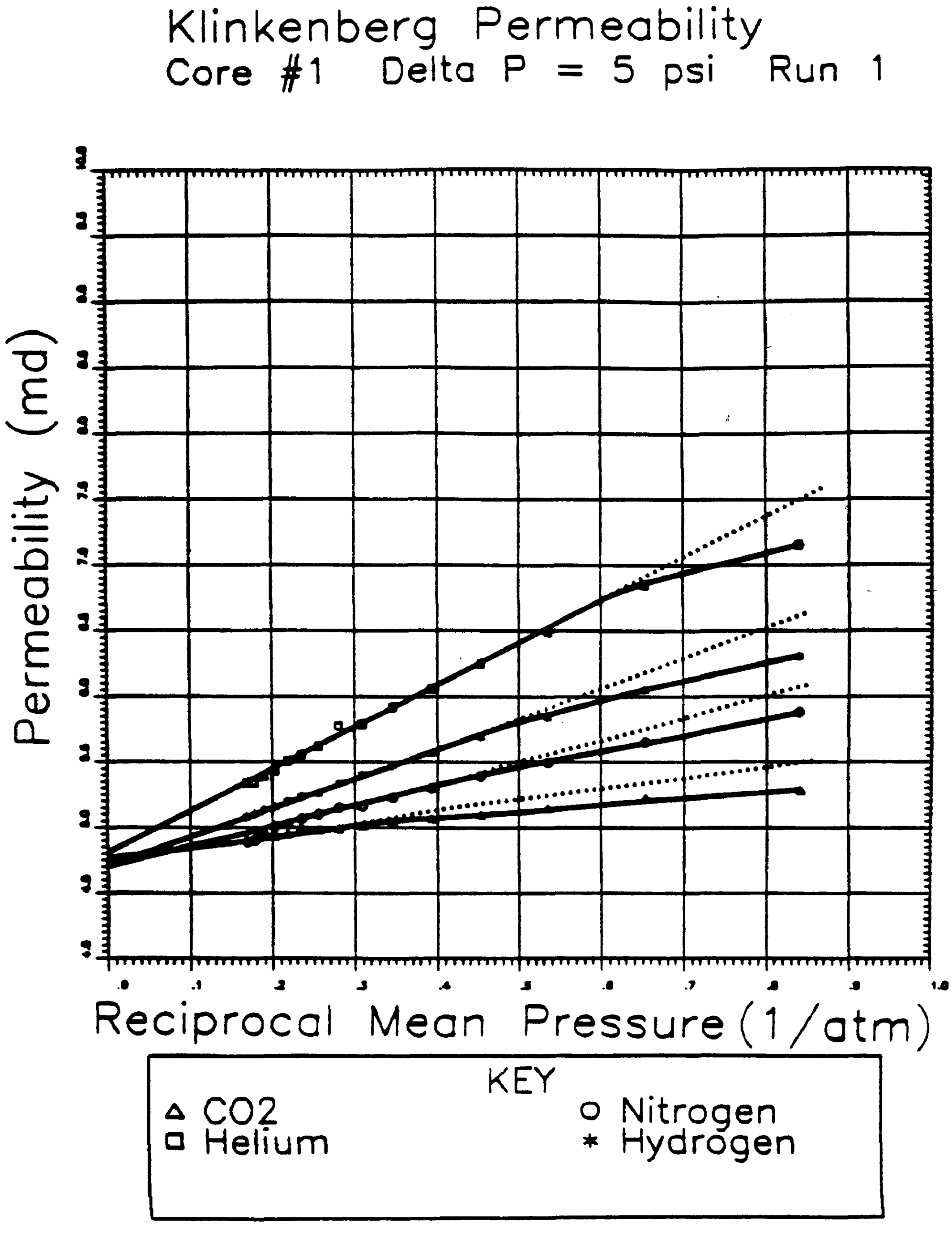

Klinkenberg Permeability
Core #1 Delta P = 5 psi Run 1
Permeability (md)
Reciprocal Mean Pressure (1/atm)
KEY
CO2
Helium
Nitrogen
Hydrogen

Figure B1

Delta P = 5 psi

RUN #2
Calculated Data

Core ID #1
Length 3.25 cm.

Diameter 1.89 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Helium>						
20.00	5.01	20.20	0.01942	0.155	7.037	0.8402
25.00	5.01	19.00	0.01937	0.192	6.757	0.6535
30.00	5.01	20.00	0.01941	0.223	6.443	0.5346
35.00	5.01	19.60	0.01939	0.256	6.249	0.4524
40.00	4.98	20.00	0.01941	0.284	6.052	0.3919
45.00	4.98	20.00	0.01941	0.318	5.970	0.3458
50.00	5.03	20.40	0.01943	0.349	5.821	0.3096
55.00	5.00	21.40	0.01947	0.377	5.725	0.2800
60.00	5.00	22.00	0.01949	0.408	5.665	0.2557
65.00	5.03	23.00	0.01953	0.430	5.479	0.2353
70.00	5.04	22.00	0.01949	0.459	5.396	0.2178
75.00	4.99	21.80	0.01948	0.487	5.374	0.2027
80.00	5.01	21.20	0.01946	0.519	5.328	0.1897
85.00	5.00	21.00	0.01945	0.547	5.284	0.1782
90.00	5.02	21.00	0.01945	0.578	5.248	0.1680
<Hydrogen>						
20.00	4.98	20.10	0.00875	0.303	6.220	0.8395
25.00	5.00	20.00	0.00874	0.377	5.996	0.6533
30.00	5.00	19.80	0.00874	0.430	5.604	0.5345
35.00	5.00	19.20	0.00873	0.505	5.556	0.4523
40.00	5.00	19.00	0.00872	0.575	5.479	0.3920
45.00	5.00	19.00	0.00872	0.643	5.407	0.3459
50.00	5.03	19.00	0.00872	0.712	5.325	0.3096
55.00	4.99	18.80	0.00872	0.772	5.261	0.2800
60.00	4.99	18.80	0.00872	0.839	5.218	0.2556
65.00	5.02	18.80	0.00872	0.908	5.167	0.2352
70.00	5.00	18.80	0.00872	0.975	5.157	0.2178
75.00	5.00	18.80	0.00872	1.037	5.110	0.2028
80.00	5.03	18.60	0.00871	1.110	5.085	0.1897
85.00	5.02	18.60	0.00871	1.172	5.050	0.1782
90.00	4.97	18.60	0.00871	1.225	5.028	0.1680

Table B5

Delta P = 5 psi RUN #2
Laboratory Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Helium>							
24.50	50.00	323.48	323.09	322.87	322.29	321.59	322.66
24.50	50.00	261.14	260.40	260.39	260.86	260.64	260.69
24.50	50.00	224.41	224.20	224.26	223.67	224.23	224.15
24.50	50.00	195.72	195.36	195.74	195.15	194.89	195.37
24.50	50.00	176.11	176.10	175.76	175.88	176.01	175.97
24.50	50.00	153.50	158.41	158.48	158.43	158.20	157.40
24.50	50.00	143.29	143.31	143.06	143.16	143.23	143.21
24.50	50.00	132.73	133.02	132.70	132.63	132.74	132.76
24.50	50.00	122.55	122.57	122.73	122.69	122.67	122.64
24.50	50.00	116.28	116.34	116.09	116.26	116.26	116.25
24.50	50.00	108.97	108.34	108.95	108.67	109.30	108.85
24.50	50.00	102.99	102.39	102.63	102.84	102.67	102.70
24.50	50.00	96.41	96.45	96.21	96.59	96.41	96.41
24.50	50.00	91.43	91.44	91.37	91.54	91.55	91.47
24.50	50.00	86.43	86.47	86.49	86.39	86.63	86.48
<Hydrogen>							
24.48	50.00	223.73	164.73	164.06	164.24	165.72	165.13
24.48	50.00	132.02	132.68	133.62	133.34	132.14	132.76
24.48	50.00	116.24	116.24	116.16	116.05	116.08	116.15
24.48	50.00	99.02	99.06	99.06	99.01	98.79	98.99
24.48	50.00	87.06	86.98	86.93	87.03	86.76	86.95
24.48	50.00	77.68	77.65	77.81	77.72	77.83	77.74
24.48	50.00	70.28	70.21	70.23	70.37	70.10	70.24
24.48	50.00	64.86	64.75	64.83	64.62	64.80	64.77
24.48	50.00	59.75	59.63	59.64	59.52	59.59	59.63
24.48	50.00	55.02	55.06	55.08	55.10	55.17	55.09
24.48	50.00	51.37	51.34	51.46	51.14	51.16	51.29
24.48	50.00	48.26	48.23	48.15	48.11	48.23	48.20
24.48	50.00	44.97	45.04	45.04	45.13	44.95	45.03
24.48	50.00	42.80	42.56	42.62	42.75	42.62	42.67
24.48	50.00	40.82	40.88	40.70	40.85	40.77	40.80

Table B6

Delta P - 5 psi

RUN #2
Calculated Data

Core ID #1
Length 3.25 cm.

Diameter 1.89 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Carbon Dioxide>						
20.00	5.02	23.40	0.01497	0.151	5.252	0.8405
25.00	5.00	23.20	0.01496	0.190	5.145	0.6533
30.00	4.99	23.00	0.01495	0.229	5.090	0.5344
35.00	5.02	23.00	0.01495	0.268	5.010	0.4524
40.00	5.01	23.00	0.01495	0.306	4.979	0.3921
45.00	5.02	23.10	0.01496	0.343	4.905	0.3460
50.00	5.02	23.50	0.01498	0.388	4.971	0.3095
55.00	5.02	23.00	0.01495	0.422	4.883	0.2801
60.00	5.00	23.00	0.01495	0.462	4.903	0.2557
65.00	5.02	22.70	0.01494	0.507	4.924	0.2352
70.00	5.02	22.50	0.01492	0.539	4.850	0.2178
75.00	5.01	22.20	0.01491	0.577	4.836	0.2028
80.00	5.01	22.00	0.01490	0.621	4.866	0.1897
85.00	5.03	22.00	0.01490	0.655	4.805	0.1782
90.00	5.01	22.00	0.01490	0.693	4.809	0.1680
<Nitrogen>						
20.00	5.02	21.00	0.01753	0.140	5.741	0.8405
25.00	5.00	21.00	0.01753	0.174	5.558	0.6533
30.00	5.00	21.00	0.01753	0.205	5.367	0.5345
35.00	5.04	22.00	0.01757	0.240	5.290	0.4526
40.00	5.01	23.00	0.01762	0.271	5.204	0.3921
45.00	4.97	24.00	0.01766	0.302	5.173	0.3458
50.00	5.04	24.00	0.01766	0.333	5.034	0.3096
55.00	5.02	25.00	0.01771	0.369	5.087	0.2801
60.00	4.99	25.00	0.01771	0.397	5.022	0.2556
65.00	5.05	25.00	0.01771	0.429	4.933	0.2353
70.00	5.02	25.00	0.01771	0.461	4.943	0.2178
75.00	5.00	25.00	0.01771	0.491	4.919	0.2028
80.00	4.96	25.00	0.01771	0.518	4.888	0.1896
85.00	5.06	25.00	0.01771	0.545	4.736	0.1782
90.00	4.99	25.00	0.01771	0.582	4.838	0.1680

Table B7

Delta P - 5 psi

RUN #2
Laboratory Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Carbon Dioxide>							
24.40	50.00	331.68	331.08	331.48	330.76	331.98	331.40
24.40	50.00	263.89	263.08	263.89	264.95	263.18	263.80
24.40	50.00	218.31	218.22	218.33	218.21	218.98	218.41
24.40	50.00	186.54	186.66	186.72	186.82	186.92	186.73
24.40	50.00	163.06	163.27	163.15	163.24	163.04	163.15
24.40	50.00	145.91	145.48	145.07	146.93	146.14	145.91
24.40	50.00	129.50	129.26	129.36	128.34	128.40	128.97
24.40	50.00	118.64	118.51	118.56	118.61	118.62	118.59
24.40	50.00	108.11	108.94	108.06	108.15	108.02	108.26
24.40	50.00	98.99	98.99	98.10	98.75	98.66	98.70
24.40	50.00	92.67	92.70	92.78	92.78	92.67	92.72
24.40	50.00	86.01	86.77	86.82	86.84	86.80	86.65
24.40	50.00	80.54	80.52	80.49	80.30	80.62	80.49
24.40	50.00	76.36	76.30	76.30	76.20	76.31	76.29
24.40	50.00	72.08	72.56	72.05	72.02	72.02	72.15
<Nitrogen>							
24.50	50.00	356.78	356.16	356.31	356.40	356.33	356.40
24.50	50.00	287.44	287.29	287.14	287.30	287.33	287.30
24.50	50.00	243.28	243.18	243.72	243.98	242.99	243.43
24.50	50.00	208.28	208.02	208.06	208.24	207.28	207.98
24.50	50.00	184.81	184.80	184.06	184.90	184.97	184.71
24.50	50.00	165.61	165.71	165.47	165.68	165.62	165.62
24.50	50.00	150.32	150.24	150.12	150.42	150.27	150.27
24.50	50.00	135.21	135.49	135.33	135.53	135.35	135.38
24.50	50.00	125.94	125.99	125.80	125.99	125.95	125.93
24.50	50.00	116.77	116.66	116.67	116.38	116.50	116.60
24.50	50.00	108.15	108.44	108.44	108.12	108.62	108.35
24.50	50.00	101.76	101.84	101.82	101.71	101.78	101.78
24.50	50.00	96.40	96.27	96.82	96.24	97.11	96.57
24.50	50.00	91.91	91.82	91.82	91.80	91.76	91.82
24.50	50.00	86.71	86.51	85.54	85.42	85.34	85.90

Table B8

Klinkenberg Permeability

Core #1 Delta P = 5 psi Run 2

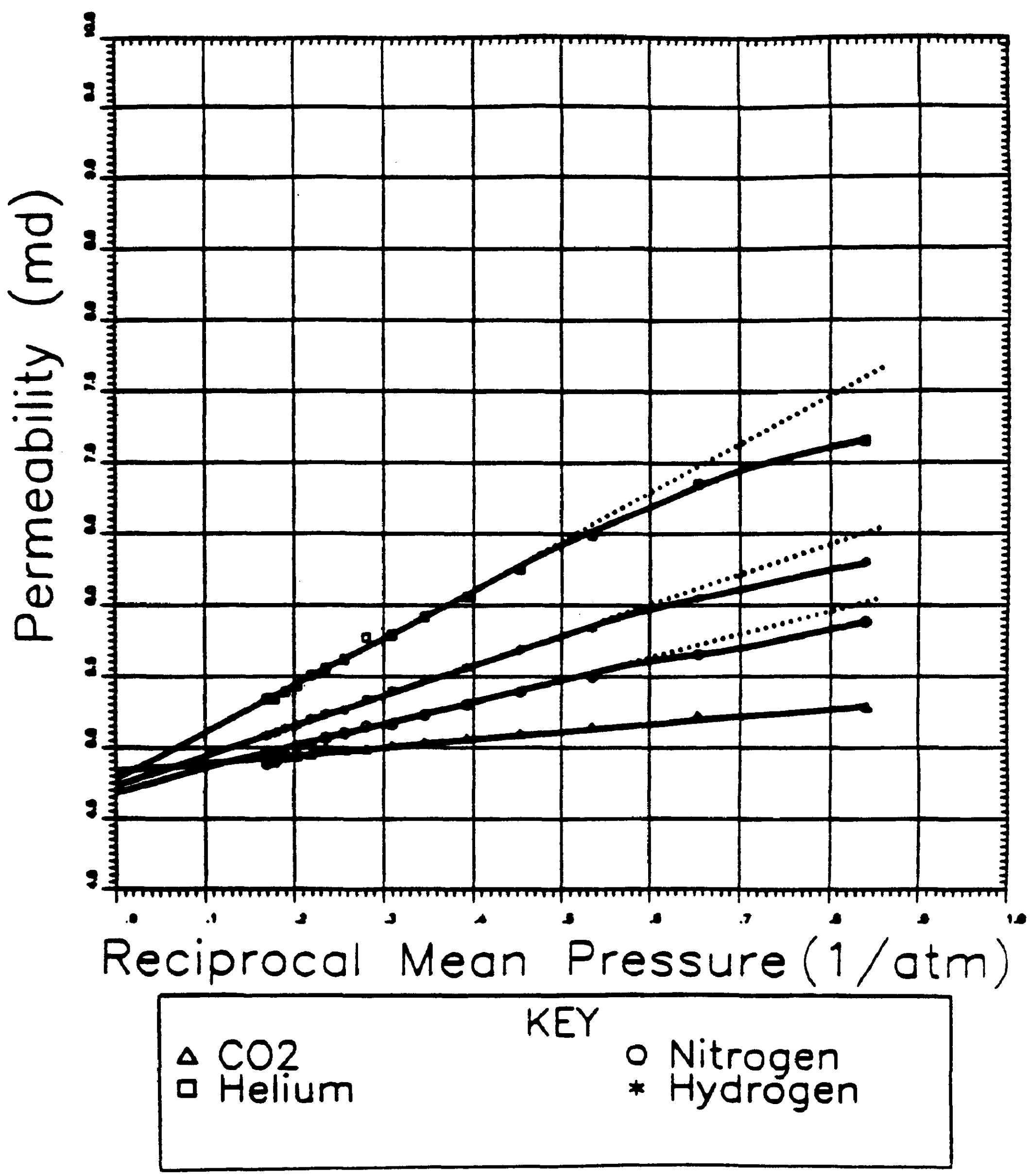


Figure B2

Delta P = 5 psi

RUN #3
Calculated Data

Core ID #1
Length 3.25 cm.
Diameter 1.89 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Helium>						
20.00	5.01	20.20	0.01942	0.162	7.281	0.8402
25.00	5.02	20.40	0.01943	0.195	6.806	0.6536
30.00	5.00	20.60	0.01943	0.226	6.473	0.5345
35.00	5.01	21.00	0.01945	0.258	6.258	0.4524
40.00	5.02	21.30	0.01946	0.273	5.728	0.3921
45.00	4.98	21.30	0.01946	0.318	5.924	0.3458
50.00	4.99	21.60	0.01947	0.349	5.802	0.3094
55.00	5.02	22.00	0.01949	0.381	5.715	0.2801
60.00	5.02	22.00	0.01949	0.409	5.608	0.2557
65.00	5.03	22.00	0.01949	0.439	5.525	0.2353
70.00	5.00	22.00	0.01949	0.467	5.471	0.2178
75.00	5.02	22.00	0.01949	0.500	5.428	0.2028
80.00	5.03	22.20	0.01950	0.531	5.383	0.1897
85.00	5.02	22.50	0.01951	0.559	5.345	0.1782
90.00	5.01	22.80	0.01952	0.587	5.306	0.1680
<Hydrogen>						
20.00	5.01	24.80	0.00885	0.304	6.232	0.8402
25.00	5.01	25.20	0.00886	0.380	6.051	0.6535
30.00	5.02	25.40	0.00886	0.452	5.884	0.5347
35.00	4.98	25.80	0.00887	0.518	5.753	0.4522
40.00	5.02	26.00	0.00887	0.590	5.644	0.3921
45.00	5.03	26.00	0.00887	0.657	5.539	0.3460
50.00	4.98	26.20	0.00888	0.718	5.466	0.3094
55.00	5.00	26.20	0.00888	0.786	5.396	0.2800
60.00	4.98	26.40	0.00888	0.847	5.332	0.2556
65.00	5.02	26.60	0.00889	0.921	5.291	0.2352
70.00	5.02	26.80	0.00889	0.987	5.254	0.2178
75.00	4.98	26.80	0.00889	1.043	5.212	0.2027
80.00	5.02	27.00	0.00890	1.115	5.172	0.1897
85.00	5.00	27.00	0.00890	1.177	5.151	0.1782
90.00	5.01	27.20	0.00890	1.245	5.128	0.1680

Table B9

Delta P = 5 psi

RUN #3
Laboratory Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Helium>							
24.22	50.00	308.39	308.32	308.11	308.23	308.42	308.29
24.22	50.00	256.04	256.04	256.35	256.34	255.97	256.15
24.22	50.00	221.10	221.49	221.06	221.04	221.40	221.22
24.22	50.00	193.72	193.59	193.22	193.43	193.24	193.44
24.22	50.00	183.07	182.77	182.96	182.93	182.89	182.92
24.22	50.00	157.36	157.19	157.21	157.26	157.19	157.24
24.22	50.00	143.75	143.73	143.74	142.52	143.58	143.46
24.22	50.00	131.26	131.19	131.09	131.05	131.11	131.14
24.24	50.00	122.15	122.04	122.05	122.10	122.21	122.11
24.24	50.00	113.87	113.85	113.78	113.81	113.79	113.82
24.24	50.00	107.13	107.05	107.08	106.94	106.99	107.04
24.24	50.00	100.12	100.12	100.06	99.96	100.06	100.06
24.24	50.00	94.38	94.22	94.26	94.07	94.28	94.24
24.24	50.00	89.49	89.31	89.37	89.40	89.38	89.39
24.24	50.00	85.22	85.09	85.24	84.97	85.03	85.11
<Hydrogen>							
24.25	50.00	164.56	164.16	164.39	164.11	164.42	164.33
24.25	50.00	131.81	131.72	131.96	131.62	131.58	131.74
24.25	50.00	110.56	110.65	110.99	110.78	110.50	110.70
24.25	50.00	96.95	96.13	96.83	96.53	96.60	96.61
24.25	50.00	84.77	84.76	84.81	84.71	84.73	84.76
24.25	50.00	76.17	76.21	75.98	76.01	75.88	76.05
24.25	50.00	69.52	69.62	69.56	69.81	69.70	69.64
24.25	50.00	63.67	63.66	63.57	63.56	63.48	63.59
24.25	50.00	59.05	59.10	58.91	58.99	59.00	59.01
24.25	50.00	54.37	54.19	54.33	54.27	54.40	54.31
24.25	50.00	50.67	50.65	50.67	50.80	50.56	50.67
24.25	50.00	47.98	47.94	47.94	47.85	47.92	47.93
24.25	50.00	45.05	44.84	44.88	44.71	44.80	44.86
24.25	50.00	42.69	42.34	42.49	42.41	42.43	42.47
24.25	50.00	40.19	40.21	40.24	40.09	40.11	40.17

Table B10

Delta P = 5 psi

RUN #3
Calculated Data

Core ID #1
Length 3.25 cm.
Diameter 1.89 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Carbon Dioxide>						
20.00	5.03	23.00	0.01495	0.153	5.292	0.8407
25.00	5.02	23.60	0.01498	0.194	5.241	0.6536
30.00	5.01	23.80	0.01499	0.233	5.169	0.5346
35.00	4.96	24.00	0.01500	0.271	5.130	0.4520
40.00	5.01	24.00	0.01500	0.314	5.099	0.3921
45.00	5.02	24.00	0.01500	0.355	5.080	0.3460
50.00	4.96	24.80	0.01504	0.390	5.071	0.3093
55.00	4.96	25.00	0.01505	0.431	5.065	0.2799
60.00	5.00	25.00	0.01505	0.474	5.052	0.2557
65.00	5.01	25.60	0.01508	0.517	5.067	0.2352
70.00	5.00	25.80	0.01509	0.551	5.017	0.2178
75.00	5.00	25.60	0.01508	0.591	5.002	0.2028
80.00	5.04	25.60	0.01508	0.636	4.997	0.1897
85.00	4.99	26.00	0.01510	0.670	5.000	0.1782
90.00	5.02	26.20	0.01511	0.713	4.996	0.1680
<Nitrogen>						
20.00	5.00	26.20	0.01776	0.145	5.980	0.8400
25.00	5.02	26.40	0.01777	0.178	5.703	0.6536
30.00	4.97	27.00	0.01780	0.210	5.558	0.5343
35.00	5.00	27.20	0.01781	0.242	5.399	0.4523
40.00	5.04	27.40	0.01781	0.277	5.309	0.3922
45.00	5.04	27.60	0.01782	0.308	5.214	0.3460
50.00	5.01	27.40	0.01781	0.339	5.156	0.3095
55.00	5.04	27.20	0.01781	0.372	5.096	0.2801
60.00	5.01	27.00	0.01780	0.402	5.053	0.2557
65.00	5.00	27.00	0.01780	0.434	5.019	0.2352
70.00	5.04	27.00	0.01780	0.470	4.998	0.2178
75.00	5.01	27.00	0.01780	0.500	4.977	0.2028
80.00	4.99	27.00	0.01780	0.529	4.946	0.1897
85.00	5.01	26.80	0.01779	0.563	4.921	0.1782
90.00	4.93	26.60	0.01778	0.592	4.957	0.1679

Table B11

Delta P - 5 psi

RUN #3
Laboratory Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Carbon Dioxide>							
24.33	50.00	327.38	326.47	327.11	327.25	326.32	326.91
24.33	50.00	257.89	257.77	257.68	257.47	257.62	257.69
24.33	50.00	214.57	214.41	213.89	214.46	214.04	214.27
24.33	50.00	184.32	184.79	184.49	184.52	184.35	184.49
24.33	50.00	159.17	159.29	159.88	159.25	159.37	159.39
24.33	50.00	140.85	140.93	140.97	140.86	140.81	140.88
24.33	50.00	128.47	128.17	128.25	127.18	128.25	128.06
24.33	50.00	116.29	116.08	115.97	116.06	116.06	116.09
24.33	50.00	105.27	105.41	105.67	105.51	105.48	105.47
24.33	50.00	96.75	96.81	96.81	96.58	96.75	96.74
24.33	50.00	90.70	90.64	90.93	90.66	90.62	90.71
24.33	50.00	84.70	84.62	84.77	84.60	84.58	84.65
24.33	50.00	78.61	78.80	78.70	78.59	78.57	78.65
24.33	50.00	74.73	74.57	74.62	74.71	74.67	74.66
24.33	50.00	70.13	69.96	70.21	70.00	70.13	70.09
<Nitrogen>							
24.29	50.00	344.98	344.80	345.00	344.98	344.72	344.90
24.29	50.00	280.94	280.68	280.42	280.06	280.08	280.44
24.29	50.00	237.98	238.16	238.29	237.64	237.57	237.93
24.29	50.00	206.12	206.41	206.44	206.20	205.97	206.23
24.29	50.00	180.36	180.43	180.47	180.59	180.58	180.49
24.29	50.00	162.29	162.40	162.12	162.32	162.08	162.24
24.29	50.00	147.67	147.55	147.65	147.43	147.41	147.54
24.29	50.00	134.02	134.06	134.05	134.06	134.98	134.23
24.29	50.00	124.14	124.28	124.29	124.40	124.08	124.24
24.29	50.00	115.43	115.28	115.30	115.30	115.12	115.29
24.29	50.00	106.29	106.47	106.34	106.49	106.28	106.37
24.29	50.00	100.09	100.09	100.09	99.98	99.91	100.03
24.29	50.00	94.51	94.49	94.57	94.44	94.67	94.54
24.29	50.00	88.90	88.90	88.89	88.69	88.99	88.87
24.29	50.00	84.44	84.55	84.43	84.33	84.46	84.44

Table B12

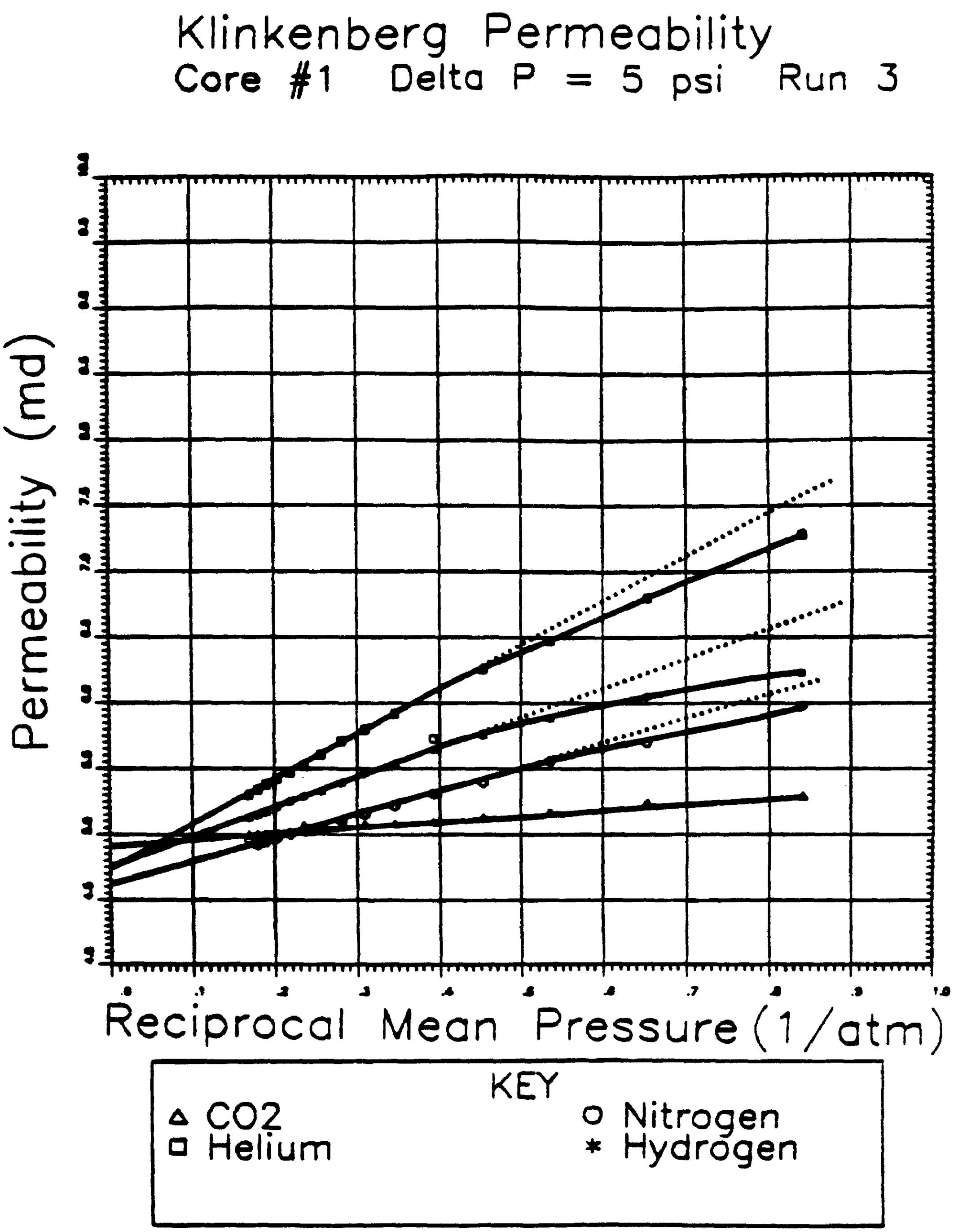

Klinkenberg Permeability
Core #1 Delta P = 5 psi Run 3
Permeability (md)
Reciprocal Mean Pressure (1/atm)
KEY
CO2
Helium
Nitrogen
Hydrogen

Figure B3

Delta P = 10 psi

RUN #1
Calculated Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Helium>						
25.00	9.99	18.00	0.01933	0.357	7.087	0.7348
30.00	10.00	18.00	0.01933	0.417	6.630	0.5880
35.00	9.99	18.00	0.01933	0.421	5.576	0.4899
40.00	10.01	18.10	0.01933	0.538	6.103	0.4201
45.00	9.98	18.20	0.01934	0.601	5.980	0.3674
50.00	10.00	18.30	0.01934	0.662	5.848	0.3267
55.00	9.99	18.40	0.01935	0.722	5.748	0.2940
60.00	10.01	18.50	0.01935	0.785	5.668	0.2673
65.00	10.01	18.60	0.01935	0.845	5.594	0.2450
70.00	10.01	19.00	0.01937	0.905	5.536	0.2262
75.00	10.00	19.00	0.01937	0.969	5.508	0.2100
80.00	10.02	19.00	0.01937	1.028	5.446	0.1960
85.00	9.98	19.10	0.01937	1.078	5.373	0.1837
90.00	10.02	19.10	0.01937	1.147	5.362	0.1730
<Hydrogen>						
25.00	10.01	25.00	0.00885	0.690	6.275	0.7352
30.00	9.98	25.00	0.00885	0.826	6.026	0.5878
35.00	9.98	25.40	0.00886	0.959	5.830	0.4898
40.00	9.99	26.00	0.00887	1.089	5.678	0.4199
45.00	10.02	26.00	0.00887	1.222	5.564	0.3676
50.00	10.01	26.00	0.00887	1.353	5.481	0.3267
55.00	10.04	26.00	0.00887	1.487	5.404	0.2941
60.00	9.97	26.20	0.00888	1.609	5.354	0.2672
65.00	10.04	26.40	0.00888	1.746	5.294	0.2451
70.00	10.03	26.40	0.00888	1.868	5.233	0.2262
75.00	9.97	26.60	0.00889	1.985	5.194	0.2100
80.00	9.99	26.60	0.00889	2.122	5.174	0.1960
85.00	10.00	26.80	0.00889	2.250	5.141	0.1838
90.00	10.01	27.00	0.00890	2.372	5.099	0.1730

Table B13

Delta P = 10 psi

RUN #1
Laboratory Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Helium>							
24.56	50.00	140.20	140.21	140.22	140.23	140.23	140.22
24.56	50.00	119.80	119.79	119.81	119.82	119.83	119.81
24.56	50.00	104.40	104.41	140.42	104.41	140.40	118.81
24.56	50.00	92.90	92.92	92.91	92.91	92.90	92.91
24.56	50.00	83.21	83.22	83.20	83.21	83.19	83.21
24.56	50.00	75.51	75.49	75.50	75.55	75.48	75.51
24.56	50.00	69.22	69.24	69.21	69.21	69.23	69.22
24.56	50.00	63.70	63.68	63.69	63.71	63.76	63.71
24.56	50.00	59.18	59.16	59.19	59.19	59.22	59.19
24.56	50.00	55.26	55.24	55.23	55.24	55.28	55.25
24.56	50.00	51.82	51.78	51.59	51.30	51.58	51.61
24.56	50.00	48.60	48.59	48.61	48.62	48.75	48.63
24.56	50.00	46.40	46.37	46.37	46.41	46.42	46.39
24.56	50.00	43.57	43.55	43.55	43.60	43.67	43.59
<Hydrogen>							
24.57	50.00	72.59	72.54	72.28	72.33	72.48	72.44
24.57	50.00	60.47	60.52	60.45	60.50	60.55	60.50
24.57	50.00	52.20	52.12	52.14	52.17	52.17	52.16
24.57	50.00	45.99	45.99	45.99	45.87	45.83	45.93
24.57	50.00	40.96	40.97	40.85	40.91	40.87	40.91
24.57	50.00	36.91	36.93	36.98	36.97	36.93	36.94
24.57	100.00	67.27	67.32	67.25	67.23	67.29	67.27
24.57	100.00	62.12	62.16	62.19	62.11	62.13	62.14
24.57	100.00	57.27	57.31	57.19	57.27	57.33	57.27
24.57	100.00	53.58	53.50	53.53	53.55	53.50	53.53
24.57	100.00	50.40	50.36	50.40	50.38	50.41	50.39
24.57	100.00	47.13	47.11	47.13	47.10	47.14	47.12
24.57	100.00	44.44	44.43	44.41	44.43	44.49	44.44
24.57	100.00	42.15	42.08	42.22	42.17	42.14	42.15

Table B14

Delta P = 10 psi

RUN #1
Calculated Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Carbon Dioxide>						
25.00	10.02	27.00	0.01515	0.310	4.816	0.7354
30.00	9.99	27.20	0.01516	0.380	4.738	0.5879
35.00	10.00	27.40	0.01517	0.461	4.788	0.4900
40.00	10.01	27.60	0.01518	0.541	4.815	0.4201
45.00	10.01	27.80	0.01519	0.624	4.862	0.3675
50.00	9.96	28.00	0.01520	0.702	4.891	0.3265
55.00	10.00	28.00	0.01520	0.772	4.824	0.2940
60.00	10.03	28.00	0.01520	0.858	4.859	0.2673
65.00	10.02	28.20	0.01521	0.932	4.846	0.2450
70.00	9.99	28.40	0.01522	1.005	4.842	0.2261
75.00	10.04	28.40	0.01522	1.085	4.828	0.2101
80.00	10.03	28.60	0.01523	1.159	4.821	0.1960
85.00	9.96	28.60	0.01523	1.227	4.819	0.1837
90.00	9.99	28.80	0.01524	1.305	4.814	0.1729
<Nitrogen>						
25.00	10.01	20.00	0.01748	0.316	5.652	0.7352
30.00	10.02	20.00	0.01748	0.381	5.451	0.5882
35.00	10.00	20.00	0.01748	0.445	5.320	0.4900
40.00	10.00	19.80	0.01747	0.509	5.209	0.4200
45.00	10.03	19.80	0.01747	0.579	5.171	0.3676
50.00	9.99	19.80	0.01747	0.639	5.088	0.3266
55.00	10.01	19.60	0.01746	0.702	5.020	0.2940
60.00	9.98	19.60	0.01746	0.774	5.049	0.2672
65.00	10.02	19.50	0.01746	0.842	5.011	0.2450
70.00	9.98	19.50	0.01746	0.904	4.985	0.2261
75.00	9.97	19.40	0.01746	0.972	4.985	0.2100
80.00	9.99	19.00	0.01744	1.027	4.900	0.1960
85.00	10.00	19.00	0.01744	1.095	4.893	0.1838
90.00	9.98	18.80	0.01743	1.145	4.821	0.1729

Table B15

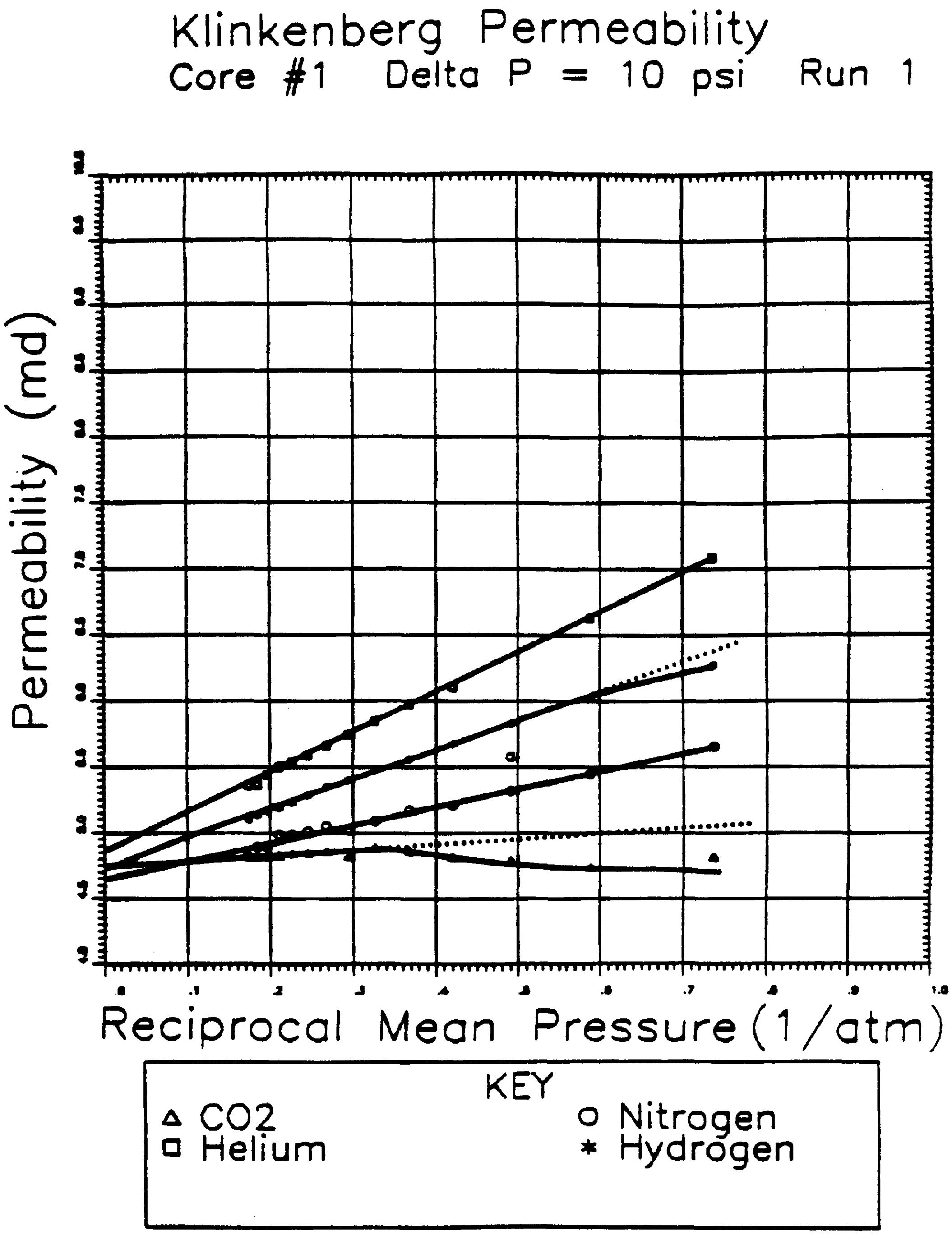
Delta P = 10 psi

RUN #1
Laboratory Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Carbon Dioxide>							
24.56	50.00	161.71	161.82	161.38	161.03	160.82	161.35
24.56	50.00	131.64	131.61	131.51	131.52	131.65	131.59
24.56	50.00	108.59	108.76	108.73	108.43	108.03	108.51
24.56	50.00	92.33	92.66	92.63	92.63	92.10	92.47
24.56	50.00	80.15	80.23	80.21	80.23	80.10	80.18
24.56	50.00	71.21	71.24	71.20	71.21	71.16	71.20
24.56	50.00	64.84	64.82	64.75	64.64	64.66	64.74
24.56	50.00	58.25	58.34	58.22	58.25	58.31	58.27
24.56	50.00	53.64	53.66	53.63	53.63	53.66	53.64
24.56	50.00	49.75	49.35	49.83	49.90	49.84	49.73
24.56	50.00	46.06	46.14	46.06	46.10	46.14	46.10
24.56	50.00	43.10	43.14	43.19	43.15	43.18	43.15
24.56	50.00	40.73	40.69	40.78	40.75	40.76	40.74
24.56	50.00	38.36	38.26	38.26	38.36	38.26	38.30
<Nitrogen>							
24.50	50.00	158.31	158.49	158.03	158.83	158.28	158.39
24.50	50.00	131.25	131.30	131.25	131.15	131.42	131.27
24.50	50.00	112.07	112.24	112.34	112.37	112.30	112.26
24.50	50.00	98.20	98.25	98.36	98.36	98.01	98.24
24.50	50.00	86.75	86.57	86.32	86.12	86.03	86.36
24.50	50.00	78.24	78.42	78.12	78.02	78.61	78.28
24.50	50.00	70.87	70.78	71.46	71.57	71.56	71.25
24.50	50.00	64.72	64.08	64.85	64.22	65.01	64.58
24.50	50.00	59.64	59.55	59.36	59.36	59.13	59.41
24.50	50.00	55.24	55.45	55.09	55.38	55.48	55.33
24.50	50.00	51.68	51.37	51.01	51.60	51.41	51.41
24.50	50.00	48.62	48.54	48.51	48.91	48.81	48.68
24.50	50.00	45.19	45.97	45.57	45.87	45.67	45.65
24.50	50.00	43.58	43.92	43.63	43.62	43.62	43.67

Table B16



Klinkenberg Permeability
Core #1 Delta P = 10 psi Run 1
Permeability (md)
Reciprocal Mean Pressure (1/atm)
KEY
CO2
Helium
Nitrogen
Hydrogen

Figure B4

Delta P - 10 psi

RUN #2
Calculated Data

Core ID #1
Length 3.25 cm.

Diameter 1.89 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Helium>						
25.00	10.00	17.80	0.01932	0.356	7.068	0.7350
30.00	9.99	17.80	0.01932	0.418	6.636	0.5879
35.00	9.98	18.00	0.01933	0.479	6.356	0.4898
40.00	9.99	18.00	0.01933	0.540	6.132	0.4199
45.00	9.98	18.20	0.01934	0.601	5.982	0.3674
50.00	9.99	18.20	0.01934	0.662	5.849	0.3266
55.00	10.00	18.40	0.01935	0.723	5.752	0.2940
60.00	10.01	18.40	0.01935	0.784	5.661	0.2673
65.00	10.01	18.60	0.01935	0.844	5.587	0.2450
70.00	10.01	19.00	0.01937	0.904	5.527	0.2262
75.00	10.02	19.00	0.01937	0.967	5.488	0.2100
80.00	10.02	19.00	0.01937	1.025	5.428	0.1960
85.00	9.98	19.00	0.01937	1.080	5.383	0.1837
90.00	10.02	19.00	0.01937	1.143	5.343	0.1730
<Hydrogen>						
25.00	9.99	19.20	0.00873	0.630	5.653	0.7348
30.00	10.01	20.00	0.00874	0.792	5.686	0.5881
35.00	9.99	20.00	0.00874	0.950	5.692	0.4899
40.00	9.96	20.00	0.00874	1.093	5.628	0.4198
45.00	10.02	20.00	0.00874	1.237	5.548	0.3676
50.00	10.01	20.20	0.00875	1.372	5.477	0.3267
55.00	9.98	20.80	0.00876	1.496	5.395	0.2939
60.00	9.99	21.00	0.00877	1.635	5.360	0.2672
65.00	10.03	22.00	0.00879	1.772	5.319	0.2451
70.00	10.04	22.00	0.00879	1.898	5.253	0.2262
75.00	10.03	22.00	0.00879	2.034	5.232	0.2100
80.00	10.01	22.20	0.00879	2.149	5.172	0.1960
85.00	10.00	22.40	0.00880	2.290	5.173	0.1838
90.00	10.04	23.00	0.00881	2.428	5.151	0.1730

Table B17

Delta P = 10 psi

RUN #2
Laboratory Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Helium>							
24.56	50.00	140.19	140.44	140.65	140.49	140.36	140.43
24.56	50.00	119.77	119.59	119.68	119.90	119.80	119.75
24.56	50.00	104.46	104.39	104.40	104.18	104.19	104.32
24.56	50.00	92.85	92.54	92.39	92.72	92.56	92.61
24.56	50.00	83.13	83.24	83.07	83.32	83.12	83.18
24.56	50.00	75.49	75.79	75.50	75.52	75.41	75.54
24.56	50.00	69.24	68.84	69.02	69.22	69.23	69.11
24.56	50.00	63.68	63.85	63.75	63.79	63.82	63.78
24.56	50.00	59.15	59.40	59.19	59.22	59.34	59.26
24.56	50.00	55.29	55.24	55.54	55.35	55.28	55.34
24.56	50.00	51.95	51.75	51.89	51.32	51.61	51.70
24.56	50.00	48.79	48.81	48.75	48.82	48.78	48.79
24.56	50.00	46.37	46.37	46.21	46.22	46.31	46.30
24.56	50.00	43.67	43.95	43.60	43.66	43.78	43.73
<Hydrogen>							
24.56	50.00	79.35	79.50	79.49	79.25	79.22	79.36
24.56	50.00	63.14	63.09	63.39	63.02	63.10	63.15
24.56	50.00	52.74	52.69	52.65	52.58	52.63	52.66
24.56	50.00	45.81	45.79	45.77	45.69	45.75	45.76
24.56	50.00	40.42	40.38	40.40	40.43	40.45	40.42
24.56	100.00	73.04	72.89	72.75	72.96	72.74	72.88
24.56	100.00	66.92	66.91	66.70	66.86	66.91	66.86
24.56	100.00	61.11	61.24	61.13	60.92	61.39	61.16
24.56	100.00	56.53	56.55	56.45	56.26	56.34	56.43
24.56	100.00	52.81	52.57	52.69	52.71	52.67	52.69
24.56	100.00	49.17	49.07	49.24	49.13	49.24	49.17
24.56	100.00	46.53	46.46	46.70	46.51	46.44	46.53
24.56	100.00	43.79	43.66	43.56	43.76	43.61	43.68
24.56	100.00	41.22	41.17	41.23	41.18	41.15	41.19

Table B18

Delta P = 10 psi

RUN #2
Calculated Data

Core ID #1
Length 3.25 cm.

Diameter 1.89 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Carbon Dioxide>						
25.00	9.97	18.20	0.01471	0.347	5.245	0.7344
30.00	10.02	18.40	0.01472	0.426	5.144	0.5882
35.00	9.98	18.80	0.01474	0.505	5.097	0.4898
40.00	10.01	19.00	0.01475	0.587	5.071	0.4201
45.00	10.01	19.00	0.01475	0.662	5.007	0.3675
50.00	10.00	19.00	0.01475	0.740	4.981	0.3267
55.00	10.01	19.00	0.01475	0.821	4.968	0.2940
60.00	9.98	19.20	0.01476	0.896	4.943	0.2672
65.00	10.01	19.40	0.01477	0.974	4.915	0.2450
70.00	10.04	20.00	0.01480	1.059	4.929	0.2262
75.00	10.01	20.00	0.01480	1.133	4.912	0.2100
80.00	10.00	20.10	0.01481	1.211	4.904	0.1960
85.00	10.02	20.10	0.01481	1.290	4.890	0.1838
90.00	10.01	20.20	0.01481	1.364	4.875	0.1730
<Nitrogen>						
25.00	10.02	20.00	0.01748	0.316	5.659	0.7354
30.00	10.04	20.00	0.01748	0.381	5.438	0.5885
35.00	10.03	20.00	0.01748	0.446	5.308	0.4902
40.00	10.00	19.80	0.01747	0.509	5.212	0.4200
45.00	10.03	19.80	0.01747	0.577	5.150	0.3676
50.00	9.98	19.80	0.01747	0.640	5.104	0.3266
55.00	9.97	19.60	0.01746	0.704	5.054	0.2939
60.00	9.98	19.60	0.01746	0.771	5.025	0.2672
65.00	10.03	19.50	0.01746	0.839	4.988	0.2451
70.00	9.97	19.50	0.01746	0.899	4.964	0.2261
75.00	10.02	19.40	0.01746	0.966	4.931	0.2100
80.00	10.01	19.00	0.01744	1.029	4.900	0.1960
85.00	9.98	19.00	0.01744	1.091	4.886	0.1837
90.00	9.99	18.80	0.01743	1.155	4.861	0.1729

Table B19

Delta P = 10 psi

RUN #2
Laboratory Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Carbon Dioxide>							
24.53	50.00	144.47	144.18	144.23	144.06	144.15	144.22
24.53	50.00	117.50	117.30	117.28	117.06	117.16	117.26
24.53	50.00	99.08	99.19	99.16	98.95	99.00	99.08
24.53	50.00	85.05	85.16	85.18	85.27	85.34	85.20
24.53	50.00	75.25	75.53	75.68	75.47	75.60	75.51
24.53	50.00	67.56	67.50	67.44	67.66	67.46	67.52
24.53	50.00	60.97	60.79	60.85	60.98	60.82	60.88
24.53	50.00	55.73	55.66	55.84	55.91	55.95	55.82
24.53	50.00	51.37	51.40	51.16	51.48	51.33	51.35
24.53	50.00	47.31	47.11	47.28	47.21	47.22	47.23
24.53	50.00	44.16	44.21	44.14	44.12	44.03	44.13
24.53	50.00	41.17	41.43	41.36	41.26	41.29	41.30
24.53	50.00	38.93	38.78	38.79	38.72	38.61	38.77
24.53	50.00	36.64	36.61	36.58	36.68	36.71	36.64
<Nitrogen>							
24.50	50.00	158.07	157.89	158.10	158.22	158.03	158.06
24.50	50.00	131.39	131.29	131.44	131.51	131.24	131.37
24.50	50.00	112.23	112.02	112.18	112.44	112.29	112.23
24.50	50.00	98.18	98.22	97.91	98.20	98.34	98.17
24.50	50.00	86.69	86.76	86.60	86.73	86.78	86.71
24.50	50.00	78.10	78.13	78.23	77.96	78.12	78.11
24.50	50.00	70.99	71.05	71.01	70.97	71.08	71.02
24.50	50.00	64.83	64.78	64.80	64.90	65.10	64.88
24.50	50.00	59.53	59.65	59.55	59.68	59.74	59.63
24.50	50.00	55.56	55.67	55.54	55.72	55.59	55.62
24.50	50.00	51.59	51.88	51.73	51.63	51.84	51.73
24.50	50.00	48.55	48.69	48.45	48.60	48.66	48.59
24.50	50.00	45.71	45.89	45.79	45.98	45.69	45.81
24.50	50.00	43.26	43.34	43.29	43.16	43.31	43.27

Table B20

Klinkenberg Permeability

Core #1 Delta P = 10 psi Run 2

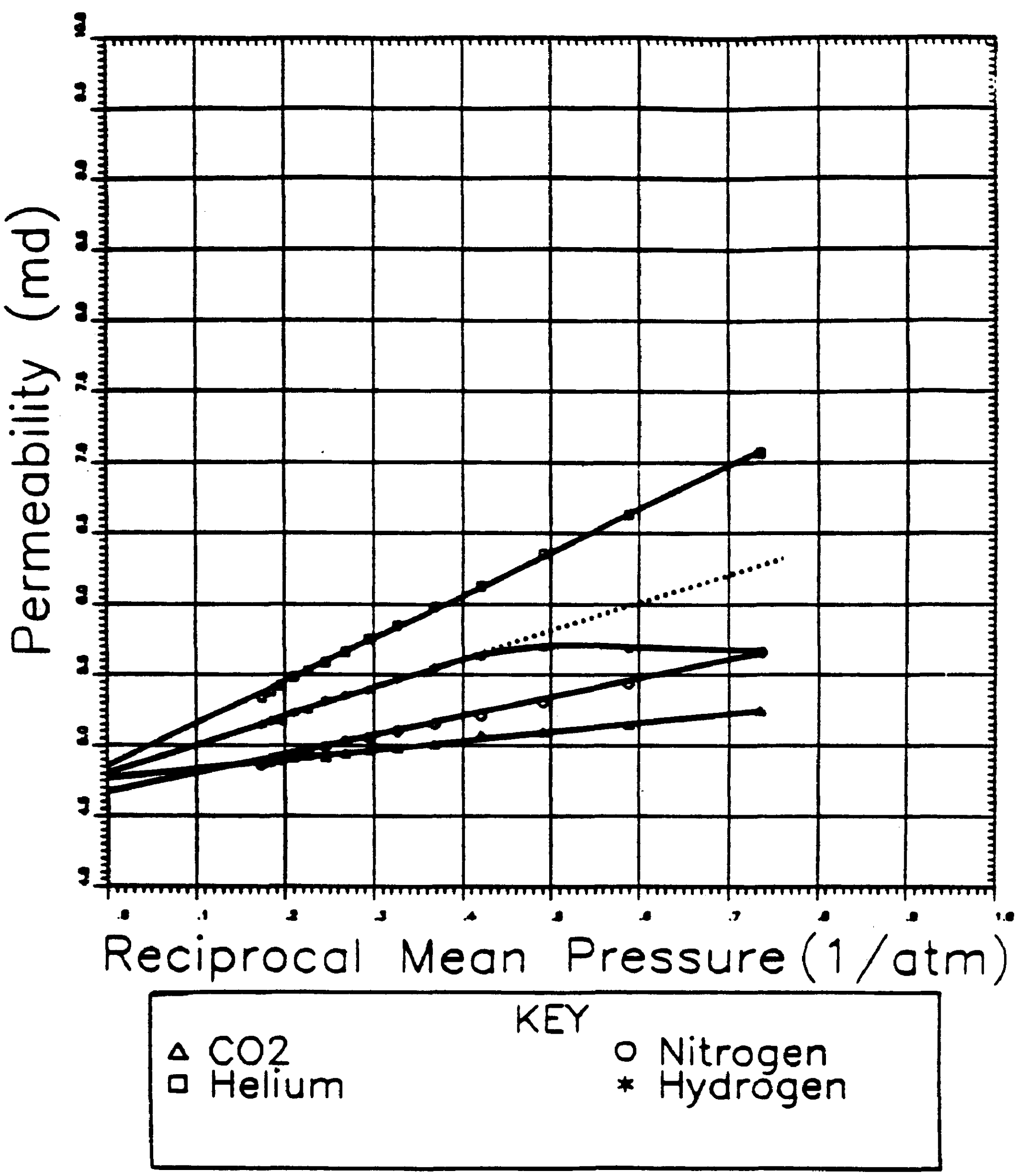


Figure B5

Delta P - 10 psi

RUN #3
Calculated Data

Core ID #1
Length 3.25 cm.

Diameter 1.89 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp).	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Helium>						
25.00	10.02	20.00	0.01941	0.357	7.066	0.7354
30.00	9.98	20.00	0.01941	0.419	6.662	0.5878
35.00	10.02	20.20	0.01942	0.484	6.388	0.4902
40.00	10.02	20.20	0.01942	0.546	6.180	0.4201
45.00	9.97	20.20	0.01942	0.605	6.015	0.3674
50.00	9.98	20.60	0.01943	0.665	5.877	0.3266
55.00	9.98	20.60	0.01943	0.728	5.792	0.2939
60.00	10.03	20.80	0.01944	0.792	5.706	0.2673
65.00	9.96	21.00	0.01945	0.848	5.638	0.2449
70.00	10.02	21.00	0.01945	0.912	5.564	0.2262
75.00	10.02	21.00	0.01945	1.010	5.725	0.2100
80.00	10.02	21.00	0.01945	1.033	5.461	0.1960
85.00	10.04	21.00	0.01945	1.094	5.414	0.1838
90.00	9.98	21.20	0.01946	1.146	5.371	0.1729
<Hydrogen>						
25.00	9.98	21.60	0.00878	0.667	5.986	0.7346
30.00	10.00	22.00	0.00879	0.827	5.934	0.5880
35.00	10.04	22.40	0.00880	0.974	5.811	0.4903
40.00	9.96	23.00	0.00881	1.105	5.696	0.4198
45.00	10.04	23.00	0.00881	1.243	5.569	0.3677
50.00	10.04	23.00	0.00881	1.360	5.417	0.3268
55.00	10.03	23.00	0.00881	1.495	5.361	0.2941
60.00	10.00	23.00	0.00881	1.631	5.332	0.2673
65.00	10.00	23.00	0.00881	1.760	5.275	0.2450
70.00	10.00	23.00	0.00881	1.897	5.250	0.2262
75.00	9.99	23.00	0.00881	2.031	5.223	0.2100
80.00	10.01	23.00	0.00881	2.155	5.161	0.1960
85.00	10.00	23.00	0.00881	2.287	5.142	0.1838
90.00	10.03	23.00	0.00881	2.433	5.132	0.1730

Table B21

Delta P = 10 psi

RUN #3
Laboratory Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Helium>							
24.42	50.00	140.05	140.03	140.21	140.17	140.06	140.10
24.42	50.00	119.19	119.18	119.12	119.38	119.37	119.25
24.42	50.00	103.35	103.20	103.33	103.48	103.32	103.34
24.42	50.00	91.54	91.68	91.39	91.64	91.53	91.56
24.42	50.00	82.69	82.61	82.65	82.72	82.67	82.67
24.42	50.00	75.20	75.09	75.38	75.20	75.17	75.21
24.42	50.00	68.76	68.68	68.63	68.72	68.62	68.68
24.42	50.00	63.15	63.10	63.01	63.18	63.14	63.12
24.42	50.00	58.96	58.96	58.95	58.98	58.94	58.96
24.42	50.00	54.83	54.88	54.85	54.79	54.85	54.84
24.42	50.00	51.41	41.48	51.52	51.51	51.53	49.49
24.42	50.00	48.52	48.43	48.28	48.57	48.33	48.43
24.42	50.00	45.69	45.79	45.69	45.68	45.65	45.70
24.42	50.00	43.61	43.64	43.64	43.70	43.54	43.63
<Hydrogen>							
24.40	50.00	74.93	75.05	75.04	74.91	74.90	74.97
24.40	50.00	60.41	60.51	60.56	60.41	60.40	60.46
24.40	50.00	51.36	51.36	51.39	51.27	51.26	51.33
24.40	50.00	45.33	45.25	45.19	45.24	45.26	45.25
24.40	100.00	80.41	80.53	80.44	80.44	80.42	80.45
24.40	100.00	73.42	73.53	73.51	73.53	73.56	73.51
24.40	100.00	66.84	66.87	66.91	66.91	66.99	66.90
24.40	100.00	61.39	61.36	61.26	61.31	61.27	61.32
24.40	100.00	56.77	56.80	56.77	56.91	56.84	56.82
24.40	100.00	52.67	52.60	52.78	52.73	52.73	52.70
24.40	100.00	49.25	49.27	49.16	49.23	49.25	49.23
24.40	100.00	46.46	46.42	46.45	46.38	46.36	46.41
24.40	100.00	43.76	43.75	43.63	43.69	43.77	43.72
24.40	100.00	41.03	41.16	41.15	41.08	41.12	41.11

Table B22

Delta P - 10 psi

RUN #3
Calculated Data

Core ID #1
Length 3.25 cm.

Diameter 1.89 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Carbon Dioxide>						
25.00	9.99	21.00	0.01485	0.349	5.281	0.7348
30.00	9.98	21.40	0.01487	0.427	5.179	0.5878
35.00	10.04	21.20	0.01486	0.509	5.114	0.4903
40.00	9.97	21.00	0.01485	0.581	5.037	0.4198
45.00	10.01	21.00	0.01485	0.667	5.042	0.3675
50.00	9.97	21.20	0.01486	0.745	5.027	0.3266
55.00	10.02	21.60	0.01488	0.832	5.036	0.2941
60.00	9.98	22.80	0.01494	0.914	5.068	0.2672
65.00	10.03	23.00	0.01495	0.997	5.046	0.2451
70.00	9.98	23.20	0.01496	1.096	5.146	0.2261
75.00	9.97	23.60	0.01498	1.139	4.981	0.2100
80.00	10.00	24.00	0.01500	1.184	4.823	0.1960
85.00	10.02	24.00	0.01500	1.294	4.932	0.1838
90.00	10.00	24.00	0.01500	1.374	4.940	0.1729
<Nitrogen>						
25.00	10.02	18.00	0.01739	0.315	5.594	0.7354
30.00	10.00	18.20	0.01740	0.382	5.434	0.5880
35.00	10.02	18.60	0.01742	0.449	5.322	0.4902
40.00	9.99	19.00	0.01744	0.515	5.245	0.4199
45.00	9.97	19.00	0.01744	0.580	5.178	0.3674
50.00	9.97	19.00	0.01744	0.644	5.111	0.3266
55.00	9.99	19.00	0.01744	0.709	5.056	0.2940
60.00	9.99	19.00	0.01744	0.776	5.032	0.2672
65.00	10.01	19.20	0.01745	0.844	5.011	0.2450
70.00	10.01	19.40	0.01746	0.908	4.981	0.2262
75.00	9.99	19.40	0.01746	0.972	4.958	0.2100
80.00	10.02	19.60	0.01746	1.041	4.947	0.1960
85.00	9.99	20.00	0.01748	1.100	4.916	0.1837
90.00	10.02	20.00	0.01748	1.163	4.882	0.1730

Table B23

Delta P - 10 psi

RUN #3
Laboratory Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Carbon Dioxide>							
24.35	50.00	143.24	143.51	143.45	143.27	143.10	143.31
24.35	50.00	117.23	117.36	117.21	117.00	117.02	117.16
24.35	50.00	98.40	98.22	98.28	98.45	98.29	98.33
24.35	50.00	85.96	86.10	86.06	86.02	85.97	86.02
24.35	50.00	74.95	75.00	74.86	74.83	75.02	74.93
24.35	50.00	67.14	67.07	67.17	67.04	67.02	67.09
24.35	50.00	60.15	60.15	60.11	59.97	60.03	60.08
24.35	50.00	54.84	54.74	54.87	54.36	54.69	54.70
24.35	50.00	50.09	50.09	50.23	50.07	50.30	50.16
24.35	50.00	41.19	46.67	46.78	46.82	46.73	45.64
24.35	50.00	43.85	43.84	43.90	43.94	43.90	43.89
24.35	50.00	46.39	41.19	41.26	41.25	41.11	42.24
24.35	50.00	38.68	38.61	38.72	38.67	38.58	38.65
24.35	50.00	36.37	36.34	36.37	36.42	36.44	36.39
<Nitrogen>							
24.43	50.00	158.73	158.74	158.57	158.60	158.50	158.63
24.43	50.00	130.95	130.91	130.82	130.79	131.04	130.90
24.43	50.00	111.33	111.41	111.21	111.37	111.30	111.32
24.43	50.00	97.25	97.05	97.24	97.15	97.14	97.17
24.43	50.00	86.37	86.20	86.22	86.45	86.12	86.27
24.43	50.00	77.62	77.61	77.83	77.74	77.63	77.69
24.43	50.00	70.48	70.63	70.50	70.61	70.54	70.55
24.43	50.00	64.26	64.44	64.49	64.43	64.63	64.45
24.43	50.00	59.24	59.21	59.21	59.30	59.31	59.25
24.43	50.00	55.10	55.00	55.10	54.97	55.05	55.04
24.43	50.00	51.49	51.40	51.45	51.46	51.44	51.45
24.43	50.00	48.06	47.93	48.01	48.01	48.05	48.01
24.43	50.00	45.50	45.43	45.44	45.49	45.48	45.47
24.43	50.00	42.93	43.01	43.04	42.94	42.97	42.98

Table B24

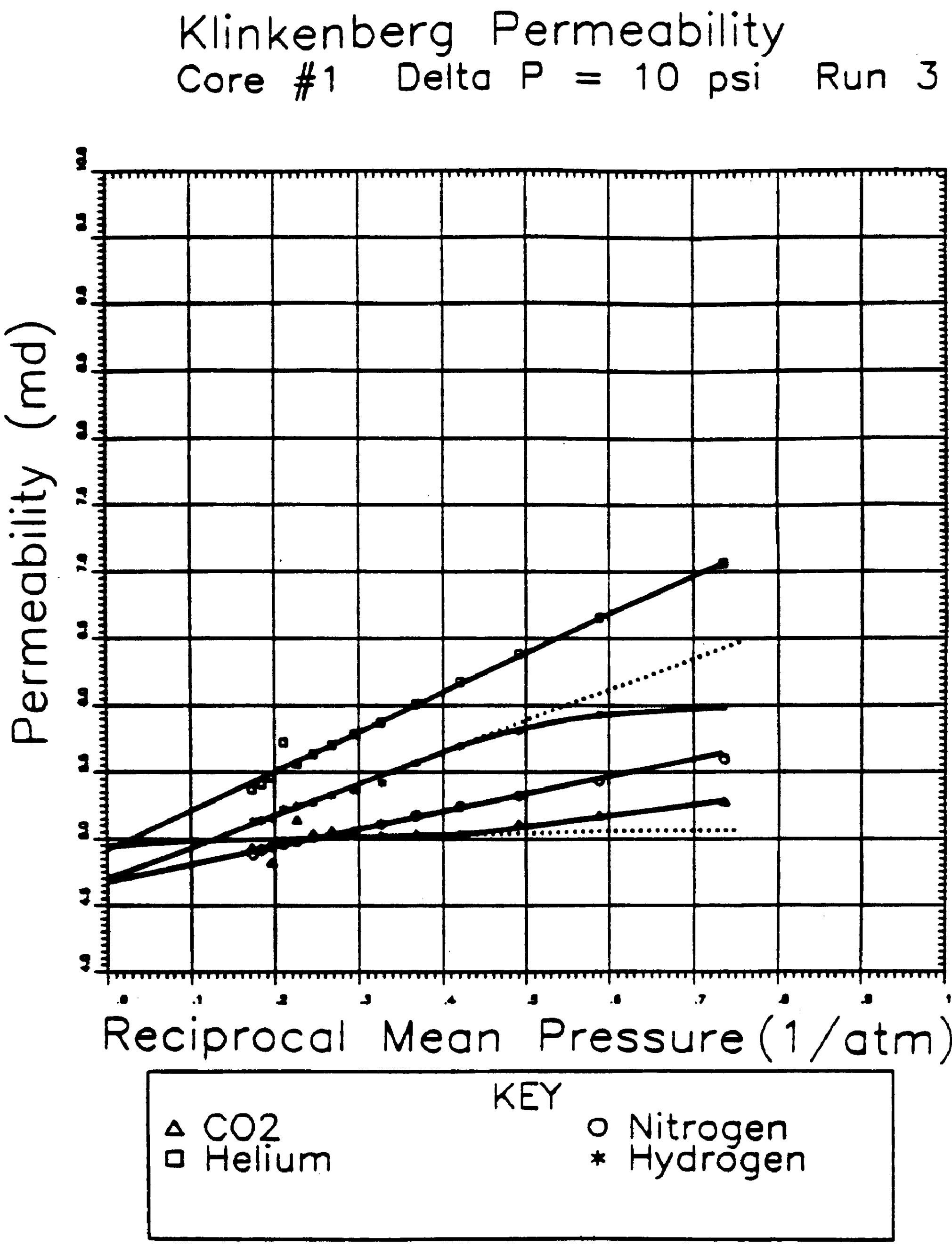

Klinkenberg Permeability
Core #1 Delta P = 10 psi Run 3
Permeability (md)
Reciprocal Mean Pressure (1/atm)
KEY
CO2
Helium
Nitrogen
Hydrogen

Figure B6

Delta P = 15 psi

RUN #1
Calculated Data

Core ID #1
Length 3.25 cm.
Diameter 1.89 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Helium>						
30.00	14.99	21.00	0.01945	0.577	6.739	0.6532
35.00	15.00	21.10	0.01945	0.673	6.438	0.5345
40.00	14.99	21.10	0.01945	0.702	5.683	0.4522
45.00	14.99	21.10	0.01945	0.858	6.019	0.3919
50.00	15.03	21.10	0.01945	0.950	5.865	0.3460
55.00	15.02	22.00	0.01949	1.059	5.864	0.3095
60.00	15.00	22.20	0.01950	1.142	5.733	0.2800
65.00	14.97	22.20	0.01950	1.241	5.697	0.2556
70.00	15.01	22.20	0.01950	1.327	5.591	0.2352
75.00	14.98	22.00	0.01949	1.411	5.514	0.2177
80.00	15.00	22.00	0.01949	1.508	5.478	0.2028
85.00	15.01	22.00	0.01949	1.599	5.432	0.1897
90.00	14.99	23.00	0.01953	1.678	5.372	0.1782
<Hydrogen>						
30.00	15.03	21.50	0.00878	1.156	6.126	0.6538
35.00	15.01	22.00	0.00879	1.360	5.911	0.5346
40.00	14.97	21.70	0.00878	1.575	5.798	0.4521
45.00	15.00	22.30	0.00879	1.765	5.632	0.3920
50.00	14.99	22.40	0.00880	1.980	5.577	0.3458
55.00	14.97	22.40	0.00880	2.152	5.431	0.3094
60.00	14.98	22.40	0.00880	2.347	5.355	0.2799
65.00	14.98	22.50	0.00880	2.549	5.311	0.2556
70.00	15.00	22.50	0.00880	2.738	5.244	0.2352
75.00	15.01	22.50	0.00880	2.886	5.115	0.2178
80.00	15.03	22.40	0.00880	3.178	5.236	0.2028
85.00	15.02	22.60	0.00880	3.265	5.038	0.1897
90.00	15.00	23.00	0.00881	3.507	5.095	0.1782

Table B25

Delta P = 15 psi

RUN #1
Laboratory Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Helium>							
24.23	100.00	173.32	173.65	173.26	173.04	173.91	173.44
24.23	100.00	148.65	148.14	148.25	148.63	148.81	148.50
24.23	100.00	130.21	130.46	130.44	160.19	160.77	142.41
24.23	100.00	116.22	116.70	116.83	116.25	116.71	116.54
24.23	100.00	105.12	105.24	105.43	105.74	105.04	105.31
24.23	100.00	94.54	94.69	94.03	94.44	94.63	94.47
24.23	100.00	87.19	87.81	87.72	87.86	87.19	87.55
24.23	100.00	80.62	80.43	80.52	80.83	80.52	80.58
24.23	100.00	75.63	75.41	75.32	75.24	75.24	75.37
24.23	100.00	70.84	70.69	70.10	71.25	71.43	70.86
24.23	100.00	66.95	66.20	66.02	66.34	66.14	66.33
24.23	100.00	62.34	62.91	62.81	62.52	62.08	62.53
24.23	100.00	59.46	59.77	59.71	59.14	59.88	59.59
<Hydrogen>							
24.39	100.00	86.59	86.64	86.41	86.77	86.13	86.51
24.39	100.00	73.77	73.52	73.25	73.63	73.37	73.51
24.39	100.00	63.22	63.52	63.64	63.52	63.55	63.49
24.39	100.00	56.91	56.45	56.70	56.44	56.74	56.65
24.39	100.00	50.58	50.42	50.19	50.38	50.98	50.51
24.39	100.00	46.80	46.40	46.62	46.34	46.15	46.46
24.39	100.00	42.41	42.98	42.70	42.47	42.50	42.61
24.39	100.00	39.23	39.18	39.25	39.25	39.28	39.24
24.39	100.00	36.97	36.45	36.71	36.32	36.16	36.52
24.39	100.00	34.65	34.67	34.81	34.21	34.90	34.65
24.39	100.00	31.78	31.23	31.42	31.18	31.73	31.47
24.39	100.00	30.79	30.69	30.41	30.71	30.54	30.63
24.39	100.00	28.68	28.82	28.69	28.01	28.36	28.51

Table B26

Delta P - 15 psi

RUN #1
Calculated Data

Core ID #1
Length 3.25 cm.
Diameter 1.89 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Carbon Dioxide>						
30.00	15.00	23.00	0.01495	0.577	5.166	0.6533
35.00	14.99	23.00	0.01495	0.699	5.120	0.5344
40.00	15.02	23.00	0.01495	0.816	5.052	0.4524
45.00	15.02	23.00	0.01495	0.933	5.004	0.3921
50.00	14.98	23.00	0.01495	1.050	4.981	0.3458
55.00	15.00	23.00	0.01495	1.175	4.981	0.3095
60.00	14.99	23.00	0.01495	1.273	4.884	0.2800
65.00	15.03	23.00	0.01495	1.395	4.877	0.2557
70.00	15.04	23.50	0.01498	1.505	4.845	0.2353
75.00	15.02	23.50	0.01498	1.628	4.859	0.2178
80.00	15.03	23.50	0.01498	1.735	4.818	0.2028
85.00	14.97	23.50	0.01498	1.833	4.779	0.1896
90.00	15.00	23.50	0.01498	1.951	4.769	0.1782
<Nitrogen>						
30.00	15.01	24.10	0.01767	0.559	5.921	0.6535
35.00	15.01	24.10	0.01767	0.631	5.466	0.5346
40.00	15.00	24.10	0.01767	0.724	5.311	0.4523
45.00	14.99	24.10	0.01767	0.823	5.229	0.3919
50.00	14.98	24.10	0.01767	0.924	5.185	0.3458
55.00	14.99	24.10	0.01767	1.013	5.084	0.3094
60.00	15.02	24.10	0.01767	1.106	5.015	0.2801
65.00	15.03	24.10	0.01767	1.198	4.955	0.2557
70.00	15.05	24.10	0.01767	1.288	4.895	0.2353
75.00	15.00	24.00	0.01766	1.397	4.929	0.2178
80.00	15.01	24.00	0.01766	1.495	4.909	0.2028
85.00	15.02	24.30	0.01768	1.593	4.894	0.1897
90.00	14.97	24.40	0.01768	1.682	4.870	0.1781

Table B27

Delta P - 15 psi **RUN #1**
Laboratory Data

Core ID **#1**
Length 3.25 cm. **Diameter** 1.89 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Carbon Dioxide>							
24.15	100.00	172.71	173.76	173.21	173.27	173.36	173.26
24.15	100.00	143.64	142.73	142.23	143.64	143.26	143.10
24.15	100.00	122.82	122.73	122.10	122.66	122.26	122.51
24.15	100.00	107.38	107.43	107.16	106.63	107.36	107.19
24.15	100.00	95.03	95.03	95.20	95.63	95.30	95.24
24.15	100.00	85.82	85.51	85.84	85.66	82.78	85.12
24.15	100.00	78.35	78.33	78.82	78.64	78.75	78.58
24.15	100.00	71.64	71.66	71.75	71.75	71.64	71.69
24.15	100.00	66.61	66.63	66.64	66.35	66.08	66.46
24.15	100.00	61.51	61.10	61.66	61.83	61.07	61.43
24.15	100.00	57.65	57.47	57.74	57.83	57.52	57.64
24.15	100.00	54.59	54.15	54.25	54.90	54.89	54.56
24.15	100.00	51.59	50.23	51.34	51.84	51.34	51.27
<Nitrogen>							
24.18	100.00	179.02	179.27	178.83	178.46	178.27	178.77
24.18	100.00	158.49	158.85	158.63	158.13	158.07	158.43
24.18	100.00	138.47	138.49	138.76	137.04	137.46	138.04
24.18	100.00	121.09	121.64	121.64	122.50	120.99	121.57
24.18	100.00	108.49	108.29	108.34	108.07	108.00	108.24
24.18	100.00	99.76	98.37	98.51	98.00	98.99	98.73
24.18	100.00	90.27	90.16	90.61	90.66	90.28	90.40
24.18	100.00	83.26	83.49	83.82	83.06	83.76	83.48
24.18	100.00	77.49	77.28	77.87	77.87	77.74	77.65
24.18	100.00	71.07	71.66	71.49	71.77	71.98	71.59
24.18	100.00	66.18	66.79	67.34	66.94	67.23	66.90
24.18	100.00	63.28	62.44	63.53	62.39	62.22	62.77
24.18	100.00	59.82	59.22	59.51	59.26	59.47	59.46

Table B28

Klinkenberg Permeability
Core #1 Delta P = 15 psi Run 1

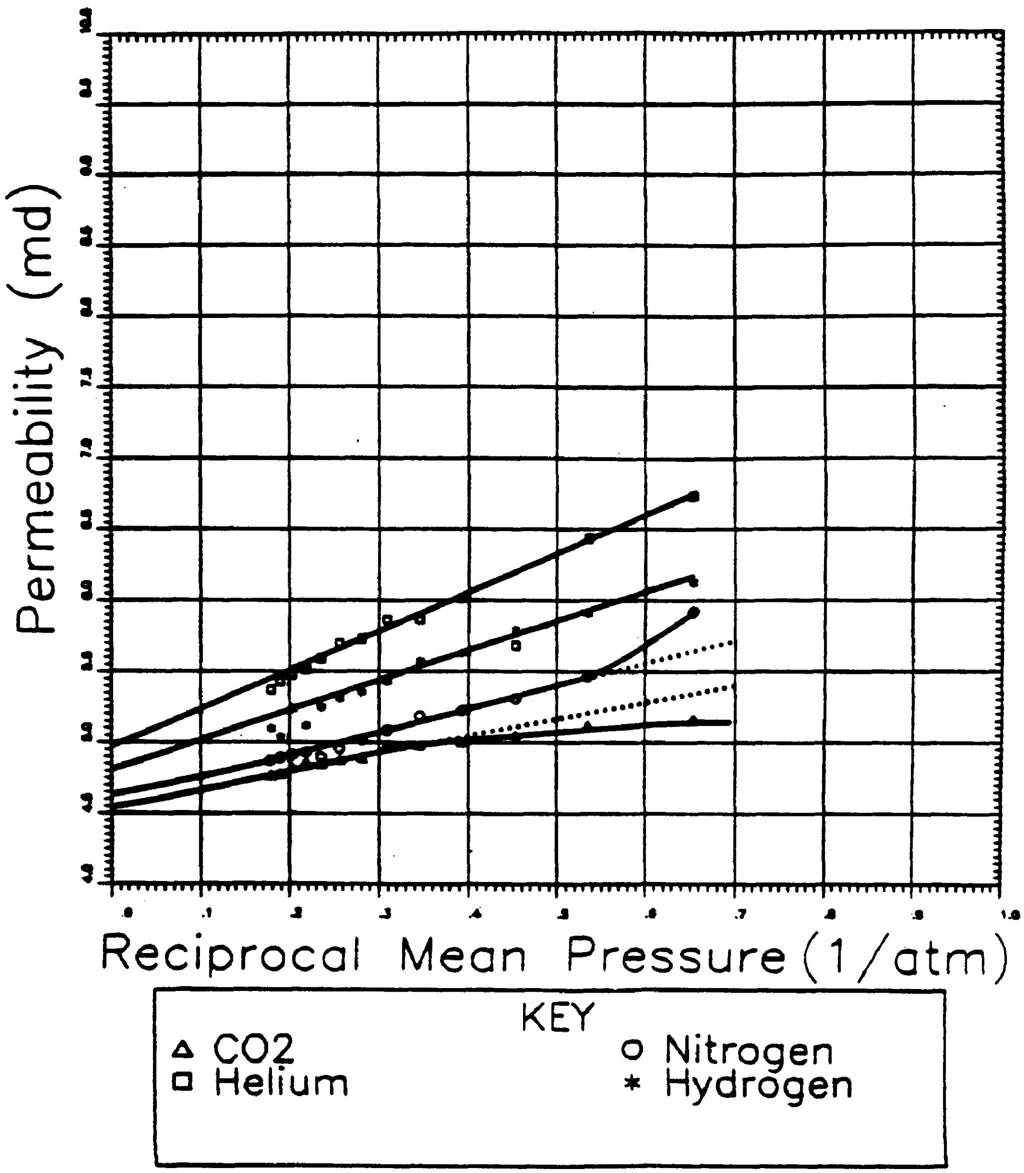


Figure B7

Delta P = 15 psi **RUN #2**
Calculated Data

Core ID #1
Length 3.25 cm. **Diameter** 1.89 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Helium>						
30.00	14.95	23.00	0.01953	0.576	6.795	0.6526
35.00	14.97	23.00	0.01953	0.673	6.490	0.5343
40.00	15.03	23.00	0.01953	0.767	6.238	0.4525
45.00	15.03	23.00	0.01953	0.860	6.061	0.3922
50.00	15.03	23.00	0.01953	0.952	5.917	0.3460
55.00	15.00	23.00	0.01953	1.058	5.893	0.3095
60.00	14.99	23.00	0.01953	1.146	5.779	0.2800
65.00	15.03	23.20	0.01954	1.238	5.690	0.2557
70.00	15.01	23.50	0.01955	1.326	5.618	0.2352
75.00	14.99	23.50	0.01955	1.418	5.566	0.2178
80.00	14.97	23.50	0.01955	1.502	5.498	0.2027
85.00	15.02	23.50	0.01955	1.602	5.468	0.1897
90.00	15.00	23.50	0.01955	1.680	5.394	0.1782
<Hydrogen>						
30.00	15.04	23.50	0.00882	1.157	6.132	0.6539
35.00	15.04	23.50	0.00882	1.360	5.897	0.5349
40.00	15.05	23.50	0.00882	1.564	5.737	0.4527
45.00	15.00	23.50	0.00882	1.761	5.611	0.3920
50.00	15.01	23.50	0.00882	1.965	5.522	0.3459
55.00	15.03	24.00	0.00883	2.166	5.447	0.3096
60.00	15.04	24.00	0.00883	2.360	5.365	0.2801
65.00	15.03	24.00	0.00883	2.555	5.308	0.2557
70.00	15.04	24.00	0.00883	2.749	5.249	0.2353
75.00	14.99	24.00	0.00883	2.933	5.202	0.2178
80.00	15.03	24.00	0.00883	3.126	5.150	0.2028
85.00	15.01	24.00	0.00883	3.322	5.125	0.1897
90.00	14.99	24.00	0.00883	3.519	5.107	0.1782

Table B29

Delta P = 15 psi

RUN #2
Laboratory Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Helium>							
24.30	100.00	173.70	173.49	173.36	173.61	173.51	173.53
24.30	100.00	148.65	148.32	148.43	148.49	148.85	148.55
24.30	100.00	130.49	130.20	130.40	130.21	130.57	130.37
24.30	100.00	116.34	116.21	116.22	116.25	116.42	116.29
24.30	100.00	105.12	104.90	105.19	105.14	105.12	105.09
24.29	100.00	94.34	94.61	94.40	94.64	94.71	94.54
24.29	100.00	87.19	87.25	87.32	87.37	87.18	87.26
24.29	100.00	80.82	80.62	80.70	80.96	80.79	80.78
24.29	100.00	75.57	75.54	75.36	75.35	75.13	75.39
24.29	100.00	70.63	70.60	70.45	70.48	70.55	70.54
24.29	100.00	66.57	66.62	66.60	66.48	66.59	66.57
24.29	100.00	62.77	62.62	62.56	61.59	62.63	62.43
24.29	100.00	59.64	59.57	59.51	59.44	59.46	59.52
<Hydrogen>							
24.29	100.00	86.64	86.49	86.37	86.39	86.40	86.46
24.29	100.00	73.67	73.52	73.38	73.55	73.59	73.54
24.29	100.00	63.92	63.92	64.05	63.88	63.87	63.93
24.29	100.00	56.80	56.74	56.75	56.84	56.80	56.79
24.29	100.00	50.82	50.88	50.94	50.91	50.91	50.89
24.29	100.00	46.15	46.15	46.13	46.20	46.20	46.17
24.29	100.00	42.28	42.29	42.42	42.44	42.46	42.38
24.29	100.00	39.18	39.05	39.16	39.15	39.13	39.13
24.29	100.00	36.37	36.39	36.37	36.42	36.36	36.38
24.29	100.00	34.12	34.19	34.00	34.02	34.14	34.09
24.29	100.00	31.99	31.94	32.01	31.99	32.00	31.99
24.29	100.00	30.19	30.14	30.16	30.01	30.01	30.10
24.29	100.00	28.39	28.40	28.42	28.38	28.49	28.42

Table B30

Delta P = 15 psi

RUN #2
Calculated Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Carbon Dioxide>						
30.00	15.01	20.00	0.01480	0.587	5.277	0.6535
35.00	15.01	20.00	0.01480	0.703	5.170	0.5346
40.00	14.98	20.20	0.01481	0.821	5.115	0.4522
45.00	15.00	20.20	0.01481	0.940	5.071	0.3920
50.00	14.98	20.40	0.01482	1.054	5.026	0.3458
55.00	14.97	20.60	0.01483	1.167	4.989	0.3094
60.00	14.99	20.80	0.01484	1.286	4.972	0.2800
65.00	14.98	21.00	0.01485	1.402	4.952	0.2556
70.00	14.98	21.00	0.01485	1.517	4.933	0.2352
75.00	14.99	21.20	0.01486	1.630	4.906	0.2178
80.00	15.02	21.40	0.01487	1.738	4.867	0.2028
85.00	15.00	22.00	0.01490	1.859	4.885	0.1897
90.00	15.04	22.00	0.01490	1.979	4.873	0.1782
<Nitrogen>						
30.00	14.97	24.00	0.01766	0.525	5.593	0.6529
35.00	15.00	24.00	0.01766	0.626	5.442	0.5345
40.00	14.96	23.80	0.01765	0.719	5.300	0.4520
45.00	15.00	24.00	0.01766	0.812	5.181	0.3920
50.00	15.02	23.80	0.01765	0.914	5.138	0.3460
55.00	15.00	23.80	0.01765	1.009	5.077	0.3095
60.00	15.04	23.80	0.01765	1.107	5.029	0.2801
65.00	15.05	23.30	0.01763	1.206	4.992	0.2558
70.00	15.05	23.50	0.01764	1.302	4.961	0.2353
75.00	15.00	23.30	0.01763	1.392	4.925	0.2178
80.00	14.98	23.00	0.01762	1.481	4.880	0.2027
85.00	15.01	23.00	0.01762	1.583	4.870	0.1897
90.00	15.02	23.00	0.01762	1.671	4.827	0.1782

Table B31

Delta P - 15 psi **RUN #2**
Laboratory Data

Core ID #1
Length 3.25 cm. **Diameter** 1.89 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Carbon Dioxide>							
24.50	100.00	170.50	170.39	170.16	170.04	170.05	170.23
24.50	100.00	142.10	142.70	142.10	142.16	141.92	142.20
24.50	100.00	122.00	121.70	121.97	121.87	121.76	121.86
24.50	100.00	106.48	106.35	106.44	106.42	106.47	106.43
24.50	100.00	94.68	94.96	95.01	95.00	94.91	94.91
24.50	100.00	85.47	85.66	85.77	85.67	85.75	85.66
24.50	100.00	77.82	77.59	77.76	77.66	77.86	77.74
24.50	100.00	71.48	71.10	71.32	71.49	71.36	71.35
24.50	100.00	65.91	66.01	65.83	65.81	65.95	65.90
24.50	100.00	61.39	61.31	61.34	61.34	61.41	61.36
24.50	100.00	57.33	57.62	57.67	57.56	57.44	57.52
24.50	100.00	53.63	53.75	53.96	53.84	53.73	53.78
24.50	100.00	50.61	50.65	50.55	50.42	50.40	50.53
<Nitrogen>							
24.28	100.00	190.31	190.33	190.26	190.43	190.33	190.33
24.28	100.00	159.80	159.70	159.79	159.93	159.92	159.83
24.28	100.00	139.03	139.16	139.00	139.17	139.07	139.09
24.28	100.00	123.12	123.24	122.98	123.09	123.10	123.11
24.28	100.00	109.39	109.44	109.29	109.34	109.39	109.37
24.28	100.00	99.23	99.20	99.08	99.04	99.16	99.14
24.28	100.00	90.40	90.30	90.43	90.46	90.14	90.35
24.28	100.00	82.78	82.91	82.93	83.04	83.08	82.95
24.28	100.00	76.86	76.92	76.75	76.74	76.82	76.82
24.28	100.00	71.67	71.77	71.87	71.91	71.88	71.82
24.28	100.00	67.59	67.37	67.50	67.55	67.54	67.51
24.28	100.00	63.23	63.21	63.16	63.16	63.10	63.17
24.28	100.00	59.83	59.85	59.87	59.94	59.71	59.84

Table B32

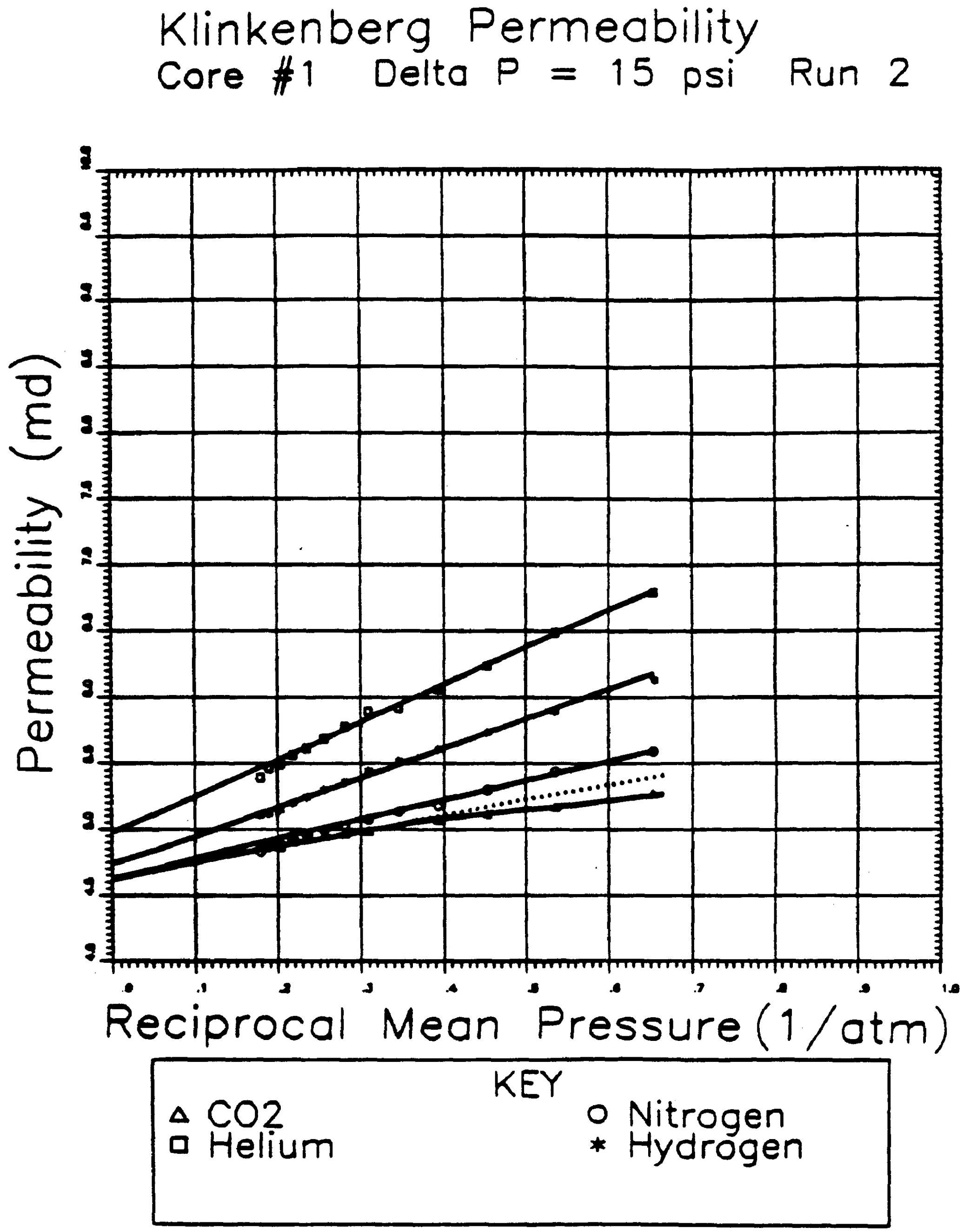

Klinkenberg Permeability
Core #1 Delta P = 15 psi Run 2
Permeability (md)
Reciprocal Mean Pressure (1/atm)
KEY
CO2
Helium
Nitrogen
Hydrogen

Figure B8

Delta P - 15 psi

RUN #3
Calculated Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Helium>						
30.00	14.98	20.00	0.01941	0.578	6.797	0.6530
35.00	15.02	20.20	0.01942	0.667	6.406	0.5347
40.00	15.02	20.20	0.01942	0.766	6.225	0.4524
45.00	14.97	20.20	0.01942	0.845	5.967	0.3918
50.00	14.98	20.60	0.01943	0.955	5.954	0.3458
55.00	14.98	20.60	0.01943	1.053	5.872	0.3094
60.00	15.03	20.80	0.01944	1.150	5.793	0.2801
65.00	14.96	21.00	0.01945	1.229	5.677	0.2556
70.00	15.02	21.00	0.01945	1.331	5.636	0.2352
75.00	15.02	21.00	0.01945	1.409	5.524	0.2178
80.00	15.04	21.00	0.01945	1.494	5.447	0.2028
85.00	14.98	21.00	0.01945	1.583	5.417	0.1897
90.00	14.98	21.20	0.01946	1.678	5.396	0.1782
<Hydrogen>						
30.00	15.00	22.00	0.00879	1.153	6.126	0.6533
35.00	15.04	22.40	0.00880	1.372	5.960	0.5349
40.00	14.96	23.00	0.00881	1.546	5.715	0.4520
45.00	15.04	23.00	0.00881	1.741	5.554	0.3922
50.00	15.04	23.00	0.00881	1.982	5.580	0.3460
55.00	15.06	23.00	0.00881	2.152	5.413	0.3097
60.00	15.00	23.00	0.00881	2.358	5.384	0.2800
65.00	15.00	23.00	0.00881	2.537	5.290	0.2557
70.00	15.00	23.00	0.00881	2.734	5.244	0.2352
75.00	14.99	23.00	0.00881	2.896	5.147	0.2178
80.00	15.01	23.00	0.00881	3.164	5.229	0.2028
85.00	15.00	23.00	0.00881	3.275	5.066	0.1897
90.00	15.03	23.00	0.00881	3.496	5.072	0.1782

Table B33

Delta P - 15 psi **RUN #3**
Laboratory Data

Core ID **#1**
Length **3.25** **cm.** **Diameter** **1.89** **cm.**

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Helium>							
24.42	50.00	86.85	86.72	86.27	86.19	86.55	86.52
24.42	50.00	74.33	74.49	75.02	75.67	75.49	75.00
24.42	50.00	65.26	65.37	65.06	65.29	65.50	65.30
24.42	50.00	58.17	59.26	59.05	59.56	59.95	59.20
24.42	50.00	52.56	52.01	52.71	52.25	52.29	52.36
24.42	50.00	47.17	47.09	47.65	47.89	47.72	47.50
24.42	50.00	43.60	43.69	43.06	43.12	43.83	43.46
24.42	50.00	40.41	40.91	40.71	40.88	40.47	40.68
24.42	50.00	37.79	37.27	37.92	37.37	37.46	37.56
24.42	50.00	35.32	35.66	35.84	35.42	35.18	35.48
24.42	50.00	33.29	33.48	33.28	33.62	33.66	33.47
24.42	50.00	31.31	32.01	31.55	31.87	31.21	31.59
24.42	50.00	29.82	29.75	29.83	29.66	29.96	29.80
<Hydrogen>							
24.40	50.00	43.32	43.09	43.95	43.01	43.53	43.38
24.40	50.00	36.76	36.55	36.14	36.17	36.63	36.45
24.40	50.00	32.01	32.09	32.46	32.43	32.72	32.34
24.40	50.00	28.42	28.98	28.70	28.68	28.81	28.72
24.40	100.00	50.28	50.57	50.24	50.23	50.91	50.45
24.40	100.00	46.51	46.92	46.69	46.23	46.01	46.47
24.40	100.00	42.24	42.24	42.81	42.68	42.11	42.42
24.40	100.00	39.51	39.04	39.43	39.81	39.28	39.41
24.40	100.00	36.63	36.19	36.69	36.42	36.97	36.58
24.40	100.00	34.90	34.47	34.20	34.82	34.25	34.53
24.40	100.00	31.99	31.68	31.91	31.17	31.29	31.61
24.40	100.00	30.41	30.24	30.77	30.74	30.51	30.53
24.40	100.00	28.24	28.70	28.34	28.98	28.75	28.60

Table B34

Delta P - 15 psi

RUN #3
Calculated Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Carbon Dioxide>						
30.00	15.01	24.00	0.01500	0.577	5.213	0.6535
35.00	15.02	24.00	0.01500	0.699	5.161	0.5347
40.00	14.98	24.00	0.01500	0.816	5.108	0.4522
45.00	15.01	24.00	0.01500	0.934	5.057	0.3921
50.00	14.96	24.00	0.01500	1.046	5.012	0.3457
55.00	15.01	24.00	0.01500	1.166	4.987	0.3095
60.00	15.02	24.00	0.01500	1.278	4.942	0.2801
65.00	15.03	24.00	0.01500	1.392	4.910	0.2557
70.00	14.95	24.00	0.01500	1.498	4.884	0.2351
75.00	15.03	24.00	0.01500	1.619	4.865	0.2178
80.00	15.04	24.00	0.01500	1.734	4.849	0.2028
85.00	15.02	24.00	0.01500	1.844	4.831	0.1897
90.00	15.03	24.00	0.01500	1.959	4.818	0.1782
<Nitrogen>						
30.00	15.02	24.00	0.01766	0.560	5.953	0.6536
35.00	15.00	24.00	0.01766	0.632	5.500	0.5345
40.00	15.01	24.00	0.01766	0.725	5.341	0.4524
45.00	15.00	24.00	0.01766	0.821	5.240	0.3920
50.00	15.04	24.00	0.01766	0.919	5.169	0.3460
55.00	14.97	24.00	0.01766	1.011	5.104	0.3094
60.00	14.98	24.00	0.01766	1.107	5.055	0.2799
65.00	15.01	24.00	0.01766	1.203	5.006	0.2557
70.00	15.00	24.00	0.01766	1.295	4.961	0.2352
75.00	15.04	24.00	0.01766	1.396	4.940	0.2178
80.00	15.05	24.00	0.01766	1.494	4.920	0.2028
85.00	15.03	24.70	0.01769	1.587	4.904	0.1897
90.00	15.00	24.50	0.01768	1.682	4.890	0.1782

Table B35

Delta P - 15 psi

RUN #3
Laboratory Data

Core ID #1
Length 3.25 cm. Diameter 1.89 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Carbon Dioxide>							
24.29	100.00	172.91	173.03	173.10	173.16	173.66	173.17
24.29	100.00	143.09	142.96	142.95	143.16	143.14	143.06
24.29	100.00	122.69	122.52	122.56	122.40	122.55	122.54
24.29	100.00	107.13	107.26	107.19	106.86	107.05	107.10
24.29	100.00	95.43	95.71	95.60	95.73	95.61	95.62
24.29	100.00	85.95	85.04	85.89	85.93	85.94	85.75
24.29	100.00	78.27	78.38	78.09	78.11	78.37	78.24
24.29	100.00	71.90	71.78	71.81	71.90	71.88	71.85
24.29	100.00	66.88	66.69	66.79	66.75	66.77	66.78
24.29	100.00	61.83	61.77	61.86	61.62	61.82	61.78
24.29	100.00	57.67	57.70	57.63	57.72	57.63	57.67
24.29	100.00	54.28	54.19	54.18	54.23	54.21	54.22
24.29	100.00	51.16	50.88	51.01	51.05	51.09	51.04
<Nitrogen>							
24.31	100.00	179.06	179.02	178.63	178.08	178.46	178.65
24.31	100.00	158.27	158.59	158.38	158.25	158.22	158.34
24.31	100.00	138.08	138.09	137.83	137.67	137.81	137.90
24.31	100.00	121.57	121.68	121.99	122.13	121.95	121.86
24.31	100.00	108.81	108.78	108.69	108.75	108.80	108.77
24.31	100.00	99.12	98.85	98.99	98.86	98.93	98.95
24.31	100.00	90.62	90.18	90.21	90.31	90.37	90.34
24.31	100.00	83.28	83.14	83.09	83.03	83.19	83.15
24.31	100.00	77.22	77.24	77.16	77.27	77.29	77.24
24.31	100.00	71.70	71.67	71.59	71.61	71.66	71.65
24.31	100.00	66.88	66.88	67.00	66.84	67.06	66.93
24.31	100.00	63.09	62.95	63.02	62.97	62.99	63.00
24.31	100.00	59.49	59.46	59.35	59.42	59.50	59.44

Table B36

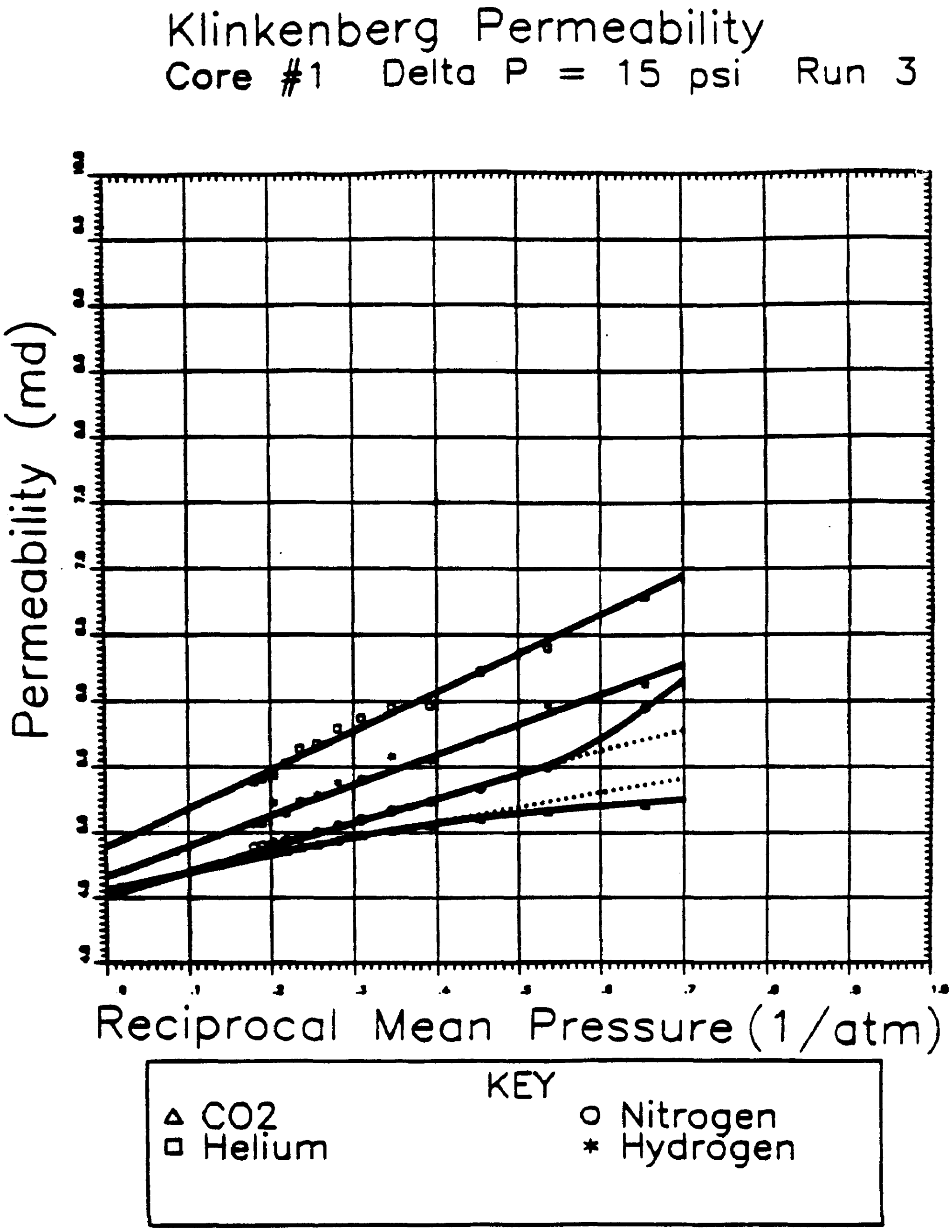

Klinkenberg Permeability
Core #1 Delta P = 15 psi Run 3
Permeability (md)
Reciprocal Mean Pressure (1/atm)
KEY
CO2
Helium
Nitrogen
Hydrogen

Figure B9

Calculated Data

Core ID #4828
Length 2.99 cm. Diameter 3.08 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Carbon Dioxide>						
59.80	4.07	24.00	0.01500	0.248	1.121	0.2545
73.95	4.77	24.00	0.01500	0.364	1.137	0.2054
92.10	4.61	24.00	0.01500	0.438	1.127	0.1637
30.60	4.96	24.00	0.01500	0.159	1.212	0.5228
44.60	7.01	24.00	0.01500	0.325	1.201	0.3577
<Nitrogen>						
25.00	7.30	25.00	0.01771	0.188	1.514	0.6885
44.30	4.21	25.00	0.01771	0.183	1.292	0.3484
66.50	5.95	25.00	0.01771	0.362	1.203	0.2314
90.40	5.21	25.00	0.01771	0.421	1.155	0.1674
<Helium>						
33.40	3.75	24.00	0.01957	0.147	1.725	0.4663
50.90	6.52	24.00	0.01957	0.336	1.501	0.3086
66.35	6.37	23.00	0.01953	0.396	1.362	0.2327
82.10	5.61	22.50	0.01951	0.423	1.315	0.1854
<Hydrogen>						
31.90	6.64	22.00	0.00879	0.445	1.448	0.5143
44.90	7.49	23.00	0.00881	0.662	1.330	0.3572
60.30	5.49	23.00	0.00881	0.633	1.240	0.2554
92.20	5.41	23.00	0.00881	0.894	1.144	0.1643

Table B37

Laboratory Data

Core ID #4828
Length 2.99 cm. Diameter 3.08 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Carbon Dioxide>							
24.40	50.00	202.08	201.87	201.73	201.89	201.71	201.86
24.40	50.00	137.31	137.47	137.29	137.16	137.20	137.29
24.40	50.00	114.30	114.23	114.26	114.13	114.14	114.21
24.40	50.00	314.57	314.61	314.69	314.88	315.49	314.85
24.40	50.00	154.18	154.09	153.71	153.49	153.38	153.77
<Nitrogen>							
24.40	50.00	266.36	266.32	266.77	266.01	265.56	266.20
24.40	50.00	274.01	274.20	273.45	273.53	273.38	273.71
24.40	50.00	138.25	138.15	138.12	137.93	138.19	138.13
24.40	50.00	118.72	118.63	118.76	119.52	118.85	118.90
<Helium>							
24.40	50.00	341.29	340.29	340.32	340.07	340.31	340.46
24.40	50.00	148.84	149.03	148.84	149.00	148.84	148.91
24.40	50.00	126.42	126.42	126.35	126.42	126.41	126.40
24.40	50.00	119.73	120.11	119.82	119.92	112.00	118.32
<Hydrogen>							
24.18	50.00	112.32	112.21	112.62	112.47	112.50	112.42
24.18	50.00	75.52	75.51	75.57	75.66	75.56	75.56
24.18	50.00	79.05	78.95	79.09	79.05	79.11	79.05
24.18	50.00	55.83	56.07	55.94	55.76	55.89	55.90

Table B38

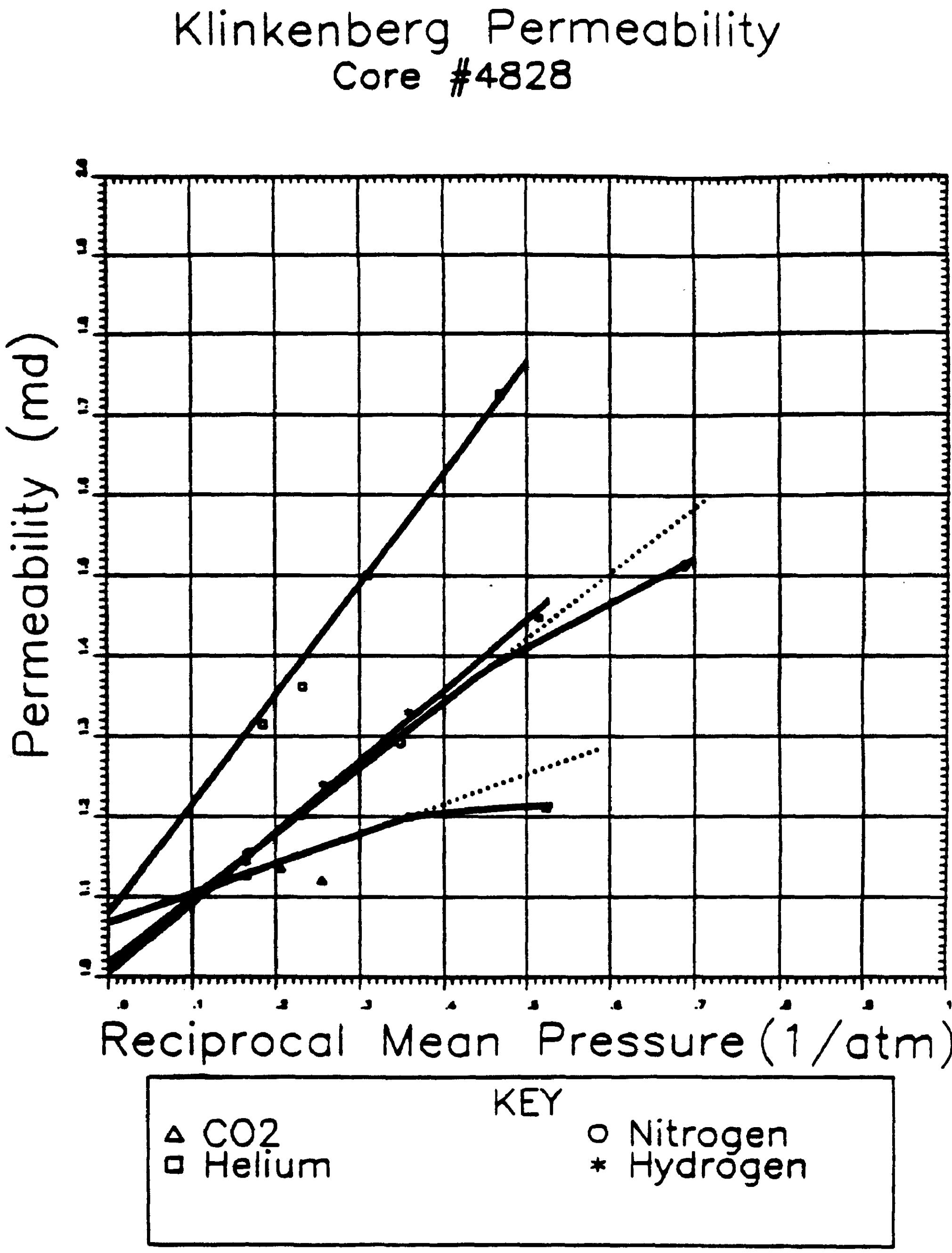

Klinkenberg Permeability
Core #4828
Permeability (md)
Reciprocal Mean Pressure (1/atm)
KEY
CO2
Helium
Nitrogen
Hydrogen

Figure B10

Calculated Data

Core ID #4847

Length 2.91 cm. Diameter 2.55 cm.

Inlet Pressure (psia)	Delta P (psi)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Carbon Dioxide>						
25.30	0.80	26.00	0.01510	0.656	49.774	0.5904
40.30	0.94	26.00	0.01510	1.654	66.806	0.3691
50.10	0.92	26.00	0.01510	2.027	67.119	0.2961
65.10	0.87	26.00	0.01510	2.464	66.245	0.2273
80.80	0.76	26.00	0.01510	2.659	65.798	0.1828
<Nitrogen>						
25.20	1.07	26.00	0.01775	1.014	68.290	0.5960
39.40	1.06	26.00	0.01775	1.548	66.796	0.3782
53.50	1.03	26.00	0.01775	2.018	65.769	0.2774
68.20	0.88	26.00	0.01775	2.184	65.132	0.2169
75.30	0.86	26.00	0.01775	2.324	64.190	0.1963
<Helium>						
28.30	0.80	26.00	0.01965	0.798	70.385	0.5269
43.20	1.23	26.00	0.01965	1.852	69.609	0.3452
57.90	0.76	26.00	0.01965	1.499	67.495	0.2556
73.10	0.81	26.00	0.01965	1.980	66.208	0.2022
<Hydrogen>						
23.20	1.06	18.00	0.00870	1.841	66.778	0.6484
37.50	0.93	18.00	0.00870	2.539	64.258	0.3969
52.50	0.69	18.00	0.00870	2.547	61.692	0.2819
66.40	0.57	18.00	0.00870	2.610	60.356	0.2223

Table B39

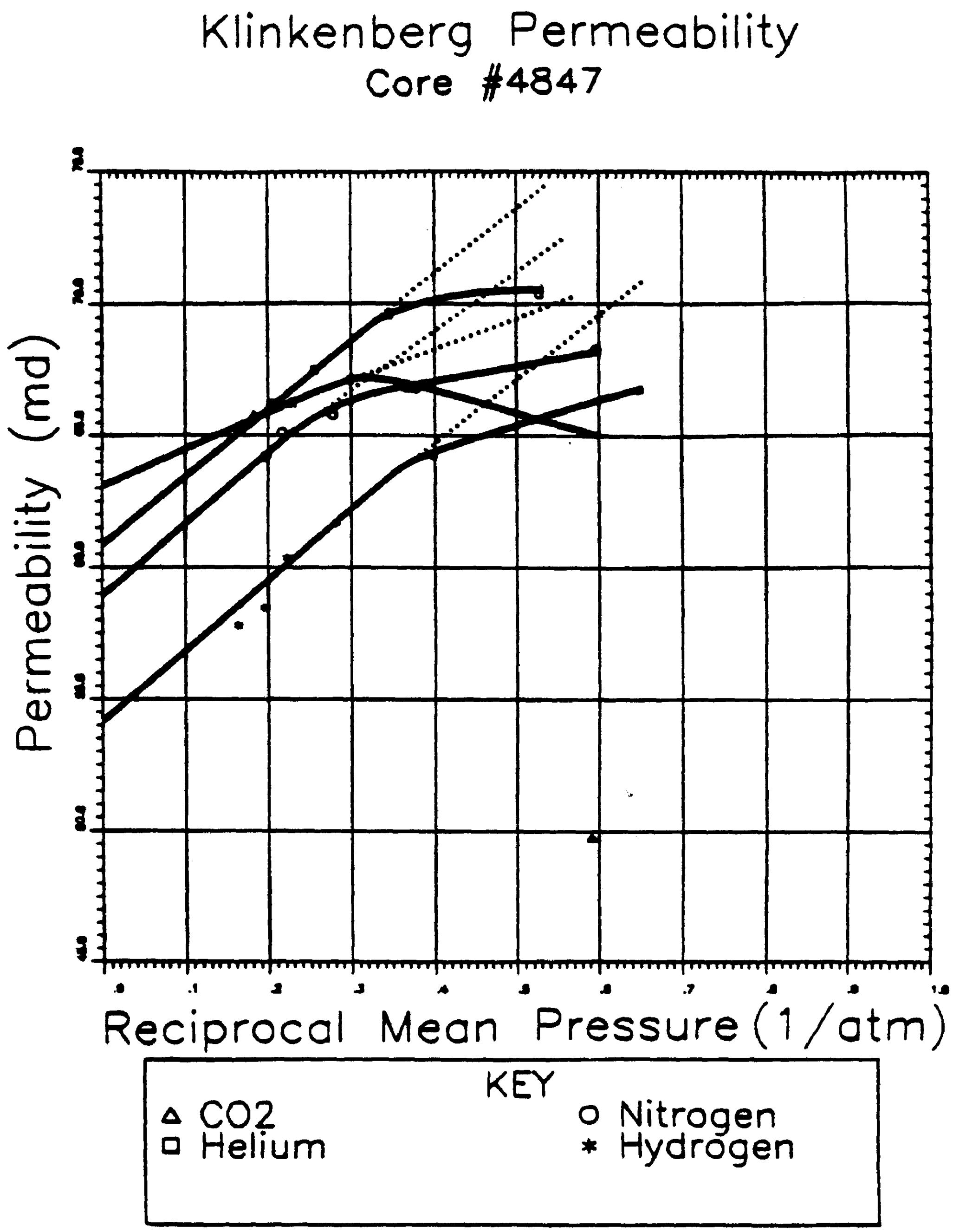
Laboratory Data

Core ID #4847

Length 2.91 cm. Diameter 2.55 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Carbon Dioxide>							
24.32	100.00	152.75	152.48	152.47	152.54	152.53	152.55
24.32	100.00	60.59	60.42	60.39	60.46	60.51	60.47
24.32	100.00	49.25	49.11	49.40	49.58	49.39	49.35
24.32	100.00	40.64	40.61	40.55	40.52	40.61	40.59
24.32	100.00	37.63	37.65	37.67	37.53	37.58	37.61
<Nitrogen>							
24.32	100.00	98.53	98.68	98.65	98.78	98.68	98.66
24.32	100.00	64.68	64.67	64.49	64.59	64.63	64.61
24.32	100.00	49.47	49.59	49.39	49.69	49.57	49.54
24.32	100.00	45.77	45.67	45.78	45.79	45.92	45.79
24.32	100.00	43.04	43.01	43.05	43.06	42.96	43.02
<Helium>							
24.32	100.00	125.55	125.40	125.36	125.15	125.11	125.31
24.32	100.00	54.01	53.92	53.94	54.04	54.06	53.99
24.32	100.00	66.76	66.71	66.69	66.74	66.71	66.72
24.32	100.00	50.69	50.73	50.01	50.57	50.49	50.50
<Hydrogen>							
24.32	100.00	54.30	54.34	54.27	54.28	54.39	54.32
24.32	100.00	39.35	39.37	39.27	39.42	39.50	39.38
24.32	100.00	39.20	39.25	39.26	39.27	39.32	39.26
24.32	100.00	38.35	38.24	38.23	38.34	38.44	38.32

Table B40



Klinkenberg Permeability
Core #4847
Permeability (md)
Reciprocal Mean Pressure (1/atm)
KEY
CO2
Nitrogen
Helium
Hydrogen

Figure B11

Calculated Data

Core ID #4850
Length 2.83 cm. Diameter 3.08 cm.

Inlet Pressure (psia)	Delta P (psia)	Room Temp. (Deg C)	Gas Viscosity (cp)	Flow Rate (cc/sec)	Perm (md)	Reciprocal Mean Pressure (1/atm.)
<Carbon Dioxide>						
30.10	0.25	24.00	0.01500	1.046	139.61	0.4904
45.10	0.24	24.00	0.01500	1.522	141.01	0.3268
60.60	0.26	24.00	0.01500	2.096	133.37	0.2431
75.00	0.20	24.00	0.01500	1.981	132.25	0.1963
88.60	0.22	24.50	0.01503	2.607	134.15	0.1661
<Nitrogen>						
30.00	0.25	25.00	0.01771	0.880	139.12	0.4921
44.60	0.27	25.00	0.01771	1.358	133.60	0.3306
59.40	0.26	25.00	0.01771	1.753	134.30	0.2480
74.80	0.25	25.50	0.01773	2.080	131.70	0.1969
82.60	0.25	25.50	0.01773	2.327	133.43	0.1782
<Helium>						
30.40	0.26	26.00	0.01965	0.889	147.97	0.4856
45.00	0.25	27.00	0.01969	1.210	141.63	0.3276
59.90	0.25	27.00	0.01969	1.584	139.20	0.2459
74.80	0.25	29.00	0.01977	1.948	137.58	0.1969
96.50	0.24	29.00	0.01977	2.289	130.51	0.1525
<Hydrogen>						
31.30	0.20	22.00	0.00879	1.524	143.16	0.4712
45.00	0.27	22.00	0.00879	2.905	140.53	0.3276
58.80	0.17	22.50	0.00880	2.389	140.45	0.2504
69.60	0.20	23.00	0.00881	3.051	128.93	0.2115
89.50	0.21	23.50	0.00882	4.150	130.03	0.1644

Table B41

Laboratory Data

Core ID #4850
Length 2.83 cm. Diameter 3.08 cm.

Barometric Pressure (in. Hg)	Meter Volume (cc)	Time #1 (seconds)	Time #2 (seconds)	Time #3 (seconds)	Time #4 (seconds)	Time #5 (seconds)	Time Average (seconds)
<Carbon Dioxide>							
24.23	100.00	95.68	95.61	95.64	95.43	95.71	95.61
24.23	100.00	65.67	65.71	65.77	65.67	65.73	65.71
24.23	100.00	47.61	47.70	47.65	47.76	47.80	47.70
24.23	100.00	50.45	50.47	50.48	50.43	50.63	50.49
24.23	100.00	38.32	38.31	38.36	38.42	38.41	38.36
<Nitrogen>							
24.23	100.00	113.58	113.78	113.46	113.72	113.67	113.64
24.23	100.00	73.72	73.54	73.65	73.60	73.57	73.62
24.23	100.00	56.97	57.08	57.10	57.13	57.00	57.06
24.23	100.00	48.15	48.09	48.09	47.97	48.14	48.09
24.23	100.00	42.99	42.90	43.01	42.99	42.98	42.97
<Helium>							
24.23	100.00	112.69	112.44	112.50	112.47	112.60	112.54
24.23	100.00	82.67	82.67	82.72	82.52	82.68	82.65
24.23	100.00	63.06	63.36	63.13	63.15	62.97	63.13
24.23	100.00	51.37	51.37	51.39	51.26	51.31	51.34
24.23	100.00	43.84	43.88	43.49	43.47	43.72	43.68
<Hydrogen>							
24.23	100.00	65.77	65.55	65.44	65.65	65.60	65.60
24.23	100.00	34.82	34.82	32.98	34.78	34.72	34.42
24.23	100.00	42.00	41.85	41.93	41.75	41.73	41.85
24.23	100.00	33.42	33.37	32.37	32.39	32.35	32.78
24.23	100.00	24.18	23.98	24.12	24.20	23.99	24.09

Table B42

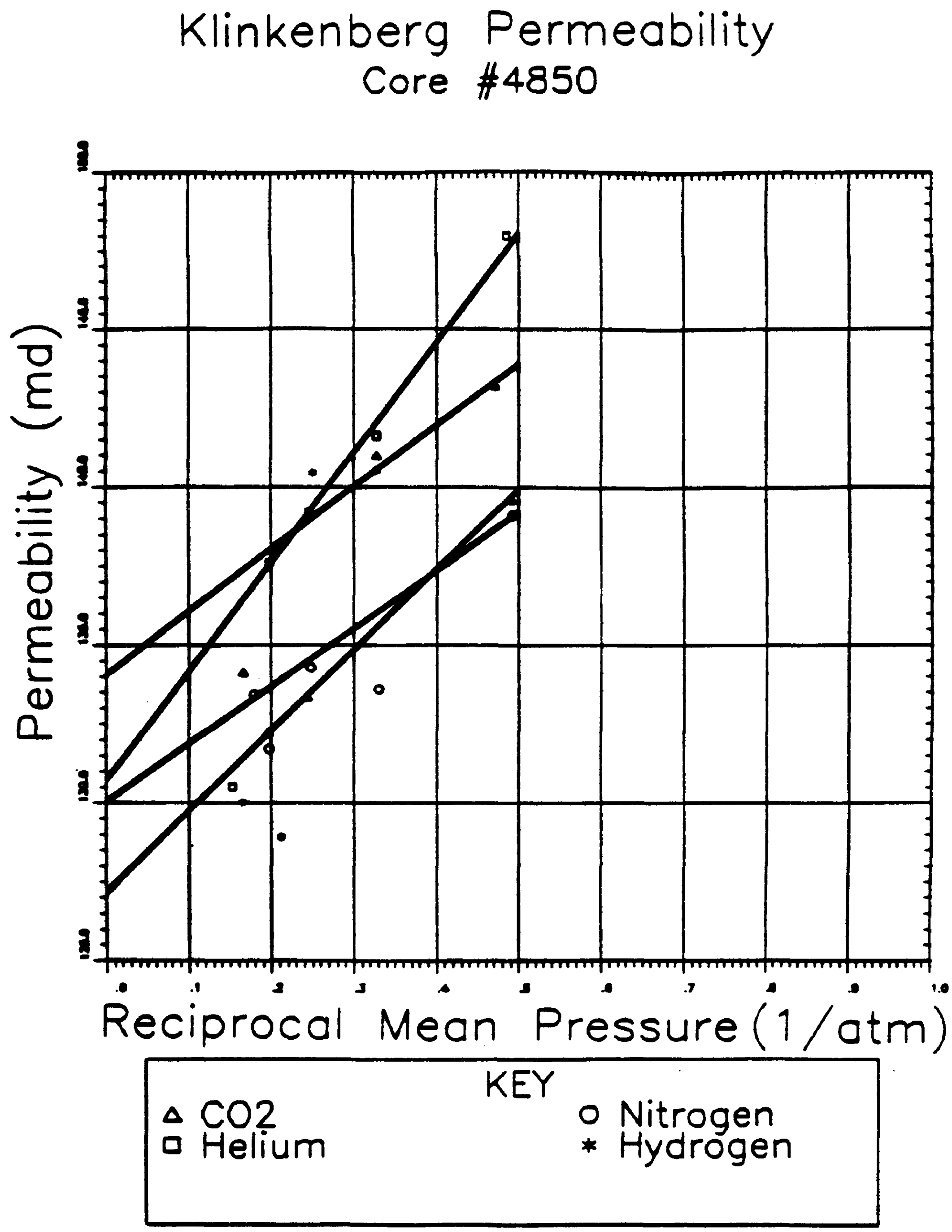

Klinkenberg Permeability
Core #4850
Permeability (md)
.0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Reciprocal Mean Pressure (1/atm)
KEY
CO2
Helium
Nitrogen
Hydrogen

Figure B12