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engineering experiment station

Development of an Asphalt Pavement Air Permeameter and Evaluation of its Use

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Idaho Department of Highways
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DEVELOPMENT OF AN ASPHALT PAVEMENT AIR PERMEAMETER AND EVALUATION OF ITS USE

by

N. C. Pyk
C. W. Hathaway
C. C. Warnick

Engineering Experiment Station
College of Engineering
University of Idaho
Moscow, Idaho

In Cooperation With

IDAHO DEPARTMENT OF HIGHWAYS

and the

BUREAU OF PUBLIC ROADS
U. S. DEPARTMENT OF COMMERCE

September, 1965

FOREWORD

This report is essentially the thesis of N. C. Pyk in fulfillment of the research and thesis requirements for the degree of Master of Science of Civil Engineering at the University of Idaho

The air permeameters and the procedures for their use developed especially for this project are the work of N. C. Pyk under the guidance of Professor C. C. Warnick. The investigation was supervised by Professor C. W. Hathaway. Mr. L. F. Erickson, Research Engineer of the Idaho Department of Highways, coordinated assistance from the Department of Highways and contributed significantly to the organization and management of the total project.

The project was administered through the Engineering Experiment Station of the University of Idaho as project CE-8g, Highways-Asphalt Permeability. Financial sponsorship was provided through H.P.R. funds by the Idaho Department of Highways and the U. S. Bureau of Public Roads as Highway Research Project No. 4.

SUMMARY

One objective of sealcoating asphalt pavements is to prevent surface runoff from percolating through highly permeable surfacings into the base and subgrade. Visual inspection and individual judgment are the usual basis for determining the need for sealcoating.

During this investigation, equipment, called the Idaho Pavement Permeameter, and procedures for measuring field and laboratory permeabilities by drawing air through the asphalt pavement surfacings were developed. Numerous tests were made for pavements throughout the system of the Idaho Department of Highways. These data were compared with theoretical considerations, pavement age, field location, seasonal trends, pavement temperature, data from testing with the Soiltest Paving Meter and with engineers' opinions as to the need of the respective test pavements for sealcoating. A study was also made of the range of permeability values that might be expected from typical asphalt pavements.

The equipment and procedures for measuring permeabilities in the field gave results that appeared to be consistent and reasonable. For a standardized pressure drop of 10 g/cm^2, permeability values of k/L, where k is the intrinsic permeability and L is the thickness of the asphaltic surfacing, were measured as low as 0.025 x 10^{-9}cm and in excess of 22 x 10^{-9}cm. Most field permeability values were less than 1.0 x 10^{-9}cm. A good relationship developed between increasing pavement age and decreasing permeability. Permeability decreased generally from spring to autumn and with increased pavement temperatures, although there were limited data with which to study these variations.

No relationship was apparent between the results obtained with the Idaho Pavement Permeameter and either the Soiltest Paving Meter or the engineers' opinions for the need for sealcoating. The laboratory data also proved to be irregular and the equipment is suspect. Theoretical comparisons also could not be made.

Further testing whereby greater attention is devoted to correlating the many variables with the pavement permeability value is recommended. Development of regression equations would be expecially helpful for understanding the meaning of the test results and could be easily obtained through use of computer techniques.

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INTRODUCTION

Our present highway system has grown to be such a size that every detail in construction and maintenance involves large sums of money. The large expenditures necessary to keep our highways in condition in many instances are largely dependent upon judgment rather than analytical methods. One of the largest expenditures in a maintenance program is the upkeep of bituminous surfacings by the use of a seal coat which is applied to give better night time driving delineation, to afford greater skid resistance, to give back to the asphalt binder its viscosity and ductility, and to keep the surfacing water-tight.

Without a good test to determine the factual condition of the pavement, one runs the risk of either applying the seal coat too early, which is poor utilization of sparse funds; of not applying the seal coat when it is needed, thereby letting the surface deteriorate; or of applying a seal coat of the wrong kind that will not provide the best solution to the surfacing problem.

I. PURPOSE

The purpose of this study was to establish a qualitative procedure for evaluating the need for sealing asphalt surfacings to prevent percolation of water through the pavement and to give the bitumen back its original properties. At present, qualitative warrants for sealing either do not exist or have not been reported in the voluminous literature reviewed for this study.

II. STATEMENT OF THE PROBLEM

The particular problems of the study were (1) to investigate the possibilities of using air permeability of asphalt surfacings as an indication of the need for sealing; (2) to develop the equipment and the technique for using it, such that it would give data useful in defining correlations that might be indicative of the need for sealing the pavement; and (3) to collect and analyze data that could be used in an attempt to establish limiting values for permeability to be expected from the different types of pavement and in an attempt to determine the magnitude of some of the inherent variables.

III. HISTORY

Since 1856, when Darcy presented his theory on permeability and liquid flow through porous media, there has been much work done in the field of permeability measurement. It was not, however, until 1941 that permeability of bituminous pavements was thought to give information about their serviceability and characteristics. Mr. S. C. Ells of the Department of Transport in Ottawa, Canada, was reported to have developed a device for measuring the flow rate of water through a bituminous pavement at a given head (19). He arbitrarily adopted a flow rate limit of 0.875 cm^3/in^2 of surfacing area in 180 seconds as an indication of permissible leakage for a bituminous surface. This value was approximately one-third the rate suggested by the Asphalt Institute, at that time, as justification for sealing.

In 1948 McKesson (10) discussed the importance of permeability of a bituminous pavement and pointed out how a too pervious and a too impervious surfacing could be equally detrimental to a pavement structure.

In 1955 McLaughlin and Goetz (11) compared permeability with voids, asphalt content, film thickness, and compaction to determine the influence of these variables on the permeability with the object to know more about durability of bituminous pavements.

Later, Krchma and Groening (8) and Pfeiffer (15) correlated void content with the hardening rates in bituminous pavements and pointed out the significant effect of permeability on binder hardening rates.

Schlarsky and Kimchi (17) in 1962 studied water flow through asphalt mixes to test the validity of Darcy's Law for such media and they discussed the influence of voids, bitumen, and filler content on the permeability.

One of the first methods used to any extent to determine the permeability in the field was described by Zube in 1959 (21). He used the flow rate of water under the force of gravity to determine the porosity of a surfacing. The test was designed to give indications about the absorption characteristics of a pavement that is ready for sealing so the amount of binder in the seal coating could be determined.

In 1960 Ellis and Schmidt (2) developed an air permeameter that measured the permeability in the field. Later Hein and Schmidt (3) and Kari and Santucci (5) used the device with minor alterations to control compaction of new pavements.

The above ideas on pavement permeability have been utilized by the author to develop the devices used for this project in the field. A laboratory testing device was also designed to create flow paths in cores so that comparisons could be made with field pavement permeability measurements.

CHAPTER II

FACTORS INFLUENCING PAVEMENT PERMEABILITY

Permeability measurements are dependent upon many interrelated and independent variables which can be grouped into four main categories. These categories are (1) the variables due to the charactersitics of the fluid, (2) the variables in the bituminous mix itself, (3) the variables caused by outside effects after the pavement is placed, and (4) the variables inherent in the measuring device.

Variables Due to Fluid Properties

Richards (16) defines permeability as follows: "Permeability is the quality or state of a porous medium relating to the readiness with which such a medium conducts or transmits fluids under standard conditions." This definition encompasses both the properties of the fluid and the porous media. When air is the fluid to be considered, the conductivity of the medium to air can be used to designate the permeability. Viscosity, density, and mean free path are the fluid properties that affect the hydraulic conductivity. The mean free path is the average distance between collision of fluid particles. With an increase in temperature, the viscosity and the mean free path would increase and the density decrease. With an increase of pressure, the density would increase and the mean free path would decrease. The conductivity would decrease with an increase in viscosity, and would decrease with a decrease in density. In some cases, the conductivity would decrease with a decrease in mean free path, dependent upon the size of the capillaries in the porous media. The law of flow through porous media that is usually applicable is the Darcy equation:

$$q = \frac{KA\Delta h}{L}$$

where q = volume per unit time (cc per sec)

A = Area of cross section (cm^2)

K = hydraulic conductivity (cm per sec)

Δh = change in fluid head between inlet and outlet faces (cm)

L = length of flow (cm)

A more general value for how the medium conducts any fluid is given by the intrinsic permeability k'.

$$k' = \frac{K\mu}{\rho g}$$

where k' = intrinsic permeability (cm^2)

K = hydraulic conductivity (cm per sec)

μ = dynamic viscosity (g per cm-sec)

ρ = density of the fluid (g per cm^3)

g = acceleration of gravity (cm per sec^2)

The intrinsic permeability is solely a property of the porous media and it is independent of the fluid used. Factors influencing the intrinsic permeability are: the size and the shape of the void spaces, the grain size, the density, and the shape of the grains.

These fundamental assumptions were illustrated by Muskat (12) with measurements on highly permeable sands and sandstones to air and liquids. However, in the same book Muskat presented a table of results of sands, showing large discrepancies between the permeability to air and water. Most values found for water were lower than for air.

Kundt and Warburg (9) proved in 1875 that the quantity of gas flowing through a capillary is larger than would be expected according to Darcy's Law which is based upon the assumption of laminar flow. The velocity gradient across the flow path of a liquid passing through a capillary has a parabolic shape with zero velocity at the walls and maximum velocity at the center. The velocity gradient across the same flow path for a gas flow will differ from the laminar liquid flow in that the gas next to the wall will have a finite velocity in the direction of the flow. As a consequence, the quantity of gas flowing would be expected to be higher than for a laminar flow. This type of flow was called slippage by Klinkenberg (6).

In his paper presented in 1951 at the American Petroleum Institute meeting, Klinkenberg (6) wrote in his abstract:

> Although this (the permeability is a property of the medium and is independent of the fluid used) is true for most liquids, the permeability constant as determined with gases is dependent upon

> the nature of the gas, and is approximately a linear function of the reciprocal mean pressure. This effect can be explained by taking into account the phenomena of slip, which are related closely to the mean free paths of the gas molecules. The apparent permeability extrapolated to infinite pressure gives a permeability constant which is a characteristic of the porous medium only.

Klinkenberg's investigations showed that the permeability to a gas is dependent on factors which influence the mean free path, such as pressure, temperature, and the nature of the gas. Therefore, when the mean free path is small, e.g., at high pressures, the permeability to a gas should be expected to approach that for liquids.

By plotting the permeability value against the reciprocal of the mean pressure a straight line relationship is obtained, which, when extrapolated to infinite pressure, intersects the permeability axis at values that are comparable to those obtained by liquids.

As indicated above, this effect of slip is most noticeable when the capillaries are small. In general, it was found that with highly permeable media, the differences between liquid and air permeabilities were small; whereas these differences were considerable for media of low permeability.

Klinkenberg's investigations did conclusively show that (1) gas permeability does not depend upon the pressure difference (P_1-P_2) as long as the mean pressure $\left(\frac{P_1+P_2}{2}\right) = \bar{P}$ remains constant; (2) gas permeability is a linear function of the reciprocal mean pressure; and (3) at the same mean pressure, the permeability is different for different gases, as the mean free path λ has different values for different gases.

<u>Variables in the Bituminous Surfacing</u>

When referring to the properties of the porous medium itself, intrinsic permeability should be the term used. The factor that affects intrinsic permeability is the pavement porosity which in turn is influenced by the size, shape and arrangement of particles, and pore size distribution.

Tortuosity is a dimensionless constant related to the shape and orientation of the pores. It is mathematically expressed as the ratio of the length of the flow path to the length of the porous media itself. Hence, permeability of a medium will decrease with an increase in tortuosity. The permeability of the medium will also decrease if the porosity is increased and the number of capillaries per unit area remains constant.

This increase in porosity can only be accomplished by increasing the length of the flow path.

A bituminous asphalt pavement consists of a mixture of several ingredients, none of which are actually distributed uniformly nor are the ingredients precisely known in quantity. Each of these ingredients is a variable, which, in addition to many external factors, affects the intrinsic permeability. It is not within the scope of this project to isolate and evaluate each of these factors but a brief discussion of the variables is necessary for an understanding of the problems encountered in this research.

The gradation of aggregate and the amount of filler in a bituminous mixture do markedly determine the void ration if other factors are held constant. Schlarsky and Kimchi (17) found that if the gradation is held constant, a straight line relationship on a log-log scale exists between the coefficient of permeability or hydraulic conductivity and the void content of the total mix. Experiments done by Hein and Schmidt (3) show, however, that this relationship cannot always be counted upon. Two samples may have the same void content but the permeability will be dependent upon how the voids are distributed, and whether the voids are interconnected.

In asphalt surfacings the percentage of bitumen in the mix has been found to have a very strong effect on the characteristics of the mix and the life of the pavement. Research done by Schlarsky and Kimchi (17) shows that the void content is very sensitive to change in bitumen. They found, for example, that with a given mixture, an increase of bitumen by 1 per cent decreases the void content by the same amount as an increase of 2 per cent of dust filler. For a given framework of aggregate, an addition of bitumen will not drive the aggregate particles apart but will gradually fill the voids and subsequently lower the permeability.

McLaughlin and Goetz (11) show that a linear relationship exists between voids in the mixture and the log of the permeability for a given aggregate grading having varying amounts of asphalt but compacted to a constant value of aggregate voids. They also found that for a given aggregate gradation, variable asphalt content, and a constant compactive effort, which results in varying aggregate densities, a particular permeability is achieved at a higher value of total void content for a specimen containing less asphalt. This is explained by the fact that a mixture containing the lesser amount of asphalt will have a denser aggregate framework.

The effect of a change in asphalt content also is dependent upon the initial asphalt content. At higher asphalt content the permeability is much more sensitive to changes in void content than it is at lower asphalt contents due to the relatively smaller available void space in a mix with higher asphalt content.

The life of an asphalt surfacing also is very strongly affected by the asphalt content. Krchma and Groening (8) found that not only the permeability, voids, and pore surface area were increased by a reduction of the asphalt in the mix but it also resulted in thinner and more reactive films around the aggregate particles. This in turn influences the strength of the surfacing and changes its ability to densify and flex under traffic loads. These results, therefore, may be caused by a combination of two or more variables. Figure 1 shows how sensitive the wear strength of a bituminous surfacing is to a change in asphalt content. Only one-half of 1 per cent increase in asphalt changed the wear from 0.4 inches to practically nothing within the time interval shown. Figures 2, 3 and 4 show even better how the asphalt content determines the behavior of a pavement. These show that a change of one-half of 1 per cent is enough to cut the life of the pavement to less than half. This effect is due to interaction of the many variables mentioned above and it remains to isolate each of these effects to find the importance of each of them before these problems can be fully understood.

Generally, all other things held constant, a higher degree of compaction will reduce the void content and give a lower permeability. The permeability, therefore, will be somewhat dependent upon the degree of initial rolling. Through tests, however, it has been found that the permeability of new pavements was very high compared to similar roads that had some years of traffic on them. It seems that the pavement reaches its ultimate value of low permeability only after the traffic has traveled on the pavement through the hot summer.

The temperature in the bituminous surfacing is expected to have a marked effect on the permeability. As previously mentioned, the void content is very sensitive to changes in the asphalt content and with a normal temperature range of at least 10°C to 50°C in the pavement, the thermal expansion of the asphalt will account for a variation of about 2.5 per

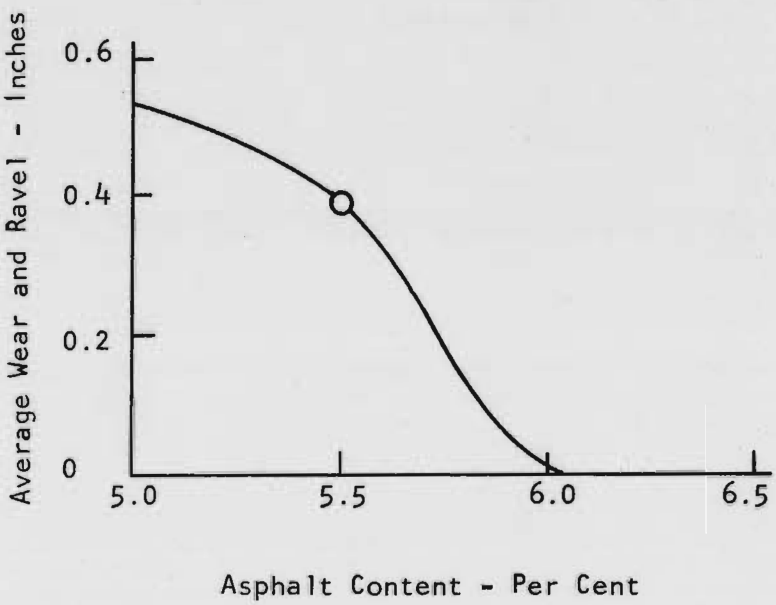


Figure 1. Wear and Raveling as a Function of Asphalt Content

(From: Krchma and Groening, "Influence of Pavement Voids, Asphalt Content, and Asphalt Grade on Asphalt Performance." Proceedings of The Association of Asphalt Paving Technologists, Vol. 28, 1959, p. 36)

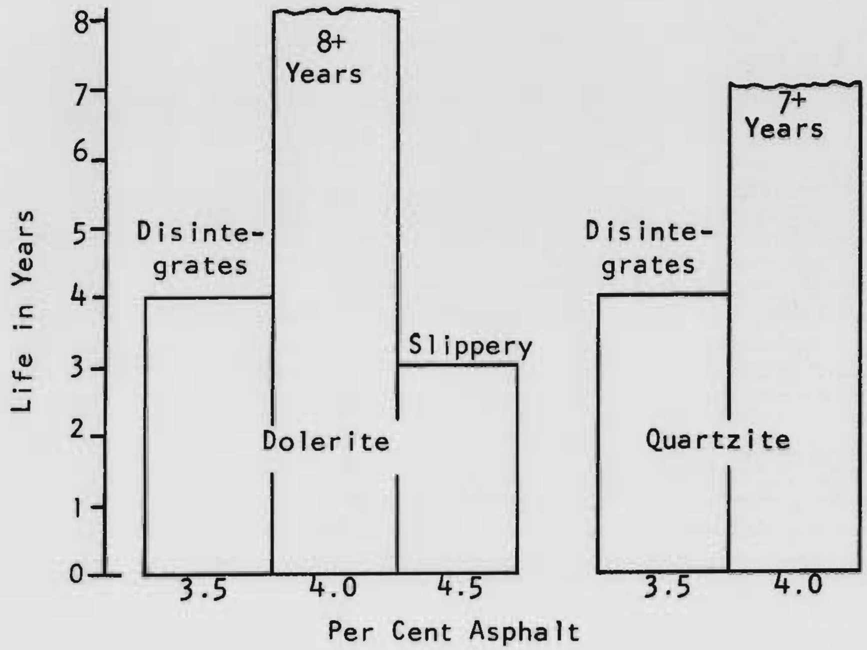


Figure 2. Life versus Per Cent Asphalt

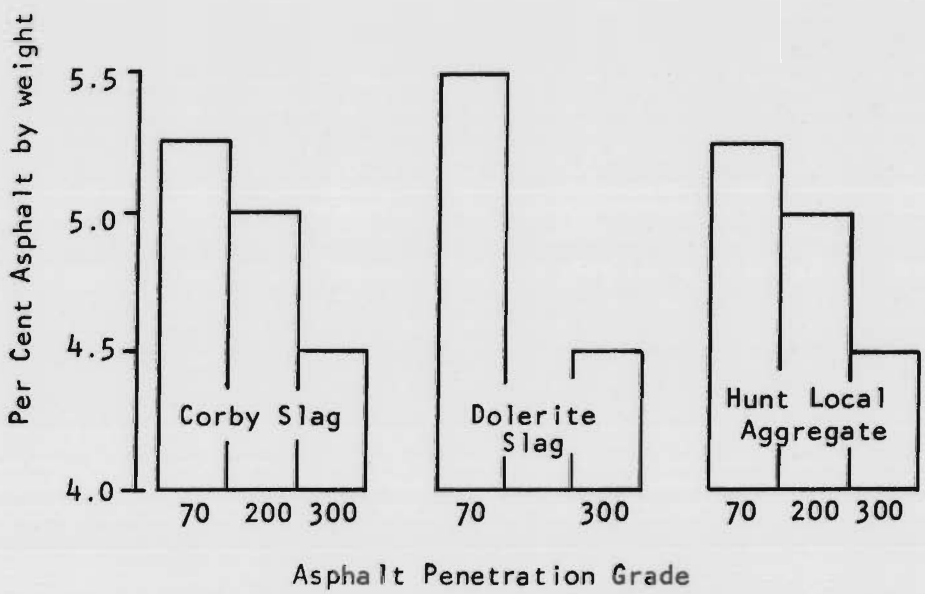


Figure 3. Influence of Asphalt Grade
On Service Optimum Per Cent Asphalt

(From: Krchma and Groening, "Influence of Pavement Voids, Asphalt Content, and Asphalt Grade on Pavement Performance." Proceedings of The Association of Asphalt Paving Technologists, Vol. 28, p. 28)

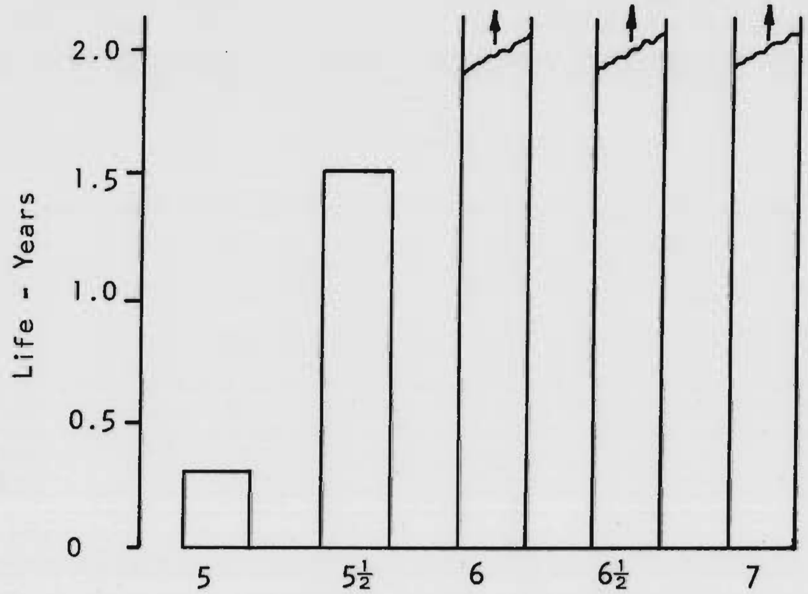


Figure 4. Life versus Asphalt Content

(From: Krchma and Groening, "Influence of Voids, Asphalt Content, and Asphalt Grade on Pavement Performance." Proceedings of The Association of Asphalt Paving Technologists, Vol. 28, 1959, p. 37) cent in volume of asphalt in the mix. Normally, the asphalt content used in a mix will be approximately 5 per cent and the void content will range from 5 per cent to 25 per cent. Obviously not all the expansion of the asphalt will be absorbed by the voids but even a small amount of expansion into the voids can be expected to affect the permeability. For instance, tests by McLaughlin and Goetz (11) show that a reduction in the void content by one-half may reduce the permeability 10 to 100 times. How much of the thermal expansion that is absorbed by the voids is not known but the relationship deserves to be investigated.

A bituminous surfacing is sometimes laid down in two or more layers, each layer being rolled separately. If the asphalt is allowed to cool too much between subsequent layers, lamination may result, affecting the permeability values because it will allow lateral flow in the surfacing. Also, because of the time interval between placing of the mix and the rolling, there will be a substantial temperature difference through the mix. When the rolling takes place, the shear resistance in the mix will vary with depth and a different degree of compaction will result. For instance, tests taken at the Zaca-Wigmore Road by Kari and Santucci (5) show that the density of the surface course changes from a low at the surface to a high around the mid-depth and then the density again drops off towards the bottom part as shown in Figure 5. This is explained by the quicker cooling of the bottom part because it is placed on a cold base and the cooling of the surface part by exposure to the atmosphere with cooling temperatures and winds. The degree of compaction may determine how closely the results from tests on laboratory cores will correlate with field tests. If the pavement initially has a fairly high permeability throughout, the air will pass through the entire pavement in both field tests and laboratory tests, and one can expect similar values for the two tests. If, however, there exists a layer in the mix that has a very low permeability, the difference between the laboratory test results and the field test results may be large. In the laboratory, the air is only allowed to flow in through the bottom of the core and pass out through the top. When the pavement is being tested in place, the air can also pass laterally through the bituminous surfacing structure by following the path of least resistance. However, if most of the restrictions to the air flow through

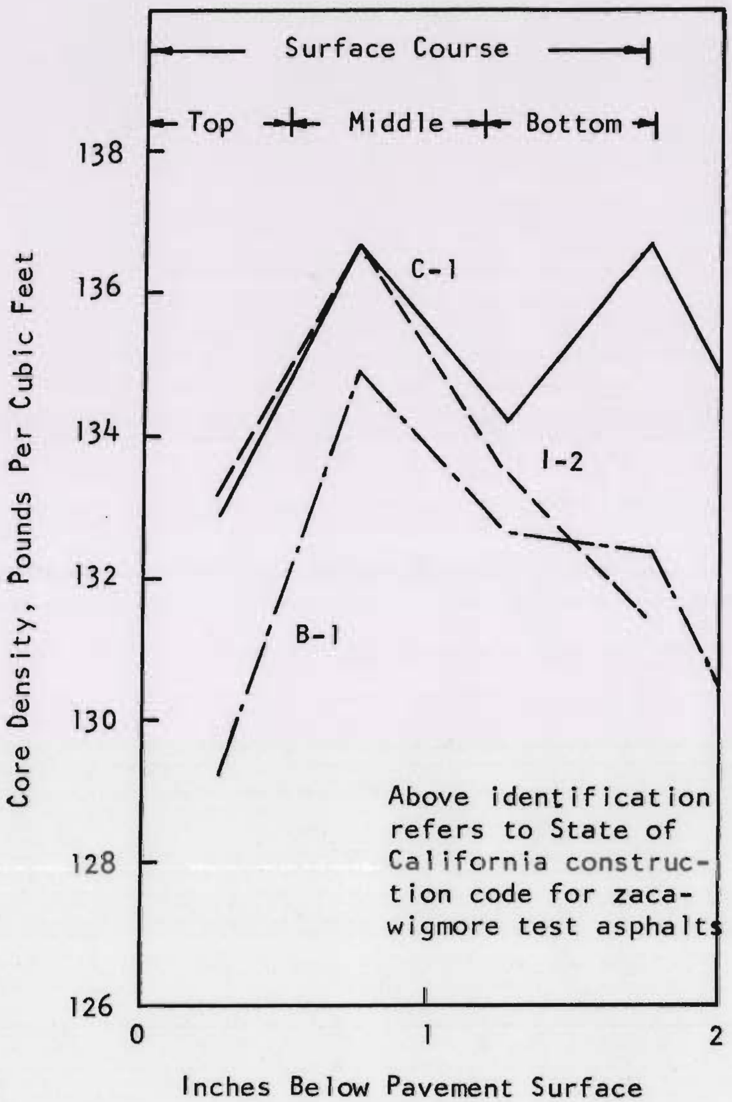


Figure 5. Pavement Density Varies With Depth

(From: Kari and Santucci, "Control of Asphalt Concrete Construction by the Air Permeability Test." California Research Corp., Fig. 6) the pavement is in the top layer of the pavement, there might also be a close relation between the field results and the laboratory results. This correlation would be expected to vary with age of pavement and type of mix, and whether the mix is either initially very dense or very open.

A tack coat is normally required before the bituminous mat is placed to secure a good bond between the surfacing and the base course. This tack coat, if heavy enough, can form an almost impermeable film that will completely prevent air from entering the surfacing from the underlying base course. In-place field tests in this instance will be significantly affected by this resistance to vertical flow between the surface and the base. Since an asphalt surfacing is usually in good contact with the base course and the permeability values obtained from in-place tests might represent a combined effect of both base course and surfacing.

Disregarding changing densities and void content through the depth of the surfacing, the volume of air flowing through at a given head can be said to be inversely proportional to the thickness of the bituminous mat. It, therefore, may be of importance to obtain accurate measurements of the mat thickness at the test site to determine the permeability.

The intrinsic permeability may not be, however, the value to use as a warrant for asphalt pavement sealing. The value of the overall resistance to air flow, no matter what the cause may be, might give a better indication of the overall condition of the pavement. What is important is whether or not water can seep through the surfacing or if the asphalt has reached such a degree of aging that the mixture has lost its original characteristics. A low value for permeability strongly suggests that water will not seep through the pavement. Whether the flow is lateral or vertical in the mix or whether the resistance to the flow is caused by a thick surfacing or a dense mix may be of no concern.

For mixes that allow a high degree of lateral flow, most of the air might flow in from the surrounding layers and very little from the base. In this case, the type of base would not affect the values significantly. On the other hand, with mixes that are homogenous and isotropic the flow path of least resistance would be straight through the surfacing and in this case the permeability of the base course could influence the value.

Variables Due to Environment

When the pavement is new, the surfacing is relatively pervious and will give high permeability values. However, the kneading action of traffic tires on new pavements, mainly during hot summer temperatures, results in a change in density distribution, especially increasing the density of the upper surface so as to make it less permeable. Parr and Serafin (13), Pauls and Halstead (14), and Zube (20) found that this compaction took place the first year to year and one-half of service.

Parr and Serafin noted that bituminous surfacings, each having initially different void content, all appeared to approach the same value for their ultimate void content as the traffic continued its compaction effect. This might strengthen the chances of finding limiting values for permeability as warrants for sealing, because it may be an indication that the final void content for a constant compactive effort will be mainly dependent upon gradation of the aggregate, and asphalt content in the mix.

The tightening effect mentioned above also takes place on old roads and is generally called "healing." During the winter, small cracks develop when cold and brittle pavement deflects under load or during frost heaving. As the temperature during the summer increases, often up to 140°F, the viscosity decreases and the traffic will knead the surface such that some of the bond between the aggregate particles may be recovered.

Sometimes the cracks or fissures through the bituminous surfacings are filled with water. The action of traffic creates a pumping effect in the pavement so as to bring colloidal fines from the base material into the pavement mixture. Accumulation of these fines in the channels and cracks will reduce the cohesion in the mix and therefore prevent any possibility of healing through traffic action. These cracks will also allow further penetration of water and air into the deeper parts of the pavement surfacing and accelerate the deterioration in the mat.

The binder in an asphalt surface is the bitumen, usually amounting to 5 to 6 per cent by weight; enough is added to coat the aggregate and to give adequate bond between the aggregate particles. The asphalt is chosen at a grade that has values of viscosity and ductility that are compatible with the strength requirements. The ideal case would be where the bitumen keeps its design properties throughout the life of the road, but it has been shown by many investigators that this does not happen. In the presence of air, the bitumen will slowly loose its properties by oxidation, evaporation, and bacterial attack.

The major and most significant effect on the bitumen is that of oxidation. When exposed to the atmosphere, the bitumen slowly oxidizes and asphaltenes and carbenes are formed and cause the surface to harden. This has been described by Pfeiffer (15) in his book, The Properties of Asphalt Bitumen, where he reported that sunlight and higher temperatures tend to accelerate the process. When the hardening process has progressed far enough, the ductility of the bitumen no longer allows the deflections under traffic loads without losing the bonds between the particles. The road, therefore, also loses its ability to recuperate through the traffic action in the summer and the resulting breakdown of the road takes place at an accelerated pace. Figure 6 gives a classification of these failures.

The oxidation process is slow, even in the worst cases. According to observations by Heithaus and Johnson (4), 65 per cent of the ultimate hardening process takes place within the first three to four years of service of the road. The hardening process is very sensitive to void content as shown in Figures 7 and 8. Within ten years, the pavement with 2 per cent voids experienced a drop in penetration of 15 points and the pavement with 14 per cent voids experienced a drop in penetration of approximately 42 points. Over the first three to four years, the difference was even more pronounced. Figure 7 also shows that the first 65 per cent of the hardening takes place within the first three years.

Discussion of the effect of voids requires some clarification. The isolated voids in the mat do not have any ventilation and, therefore, take no part in the hardening process. What Krchma (7) calls the "Pore Surface Area," is the interconnected pores that are subject to ventilation and actually expose the bitumen to the atmosphere. As permeability of the asphalt indicates the ease of entry and exit of a fluid, the pore surface area determines "how much" bitumen is exposed. Krchma points out that the permeability of asphalt of different gradations compacted to the same void content can differ a hundredfold. Likewise, it is probable that the pore surface area for such systems differ very much from the same void content. Therefore, void content does not consistently indicate what might influence the binder hardening rate.

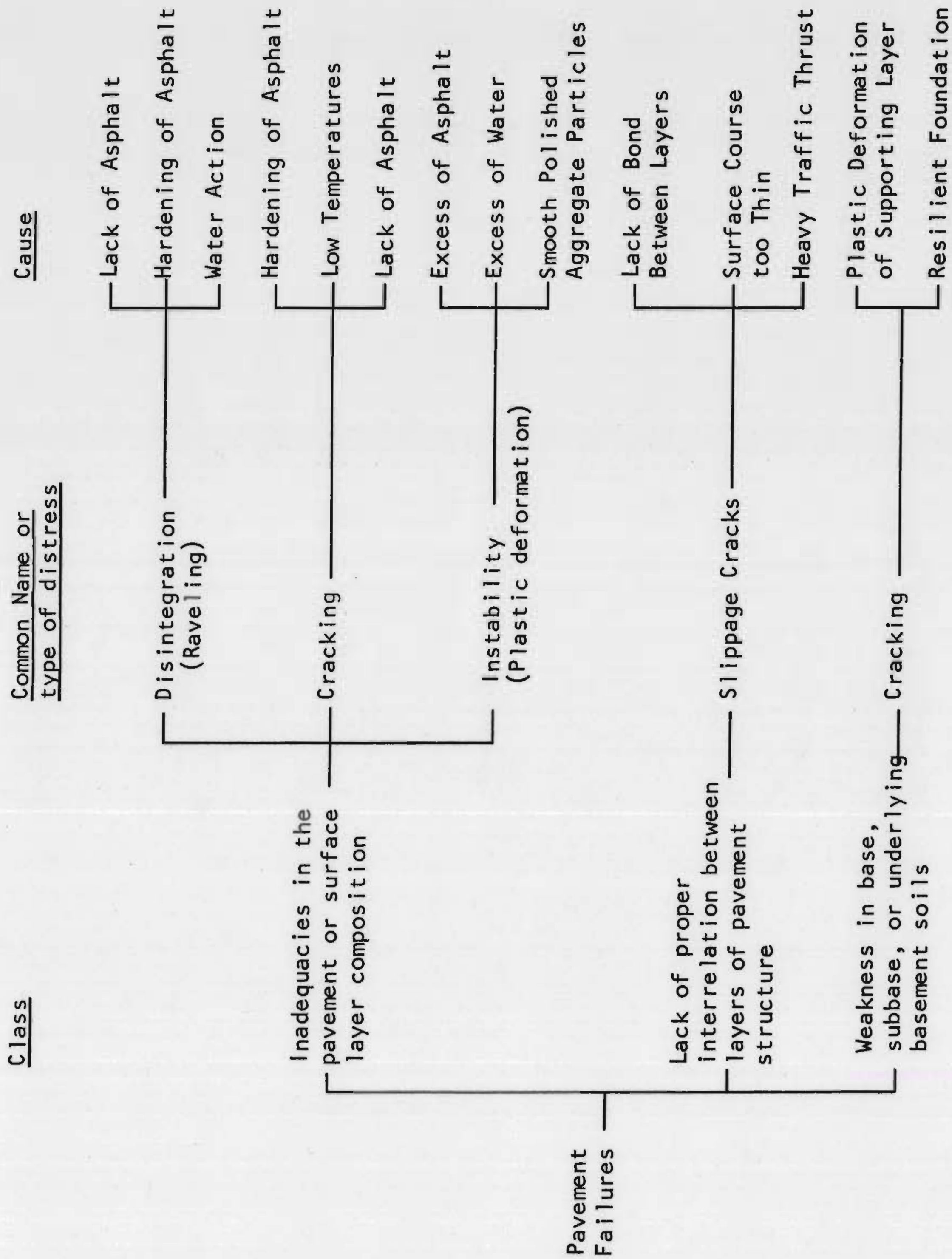


Figure 6. Classification Failures of Bituminous Road Surfaces

(From: F. N. Hveem, "Types and Causes of Failure in Highways Pavements," Highway Research Board, Bulletin 187, 1958)

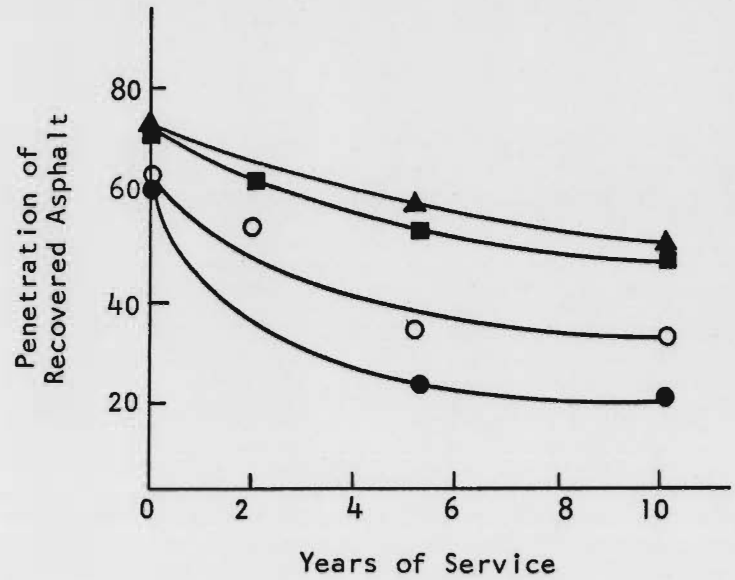


Figure 7. Asphalt Hardening

(From: Heithaus and Johnson, "A Microviscometer Study of Road Asphalt Hardening in the Field and Laboratory." Proceedings of The Association of Asphalt Paving Technologists, Vol. 27, 1958)

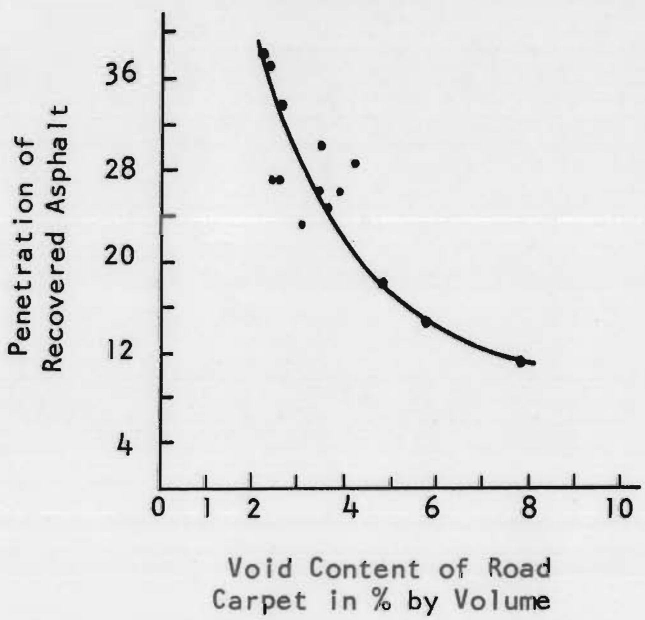


Figure 8. Penetrations of a Mexican Bitumen, Extracted from Road Carpets 15 Years Old, in Relation to the Voids Content of the Carpets

(From: Pfeiffer, The Properties of Asphaltic Bitumen. Elsevier Publishing Company, Inc., New York, 1950, p. 266)

There is, however, reason to believe that some proportionality exists between void content and pore surface area. As seen from Figures 7 and 8, the hardening rate is given by the change in penetration value. This might be somewhat erroneous since penetration represents both the viscosity and the elasticity of the bitumen and does not give a measure of the ductility that is recognized by many asphalt technologists to be the most significant single property of the bitumen. However, both Pfeiffer (15) and Heithaus and Johnson (4) show that there exists a proportionality between an increase in viscosity and a decrease in ductility.

The difference in temperature in the pavement on a hot, sunny day as compared to a cold, windy day would be expected to result in large thermal volume variations. This might induce large variations on the void content of the mat and produce varying permeability values.

The only passage of air through the mix is through the interconnected voids. If, during a rainy season, these voids get partly filled with water, some of the water will remain there for a long time. The interstices are often so small that capillary forces of great magnitude develop which resist mechanical removal of the water. The permeabilities observed with a wet or moist asphalt mix, therefore, would be significantly lower than the values obtained from a dry pavement.

There does not seem to have been much investigation done on the possible effects of bacterial attacks in bituminous pavements, but investigation and literature studies by Burgess (1) in 1955 brought forth that:

1. Bacteria found in garden soils do attack asphalts.

2. Heavy viscous oil fractions are more resistant to bacterial breakdown than the light or medium weight fractions.

3. Bacteria do not exhibit a specific ability to attack one type of oil, but rather a capacity to adapt themselves according to conditions, i.e., to attack the particular oil that is present.

4. Bacterial breakdown is an oxidation change.

5. Everything else being equal, the rate of asphalt oxidation by micro-organisms appears to be in direct proportion to the asphalt viscosity or penetration.

The effect of bacterial attack, however, has been found to be a slow process. It takes a long time and especially favorable conditions must exist for the bacteria to become adapted. For a modern highway, it will take years before the pavement becomes contaminated. This is due to its wide shoulders and often its elevation above the surrounding land. The magnitude of the bacterial breakdown, therefore, in this research, was judged to be negligible.

CHAPTER III

PREMISES FOR DEVELOPMENT OF APPARATUS AND PROCEDURE

The development of the apparatus and the testing procedures was based on findings of previous researchers and on assumptions which it was thought would produce the desired results. A discussion of these premises follows to afford the reader an understanding of the reasoning which lead to the equipment and methods adopted.

Field Testing

The in-place values for permeability were to be obtained by placing a suction cup covering a defined area on the pavement and applying a partial vacuum to this area. The time required for a measured pressure was considered to yield a permeability value that could be used for comparison of the conditions of different road surfacings.

Two suction cups were to be built, one that covered $79.5cm^2$, and one that covered $985cm^2$. The larger cup was used to find out how the cup size would affect the preciseness of the measurements. It was thought that because of its larger area, this larger cup would give a better average for the pavement permeability and would be less sensitive to local variations. On the other hand- the larger size made it difficult to seal against leakage around the edges and in preliminary testing proved to require unduly large volumes of air for operating. The smaller cup, therefore, was considered preferable for practical reasons.

The suction cup was designed to be sealed to the pavement by ordinary heavy automotive grease that was to be applied to the pavement and worked in with a short-haired brush.

The method that was to be used to measure the volume of air passing through the bituminous mix and to create the necessary pressure during the test utilized two water-filled plexiglas cylinders. The water head between the cylinder and a container at a lower elevation was to be used for pressure and the displacement of the water by the air flowing through the asphalt mix was to give a measurement of the volume. A small cylinder was to be used for low flow rates and a large cylinder was to be used for high flow rates. The cylinders were to be graduated for volume directly and time was to be recorded as the water level passed chosen volumetric marks. The error due to inaccuracies in determining the exact water surface was to be reduced by chosing as large volumes as practically possible. The pressure was to be read on a U-shaped water-filled manometer. The device was to utilize a falling water head, but it was to be designed so that the pressure could be held constant by regulating valves.

It was originally decided that each test site should be tested a sufficient number of times so as to obtain reliable average. However, the variations were expected to be large and the number of tests that would be required to obtain a statistically reliable average would require more time than was available.

After consultation with L. F. Erickson, Research Engineer of the Idaho Department of Highways, it was decided to limit the number of tests at each site. In order to maintain the best possible consistency of results, the tests were to be taken along a line parallel to the center-line. Research by Zube (20) had shown that the most consistent results could be obtained in that way.

To avoid accidents caused by the grease used for sealing, the areas were always to be covered by sand after the tests were completed. The traffic would then wear off the grease or distribute it along the pavement in the direction of the travel. Since this grease would change the characteristics of the asphalt, it was made clear that any repetitive testing had to be made behind previous test spots.

The tests were to be performed with pressures ranging from 0 to 30 g/cm^2. Previous researchers have stressed the importance of maintaining laminar flow and have set as a tentative limit a Reynolds number of about one. There is, however, no way to determine the shape or size of the connected pores in an asphalt pavement mix and, therefore, it is not possible to calculate what pressures would guarantee laminar flow. Klinkenberg (6) shows how one can use the permeability values obtained for different pressures to determine the true value comparable to values obtained with liquids. The asphalt pavement or core sample, however, cannot be subjected to large pressure drops. The high flow rates that would occur might change the size and shape of the interstices and, therefore, give misleading results. For very low pressures at the suction side, it would also probably cause the air entrapped in the aggregate and the sealed-off voids to expand and force the bitumen into flow channels, where the pressure was lower.

The limits mentioned above were arbitrarily set, and the tests were to be run with a wide variation of pressures so the results could be plotted and a suitable value for standard pressure chosen.

Labbratory Tests

Laboratory tests were to be used to check some of the field tests and to attempt to determine the influence of variations in temperature, pressure, and area exposed to suction. The testing apparatus was designed to create flow patterns similar to what would be expected in the field. It was anticipated that comparison between results obtained in the field and in the laboratory would permit drawing some conclusions regarding how the air flows through the pavement.

The samples were first to be tested at room temperatures at pressures from 0 and 30 g/cm^2 and areas of 20.2cm^2 and 45.5cm^2, respectively. This was proposed to give an indication of the similarity of flow through the sample and flow through in-place pavement. If the major resistance to the flow is given by the upper layer of the pavement, an equal value of permeability for both laboratory and field tests of a particular pavement would indicate that the main volume of air was actually flowing vertically through the pavement, and not laterally.

Due to the lack of time, the temperature effect was to be studied on laboratory samples only. It was not expected to give results that could be used in the discussion of field tests, because the restriction to lateral expansion does not exist for the laboratory sample as it does in the pavement, but the results were expected to give an indication as to the sensitivity of the permeability to temperature changes.

CHAPTER IV

APPARATUS, PROCEDURE AND CALCULATIONS

All field and laboratory data for this research project were collected and reduced by use of equipment and procedures developed as part of this study. In many instances devices used by previous researchers or permeability of other-than-asphaltic materials were used as guides or similar principles were adopted. An asphalt surfacing permeameter manufactured by Soiltest Incorporated of Chicago, Illinois was purchased during the later stages of the study and some testing was done with this additional piece of equipment.

I. FIELD TESTING

Field testing consisted of establishing the pressure-flow relationship of an existing asphalt surfacing by use of an air permeameter which subjected the asphalt surface to a partial vacuum. The total apparatus is hereafter referred to as the Idaho Pavement Permeameter.

Apparatus

Components of the Idaho Pavement Permeameter are described below:

a. Volumeter. Two plexiglas cylinders, as illustrated in Figure 9, were used. The 8000 cc cylinder was 6 inches in inside diameter and 18 inches high. The 1200 cylinder was 2 inches in diameter and 25 inches high. These cylinders were used for the purpose of measuring air flow volumes and served as a water reservoir for creation of vacuum pressures during the test. Both cylinders, graduated for reading volumes directly in cubic centimeters, were closed at the ends with 1/2-inch plexiglas. Hose connections were fitted into each end and connected to a 1/4-inch brass plug

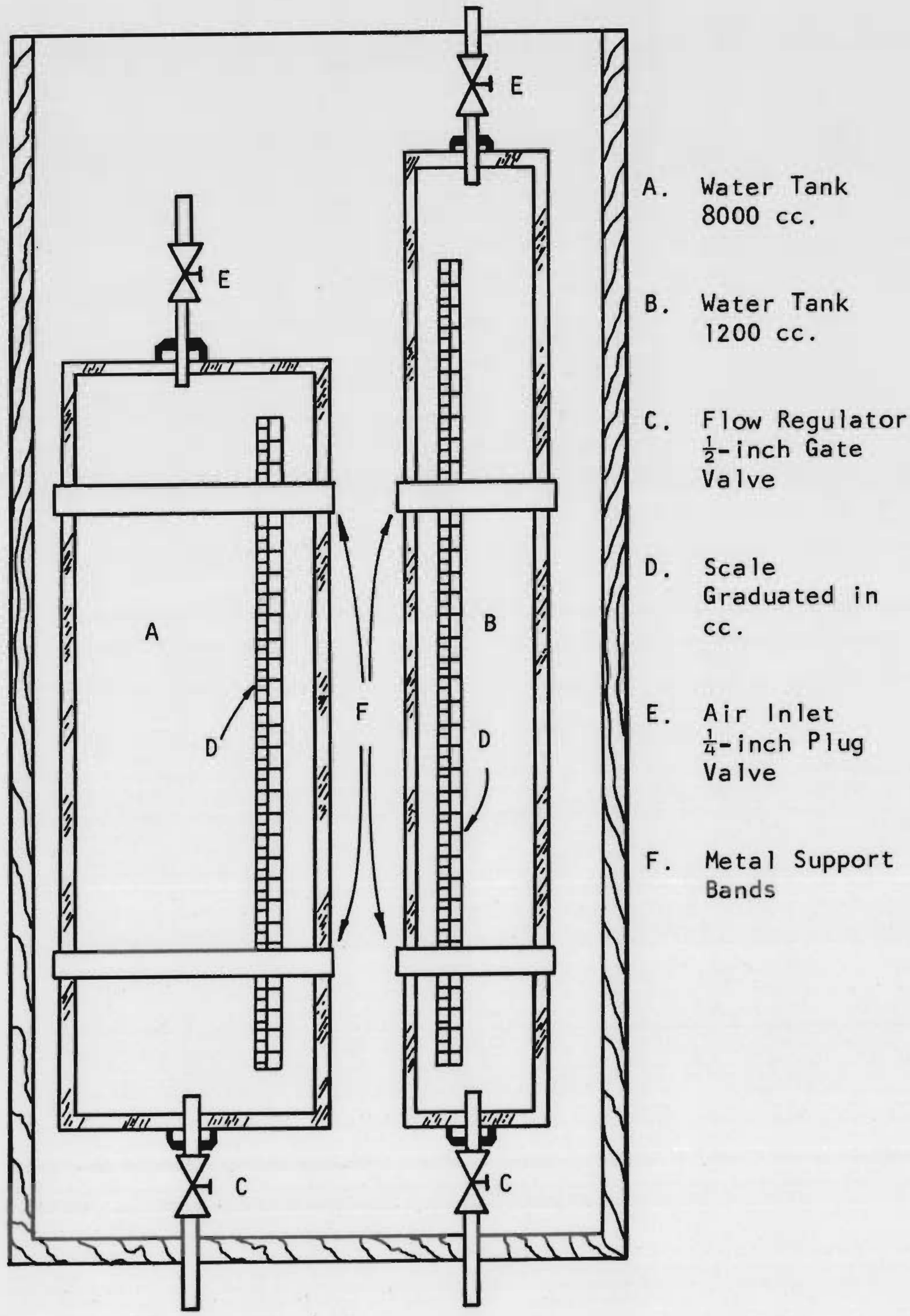


Figure 9. Volumeter Used for Both Field and Lab Tests

valve on top and a 1/2-inch gate valve at the bottom. The two cylinders were fastened to a wooden box 30 inches by 18 inches with 10-inch deep walls on all four sides. Holes, 2 inches in diameter, were drilled in the top and bottom of the box to provide room for the hoses to pass through. The cylinders were fastened to the back of the box with two metal bands 3/4-inch wide.

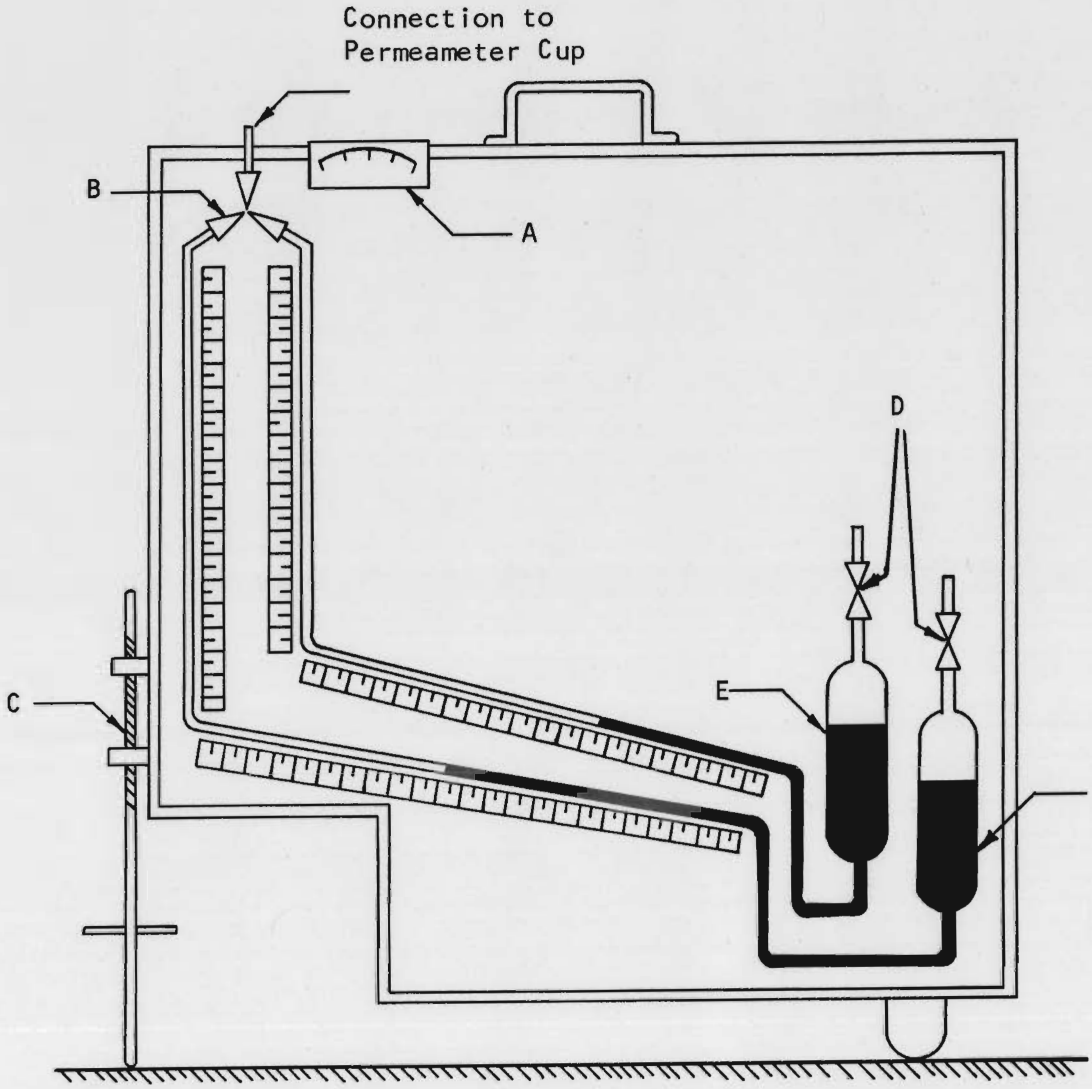
b. Portable Manometer. The manometer shown in Figure 10, was composed of two units, one that used gage oil with specific gravity 0.826 and one that used mercury. Both started out as sloping manometers to afford greater precision for low pressures and ended with vertical tubes where the higher pressures were indicated. The gage oil metered from 0 to 5 g/cm^2 on the slope and from 5 to 30 g/cm^2 on the vertical scale whereas the mercury manometer measured pressures from 0 to 60 g/cm^2 and 60 - 400 g/cm^2 on the sloped and vertical scales, respectively. The system was mounted on a wooden plate 18 inches by 18 inches covered with a half-inch foam rubber padding. The manometer board was supported on one end by a rounded foot 12 inches long positioned crosswise to the board. The other end had a pointed foot made from a 1/4-inch diameter by 6-inch long steel rod that was threaded and fastened through two nuts attached to the other end of the manometer plate. With the aid of a 1-inch level tube this system permitted obtaining a suitable slope for the sloping manometers. Both the gage oil manometer and the mercury manometer were furnished with calibrated scales that gave pressures directly in g/cm^2. The scales were adjustable to regulate the zero point. The portable manometer had a handle for easy carrying.

c. Water Container. A container that could be closed with a cork was used to provide a water reservoir.

d. Thermometer. Temperatures were measured with a 3/8-inch diameter mercury type thermometer having a range of -10 to 60 degrees centigrade.

e. Stop Watch. Time was measured by a Cletimer stopwatch calibrated to tenths of a second and a 60 minute range.

f. Vacuum Hoses. Vacuum pressures were conducted through 1/4-inch inside diameter thick-walled rubber hoses capable of withstanding one atmosphere of vacuum without collapsing.



A. Bubble Level
B. Three-way Stop-cock
C. Adjustable Foot for Leveling
D. Stop-cocks
E. Mercury
F. Gage Oil

Figure 10. Portable Manometer

g. Clamps. Hose clamps were used to insure a tight fit at all hose connections.

h. Grease. Ordinary automotive grease was used to obtain a tight seal between the suction cup and the pavement.

i. Brush. A short-haired brush was used to apply the grease to the pavement.

j. Suction Cups. Two domes, similar in design to the one shown in Figure 11, were made from 3/16-inch steel and provided with 1/2-inch wide rubber edges. The respective cup areas were $79.5cm^2$ and $985cm^2$. Both cups had an 18-inch long by 2-inch diameter tube stander welded on top. Another tube sliding on the inside of the 2-inch tube provided means for adjustment of the length of the stander.

k. Jack. A bumper jack was used to lift the bumper of the test car and to release that weight onto the stander.

l. Drill. A drill or spike was used to make a 1/2-inch hole 4 inches deep in the pavement for the thermometer.

m. Marking Paint. White enamel spray paint from a pressurized can was used to mark each test site for future reference.

n. Tape. A measuring tape was used to locate the test spot relative to center line and to core tests taken previously.

o. Turpentine. Turpentine was used to clean grease from the equipment.

p. Traffic Information Devices. Standard 18-inch yellow rubber cones and 24-inch warning signs mounted on low tripods were placed on both approaches to the test area to forewarn traffic of the testing operation. A 30-inch by 60-inch sign was attached to the rear of the test car to inform motorists of the nature of the investigation and the sponsoring agencies.

q. Shields. Round plates of corrugated cardboard and equipped with handles were made of the same diameter as the two suction cups. These shields were used to define the areas to be tested by placing them on the pavement and applying grease around them.

A. Suction Cup
B. 3-Inch Pipe
C. Rubber Seal
D. Tightening Bolt
E. 2 1/2-Inch Pipe
F. Regulating Bolt

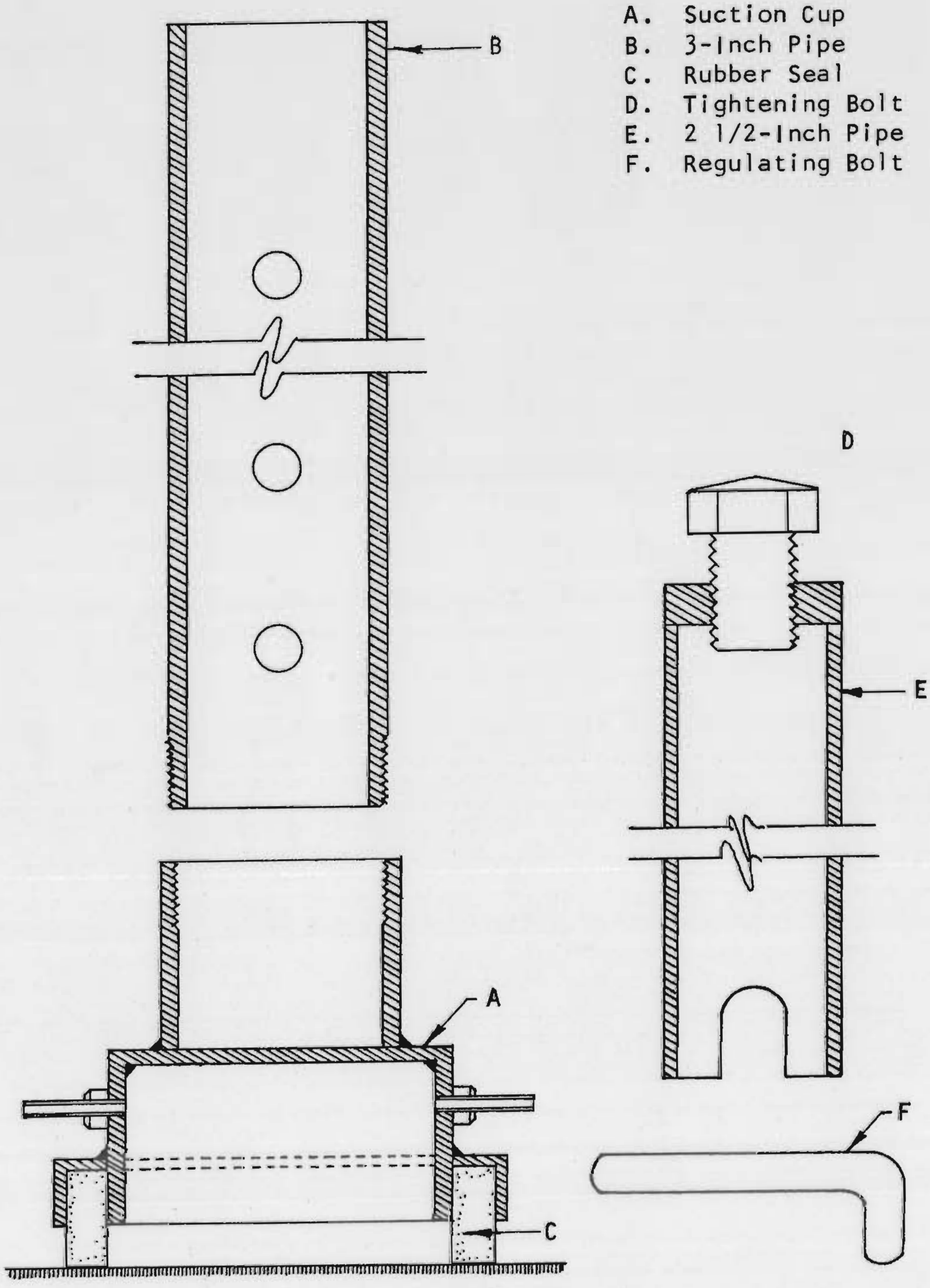


Figure 11. Field Test Suction Cup

Procedure

The detailed procedures followed in conducting field tests are described below:

a. A location was selected in the road being tested, usually in the right wheel path and, in the case of multilane highways, in the right lane. Tangent sections with no more than moderate grade were preferred.

b. The highway number, milepost and direction of travel were recorded. If special landmarks were observed nearby, these were also noted.

c. The shield was placed on the selected location and grease was applied around the shield for a distance of about 6 to 7 inches.

d. The bumper of the car was placed over the open spot in the grease and jacked up.

e. The suction cup was placed directly over the open spot in the grease and the stander on top of the suction cup was regulated to receive weight from the bumper of the car.

f. The jack was let down until the bumper rested on the stander and cup assembly.

g. Grease was applied with a short-haired brush around the edges of the suction cup to insure that no leakage would occur.

h. A 1/2-inch diameter, 4 inches deep, hole was drilled in the pavement and the thermometer was inserted. The spot was shaded as the thermometer sought the surfacing temperature.

i. The volumeter was placed on the car as shown in Figure 12.

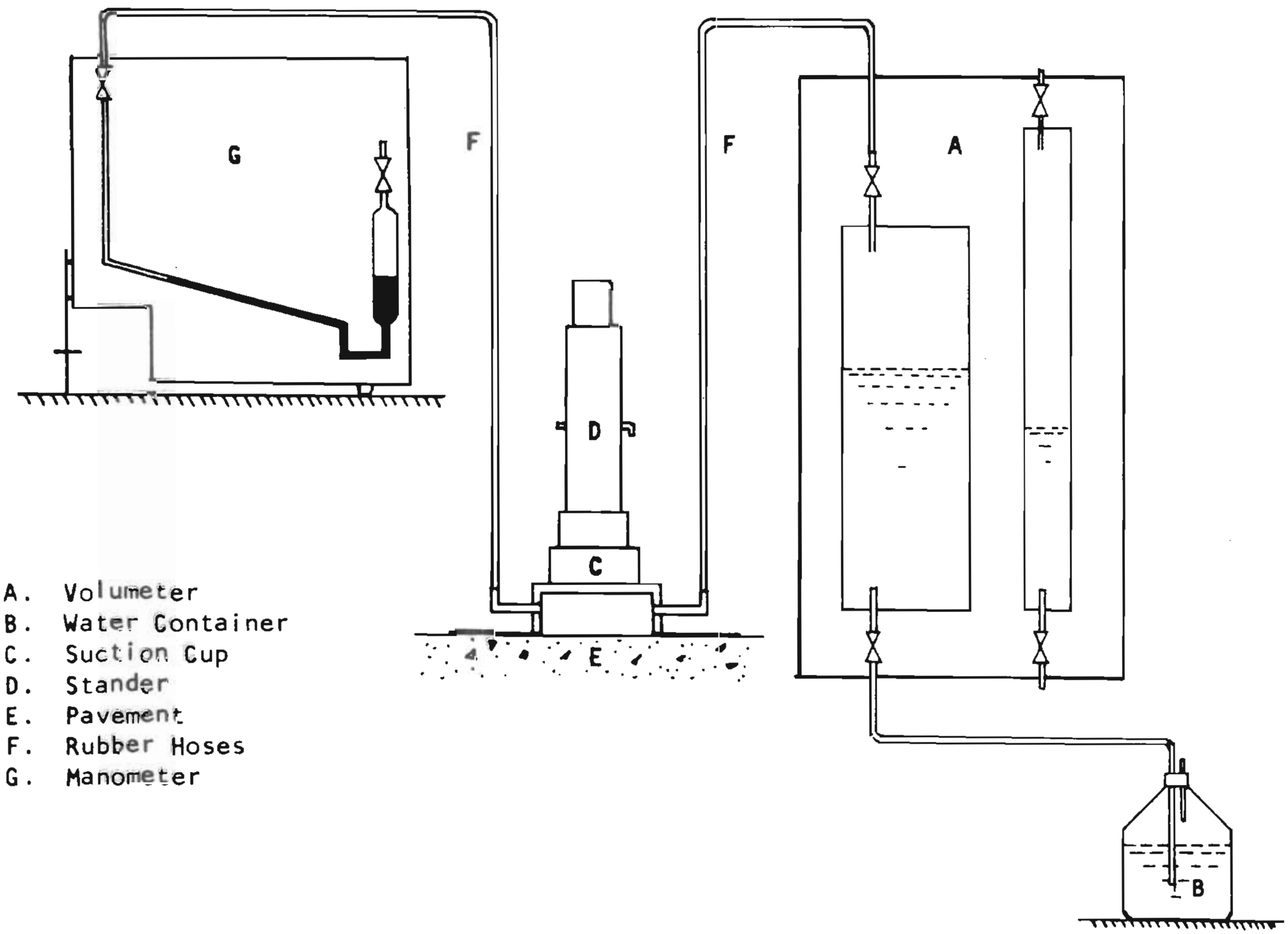
j. The hoses were connected as shown in Figure 12 with:

1. One hose from the bottom of the cylinder into the water container.

2. One hose from the top of the cylinder to the suction cup.

3. One hose from the suction cup to the portable manometer.

k. The manometer selected was the one that covered the range of pressures with the highest degree of precision.



A. Volumeter
B. Water Container
C. Suction Cup
D. Stander
E. Pavement
F. Rubber Hoses
G. Manometer

Figure 12. Field Air Permeameter

l. The manometer was leveled and the scales zeroed.

m. With all valves open the system was flushed in order to remove all air bubbles from the hose connecting the cylinder with the water container.

n. The cylinder was filled with water by lifting the water container above the cylinder and all valves closed. No water was allowed to enter the air hoses.

o. The valve on top of the cylinder was opened.

p. The bottom valve on the cylinder was slowly opened until the manometer showed approximately the chosen pressure, P_2.

q. As the water level lowered in the cylinder, the stopwatch was started as the water surface passed a preselected gradation mark.

r. According to flow rate, a volume, Vm, was chosen that could be accurately timed for the given situation.

s. As the water level passed the halfway mark for the chosen volume, the pressure, P_2, was recorded.

t. As the water passed the mark for the full volume, the stopwatch was stopped.

u. The time, T, and measured volume, Vm, were recorded.

v. The temperature of the air and in the pavement was recorded.

w. The tank was refilled. (The escape valve was open to prevent back flush of the manometer.)

x. The procedure, m through v, was repeated with different pressures.

y. After one set of reading at various pressures, a new test spot was chosen on a line parallel with the direction of the road and the tests were repeated.

z. Repeated tests were made until sufficient data were collected to provide consistent results or a reliable average. After the test the grease spots were cleaned and covered with sand so as to prevent slipperiness.

Calculations

The calculations below describe the method used for reducing the field data and determining the permeability value for each test.

The intrinsic permeability of the location tested may be computed by use of the equation:

$$\frac{k}{L} = \frac{Q\mu}{P_2 A T}$$

where k = intrinsic permeability in cm.

μ = viscosity of the air at the temperature measured in the pavement in micropoises.

A = area inside of the suction cup in cm^2.

T = time in seconds.

P_2 = pressure in cylinder during test in g/cm^2 as measured with the manometer.

L = thickness of the asphalt surfacing in cm.

Q = volume of air in cc drawn through the asphalt surfacing corrected to one atmosphere of pressure.

Correction of the volume of air drawn through the asphalt surfacing was calculated by the formula:

$$Q = \frac{Vm(P_1 - P_2)}{1033}$$

where Q = volume of air in cc drawn through the asphalt surfacing in cc, corrected to one atmosphere of pressure.

Vm = volume of water displaced in the plexiglas cylinder, in cc, which was a measure of the uncorrected volume of air drawn through the pavement surface.

P_1 = atmospheric pressure at the test site during the time of the test.

P_2 = pressure in cylinder during test in g/cm^2 as measured with manometer.

1033 = one atmosphere of pressure in g/cm^2.

II. LABORATORY TESTING

Permeability tests were conducted in the laboratory on 4-inch diameter, diamond-drilled cores taken from asphalt surfacings of highways throughout the state of Idaho. All of the field permeability apparatus, except the cups and stander, were used in the laboratory tests as well as considerable other apparatus which is hereafter described. Laboratory testing procedures and calculations used for determining the intrinsic permeability of the cores are also explained in detail. For routine tests, pressures up to 300 g/cm^2 were used and this test will henceforth be referred to as Method A. Method B was developed for more specialized testing and is distinguished by use of pressures as high as 800 g/cm^2.

Method A

In the following laboratory test, equipment was used which has been previously described under Field Testing. Included in this category are the volumeter, portable manometer, water container, thermometer, stopwatch, vacuum hoses and clamps.

Apparatus. A photograph of the disassembled laboratory permeameter is shown in Figure 13. Its component parts illustrated in Figures 14 and 15 on pages 39 and 40 are described further below.

a. Sample Holder. The sample holder was a 10-inch long plexiglas cylinder, having a diameter of 6 inches and wall thickness of 1/4 inch. A 1/2-inch top plate was machined and glued to close one end of the cylinder. The plate had two 1/4-inch copper tubings attached. Two inches from the closed end, a 1/2-inch thick plexiglas retainer collar was fitted into the cylinder. The inside diameter of the retainer collar was 3 inches. The ring was glued firmly and air-tight to the cylinder walls. The cylinder was threaded approximately 6 inches from the open end.

b. Area Rings. Two plexiglas rings 1/4-inch thick were machined to slide closely inside the cylinder with inside diameters of 2 inches and 3 inches, respectively.

c. Seal. A rubber ring 1/4-inch thick and same dimension as the collar inside the sample tester was used to seal between the area ring and the retainer collar.

d. Tightening Ring. A 1/2-inch metal ring was threaded to fit the threads in the sample holder. The inside diameter of the ring was 4 inches. Two 1/4-inch holes were drilled on a diameter for receiving a tightening key.

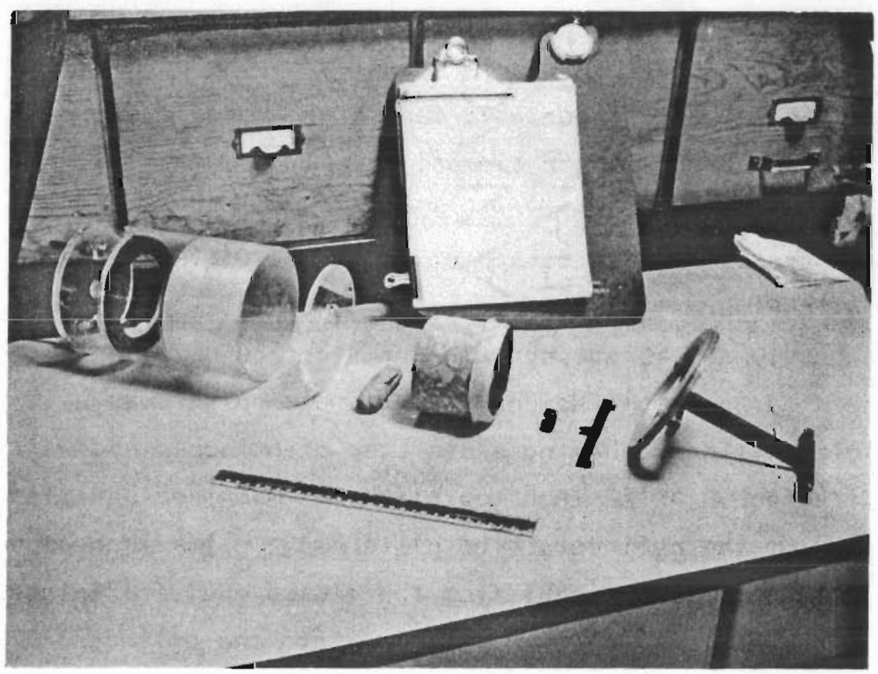


Figure 13. Dissassembled Asphalt Surfacing Core Sample Holder for Laboratory Permeability Measurements

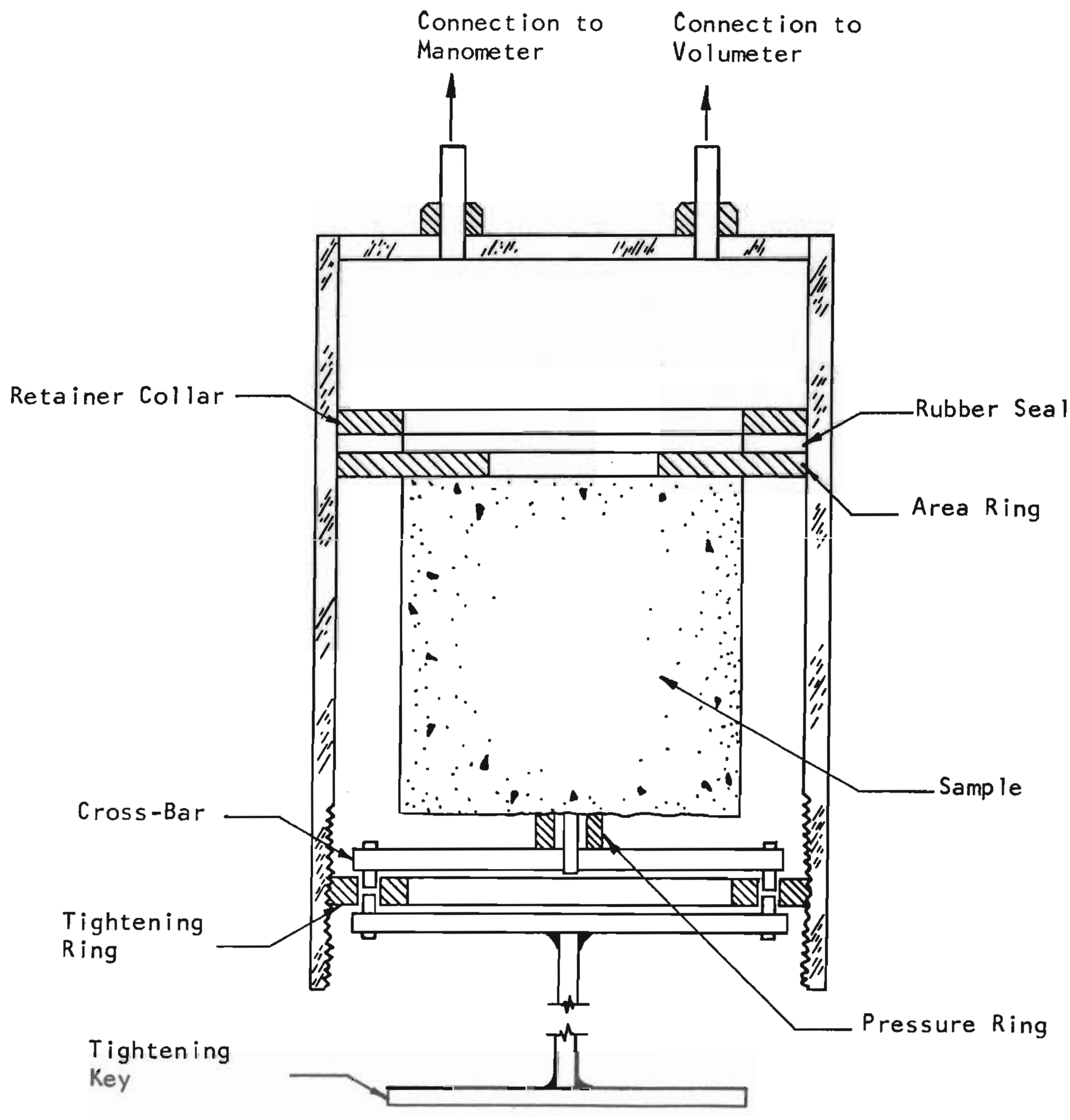
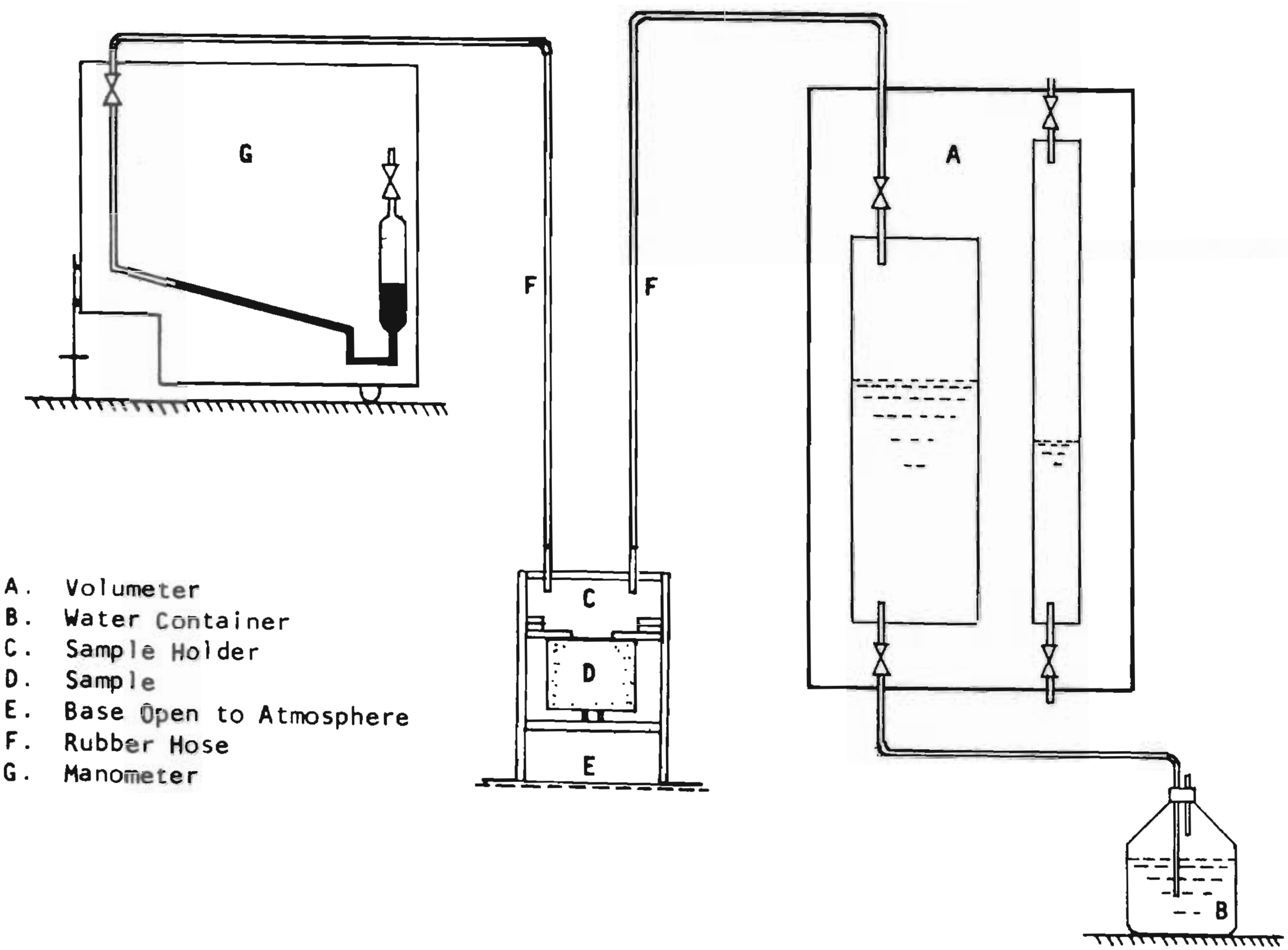


Figure 14. Sample Holder



A. Volumeter
B. Water Container
C. Sample Holder
D. Sample
E. Base Open to Atmosphere
F. Rubber Hose
G. Manometer

Figure 15. Laboratory Air Permeameter as Used with Low Pressure Drops

e. Cross Bar. A 3/8-inch x 3/8-inch metal bar was provided with 3/16-inch long tap on the middle of the opposite side of the two taps to fit into the pressure ring.

f. Pressure Ring. A hexagonal nut with a 3/8-inch inside diameter was used to apply pressure to underside of the sample.

g. Tightening Key. An H-shaped key made from three 1/4-inch flat steel pieces all 3/4-inch wide and 5-1/4-inches long. One of the pieces had taps, approximately 1/2-inch long, to fit into the tightening ring.

h. Latex Triaxial Membranes. Latex membranes, such as are used in tiaxial compression testing of soils, were used to seal off the outer walls of the cores. Each membrane has a 10-inch length, 2.80-inch diameter, and a 0.012-inch wall thickness.

i. Sealing Compound. A kneadable erasure compound, "Artist's Vita" manufactured by A. W. Faber Castell, was used to seal the sample to the area ring. This compound did not stick to the asphalt core, thereby permitting repetitive testing of a core without changing the surface characteristics of the sample.

j. Straight Edge. Any type straight edge with scale in cm at least 20cm long was used to measure the specimen dimensions.

Procedure. A detailed outline of the laboratory procedure for test Method A follows:

a. The length of a core was measured and recorded in centimeters.

b. A 1-inch wide ring of sealing compound, approximately 1/8-inch thick, was formed with the inside diameter of the sealing compound being slightly larger than that of the area ring to be used.

c. The latex membrane was slipped over the core sample and the top end was left extending half of the distance from the sample edge to the inside of the area ring. The extra length of the membrane at the bottom was rolled up as close to the bottom edge of the core as possible.

d. The sealing compound ring was placed concentric on the area ring and squeezed until it stuck to the plexiglas; the irregularities in the sealing compound were then adjusted.

e. The ring with seal was pressed concentrically onto the face of the sample until the seal adhered uniformly to the sample.

f. The sample was held by the bottom end and pushed, ring first, down into the sample holder until the ring rested on the rubber seal ring.

g. The pressure ring was then placed on the center of the sample with the crossbar on top with the middle tap in the hole of the pressure ring.

h. The tightening ring was threaded into the sample holder with the key until contact was made with the crossbar taps. The key was then removed and the taps on the crossbar inserted into the tightening ring. The ring was turned until pressure was applied on the sample. The key was inserted again and turned until the compound squeezed out onto the inside of the area ring. Some time was allowed for plastic deformation to take place in the sealing compound and a final tightening was then made.

i. The sample holder was placed on an open grid that would allow air to enter the bottom of the sample holder. Hoses between the different parts of the permeameter were connected as shown in Figure 15 on page 40 as follows:

1. One hose connected the top of the cylinder to the top of the sample holder. The cylinder that gave the fastest volûmetric reading within wanted accuracy was chosen. The large cylinder was used for high permeability, and the small cylinder was used for low permeability.

2. One hose connected the manometer to the sample holder.

3. One hose connected the bottom of the cylinder to the water container. The end of the hose in the water container was kept submerged at all times.

j. The water was flushed through the system several times by placing the water container at a lower level than the cylinder while all valves were open. The water was brought back into the cylinder by placing the water container above the top of the cylinder. No air bubbles were allowed to remain in the hose between cylinder and the water container below the cylinder, the system was ready for testing.

The actual testing sequence was as follows:

a. Close valves.

b. Adjust manometer scales to zero.

c. Open valve on top of cylinder.

d. Slowly open bottom valve on cylinder while watching manometer.

e. After the desired pressure is reached, the stopwatch is started as the water level passed one of the graduation marks on the cylinder.

f. When half the predetermined water volume was reached, the pressure, P_2, was read on the manometer and recorded.

g. As the water level passed the total volume, V_m, gradation mark, the watch was stopped and the time and volume recorded.

h. The test was then repeated for different pressures.

A sample of the data record sheet used for laboratory test Method A may be found in Appendix D on page 217.

Calculations. Reduction of the laboratory data for determination of the permeability of the asphalt cores was done in a manner identical to that used for field data.

Method B

Test Method B was designed to permit correlation of permeability of the asphalt cores when tested at high vacuum pressures.

Apparatus. Test Method B used several pieces of apparatus previously described in Field Testing and Test Method A, including the volumeter, water container, brush, grease, thermometer, stopwatch, vacuum hoses, clamps, sample holder, area rings, rubber seal, tightening ring, cross bar, pressure ring, tightening key, latex membranes, and the sealing compound. Additional apparatus required were:

a. Mercury Manometer. A standing mercury manometer was required for reading large vacuum pressures up to 76.0cm of mercury.

b. Vacuum Pump. A high volume vacuum pump was used that was able to maintain at least 80 per cent of full vacuum under flows up to 2000 cc per minute.

c. Air Tight Base for Sample Holder. A 1/2-inch thick sheet of rubber was used to cover the bottom opening of the sample holder. Two 1/4-inch copper tubings were passed through the rubber, one for a manometer hose connection and the other, which was equipped with a valve, for regulation of the pressure and volume of the air flow into the base of the sample. The rubber was held evenly against the bottom of the sample holder by a 3/4-inch sheet of plywood which was clamped by use of 2-inch by 2-inch boards and 1/4-inch bolts as illustrated in Figure 16. The plywood sheet had a 4-inch diameter hole through which the tubings passed.

d. Flow Meter. A flow meter, manufactured by Gelman Instrument Co. of Chelsea, Michigan, which could regulate the flow rate under any pressure from five to twenty liters per minute, was used.

e. Grease. Ordinary automotive grease insured a tight seal between the sample holder and the rubber base.

<u>Procedure</u>. The procedure followed for Test Method B was:

a. A thin film of grease was applied on the rubber base.

b. The sample holder with the sample was placed on the rubber base and tightened down with the clamps.

c. The hose connections, illustrated in Figure 17, were made as follows:

1. One hose connected the top of sample holder to the vacuum pump.
2. One hose connected the top of the sample holder to the open mercury manometer.
3. One hose connected the base to the portable manometer.
4. One hose connected the base to the air flow meter and valve.
5. One hose connected the flow meter to top of graduated cylinder.
6. One hose connected the bottom of the cylinder to the tube submerged in the water container.

d. The cylinder was emptied of water.

e. All valves were closed.

A. Sample Holder
B. Rubber Base
C. Clamps
D. Footing
E. Tightening Bolts
F. Sample
G. Air Inlet
H. Air Outlet
I. Connections to Manometers

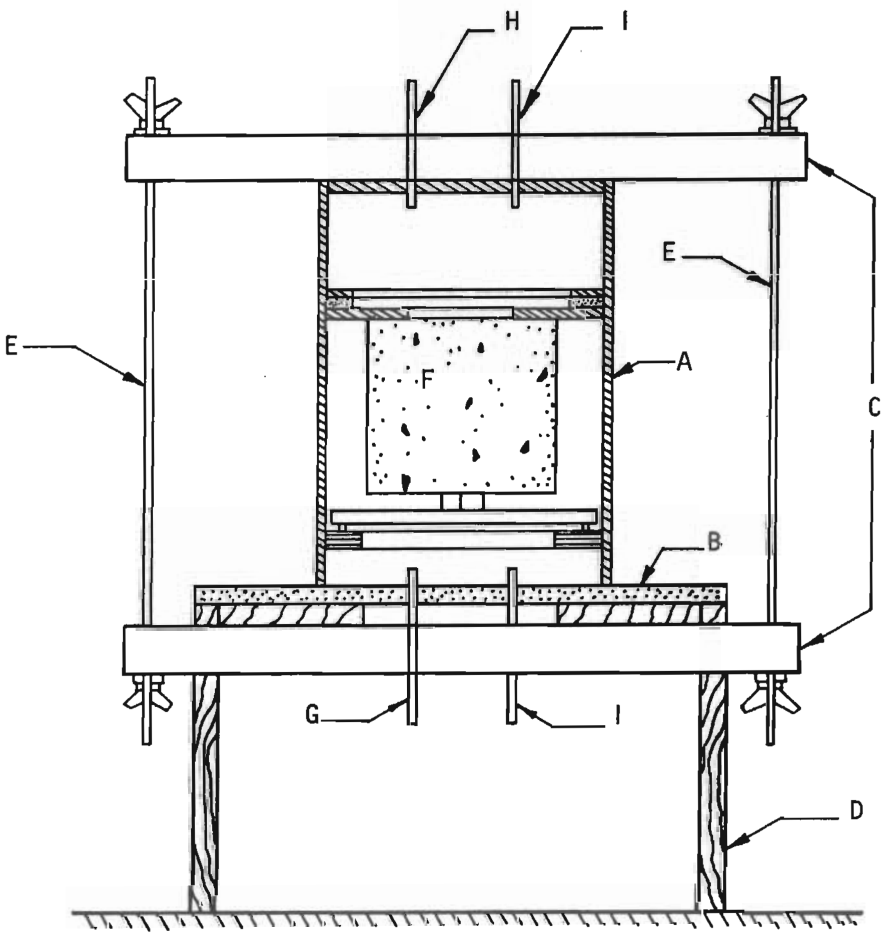


Figure 16. Sample Holder Used for Testing Asphalt Cores with High Pressure Drops

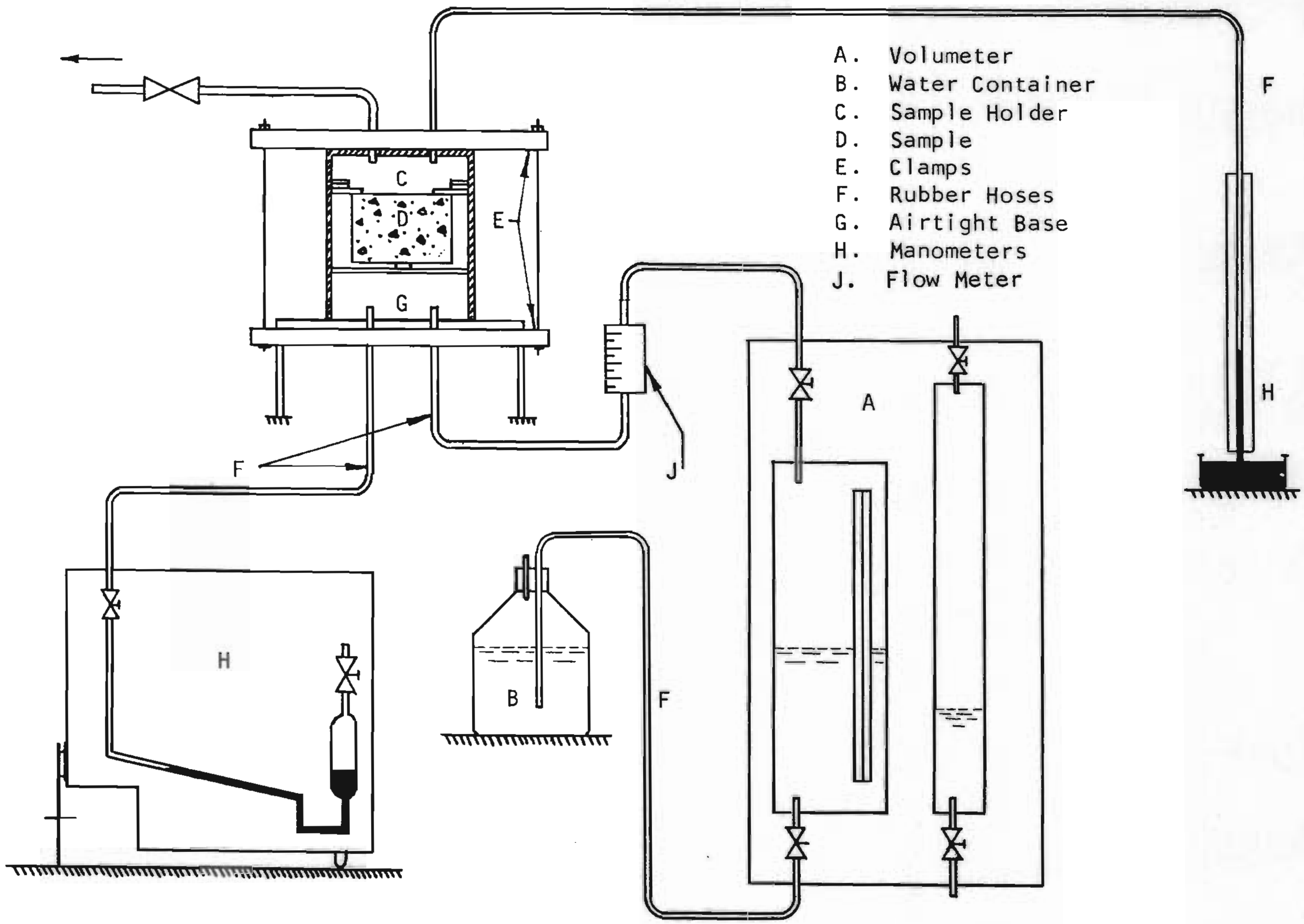


Figure 17. Air Permeameter Used in the Laboratory Tests with High Pressure Drops

f. The vacuum pump was started.

g. Both valves on the cylinder were opened.

h. The air flow valve was slowly opened until the standing mercury manometer showed the chosen pressure, P_1.

i. When water level in cylinder passed the preselected beginning mark, V_3, the stopwatch was started and the pressure at bottom of sample, P_3, was read from the portable manometer and recorded.

j. When the water level in the cylinder passed the one-half volume mark, the pressure at the bottom of the sample, P_2, was read and recorded.

k. When the water level in the cylinder passed the preselected ending volume mark, the watch was stopped and the pressure, P_4, at the bottom of the sample was read and recorded.

l. The vacuum pump was stopped.

m. The procedure was repeated for several pressure drops through the samples in the range of 2 g/cm^2 to 900 g/cm^2.

Calculations. All pressures were converted into grams per square centimeter as follows:

1 inch of mercury = 34.6 g/cm^2

1 cm of mercury = 13.6 g/cm^2

1 cm of water = 1 g/cm^2

The volume of air in the volumeter at the start of the test was corrected to volume at one atmosphere by the equation:

$$Vo_3 = \frac{V_3(P_1 - P_3)}{1033}$$

where Vo_3 = Volume of air in cc contained in the volumeter at the beginning of the test at pressure $(P_1 - P_3)$ corrected to volume at 1 atmosphere.

V_3 = Volume in cc in the volumeter not filled with water at the beginning of the test.

P_1 = Normal atmospheric pressure at the test site elevation in g/cm^2.

P_3 = Difference between the atmospheric pressure at test site and pressure in volumeter at beginning of test in g/cm^2.

1 atmosphere = Normal atmospheric pressure at sea level of 1033 g/cm^2

Expansion of air in the volumeter during the test due to the change in pressure from (P_1-P_3) to (P_1-P_4) was found by the equation:

$$V_1 = Vo_3 - Vo_4$$

where: V_1 = Expansion of original volume of air V_3 during the test due to change in pressure during the test expressed in cc.

Vo_4 = Volume of air in the volumeter corrected to volume at 1 atmosphere from the volume V_3 at pressure (P_1-P_4).

Vo_4 was found by the equation:

$$Vo_4 = \frac{V_3 \ (P_1-P_4)}{1033}$$

where: V_3 = Volume in volumeter not filled with water at the beginning of the test in cc.

P_1 = Normal atmospheric pressure.

P_4 = Normal atmospheric pressure at the test site and the pressure in the volumeter at the end of the test in g/cm^2.

The volume of air at 1 atmosphere of pressure that passed through the sample during the test was found by the equation:

$$Q = V_1 + V_c$$

where: V_1 = Expansion of air in the volumeter due to decrease in the pressure during the test in cc.

V_c = Volume of air in cc displaced by water during the test corrected to volume at 1 atmosphere.

V_c was found by the equation:

$$V_c = \frac{Vm \ (P_1-P_4)}{1033}$$

where: Vm = Volume of water in cc entering the volumeter during the test displacing air-filled space, measured directly on the graduated cylinder.

P_1 = Normal atmospheric pressure at the test site elevation in g/cm^2.

P_4 = Difference between the atmospheric pressure at the test site and the pressure in the volumeter at the end of the test in g/cm^2.

To calculate the intrinsic permeability k:

$$\frac{k}{L} = \frac{Q\mu}{(P_1 - P_2)AT}$$

where: k = intrinsic permeability in cm^2.

Q = Volume of air passing through the sample in cc.

μ = Viscosity of the air at its temperature as it goes through the sample in micropoises.

L = Thickness of sample in cm.

$(P_1 - P_2)$ = Pressure differential flowing through the sample in g/cm^2.

A = Area over which suction is applied in cm^2.

T = Time it takes for the air to pass through the sample in sec.

The value of k/L is then plotted on a graph, the ordinate being $k/L \times 10^9$ and the absicissa being $1/\Delta P$ where

$$1/\Delta P = \frac{1}{P_1 - P_2}$$

CHAPTER V

PAVEMENT TESTING

The primary objectives of this investigation were to develop an asphalt surfacing permeameter, to establish procedures for measuring permeabilities of asphalt surfacings and to collect and evaluate asphalt surfacing permeability data. Permeameters and techniques for using them were developed for both laboratory and field testing and considerable data have been collected throughout the highway system of the State of Idaho.

Equipment

The permeameters developed for testing the permeability of asphalt surfacings have been described in Chapter IV under Apparatus. Illustrations of the components of these devices may be seen in Figures 9 through 16, pages 28, 30, 32, 34, 38, 39, 40, and 45, respectively.

While the basic concepts for permeameters were adopted from earlier researchers, most of the apparatus used on this investigation was originally designed by the author and built jointly by the Physical Plant Division of the University and the author. In order to minimize the use of mechanically powered devices, differential water levels were used to create vacuum pressures for the field and laboratory permeameters first developed. An electric vacuum pump was used to develop the very high differential pressures needed in the laboratory to test the theory developed by Klinkenberg.

Accurate measurement of pressures was possible by use of the sloping manometers shown in Figure 10 and described on page 29. In the interest of economy and expedience, these manometers were similarly designed by the author and built with some assistance from a glass blower on the Washington State University campus. These components could be replaced by standard units available from several different companies handling scientific supplies.

The cups used for field tests were made by heavy gage steel with a dense rubber edge where the cup made contact with the asphalt pavement. This construction permitted the use of heavy weight on the cup so as to ensure a minumum of leakage around and under the edge of the cup without resulting in distortion of the cup or the area being tested.

A test for leaks in the field equipment was made in the laboratory prior to any field testing. The permeameter cup was placed on a sheet of greased sheetmetal and loaded lightly. A partial vacuum was created by use of a differential head of approximately 6 feet of water. At the end of 24 hours there was no change in the water levels thereby assuring no leaks in the system.

Extent of Testing

Field tests conducted on 28 different state highways throughout Idaho resulted in 117 tests and 659 separate readings. The locations of these tests are shown in Figure 18 and a complete description of each test site is given in Table A-1 on page 111 of Appendix A. The purpose of this widespread testing program was to obtain a range of permeability values that might be expected in a wide variety of pavements that differed in age, type of surfacing, traffic conditions and climatic conditions.

Further, many of the field tests were conducted on highway surfaces that were scheduled for seal coating later during the summer that the testing was done. It was hoped that these roads would help establish limiting permeability values that could be correlated with the need for sealing.

Some roads were tested more than once during the spring and summer to ascertain any trends that might exist for variations in the permeability characteristics as related to time. These sites are designated as Repetitive Testing Sites on Figure 18.

More than 400 laboratory readings were conducted on 16 pavement surfacing cores taken from six different state highways. Each core was taken from a location where a field test had also been made.

Testing Procedures

The procedures finally adopted and recommended for future testing have been described also in Chapter IV under Procedures. Routine testing

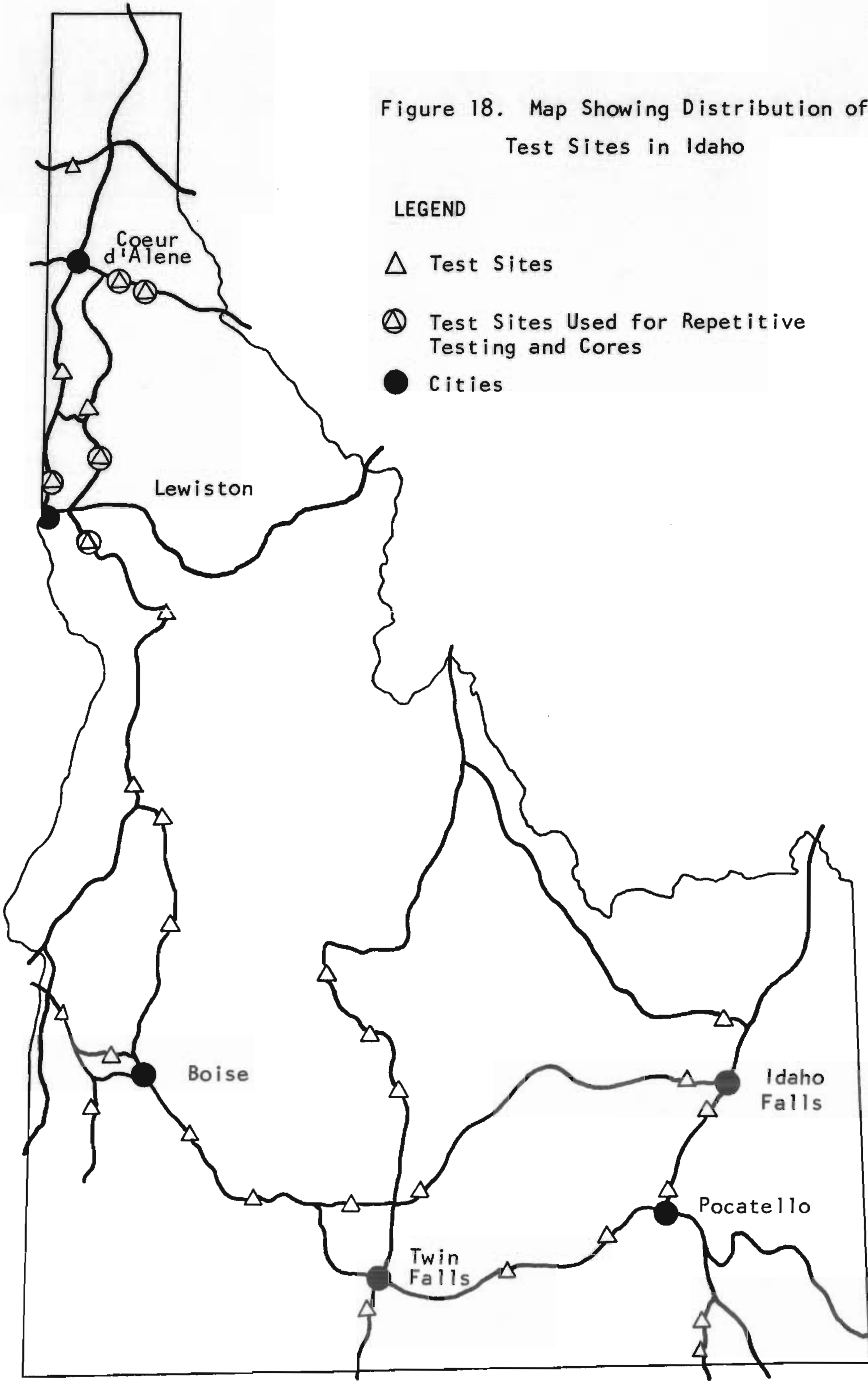
Figure 18. Map Showing Distribution of Test Sites in Idaho

LEGEND

△ Test Sites

Ⓐ Test Sites Used for Repetitive Testing and Cores

● Cities



of core samples will not require the use of the specialized procedures involving pressures above 400 g/cm^2 as described on page 43.

In the initial phases of testing it was anticipated that the air flowing through the surfacing would follow the path of least resistance which could be just under the edge of the cup. To prevent this undesirable flow path and to force the air to be drawn up from the base material under the surfacing, the asphalt surface around the cup was sealed with automotive grease.

In preliminary testing it was found that a sealed width of approximately six inches beyond the edge of the permeameter cup would achieve the desired results and that sealed width was used throughout the testing program. A subsequent test was conducted to document this finding and the results are given in Table I. The values are illustrated in Figure 19 on page 58 with a separate curve showing the permeability variations for each width of sealed area.

The apparent permeability values for the various sealed widths were then compared at a standard pressure drop of 10 g/cm^2 and this comparison is shown in Figure 20 on page 59. Grease was also used to seal the rubber edge of the cup to the asphalt surface. Since, for higher vacuum pressures, the grease alone would not adequately bond the cup to the pavement surface, a weight was placed on the cup. This was accomplished by jacking up the back bumper of the test car and releasing it onto the stander. By testing the rubber edge ring under loads as high as 1500 pounds in a testing machine it was determined that the shape distortion and area change were negligible.

Test Results

Field test data with the computed results are listed in Table A-II of Appendix A, pages 113 through 125. It should be noted that the values have been reduced to the ratio of k/L which is the intrinsic permeability divided by the thickness of the pavement surfacing. This has been necessary because in many instances the thickness value L was not available. In some cases, where cores were taken so that a value of L might be measured, it was found that the bottom surface was frequently quite irregular so as to preclude measuring a precise length. Consequently, the k/L relationship was used for comparing both laboratory and field test results.

TABLE I

TEST OF EFFECT OF WIDTH OF SEALED AREA
OUTSIDE OF PERMEAMETER CUP

P_1 Atmos. Pressure g/cm^2	P_2 Test Pressure g/cm^2	P_1-P_2 Pressure Drop g/cm^2	Q Volume cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	Permeability Value $k/L \times 10^9$ cm	$k/L \times 10^9$ at 10 g/cm^2 Pressure Drop cm
Sealed Band Width @1"								
955	936.7	18.3	180.8	14.8	28	184.6	1.552	
"	939.2	15.8	181.6	14.9	28		1.791	
"	948.5	6.5	92	16.2	28		2.03	1.93
"	948.9	6.1	92	16.4	28		2.13	
"	945.0	10.0	91.4	11.0	28		1.93	
Sealed Band Width @2"								
955	937.4	17.6	90.6	12.5	29	185.1	1.058	
"	938.7	16.3	90.8	13.0	29		0.996	
"	944.6	10.4	91.4	17.5	29		1.162	1.18
"	945.2	9.8	91.4	18.0	29		1.197	
"	950.0	5.0	92.2	34.2	29		1.232	
Sealed Band Width @4"								
955	935.5	19.5	90.0	16.2	30	185.6	0.673	
"	936.6	18.4	90.4	18.6	30		0.622	
"	943.7	11.3	91.2	21.8	30		0.863	0.9
"	944.3	10.7	91.4	21.9	30		0.908	
"	950.0	5.0	92.2	43.0	30		0.988	

TABLE I (Continued)

P_1 Atmos. Pressure g/cm^2	P_2 Test Pressure g/cm^2	P_1-P_2 Pressure Drop g/cm^2	Q Volume cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	Permeability Value k/L x 10^9 cm	k/L x 10^9 at 10 g/cm^2 Pressure Drop cm
Sealed Band Width @6"								
955	937.0	18.0	90.4	15.2	31	186.1	0.780	
"	938.0	17.0	90.6	16.0	31		0.785	
"	942.5	12.5	91.2	22.3	31		0.764	.83
"	943.4	11.6	91.4	23.2	31		0.793	
"	949.7	5.3	92.2	44.0	31		0.916	
Sealed Band Width @8"								
955	936.3	18.7	90.4	17.2	32	186.6	0.665	
"	937.7	17.3	90.6	18.1	32		0.684	
"	944.9	10.1	91.4	26.5	32		0.799	.80
"	945.4	9.6	91.4	27.8	32		0.802	
"	948.7	6.3	91.8	46.3	32		0.733	
Sealed Band Width @13"								
955	936.2	18.8	90.4	16.3	32	186.6	0.698	
"	937.0	18.0	90.6	17.2	32		0.691	
"	943.8	11.2	91.4	25.0	32		0.765	
"	944.3	10.7	91.4	26.0	32		0.768	.77
"	949.0	6.0	91.8	45.0	32		0.793	

TABLE I (Continued)

P_1 Atmos. Pressure g/cm^2	P_2 Test Pressure g/cm^2	P_1-P_2 Pressure Drop g/cm^2	Q Volume cc	T Time Sec.	Temp. ^oC	μ Air Visc. Micropoises	Permeability Value k/L x 10^9 cm	k/L x 10^9 at 10 g/cm^2 Pressure Drop cm
	Sealed Band Width @6"							
955	938.7	16.3	90.8	20.5	32	186.6	0.641	
"	939.6	15.4	90.8	21.7	32		0.641	
"	945.1	9.9	91.4	31.0	32		0.697	.76
"	945.5	9.5	91.4	32.0	32		0.704	
"	948.9	6.1	91.8	46.6	32		0.752	

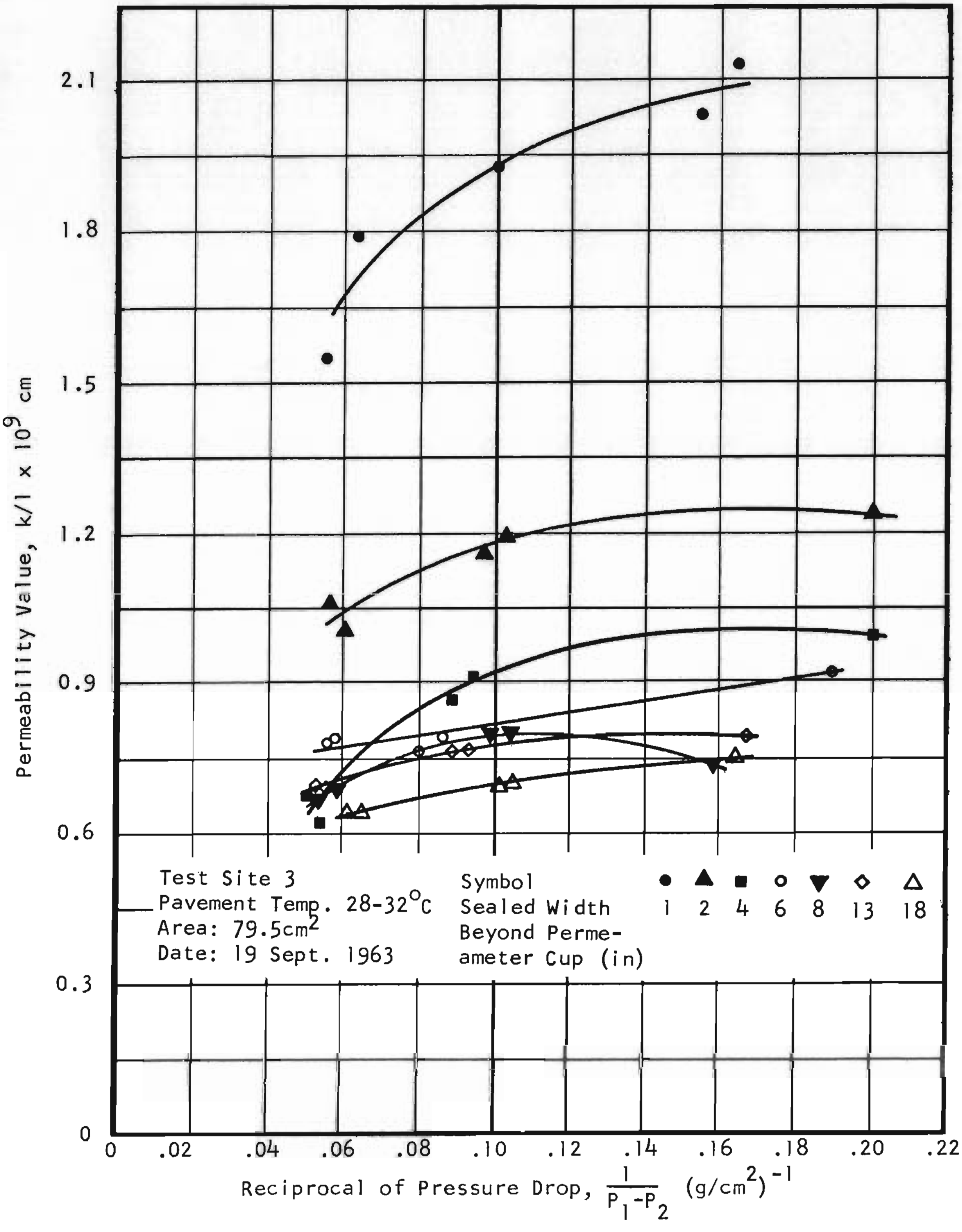


Figure 19. Variations in Permeability as a Function of Pressure Drop and the Width of Grease Sealed Pavement Outside of the Permeameter Cup.

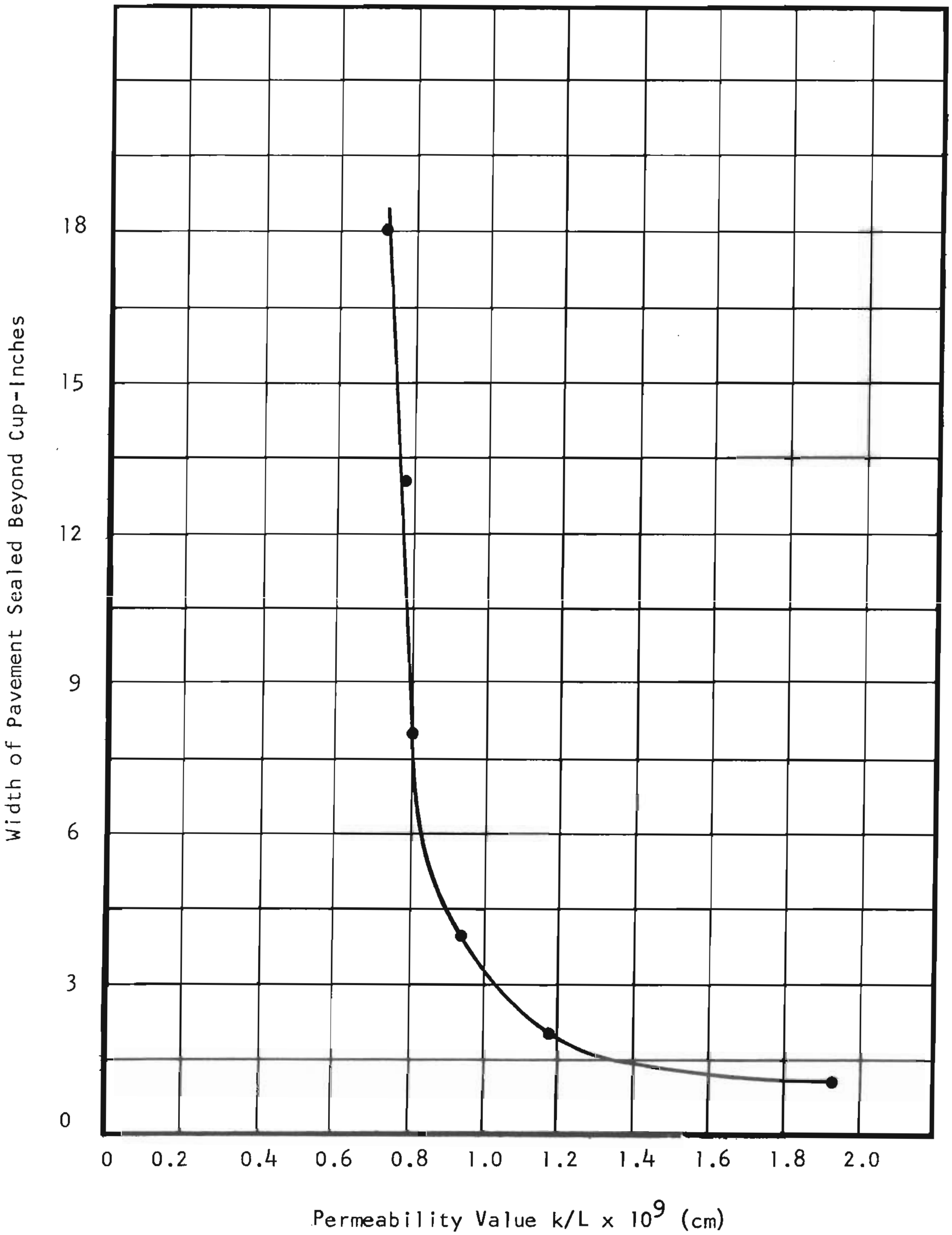


Figure 20. Variation in Permeability Value at a Constant Pressure Drop of 10 g/cm^2 as a Function of the Width of Grease Sealed Pavement Outside of the Permeameter Cup.

CHAPTER VI

ANALYSIS

Results of the field and laboratory testing were analyzed for conformance to theory, for range of typical values, for reproducibility of results and for correlation with various characteristics of the pavements tested. An attempt also was made to correlate laboratory with field testing results and field testing results with the need for a pavement to be seal coated. Finally, a comparison was made between the results of tests made with the Idaho Pavement Permeameter developed for this investigation and results with the Soiltest Corporation's Asphalt Paving Meter.

Conformance to Theory

The pressure drop (P_1-P_2) or the difference between the atmospheric pressure and the pressure on the surface of the pavement area being tested has been expressed as a reciprocal, $\frac{1}{P_1-P_2}$. This value was used to investigate the permeability characteristics of the asphalt surfacings studied. Table A-III, in Appendix A, pages 126 through 132, shows a summary of results obtained from the laboratory permeability tests of core samples. In addition, these data were used in the form of the reciprocal of the average of $P_1 + P_2$ to investigate the "liquid" permeability concept of Klinkenberg (6) which was explained earlier on page 6. It was possible to use only a few of the tests where a large range of pressure differences was experimented with in the laboratory. A plot showing the relation of the reciprocal of the mean pressure ($\frac{2}{P_1 + P_2}$) versus the permeability value (k/L) is shown in Figure 21. The curvilinear nature of these plots indicates that for this particular arrangement the relation does not follow Klinkenberg's Theory that the permeability is a linear function of the reciprocal mean pressure.

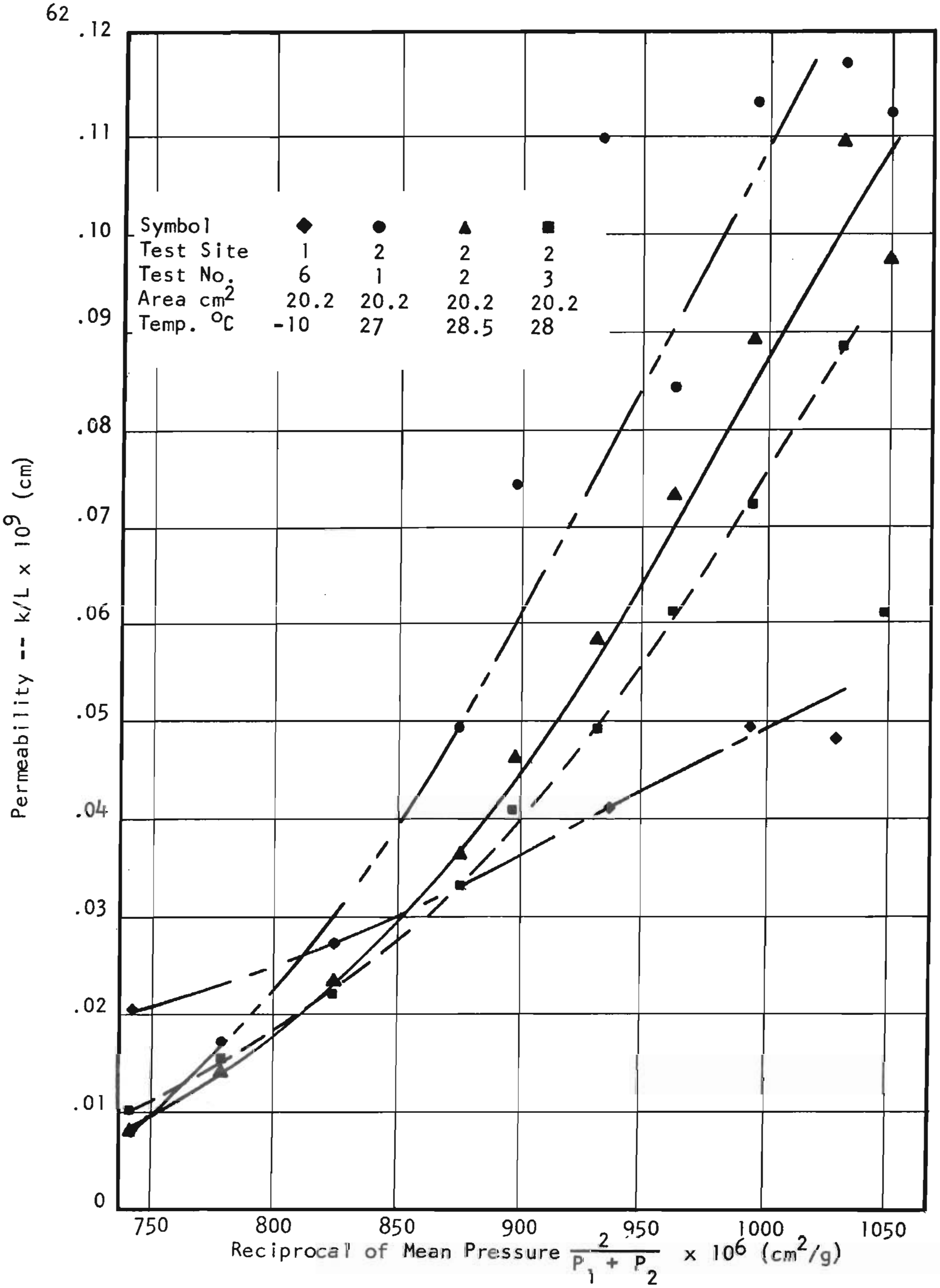


Figure 21. Permeability as a Function of the Reciprocal of the Mean Pressure Above and Below an Asphalt Pavement Core

Field test data were next plotted on a linear graph for k/L versus the reciprocal of the pressure drop, $\frac{1}{P_1-P_2}$. A best curve was fitted by eye to the plotted values as shown in Figures B-1 through B-48 of Appendix B on pages 135 to 182. From the graphs a value for k/L was arbitrarily selected for a pressure drop of 10 g/cm^2 or a $\frac{1}{P_1-P_2}$ value of 0.1 and these values are recorded in Table II commencing on page 64. For some of the tests a k/L value was not selected because the data collected would have required unreasonable extrapolation or interpretation.

Table III commencing on page 68 gives the results of similar manipulation of the Table A-III data obtained in the laboratory from core samples and these results are illustrated in Figures C-1 through C-31 in Appendix C on pages 185 to 215.

Reproducibility of Field Tests

As a check of the precision and reproducibility of the field test results, several tests were repeated in-place at the same pressures. The results of these tests have been extracted from Table II and summarized in Table IV on page 69 for easy comparison. While it is unusual to find the same results produced from two or more tests conducted under the same or nearly the same conditions, it is felt that the permeability values are close enough to be significant and useful. Visual examination of Table IV will make the inconsistencies readily apparent.

Discrepancies that do exist might be attributable to at least two possible sources: changes in the characteristics of the pavement structure and human error. It is conceivable that the air flow and vacuum pressure, especially large air flows and high vacuum pressures, could cause a change in the flow paths. This might be brought about by the shifting of fines so as to plug up or open up the pores. Another possibility might be through expansion or contraction of the asphalt when it is fresh or very hot and susceptible to flowing.

Two observers conducted the tests. One man operated the stopwatch and called the beginning and end times while the other man read the pressure value on the manometer for the midpoint position of the falling head. An error in making these observations would be quite easy and could reflect

TABLE II

FIELD PERMEABILITY VALUES FOR PRESSURE DROP OF 10 g/cm^2

TEST SITE	TEST NUMBER	LATERAL POSITION*	DATE 1963	TEMP. ^oC	AGE YEARS	PERM VALUE k/L x 10^9 cm
1	4	RWT 17	23 June	33		0.080
	5	RWT 17	"	30	3	0.078
	6	RWT 17	"	30		0.071
2	1	RWT	14 Apr.	21		0.175
	2	RWT	"	21		0.375
	1	RWT	12 May	17		0.295
	1	RWT 9	22 June	24	5	0.068
	2	RWT 9	"	23		0.240
	3	RWT 9	"	23		0.069
	1	RWT 9½	10 Aug.	38		0.033
	2	RWT 9	14 Aug.	39		0.040
	3	RWT 9¼	"	40		0.036
3	1	RWT 10	19 July	46		0.181
	2	RWT 8	"	46		0.470
	3	BWT 7½	"	46		7.900
	1	RRWT 9'8"	28 Aug.	40	1	0.330
	2	RWT 8	"	40		1.510
	3	BWT 7¼	"	40		22.200
4	1	RWT 7	18 July	33	1	0.245
	2	RWT 7	"	46		0.830
5	1	RWT 8	21 June	27		0.068
	2	RWT 8	25 July	27	12	0.040
	3	RWT 8	26 July	28		0.035
6	1	RWT 20	12 Apr.	18		2.450
	2	RWT 20	"	17		2.000
	3	RWT	"	17		2.100
	1	RRWT 9½	24 July	33	2	0.170
	2	RWT 9½	16 Aug.	33		0.041
	3		"	33		0.038

* = Abbreviations Used: RWT - Right Wheel Track, RRWT - Right of Right Wheel Track, BWT - Between Wheel Tracks, LWT - Left Wheel Track. Number denotes distance in feet to centerline.

TABLE II (Continued)

TEST SITE	TEST NUMBER	LATERAL POSITION*	DATE 1963	TEMP. °C	AGE YEARS	PERM. VALUE k/L x 10^9 cm
7	1	RWT 7½	17 July	25		1.050
	2	"	"	25	1	2.280
	3	"	"	29		2.040
	4	"	"	28		0.650
	5	"	"	28		2.250
	6	BWT 9½	"	28		1.500
7	1	RWT 9	19 Aug.	33		2.46
	2	"	"	33		2.32
	3	"	"	34		1.70
	4	"	"	34	1	1.86
	5	"	"	35		2.17
	6	"	"	36		2.01
8	1	RWT 7½	11 Aug.	28	28	0.041
9	1	RWT	10 Aug.	33		0.029
10	1	RWT 10	14 July	30	8	0.025
11	1	RWT 8	13 July	45		1.12
	2	"	"	45		1.39
	3	"	"	49		1.78
	4	"	"	49	3	5.07
	5	"	"	50		2.51
	6	"	"	45		1.84
12	1	6	14 June	20	7	0.38
	2	6	"	20		0.43
13	1	RWT 8	13 June	36		0.525
	2	"	"	36		0.580
	3	"	"	34	5	0.51
	4	"	"	34		0.71
	5	"	"	34		0.53

* = Abbreviations Used: RWT - Right Wheel Track, RRWT - Right of Right Wheel Track, BWT - Between Wheel Tracks, LWT - Left Wheel Track. Number denotes distance in feet to centerline.

TABLE II (Continued)

TEST SITE	TEST NUMBER	LATERAL POSITION*	DATE 1963	TEMP. °C	AGE YEARS	PERM. VALUE $k/L \times 10^9$ cm
14	1	LWT 3	15 June	25		1.7
	2	"	"	25		2.9
	3	"	"	27		3.8
	4	"	"	27		6.3
	5	"	"	29	3	10.3
	6	"	"	29		6.7
	7	"	"	29		7.7
15	1	RWT 9	2 July	45.5		0.038
	2	"	"	45.5	17	0.035
	3	"	"	45.5		0.042
16	1	RWT 8½	2 July	41		2.03
	2		"	41		1.85
	3	RWT 8½	"	41.6	1	2.61
	4	"	"	41.6		1.79
	5	"	"	42		2.25
17	1	RWT 7½	30 June	27		0.043
	3	RWT 8	"	25	13	0.037
	4	RWT 7½	"	27		0.0425
18	1	RWT 7½	30 June	27		0.046
	2	RWT 7½	"	27		0.102
	3	"	"	27	30	0.245
	4	"	"	27		0.071
19	2	RWT 8	1 July	30		0.045
	3	"	"	30	8	0.099
	4	"	"	28		0.088
20	1	RWT 8	1 July	22.8		0.035
	2	"	"	22.8	8	0.038
	3	"	"	23		0.044

* = Abbreviations Used: RWT - Right Wheel Track, RRWT - Right of Right Wheel Track, BWT - Between Wheel Tracks, LWT - Left Wheel Track. Number denotes distance in feet to centerline.

TABLE II (Continued)

TEST SITE	TEST NUMBER	LATERAL POSITION*	DATE 1963	TEMP. °C	AGE YEARS	PERM. VALUE $k/L \times 10^9$ cm
21	1	RWT 8	2 July	33	35	0.0375
	2	RWT 8	"	32		0.040
23	1	LWT 12	29 June	40		6.7
	2	"	"	38	0	1.2
	3	"	"	40		3.5
	4	"	"	40		6.8
24	1	RWT 9	28 June	43	9	0.048
	3	"	"	42		0.052
25	1	RWT 8	27 June	43		0.08
	2	"	"	41	3	0.127
	3	"	"	41		0.06
26	1	RWT 8	27 June	31		0.06
	2	"	"	34	3	0.063
	3	"	"	35		0.061
27	1	RWT 7½	26 June	33		0.066
	2	RWT 7	"	33	12	0.057
28	1	RWT 9	26 June	34		0.61
	2	"	"	34		0.725
	3	RWT 7	"	36	3	0.615
	4	"	"	36		0.745

* = Abbreviations Used: RWT - Right Wheel Track, RRWT - Right of Right Wheel Track, BWT - Between Wheel Tracks, LWT - Left Wheel Track. Number denotes distance in feet to centerline.

TABLE III

LAB PERMEABILITY VALUES FOR PRESSURE DROP OF 10 g/cm^2

TEST SITE	TEST NO.	DIST. TO CENTERLINE FT.	1963 TEST DATE	AREA cm^2	TEMP °C	1963 AGE YEARS	PERM. VALUE k/L x 10^9 cm
1	6		5 Aug.	45.5	31	3	1.38
	6	16	"	20.2	31		1.01
2	1	10	16 July	45.5	26	5	0.22
	1	10	17 July	45.5	25		0.38
	2	10	16 July	45.5	26		0.33
	2	10	"	20.2	25.5		0.41
	3	10	1 Aug.	20.2	25		1.04
3	1	12	1 Aug.	20.2	25	1	11.9
	1	12	1 Aug.	45.5	25		5.8
	2	10	1 Aug.	20.2	25		28.5
	2	10	1 Aug.	45.5	26		12.9
	3	10	30 July	20.2	27		13.7
	3	10	30 July	45.5	27		4.5
5	1	6	23 July	20.2	25	12	1.15
	1	6	"	45.5	25		0.6
	2	6	30 July	20.2	27		0.9
	2	6	"	45.5	27		1.1
	3	6	1 Aug.	45.5	26		1.9
	3	6	"	20.2	26		0.9
6	1	20	23 June	45.5	27	3	3.35
	1	20	23 July	20.2	27		3.30
	2	20	"	45.5	24		2.50
	2	20	"	20.2	25		0.46
	3	20	"	45.5	25		1.68

TABLE IV

COMPARISON OF FIELD PERMEABILITY VALUES TO DETERMINE REPRODUCIBILITY OF RESULTS

TEST SITE	TEST NO.	DATE 1963	P_1-P_2 PRESSURE DROP g/cm^2	Q VOLUME cc	T TIME Sec.	TEMP. ^oC	$k/L \times 10^9$ PERM. VALUE cm
4	2	13 April	31.0	441	80.0	16	0.395
			31.0	441	89.0	16	0.360
			31.0	441	92.0	16	0.349
6	2	12 April	4.3	476	83.0	17	2.99
			4.3	476	101.0	17	2.45
			4.2	475	97.0	17	2.62
			4.06	475	104.0	17	2.54
6	3	12 April	3.3	476	118	17	2.73
			3.3	476	72.2	17	2.67
7	1	19 Aug.	3.82	88.6	23.0	33	2.36
			3.81	88.6	22.8	33	2.39
11	1	13 July	1.60	91.7	60.0	45	1.16
			1.60	91.7	61.7	45	1.13
			1.60	91.7	64.0	45	1.08
11	3	13 July	1.68	45.8	34.5	49	1.94
			1.65	45.8	34.5	49	1.94
17	4	30 June	10.90	43.0	132.5	27	0.069
			10.90	43.0	187.0	27	0.049
			11.05	43.0	251.4	27	0.036
19	3	1 July	7.90	39.8	106.5	30	0.110
			7.90	39.8	101.4	30	0.083
20	3	1 July	7.1	87.4	455.8	23	0.056
			7.1	39.2	309.4	23	0.041
23	1	20 June	5.60	423	21.8	40	8.43
			5.40	423	24.8	40	7.56
			5.40	423	23.8	40	7.90
			5.40	423	25.0	40	7.52

in the results. For highly impermeable surfaces the water level changed rather rapidly and discerning the exact moment or pressure as the level passed a particular gradation could be an error source. With highly impermeable surfaces much smaller volumes were used so that any discrepancies from the exact value would constitute a larger percentage difference in the results.

Field Location

Most tests were taken in the wheel track where the kneading action of traffic caused the asphalt surfacing to be least permeable. In all but one location the pavement had been in service for at least one year and consequently sufficient time had passed to permit some consolidation. The comparisons described below may be studied in Table II on page 59.

At test site 3, which was constructed in 1962, 1 and 2 were taken in or very near the wheel track whereas test 3 was definitely taken between the wheel tracks. Permeability values for test 1 were 0.181 x 10^{-9}cm and 0.33 x 10^{-9}cm; for test 2, 0.47 x 10^{-9}cm and 1.51 x 10^{-9}cm; and for test 3 the values were 7.90 x 10^{-9}cm and approximately 22.2 x 10^{-9}cm. The first set of tests for each location were taken on July 19, 1963, when the pavement temperature was 46°C whereas the higher results were obtained August 28 when the pavement temperature was lower at 40°C. For each set of tests the permeability value was significantly higher for the test conducted between the wheel track than for either of the other two taken in the wheel track.

The three test locations described above were spaced at 100-foot intervals and consequently the physical characteristics of the pavement should be reasonably uniform. A series of tests were later conducted on September 19, 1963, at test number 1 location, but between the wheel tracks, to permit documentation of the effect of sealed width around the permeameter cup. Curiously enough, the permeability value obtained was only 0.8 x 10^{-9}cm, not too different from the earlier tests 1 and 2 which were in the wheel track.

Conceivably then, test 3 was located over a non-uniform piece of surfacing. Another explanation might be that the lateral travel width at test location 1 was greater or that the additional time and summer heat could have caused the between-wheel-tracks position to become less permeable.

Test site 6 was at a point where a truck lane had been constructed. The first set of tests were conducted in mid-April on the outside truck lane wheel tracks whereas the second set of tests were conducted in late July and mid-August in the inner fast lane. Permeability values for the first tests were 2.45, 2.0 and 2.1 x 10^{-9}cm whereas the later tests were only 0.17, 0.041, and 0.038 x 10^{-9}cm for respective locations. Though these differences appear to be significant, it is quite possible that factors other than location, such as seasonal change or temperature, may be responsible. This pavement had been constructed in the summer of 1958 and seal coated in 1961.

At test site 22, not listed in Table II, the tests were conducted on a new ramp for an interchange with I-80N, located just north of Heyburn, Idaho. No traffic had been on this pavement prior to the time of testing. The permeability of this surface was so great that a pressure drop of 10 g/cm^2 could not be maintained. This is quite apparently a reflection of the lack of compaction that normally results from traffic.

Range of Field Permeability Values

Table V summarizes the variations found in the field permeability values for a 10 g/cm^2 pressure drop as might be expected for typical highway pavements. For a more complete treatment, the reader should refer back to Table II on page 64.

The highest permeability was found at test site 22, as previously mentioned, where the permeability was so great that the arbitrarily selected standard pressure drop of 10 g/cm^2 could not be maintained at any one of three different test locations. By rough extrapolation of the curves in Figure B-40 on page 174, it would appear that a permeability value in excess of 22 x 10^{-9}cm would result.

Results from test location 3 at test site 3 on August 28 were nearly as great (+20 x 10^{-9}cm) although two other test locations at the same test site were much lower and more typical of what was found on other highways. In this case, however, the test was conducted between the wheel tracks on a one year old plant mix pavement so that compaction and consolidation by traffic was probably limited. An earlier test at this location gave a permeability value of 7.90 x 10^{-9}cm and a series of tests as

TABLE V

SUMMARY OF FIELD PERMEABILITY VALUE VARIATIONS

TEST SITE	1963 PAVEMENT AGE	1963 TEST DATE	$k/L \times 10^9$ PERM. VALUES cm	$k/L \times 10^9$ AVE. PERM VALUE cm
1	3	23 June	0.080+0.078+0.071	0.076
2	5	14 April	0.175+.375	0.275
		22 June	0.068+0.24+0.069	0.125
		(Adjusted)	0.068+0.069	0.068
		10-14 August	0.033+0.040+0.036	0.036
3	1	19 July	0.181+0.470+7.90	2.8
		28 August	0.33+1.51+22.2	8.0
4	1	18 July	0.24+0.83	0.53
5	12	21 June-26 July	0.068+0.04+0.035	0.046
6	3	12 April	2.45+2.0+2.1	2.2
		24 July-16 Aug.	0.17+0.041+0.038	0.008
7 EBL	1	17 July	1.05+2.28+2.04+0.65+2.25+1.50	1.63
		(Adjusted)	1.05+2.28+2.04+2.25+1.50	1.82
7 WBL	1	19 August	2.46+2.32+1.70+1.86+2.17+2.01	2.09
8	28	11 August	0.041	0.041
9	?	10 August	0.029	0.029
10	7	14 July	0.025	0.025
11	3	12 July	1.19+1.47+1.82+5.07+2.51+1.97	2.34
		(Adjusted)	1.19+1.47+1.82+2.51+1.97	1.79
12	7	14 June	0.38+0.43	0.40
13	5	13 June	0.525+0.58+0.51+0.71+0.53	0.571
14	1	15 June	1.7+2.9+3.8+6.3+10.3+6.7+7.7	5.6
15	17	2 July	0.038+0.035+0.042	0.038
16	1	2 July	2.03+1.85+2.61+1.79+2.25	2.11

TABLE V (Continued)

TEST SITE	1963 PAVEMENT AGE	1963 TEST DATE	k/L x 10^9 PERM. VALUES cm	k/L x 10^9 AVE. PERM VALUE cm
17	13	30 June	0.043+0.037+0.0425	0.0408
18	30	30 June	0.046+0.102+0.245+0.071	0.116
19	8	1 July	0.045+0.099+0.088	0.074
20	8	1 July	0.035+0.038+0.044	0.039
21	35	2 July	0.0375+0.040	0.0388
23	0	29 June	6.7+1.2+3.5+6.8	4.6
24	9	28 June	0.048+0.052	0.050
25	3	27 June	0.08+0.127+0.06	0.089
26	3	27 June	0.06+0.063+0.061	0.061
27	12	26 June	0.066+0.057	0.062
28	3	26 June	0.61+0.725+0.615+0.745	0.674

late as September 19, 1963 between the wheel tracks of test location 1 gave a permeability value of approximately 0.80 x 10^{-9}cm. The latest tests, therefore, suggest, as has been mentioned previously, that test location 3 might have been over an open graded section of surfacing or that considerable consolidation had taken place between the wheel tracks at test location 1. In Table V it will be noted that the highest permeability value found at test site 14, which was a three year old plant mix pavement, was 10.3 x 10^{-9}cm. The test was conducted in the left wheel track of the outside lane on June 15, 1963, a date fairly early in the year. Three other tests at the same test site also gave values in excess of 6 x 10^{-9}cm.

Two of the four test locations at test site 23 also had permeability values of 6.7 x 10^{-9}cm or more. These tests were made on the first of two new lifts of plant mix surfacing that was being laid over a five year old bituminous surface treatment. Traffic had had little opportunity to compact this new surfacing material and, furthermore, the tests were made at the edge of the lane, or 12 feet from the lane line. This highway was a portion of I-15W, south of American Falls.

Two other test sites had average permeability values in excess of 2.0 x 10^{-9}cm and each of these locations were on one year old pavements. Test site 16, between Gooding and Bliss, had a range of values from 1.70 x 10^{-9}cm to 2.61 x 10^{-9}cm and averaged 2.11 x 10^{-9}cm.

Six tests were conducted on each of the opposing lanes of test site 7, Grangeville's Main Street. The July 17 tests in the eastbound lane had two low values so as to bring the average down to 1.63 x 10^{-9}cm, but by excluding these two tests, the average permeability value would exceed 2.0 x 10^{-9}cm. Results from the westbound lane were more uniform and had an average value of 2.09 x 10^{-9}cm.

Lastly, test site 2, a three year old portion of I-80N seven miles east of the Oregon state line, had an average permeability value of 2.34 x 10^{-9}cm; however, one of the six tests was irregularly high. By excluding this one high result, the average dropped to 1.79 x 10^{-9}cm.

Permeability values of approximately 2.0 x 10^{-9}cm can be consistently identified with pavements three years old or younger. On the other hand, two comparatively new (three years old) interstate pavements between

Pocatello and Idaho Falls (test sites 25 and 26) had average values of less than 0.1×10^{-9}cm. Since traffic volumes on these two sections were very comparable to test site 2 and equal to only half of the volume on test site 14; and since the age of these four pavements, date of testing, pavement temperature and lateral position of tests do not appear to be responsible, it must be that construction practice or design characteristics account for the difference.

While the permeability values in excess of 2.0×10^{-9}cm were conspicuous in their identification with new pavements, many more than half of all the test results were less than 0.50×10^{-9}cm. Of these, the bulk, or more than one third of all tests, were less than 0.10×10^{-9}cm. Figure 22 is a bar chart illustrating the distribution of the various values recorded.

The smallest values, at test sites 9 and 10, were 0.029×10^{-9}cm and 0.025×10^{-9}cm, respectively. Test site 9, the Main Street of McCall and a portion of State Highway 15, has an unknown history but the pavement is very old. Test site 10, also on State Highway 15, three miles south of Cascade, was approximately eight years old at the time of testing.

Permeability Value as a Function of Age

Pavements over eight years old consistently gave average results of less than 0.075×10^{-9}cm, with one exception. The thirty year old pavement of test site 18 between Hailey and Ketchum gave an average value for four tests of 0.116×10^{-9}cm; however, the results were somewhat erratic, ranging from 0.046×10^{-9}cm to 0.245×10^{-9}cm. By dropping the highest value this pavement has an average permeability of only 0.073×10^{-9}cm. Only one other pavement, test site 19, in this over-eight-years age group had an average permeability value in excess of 0.05×10^{-9}cm.

The range of values found seems to be fairly well correlated with pavement age as shown by the plots of Figure 23. Considerable history regarding frequency of sealcoating is not known on the older pavements nor has any attempt been made to correlate the results with the design of the asphalt mat and the manner in which construction was performed. Such a study might develop an even closer relation between the permeability values and the pavement characteristics.

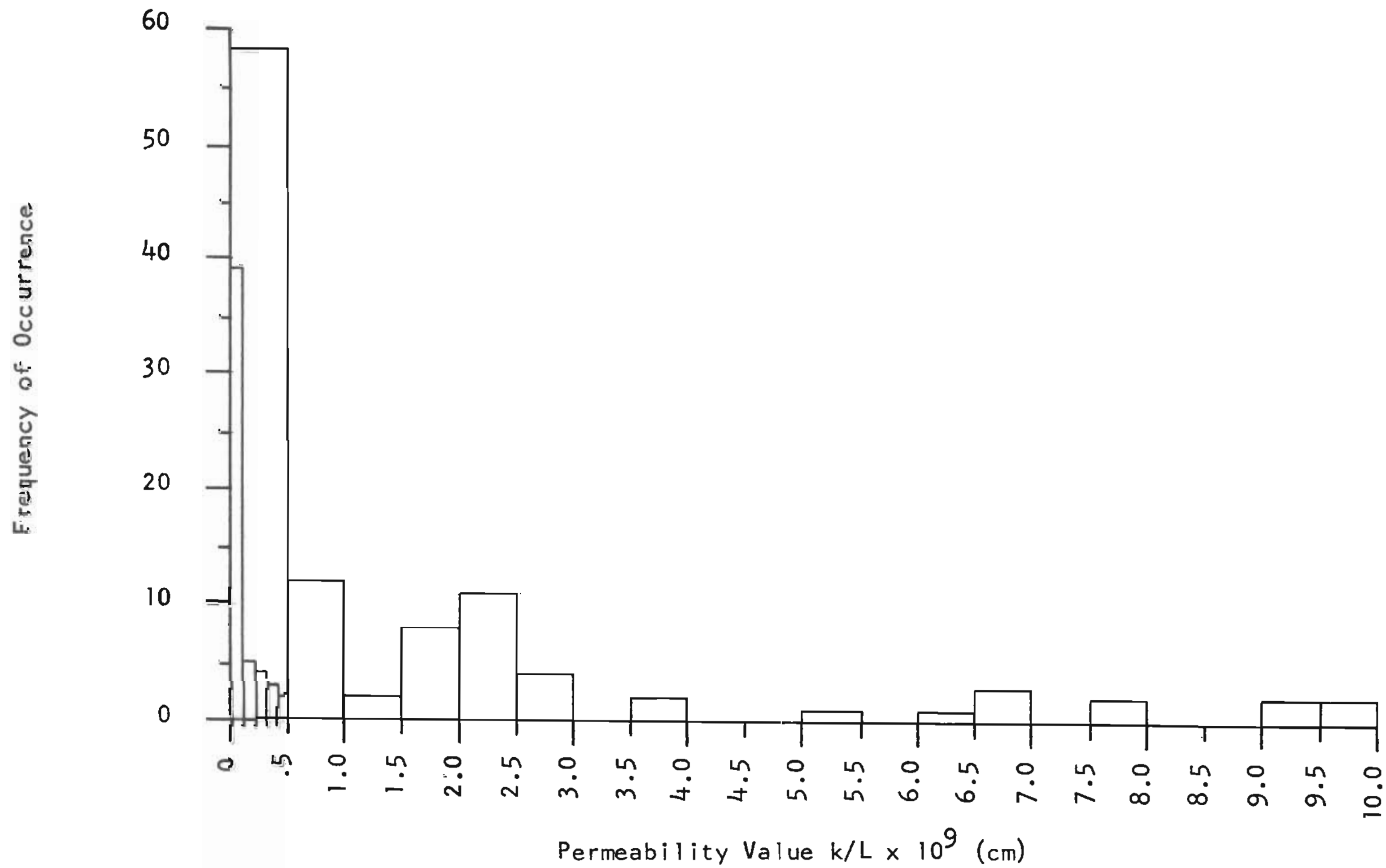


Figure 22. Frequency of Occurrence of Average Permeability Values for 106 Highway Test Locations

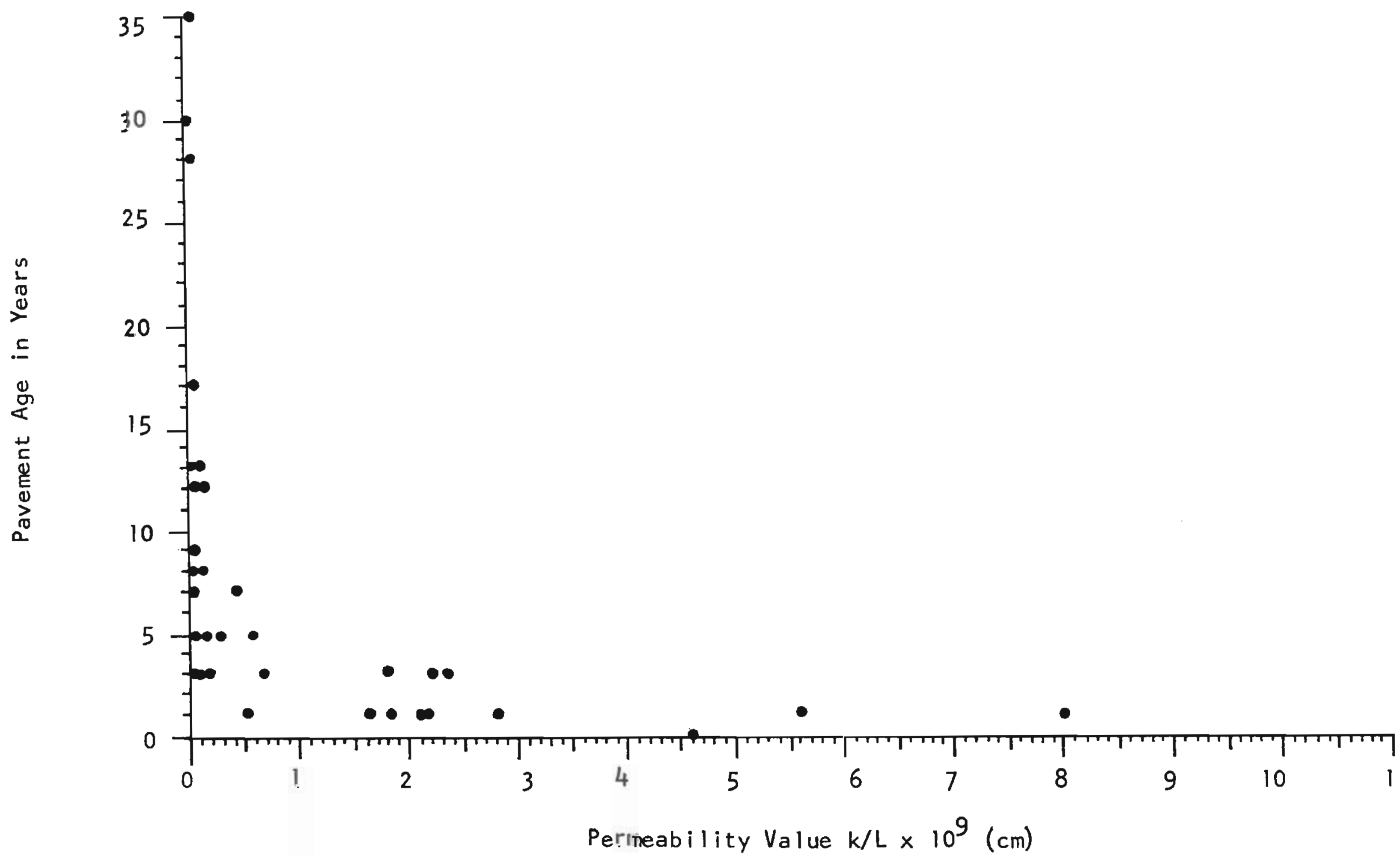


Figure 23. Scatter Diagram of Permeability as a Function of Pavement Age.

Certainly the validity of the data is greater where more tests have been conducted. It would appear that a minimum of six tests should be made at each test location and where results vary to any extent, perhaps ten tests should be made.

Range of Laboratory Permeability Values

Asphalt surfacing cores were tested from six different highway pavements, all of which were taken from test sites where field permeability tests had also been taken. Of these six sites, permeability values were obtained for five; permeability of the sixth core was so great that the standard pressure drop of 10 g/cm^2 could not be maintained which was also true for the field tests at this particular site.

Three cores were available for testing on all but test site 1 and testing was extremely limited for this site because of damaged cores. Cores from the other sites were usually tested for surface areas of $2.02cm^2$ and $45.5cm^2$. Temperatures for the routine tests were usually room temperature, ranging from 25^oC to 27^oC. Table III on page 68 summarizes these results.

Permeability values ranged from $0.41 \times 10^{-9}cm$ to $28.5 \times 10^{-9}cm$ for the smaller surface area of $2.02cm^2$ and from $0.22 \times 10^{-9}cm$ to $12.9 \times 10^{-9}cm$ for the $45.5cm^2$ surface area. The smallest values were both from five year old test site 2 and the largest values were from the one year old pavement of test site 22, on which traffic had never traveled, had it been possible to maintain the standard pressure drop of 10 g/cm^2.

As may be seen in Figure 24, there is a fair correlation between pavement age and the average permeability values for the five test sites. The exception is the 12 year pavement of test site 5; however, cores from this highway were taken between the wheel tracks rather than in the wheel tracks as was done at the other test sites. Although the evidence is not conclusive, there is good reason to believe from various indications throughout this investigation that permeabilities between the wheel tracks should be significantly higher than in the wheel tracks.

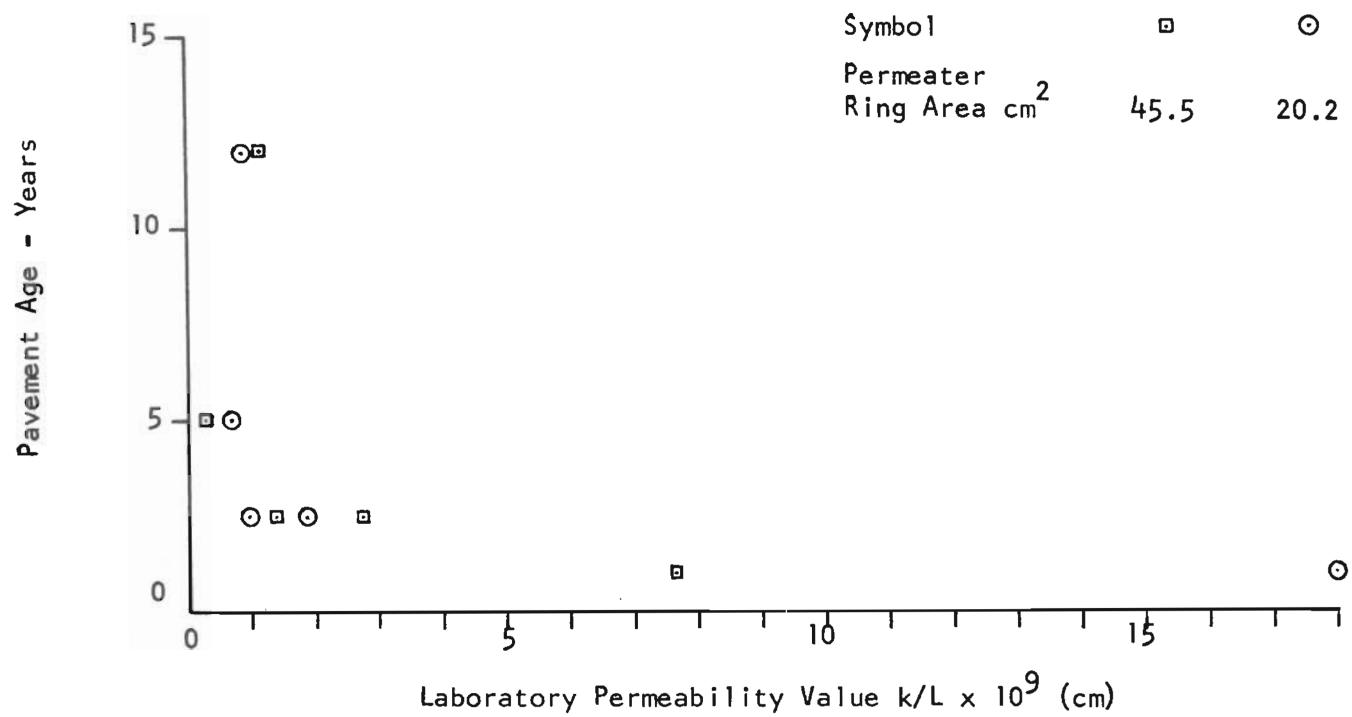


Figure 24. Laboratory Permeability Values as Related to Pavement Age

Seasonal Variations

At test sites 2, 3, and 6, tests were made of the pavement permeability at different times during the summer of 1963. Of these three highway test sections, the greatest number and the most reliable tests were made at test site 2, a plant mix pavement constructed in 1958. Results were obtained on four different dates between April 14 and August 10 at test location number 1 and three successful tests were performed on each of the other two locations.

At test sites 3 and 6, tests were made on two different dates for three different test locations on each highway. Test site 3, which was only one year old, gave variable and erratic results creating some question as to the uniformity of the surfacing. Each pair of tests at test site 6 gave results which agree with the trends found at test site 2 and which appear to be reasonable.

The seasonal trends found for the three test sites are illustrated in Figures 25 to 27 on pages 81, 82, and 83. Test sites 2 and 6 indicate that permeability values are comparatively high in the spring of the year. As the summer progresses, the permeability becomes less, probably due to compaction by traffic on the hot surfacing material.

The data do show, however, exceptions to this general theory and no conclusive explanation is apparent. As mentioned previously, test site 3 results are quite inconsistent by comparison to the results at all other sites and this may account for the difference in trends between test site 3 and test sites 2 and 6. A test at test site 2, test location number 1, on May 12 gave results significantly off the trend line; however, evaporation from a rain shower one hour prior to testing might have cooled the surfacing enough to affect the result. The relationship between pavement temperature and permeability value will be discussed later.

Laboratory Permeability Value as a Function of Temperature

A total of ten cores from three test sites were each tested at temperatures of approximately 45°C, room temperature (25°C-28°C) and -10°C. Surface area in each case was 20.2cm^2. These tests were incorporated into the Method B series of tests using high pressures; and, consequently, the permeability values obtained have been compared at pressure drops of 133.5 g/cm^2 rather than the standard pressure drop of 10 g/cm^2.

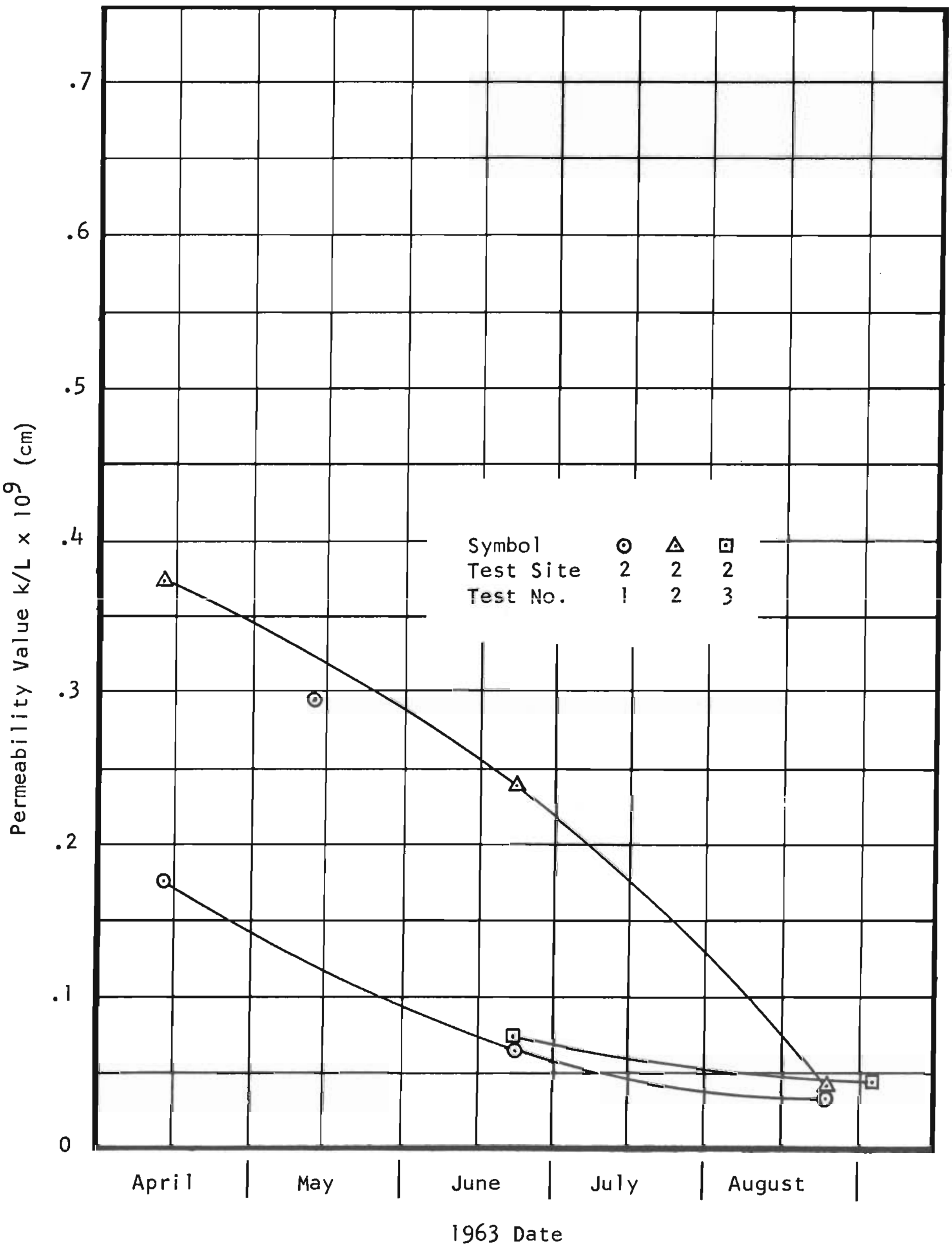


Figure 25. Seasonal Variation of the Permeability Value at Test Site 2

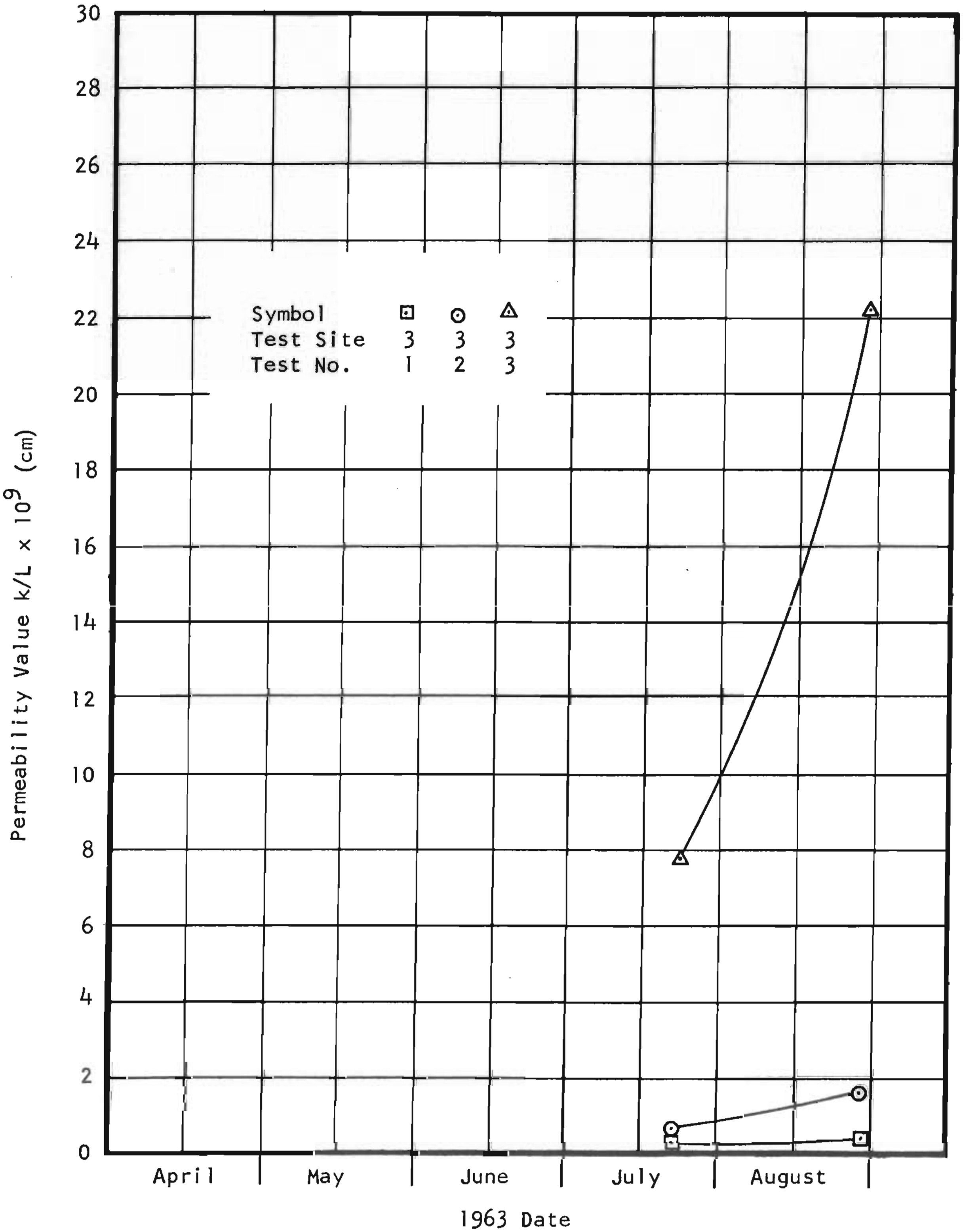


Figure 26. Seasonal Variation of the Permeability Value at Test Site 3

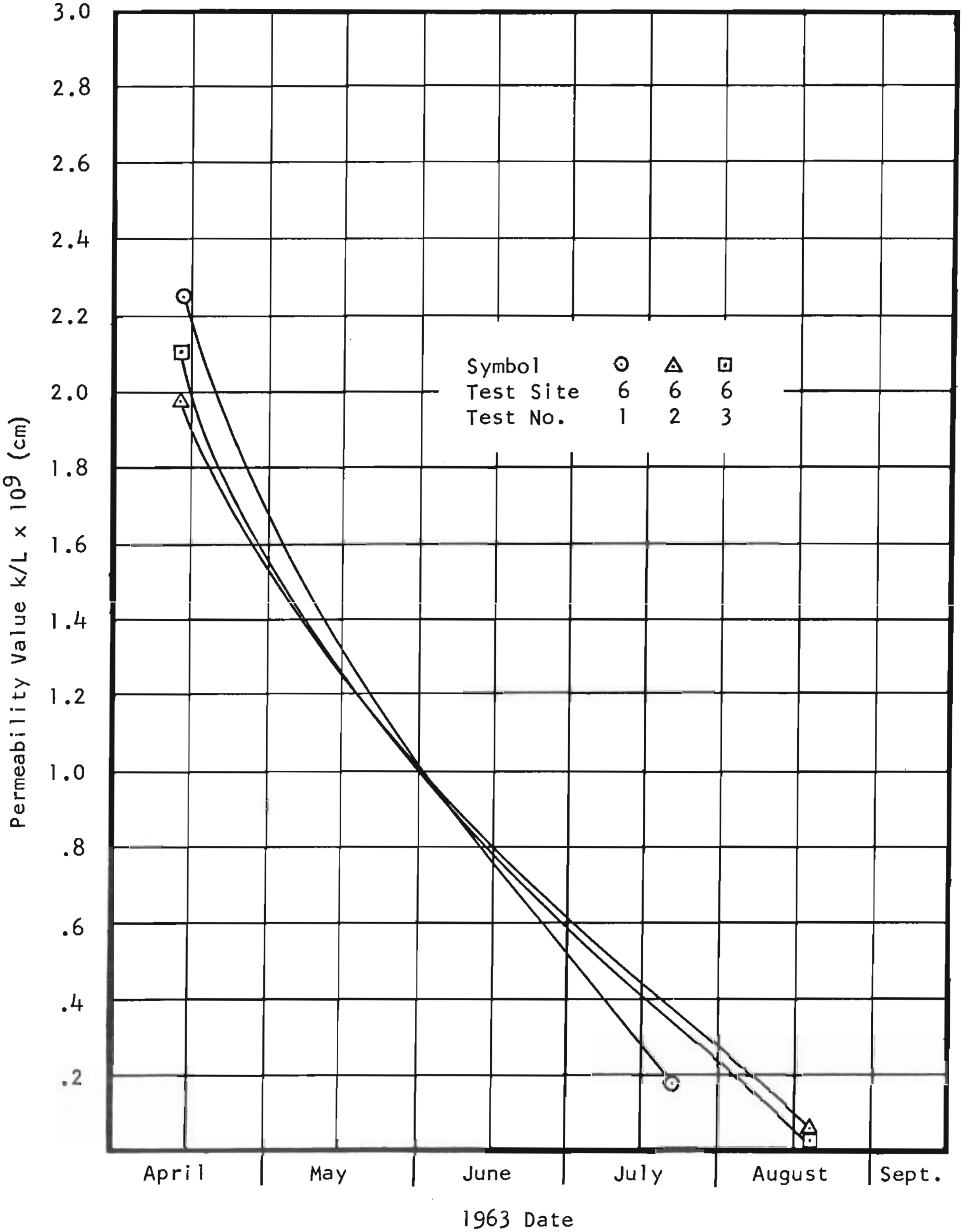


Figure 27. Seasonal Variation of the Permeability Value at Test Site 6

TABLE VI

LABORATORY PERMEABILITY VALUES FOR PRESSURE DROP OF 133.5 g/cm^2

TEST SITE	TEST NO.	1963 DATE	TEMP. °C	k/L x 10^9 cm
1	6	10 Sept.	-10	0.051
2	1	5 Sept.	27	0.114
	1	12 Sept.	45	0.129
	2	5 Sept.	28	0.092
	2	10 Sept.	-10	0.0525
	2	12 Sept.	45	0.129
	3	4 Sept.	28	0.073
3	1	6 Sept.	27	4.3
	1	10 Sept.	-10	0.22
	1	13 Sept.	45	0.35
	2	4 Sept.	27	9.1
	2	10 Sept.	-10	1.23
	2	13 Sept.	45	0.62
	3	6 Sept.	28	3.5
	3	10 Sept.	-10	0.35
	3	13 Sept.	45	2.0
5	1	3 Sept.	26	0.82
	1	10 Sept.	-10	0.051
	1	12 Sept.	45	0.0263
	2	4 Sept.	28	0.09
	2	10 Sept.	-10	0.025
	2	12 Sept.	45	0.271
	3	5 Sept.	30	0.168
	3	10 Sept.	-10	0.027
	3	12 Sept.	45	0.146
6	1	4 Sept.	27	0.08
	1	10 Sept.	-10	0.42
	1	12 Sept.	45	1.03
	2	4 Sept.	30	0.103
	2	10 Sept.	-10	0.36
	2	13 Sept.	45	0.14
	3	5 Sept.	25	0.133
	3	10 Sept.	-10	0.28
	3	12 Sept.	45	0.19

Results of the tests to determine the relationship between laboratory permeability value and sample temperature are summarized in Table VI. These results are also illustrated in Figures C-1 through C-29 on pages 185 to 215. A study of the illustrations discloses no conspicuous relationships. When the values are plotted and the points connected, nearly all shapes are developed.

Any explanation of the erratic results of this phase of the study must be pure speculation. Test results for different temperatures were so limited in range that the normal error found in a particular test could be greater than the difference found for the test for temperature change. Further, all of the tests for temperature variation were made at comparatively large pressure drops and in some instances the pressures on both ends of the sample were different from the pressure in which the core had been stored. The effect of these great pressure changes could have affected the pore characteristics of the sample to a greater degree than the temperature change.

Lastly, in some instances, it was noted that moisture accumulated on the surface of the samples as the cold tests were being performed. Presumably vapor in the air being drawn through the sample was cooled by the sample and was being condensed. Probably this condensation was taking place on the air-intake side of the core. Therefore, moisture may have been clogging many or all of the interstices in the samples which would significantly reduce the permeability value. The magnitude of this process would vary with humidity and temperature both of which are subject to change on different days and as the test progresses.

Field Permeability as a Function of Pavement Temperature

No special attempt was made to collect data for correlation of field permeability values with the temperature of the asphalt surfacing. Enough data were collected at test site 2 and 6, however, to permit some comparisons and it is believed these comparisons are sufficiently suggestive to warrant reporting. Unfortunately, the range of surfacing temperatures found at other test sites was so narrow as to preclude any further investigation of the relationship.

Temperatures and permeability values from test sites 2 and 6 are plotted in Figures 28 and 29 on pages 87 and 88, respectively. It appears from these plots that higher pavement temperatures produce lower permeability values. This seems reasonable since with an increase in temperature the asphalt expands and becomes less viscose. Expansion of the asphalt would tend to close the interstices, thereby reducing permeability. A less viscose asphalt surrounding an air bubble would also have greater tendency to expand into the pores when subjected to the partial vacuum of the permeameter and adversely affect permeability.

Soiltest Paving Meter

Tests were conducted with the Soiltest Paving Meter and results were obtained at test sites 3, 7, and 11. Attempts to get results at six other test sites were unsuccessful due to the impermeable nature of these other pavements and the low pressure range of the Asphalt Paving Meter.

Two or three tests at one pressure drop were made at each location with the Paving Meter. These permeability values, which for any one location and pressure drop were always very similar, were then averaged together and recorded in Table VII. A permeability value by use of the Idaho Pavement Permeameter was obtained from the appropriate curve in Appendix B that would make the most realistic comparison in terms of location, temperature, time, and pressure drop.

No conspicuous relationships are apparent. In some instances, the results from the Soiltest Paving Meter are higher and in other instances, lower. With so little data and due to the differences in their operation, it is difficult to draw any specific conclusions regarding the results.

Some pertinent differences between the two devices deserve discussion. The intended purpose of the Soiltest Paving Meter was primarily to evaluate the compaction or density of new asphalt surfacings which are generally much more permeable than old pavements, according to this investigation. This compaction evaluation is achieved by forcing a measured volume of air into the pavement surface at a pressure not to exceed 1 inch of water. Recommended testing pressure differential is 0.25 inches of water.

The manufacturer reports that the air flow rate is not affected by the permeability characteristics of the material more than one to two inches

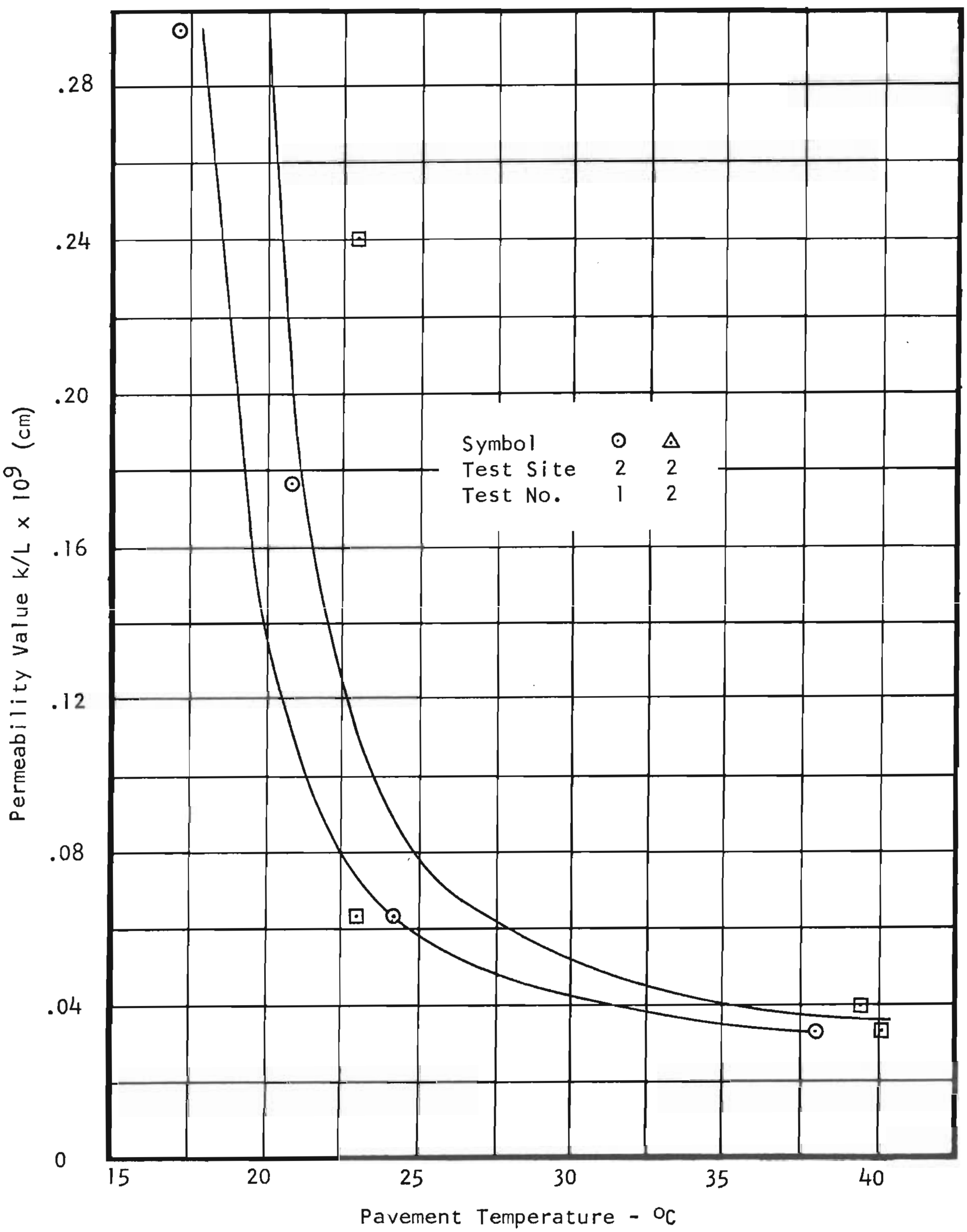


Figure 28. Permeability Value as Related to the Pavement Temperature at Test Site 2

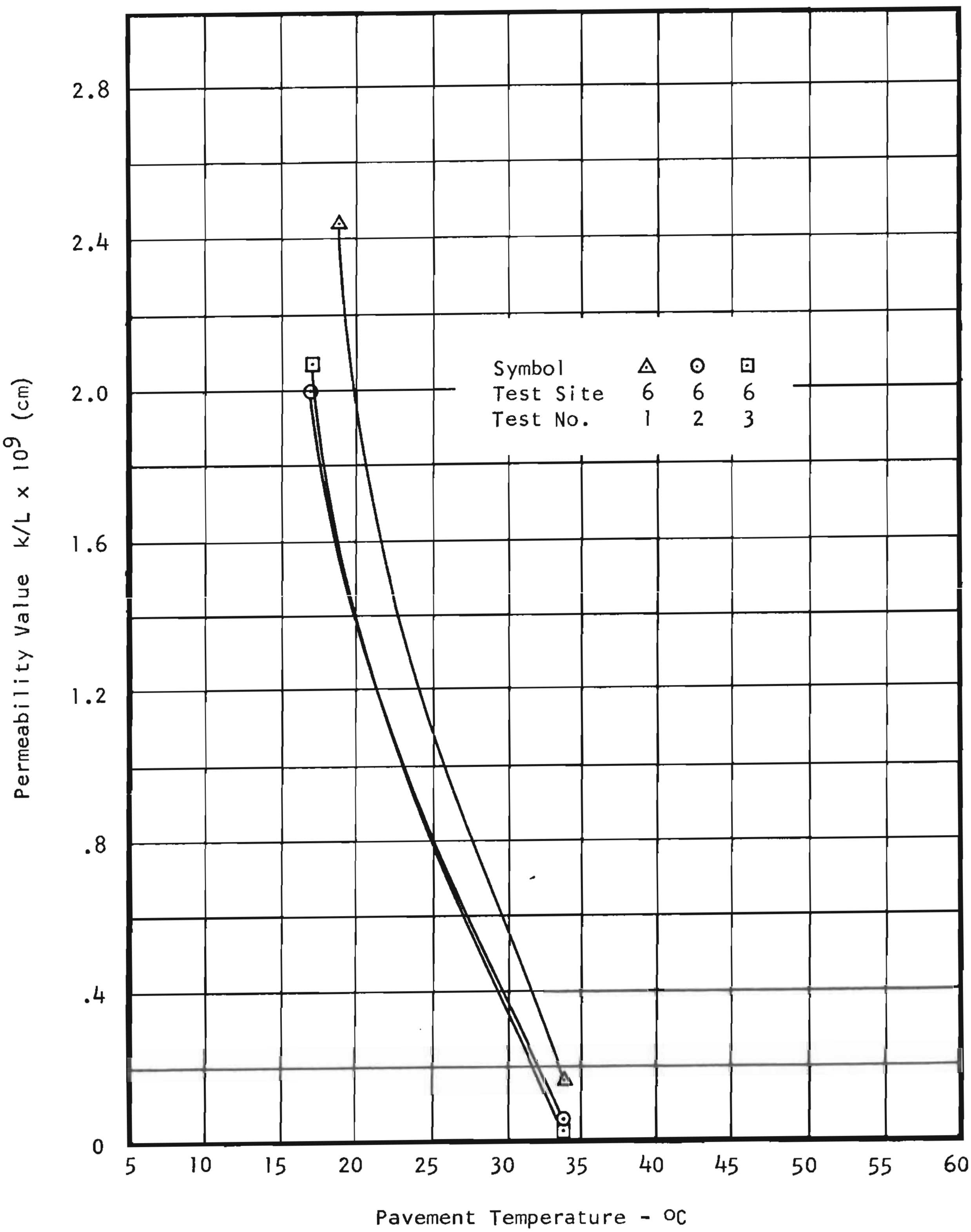


Figure 29. Permeability Value as Related to the Pavement Temperature at Test Site 6

TABLE VII

COMPARISON OF PERMEABILITY VALUES BY SOILTEST PAVING METER AND IDAHO PAVEMENT PERMEAMETER

TEST SITE	TEST NO.	ΔP g/cm^2	$\frac{1}{\Delta P}$ cm^2/g	SOILTEST PAVING METER $k/L \times 10^9$ cm	IDAHO PAVEMENT PERMEAMETER $k/L \times 10^9$ cm	1963 TEST DATE
3	2	1.27	.79	2.53	.63	19 July
	3	1.27	.79	29.3	10.5	"
7 EAST	1	1.27	.79	1.45	.92	17 July
	2			1.38	2.20	"
	3			1.76	2.01	"
	4			1.54	.58	"
	5			1.79	2.20	"
	6			1.77	1.6	"
11	1A	2.28	.437	13.3	1.15	13 July
		1.60	.625	14.3	1.13	"
	1B	2.28	.437	1.26	1.15	13 July
		1.60	.625	1.29	1.13	"
	3	1.60	.625	1.85	1.92	13 July

below the surface; that is, the permeability value evaluates only the top one or two inches of the asphalt surfacing. This is as might be expected because the sealed area around the permeameter cup is only about 1 inch wide and the shortest path for the air to flow would be immediately be-beath the sealed section where it could exhaust to the atmosphere.

The Idaho Pavement Permeameter was designed to evaluate the permeability characteristics of that depth of pavement that might retard infiltration of moisture into the subgrade. Of greatest importance is the full depth of asphalt surfacing material which may consist of layered courses of differing permeability characteristics attaining a total depth of one to six inches. Accordingly, the six-to-eight inch sealed width used is consistent with the maximum probable depth. A vacuum was used so as to draw the permeameter cup down and seal it onto the pavement, and weight was applied to further insure that there was no leakage under the cup edge. While a wide range of pressures was used for this study, it is not necessary once a standard pressure has been selected. Higher pressures do, however, tend to speed up the testing procedure.

Comparison of Laboratory and Field Permeability Values

Laboratory and field permeability values that can be compared are shown in Table VIII. The upper half of the table compares results of field permeability tests taken in late June and the bottom half of the table is from tests taken in mid-August. All core samples were removed from the pavements between April 3 and April 5, 1963.

No relationship is discernable by inspection of the data. The limited amount of data available precludes making any conclusive analysis and an error in any one test would greatly affect any conclusions drawn. Adjustment of the permeability values for temperature differences might change the relationships somewhat; however, insufficient information is available from this study to permit making reliable corrections for temperature.

Permeability as a Warrant for Sealing

One objective of sealcoating asphalt pavements is to reduce the permeability of the asphalt surfacing material and thereby prevent percolation

TABLE VIII

COMPARISON OF FIELD AND LABORATORY PERMEABILITY VALUES

TEST SITE	TEST NO.	FIELD TESTS 1963 DATE	TEMP °C	k/Lx10^9 cm	LABORATORY TESTS TEMP °C	k/L x 10^9 cm CUP AREA 20.2 cm^2	45.5 cm^2
1	6	23 June	30	0.071	31	1.01	1.38
2	1	22 June	23	0.068	26		0.22 & 0.38
	2	22 June	23	0.24	26	0.41	0.33
	3	22 June	23	0.069	25	1.04	
5	1	21 June	27	0.068	25	1.15	0.6
2	1	10 Aug.	38	0.033	26		0.22 & 0.38
	2	14 Aug.	39	0.04	26	0.41	0.33
	3	14 Aug.	40	0.036	25	1.04	
3	1	28 Aug.	40	0.33	25	11.9	5.8
	2	28 Aug.	40	1.51	26	28.5	12.9
	3	28 Aug.	40	22.2	27	13.7	4.5
6	2	16 Aug.	33	0.04	25	0.46	2.50
	3	16 Aug.	33	0.04	25		1.68

of water into the base courses and subgrade. In the past, experienced engineers have judged the need for sealcoating by visual inspection for cracks or other signs indicative of high permeability characteristics. Accordingly, the opinion of experienced engineers was used for comparison with the permeability values to see if any conspicuous relationships could be established.

Two rating techniques were employed. In the first technique, the evaluator estimated how many years it would be until the section of highway would need to be sealed. It was emphasized in the instructions to the raters that, although there are several reasons for sealcoating, only the permeability characteristics should be considered. Each highway test section was rated, although there was a different rater for each of the six districts of the state.

The second technique used procedures developed by the South Dakota Department of Highways for evaluation of cracking (18). A perfect pavement was rated at 20 points; lesser values were given to cracked surfaces in conformance with illustrations and descriptions. For this rating, two experienced engineers independently rated 16 different sites where the permeability tests had been made.

Average permeability values, based on a pressure drop of 10 g/cm^2, were developed for each highway test site or section by eliminating extremely low or high values in comparison to the other test results. In each case, the data used were from field tests made in the wheel tracks and during the summer period between mid-June and mid-August.

Table IX compares the average permeability value with the two opinion ratings. This information has also been plotted in Figure 30 on page 94 on a semi-logarithmic scale. Again, no correlation is apparent.

TABLE IX

COMPARISON OF PERMEABILITY VALUES WITH ENGINEERS OPINION FOR NEED TO SEALCOAT

TEST SITE	1963 TEST DATE	SURFACE TEMP. °C	AVE. PERM. VALUE, cm k/L x 10^9	PREVIOUS SEAL COATS	ENGINEERS RATING YEARS TO SEAL	ENGINEERS RATING 20 POINT PAR
1	23 June	39	0.076	20 June	6	
	10-14 Aug.		0.036			
2	19 July	46		New	3	
3	28 Aug.	40		New 1962	3	
5	21 June-26 July	27	0.046	1957	2	18, 20
7	19 Aug.	34	2.09	New 1962	0	16, 20
8	11 Aug.	28	0.041		1	18
9	10 Aug.	33	0.029		0	16
11	13 July	47	1.79		0	
13	13 June	35	0.571		0	
14	15 June	27	5.6	New	0	18, 20
15	2 July	45	0.038	1960	0	20, 20
16	2 July	41	2.11	None	3	20
17	30 June	27	0.041		1	
18	30 June	27	0.116		0	18
19	1 July	30	0.074		0	20
20	1 July	23	0.039		0	20
21	27 June		0.039		5	
23	29 June		4.6		4	20, 20
24	28 June		0.050	1961	0	
25	27 June	42	0.089	None	3	20
26	27 June	33	0.661	None	4	20
27	26 June	33	0.062		1	13
28	26 June	35	0.674		4	20

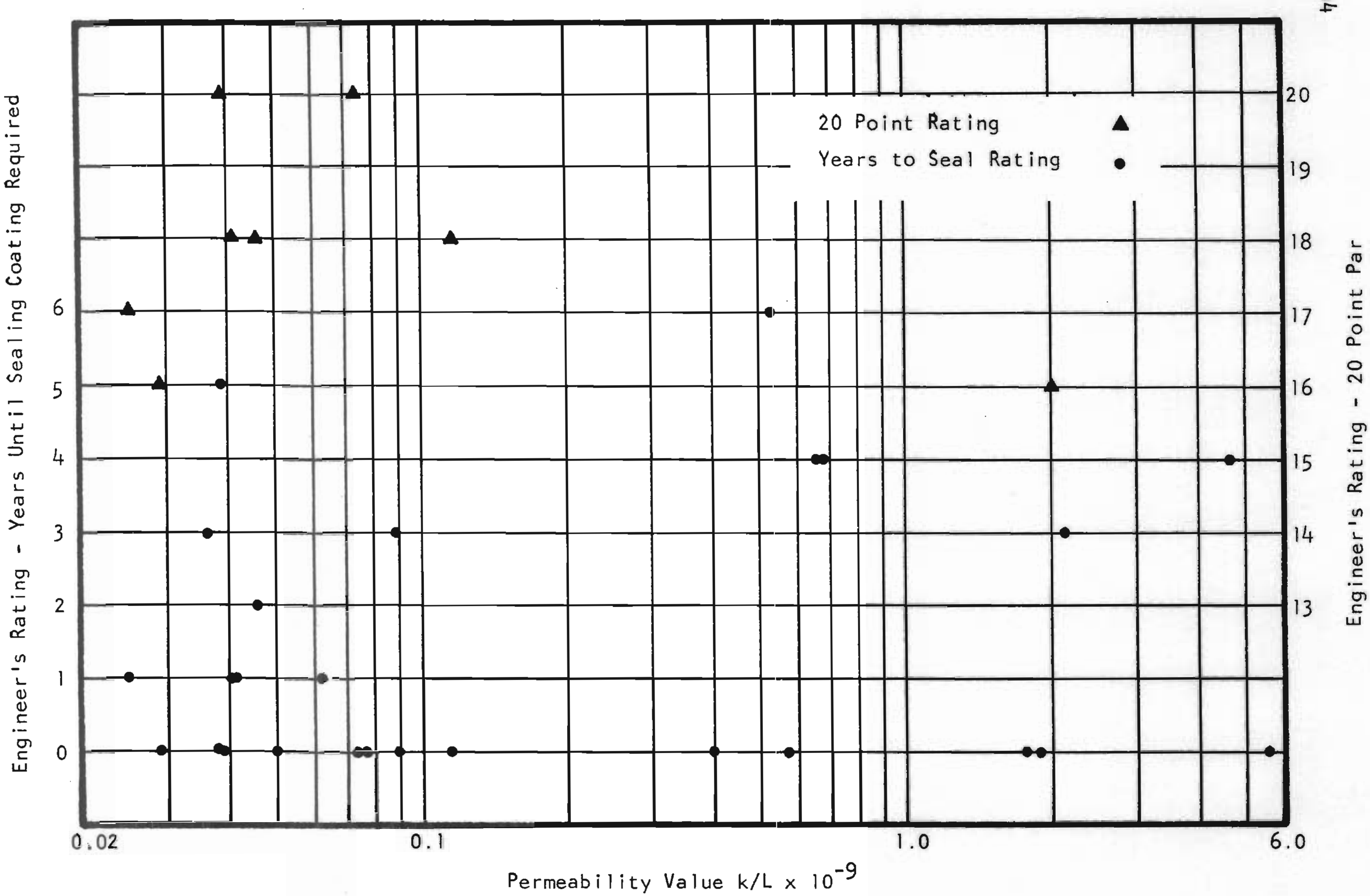


Figure 30. A Comparison of Permeability Value of Asphalt Pavements with Engineer's Opinion Rating of the Need for Sealcoating

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

I. CONCLUSIONS

Data were collected for this investigation of asphalt surfacing permeability with no concerted attempt made toward isolating any of the variables. It was believed that an analysis of a wide range of highway conditions and types would serve to determine the applicability of permeability as a criteria for sealcoating. The premise appears to be valid; however, the study does leave many questions unanswered concerning the relationship between permeability and the many variables. Further, since the time period in which data were collected was relatively short--less than six months--establishment of trends could not be done with reliability. Nevertheless, some worthwhile conclusions have been drawn from the analysis of the data.

Reliablilty of the Procedure and Equipment

The Idaho Pavement Permeameter and the testing techniques developed for its use appear to produce reasonable and consistent results. This conclusion is supported primarily by the fact that the results of tests at any one location could be reproduced within an acceptable range of accuracy. Also, comparison of results are in keeping with what should be expected in many instances. Unused pavements had much higher permeabilities than older compacted surfacings. Non-wheel track locations produced higher values than wheel track locations, and cold pavements were more permeable than hot ones.

Erratic results with the laboratory permeameter suggest that there is a flaw in either the equipment (possible air leaks) or the procedure. With the close control possible when testing core samples in the laboratory, more consistent and meaningful results should be obtainable. While the design and operating techniques of the laboratory permeameter appear to be sound, it must be concluded that the results of this investigation are not likely reliable.

Permeability as a Function of Pavement Age

Although the best correlation developed was between the permeability value and the age of the pavement, it may be that there are many factors other than age that actually are reflected in this apparent relationship. These other factors could include traffic, number of sealcoats, surfacing thickness, and change in any one of several asphalt pavement characteristics.

The effect of traffic was evident, although not conclusive, in several phases of the testing program. It may well be that number of passes of traffic, with due consideration given to wheel loads, are more important than the particular age of a highway.

Engineers of the Idaho Department of Highways report that most highways are sealcoated regularly on a schedule of four to seven years. New highways have been sealed in years past shortly after initial construction. It would seem that repeated applications of pure asphalt and overcoat material would significantly reduce the permeability value regardless of the pavement age.

Surfacing thickness will tend to increase as a pavement gets older because of the repeated sealcoats. The increase in depth varies with frequency of sealcoating, amount of asphalt used, type of covercoat material, retention of covercoat material and probably other considerations. Although the surfacing depth is listed in Table I, it was not used as a factor for correlation with the permeability value because the depth data were not complete or reliable in enough locations. The depth values given were, for the most part, intended construction depths and as such did not take into account subsequent increases due to maintenance.

As an asphalt pavement ages it tends to change its characteristics. An increase in viscosity with age, even to the point of brittleness, would suggest that the pores would be less susceptible to collapsing when subjected to negative pressures and as a result would give higher permeability values. This may not be correct, however, and the pores, in fact, may be affected in some manner so as to reduce their ability as conduits of air. Particles of fine soil may be carried up the underface of the surfacing and lodged in the pores so as to constrict the interstices.

It can only be concluded from this study that some action related to pavement age in some respect apparently adversely influences pavement permeability. The exact cause remains unknown.

Permeability Values as a Warrant for Sealing

The opinions of experienced highway engineers as to the need of different highway sections to be sealcoated due to permeability characteristics did not correlate with the measured permeability values. Inasmuch as the permeameter produced results which appear to be reasonable and reliable, it is concluded that even experienced engineers cannot judge by traditional methods this quality of a highway surface with an adequate degree of accuracy. It may be noted that the opinion ratings for individual sections varied widely in some cases.

The lack of correlation between the engineers' opinions and the permeability values might be due to many possible causes. Certainly much more needs to be known about the variables that affect pavement permeability. Also there is no assurance that the opinion ratings were influenced only by apparent permeability characteristics since it is customary for engineers to consider many characteristics of a surface when judging the need for sealcoating.

This investigation suggests that the need for sealing an asphalt surface to prevent water from percolating into the subsurface layers can be better determined by tested permeability values than by engineering judgment. However, in view of the limited knowledge of pavement permeability, it is too early to draw any definite conclusions or to establish any warrants.

Comparison with Soiltest Paving Meter

There is no correlation between the results with the Soiltest Paving Meter and the Idaho Pavement Permeameter. As mentioned in the analysis of the data, the purpose of the Paving Meter is to evaluate the permeability characteristics of only that portion of the pavement within an inch or two the surface. Since this project had the purpose of investigating the permeability characteristics for the full depth of the asphalt surfacing, it must be concluded that the Paving Meter does not give comparative results.

Field Location

Comparison of permeability characteristics for the different highway sections has been based on tests made in the wheel tracks. These values seem to be satisfactory for comparison purposes, although tests taken out of the wheel tracks might produce results closer to the true permeability and might serve as a better indicator of the potential of a surface to permit water penetration.

Of greatest importance, however, is consistency in selecting a test location with respect to the wheel tracks. Test values cannot be compared if the distance from the center line or the amount of compactive effort resulting from the kneading action of traffic differs. Accordingly, testing should also always be on tangent sections of pavement since traffic may tend to cut across lanes on curves.

Range of Permeability Values

Wheel track permeability values during the summer might be expected in the range of 25×10^{-9}cm for new pavements to 0.02×10^{-9}cm for very old pavements. Most pavements over four years of age will have values of less than 1.0×10^{-9}cm. Cold pavement temperatures and nonwheel track locations will tend to produce higher permeability values.

Number of Tests

A minimum of six tests should be made at each test location to permit computation of a reliable average. When the data indicate that widely varied results are being obtained the number of tests should be increased to as many as ten or twelve.

Conformance to Theory

From tests made in this study of asphalt surfacings, the relationship between air permeability and "Liquid Permeability" has not been established. Further, the relationship between permeability and mean pressure in the sample does not seem to follow the theory of "slippage" and mean free path as outlined in other literature and discussed in Chapter II of this report.

II. RECOMMENDATIONS

Equipment

The Idaho Pavement Permeameter is believed to be a basically reliable device; however, it is admittedly crude in some ways. It is recommended that the design be revised and streamlined with particular attention given to compactness, better gauges for measuring differential pressures, and better friction-free flow control devices which will be easier to operate. From experience in this study, the smaller volumeter does not appear to be needed and can be eliminated.

Further development of the laboratory permeameter needs to be done to ensure consistent and reliable results. Many variables can be eliminated by laboratory testing and a reliable device would be valuable for correlation of the many variables with the permeability value. In view of the pavement core drilling program carried out by the Idaho Department of Highways, an efficient and dependable laboratory permeability test would potentially be more economical than field testing.

Procedures

Procedures outlined for the field testing of asphalt surfaces are also satisfactory except that greater emphasis should be given to the number of tests needed to establish a reliable average. It is recommended that not less than six tests be made at any one test location and in the event that any of the tests appear to produce significantly variable results the testing should be continued until six tests with reasonable proximity be obtained or until a total of twelve tests have been made.

A ring of grease was smeared around the permeameter cup on the surfacing for a width of approximately six to eight inches. This width could be increased to ten or twelve inches with very little extra effort and thereby greater assurance could be given that the total air flow was through the depth of the pavement surface. It is recommended that such practice be adopted in future testing.

Correlation of Permeability Variables

It is apparent that there is a great lack of knowledge of the relationship between the many variables that influence the permeability of an asphalt surface. It is recommended that further testing be done with the objective of determining these relationships.

A recommended testing program is as follows: Confine the testing program to a few pavements having a wide range of a few characteristics such as thickness, age, type of surfacing, base, subbase and subgrade, number of sealcoats, traffic volumes and types, or temperature ranges. Only a few of these characteristics or variables should be studied initially, however. Each test section must be very uniform in materials and manner of construction. The testing program should be continuous in nature so as to produce trends as well as absolute values. Tests should be conducted for a period before and after different types of sealcoats have been applied. The uniformity of results achieved by testing in wheel track and non-wheel track locations should also be ascertained with the objective of determining the most desirable location.

Limiting each test location to a short section of highway which has uniform characteristics will eliminate many of the unknown variables and accordingly will facilitate the identification of relationships between known variables. From this study, the variables which appear to have the greatest influence on permeability are age, traffic action, seasonal variation and surfacing temperature. These factors, as well as many others, could easily be assigned numerical values for regression analysis by electronic computers and should be evaluated by that technique.

Permeability as a Warrant for Sealing

It is recommended that the technique for evaluating the need for sealing an asphalt surfacing be investigated further with the objective of making the procedure more rational.

In the past, and even now, the need for sealing of Idaho highways is based exclusively on engineering judgment and visual field investigations.

The alternate procedure of the South Dakota Department of Highways was somewhat better insofar as each judgment could be based on a comparison with a photograph of a standardized condition or rating. Even so, the procedure still has the weakness that the rating is dependent upon subjective judgment and superficial conditions. Sealcoats represent significant investments and if done more or less often than is required, sizable sums are wasted.

There are two bits of evidence to support this recommendation. First, the raters could not consistently agree on a rating for a pavement. Further exploration of this variation might be interesting and enlightening. It is widely recognized that opinion concerning the need for sealing a pavement varies widely for new pavements and this is probably equally valid for older pavements. In fact, in at least one district of the state a plan has been initiated to seal all pavements in respective areas on a rotation basis. Thus, even judgment of the needs for sealcoating of different pavements within the same area has been eliminated also.

The second bit of evidence is not as strong as the first, but nevertheless tends to support the need for more rational techniques. The most apparent relationship discovered was that the least permeable surfacings were the oldest surfacings. If the permeability measuring technique is reliable, it is apparent that seal coats are unnecessary to prevent water from percolating through the older pavements. Just when this condition exists should be a measurable factor.

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APPENDIX A

TABLE A-1

DESCRIPTION OF SITES WHERE FIELD TESTS AND PAVEMENT CORE SAMPLES WERE TAKEN

Test Site Number	Highway Name	Route Number	Mile Post	Testing Location*	Pavement Age in 1963	Thickness of Surface - In.	Pavement Condition A
1	Priest River Urban	US 2-195		WBL--Nearby the following core locations: Core 4, 20' S of House No. 1316, Opposite Power Pole No. 6/12	3	3.6	Very exposed aggregate, bleeding in the wheel track. Surface uneven.
2	Fourth of July Canyon	US-10	33	EBL--Nearby the following core locations: Core 1, Opposite MP 33 Core 2, 100' E of MP 33 Core 3, 200' E of MP 33	5	3.6	Pavement cracked lengthwise and crosswise, particularly along pavement centerline. Aggregate less exposed in wheel track.
3	Rose Lake-Dudley	US-10	35	EBL--Nearby the following core locations: Core 1, Opposite MP 35 Core 2, 100' E of MP 35 Core 3, 200' E of MP 35	1	3.6	Good
4	Deary-Bear Ridge	SH-7	347	SBL--Nearby the following core locations: Core 1, Opposite MP 347 Core 2, 100' S of MP 347	1	2.4	Uneven and rough, some raveling
5	Genesee Junction	US-95	349	NBL--Nearby the following core locations: Core 1, Opposite MP 349 Core 2, 100' N of MP 349 Core 3, 200' N of MP 349	12	2.4	Very rough, bleeding or gravel worn off
6	Culdesac Grade	US-95	304	SBL--Nearby the following core locations: Core 1, station 688 + 00 Core 2, station 687 + 00 Core 3, station 686 + 00	3	2.4	New, rough, some raveling in the wheel tracks
7	Grangeville City Center	SH-13		EBL, Tests 1-4 at City Center Tests 5, 6 across from Fire Station	1	3.6	Pitting, bleeding, raveling, giving, some places base seems to have worked its way through pavement
				WBL, Tests 1-6 at City Center	1	3.6	Good, no raveling or cracks
8	New Meadows	US-95	167	SBL	28	2.5++	Good
9	McCall Urban	SH-15		WBL, 80 ft. W of Memorial Hospital Intersection	UNKNOWN		Surface raveled
10	Cascade South	SH-15	67	SBL, Going S from Cascade	7	2.4	Very good, excess bitumen in wheel track in placed
11	Oregon Line East	I-80N	7	WBL	3	3.6	Good
12	Nampa South	SH-45	24	SBL	7	2.4	
13	Eagle-Star	SH-44	47	WBL, Opposite Power Pole No. 281	5	2.4	Good, aggregate exposed
14	Boise-Mt. Home	US-30	81	EBL	1	4.8	Hairline cracks through aggregate, generally good
15	Hammett West	US-20-26-30	120+	WBL, 70 ft. W of School Xing	17	3.0	Aggregate worn off and partly worked into bitumen.
16	Gooding-Bliss	US-20-26	157	WBL	1	2.4	New
17	Twin Falls South	US-93	35	SBL	13	2.4	Alligator cracks all over surface, seemingly very thin surfacing, much fines and poor gradation
18	Hailey-Ketchum	US-93	122	NBL	30	2.4	Bleeding in wheel tracks, mostly inside track, transverse cracks at centerline, aggregate worn off
19	Ketchum-Stanley	US-93	151+	SBL, 400 ft. N of North Cherry Creek Road	8	2.4	Good surface, aggregate worn off in wheel tracks
20	Stanley South	US-93	181	NBL	8	2.4	Exposed aggregate, no defect of traffic action in wheel tracks, uniform surface
21	Shoshone-Carey	US-93A	184+	EBL, 0.55 miles past MP 184	35	3.6	Transverse and longitudinal cracks
22	Heyburn I.C.	I-80N		EBL, Station 657 + 00 and 200' W of gore for EBL on-ramp. Three cores taken in immediate area also	3	3.6	Good
23	American Falls	I-15W		WBL, near American Falls, between crossings of heavy power (steel) transmission lines. Cores taken on EBL	0	3.0	

TABLE A-I (Continued)

Test Site Number	Highway Name	Route Number	Mile Post	Testing Location*	Pavement Age in 1963	Thickness of Surface - in.	Pavement Condition
24	Malad City	US-191	13+	NBL, Divided highway bypassing Malad	9	2.4	Exposed aggregate, bleeding in wheel track, pavement cracked crosswise and along centerline
25	Pocatello-Blackfoot	I-15		NBL, 6 miles north of Pocatello from where Interstate begins about 200 ft. north of crossing power line	3	4.5	Good
26	Idaho Falls-Blackfoot	I-15		SBL, 0.6 miles south of Shelly Interchange, by 70 mph speed limit sign	3	4.8	Good, some pitting
27	Idaho Falls-Arco	US-20	318	EBL	12	2.0	Exposed aggregate, but good imbedment at the wheel tracks, both longitudinal and transverse cracks, seemed brittle when drilled
28	Rexburg West	SH-88	335	EBL	3	3.5	Aggregate is large round pebbles, very exposed, many places the bitumen cannot be seen, some bleed stripes parallel to centerline

*Abbreviations Used:

WBL = West Bound Lane	W = West
NBL = North Bound Lane	N = North
SBL = South Bound Lane	S = South
EBL = East Bound Lane	E = East
MP = Mile Post	
US = United States Highway	
SH = Idaho State Highway	

TABLE A-11

FIELD TEST DATA FOR ASPHALT PAVEMENT PERMEABILITY STUDY

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L x 10^9 Perm. Value cm	Remarks*
Test Site No. 1, Priest River Urban, US 2-195										
June 23	4	962	928	34.40	89.6	109.8	33	187.0	0.070	WBL, RL, RWT, 17' from CL
"	"	"	930	31.80	89.7	122.5	"	"	0.068	
"	"	"	955	6.75	46.2	182.3	"	"	0.088	
"	"	"	956	6.00	46.2	216.2	"	"	0.084	
"	"	"	958	4.05	46.3	296.0	"	"	0.090	
"	"	"	959	3.30	46.3	328.0	"	"	0.101	
"	"	"	958	3.55	46.3	393.8	"	"	0.078	
June 23	5	962	934	27.70	48.5	64.0	30	185.6	0.064	WBL, RL, RWT, 17' from CL
"	"	"	951	11.20	46.0	120.0	"	"	0.080	
"	"	"	952	10.30	46.0	129.0	"	"	0.082	
"	"	"	952	9.65	46.0	151.3	"	"	0.074	
"	"	"	954	8.10	46.0	153.0	"	"	0.087	
"	"	"	954	7.60	46.2	184.4	"	"	0.077	
"	"	"	954	7.50	46.2	184.3	"	"	0.078	
June 23	6	962	943	19.00	45.6	88.2	30	185.6	0.063	WBL, RL, RWT, 17' from CL
"	"	"	944	18.00	45.6	89.0	"	"	0.066	
"	"	"	953	9.15	46.0	160.7	"	"	0.072	
"	"	"	954	8.00	46.0	160.0	"	"	0.083	
"	"	"	954	7.80	46.1	180.0	"	"	0.076	
"	"	"	955	6.60	46.2	186.0	"	"	0.087	
"	"	"	956	6.10	46.2	240.0	"	"	0.073	
Test Site No. 2, Fourth of July Canyon, US-10, Mile Post 33										
April 14	1	945	923	22.40	446.0	195.0	21	181.3	0.232	EBL, RWT
"	"	"	936	18.60	448.0	280.0	"	"	0.200	
"	"	"	933	12.10	450.0	435.0	"	"	0.194	
"	"	"	936	8.60	452.0	905.0	"	"	0.132	
"	"	"	861	84.50	415.0	57.0	"	"	0.196	
"	"	"	790	155.00	382.0	32.5	"	"	0.172	
May 12	1	945	728	217.00	704.0	50.2	17	179.2	0.141	EBL, RWT
"	"	"	838	107.00	1218.0	120.0	"	"	0.213	
"	"	"	876	69.00	1271.0	223.8	"	"	0.186	
"	"	"	903	42.00	873.0	227.4	"	"	0.206	
"	"	"	933	12.10	902.0	610.0	"	"	0.275	
June 22	1	945	919	26.40	177.5	265.2	24	182.7	0.058	EBL, RL, RWT, 9' from CL
"	"	"	928	16.70	89.5	173.8	"	"	0.071	
"	"	"	932	12.60	90.0	237.0	"	"	0.069	
"	"	"	935	10.00	45.2	162.8	"	"	0.064	
"	"	"	938	7.10	45.3	204.4	"	"	0.071	
"	"	"	940	4.50	45.8	350.5	"	"	0.066	
"	"	"	926	18.50	46.2	840.0	"	"	0.068	
August 10	1	945	931	14.00	45.0	258.0	38	189.4	0.030	EBL, RL, RWT, 9-1/2' from CL
"	"	"	936	8.50	45.4	373.0	"	"	0.034	
"	"	"	940	5.20	45.5	570.0	"	"	0.037	
April 14	2	945	929	15.50	450.0	250.0	20	180.8	0.355	EBL, RWT
"	"	"	869	76.00	420.0	50.0	"	"	0.251	
"	"	"	814	131.00	394.0	39.5	"	"	0.173	
"	"	"	780	165.00	376.0	36.5	"	"	0.142	
May 12	2	945	725	220.00	1052.0	113.3	17	179.2	0.096	EBL, RWT
"	"	"	821	124.00	1191.0	172.5	"	"	0.126	
"	"	"	910	34.50	880.0	186.4	"	"	0.308	
"	"	"	917	27.60	444.0	129.2	"	"	0.280	
August 14	2	945	934	11.00	45.2	250.0	39	189.8	0.040	EBL, RL, RWT, 9' from CL
"	"	"	935	9.80	45.3	270.0	"	"	0.040	
"	"	"	940	5.00	45.5	540.0	"	"	0.040	
"	"	"	941	3.95	45.5	905.0	"	"	0.030	

TABLE A-11 (Continued)

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L x 10^9 Perm. Value cm	Remarks*
Test Site No. 2, Fourth of July Canyon, US-10, Mile Post 33 (continued)										
June 22	2	945	934	11.20	90.2	81.5	23	182.0	0.224	EBL, RL, RWT, 9' from CL
"	"	"	937	7.60	90.6	110.2	"	"	0.247	
"	"	"	938	6.60	45.4	65.1	"	"	0.290	
"	"	"	939	6.10	45.5	67.1	"	"	0.250	
"	"	"	940	5.30	45.7	77.4	"	"	0.249	
"	"	"	940	4.60	45.8	80.1	"	"	0.278	
"	"	"	942	3.20	45.9	103.2	"	"	0.301	
"	"	"	936	8.60	90.4	100.0	"	"	0.260	
"	"	"	938	7.40	90.6	115.8	"	"	0.263	
"	"	"	939	5.80	90.8	135.1	"	"	0.265	
"	"	"	940	5.08	45.5	82.0	"	"	0.245	
June 22	3	945	918	26.90	87.8	125.1	23	182.2	0.060	EBL, RL, RWT, 9' from CL
"	"	"	922	23.00	44.0	75.0	"	"	0.059	
"	"	"	937	7.90	90.6	347.5	"	"	0.075	
"	"	"	936	6.60	90.6	420.0	"	"	0.075	
"	"	"	940	5.30	45.4	235.0	"	"	0.082	
"	"	"	940	5.00	45.4	235.0	"	"	0.087	
"	"	"	940	4.70	45.4	281.0	"	"	0.077	
August 14	3	945	927	18.00	44.8	155.0	40	190.4	0.039	EBL, RL, RWT, 9-1/4' from CL
"	"	"	930	15.00	45.0	195.0	"	"	0.037	
"	"	"	937	7.80	45.4	408.0	"	"	0.034	
Test Site No. 3, Rose Lake-Dudley, US-10, Mile Post, 35										
July 19	1	955	931	24.10	90.1	65.0	46	193.2	0.139	EBL, RL, RWT, 10' from CL
"	"	"	932	23.30	45.1	32.8	"	"	0.143	
"	"	"	942	12.90	45.6	52.0	"	"	0.165	
"	"	"	951	3.54	46.0	134.5	"	"	0.235	
"	"	"	953	1.69	46.1	244.5	"	"	0.271	
"	"	"	954	1.30	46.1	413.0	"	"	0.208	
August 28	1	955	940	14.50	91.0	44.8	40	190.4	0.338	EBL, RL, R of RWT, 9.7' from CL
"	"	"	947	8.35	91.5	77.0	"	"	0.342	
"	"	"	948	6.60	91.7	96.0	"	"	0.347	
"	"	"	952	3.12	46.0	67.2	"	"	0.526	
July 19	2	955	932	23.40	90.2	21.0	46	193.2	0.446	EBL, RL, RWT, 8' from CL
"	"	"	932	23.00	45.2	11.2	"	"	0.427	
"	"	"	943	11.60	91.3	40.6	"	"	0.471	
"	"	"	950	4.60	46.0	42.8	"	"	0.567	
"	"	"	950	4.50	46.0	46.4	"	"	0.535	
"	"	"	953	2.15	46.1	96.3	"	"	0.540	
"	"	"	954	1.15	46.1	152.5	"	"	0.635	
August 28	2	955	934	21.30	180.0	11.0	40	190.4	1.850	EBL, RL, RWT, 8' from CL
"	"	"	935	19.60	181.0	11.8	"	"	1.880	
"	"	"	938	16.80	181.5	17.5	"	"	1.480	
"	"	"	947	8.30	182.0	43.0	"	"	1.220	
"	"	"	951	4.40	92.5	32.0	"	"	1.570	
"	"	"	952	2.55	92.8	54.5	"	"	1.600	
July 19	3	955	940	14.50	364.0	8.3	46	193.2	7.450	EBL, RL, between Wheel Tracks, 7-1/2' from CL
"	"	"	938	16.80	363.0	7.3	"	"	7.200	
"	"	"	950	5.00	368.0	19.5	"	"	9.150	
"	"	"	951	3.90	184.0	12.0	"	"	9.550	
"	"	"	952	2.62	184.0	17.0	"	"	10.010	
"	"	"	954	1.40	92.4	15.2	"	"	10.500	
"	"	"	954	0.62	46.1	16.8	"	"	10.750	
August 28	3	955	949	6.20	551.0	9.0	40	190.4	23.900	EBL, RL, RWT, 7-1/4' from CL
"	"	"	948	6.80	735.0	11.6	"	"	22.400	
"	"	"	948	6.50	735.0	11.7	"	"	23.200	
"	"	"	952	3.05	553.0	17.0	"	"	25.600	
"	"	"	951	4.05	369.0	8.8	"	"	24.800	

TABLE A-II (Continued)

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L x 10^9 Perm. Value cm	Remarks*
Test Site No. 4, Deary-Bear Ridge, SH-7, Mile Post 347										
April 13	1	945	862	83.0	417.0	65.5	16	178.8	0.173	SBL, RWT
"	"	"	869	76.0	420.0	78.6	"	"	0.159	
"	"	"	904	41.4	437.0	102.1	"	"	0.231	
"	"	"	727	217.5	352.0	37.0	"	"	0.098	
"	"	"	738	207.0	357.0	30.2	"	"	0.128	
April 13	2	945	914	31.0	441.0	80.0	16	178.8	0.395	SBL, RWT
"	"	"	914	31.0	441.0	89.0	"	"	0.360	
"	"	"	914	31.0	441.0	92.0	"	"	0.349	
"	"	"	748	197.0	362.0	24.0	"	"	0.180	
"	"	"	759	186.0	367.0	24.3	"	"	0.183	
July 18	1	945	822	12.3	79.5	15.0	33	187.0	0.101	SBL, RWT, 7' from CL
"	"	"	829	11.6	160.0	32.0	"	"	0.101	
"	"	"	838	10.7	162.0	34.0	"	"	0.105	
"	"	"	580	36.5	175.0	56.5	"	"	0.199	
"	"	"	592	35.3	176.0	59.0	"	"	0.198	
"	"	"	689	25.6	178.0	84.6	"	"	0.193	
"	"	"	936	9.1	90.5	84.2	"	"	0.277	
"	"	"	941	4.2	45.5	60.0	"	"	0.386	
"	"	"	942	3.4	45.6	111.3	"	"	0.284	
"	"	"	944	0.9	45.6	236.5	"	"	0.462	
July 18	2	945	812	133.0	157.0	31.5	46	193.2	0.09	SBL, RWT, 7' from CL
"	"	"	906	39.0	175.0	22.8	"	"	0.49	
"	"	"	837	108.0	162.0	7.8	"	"	0.48	
"	"	"	922	22.5	178.0	15.5	"	"	1.27	
"	"	"	924	20.7	179.0	36.0	"	"	0.60	
"	"	"	934	10.7	180.0	50.0	"	"	0.83	
"	"	"	940	4.6	184.0	84.0	"	"	1.17	
"	"	"	942	2.9	91.0	69.0	"	"	1.14	
"	"	"	943	1.5	91.0	110.0	"	"	1.38	
Test Site No. 5, Genesee Junction, US-95, Mile Post 349										
June 21	1	950	926	24.1	448.0	660.0	27	184.1	0.065	NBL, RWT, 8' from CL
"	"	"	916	34.0	177.5	207.0	"	"	0.058	
"	"	"	926	24.1	179.0	291.4	"	"	0.061	
"	"	"	934	16.2	90.3	195.2	"	"	0.066	
"	"	"	939	11.4	90.7	270.0	"	"	0.068	
"	"	"	944	6.3	91.0	462.0	"	"	0.072	
June 21	2	950	918	32.2	88.8	111.2	27	184.1	0.058	NBL, RWT, 8' from CL
July 25	"	"	928	22.2	44.8	110.0	"	"	0.042	
"	"	"	928	21.8	44.8	115.8	"	"	0.041	
"	"	"	939	10.7	45.4	239.0	"	"	0.040	
July 26	3	950	927	22.9	44.8	138.6	28	184.6	0.033	NBL, RWT, 8' from CL
"	"	"	946	3.5	45.7	755.0	"	"	0.040	
Test Site No. 6, Culdesac Grade, US-95, Mile Post 304										
April 12	1	985	982	2.7	476.0	113.0	18	180.1	3.52	SBL, RWT, 20' from CL
"	"	"	982	3.3	476.0	105.0	"	"	3.11	
"	"	"	982	2.7	476.0	120.0	"	"	3.32	
"	"	"	969	16.3	467.0	31.0	"	"	2.09	
July 24	1	985	959	25.5	92.7	51.2	33	187.0	0.168	SBL, RL, R of RWT, 9-1/2' from CL
"	"	"	975	10.4	94.1	113.0	"	"	0.164	
"	"	"	981	3.6	42.4	151.1	"	"	0.204	
"	"	"	983	2.3	47.4	244.3	"	"	0.197	
April 12	2	985	981	4.3	476.0	83.0	17	179.0	2.99	SBL, RWT, 20' R of CL
"	"	"	981	4.3	476.0	101.0	"	"	2.45	
"	"	"	981	4.2	475.0	97.0	"	"	2.62	
April 12	2	985	981	4.06	475.0	104.0	17	179.0	2.54	
"	"	"	969	16.70	468.0	39.0	"	"	1.61	
August 16	2	985	963	21.80	46.5	180.0	36	188.5	0.028	SBL, RWT, 9-1/2' from CL
"	"	"	969	15.70	46.8	250.0	"	"	0.028	
"	"	"	975	9.70	47.1	281.0	"	"	0.041	

TABLE A-11 (Continued)

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L x 10^9 Perm. Value cm	Remarks*
Test Site No. 6, Culdesac Grade, US-95, Mile Post 304 (continued)										
April 12	3	920	985	3.3	476.0	118.0	17	179.0	2.73	Truck Lane, RWT, 20' from CL
"	"	"	"	3.3	476.0	72.2	"	"	2.67	
"	"	"	"	11.7	469.0	30.0	"	"	3.03	
"	"	"	"	16.8	467.0	37.0	"	"	1.69	
"	"	"	"	16.3	467.0	37.0	"	"	1.72	
"	"	"	"	16.0	467.0	38.0	"	"	1.71	
August 16	3	920	985	21.0	46.5	180.0	28½	188.5	0.0292	
"	"	"	"	13.0	46.8	230.0	"	"	0.0354	
"	"	"	"	8.0	47.0	340.0	"	"	0.0408	
Test Site No. 7, Grangeville City Center, SH-13										
August 19	1	920	899	21.40	347.0	14.5	33	187.0	2.62	WBL, RL, RWT, 9' from CL
"	"	"	903	16.50	349.0	22.5	"	"	2.19	
"	"	"	911	8.80	176.0	20.0	"	"	2.34	
"	"	"	915	5.40	177.0	31.1	"	"	2.64	
"	"	"	916	3.82	88.6	23.0	"	"	2.36	
"	"	"	916	3.81	88.6	22.8	"	"	2.39	
"	"	"	918	2.42	88.8	34.6	"	"	2.50	
"	"	"	919	0.92	44.6	46.3	"	"	2.46	
August 19	2	920	897	23.20	347.0	16.4	33	187.3	2.15	WBL, RL, RWT, 9' from CL
"	"	"	905	14.90	350.0	25.2	"	"	2.23	
"	"	"	910	9.70	176.0	18.2	"	"	2.35	
"	"	"	916	4.18	88.6	20.0	"	"	2.50	
"	"	"	918	2.48	88.8	32.6	"	"	2.59	
"	"	"	919	1.15	44.6	35.0	"	"	2.61	
August 19	3	920	897	23.10	347.0	20.6	34	187.5	1.73	WBL, RL, RWT, 9' from CL
"	"	"	904	15.60	349.0	31.0	"	"	1.71	
"	"	"	912	8.30	176.0	29.0	"	"	1.72	
"	"	"	916	4.07	88.6	32.0	"	"	1.60	
"	"	"	918	2.48	44.5	26.7	"	"	1.51	
"	"	"	919	1.09	44.6	63.0	"	"	1.53	
August 19	4	920	898	21.80	347.0	20.8	34	187.5	1.81	WBL, RL, RWT, 9' from CL
"	"	"	906	13.90	350.0	32.0	"	"	1.86	
"	"	"	913	7.10	176.0	31.0	"	"	1.89	
"	"	"	915	4.70	88.5	23.2	"	"	1.92	
"	"	"	917	3.14	44.5	18.0	"	"	1.86	
"	"	"	919	1.18	44.6	47.2	"	"	1.89	
August 19	5	920	899	20.80	347.0	18.2	35	188.0	2.17	WBL, RL, RWT, 9' from CL
"	"	"	904	15.70	349.0	24.3	"	"	2.17	
"	"	"	912	8.30	176.0	23.0	"	"	2.18	
"	"	"	916	4.18	177.0	48.3	"	"	2.07	
"	"	"	918	2.05	44.5	26.2	"	"	1.96	
"	"	"	919	1.06	44.6	49.2	"	"	2.02	
August 19	6	920	897	22.80	347.0	18.4	36	188.5	1.96	WBL, RL, RWT, 9' from CL
"	"	"	904	15.70	349.0	26.0	"	"	2.03	
"	"	"	911	9.10	88.2	11.0	"	"	2.09	
"	"	"	916	4.05	88.6	26.5	"	"	1.96	
"	"	"	918	2.29	88.8	48.0	"	"	1.93	
"	"	"	919	1.11	44.6	51.0	"	"	1.87	
July 17	1	920	897	22.50	179.0	17.5	25	183.2	1.05	EBL, RL, RWT, 7-1/2' from CL
"	"	"	899	20.90	179.5	18.8	"	"	1.05	
"	"	"	900	19.50	179.5	20.0	"	"	1.06	
"	"	"	909	11.10	87.8	17.6	"	"	1.04	
"	"	"	909	10.60	87.9	18.0	"	"	1.06	
"	"	"	916	4.30	88.5	47.6	"	"	1.00	
"	"	"	916	4.00	88.5	50.5	"	"	1.01	
"	"	"	918	2.07	44.4	46.0	"	"	0.98	
"	"	"	919	1.08	44.5	105.6	"	"	0.90	

TABLE A-11 (Continued)

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L x 10^9 Perm. Value cm	Remarks*
Test Site No. 7, Grangeville City Center, SH-13 (continued)										
July 17	2	920	901	19.00	179.5	9.5	25	183.2	2.29	EBL, RL, RWT, 9-1/2' from CL
"	"	"	903	17.30	349.0	20.5	"	"	2.27	
"	"	"	910	9.90	181.0	18.5	"	"	2.26	
"	"	"	910	9.50	181.0	19.0	"	"	2.31	
"	"	"	916	3.90	88.5	23.0	"	"	2.28	
"	"	"	916	3.88	88.5	24.5	"	"	2.15	
"	"	"	917	2.75	88.6	24.8	"	"	3.00	
"	"	"	917	2.71	88.7	53.0	"	"	2.26	
July 17	3	920	898	22.00	347.0	17.8	29	185.1	2.06	EBL, RL, RWT, 7-1/2' from CL
"	"	"	909	11.00	181.0	17.9	"	"	2.14	
"	"	"	916	3.74	88.5	27.1	"	"	2.02	
"	"	"	919	1.16	88.7	87.4	"	"	2.03	
July 17	4	920	895	24.50	177.5	26.6	28	184.6	0.63	EBL, RL, RWT, 9-1/2' from CL
"	"	"	909	10.70	87.9	30.3	"	"	0.63	
"	"	"	916	4.02	88.5	74.3	"	"	0.68	
"	"	"	918	2.41	88.6	137.4	"	"	0.62	
"	"	"	919	0.92	44.4	200.0	"	"	0.56	
July 17	5	920	899	21.00	348.0	17.3	28	184.6	2.22	EBL, RL, RWT, 7-1/2' from CL
"	"	"	910	9.80	181.0	18.7	"	"	2.29	
"	"	"	916	3.98	88.5	24.0	"	"	2.15	
"	"	"	917	2.60	88.6	36.0	"	"	2.20	
"	"	"	919	1.18	88.7	79.0	"	"	2.21	
July 17	6	920	896	23.80	346.0	24.0	28	184.6	1.40	EBL, RL, between Wheel Tracks, 9-1/2' from CL
"	"	"	909	10.80	181.0	24.8	"	"	1.56	
"	"	"	916	4.09	88.5	32.7	"	"	1.54	
"	"	"	917	2.85	88.6	48.0	"	"	1.50	
"	"	"	919	0.91	88.8	136.4	"	"	1.66	
Test Site No. 8, New Meadows, US-95, Mile Post 167										
August 11	1	895	876	19.0	42.4	135.0	28	184.6	0.038	SBL, RL, RWT, 7-1/2' from CL
"	"	"	880	14.9	42.6	162.0	"	"	0.04	
"	"	"	889	6.1	43.0	383.0	"	"	0.043	
"	"	"	894	0.69	43.0	1935.0	"	"	0.075	
Test Site No. 9, McCall Urban, SH-15										
August 10	1	845	821	24.0	39.7	146.6	33	187.0	0.027	WBL, RL, RWT
"	"	"	825	19.7	40.0	160.0	"	"	0.030	
"	"	"	832	13.2	40.3	263.0	"	"	0.027	
"	"	"	834	10.8	40.4	313.0	"	"	0.028	
"	"	"	838	6.7	40.6	456.0	"	"	0.031	
"	"	"	841	3.8	46.7	578.0	"	"	0.043	
Test Site No. 10, Cascade South, SH-15, Mile Post 67										
July 14	1	865	845	20.2	40.8	187.3	30	185.6	0.025	SBL, RL, RWT, 10' from CL
"	"	"	850	14.8	41.2	228.0	"	"	0.023	
"	"	"	863	1.6	41.8	500.0	"	"	0.041	
Test Site No. 11, Oregon Line East, I-80N, Mile Post 7										
July 13	1	950	926	23.50	179.0	17.5	45	193.0	1.06	WBL, RL, RWT, 8' from CL
"	"	"	936	14.00	182.5	27.7	"	"	1.14	
"	"	"	946	3.70	91.5	52.0	"	"	1.16	

TABLE A-11 (Continued)

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	$k/L \times 10^9$ Perm. Value cm	Remarks*
Test Site No. 11, Oregon Line East, I-80N, Mile Post 7 (continued)										
July 13	1	950	946	3.50	91.5	55.0	45	193.0	1.16	WBL, RL, RWT, 8' from CL
"	"	"	946	3.55	91.7	58.0	"	"	1.24	
"	"	"	948	1.60	91.7	60.0	"	"	1.16	
"	"	"	948	1.60	91.7	61.7	"	"	1.13	
"	"	"	948	1.60	91.7	64.0	"	"	1.08	
July 13	2	950	930	20.00	181.0	16.0	45	193.0	1.38	WBL, RL, RWT, 8' from CL
"	"	"	931	18.90	182.0	16.8	"	"	1.39	
"	"	"	932	17.60	182.0	17.8	"	"	1.41	
"	"	"	946	3.50	91.5	44.5	"	"	1.43	
"	"	"	947	3.45	91.5	47.2	"	"	1.30	
"	"	"	948	1.70	91.7	91.5	"	"	1.43	
"	"	"	948	1.60	45.8	49.5	"	"	1.41	
"	"	"	948	1.55	45.8	49.0	"	"	1.47	
"	"	"	948	1.45	45.8	51.0	"	"	1.51	
July 13	3	950	927	22.50	179.5	11.7	49	194.8	1.69	WBL, RL, RWT, 8' from CL
"	"	"	929	21.00	180.0	13.8	"	"	1.52	
"	"	"	946	3.65	91.5	32.0	"	"	1.92	
"	"	"	946	3.60	45.6	16.2	"	"	1.92	
"	"	"	948	1.68	45.8	34.5	"	"	1.94	
"	"	"	948	1.65	45.8	35.0	"	"	1.94	
"	"	"	948	1.65	45.8	35.0	"	"	1.94	
July 13	4	950	934	16.00	362.0	12.0	49	194.8	4.62	WBL, RL, RWT, 8' from CL
"	"	"	946	3.55	183.0	24.6	"	"	5.14	
"	"	"	947	3.30	183.0	26.0	"	"	5.23	
"	"	"	948	1.65	91.7	25.7	"	"	5.30	
"	"	"	948	1.57	91.7	26.0	"	"	5.50	
July 13	5	950	926	23.60	179.0	17.6	50	195.4	2.38	WBL, RL, RWT, 8' from CL
"	"	"	946	3.50	137.5	33.5	"	"	2.86	
"	"	"	947	3.25	91.5	24.6	"	"	2.80	
"	"	"	948	2.05	91.6	35.2	"	"	3.11	
"	"	"	948	1.95	91.7	39.0	"	"	2.96	
July 13	6	950	928	22.40	359.0	22.5	45	192.7	1.73	WBL, RL, RWT, 8' from CL
"	"	"	946	3.55	91.5	30.0	"	"	2.08	
"	"	"	946	3.55	91.5	31.2	"	"	2.00	
"	"	"	948	1.90	91.7	27.4	"	"	2.13	
Test Site No. 12, Nampa South, SH-45, Mile Post 24										
June 14	1	945	923	21.6	221	73.0	20	180.8	0.318	SBL, RL, 6' from CL
"	"	"	926	18.8	223	79.0	"	"	0.339	
"	"	"	929	16.3	223	31.0	"	"	0.340	
"	"	"	931	13.7	224	101.5	"	"	0.360	
"	"	"	934	10.9	225	120.6	"	"	0.388	
"	"	"	941	3.53	228	303.5	"	"	0.480	
"	2	"	922	23.4	220	60.8	19	180.3	0.352	SBL, RL, 6' from CL
"	"	"	924	20.6	221	69.5	"	"	0.350	
"	"	"	927	17.5	222	77.0	"	"	0.373	
"	"	"	930	15.0	223	75.0	"	"	**	
"	"	"	932	12.5	225	95.0	"	"	0.428	
"	"	"	942	3.3	228	294.5	"	"	0.532	
Test Site No. 13, Eagle-Star, SH-44, Mile Post 47										
June 13	1	940	916	23.90	443	79.2	36	188.5	0.552	WBL, RL, RWT, 8' from CL
"	"	"	922	18.30	446	103.8	"	"	0.553	
"	"	"	926	13.70	448	215.3	"	"	0.356	
"	"	"	937	2.54	227	319.4	"	"	0.663	

**unreasonable value

TABLE A-II (Continued)

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L x 10^9 Perm. Value cm	Remarks*
Test Site No. 13, Eagle-Star, SH-44, Mile Post 47 (continued)										
June 13	2	940	918	22.30	443	89.4	36	188.5	0.526	WBL, RWT, 8' from CL
"	"	"	923	16.50	445	115.8	"	"	0.551	
"	"	"	932	7.62	226	113.7	"	"	0.611	
"	"	"	935	5.08	226	171.0	"	"	0.610	
"	"	"	937	2.54	227	355.2	"	"	0.591	
June 13	3	940	927	12.95	224	79.4	34	187.5	0.513	WBL, RWT, 8' from CL
"	"	"	929	10.65	225	101.0	"	"	0.494	
"	"	"	932	7.62	225	133.2	"	"	0.522	
"	"	"	935	5.08	226	205.6	"	"	0.510	
"	"	"	938	2.28	227	460.6	"	"	0.509	
June 13	4	940	923	17.0	446	99.0	34	187.5	0.626	WBL, RWT, 8' from CL
"	"	"	928	12.4	448	121.0	"	"	0.699	
"	"	"	930	9.6	225	76.0	"	"	0.724	
"	"	"	933	6.6	225	95.0	"	"	0.844	
"	"	"	935	4.8	226	150.0	"	"	0.735	
"	"	"	938	2.3	227	292.2	"	"	0.804	
June 13	5	940	923	16.5	223	65.1	34	187.5	0.491	WBL, RWT, 8' from CL
"	"	"	927	13.2	224	80.0	"	"	0.501	
"	"	"	930	10.4	225	90.0	"	"	0.564	
"	"	"	932	7.9	225	127.0	"	"	0.532	
"	"	"	935	5.3	226	166.0	"	"	0.601	
"	"	"	937	2.5	227	362.0	"	"	0.583	
Test Site No. 14, Boise-Mt. Home, US-30, Mile Post 81										
June 15	1	928	908	20.0	439	35.0	25	183.2	1.43	EBL, RL, LWT, 3' R of CL
"	"	"	917	10.7	444.0	58.0	"	"	1.64	
"	"	"	905	23.4	438.0	31.0	"	"	1.39	
"	"	"	909	19.3	439.0	35.0	"	"	1.48	
"	"	"	914	13.7	442.0	43.2	"	"	1.71	
"	"	"	917	10.7	444.0	58.2	"	"	1.64	
"	"	"	921	7.4	223.0	37.1	"	"	1.87	
"	"	"	923	5.1	223	57.0	"	"	2.04	
June 15	2	928	913	14.50	442	25.0	25	183.2	2.80	EBL, RL, LWT, 3' R of CL
"	"	"	917	10.70	444	32.4	"	"	2.94	
"	"	"	918	9.60	444	35.0	"	"	3.04	
"	"	"	920	7.60	445	44.0	"	"	3.08	
"	"	"	924	4.10	446	80.0	"	"	3.12	
"	"	"	927	1.27	447	125.0	"	"	3.23	
June 15	3	928	908	20.00	439	15.0	27	184.1	3.40	EBL, RL, LWT, 3' R of CL
"	"	"	913	14.70	442	20.0	"	"	3.48	
"	"	"	919	9.40	444	25.0	"	"	4.37	
"	"	"	922	6.35	445	40.0	"	"	4.08	
"	"	"	924	3.56	223	31.0	"	"	4.71	
"	"	"	926	1.78	223.5	70.0	"	"	4.08	
June 15	4	928	916	12.20	443	13.5	27	184.1	6.22	EBL, RL, LWT, 3' R of CL
"	"	"	917	10.65	444	16.2	"	"	5.95	
"	"	"	919	8.90	445	17.5	"	"	6.60	
"	"	"	921	6.60	445	24.0	"	"	6.51	
"	"	"	924	4.06	446	40.5	"	"	6.27	
"	"	"	926	1.52	223	54.5	"	"	6.24	
June 15	5	928	920	8.15	445	12.0	29	185.1	10.60	EBL, RL, LWT, 3' R of CL
"	"	"	921	6.60	445	11.0	"	"	14.30	
"	"	"	922	5.60	446	17.5	"	"	10.60	
"	"	"	924	3.56	447	25.0	"	"	11.80	
"	"	"	926	1.78	447	62.4	"	"	10.20	
June 15	6	928	916	11.70	444	14.5	29	185.1	6.20	EBL, RL, LWT, 3' R of CL
"	"	"	918	9.65	444	17.0	"	"	6.40	
"	"	"	920	7.60	445	19.0	"	"	7.20	
"	"	"	923	5.10	446	28.0	"	"	7.20	

TABLE A-11 (Continued)

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L x 10^9 Perm. Value cm	Remarks*
Test Site No. 14, Boise-Mt. Home, US-30, Mile Post 81 (continued)										
June 15	6	928	925	2.54	447	64.0	29	185.1	6.40	EBL, RL, LWT, 3' R of CL
June 15	7	928	917	11.40	444	11.5	29	185.1	7.90	EBL, RL, LWT, 3' R of CL
"	"	"	918	9.65	444	14.0	"	"	7.70	
"	"	"	920	8.15	445	16.5	"	"	7.70	
"	"	"	922	6.10	446	21.0	"	"	8.15	
"	"	"	924	3.80	447	32.5	"	"	8.45	
"	"	"	926	2.28	447	37.0	"	"	6.20	
Test Site No. 15, Hammett West, US-20-26-30, Mile Post 120+										
July 2	1	945	915	30.00	88.6	283.3	45.5	193.0	0.0254	WBL, RL, RWT, 9' from CL
"	"	"	935	9.65	45.2	298.7	"	"	0.0384	
"	"	"	937	8.10	45.3	321.0	"	"	0.0417	
"	"	"	940	4.95	45.4	512.0	"	"	0.0435	
July 2	2	945	915	30.3	44.2	89.3	45.5	193.0	0.0355	WBL, RL, RWT, 9' from CL
"	"	"	916	28.7	44.4	117.4	"	"	0.0320	
"	"	"	920	25.2	44.6	130.0	"	"	0.0324	
"	"	"	940	4.57	45.4	600.0	"	"	0.0380	
July 2	3	945	913	31.8	44.2	86.6	45.5	193.0	0.0395	WBL, RL, RWT, 9' from CL
"	"	"	915	30.0	44.4	111.4	"	"	0.0325	
"	"	"	917	28.0	44.5	120.0	"	"	0.0320	
"	"	"	940	4.56	45.4	508.0	"	"	0.0476	
Test Site No. 16, Gooding-Bliss, US-20-26, Mile Post 157										
July 2	1	910	894	16.25	173.0	12.9	41	190.9	2.00	WBL, RL, RWT, 8-1/2' from CL
"	"	"	900	10.40	174.0	19.7	"	"	2.04	
"	"	"	904	5.60	87.5	18.0	"	"	2.08	
"	"	"	907	3.04	43.8	18.4	"	"	1.88	
July 2	2	910	895	15.25	433.0	37.0	41	190.9	1.84	WBL
"	"	"	899	11.40	434.0	51.4	"	"	1.78	
"	"	"	903	6.85	435.0	79.0	"	"	1.92	
July 2	3	910	889	21.20	430.0	19.0	41.6	191.2	2.56	WBL, RL, RWT, 8-1/2' from CL
"	"	"	891	18.50	432.0	22.0	"	"	2.56	
"	"	"	893	16.50	433.0	23.0	"	"	2.67	
"	"	"	906	4.45	436.0	90.0	"	"	2.62	
July 2	4	910	892	18.30	432.0	30.0	41.6	191.2	1.90	WBL, RL, RWT, 8-1/2' from CL
"	"	"	893	17.00	433.0	34.5	"	"	1.78	
"	"	"	895	14.80	433.0	40.4	"	"	1.75	
"	"	"	903	6.60	436.0	90.0	"	"	1.78	
"	"	"	906	3.55	437.0	160.0	"	"	1.86	
July 2	5	910	891	19.30	431.0	24.2	42	191.3	2.22	WBL, RL, RWT, 8-1/2' from CL
"	"	"	893	17.4	432	26.8	"	"	2.18	
"	"	"	906	3.8	437	112.2	"	"	2.48	
Test Site No. 17, Twin Falls South, US-93, Mile Post 35										
June 30	1	900	868	32.00	42.0	89.0	27	184.1	0.0343	SBL, RL, RWT, 7-1/2' from CL
"	"	"	871	29.40	42.1	86.0	"	"	0.0387	
"	"	"	875	24.90	84.8	198.0	"	"	0.0399	
"	"	"	893	7.00	43.2	330.0	"	"	0.0434	
"	"	"	895	5.00	43.3	458.0	"	"	0.0432	
"	"	"	898	2.28	43.4	570.0	"	"	0.0775	
June 30	2	900	876	23.8	42.4	212.0	25	183.2	0.0193	SBL, RL, RWT, 8' from CL
June 29	3	900	882	18.2	41.6	180.0	25.5	183.4	0.0300	SBL, RL, RWT, 8' from CL
"	"	"	892	7.8	43.2	318.0	"	"	0.0400	

TABLE A-II (Continued)

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L x 10^9 Perm. Value cm	Remarks*
Test Site No. 17, Twin Falls South, US-93, Mile Post 35 (continued)										
June 29	3	900	889	11.3	43.0	200.0	25.5	183.4	0.0438	SBL, RL, RWT, 8' from CL
June 30	4	900	869	31.00	42.0	90.0	27	184.1	0.0350	SBL, RL, RWT, 7-1/2' from CL
"	"	"	871	28.6	42.2	94.0	"	"	0.0364	
"	"	"	875	24.60	84.8	210.0	"	"	0.0379	
"	"	"	889	10.90	43.0	132.5	"	"	0.0690	
"	"	"	889	10.90	43.0	187.0	"	"	0.0489	
"	"	"	889	11.05	43.0	251.4	"	"	0.0360	
"	"	"	982	8.25	43.1	290.0	"	"	0.0418	
"	"	"	893	6.6	43.2	313.6	"	"	0.0486	
"	"	"	895	4.80	43.3	454.0	"	"	0.0462	
Test Site No. 18, Hailey-Ketchum, US-93, Mile Post 122										
June 30	1	845	813	32.20	39.3	74.0	27	184.6	0.0384	NBL, RL, RWT, 7-1/2' from CL
"	"	"	816	29.40	39.4	71.0	"	"	0.0438	
"	"	"	820	25.40	79.3	162.5	"	"	0.0445	
"	"	"	830	15.40	40.1	120.0	"	"	0.0503	
"	"	"	832	12.70	40.2	155.2	"	"	0.0474	
"	"	"	835	10.15	40.4	182.0	"	"	0.0507	
"	"	"	838	7.55	40.5	280.0	"	"	0.0444	
"	"	"	840	4.80	40.6	395.5	"	"	0.0498	
June 30	2	845	812	33.00	78.8	60.0	27	184.6	0.0923	NBL, RL, RWT, 7-1/2' from CL
"	"	"	815	30.20	39.4	32.4	"	"	0.0936	
"	"	"	818	26.60	79.5	72.5	"	"	0.0955	
"	"	"	822	22.60	39.8	48.0	"	"	0.0870	
"	"	"	825	20.30	39.9	43.4	"	"	0.1050	
"	"	"	841	3.70	40.4	193.0	"	"	0.1310	
"	"	"	842	2.80	40.5	262.0	"	"	0.1270	
June 30	3	845	814	30.8	78.6	31.4	27	184.6	0.189	NBL, RL, RWT, 7-1/2' from CL
"	"	"	819	25.9	79.1	36.0	"	"	0.197	
"	"	"	824	20.8	79.5	42.0	"	"	0.211	
"	"	"	837	7.6	40.5	45.0	"	"	0.274	
"	"	"	839	5.5	40.6	61.0	"	"	0.280	
"	"	"	841	4.2	40.6	79.0	"	"	0.284	
June 30	4	845	810	35.3	39.1	41.8	27	184.6	0.0615	NBL, RL, RWT, 7-1/2' from CL
"	"	"	810	34.6	39.2	49.0	"	"	0.0536	
"	"	"	840	5.1	40.6	215.4	"	"	0.0850	
"	"	"	841	4.2	40.6	232.0	"	"	0.0965	
Test Site No. 19, Ketchum-Stanley, US-93, Mile Post 151+										
July 1	1	830	801	29.0	77.6	22.0	30	185.6	0.283	SBL, RL, RWT, 8' from CL
"	"	"	811	18.5	78.5	31.0	"	"	0.318	
"	"	"	814	13.5	78.8	38.8	"	"	0.350	
"	"	"	822	8.1	79.4	52.8	"	"	0.431	
"	"	"	826	3.6	80.0	110.0	"	"	0.476	
"	"	"	826	3.8	40.0	45.0	"	"	0.544	
"	"	"	827	2.8	40.3	50.4	"	"	0.665	
July 1	2	830	798	31.9	77.1	130.0	30	185.6	0.0354	SBL, RL, RWT, 8' from CL
"	"	"	796	33.5	77.4	154.0	"	"	0.0349	
"	"	"	802	28.4	77.7	167.8	"	"	0.0379	
"	.	"	817	12.7	39.5	161.8	"	"	0.0450	
"	"	"	820	10.4	39.5	196.5	"	"	0.0452	
"	"	"	821	8.9	39.7	218.5	"	"	0.0475	
"	"	"	822	7.6	39.8	322.0	"	"	0.0380	
"	"	"	824	5.6	40.0	347.5	"	"	0.0478	
July 1	3	830	793	37.40	38.4	27.6	30	185.6	0.0865	SBL, RL, RWT, 8' from CL
"	"	"	797	33.00	77.2	60.0	"	"	0.0906	
"	"	"	801	28.2	77.7	70.0	"	"	0.0916	

TABLE A-II (Continued)

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L x 10^9 Perm. Value cm	Remarks*
Test Site No. 19, Ketchum-Stanley, US-93, Mile Post 122 (continued)										
July 1	3	830	821	9.40	39.7	102.5	30	185.6	0.0960	SBL, RL, RWT, 8' from CL
"	"	"	822	7.90	39.8	106.5	"	"	0.110	
"	"	"	822	7.90	39.8	101.4	"	"	0.0834	
"	"	"	825	5.10	39.9	195.0	"	"	0.0940	
"	"	"	827	3.05	40.0	220.0	"	"	0.1380	
July 1	4	830	791	38.90	77.1	54.3	28	184.6	0.0847	SBL, RL, RWT, 8' from CL
"	"	"	796	33.50	77.4	68.0	"	"	0.0790	
"	"	"	799	28.70	77.7	77.5	'	"	0.0810	
"	"	"	823	6.72	39.8	148.0	"	"	0.0928	
"	"	"	824	5.85	39.9	161.2	"	"	0.0980	
"	"	"	825	5.20	39.9	195.6	"	"	0.0910	
"	"	"	825	5.08	39.9	211.0	"	"	0.0863	
July	5	830	822	8.1	159.0	35.0	28	184.6	1.30	SBL, RL, RWT, 8' from CL
"	"	"	825	4.6	79.9	25.0	"	"	1.61	
"	"	"	828	2.0	80.1	46.8	"	"	1.98	
Test Site No. 20, Stanley South, US-93, Mile Post 181										
July 1	1	820	770	30.20	38.2	90.0	22.8	182.1	0.0325	NBL, RL, RWT, 8' from CL
"	"	"	794	25.89	77.0	182.5	"	"	0.0376	
"	"	"	799	20.80	77.4	240.0	"	"	0.0359	
"	"	"	803	16.80	38.9	152.5	"	"	0.0350	
"	"	"	816	4.06	39.4	551.0	"	"	0.0404	
July 1	2	820	704	26.0	76.8	205.5	22.8	182.1	0.0332	NBL, RL, RWT, 8' from CL
"	"	"	800	19.8	77.4	238.0	"	"	0.0380	
"	"	"	814	6.0	39.3	725.0	"	"	0.0412	
"	"	"	816	4.3	39.5	440.5	"	"	0.0480	
July 1	3	820	788	32.2	38.1	78.5	23	182.2	0.0349	NBL, RL, RWT, 8' from CL
"	"	"	790	29.9	38.2	88.5	"	"	0.0334	
"	"	"	793	26.8	38.3	90.0	"	"	0.0367	
"	"	"	813	7.1	87.4	455.8	"	"	0.0560	
"	"	"	813	7.1	39.2	309.4	"	"	0.0412	
"	"	"	815	4.7	39.5	350.6	"	"	0.0556	
"	"	"	797	22.6	77.2	231.2	"	"	0.0340	
Test Site No. 21, Shoshone-Carey, US-93A, Mile Post 184+										
July 2	1	892	861	30.7	83.4	203.4	33	187.0	0.0312	EBL, RL, RWT, 8' from CL
"	"	"	866	25.6	84.0	235.0	"	"	0.0328	
"	"	"	881	11.0	42.6	232.0	"	"	0.0392	
"	"	"	883	9.0	42.7	263.0	"	"	0.0424	
"	"	"	884	7.9	42.8	229.0	"	"	0.0387	
"	"	"	886	6.1	42.9	304.0	"	"	0.0543	
"	"	"	888	4.3	43.0	540.0	"	"	0.0435	
July 2	2	892	855	37.11	82.5	172.4	32	186.6	0.0304	EBL, RL, RWT, 8' from CL
"	"	"	860	31.50	83.1	197.8	"	"	0.0315	
"	"	"	865	27.00	83.5	225.0	"	"	0.0325	
"	"	"	881	10.80	42.5	223.0	"	"	0.0415	
"	"	"	882	9.50	42.6	273.0	"	"	0.0385	
"	"	"	884	8.40	42.7	283.7	"	"	0.0420	
"	"	"	885	7.10	42.8	380.0	"	"	0.0404	
"	"	"	887	5.34	43.0	407.1	"	"	0.0464	
Test Site No. 22 Heyburn I. C., I-80N										
June 15	1	895	891	3.80	423	10.0	20	180.8	25.8	EBL, LL, RWT, 1' from CL
"	"	"	892	3.05	432	12.0	"	"	26.8	

TABLE A-II (Continued)

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L x 10^9 Perm. Value cm	Remarks*
Test Site No. 22, Heyburn I.C., I-80N (continued)										
June 15	1	895	893	2.30	433	15.0	20	180.8	21.5	EBL, LL, RWT, 1' from CL
"	"	"	893	1.78	433	21.2	"	"	26.0	
"	"	"	891	3.56	432	10.0	"	"	27.6	
"	"	"	892	3.05	432	11.0	"	"	29.2	
June 15	2	895	891	4.05	432	10.0	20	180.8	24.2	EBL, LL, RWT, 1' from CL
"	"	"	892	3.05	432	11.0	"	"	28.9	
"	"	"	892	3.05	432	12.5	"	"	25.7	
"	"	"	893	2.28	433	16.0	"	"	25.7	
"	"	"	893	1.52	433	23.7	"	"	27.4	
"	"	"	891	4.05	432	10.0	"	"	24.2	
"	"	"	891	3.55	432	12.0	"	"	23.0	
June 15	3	895	891	3.56	432	10.5	20	180.8	25.9	EBL, LL, RWT, 1' from CL
"	"	"	892	3.05	432	11.2	"	"	28.7	
"	"	"	892	2.80	432	13.0	"	"	27.0	
"	"	"	893	2.03	433	16.5	"	"	29.4	
"	"	"	893	1.52	212	11.2	"	"	29.0	
Test Site No. 23, American Falls, I-15W										
June 29	1	880	865	14.90	837.0	17.8	40	190.4	7.56	WBL, LL, LWT, 12' from CL
"	"	"	874	5.60	423.0	21.8	"	"	8.43	
"	"	"	875	5.40	423.0	24.8	"	"	7.56	
"	"	"	875	5.40	423.0	23.8	"	"	7.90	
"	"	"	875	5.40	423.0	25.0	"	"	7.52	
"	"	"	878	1.71	424.0	69.0	"	"	8.63	
"	"	"	878	1.68	424.0	69.5	"	"	8.70	
"	"	"	878	1.64	424.0	72.4	"	"	8.56	
"	"	"	878	1.59	424.0	74.0	"	"	8.55	
June 29	2	880	865	15.40	418.0	30.0	38	189.5	2.15	WBL, LL, LWT, 12' from CL
"	"	"	865	14.90	418.0	31.6	"	"	2.11	
"	"	"	874	6.10	423.0	73.7	"	"	2.26	
"	"	"	874	5.90	423.0	78.8	"	"	2.27	
"	"	"	878	1.65	424.0	221.0	"	"	2.76	
"	"	"	878	1.66	424.0	226.0	"	"	2.68	
June 29	3	880	864	16.40	417.0	15.0	40	190.4	4.07	WBL, LL, LWT, 12' from CL
"	"	"	864	15.90	418.0	15.1	"	"	4.18	
"	"	"	864	15.50	836.0	28.8	"	"	4.48	
"	"	"	874	5.90	423.0	35.4	"	"	4.78	
"	"	"	874	5.70	423.0	36.8	"	"	5.04	
"	"	"	878	1.74	424.0	125.8	"	"	4.74	
June 29	4	880	862	18.20	839.0	16.4	40	190.4	6.74	WBL, LL, LWT, 12' from CL
"	"	"	862	17.80	838.0	16.8	"	"	6.73	
"	"	"	874	6.10	422.0	17.6	"	"	9.40	
"	"	"	874	5.85	423.0	17.5	"	"	9.93	
"	"	"	874	5.70	423.0	18.4	"	"	9.50	
"	"	"	878	1.59	424.0	68.0	"	"	9.45	
Test Site No. 24, Malad City, US-191, Mile Post 13+										
June 28	1	865	835	29.90	80.6	146.8	43	191.8	0.0456	NBL, RL, RWT, 9' from CL
"	"	"	838	26.70	40.6	84.8	"	"	0.0422	
"	"	"	840	24.60	40.7	87.2	"	"	0.0459	
"	"	"	852	12.60	41.3	142.0	"	"	0.0557	
"	"	"	853	12.30	41.3	154.4	"	"	0.0525	
"	"	"	861	3.80	41.7	473.0	"	"	0.0558	
"	"	"	862	3.15	41.7	573.0	"	"	0.0558	
June 28	2	865	844	20.60	81.7	52.8	43	191.8	0.181	NBL, RL, RWT, 9' from CL
"	"	"	858	7.30	41.5	56.0	"	"	0.245	Crack in test area
"	"	"	858	6.60	41.5	65.5	"	"	0.233	

TABLE A-II (Continued)

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L x 10^9 Perm. Value cm	Remarks*
Test Site No. 24, Malad City, US-191, Mile Post 13+ (continued)										
June 28	2	865	859	5.70	41.6	70.0	43	191.8	0.252	NBL, RL, RWT, 9' from CL
"	"	"	860	4.90	41.6	85.0	"	"	0.242	Crack in test area
"	"	"	861	3.90	41.7	90.4	"	"	0.284	
"	"	"	862	3.40	41.7	122.0	"	"	0.243	
"	"	"	862	2.55	41.8	160.0	"	"	0.246	
June 28	3	865	835	29.50	80.6	136.2	42	191.3	0.049	NBL, RL, RWT, 9' from CL
"	"	"	838	26.50	40.6	81.6	"	"	0.045	
"	"	"	852	12.80	41.3	136.0	"	"	0.057	
"	"	"	853	11.50	41.4	166.0	"	"	0.052	
"	"	"	861	3.60	41.7	441.0	"	"	0.063	
"	"	"	862	3.00	41.7	552.0	"	"	0.061	
Test Site No. 25, Pocatello-Blackfoot, I-15										
June 27	1	875	852	23.00	82.4	126.4	43	191.8	0.068	NBL, RL, RWT, 8' from CL
"	"	"	867	8.40	41.9	141.8	"	"	0.084	
"	"	"	867	7.70	42.0	148.0	"	"	0.089	
"	"	"	868	7.10	42.0	178.6	"	"	0.081	
"	"	"	871	3.60	42.2	333.0	"	"	0.085	
"	"	"	872	2.80	42.2	382.2	"	"	0.095	
"	"	"	873	2.05	42.3	590.0	"	"	0.085	
June 27	2	875	853	22.0	41.3	40.8	41	190.9	0.111	NBL, RL, RWT, 8' from CL
"	"	"	867	8.40	41.9	91.4	"	"	0.131	
"	"	"	872	2.50	42.2	252.0	"	"	0.163	
June 27	3	875	850	24.75	41.2	80.4	41	190.9	0.050	NBL, RL, RWT, 8' from CL
"	"	"	875	10.30	41.8	150.0	"	"	0.065	
"	"	"	863	2.00	42.3	709.5	"	"	0.072	
Test Site No. 26, Idaho Falls-Blackfoot, I-15										
June 27	1	870	841	29.40	81.4	65.0	31.0	186.1	0.050	SBL, RL, RWT, 8' from CL
"	"	"	844	25.90	40.8	75.0	"	"	0.049	
"	"	"	846	24.00	40.9	76.5	"	"	0.052	
"	"	"	862	7.60	41.7	198.5	"	"	0.065	
"	"	"	863	6.80	41.7	212.8	"	"	0.068	
"	"	"	864	5.80	41.8	247.8	"	"	0.068	
"	"	"	868	2.35	41.9	617.0	"	"	0.068	
"	"	"	868	1.55	42.0	718.0	"	"	0.088	
June 27	2	870	843	26.80	81.5	134.4	34.0	187.5	0.053	SBL, RL, RWT, 8' from CL
"	"	"	846	24.20	40.9	78.0	"	"	0.051	
"	"	"	861	8.80	41.6	170.0	"	"	0.066	
"	"	"	861	8.75	41.6	164.8	"	"	0.068	
"	"	"	862	7.65	41.7	202.5	"	"	0.062	
"	"	"	868	1.75	42.0	806.0	"	"	0.070	
June 27	3	870	845	25.25	81.5	136.6	35.0	188.0	0.056	SBL, RL, RWT, 8' from CL
"	"	"	847	23.40	41.0	79.2	"	"	0.053	
"	"	"	848	21.60	41.1	78.6	"	"	0.057	
"	"	"	862	8.30	41.6	186.4	"	"	0.063	
"	"	"	868	2.10	41.9	518.7	"	"	0.091	
Test Site No. 27, Idaho Falls-Arco, US-20, Mile Post 318										
June 26	1	865	826	39.0	40.0	49.3	33.0	187.0	0.049	EBL, RL, RWT, 7½' from CL
"	"	"	828	37.0	40.1	48.5	"	"	0.053	
"	"	"	850	14.8	82.1	210.0	"	"	0.062	
"	"	"	852	12.6	41.2	133.2	"	"	0.058	
"	"	"	854	10.6	82.5	283.0	"	"	0.065	

TABLE A-II (Continued)

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L x 10^9 Perm. Value cm	Remarks*
Test Site No. 27, Idaho Falls - Arco, US-20, Mile Post 318 (continued)										
June 26	1	865	856	9.1	41.4	153.8	33.0	187.0	0.070	EBL, RL, RWT, 7½' from CL
"	"	"	857	7.6	41.5	210.0	"	"	0.062	
"	"	"	862	2.8	41.7	540.0	"	"	0.066	
June 26	2	865	857	8.20	41.5	195.2	33.0	187.0	0.061	EBL, RL, RWT, 7' from CL
"	"	"	858	6.90	41.5	221.0	"	"	0.063	
"	"	"	859	5.90	41.6	226.2	"	"	0.073	
"	"	"	860	5.10	83.0	534.0	"	"	0.071	
Test Site No. 28, Rexburg West, SH-88, Mile Post 335										
June 26	1	860	829	30.80	80.2	110.0	34	187.5	0.056	EBL, RL, RWT, 9' from CL
"	"	"	853	7.40	41.2	197.5	"	"	0.062	
"	"	"	854	6.35	41.3	216.0	"	"	0.071	
"	"	"	855	4.70	41.4	286.0	"	"	0.073	
"	"	"	856	3.90	41.5	329.0	"	"	0.076	
"	"	"	858	2.42	41.5	393.0	"	"	0.103	
June 26	2	860	829	31.4	80.2	41.0	34	187.5	0.147	EBL, RL, RWT, 9' from CL
"	"	"	846	14.3	40.9	99.4	"	"	0.067	
"	"	"	849	11.5	82.0	246.0	"	"	0.069	
"	"	"	852	8.0	41.2	160.0	"	"	0.077	
"	"	"	853	6.7	41.3	192.7	"	"	0.076	
"	"	"	855	4.5	41.4	280.5	"	"	0.077	
"	"	"	857	2.7	41.5	443.4	"	"	0.082	
June 26	3	860	827	32.5	160.2	209.0	36.0	188.5	0.055	EBL, RL, RWT, 7' from CL
"	"	"	845	15.0	40.9	100.0	"	"	0.064	
"	"	"	847	12.7	41.0	119.0	"	"	0.064	
"	"	"	848	11.8	41.0	134.0	"	"	0.063	
"	"	"	851	9.4	41.1	174.5	"	"	0.059	
"	"	"	852	8.0	41.2	206.0	"	"	0.059	
"	"	"	855	5.0	41.4	276.4	"	"	0.065	
June 26	4	860	827	32.9	40.10	45.0	36	188.5	0.064	EBL, RL, RWT, 7' from CL
"	"	"	831	28.9	40.20	44.0	"	"	0.075	
"	"	"	845	15.4	40.90	81.5	"	"	0.077	
"	"	"	846	13.6	41.00	94.6	"	"	0.075	
"	"	"	848	12.0	41.10	104.0	"	"	0.078	
"	"	"	850	10.2	41.10	130.2	"	"	0.073	
"	"	"	851	8.5	41.20	142.2	"	"	0.080	
"	"	"	853	6.7	41.30	202.0	"	"	0.073	
"	"	"	855	5.1	41.40	257.3	"	"	0.075	

TABLE A-III

LABORATORY TEST DATA FOR ASPHALT PAVEMENT PERMEABILITY STUDY

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	t Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L x 10^9 Perm. Value cm	Cup Area cm^2	Remarks*
Test Site No. 1, Priest River Urban, US 2-195--Core Sample Taken April 5, 1963											
Aug. 5	6	935	912.7	22.3	176.4	29.8	31	186.1	1.11	45.5	
"	"	"	922.5	12.5	178.4	44.2	"	"	1.32	"	
"	"	"	927.6	7.4	179.2	66.4	"	"	1.49	"	
"	"	"	931.2	3.8	180.0	106.8	"	"	1.82	"	
"	"	"	933.2	1.8	90.1	96.0	"	"	2.09	"	
"	"	"	933.3	1.7	90.1	101.2	"	"	2.06	"	
"	"	"	934.1	0.9	90.2	179.0	"	"	2.42	"	
Aug. 5	6	935	914.7	20.3	176.4	85.7	31	186.1	0.675	20.2	WBL, 6' from curb
"	"	"	923.9	11.1	178.4	122.2	"	"	1.20	"	
"	"	"	930.9	4.1	89.9	129.0	"	"	1.56	"	
"	"	"	931.4	3.6	90.0	136.2	"	"	1.67	"	
"	"	"	933.0	2.0	45.1	97.7	"	"	2.12	"	
"	"	"	934.0	1.0	45.1	158.4	"	"	2.77	"	
Sept. 10	6	935 + 68	932.5	70.5	94.1	242.6	-10	176.0	0.0481	20.2	
"	"	935 + 136	932.5	138.5	94.1	120.9	"	"	0.0491	"	
"	"	935 + 272	932.5	274.5	94.1	74.0	"	"	0.0405	"	
"	"	935 + 544	932.5	546.5	94.1	55.7	"	"	0.0271	"	
"	"	935 + 816	932.5	818.5	94.1	49.2	"	"	0.0204	"	
Test Site No. 2, Fourth of July Canyon, US-10, Mile Post 33--Core Sample Taken April 4, 1963											
July 16	1	935	913	22.40	44.1	39.1	26	183.6	0.204	45.5	EBL, 10' R of CL
"	"	"	913	22.10	44.2	42.0	"	"	0.193	"	
"	"	"	925	9.90	44.7	87.0	"	"	0.209	"	
"	"	"	926	9.10	44.7	90.0	"	"	0.220	"	
"	"	"	932	3.40	45.0	212.0	"	"	0.251	"	
"	"	"	934	1.06	45.1	555.0	"	"	0.308	"	
July 16	1	935	912	22.80	88.2	50.0	26	183.6	0.706	20.2	May be error
"	"	"	913	21.70	88.4	54.0	"	"	0.685	"	
"	"	"	923	11.60	44.6	45.0	"	"	0.782	"	
"	"	"	924	11.40	44.6	49.2	"	"	0.726	"	
"	"	"	922	13.20	44.5	55.0	"	"	0.560	"	
"	"	"	923	12.00	44.6	61.5	"	"	0.551	"	
"	"	"	932	3.23	45.0	159.2	"	"	0.788	"	
"	"	"	934	1.20	45.1	512.0	"	"	0.668	"	
July 17	1	935	916	19.00	88.6	56.0	25	183.2	0.336	45.5	
"	"	"	924	11.00	44.6	39.0	"	"	0.418	"	
"	"	"	924	11.20	44.6	42.5	"	"	0.377	"	
"	"	"	932	3.40	45.0	125.0	"	"	0.426	"	
"	"	"	932	3.20	45.0	128.0	"	"	0.442	"	
"	"	"	934	1.18	45.1	306.0	"	"	0.503	"	
Sept. 5	1	935 + 34	934	35	94.1	220.8	27	184.1	0.112	20.2	
"	"	935 + 68	934	69	94.6	107.1	"	"	0.117	"	
"	"	935 + 136	136	136	94.6	56.0	"	"	0.113	"	
"	"	935 + 204	935	204	94.6	49.7	"	"	0.084	"	
"	"	935 + 272	935	272	94.1	29.1	"	"	0.109	"	
"	"	935 + 340	935	340	94.1	34.1	"	"	0.074	"	
"	"	935 + 408	935	408	94.6	42.6	"	"	0.049	"	
"	"	935 + 544	935	544	94.6	57.5	"	"	0.027	"	
"	"	935 + 680	935	680	94.6	89.4	"	"	0.017	"	
"	"	935 + 816	935	818	94.6	119.2	"	"	0.008	"	
Sept. 10	1	935 + 68	933	70	94.1	418.0	-10	175.0	0.276	20.2	
"	"	935 + 136	933	138	94.1	168.4	"	"	0.350	"	
"	"	935 + 272	933	274	94.1	105.4	"	"	0.282	"	
"	"	935 + 544	933	546	94.1	104.7	"	"	0.143	"	
"	"	935 + 816	933	818	94.1	148.0	"	"	0.067	"	
Sept. 12	1	935 + 68	933	70	94.6	100.8	45	189.25	0.124	20.2	
"	"	935 + 136	933	138	94.6	50.1	"	"	0.129	"	
"	"	935 + 272	933	274	94.6	40.3	"	"	0.080	"	
"	"	935 + 544	933	546	94.6	59.3	"	"	0.040	"	

TABLE A-III (Continued)

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm²	P_2 Test Pres. g/cm²	P_1-P_2 Pres. Drop g/cm²	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L × 10³ Perm. Value cm	Cur Area cm²	Remarks*
Test Site No. 2, Fourth of July Canyon, US-10, Mile Post 33--Core Sample Taken April 4, 1963 (continued)											
Sept. 12	1	935 + 816	933	817	95.6	27.0	45	189.25	0.040	20.2	
July 16	2	935	911	23.90	176.0	95.0	26	183.6	0.314	45.5	EBL, 10' R of CL
"	"	"	914	20.50	88.4	52.2	"	"	0.334	"	
"	"	"	932	2.72	45.0	71.0	"	"	0.940	"	May be a leak
"	"	"	932	2.55	45.0	74.5	"	"	0.955	"	
"	"	"	933	2.39	45.0.	77.4	"	"	0.982	"	
"	"	"	934	1.29	45.1	88.8	"	"	1.590	"	
"	"	"	934	1.20	45.1	95.0	"	"	1.590	"	
July 16	2	935	916	18.60	210.0	179.0	26	183.6	0.254	45.5	
"	"	"	922	12.80	211.0	192.4	"	"	0.345	"	
"	"	"	932	3.20	45.0	102.2	"	"	0.555	"	
"	"	"	932	2.90	45.0	112.2	"	"	0.557	"	
"	"	"	932	2.70	45.0	155.0	"	"	0.435	"	
"	"	"	934	1.10	90.2	462.6	"	"	0.712	"	
July 16	2	935	916	18.50	88.6	114.2	25.5	183.4	0.380	20.2	
"	"	"	918	16.80	88.8	124.6	"	"	0.394	"	
"	"	"	932	3.30	45.0	256.2	"	"	0.484	"	
"	"	"	932	2.75	45.0	291.4	"	"	0.512	"	
"	"	"	934	1.02	45.1	647.0	"	"	0.621	"	
Sept. 5	2	935 + 34	934	35	94.6	259.6	28.5	187.1	0.097	20.2	
"	"	935 + 68	934	69	94.6	115.8	"	"	0.109	"	
"	"	935 + 136	935	136	94.6	721.8	"	"	0.089	"	
"	"	935 + 204	935	204	94.6	59.2	"	"	0.073	"	
"	"	935 + 272	935	272	94.6	55.6	"	"	0.058	"	
"	"	935 + 340	935	340	94.6	55.2	"	"	0.046	"	
"	"	935 + 408	935	408	94.6	58.9	"	"	0.362	"	
"	"	935 + 544	935	544	94.4	69.4	"	"	0.023	"	
"	"	935 + 680	935	680	94.4	92.8	"	"	0.014	"	
"	"	935 + 816	934	817	94.6	130.2	"	"	0.008	"	
Sept. 10	2	935 + 34	934	35.0	93.6	436.3	-10	175.0	0.050	20.2	
"	"	935 + 68	933	70.0	93.6	195.6	"	"	0.060	"	
"	"	935 + 272	933	274.0	93.1	74.0	"	"	0.040	"	
"	"	935 + 544	933	546.0	93.6	73.2	"	"	0.020	"	
"	"	935 + 816	933	818.0	93.6	93.1	"	"	0.016	"	
Sept. 12	2	935 + 68	933	70	94.1	88.9	45	188.5	0.140	20.2	
"	"	935 + 136	933	138	93.6	49.4	"	"	0.128	"	
"	"	935 + 272	933	274	94.6	42.7	"	"	0.084	"	
"	"	935 + 544	933	546	94.1	62.3	"	"	0.026	"	
"	"	935 + 816	933	818	94.6	96.2	"	"	0.011	"	
Aug. 1	3	935	915	19.70	1326.0	27.0	25	183.2	10.0	45.5	EBL, 10' R of CL
"	"	"	915	9.80	89.4	37.2	"	"	9.9	"	
"	"	"	931	4.12	499.0	36.0	"	"	12.2	"	
"	"	"	931	4.20	499.0	35.7	"	"	13.4	"	
"	"	"	933	2.27	450.0	61.8	"	"	12.9	"	May be a leak
"	"	"	933	2.25	451.0	63.1	"	"	12.8	"	
"	"	"	934	1.10	451.0	18.4	"	"	13.9	"	
Aug. 1	3	935	909.3	25.7	87.7	31.2	25	183.2	0.99	20.2	
"	"	"	920.8	14.2	89.0	54.2	"	"	1.05	"	
"	"	"	931.4	3.58	90.0.	203.9	"	"	1.12	"	
"	"	"	933	1.95	45.1	172.6	"	"	1.22	"	
Sept. 4	3	935 + 34	935	34	94.6	404.9	28	184.6	0.061	20.2	
"	"	935 + 68	935	68	94.6	144.1	"	"	0.088	"	
"	"	935 + 136	935	136	94.6	86.8	"	"	0.072	"	
"	"	935 + 204	935	204	94.6	69.2	"	"	0.061	"	
"	"	935 + 272	935	272	94.6	64.7	"	"	0.049	"	
"	"	935 + 340	935	340	94.6	61.0	"	"	0.041	"	
"	"	935 + 408	935	408	94.6	65.0	"	"	0.033	"	
"	"	935 + 544	935	544	94.6	69.6	"	"	0.022	"	
"	"	935 + 680	935	680	94.6	84.0	"	"	0.015	"	
"	"	935 + 816	935	816	94.6	96.0	"	"	0.011	"	

TABLE A-III (Continued)

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L x 10^9 Perm. Value cm	Cup Area cm^2	Remarks*
Test Site No. 3, Rose Lake-Dudley, US-10, Mile Post 35--Core Sample Taken April 4, 1963											
Aug. 1	1	935	912.0	23.0	352.8	11.8	25	183.2	11.8	20.2	
"	"	"	919.0	16.0	355.2	17.7	"	"	11.7	"	
"	"	"	923.8	11.2	178.4	12.3	"	"	11.8	"	
"	"	"	930.7	4.25	179.6	29.4	"	"	13.0	"	
"	"	"	930.8	4.15	179.6	31.0	"	"	12.7	"	
"	"	"	933.1	1.90	90.2	31.4	"	"	13.7	"	
"	"	"	933.6	1.35	90.2	43.3	"	"	14.0	"	
Aug. 1	1	935	912.6	22.4	352.8	10.8	25	183.2	6.1	45.5	EBL, 12' R of CL
"	"	"	921.5	13.5	356.0	17.7	"	"	6.0	"	
"	"	"	931.0	3.97	179.7	22.5	"	"	8.1	"	
"	"	"	932.8	2.24	180.0	38.2	"	"	8.5	"	
"	"	"	932.8	2.15	180.0	40.8	"	"	8.3	"	
"	"	"	833.8	1.16	90.2	36.5	"	"	8.6	"	
"	"	"	833.8	1.15	90.2	36.8	"	"	8.6	"	
Sept. 6	1	935 + 34	953	16	917.8	60.3	27	184.1	8.40	20.2	EBL, 12' R of CL
"	"	935 + 68	972	31	901.8	34.9	"	"	7.60	"	
"	"	935 + 136	1002	69	981.0	22.4	"	"	5.79	"	
"	"	935 + 204	1038	101	943.6	18.0	"	"	4.74	"	
"	"	935 + 272	1065	142	944.0	16.1	"	"	3.76	"	
"	"	935 + 340	1085	190	1043.6	14.6	"	"	3.43	"	
"	"	935 + 408	1105	238	1054.6	14.0	"	"	2.88	"	
"	"	935 + 544	1151	328	2140.0	25.1	"	"	2.372	"	
"	"	935 + 680	1170	445	2190.0	24.0	"	"	1.412	"	
Sept. 10	1	935 + 68	973	30	886.9	32.5	-10	175.0	.727	20.2	
"	"	935 + 136	1005	66	881.4	21.8	"	"	.535	"	
"	"	935 + 272	1075	132	832.6	15.2	"	"	.362	"	
"	"	935 + 544	1175	304	1665.0	23.1	"	"	.223	"	
Sept. 13	1	935 + 68	967	36	891.4	37.6	45	188.25	.615	20.2	
"	"	935 + 136	1000	71	874.0	23.0	"	"	.575	"	
"	"	935 + 272	1055	152	882.0	16.6	"	"	.324	"	
"	"	935 + 544	1120	359	905.0	13.3	"	"	.137	"	
"	"	935 + 680	1140	475	950.0	12.8	"	"	.145	"	
Aug. 1	2	935	915	19.80	1326.0	33.0	26	183.6	11.8	45.5	EBL, 10' R of CL
"	"	"	923	11.80	896.0	24.8	"	"	12.2	"	
"	"	"	931	3.68	900.0	61.4	"	"	16.1	"	
"	"	"	933	2.25	450.0	47.8	"	"	16.9	"	
"	"	"	933	2.10	450.0	48.4	"	"	17.1	"	
"	"	"	934	1.10	451.0	91.0	"	"	18.2	"	
"	"	"	934	1.06	451.0	93.0	"	"	18.5	"	
Aug. 1	2	935	914	21.10	1326.0	23.0	25	183.2	24.8	20.2	
"	"	"	925	10.00	1338.0	43.0	"	"	28.2	"	
"	"	"	931	3.94	899.0	62.0	"	"	33.4	"	
"	"	"	931	3.77	900.0	63.5	"	"	34.1	"	
"	"	"	933	2.23	450.0	50.8	"	"	36.1	"	
"	"	"	934	1.07	451.0	100.0	"	"	38.2	"	
"	"	"	934	1.03	451.0	100.8	"	"	39.4	"	
Sept. 4	2	935 + 34	958	11	884.0	38.2	27	184.1	19.18	20.2	
"	"	935 + 68	979	22	876.6	22.7	"	"	16.04	"	
"	"	935 + 136	1033	38	839.2	14.2	"	"	13.98	"	
"	"	935 + 204	1090	49	1596.6	22.4	"	"	13.28	"	
"	"	935 + 272	1151	56	1536.0	19.3	"	"	12.96	"	
"	"	935 + 340	1199	76	1678.0	17.7	"	"	11.36	"	
"	"	935 + 408	1250	93	1690.0	16.2	"	"	10.24	"	
"	"	935 + 544	1345	134	1954.0	14.8	"	"	8.99	"	
Sept. 10	2	935 + 68	979	24	904	26.9	-10	176	1.22	20.2	
"	"	935 + 136	1031	40	1659	35.5	"	"	1.02	"	
"	"	935 + 272	1145	62	1594	24.4	"	"	0.92	"	
"	"	935 + 816	1345	134	1696	17.8	"	"	0.62	"	
Sept. 13	2	935 + 68	986	17	867	26.7	45	188.25	1.78	20.2	
"	"	935 + 136	1040	31	831	17.5	"	"	1.43	"	
"	"	935 + 272	1175	42	726	12.6	"	"	1.30	"	
"	"	935 + 408	1265	78	721	9.9	"	"	0.87	"	

TABLE A-III (Continued)

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L × 10^9 Perm. Value cm	Cup Area cm^2	Remarks*
Test Site No. 3, Rose Lake-Dudley, US-10, Mile Post 35--Core Sample Taken April 4, 1963 (continued)											
July 30	3	935	914.0	21.0	441	21.8	27	184.1	3.90	45.5	10 RT of CL
"	"	"	913.7	21.3	882	44.8	"	"	3.75	"	
"	"	"	925.2	9.8	446	33.6	"	"	5.50	"	
"	"	"	930.9	4.12	449	62.0	"	"	7.12	"	
"	"	"	933.1	1.93	451	110.0	"	"	8.60	"	
"	"	"	934.0	0.96	451	210.5	"	"	9.05	"	
July 30	3	935	911.7	23.3	880	32.0	27	184.1	10.7	20.2	
"	"	"	922.5	12.5	892	49.8	"	"	13.1	"	
"	"	"	931.0	3.98	450	61.5	"	"	16.7	"	
"	"	"	933.1	1.92	226	58.3	"	"	18.4	"	
"	"	"	933.7	1.33	226	81.8	"	"	18.9	"	
Sept. 6	3	935 + 34	955	14	927.6	54.6	28	184.6	11.08	20.2	
"	"	935 + 68	970	33	911.6	34.5	"	"	7.32	"	
"	"	935 + 136	995	76	921.4	23.5	"	"	4.72	"	
"	"	935 + 204	1021	118	979.0	19.4	"	"	5.04	"	
"	"	935 + 272	1053	154	1859.6	34.5	"	"	3.20	"	
"	"	935 + 340	1070	205	1956	32.0	"	"	2.73	"	
"	"	935 + 408	1086	257	1971	30.0	"	"	2.34	"	
"	"	935 + 544	1110	369	2032	27.5	"	"	1.83	"	
"	"	935 + 680	1125	490	1902	26.8	"	"	1.32	"	
Sept. 10	3	935 + 68	966	37	1795	81.4	-10	176.0	0.519	20.2	
"	"	935 + 136	985	86	1763	55.7	"	"	0.321	"	
"	"	935 + 272	1012	195	1760	42.4	"	"	0.185	"	
"	"	935 + 544	1039	440	1742	36.2	"	"	0.095	"	
"	"	935 + 816	1043	572	1748	35.0	"	"	0.0761	"	
Sept. 13	3	935 + 68	953	52	462.4	27.2	45	188.25	3.04	20.2	
"	"	935 + 136	968	103	914	35.6	"	"	2.33	"	
"	"	935 + 272	987	220	889	26.5	"	"	1.43	"	
"	"	935 + 544	1015	464	891	20.7	"	"	0.866	"	
"	"	935 + 680	1035	595	928	18.5	"	"	0.786	"	
Test Site No. 5, Genesee Junction, US-95, Mile Post 349--Core Sample Taken April 3, 1963											
July 23	1	935	912	23.20	88.1	29.0	25	183.2	0.530	45.5	Center of NBL
"	"	"	920	14.70	89.0	39.1	"	"	0.625	"	
"	"	"	929	6.20	44.8	45.2	"	"	0.643	"	
"	"	"	932	2.85	45.0	85.5	"	"	0.742	"	
"	"	"	934	1.25	45.1	181.2	"	"	0.802	"	
July 23	1	935	912	23.00	88.1	36.2	25	183.2	0.965	20.2	
"	"	"	913	21.50	88.2	37.4	"	"	1.010	"	
"	"	"	922	13.40	89.0	52.8	"	"	1.140	"	
"	"	"	929	6.00	44.8	59.2	"	"	1.140	"	
"	"	"	932	3.05	45.0	102.2	"	"	1.300	"	
Sept. 3	1	935 + 136	956	115	446.7	45.0	26	183.6	.785	20.2	
"	"	935 + 34	942.5	26.5	448.0	115.3	"	"	1.333	"	
"	"	935 + 68	946.5	56.5	506.5	64.3	"	"	1.267	"	
"	"	935 + 136	952.0	119	511.1	43.7	"	"	0.893	"	
"	"	935 + 204	958.0	181	459.8	35.5	"	"	0.650	"	
"	"	935 + 272	962.0	245	457.9	31.0	"	"	0.548	"	
"	"	935 + 340	965.0	310	465.6	28.8	"	"	0.474	"	
Sept. 10	1	935 + 136	932	139	94.1	116.8	-10	175.0	0.050	20.2	
"	"	935 + 272	933	274	93.6	66.3	"	"	0.028	"	
"	"	935 + 544	933	546	93.6	100.3	"	"	0.015	"	
"	"	935 + 816	933	818	93.6	170.1	"	"	0.011	"	
"	"	935 + 68	933	70	93.6	174.6	"	"	0.067	"	
Sept. 12	1	935 + 68	933	70	94.1	54.0	45	188.25	0.223	20.2	
"	"	035 + 136	933	138	95.1	27.0	"	"	0.260	"	
"	"	935 + 272	934	273	94.6	24.9	"	"	0.130	"	
"	"	935 + 544	933	546	95.1	31.8	"	"	0.051	"	
"	"	935 + 816	933	818	94.6	44.7	"	"	0.024	"	

TABLE A-III (Continued)

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L x 10^9 Perm. Value cm	Cup Area cm^2	Remarks*
Test Site No. 5, Genesee Junction, US-95, Mile Post 349--Core Sample Taken April 3, 1963 (continued)											
July 30	2	935	910	24.80	88.0	35.0	27	184.1	0.924	20.2	Center of NBL
"	"	"	912	12.90	89.2	66.5	"	"	0.940	"	
"	"	"	931	3.66	45.0	111.8	"	"	1.000	"	
"	"	"	932	3.46	45.0	120.0	"	"	0.988	"	
"	"	"	933	2.24	45.0	172.0	"	"	1.060	"	
"	"	"	934	0.65	45.1	607.0	"	"	1.040	"	
July 30	2	935	910	19.60	176.8	33.4	27	184.1	1.09	45.5	
"	"	"	911	19.00	176.8	34.9	"	"	1.08	"	
"	"	"	924	11.00	178.4	61.2	"	"	1.07	"	
"	"	"	931	4.12	89.8	79.2	"	"	1.11	"	
"	"	"	932	2.72	45.0	55.8	"	"	1.20	"	
"	"	"	934	1.10	45.1	137.8	"	"	1.21	"	
Sept. 10	2	935 + 68	933	70	93.6	957.8	-10	175.75	0.0117	20.2	Moisture on top of sample after testing
"	"	935 + 136	932	139	94.6	232.8	"	"	0.0250	"	
"	"	935 + 272	933	274	93.6	128.0	"	"	0.0230	"	
"	"	935 + 544	933	546	93.6	74.8	"	"	0.0198	"	
"	"	935 + 816	933	818	93.6	46.6	"	"	0.0212	"	
"	"	935 + 68	932	71	94.6	199.4	"	"	0.0571	"	
Sept. 12	2	935 + 68	933	70	94.6	39.9	45	189.28	0.3160	20.2	
"	"	935 + 136	934	137	94.6	22.7	"	"	0.2830	"	
"	"	935 + 272	934	273	94.6	21.0	"	"	0.1541	"	
"	"	935 + 544	933	546	94.6	44.0	"	"	0.0365	"	
"	"	935 + 816	933	818	95.1	46.0	"	"	0.0235	"	
Sept. 14	2	935 + 34	934	35	95.6	266.2	28	184.6	0.093	20.2	
"	"	935 + 68	934	69	94.6	115.5	"	"	0.108	"	
"	"	935 + 136	935	136	94.6	70.5	"	"	0.090	"	
"	"	935 + 204	935	204	95.1	61.4	"	"	0.069	"	
"	"	935 + 272	935	272	95.1	58.0	"	"	0.055	"	
"	"	935 + 340	935	340	94.6	59.9	"	"	0.042	"	
"	"	935 + 408	934	409	94.6	62.4	"	"	0.034	"	
"	"	935 + 544	934	545	94.6	74.3	"	"	0.021	"	
"	"	935 + 680	934	681	94.6	92.3	"	"	0.014	"	
"	"	935 + 816	934	817	94.6	92.3	"	"	0.079	"	
Aug. 1	3	935	909	25.80	176.0	19.8	26	183.6	1.39	45.5	
"	"	"	924	10.80	178.4	35.2	"	"	1.88	"	
"	"	"	921	13.50	178.0	25.4	"	"	2.08	"	
"	"	"	931	3.86	90.0	37.0	"	"	2.54	"	
"	"	"	933	2.19	90.0	60.0	"	"	2.77	"	
"	"	"	934	1.17	90.2	103.2	"	"	3.00	"	
Aug. 1	3	935	909	25.70	175.6	69.4	36	183.6	0.905	20.2	
"	"	"	923	11.70	89.2	71.1	"	"	0.972	"	
"	"	"	931	4.15	89.8	186.5	"	"	1.050	"	
"	"	"	933	2.	45.0	149.3	"	"	1.090	"	
"	"	"	934	0.97	45.1	343.0	"	"	1.230	"	
Sept. 5	3	935 + 34	934	35	94.6	121.8	30	185.6	0.2041	20.2	
"	"	935 + 68	935	68	94.6	53.4	"	"	0.2380	"	
"	"	935 + 136	935	136	95.1	39.3	"	"	0.1623	"	
"	"	935 + 204	935	204	95.1	38.1	"	"	0.1118	"	
"	"	935 + 272	935	272	94.6	43.3	"	"	0.0736	"	
"	"	935 + 340	935	340	94.6	42.4	"	"	0.0603	"	
"	"	935 + 408	935	408	94.6	45.3	"	"	0.0469	"	
"	"	935 + 544	935	544	94.6	57.8	"	"	0.0276	"	
"	"	935 + 680	933	681	94.6	89.8	"	"	0.0142	"	
"	"	935 + 816	933	817	94.1	132.4	"	"	0.0080	"	
Sept. 10	3	935 + 68	931.5	71.5	94.1	480.5	-10	176.0	0.0239	20.2	
"	"	935 + 136	932.0	139	94.6	221.2	"	"	0.0268	"	
"	"	935 + 272	932.5	274	94.1	132.8	"	"	0.0226	"	
"	"	935 + 544	932.5	546	94.1	129.7	"	"	0.0116	"	
"	"	935 + 816	932.5	818	94.1	177.5	"	"	0.0056	"	
Sept. 12	3	935 + 68	933.0	70.0	94.1	72.5	45	188.25	0.174		
"	"	935 + 136	934.0	137	94.6	44.3	"	"	0.1452		
"	"	935 + 272	933.0	274	94.6	39.2	"	"	0.0822		

TABLE A-III (Continued)

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L x 10^9 Perm. Value cm	Cup Area cm^2	Remarks*
Test Site No. 5, Genesee Junction, US-95, Mile Post 349--Core Sample Taken April 3, 1963 (continued)											
Sept. 12	3	935 + 544	932.5	546	94.1	74.3	45	188.25	0.0217		
"	"	935 + 816	932.5	818	94.6	139.7	"	"	0.0077		
Test Site No. 6, Culdesac Grade, US-95, Mile Post 304--Core Sample Taken April 3, 1963											
June 23	1	935	912.7	22.3	332.8	20.4	27	184.1	2.96	45.5	SB Truck Lane, 20' RT of CL
"	"	"	925.7	9.3	178.8	22.8	"	"	3.39	"	
"	"	"	931.2	3.8	90.0	26.5	"	"	3.60	"	
"	"	"	931.4	3.59	90.0	27.4	"	"	3.67	"	
"	"	"	933.5	1.49	90.2	64.0	"	"	3.81	"	
"	"	"	933.6	1.38	90.2	67.0	"	"	3.92	"	
July 23	1	935	910.9	24.1	186.0	20.9	27	184.1	3.39	20.2	
"	"	"	919.1	15.9	88.8	19.5	"	"	2.58	"	
"	"	"	931.3	3.70	90.0	68.0	"	"	3.26	"	
"	"	"	931.3	3.66	45.0	36.2	"	"	3.08	"	
"	"	"	933.1	1.94	45.1	66.0	"	"	3.20	"	
"	"	"	933.1	1.90	45.1	71.4	"	"	3.02		
"	"	"	933.8	1.21	45.1	108.0	"	"	3.26	"	
Sept. 4	1	935 + 34	935	34	94.0	278.7	27	184.1	0.0909	20.2	
"	"	935 + 68	935	68	94.0	140.2	"	"	0.0925	"	
"	"	935 + 136	934	137	94.0	80.2	"	"	0.0842	"	
"	"	935 + 204	935	204	94.6	58.2	"	"	0.0724	"	
"	"	935 + 272	935	272	94.6	47.8	"	"	0.0557	"	
"	"	935 + 340	935	340	94.6	41.0	"	"	0.0618	"	
"	"	935 + 408	935	408	95.1	36.9	"	"	0.0573	"	
"	"	935 + 544	935	544	94.6	31.6	"	"	0.0503	"	
"	"	935 + 680	935	680	94.6	29.9	"	"	0.0425	"	
"	"	935 + 853	936	852	94.6	27.6	"	"	0.0367	"	
Sept. 10	1	935 + 68	933	70	94.1	20.4	-10	175.0	0.574	20.2	
"	"	935 + 136	934	137	94.1	14.5	"	"	0.412	"	
"	"	935 + 272	936	271	93.6	10.3	'	"	0.292	"	
"	"	935 + 544	941	539	188.7	15.4	"	"	0.197	"	
"	"	935 + 821	940	816	188.2	14.3	"	"	0.141	"	
July 23	2	935	910.6	24.4	88.0	50.8	24	182.7	2.92	45.5	SB Truck Lane, 20' RT of CL
"	"	"	911.2	23.8	88.1	52.2	"	"	2.84	"	
"	"	"	919.9	15.1	44.4	49.0	"	"	2.40	"	
"	"	"	928.3	6.7	44.8	102.8	"	"	2.61	"	
"	"	"	931.8	3.2	45.0	214	"	"	2.67	"	
"	"	"	933.5	1.5	45.1	437	"	"	2.70	"	
July 23	2	935	909.6	25.4	87.8	56.2	25	183.2	0.558	20.2	
"	"	"	921.8	13.2	89.2	103.6	"	"	0.592	"	
"	"	"	928.5	6.5	44.8	111.3	"	"	0.562	"	
"	"	"	932.2	2.75	45.0	245	"	"	0.607	"	
"	"	"	933.2	1.76	45.1	386	"	"	0.606	"	
Sept. 4	2	935 + 34	934.5	34.5	94.6	140.2	30	185.6	0.180	20.2	
"	"	935 + 68	934.5	68.5	94.6	92.6	"	"	0.138	"	
"	"	935 + 136	935	136	94.6	62.1	"	"	0.103	"	
"	"	935 + 204	935	204	94.6	52.0	"	"	0.082	"	
"	"	935 + 272	935	272	94.6	47.8	"	"	0.067	"	
"	"	935 + 340	935	340	94.6	44.8	"	"	0.057	"	
"	"	935 + 408	935	408	94.6	42.1	"	"	0.051	"	
"	"	935 + 544	935	544	95.1	31.2	"	"	0.051	"	
"	"	935 + 680	935	680	95.1	25.7	"	"	0.050		
"	"	935 + 815	935	815	94.6	25.2	"	"	0.042	"	
Sept. 10	2	935 + 68	933	70	94.1	24.6	-10	175.0	0.474	20.2	
"	"	935 + 136	934	137	94.1	17.1	"	"	0.347	"	
"	"	935 + 272	935	272	94.6	13.8	"	"	0.216	"	
"	"	935 + 544	935	544	94.6	12.5	"	"	0.119	"	
"	"	935 + 816	935	816	94.1	13.6	"	"	0.072	"	
Sept. 13	2	935 + 68	933	70	94.6	81.0	45	188.25	0.153	20.2	SBL, 20' R of CL

TABLE A-III (Continued)

1963 Test Date	Core or Test	P_1 Atmos. Pres. g/cm^2	P_2 Test Pres. g/cm^2	P_1-P_2 Pres. Drop g/cm^2	Q Vol. cc	T Time Sec.	Temp. °C	μ Air Visc. Micropoises	k/L x 10^9 Perm. Value cm	Cup Area cm^2	Remarks*
Test Site No. 6, Culdesac Grade, US-95, Mile Post 304--Core Sample Taken April 3, 1963 (continued)											
Sept. 13	2	935 + 136	933	138	94.6	45.0	45	188.25	0.141	20.2	SBL, 20' R of CL
"	"	935 + 272	935	272	94.6	32.3	"	"	0.099	"	
"	"	935 + 544	935	544	95.6	16.5	"	"	0.097	"	
"	"	935 + 816	938	813	95.6	8.1	"	"	0.133	"	
July 22	3	935	917	17.60	177.2	26.2	25	183.2	1.55	45.5	
"	"	"	927	7.50	89.6	27.2	"	"	1.77	"	
"	"	"	928	6.70	89.6	29.8	"	"	1.78	"	
"	"	"	932	3.45	90.0	54.2	"	"	1.93	"	
"	"	"	932	3.25	45.0	28.7	"	"	1.95	"	
"	"	"	933	1.62	45.1	54.8	"	"	2.05	"	
"	"	"	933	1.55	45.1	56.4	"	"	2.08	"	
Sept. 5	3	935 + 34	935	34	94.1	186.8	25	183.2	0.133	20.2	SBL, 20' R of CL
"	"	935 + 68	935	68	94.6	81.6	"	"	0.154	"	
"	"	935 + 136	935	136	94.6	47.5	"	"	0.132	"	
"	"	935 + 204	935	204	94.6	40.4	"	"	0.104	"	
"	"	935 + 272	935	272	95.1	39.8	"	"	0.079	"	
"	"	935 + 340	935	340	95.1	41.3	"	"	0.061	"	
"	"	935 + 408	935	408	94.6	45.8	"	"	0.045	"	
"	"	935 + 544	935	544	94.6	60.4	"	"	0.026	"	
"	"	935 + 680	935	680	94.6	84.8	"	"	0.014	"	
"	"	935 + 816	935	816	94.6	123.2	"	"	0.009	"	
Sept. 10	3	935 + 68	933	70	94.1	33.5	-10	176.0	0.350	20.2	
"	"	935 + 136	933	138	94.6	21.4	"	"	0.280	"	
"	"	935 + 272	934	273	94.6	16.4	"	"	0.183	"	
"	"	935 + 544	934	545	94.6	21.3	"	"	0.071	"	
"	"	935 + 816	933	818	94.6	41.0	"	"	0.025	"	
Sept. 12	3	935 + 68	933	70	94.6	47.3	45	188.25	0.286	20.2	
"	"	935 + 136	933	138	95.1	33.1	"	"	0.192	"	
"	"	935 + 272	933	274	94.6	35.8	"	"	0.089	"	
"	"	935 + 544	933	546	94.1	73.2	"	"	0.022	"	
Test Site No. 22, Heyburn I.C., I-80N--Core Sample Taken March 4, 1963											
July 30	1	935	931	4.40	1347	18.3	26.5	183.6	152.0	20.2	
"	"	"	933	2.01	1350	37.2	"	"	152.0	"	
"	"	"	934	1.21	902	41.5	"	"	163.0		
"	"	"	934	1.16	902	42.8	"	"	165.0	"	
"	"	"	935	0.70	451	35.8	"	"	164.0	"	
"	"	"	934	0.68	451	35.8	"	"	166.0	"	
July 30	1	935	931	4.30	1350	16.9	26.5	183.4	75.0	45.5	
"	"	"	933	2.25	1350	31.2	"	"	77.5	"	
"	"	"	934	1.15	902	39.6	"	"	80.0	"	
"	"	"	934	1.10	902	41.6	"	"	79.5	"	
"	"	"	934	0.69	451	33.0	"	"	80.0	"	
"	"	"	934	0.69	451	33.0	"	"	80.0	"	
Aug. 2	2	935	932	3.35	1350	23.2	27	184.1	158.0	20.2	
"	"	"	933	1.89	1354	32.0	"	"	204.0	"	Cracked sample
"	"	"	934	1.01	1354	56.3	"	"	217.0	"	
"	"	"	934	0.51	1356	105.0	"	"	230.5	"	
Aug. 2	3	935	933	2.45	1353	17.5	26	183.6	287.0	20.2	
"	"	"	934	1.07	1353	36.2	"	"	315.0	"	
"	"	"	934	0.58	902	42.0	"	"	336.0	"	
"	"	"	934	0.56	902	43.5	"	"	336.0	"	
"	"	"	935	0.27	902	85.0	"	"	358.0	"	
"	"	"	935	0.26	902	88.1	"	"	358.0	"	
Aug. 2	3	935	933	1.80	1353	16.0	26	183.6	179.0	45.5	
"	"	"	934	1.00	1353	28.2	"	"	194.0	"	
"	"	"	934	0.55	1353	48.2	"	"	206.0	"	
"	"	"	934	0.52	902	33.5	"	"	209.0	"	
"	"	"	935	0.26	902	67.2	"	"	210.0	"	

APPENDIX B

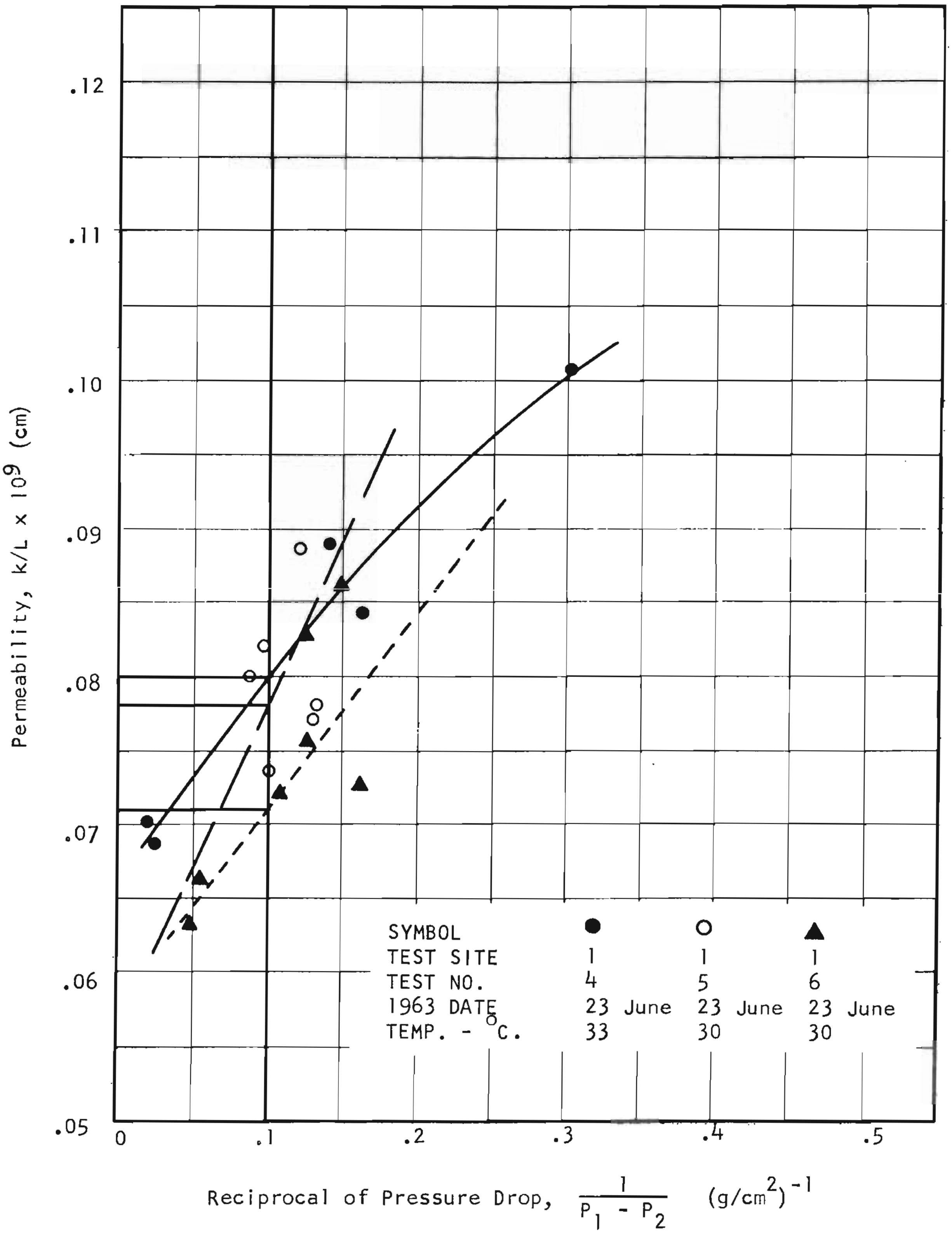


Figure B-1. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

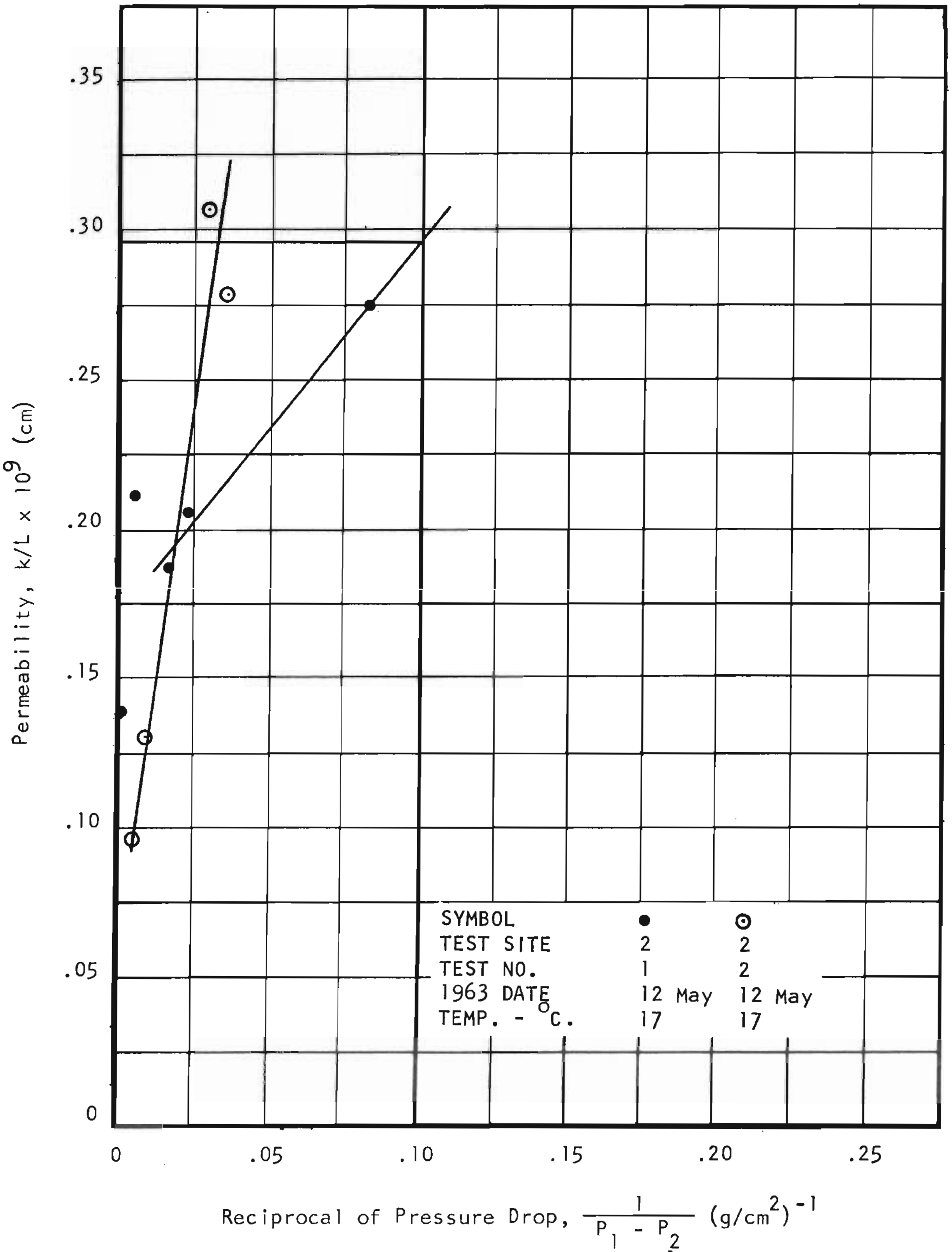


Figure B-2. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

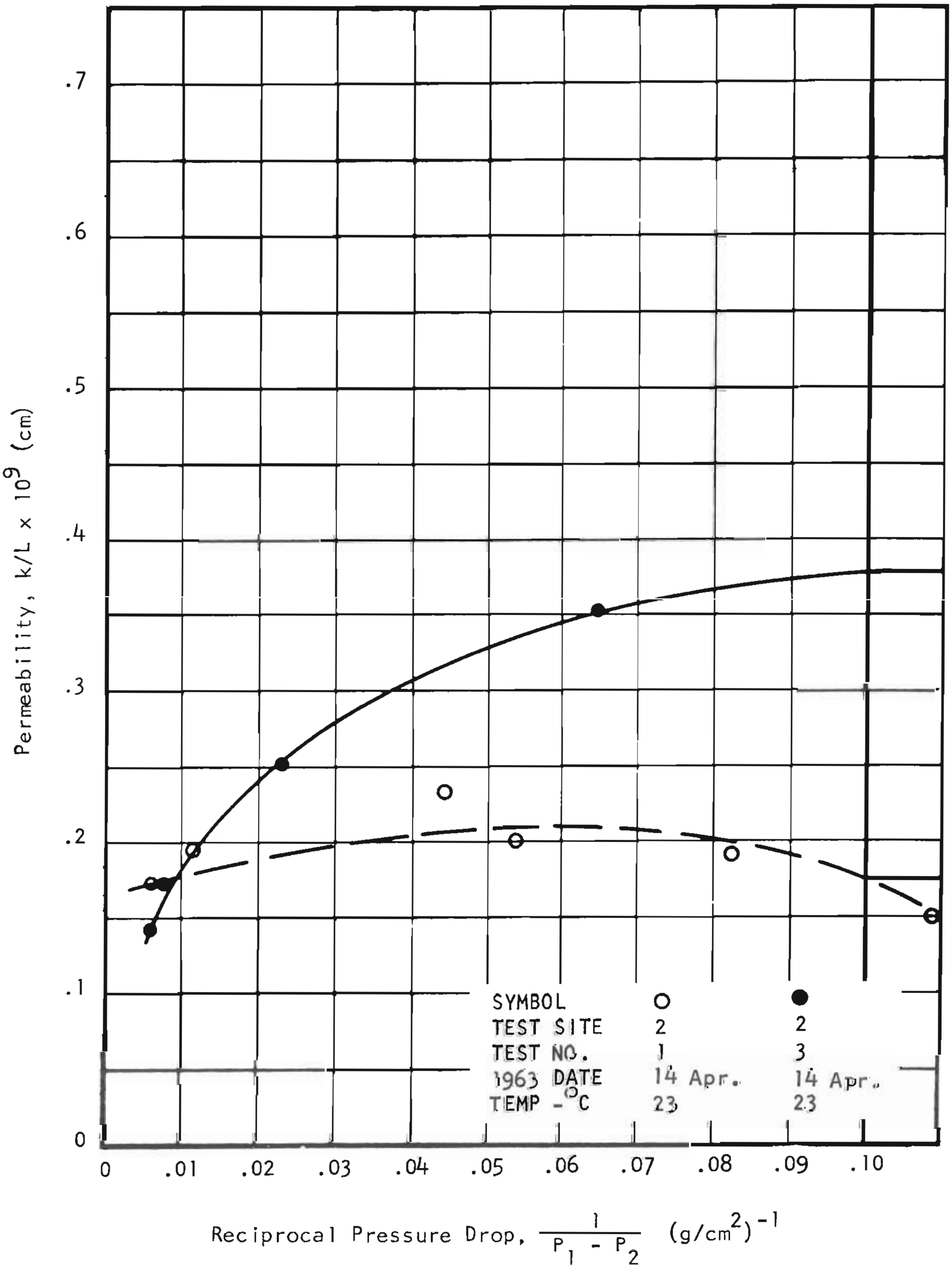


Figure B-3. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

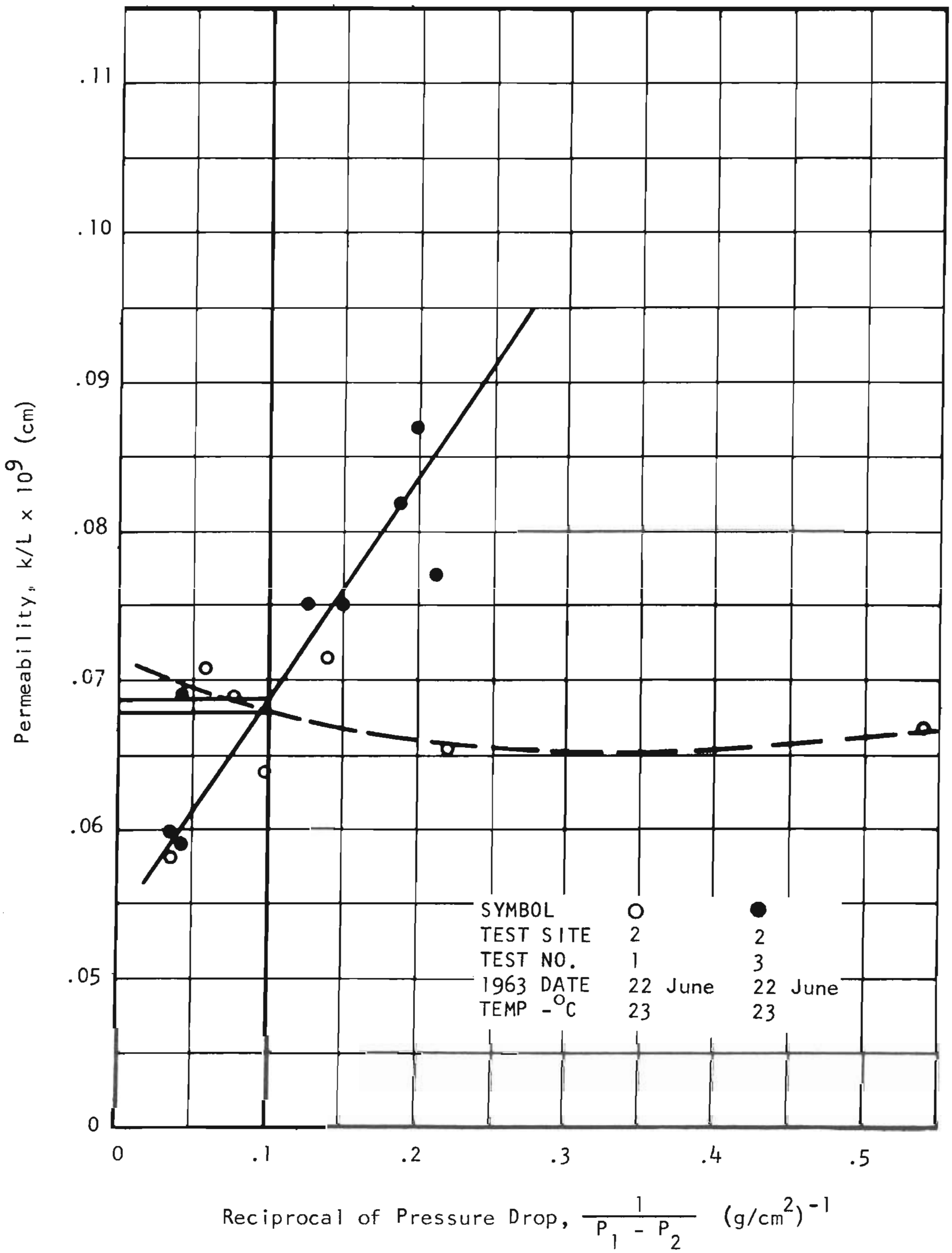


Figure B-4. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

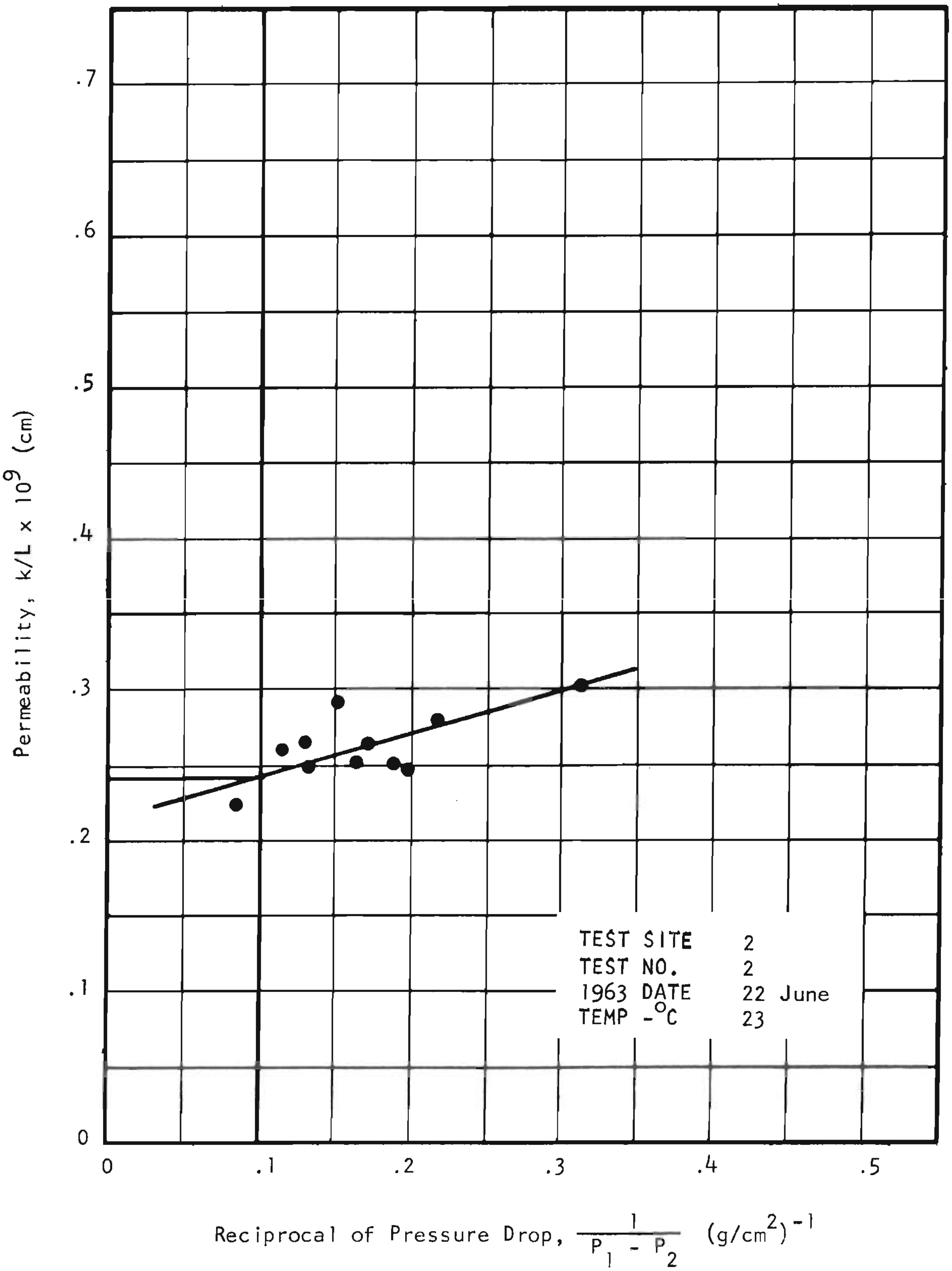


Figure B-5. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

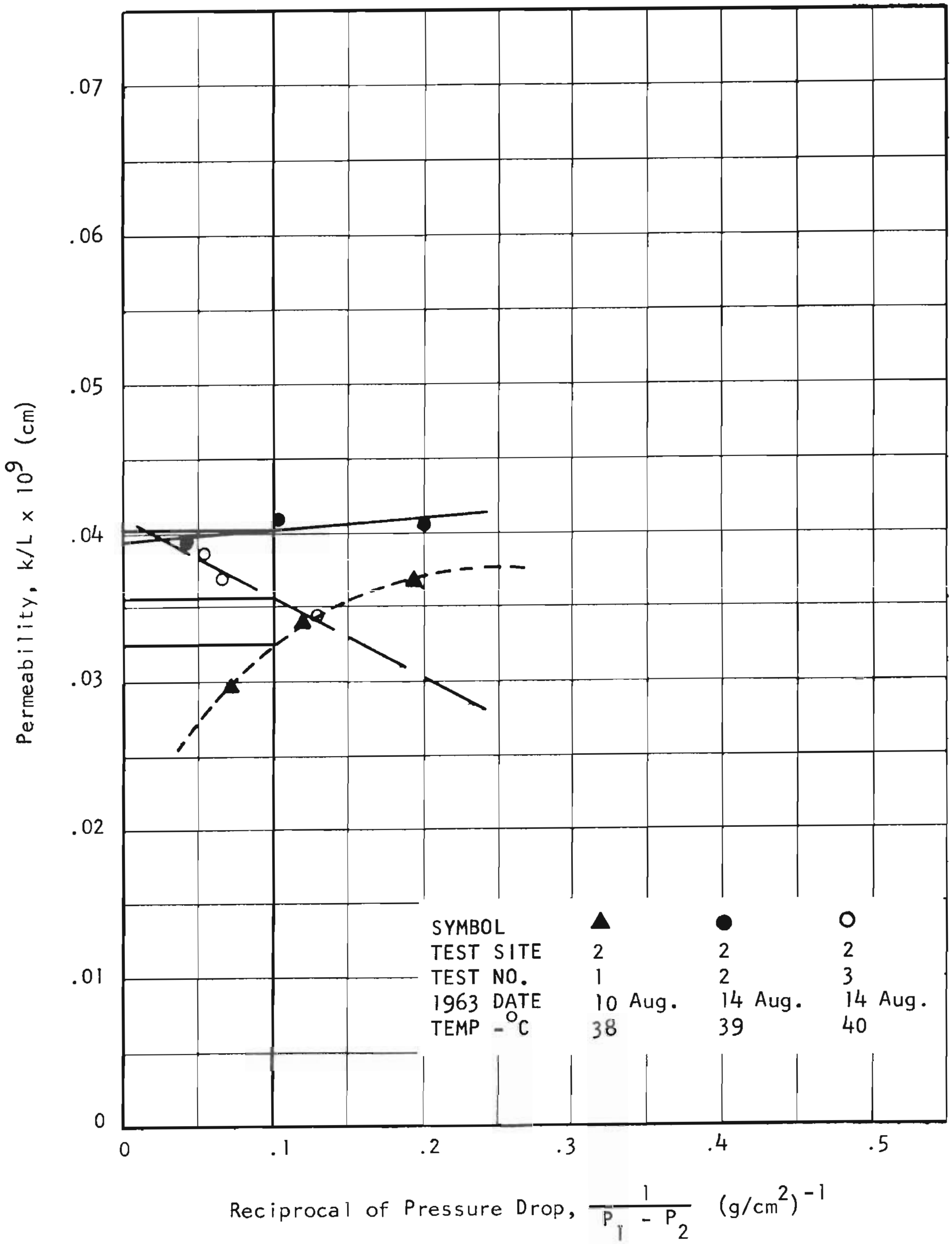


Figure B-6. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

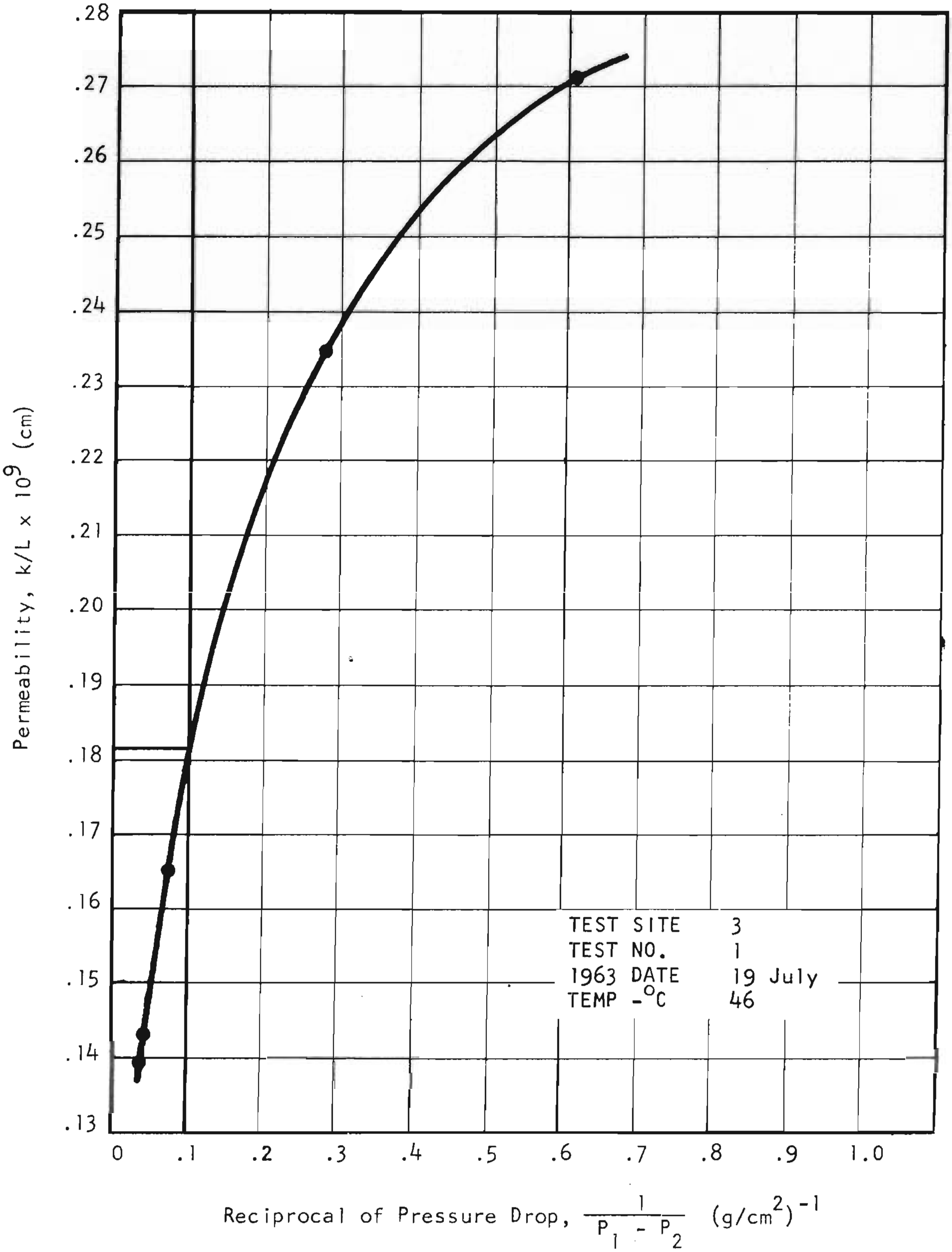


Figure B-7. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

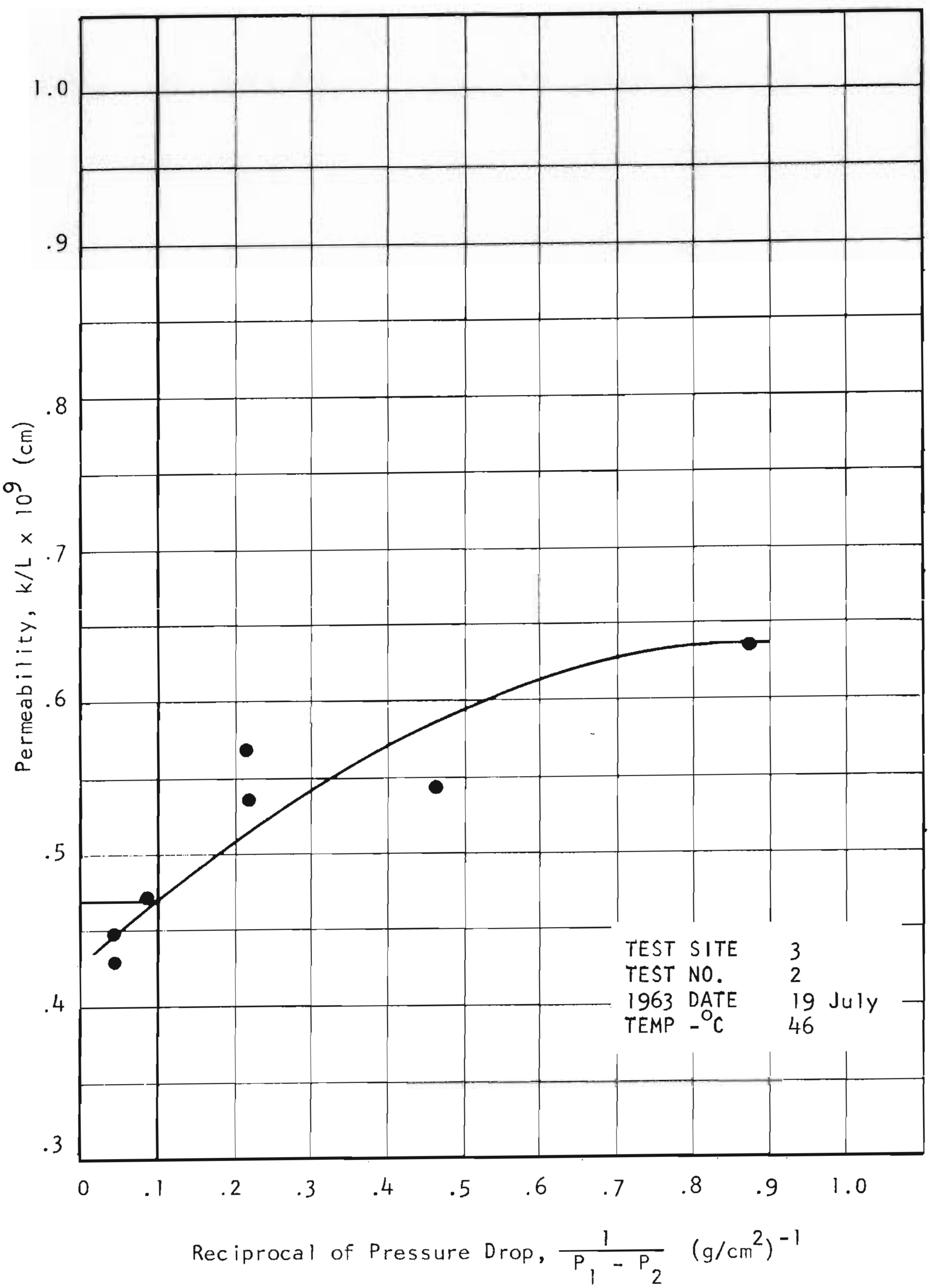


Figure B-8. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

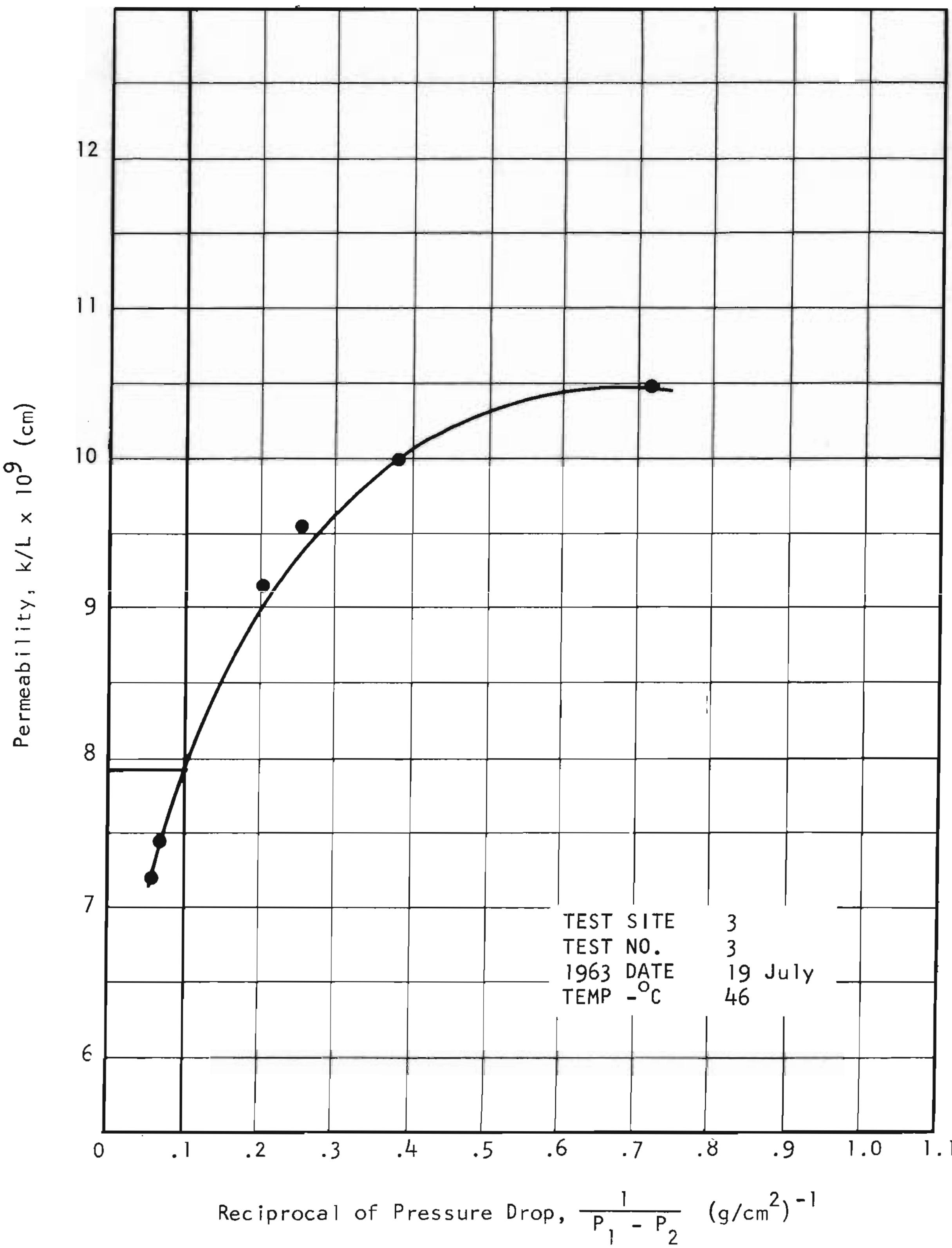


Figure B-9. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

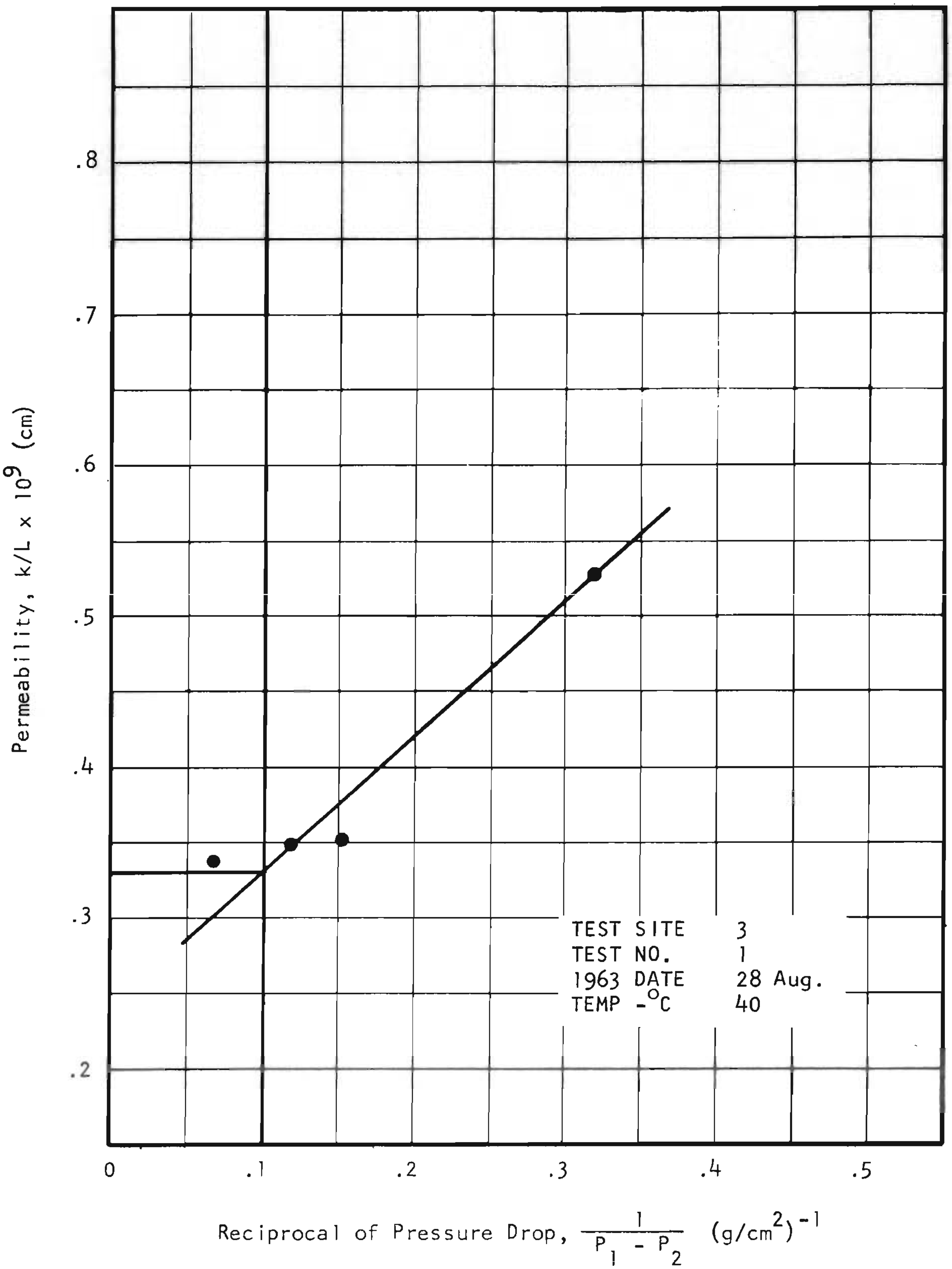


Figure B-10. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

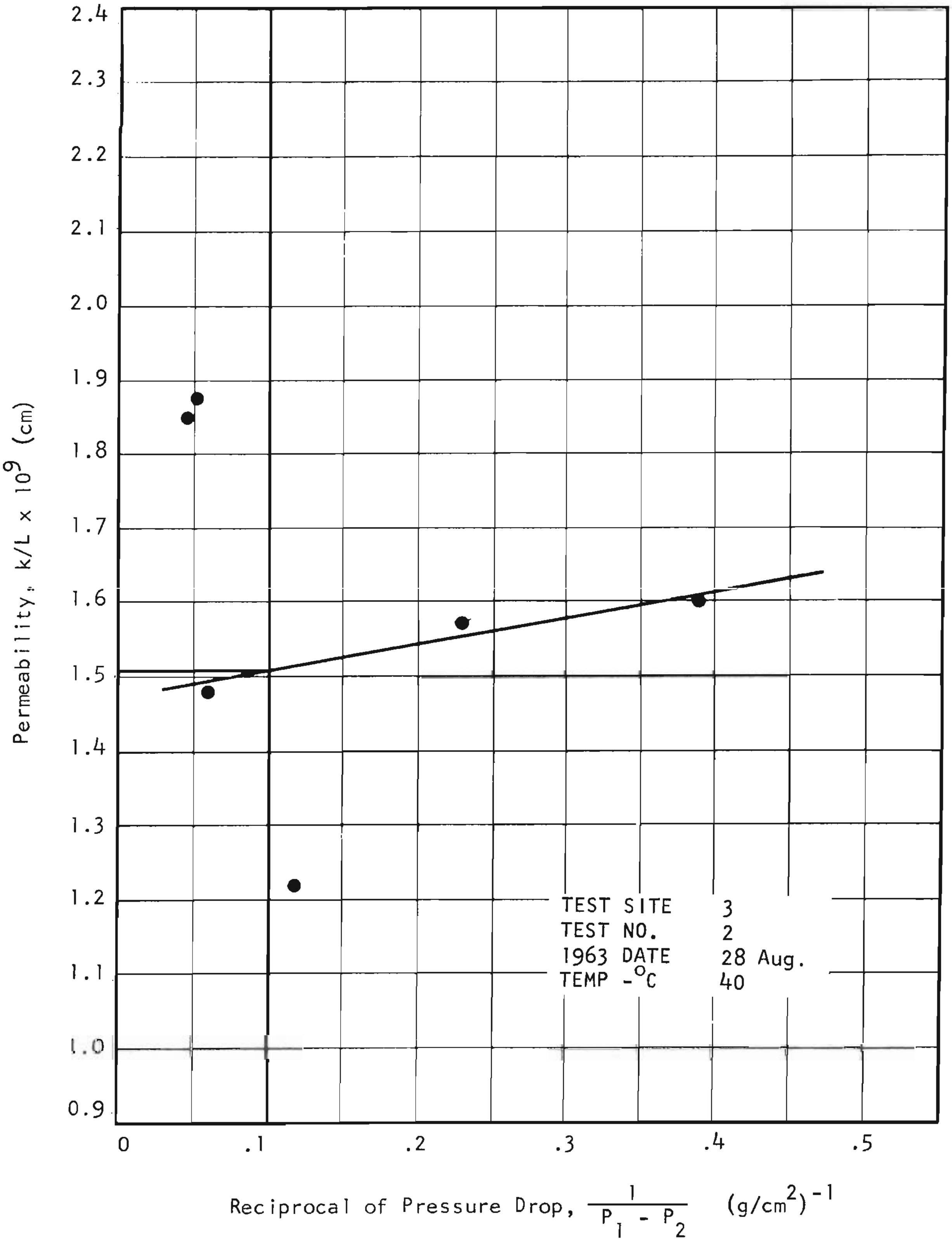


Figure B-11. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

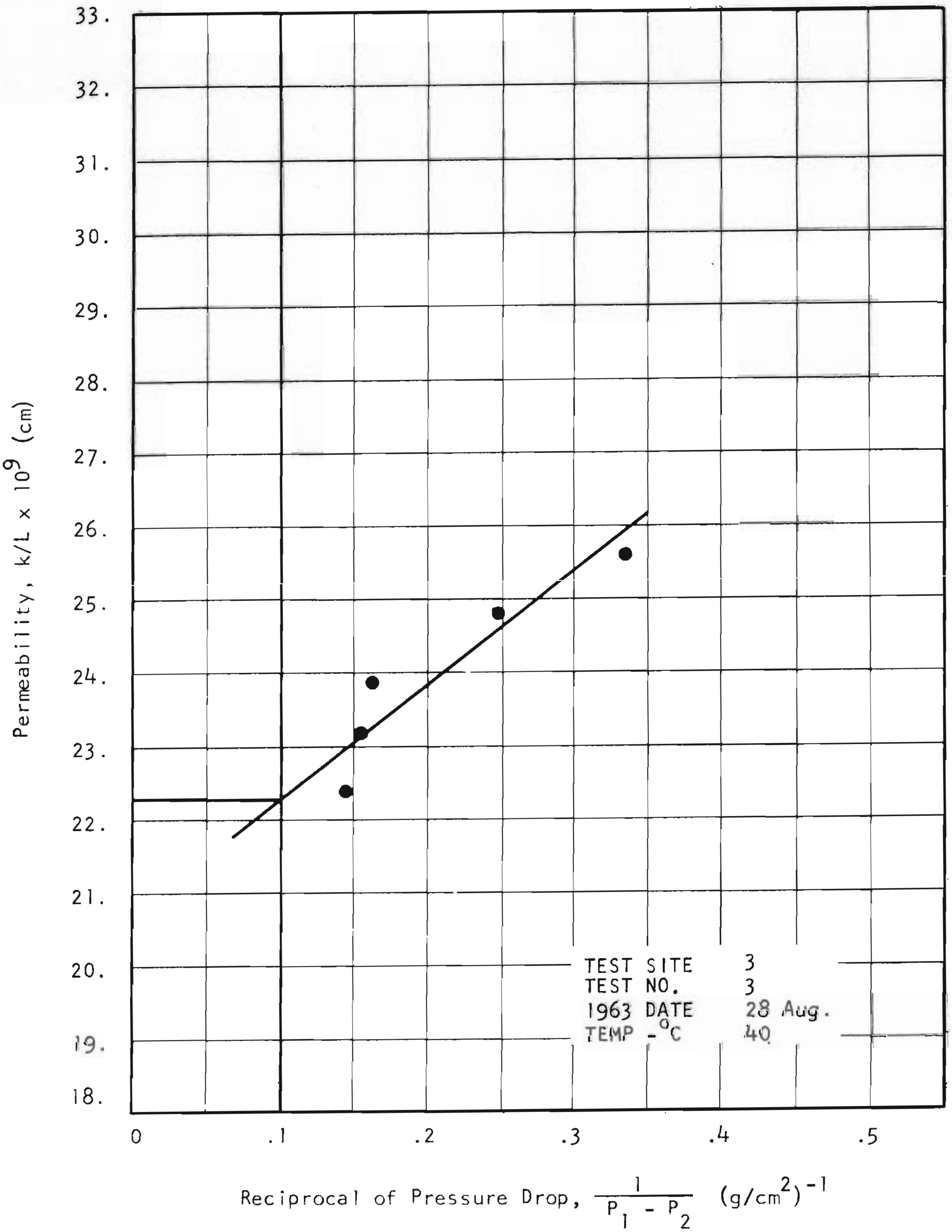


Figure B-12. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

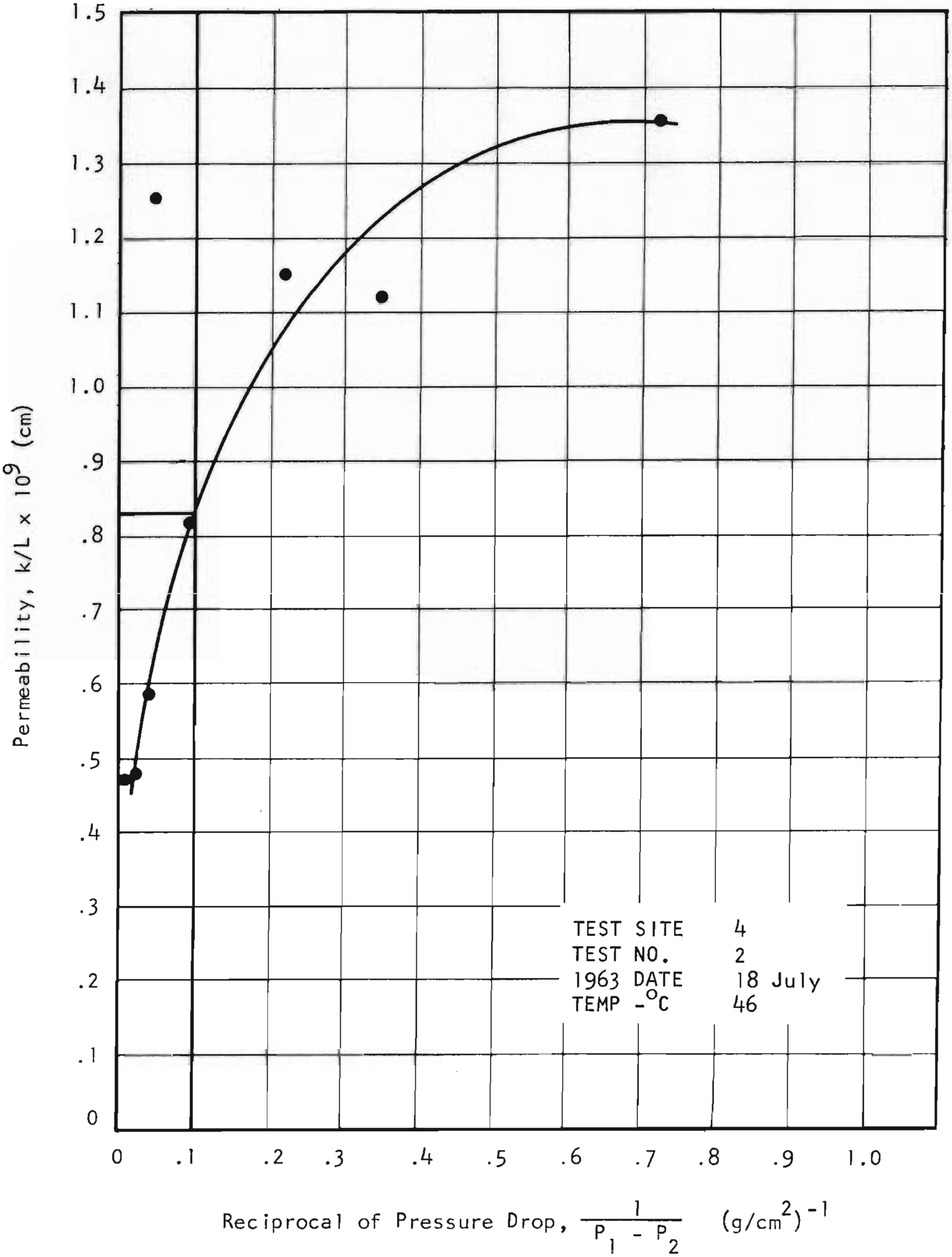


Figure B-13. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

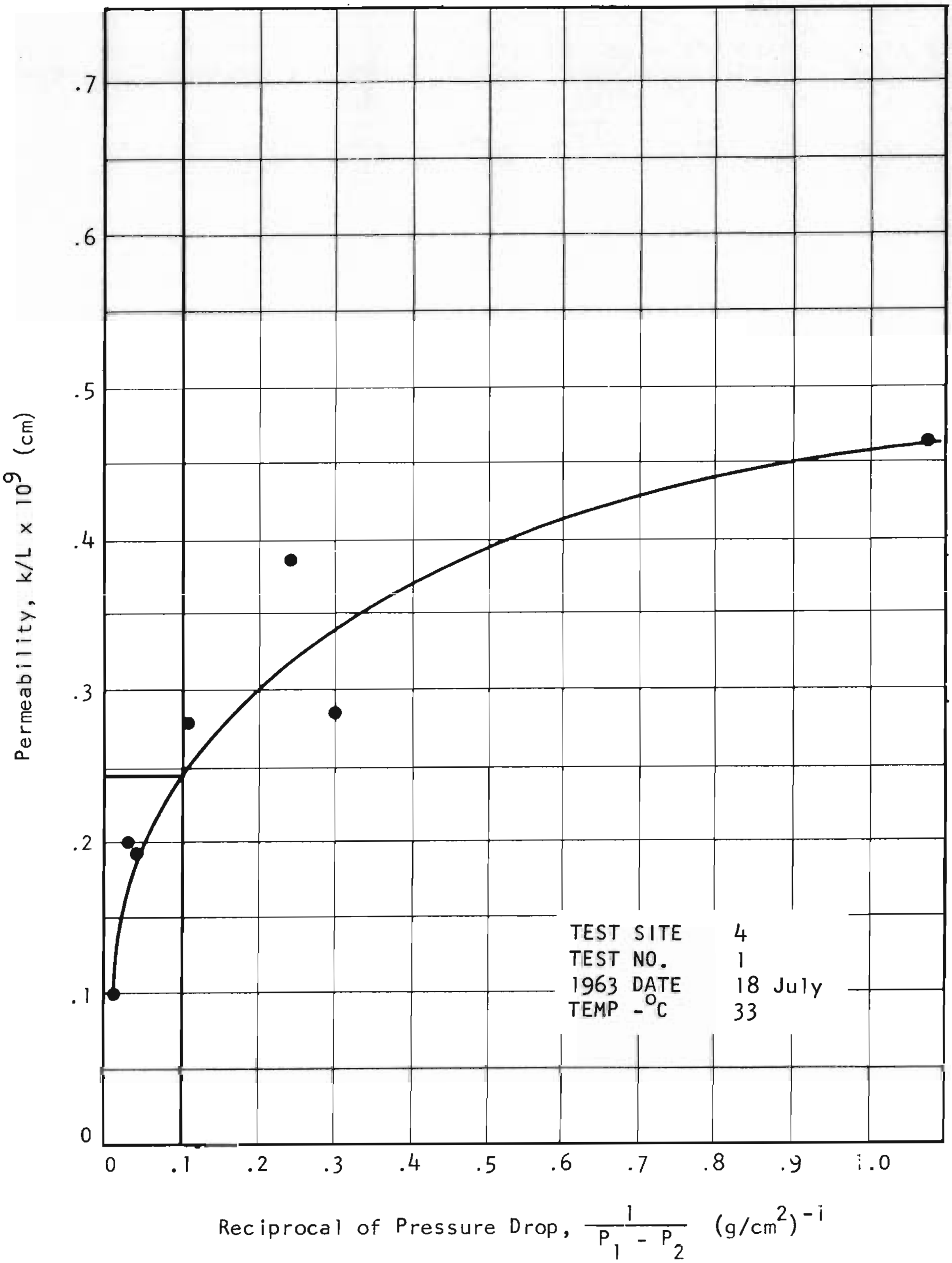
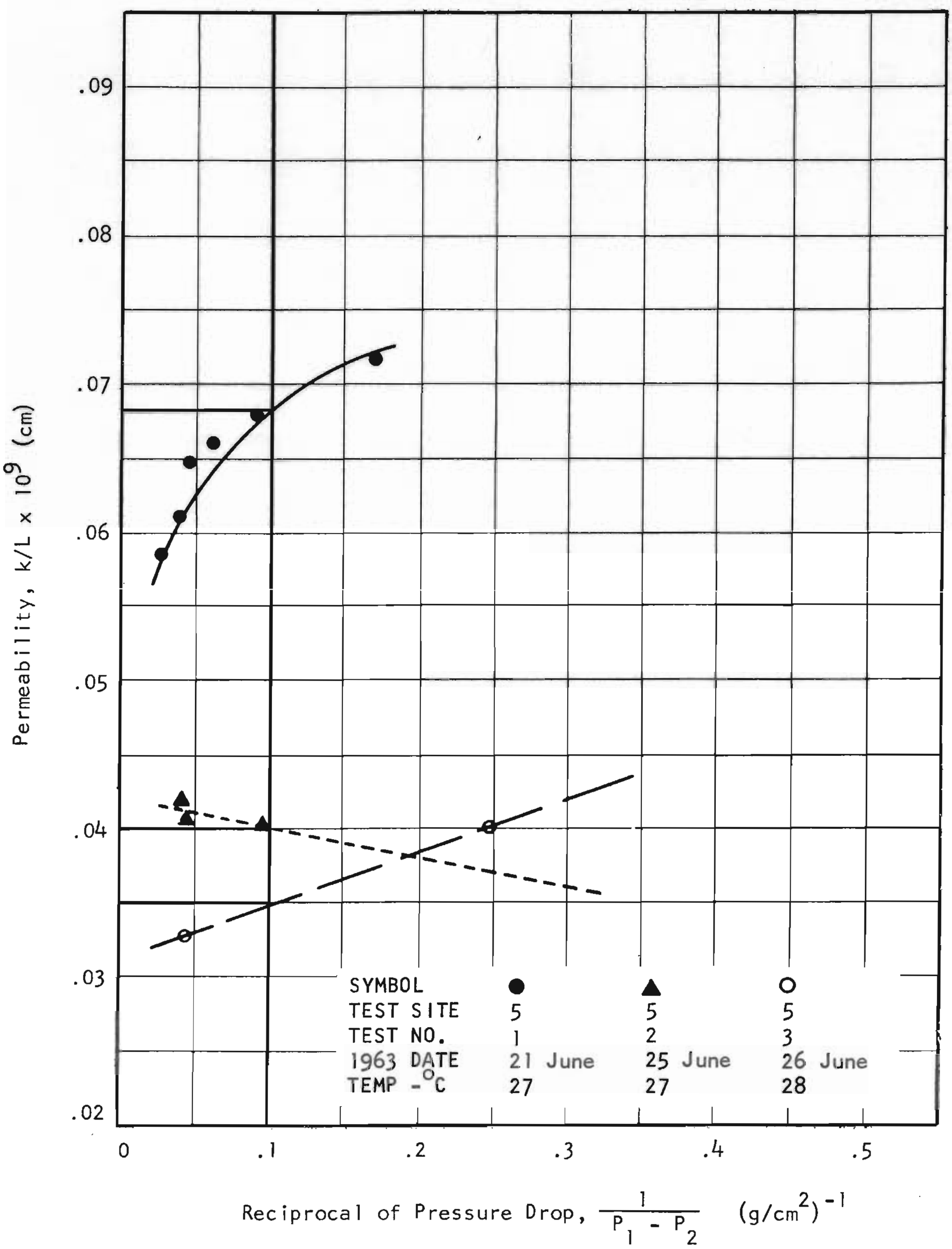


Figure B-14. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop



SYMBOL	●	▲	○
TEST SITE	5	5	5
TEST NO.	1	2	3
1963 DATE	21 June	25 June	26 June
TEMP - °C	27	27	28

Figure B-15. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

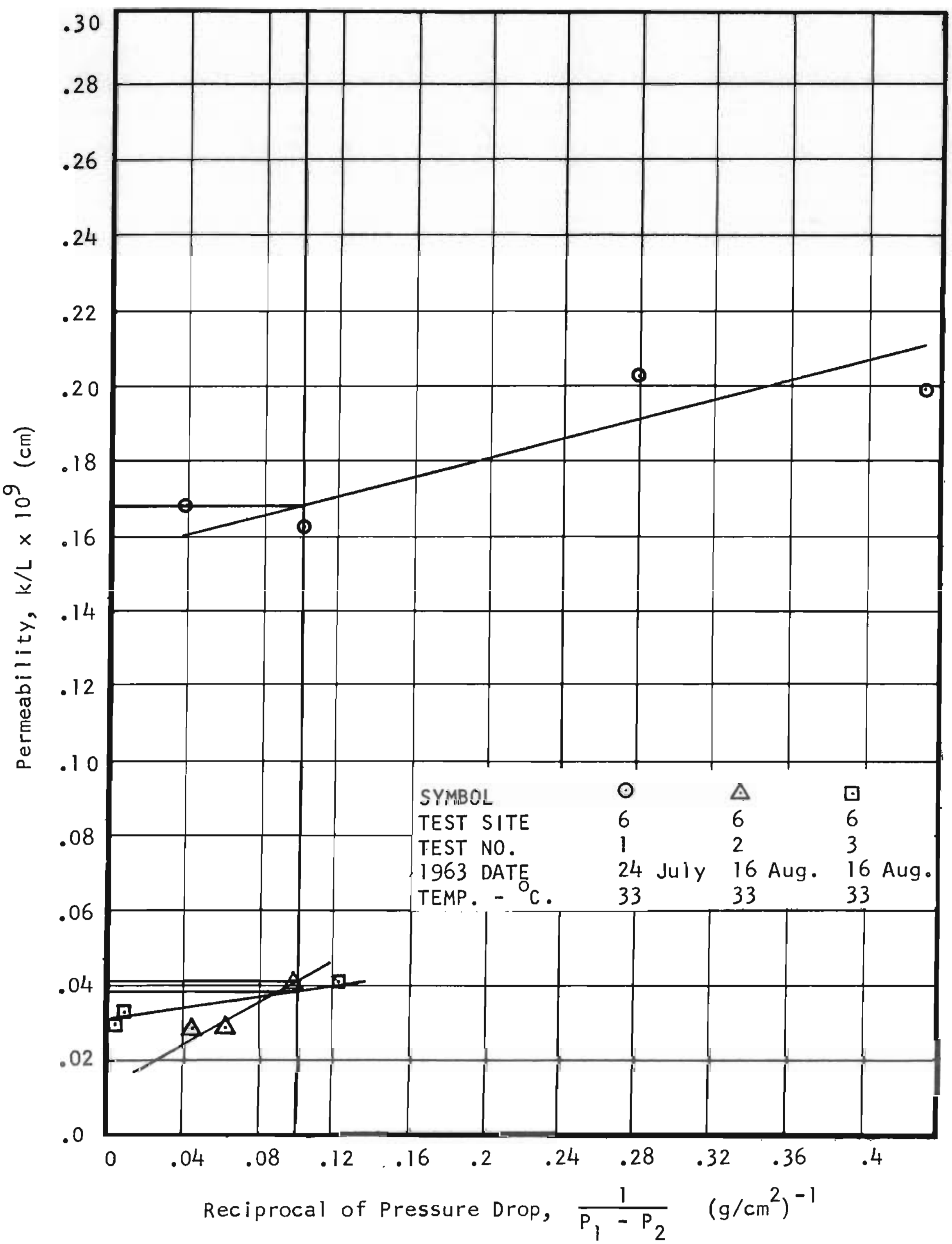


Figure B-16. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

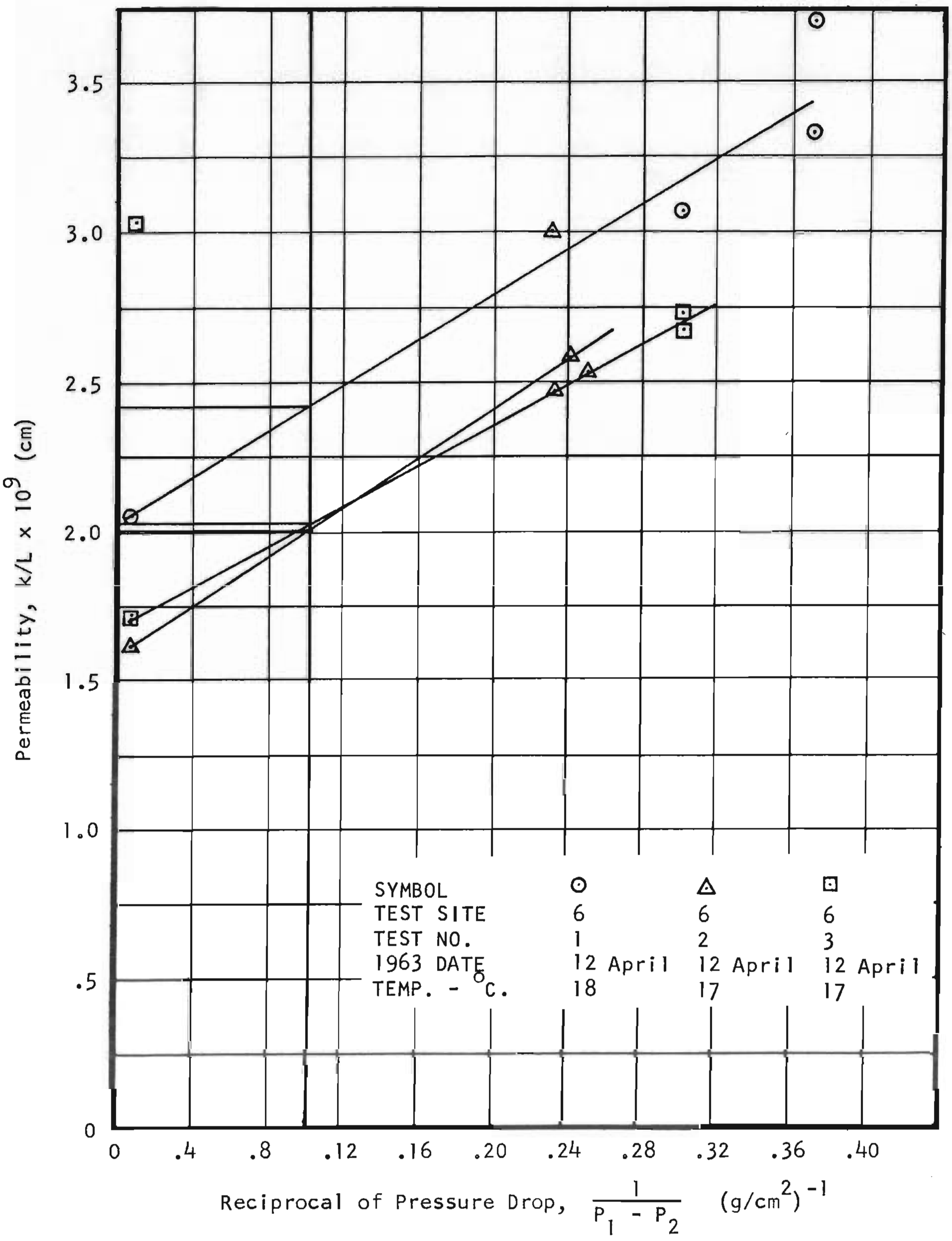


Figure B-17. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

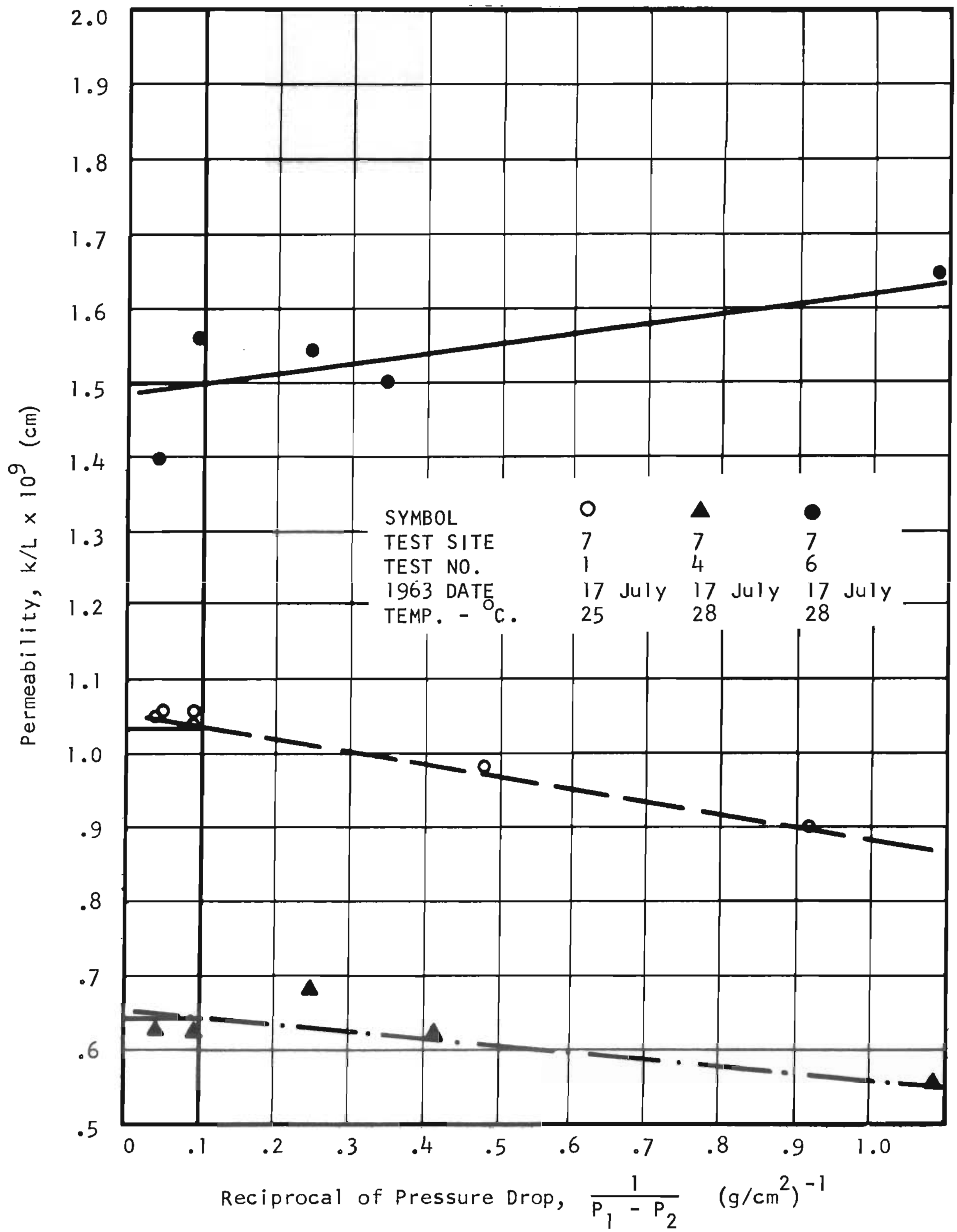


Figure B-18. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

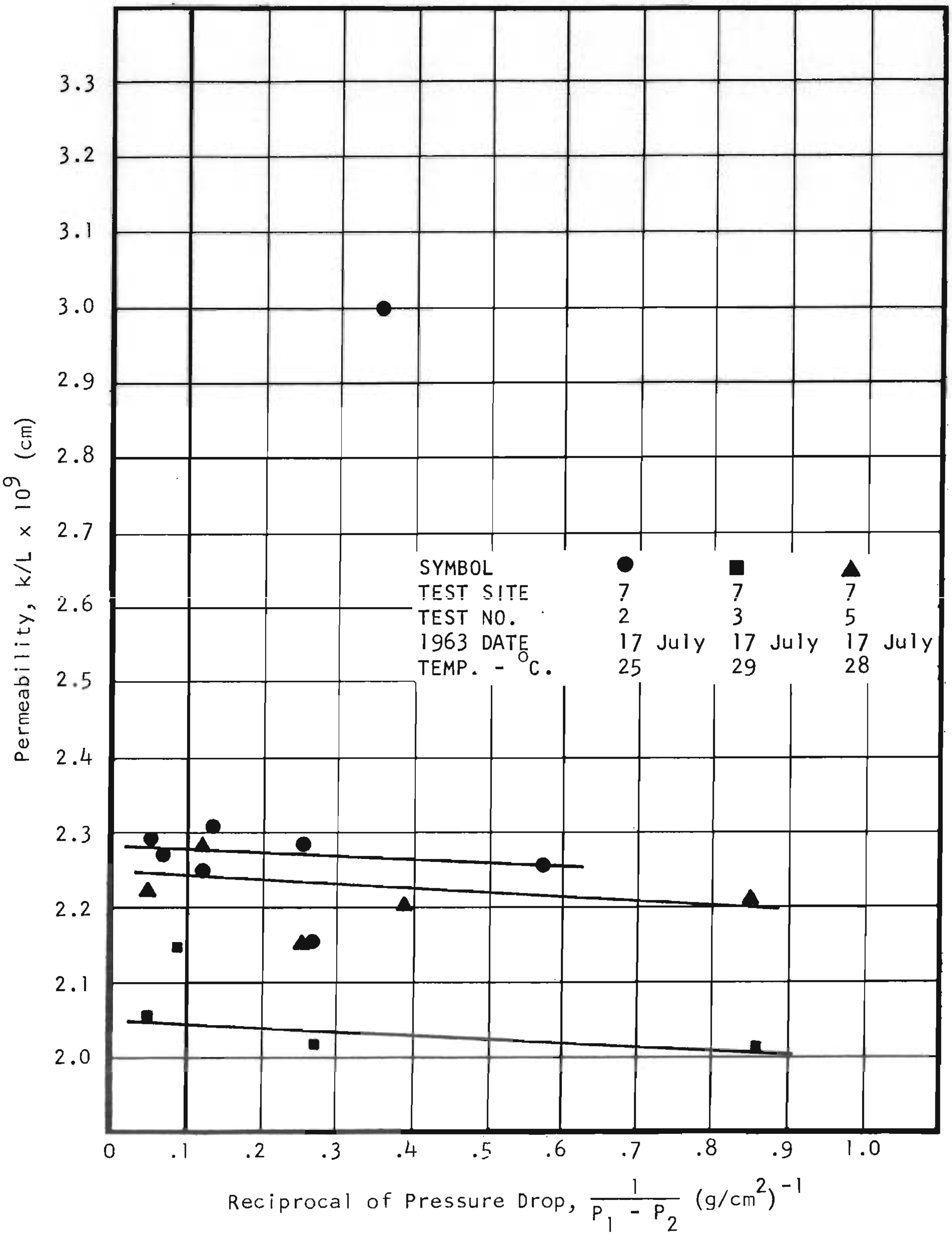


Figure B-19. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

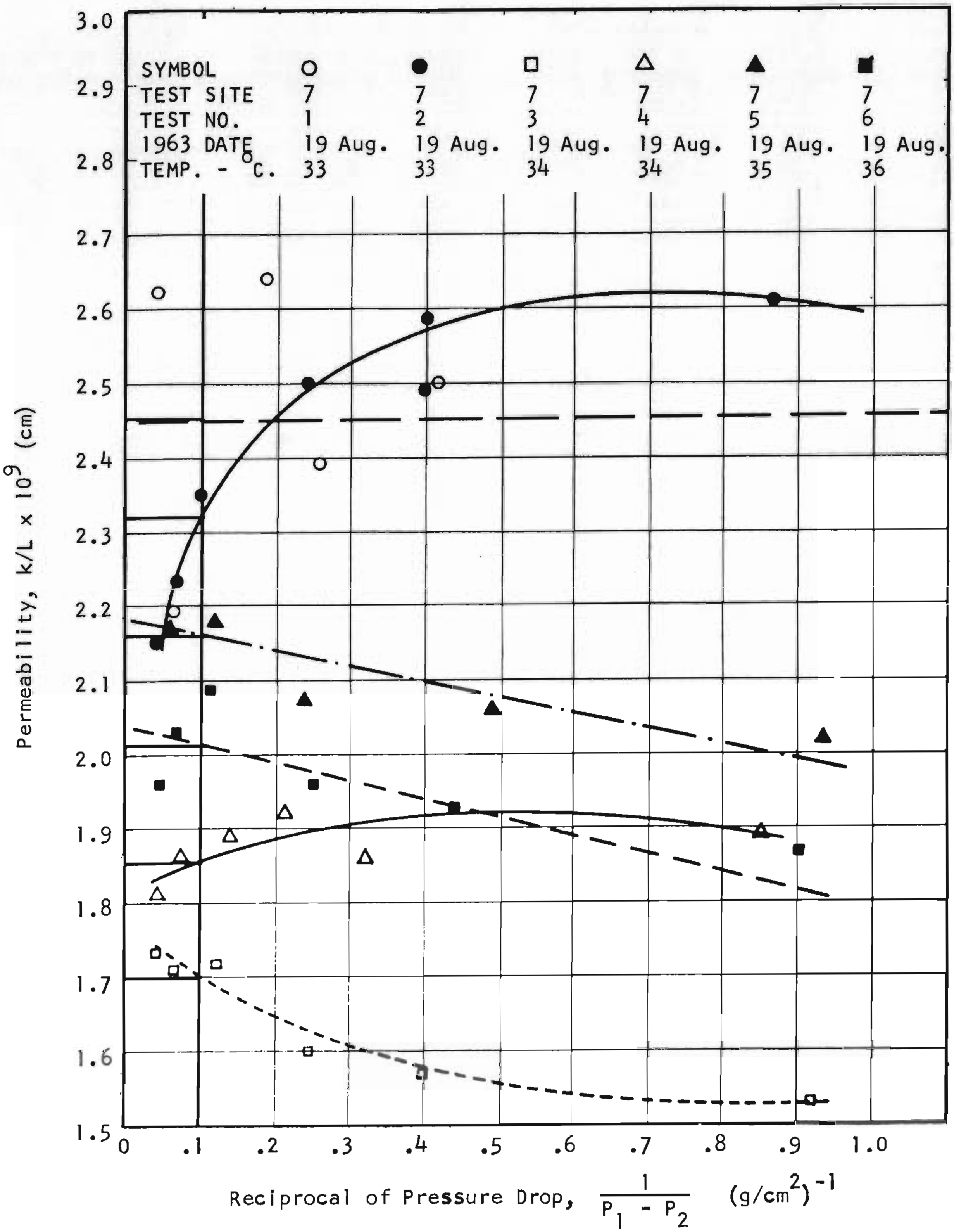


Figure B-20. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

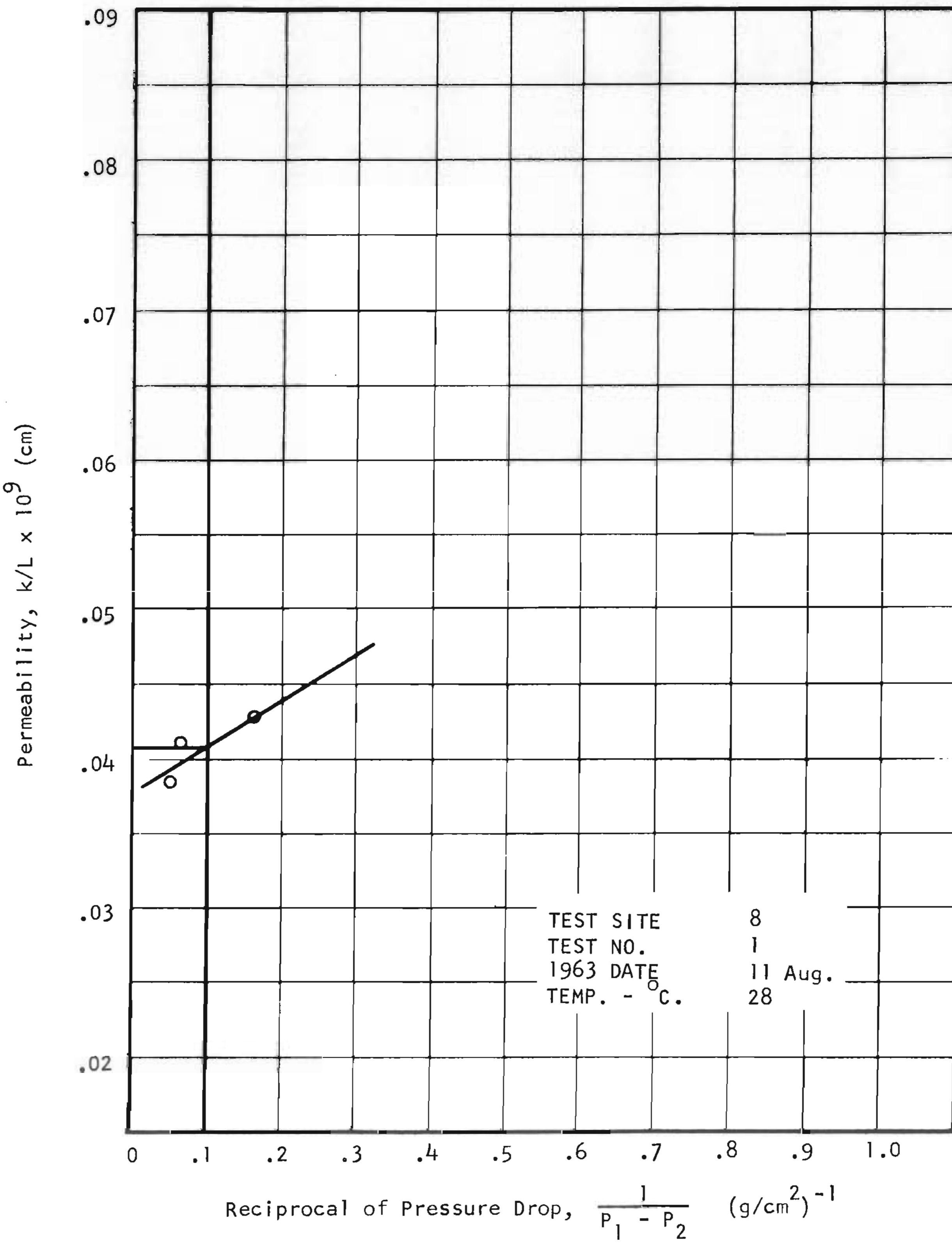


Figure B-21. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

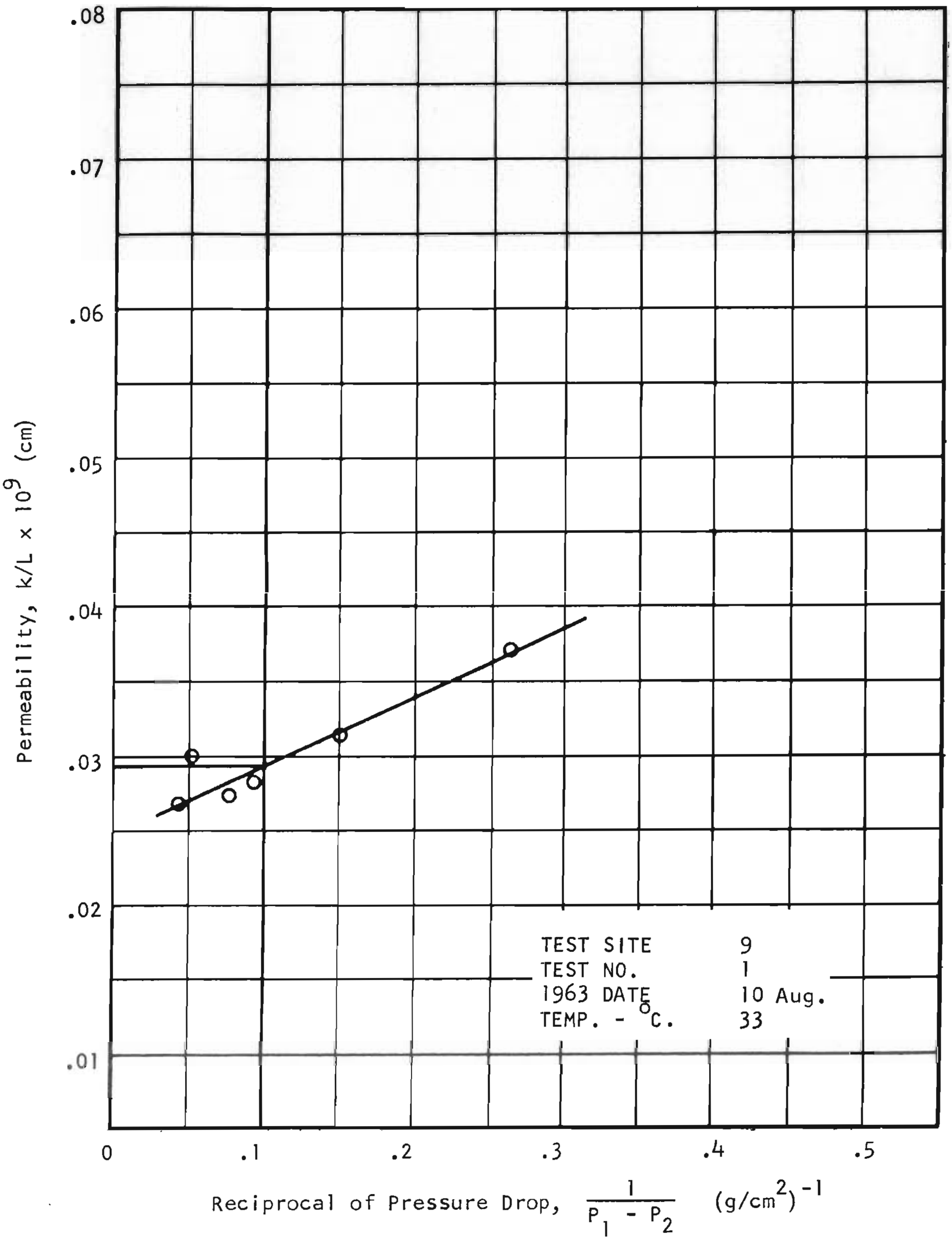


Figure B-22. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

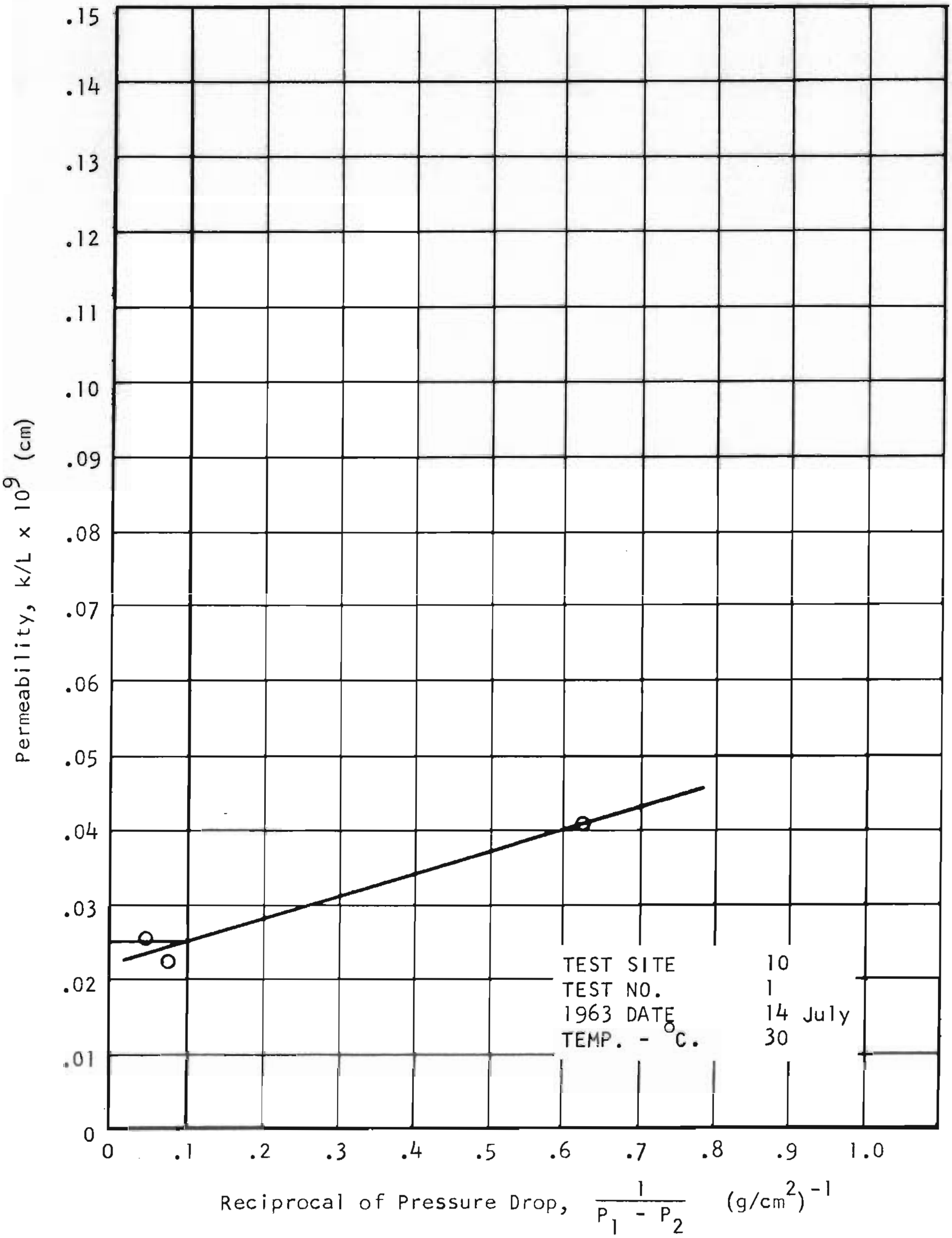


Figure B-23. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

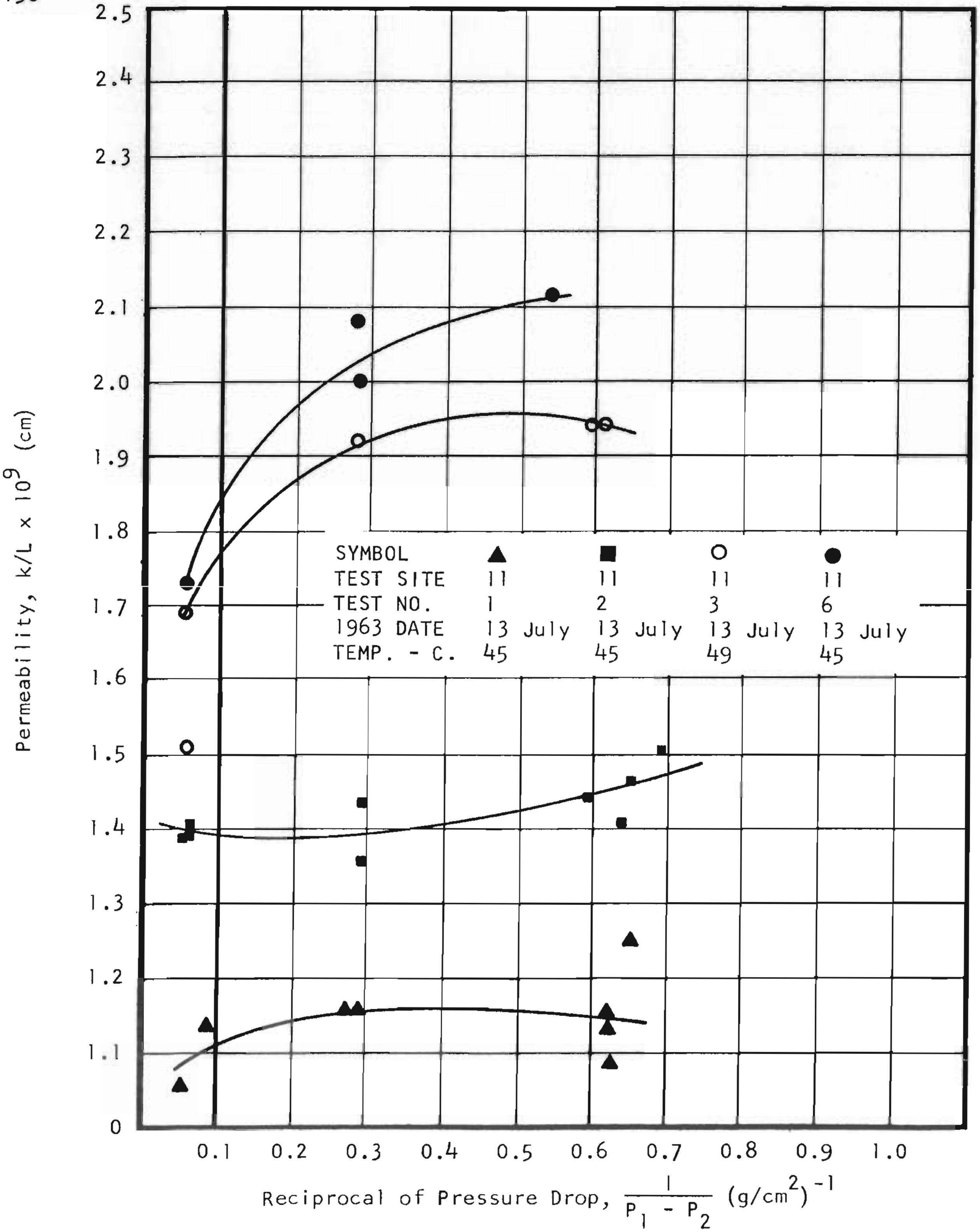


Figure B-24. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

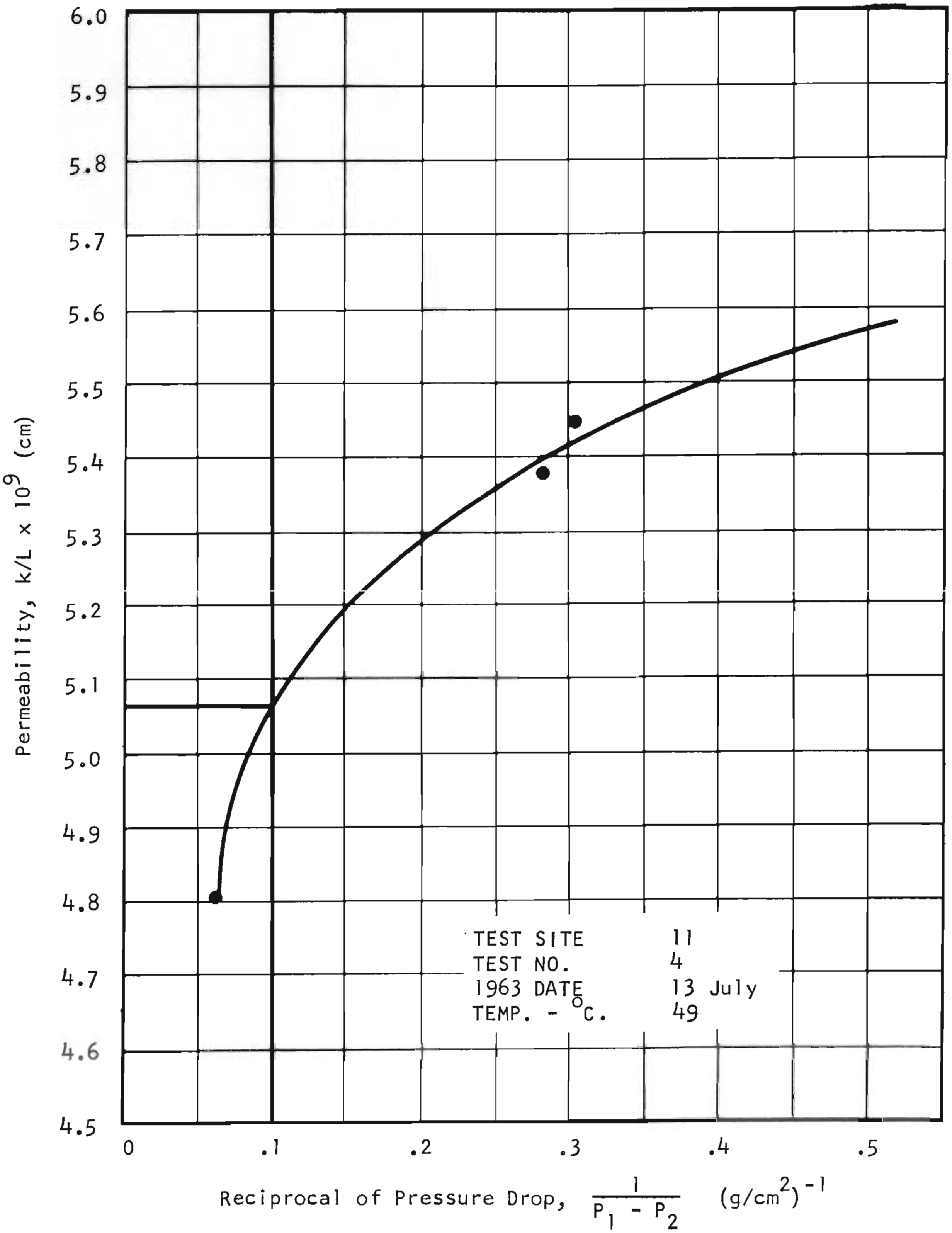


Figure B-25. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

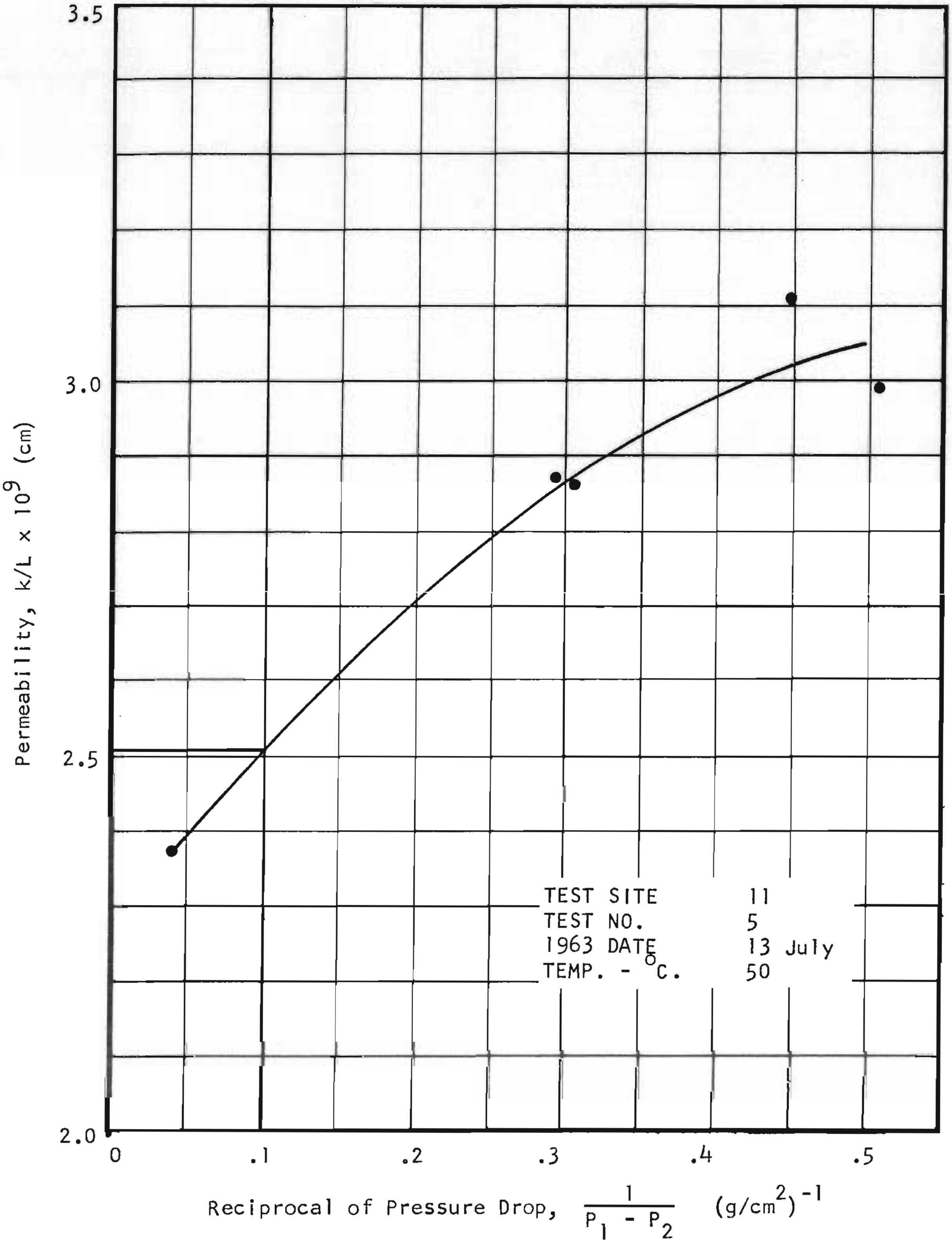


Figure B-26. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

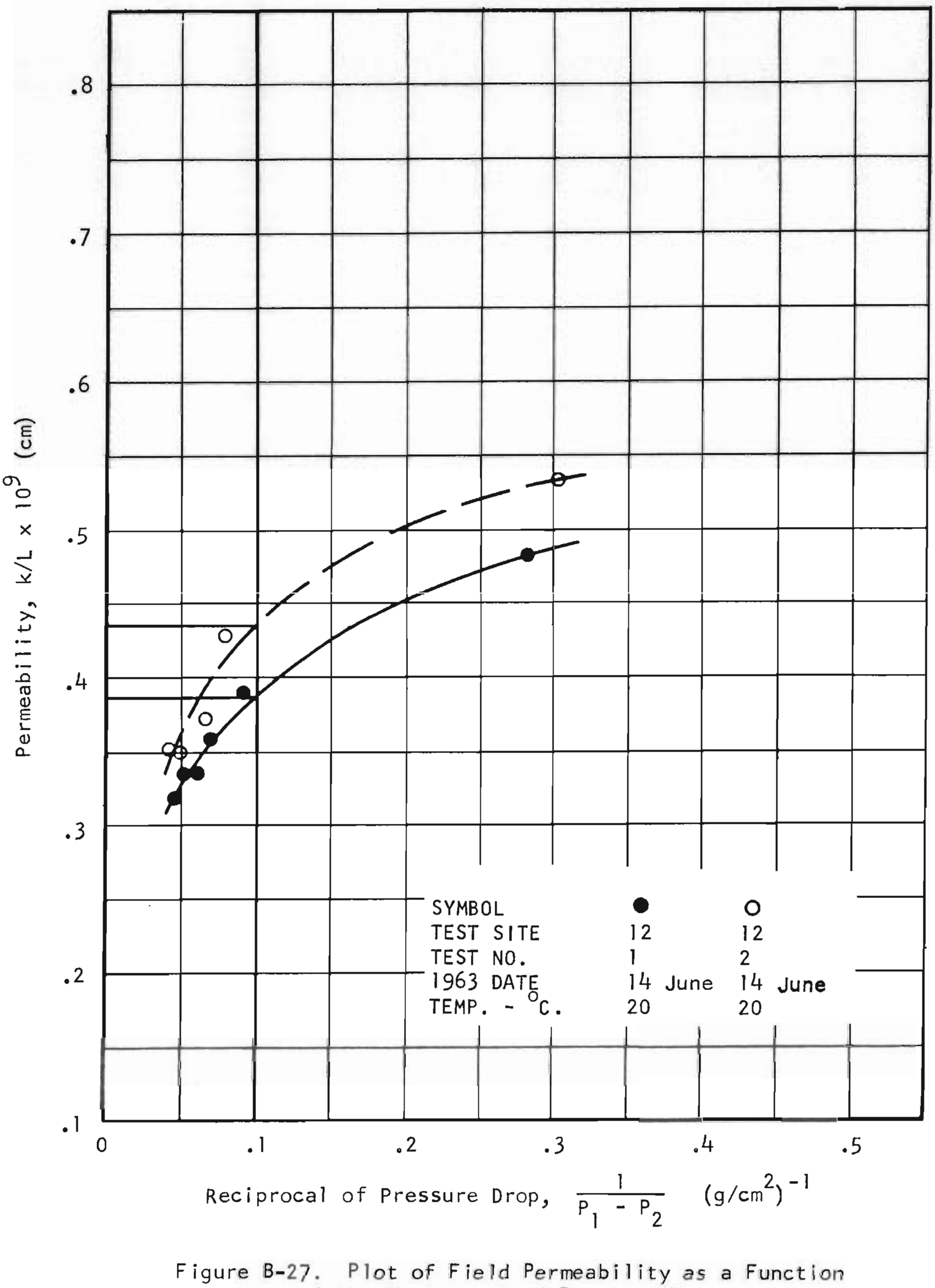


Figure B-27. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

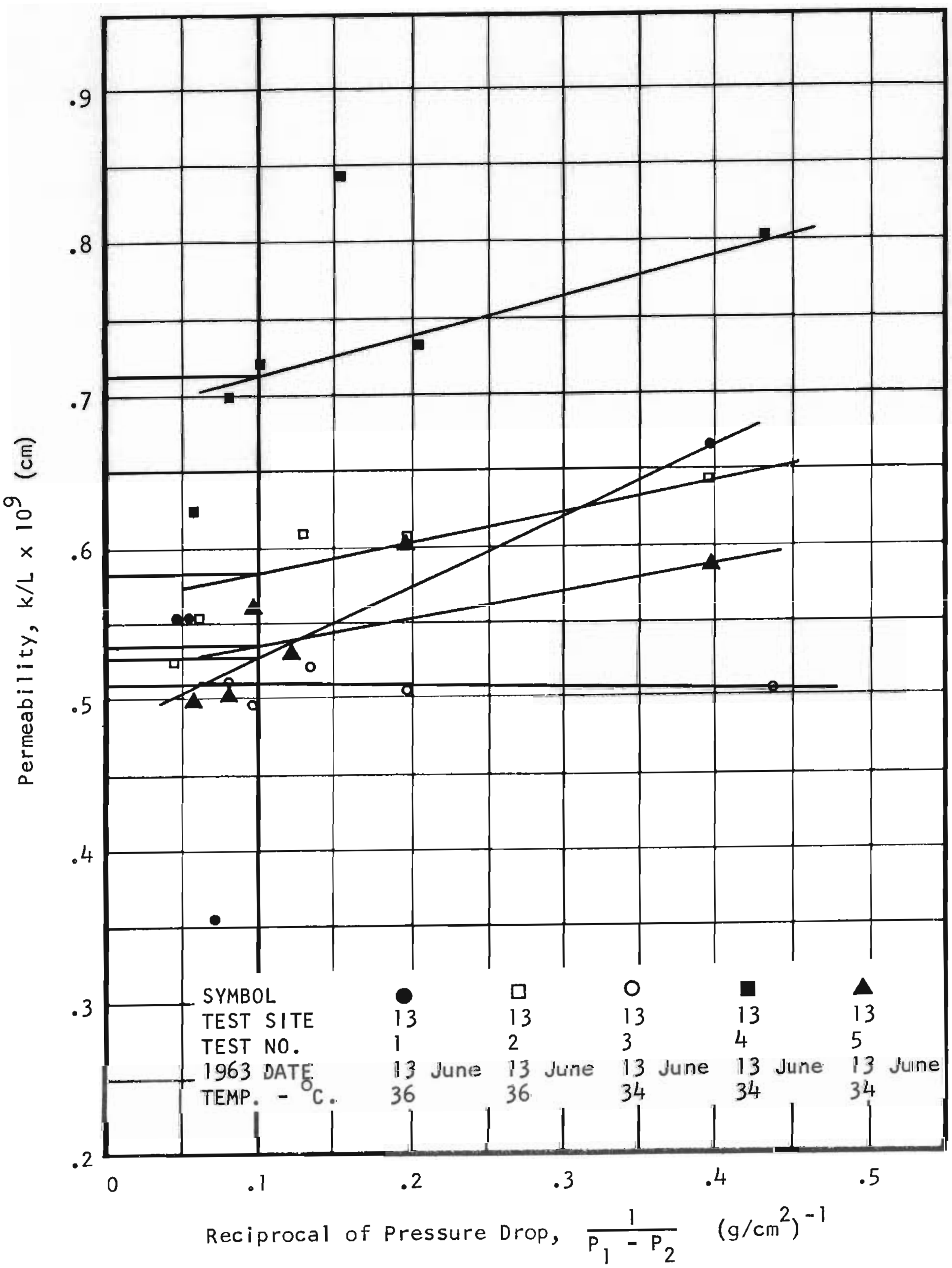


Figure B-28. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

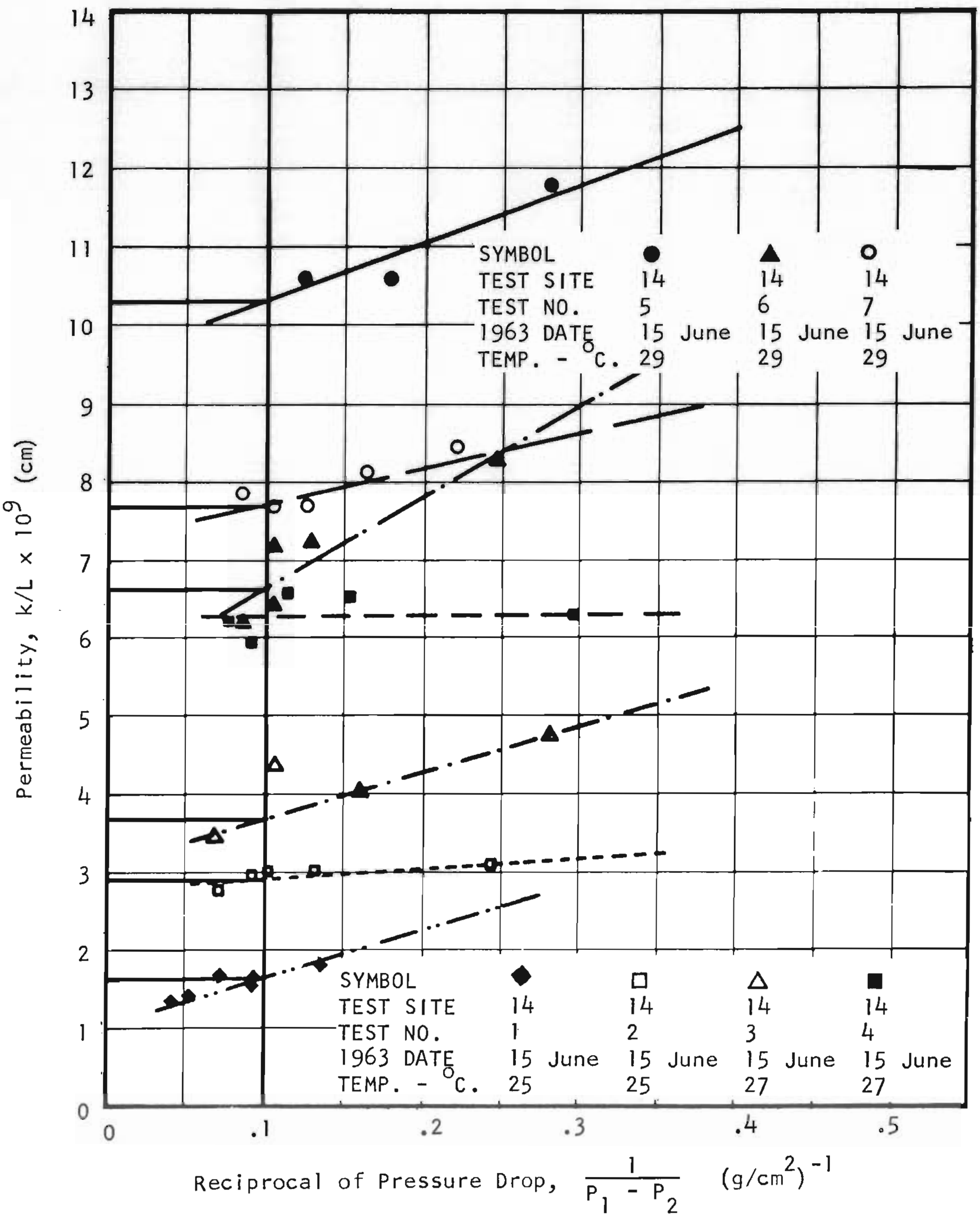


Figure B-29. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

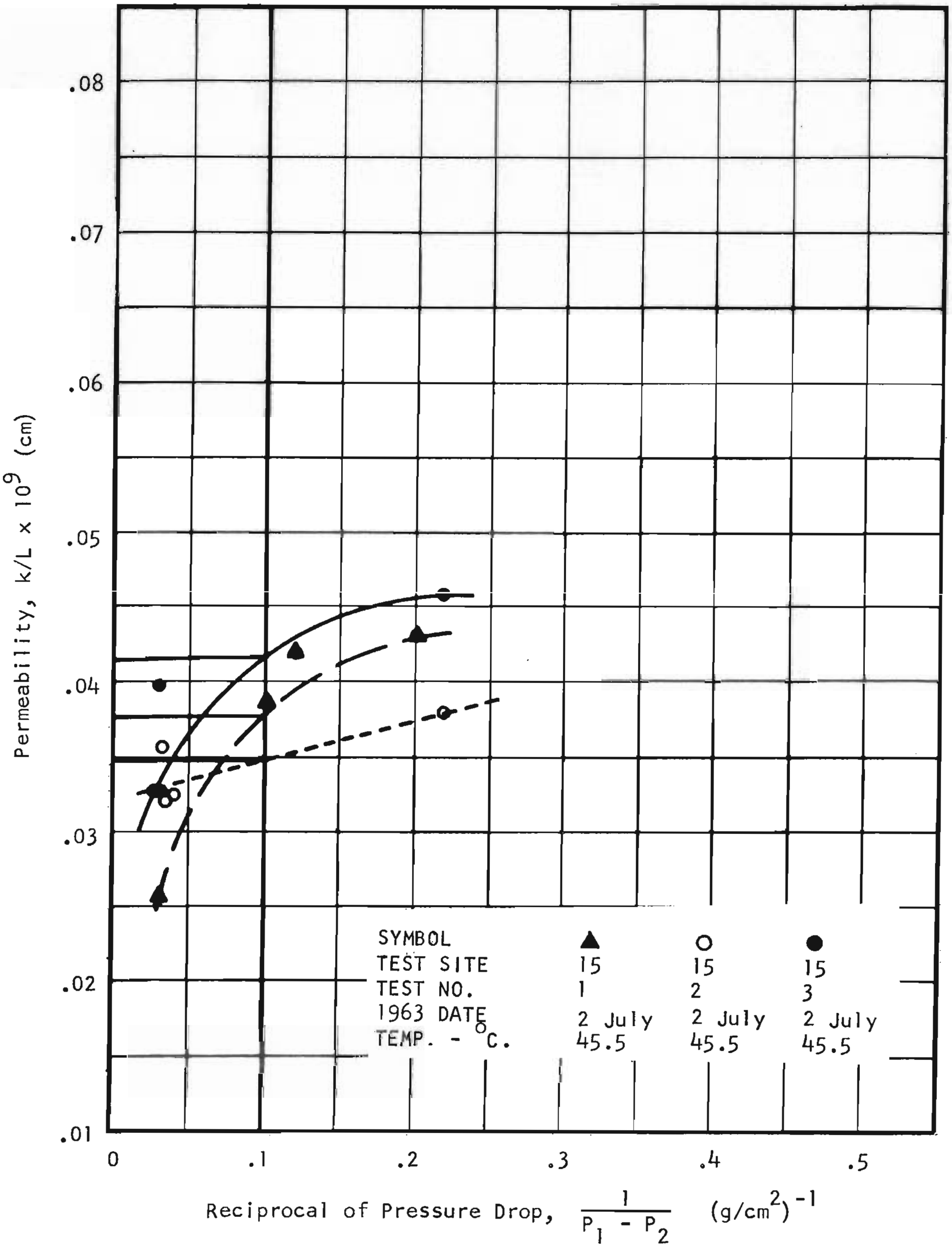


Figure B-30. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

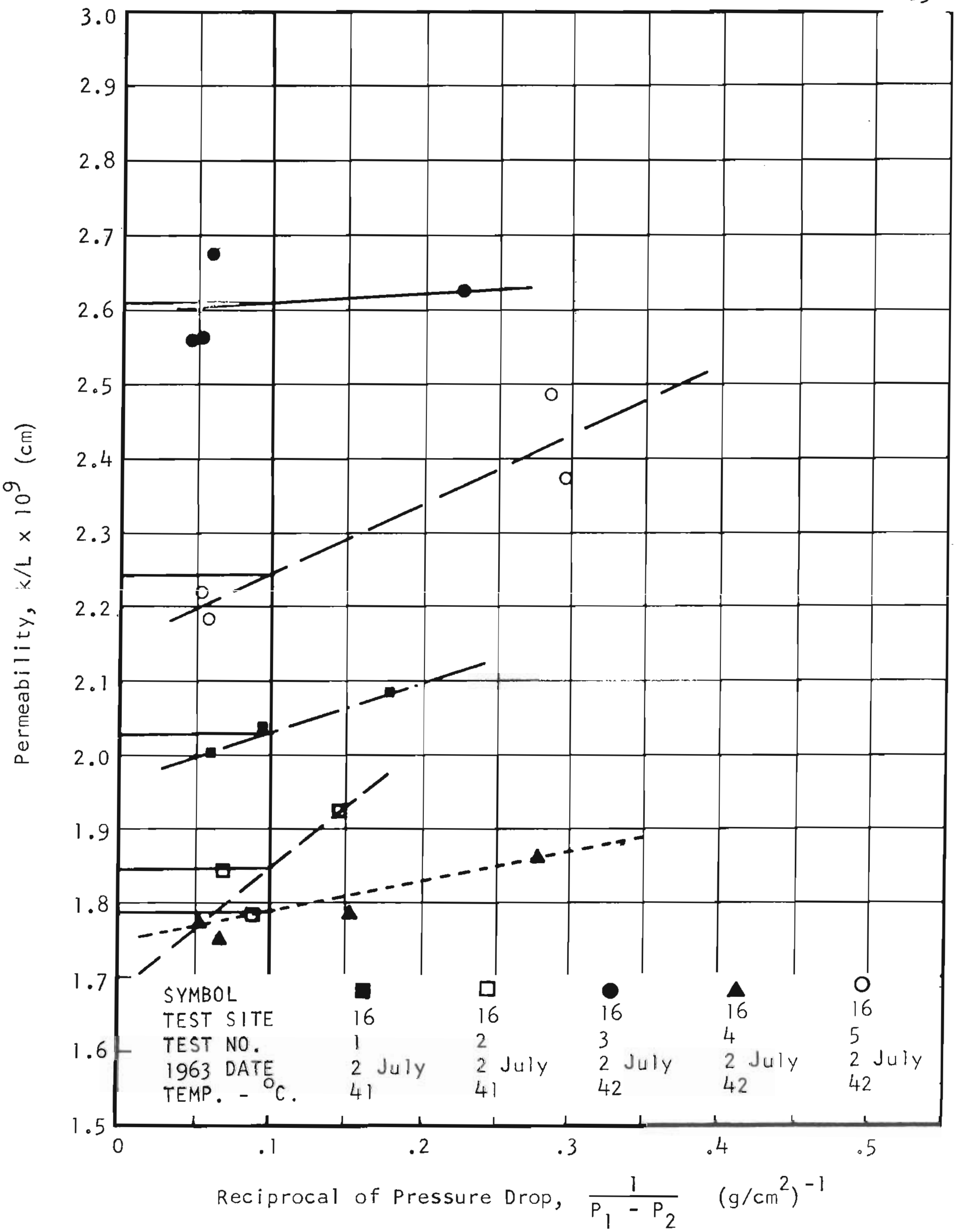


Figure B-31. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

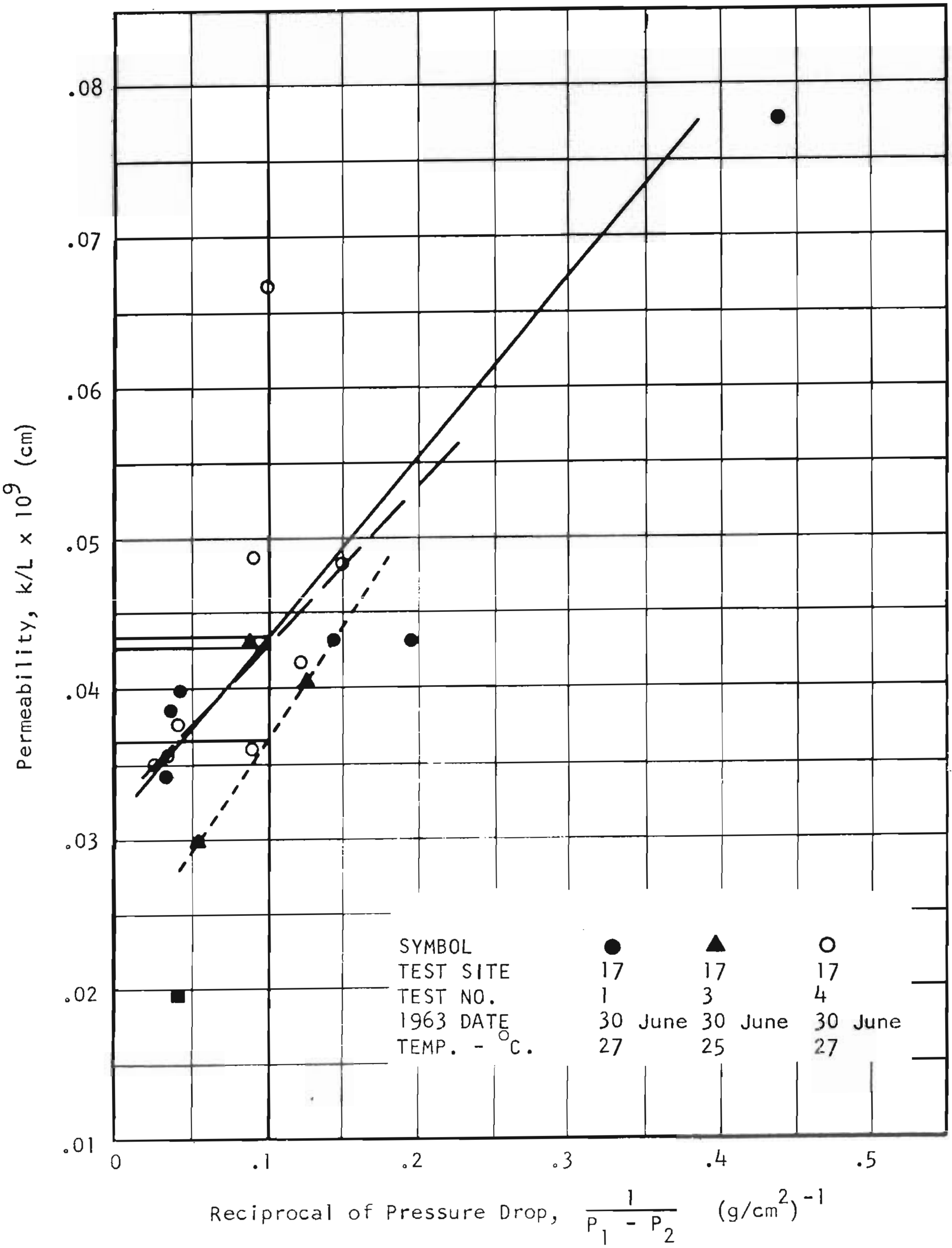


Figure B-32. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

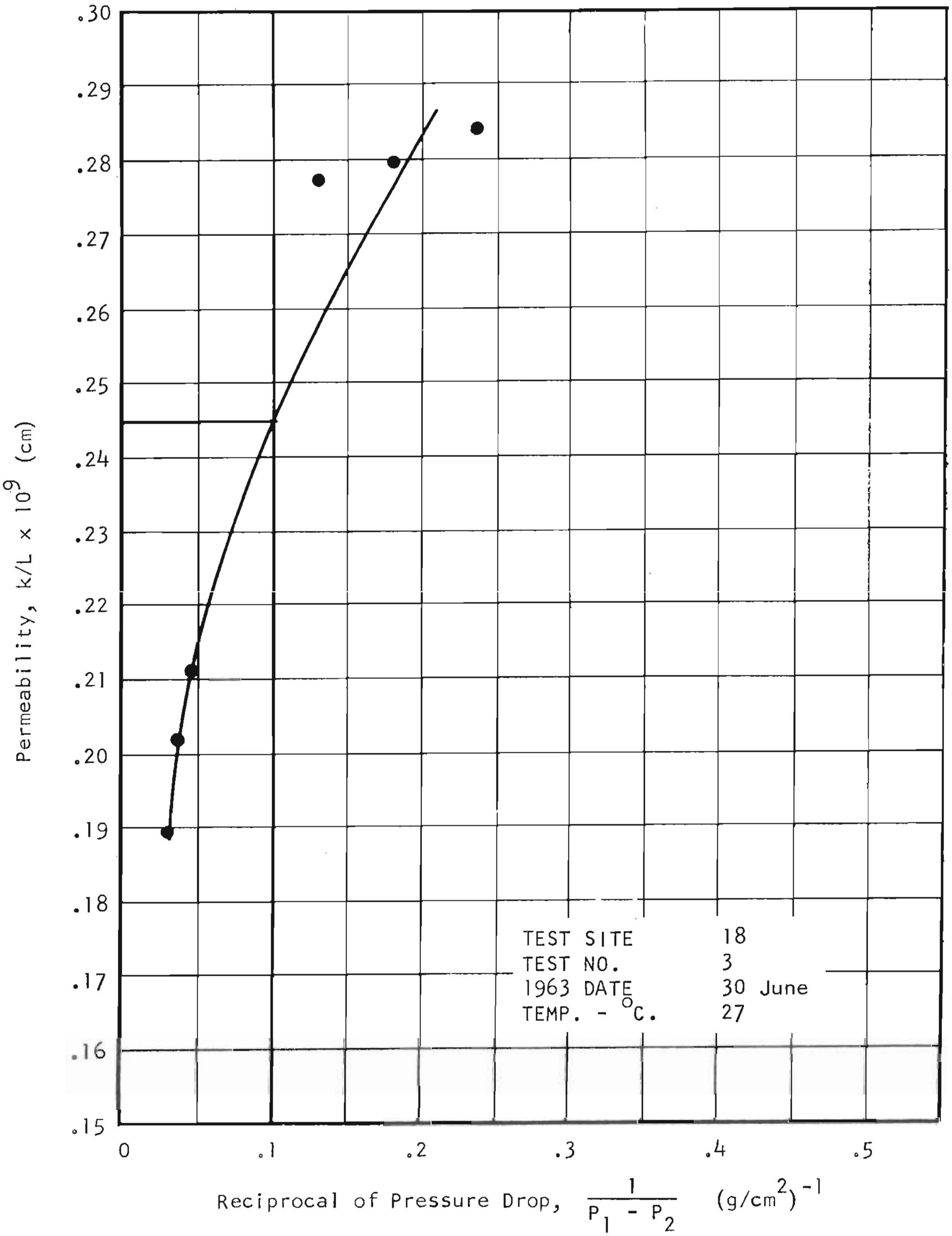


Figure B-33. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

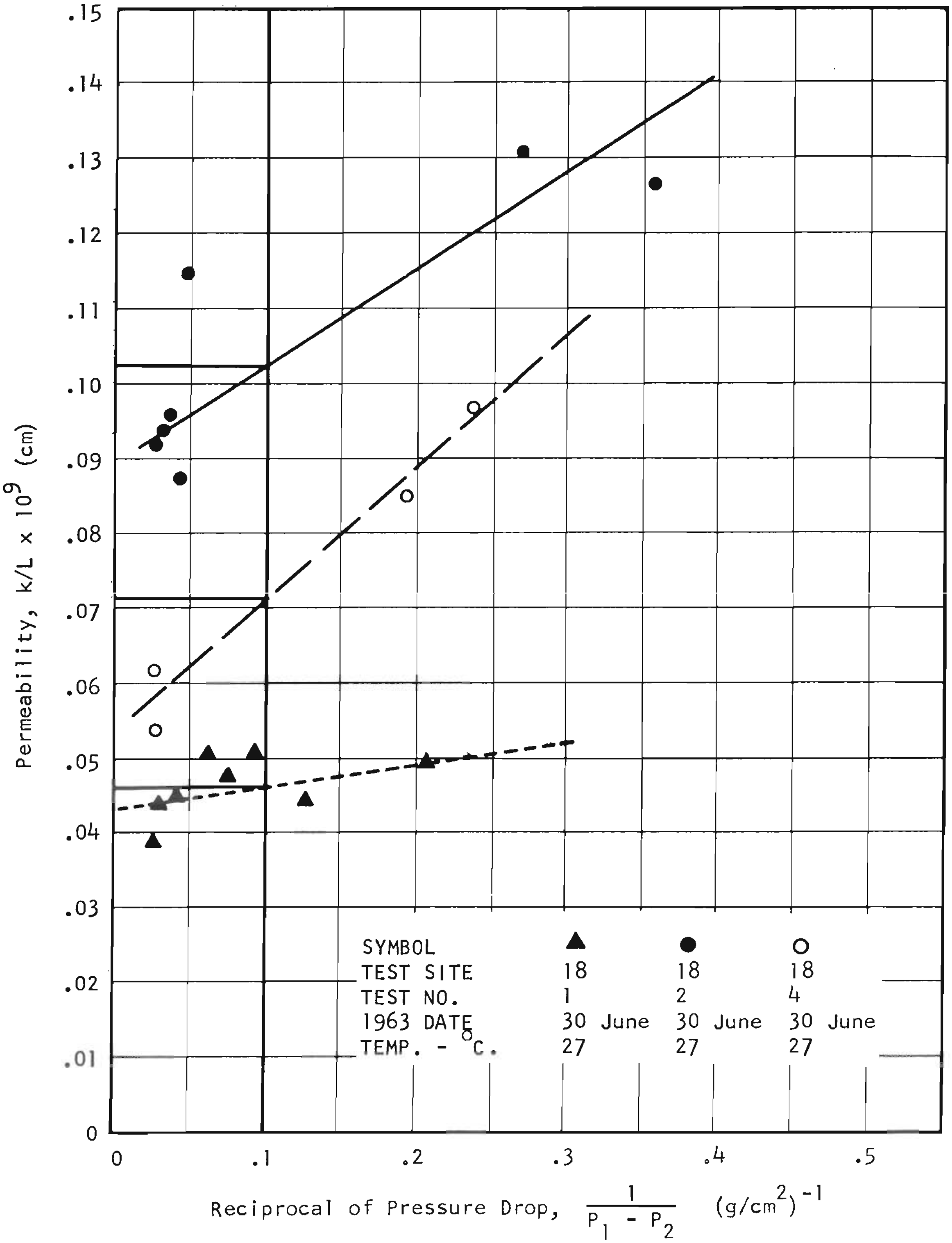
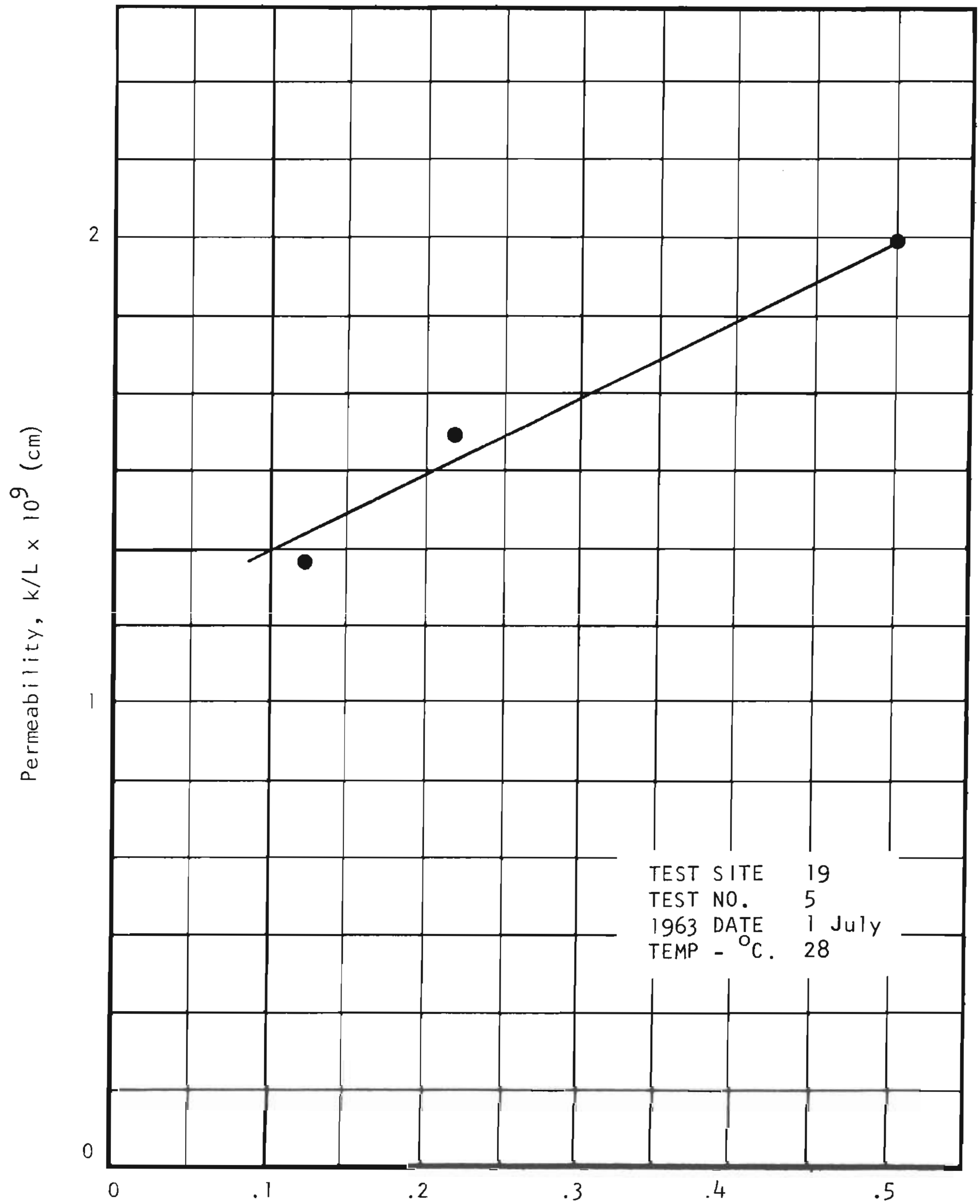


Figure B-34. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop



Reciprocal of Pressure Drop, $\frac{1}{P_1 - P_2}$ $(g/cm^2)^{-1}$

Figure B-35. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

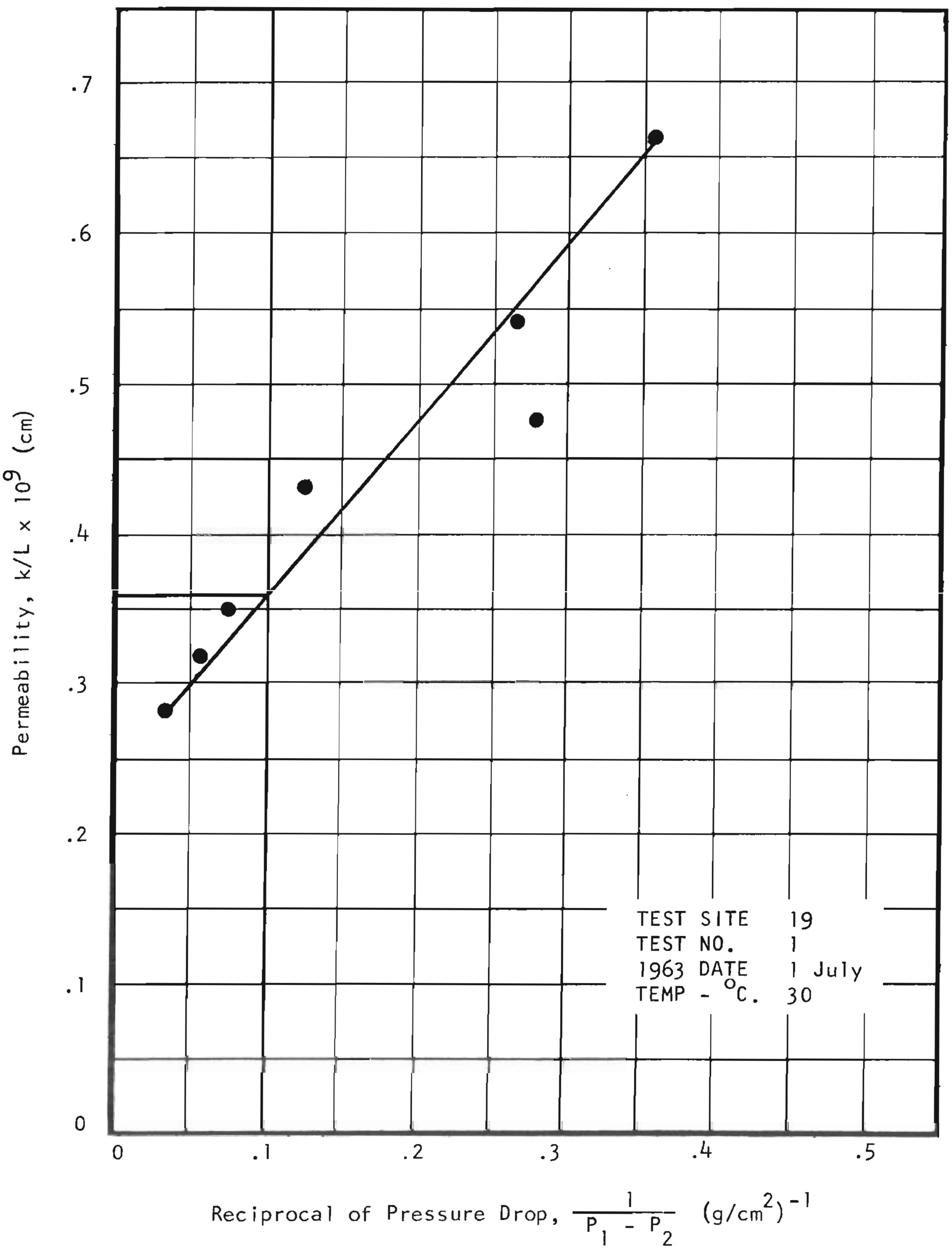


Figure B-36. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

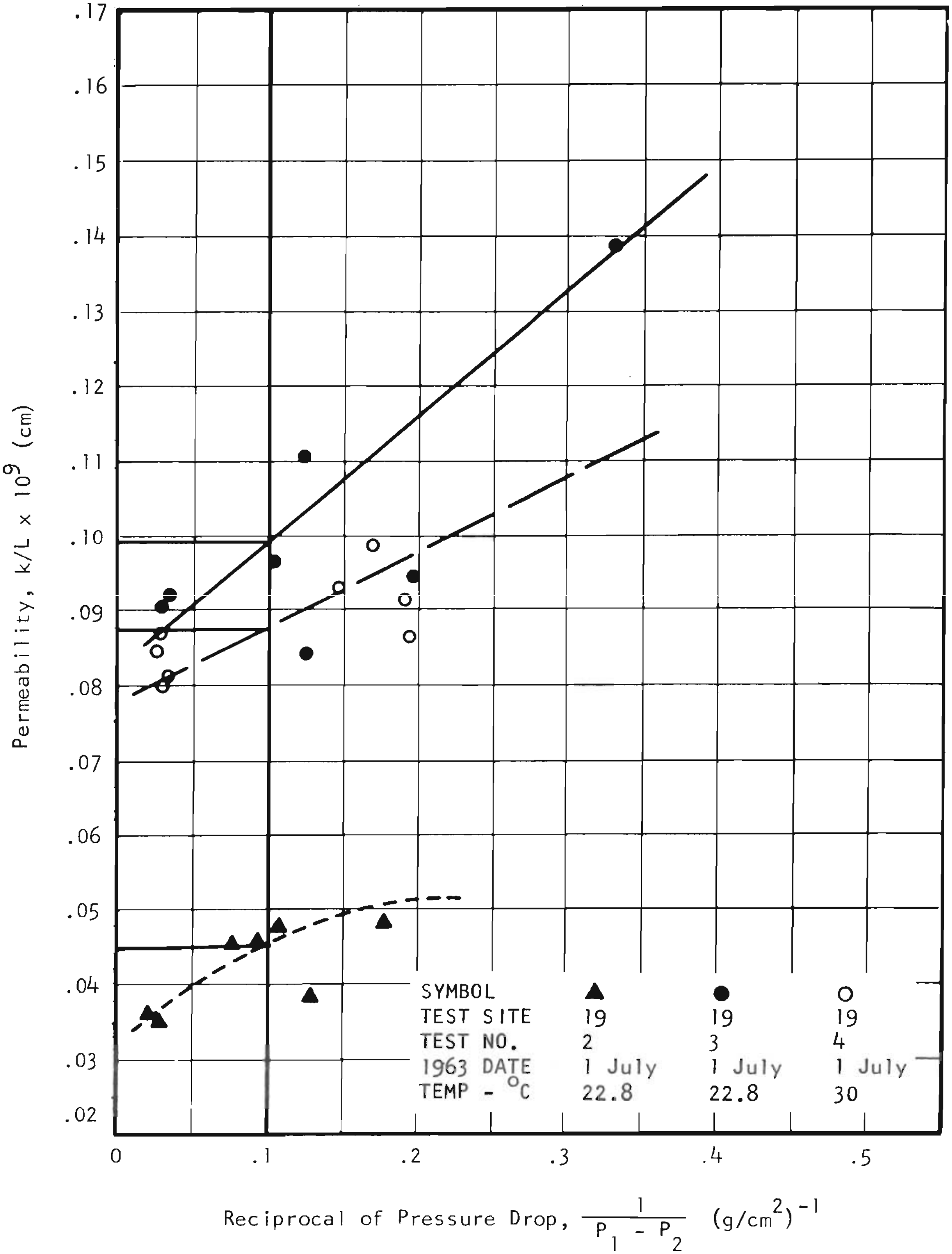


Figure B-37. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

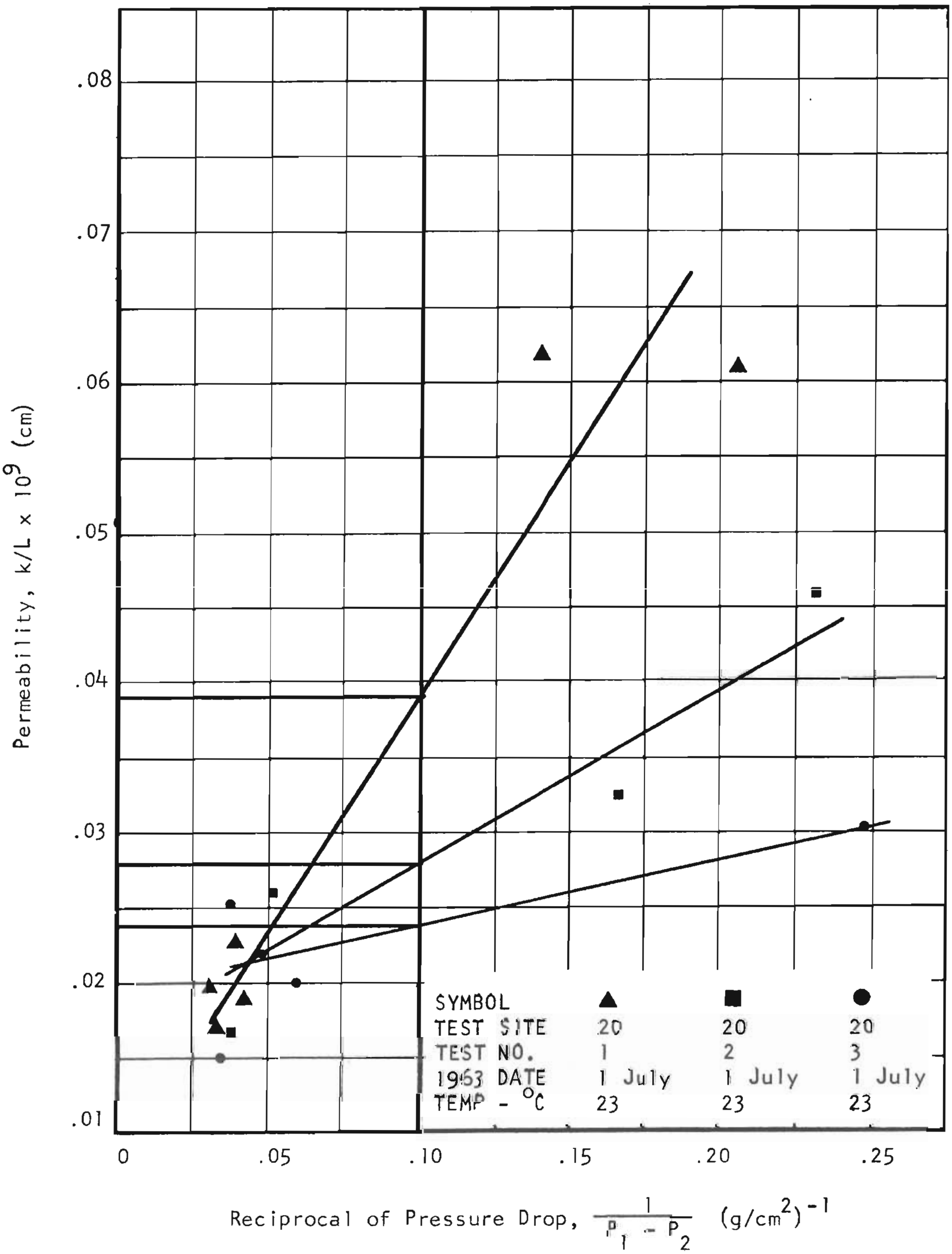


Figure B-38. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

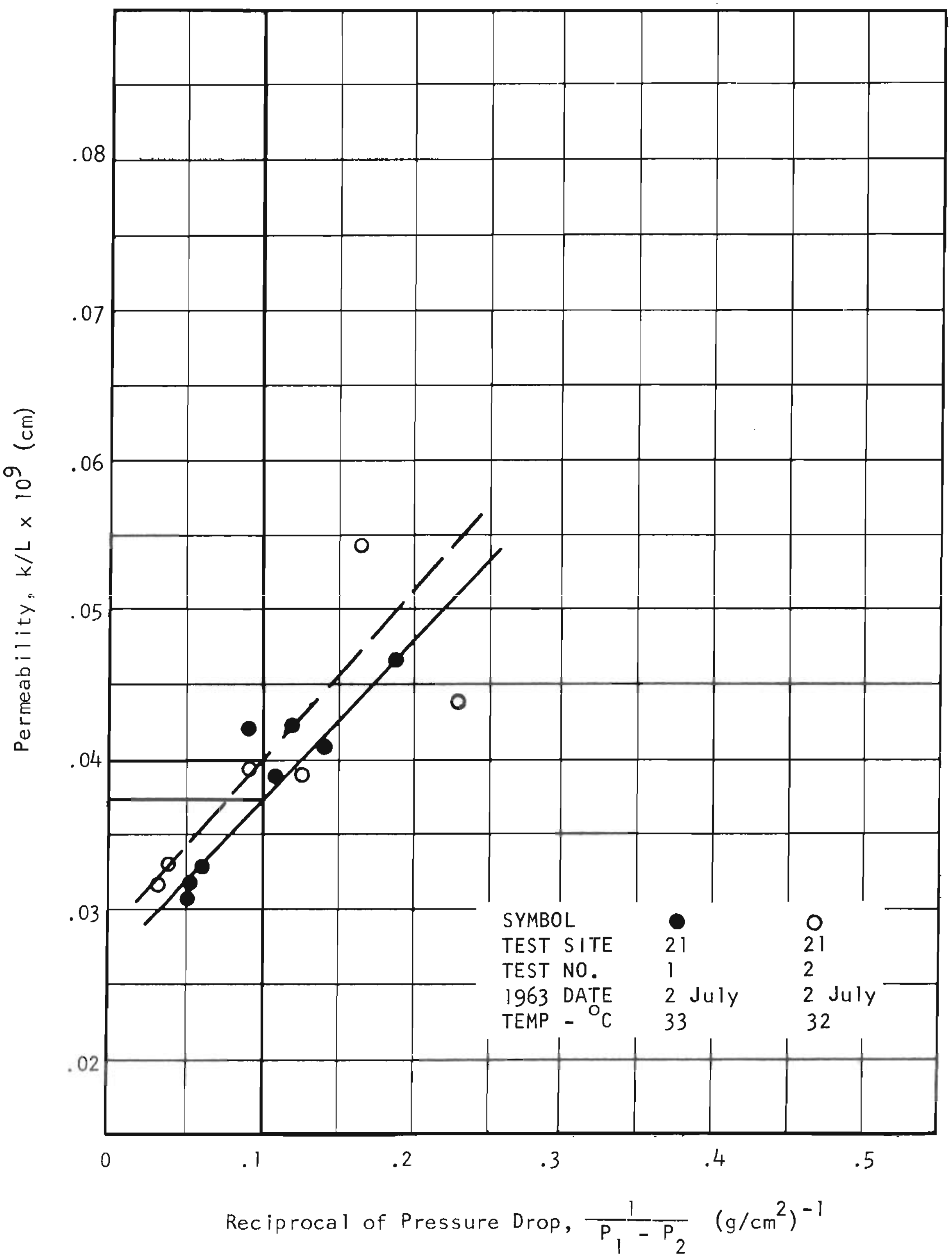


Figure B-39. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

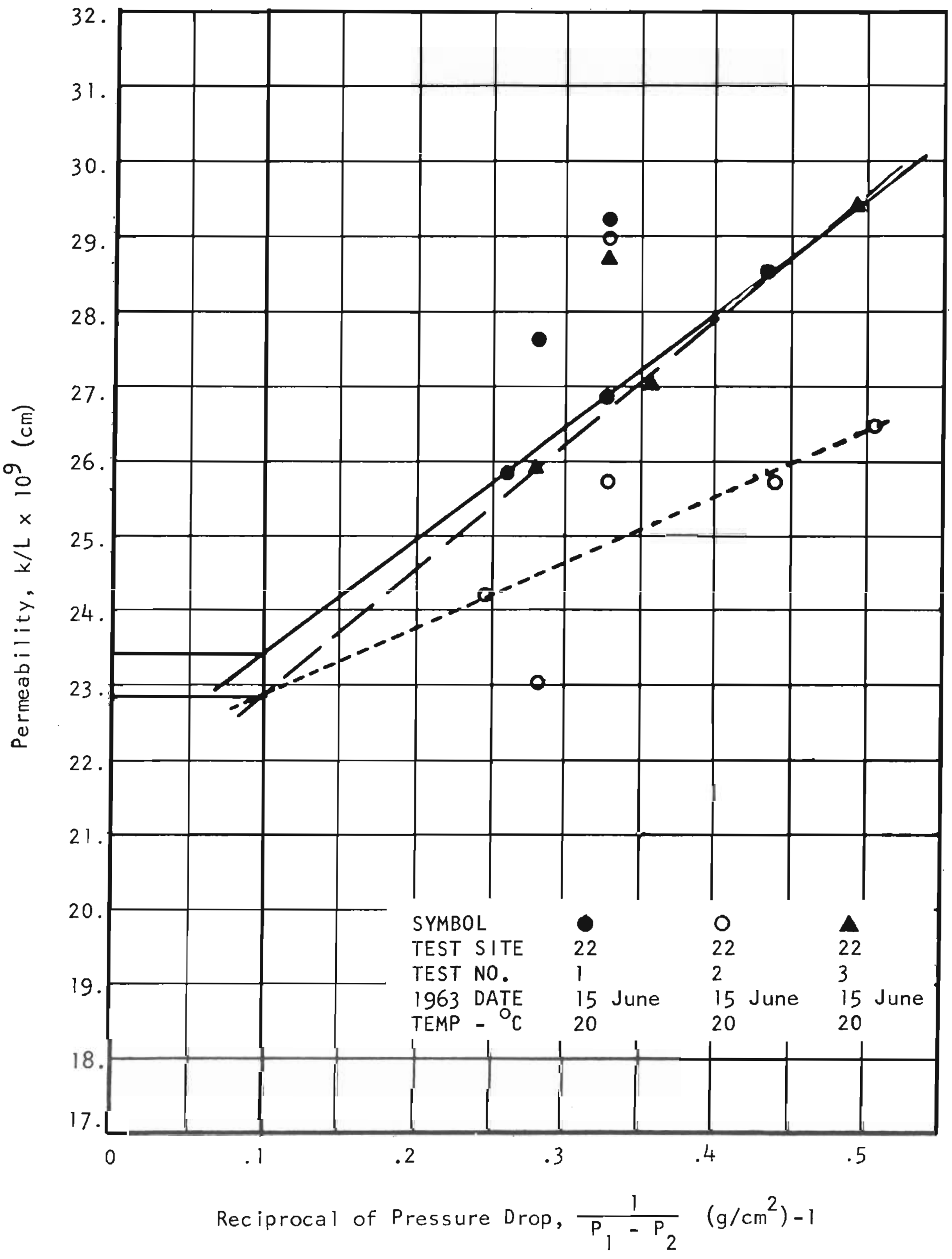


Figure B-40. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

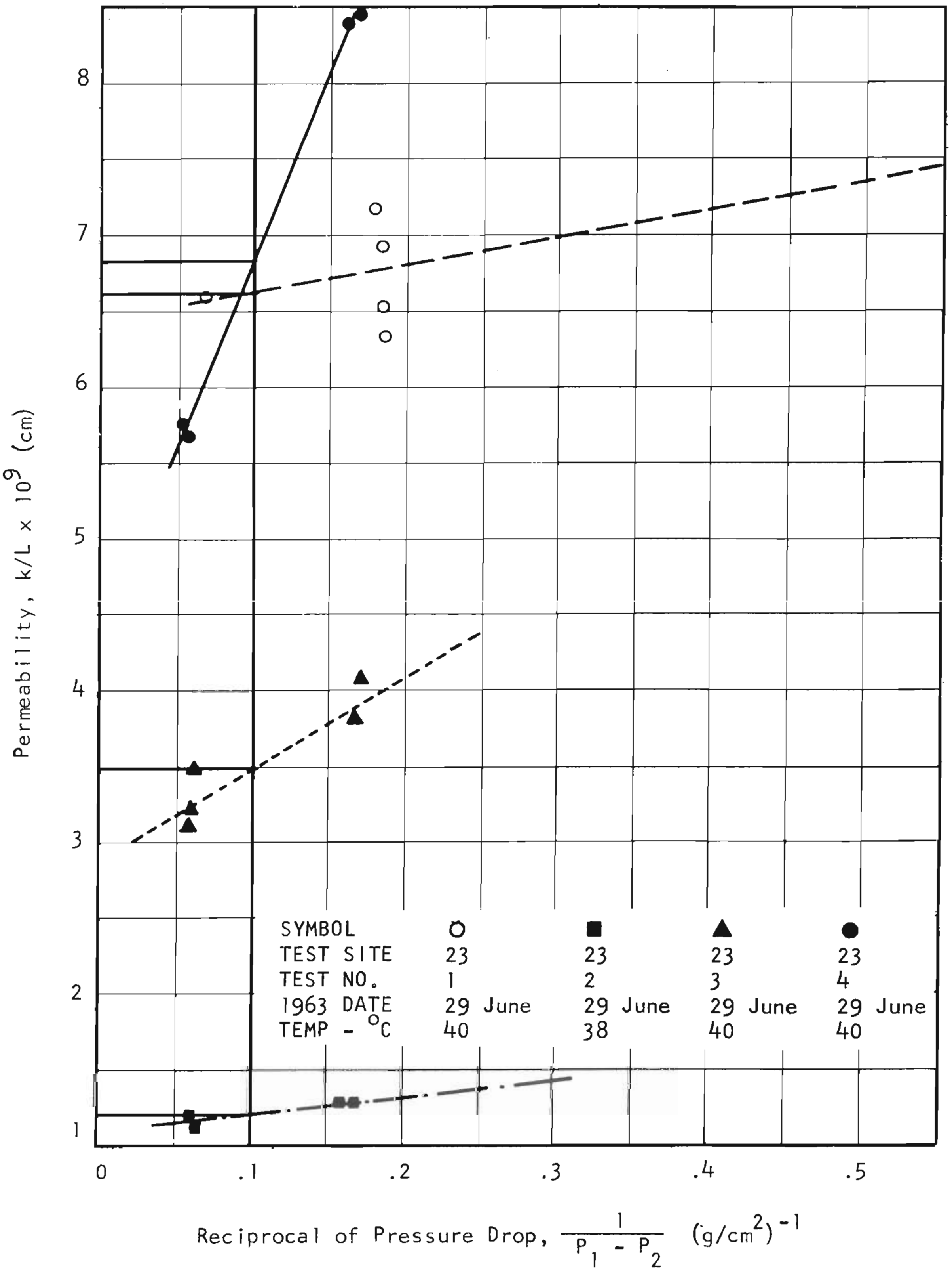


Figure B-41. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

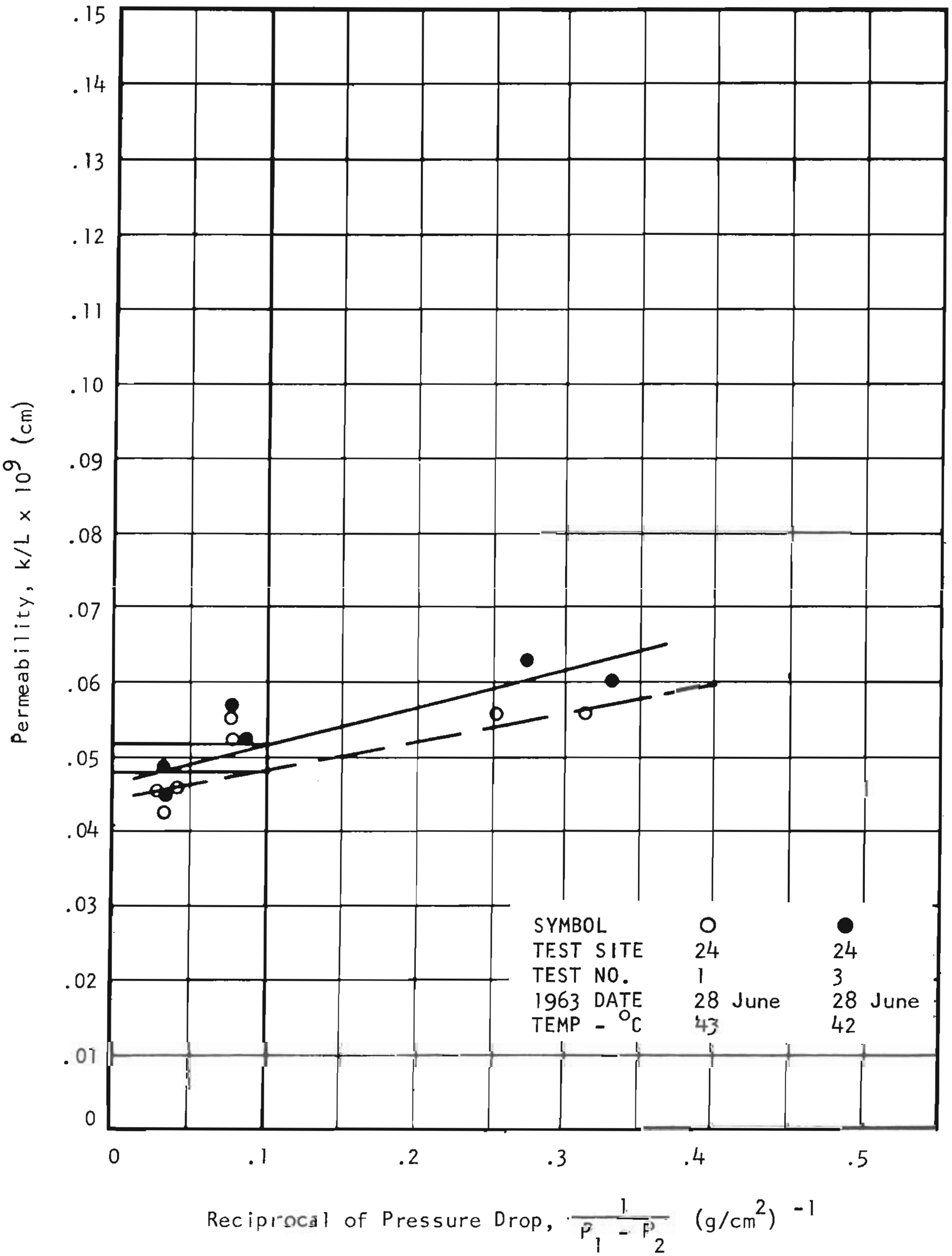


Figure B-42. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

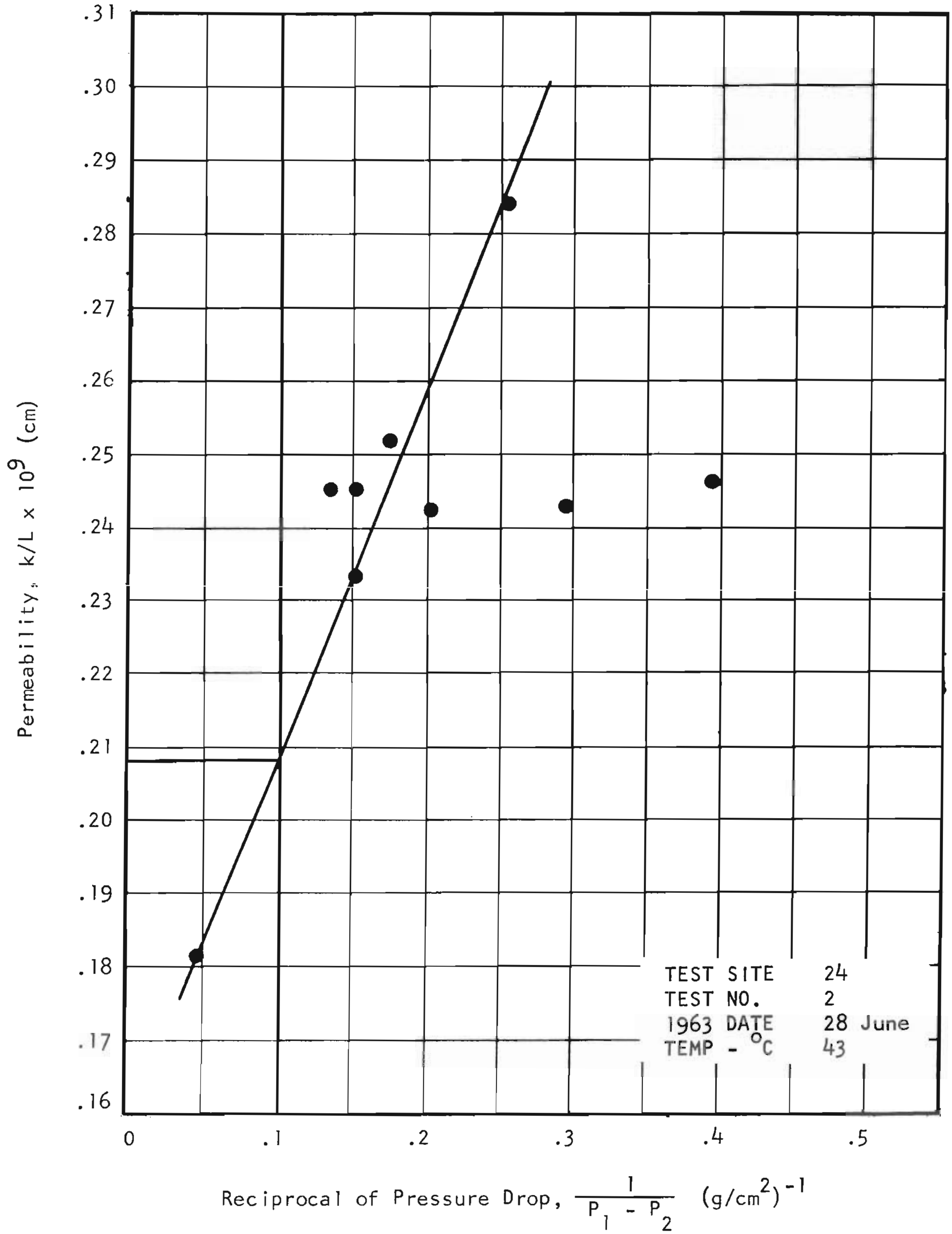


Figure B-43. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

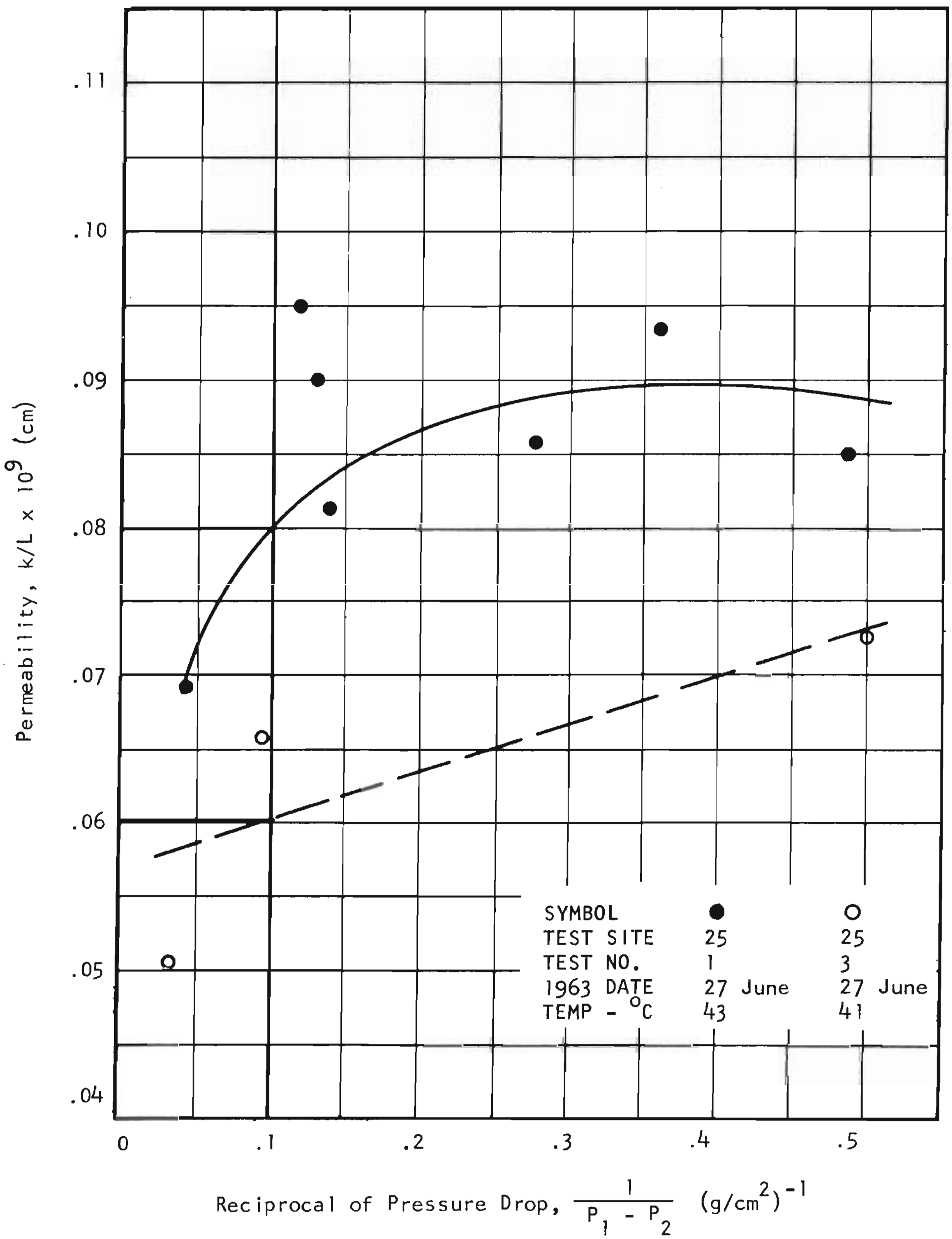


Figure B-44. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

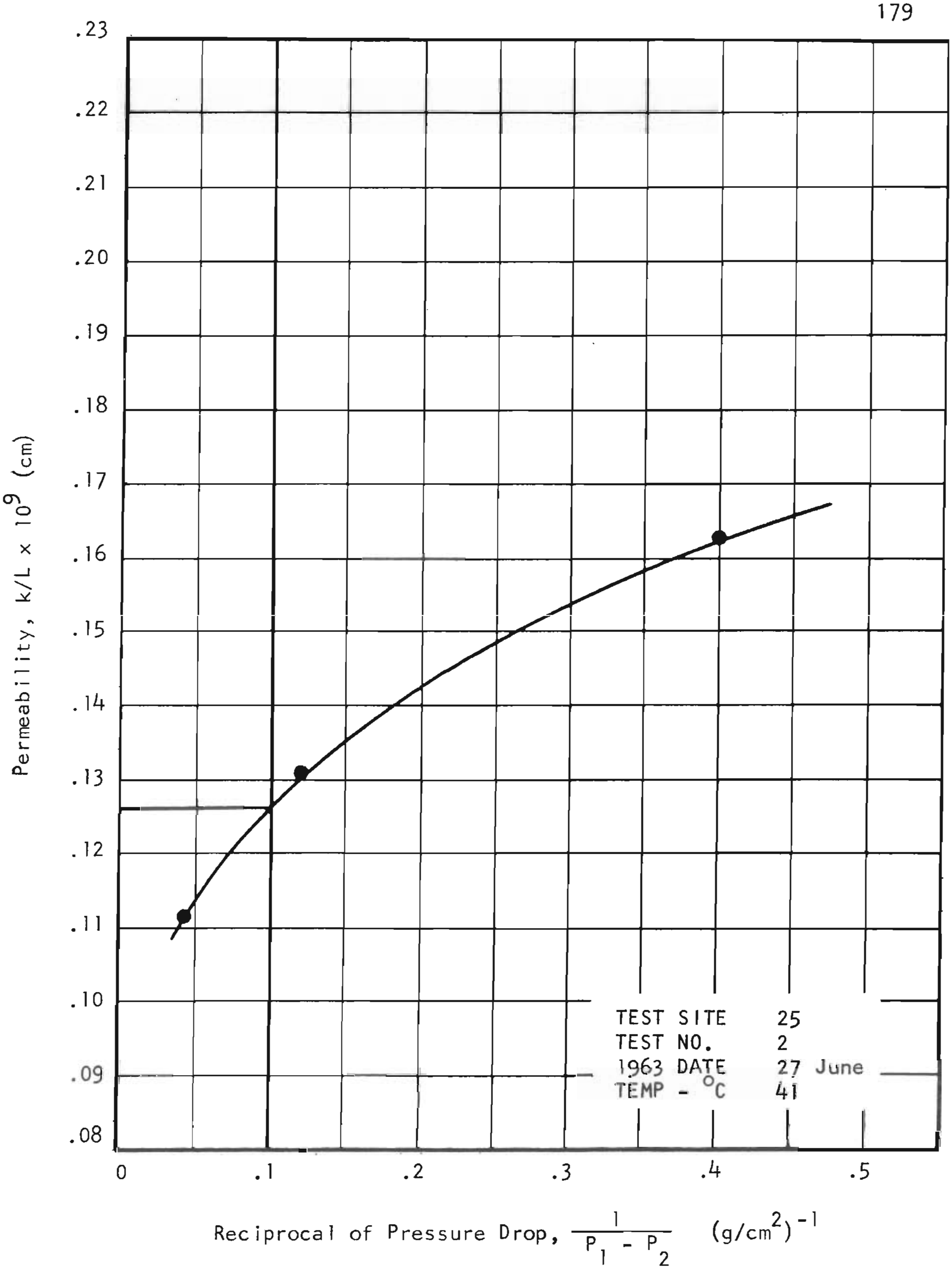


Figure B-45. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

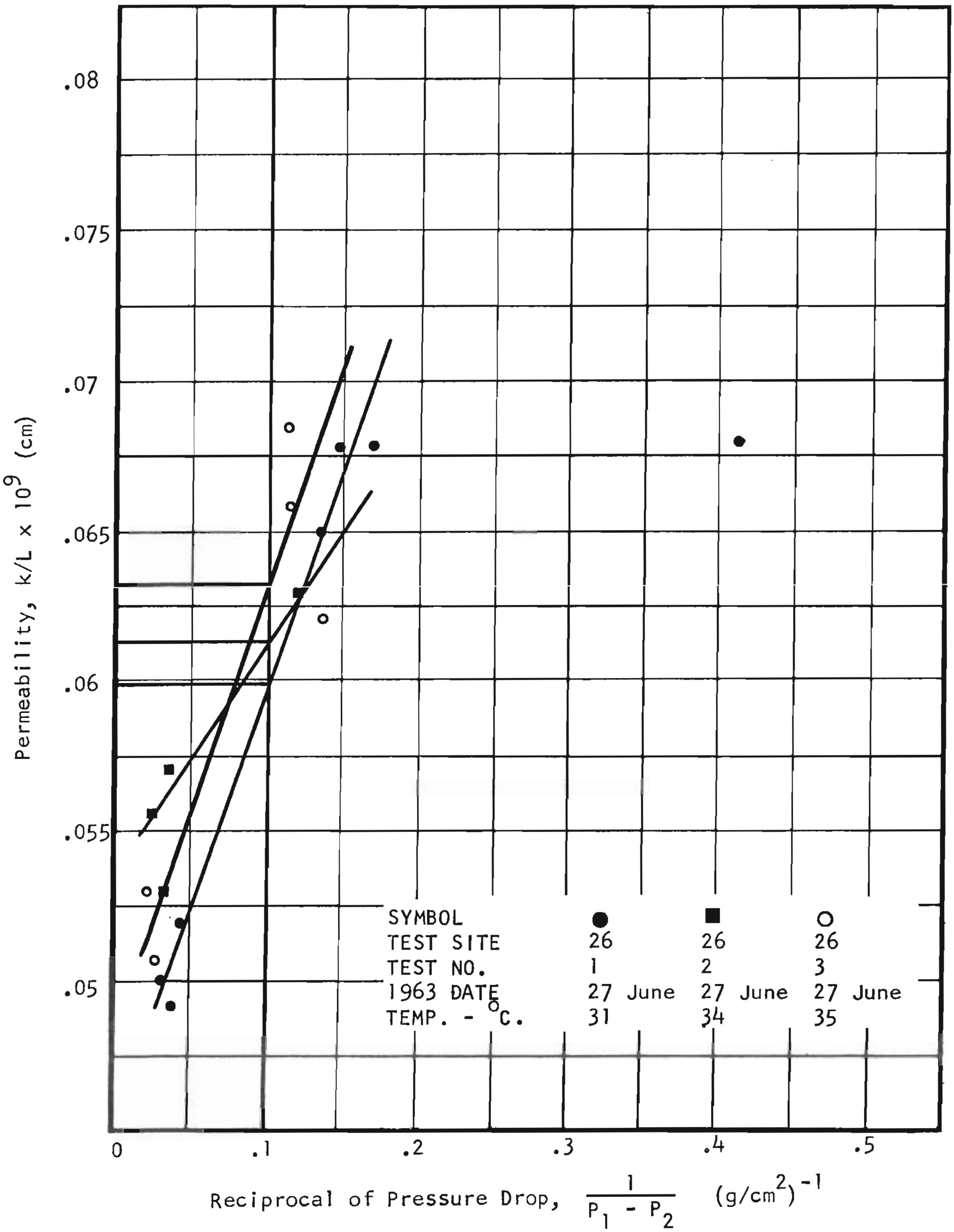


Figure B-46. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

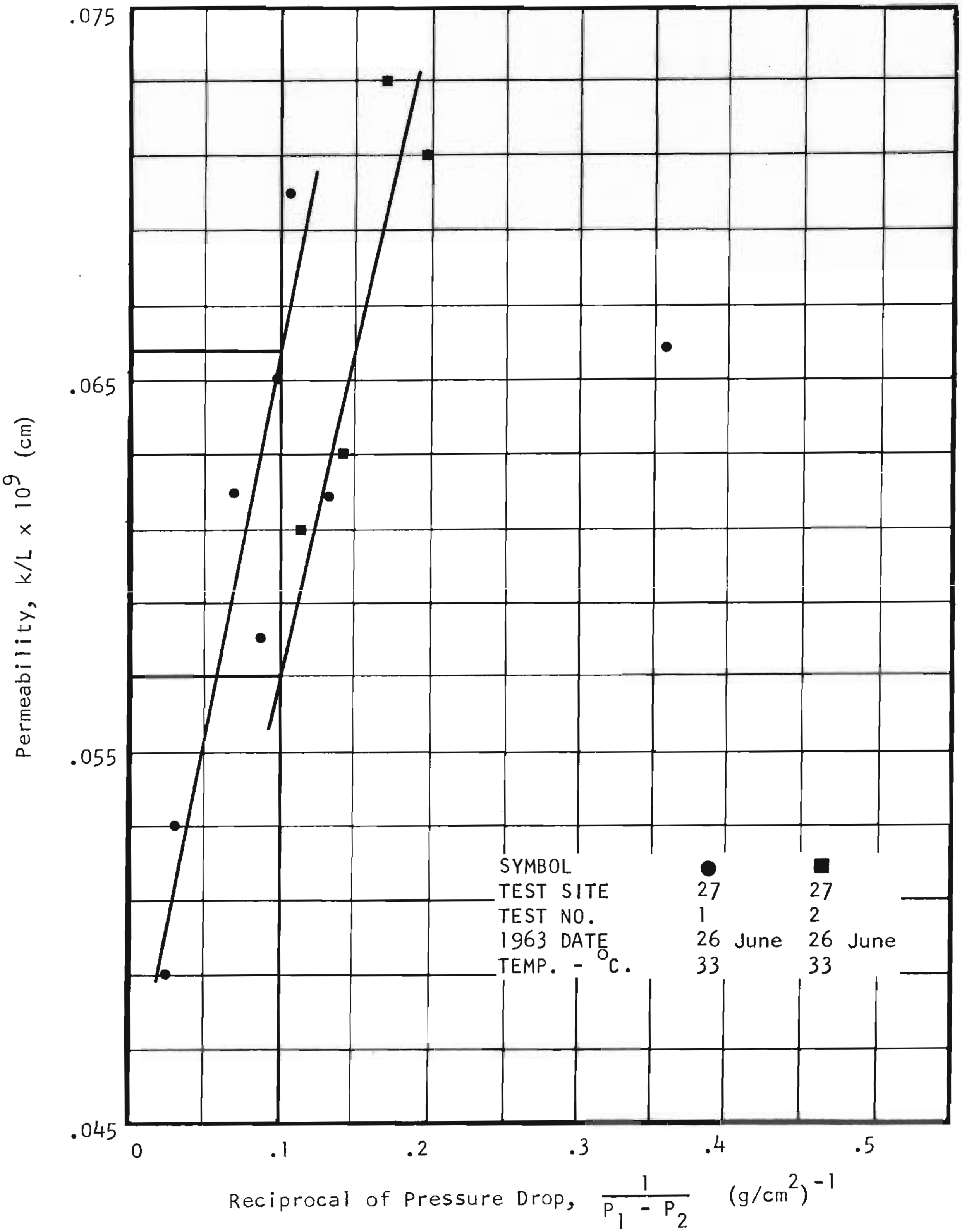


Figure B-47. Plot of Field Permeability as Function of the Reciprocal of Presuure Drop

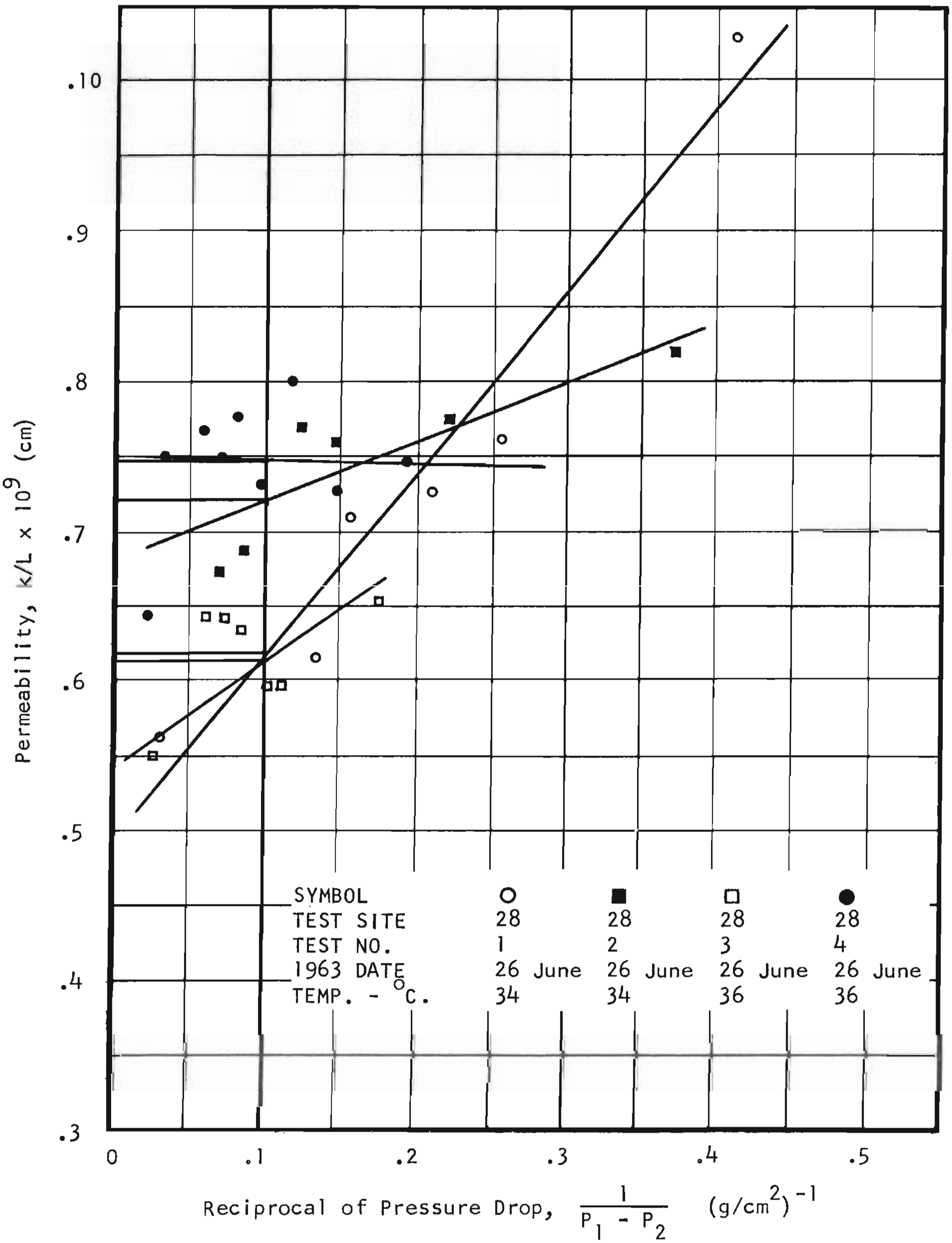


Figure B-48. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

APPENDIX C

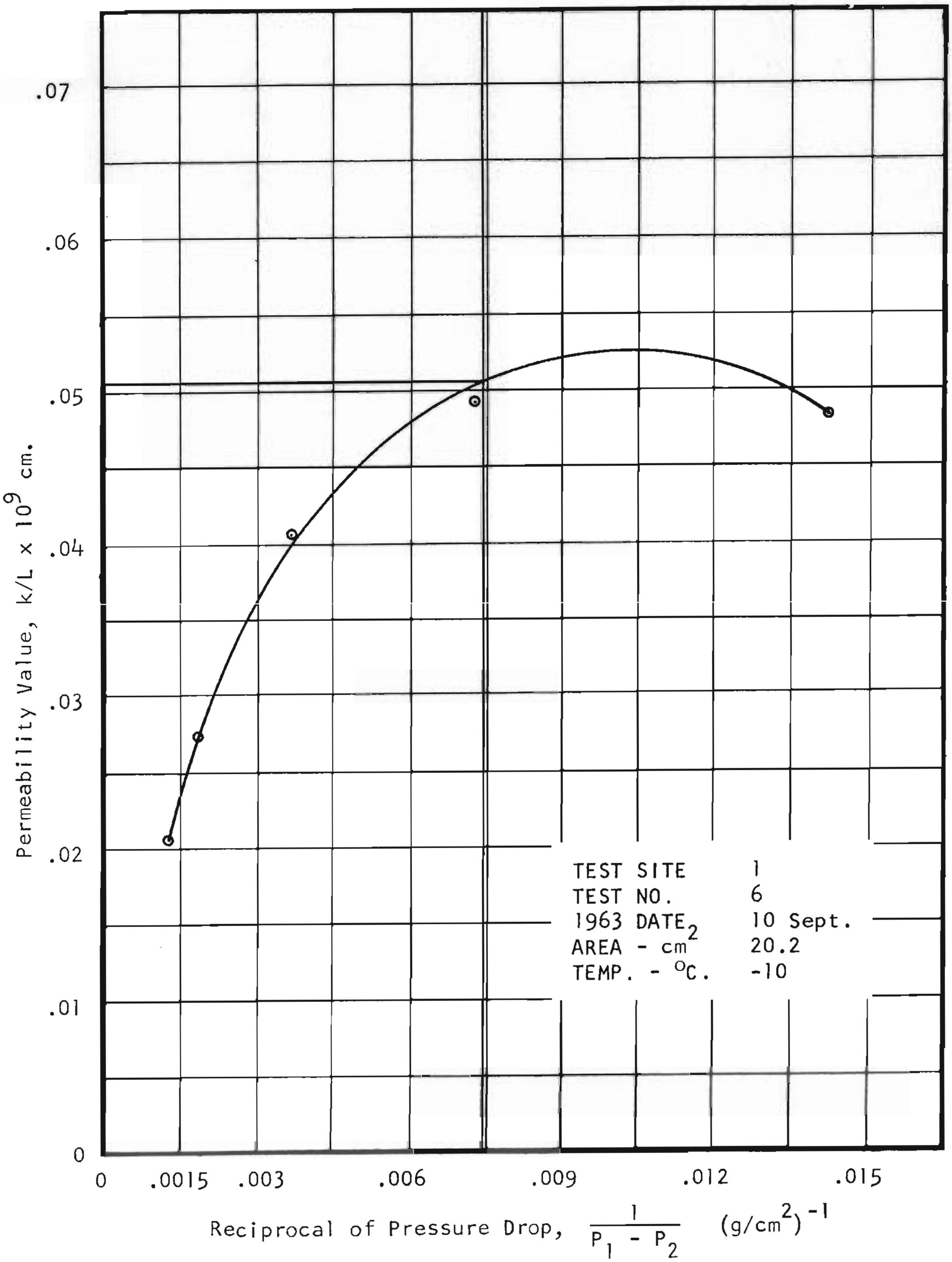


Figure C-1. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

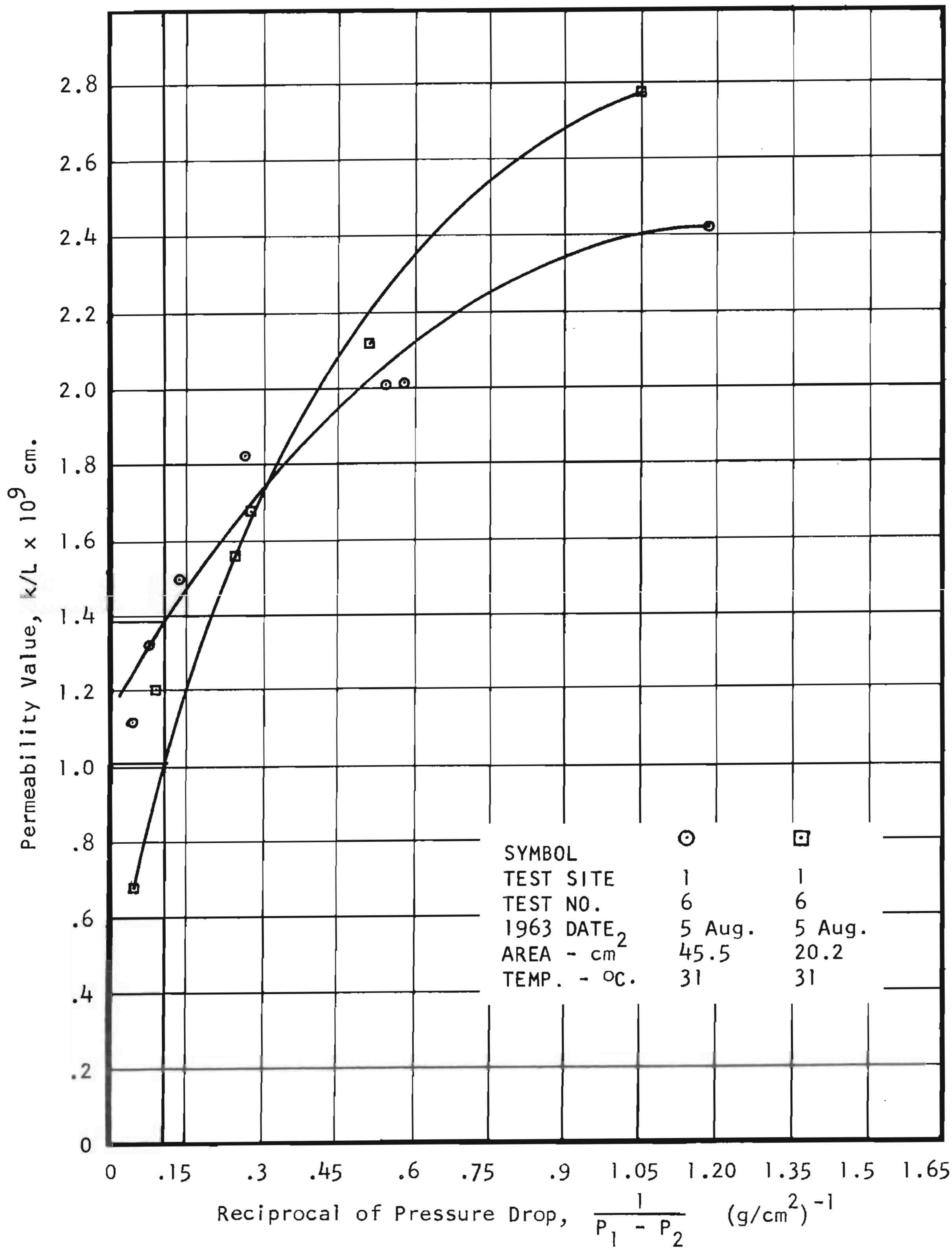


Figure C-2. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

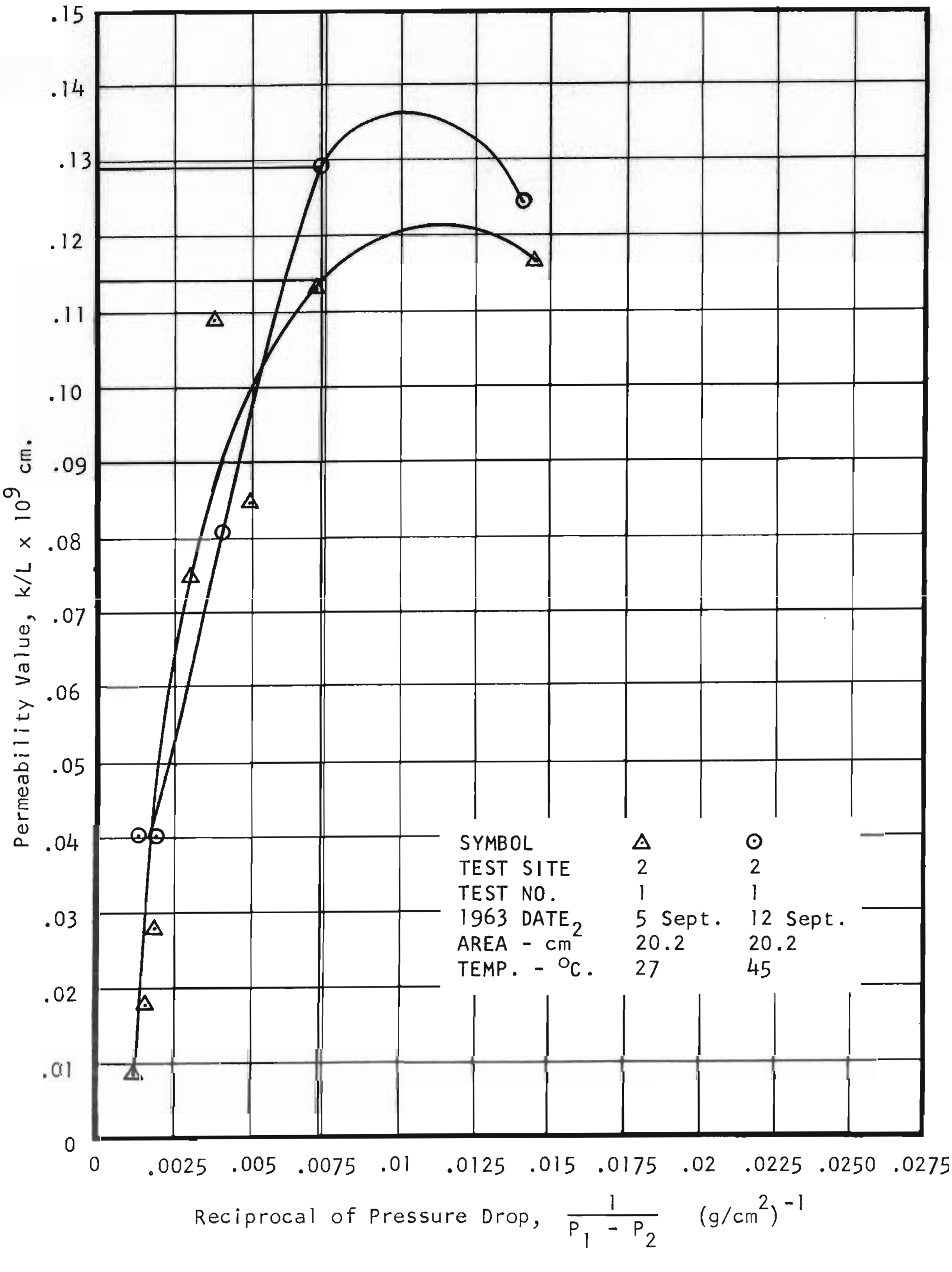


Figure C-3. Plot of Field Permeability as a Function of the Reciprocal of Pressure Drop

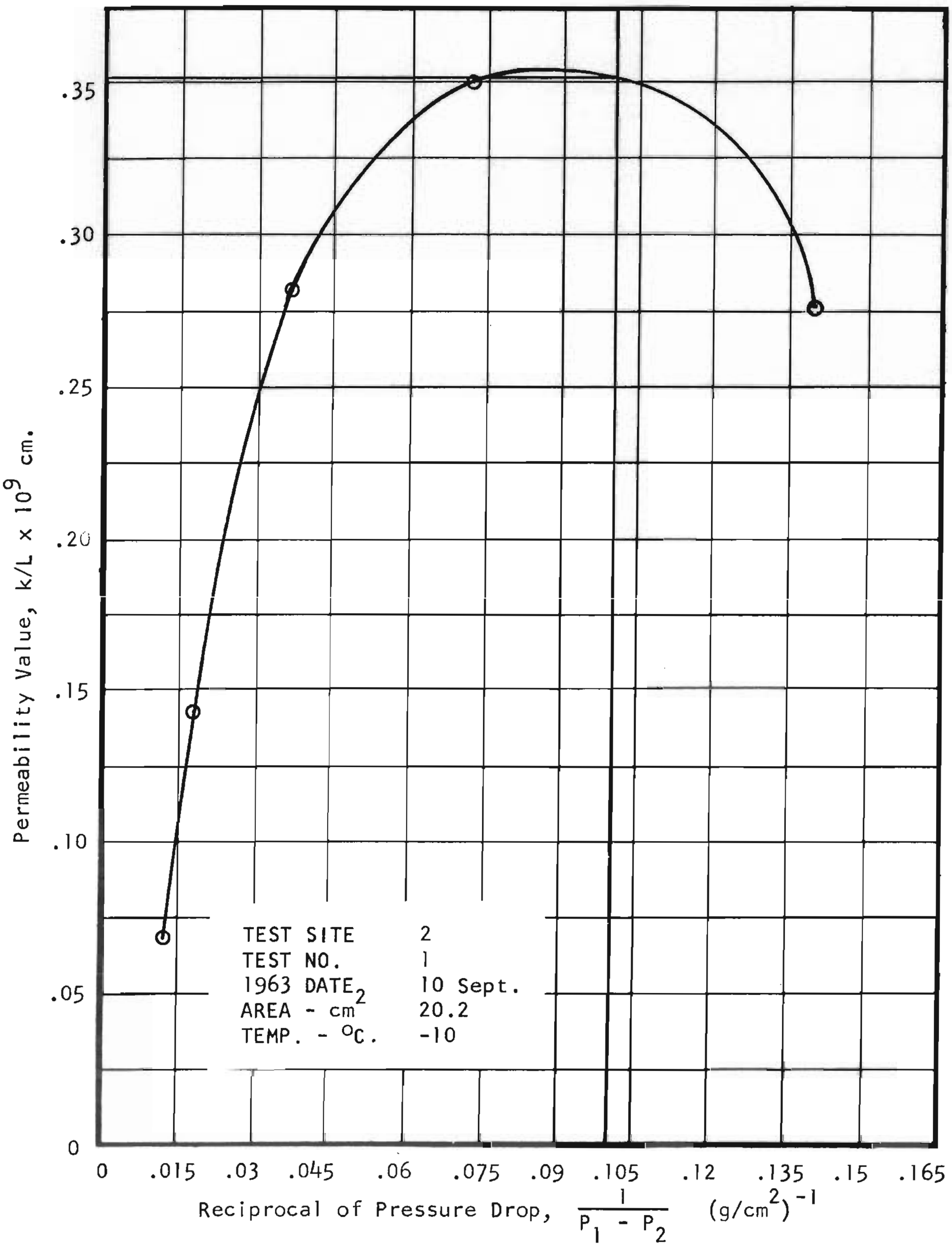


Figure C-4. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

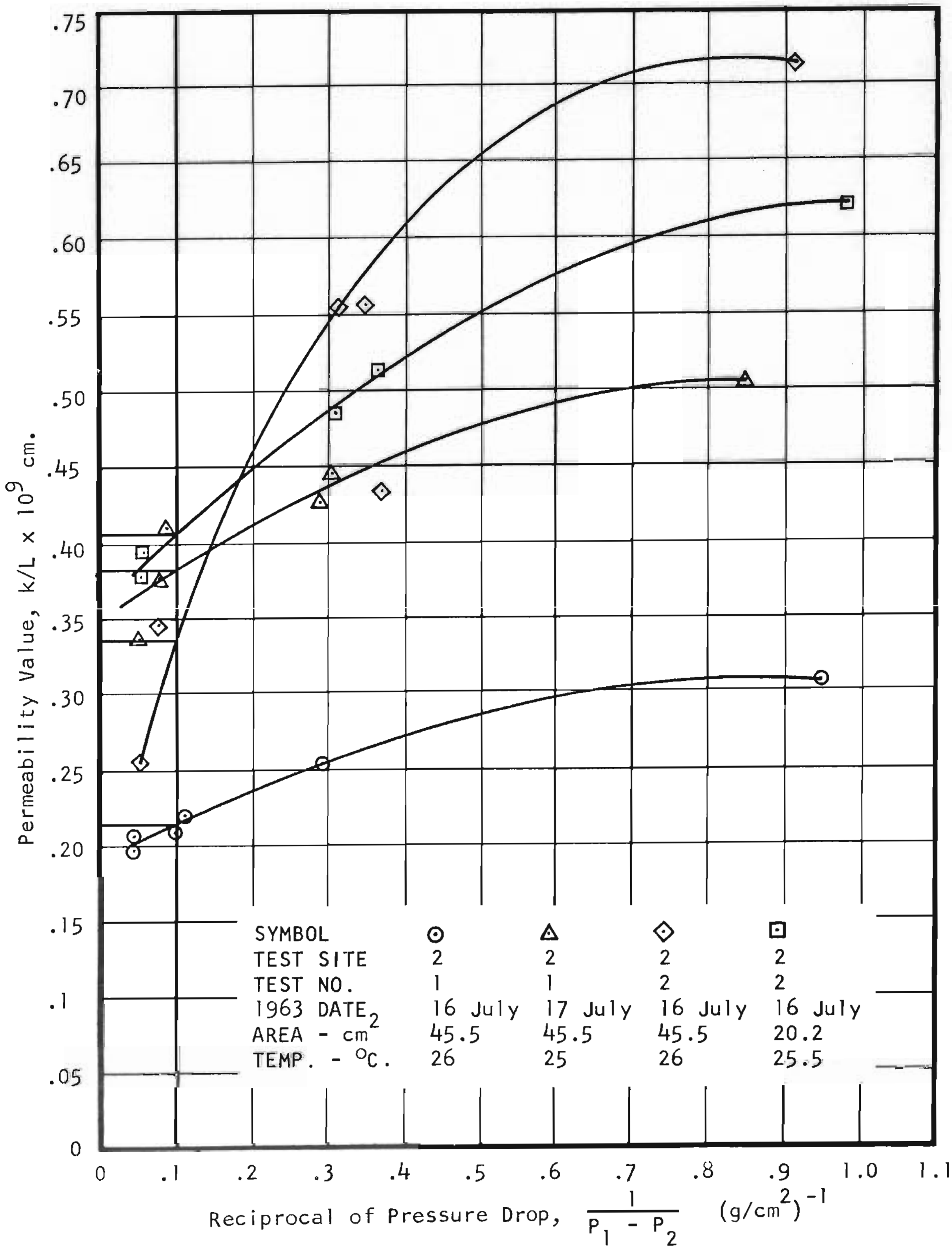


Figure C-5. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

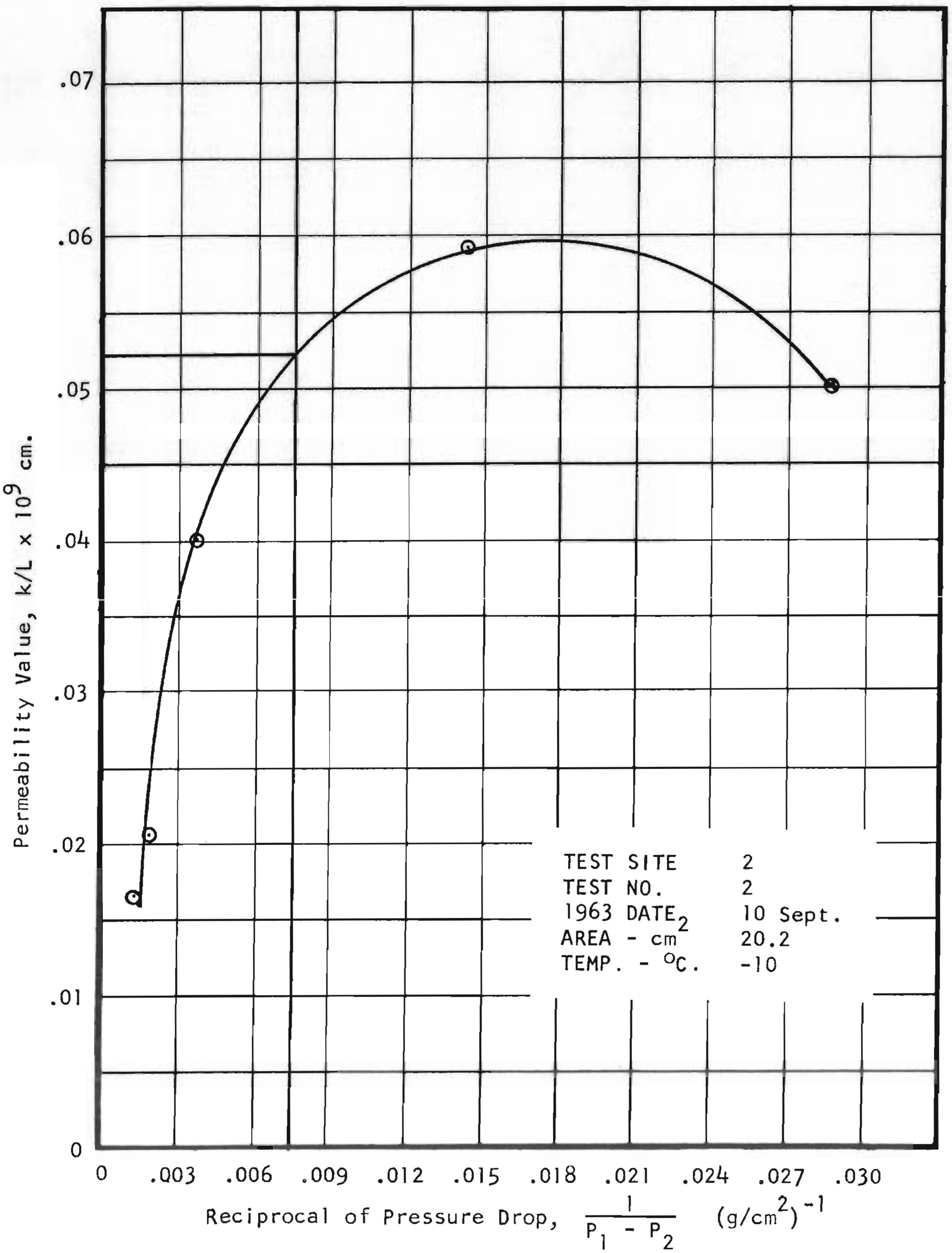


Figure C-6. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

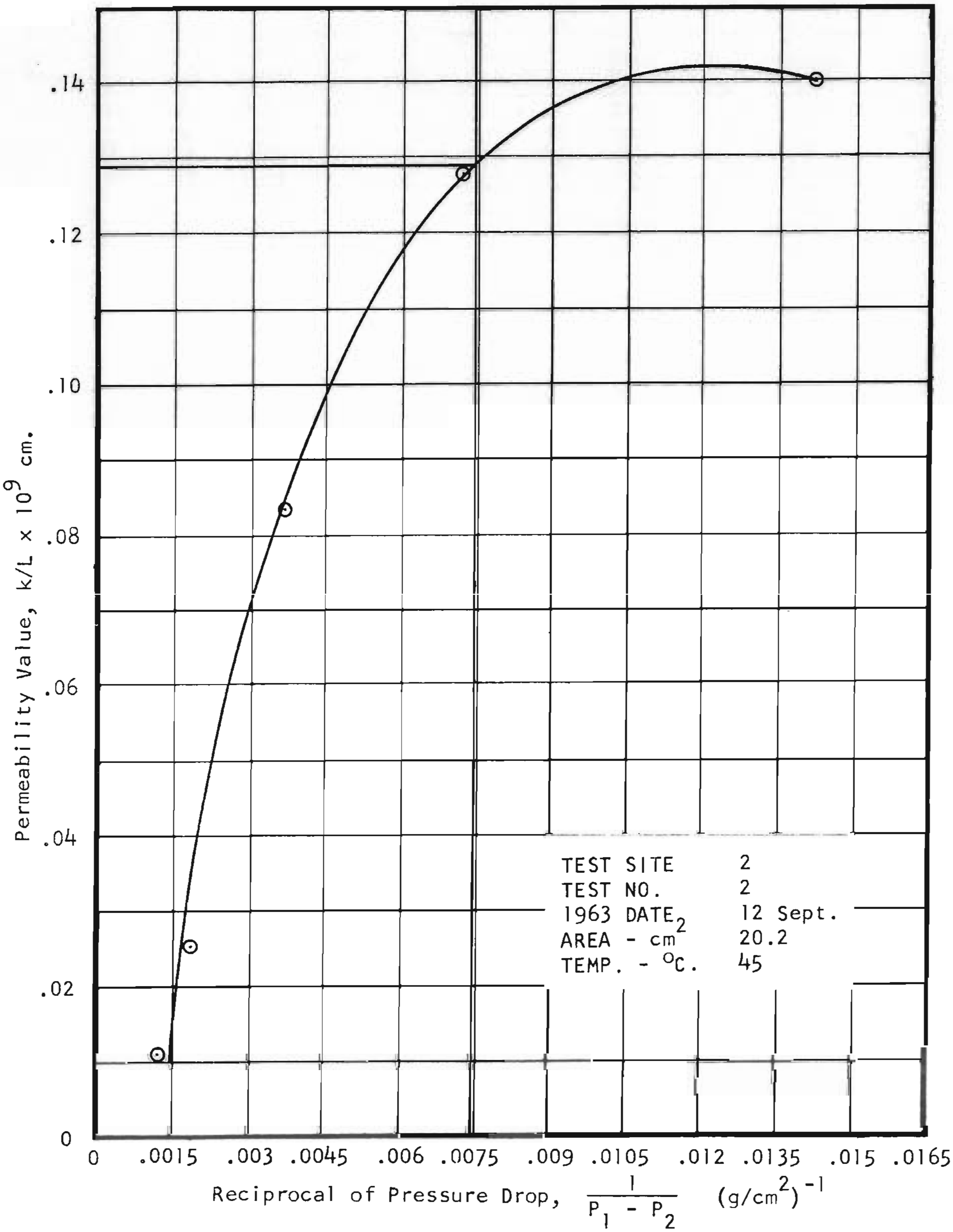


Figure C-7. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

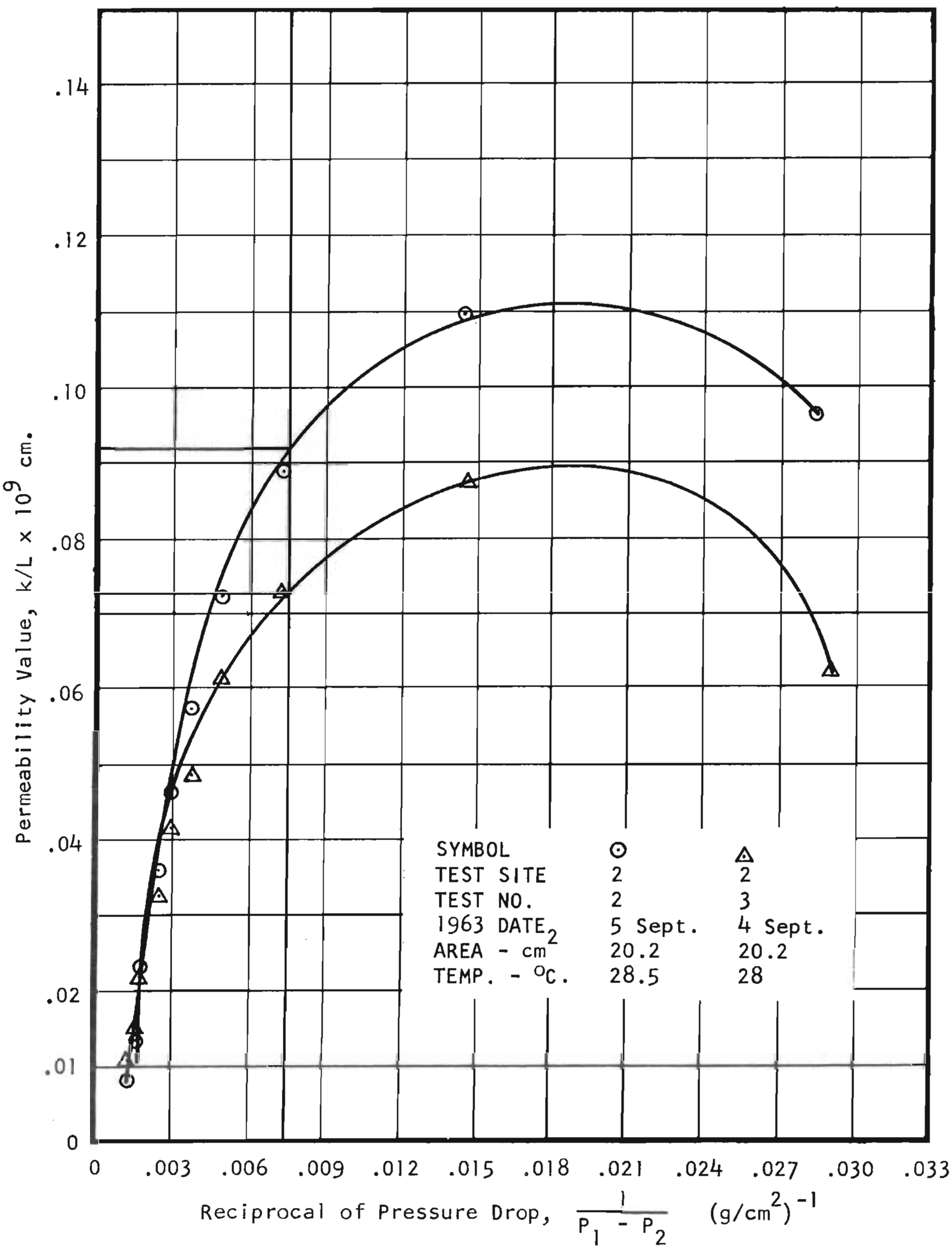


Figure C-8. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

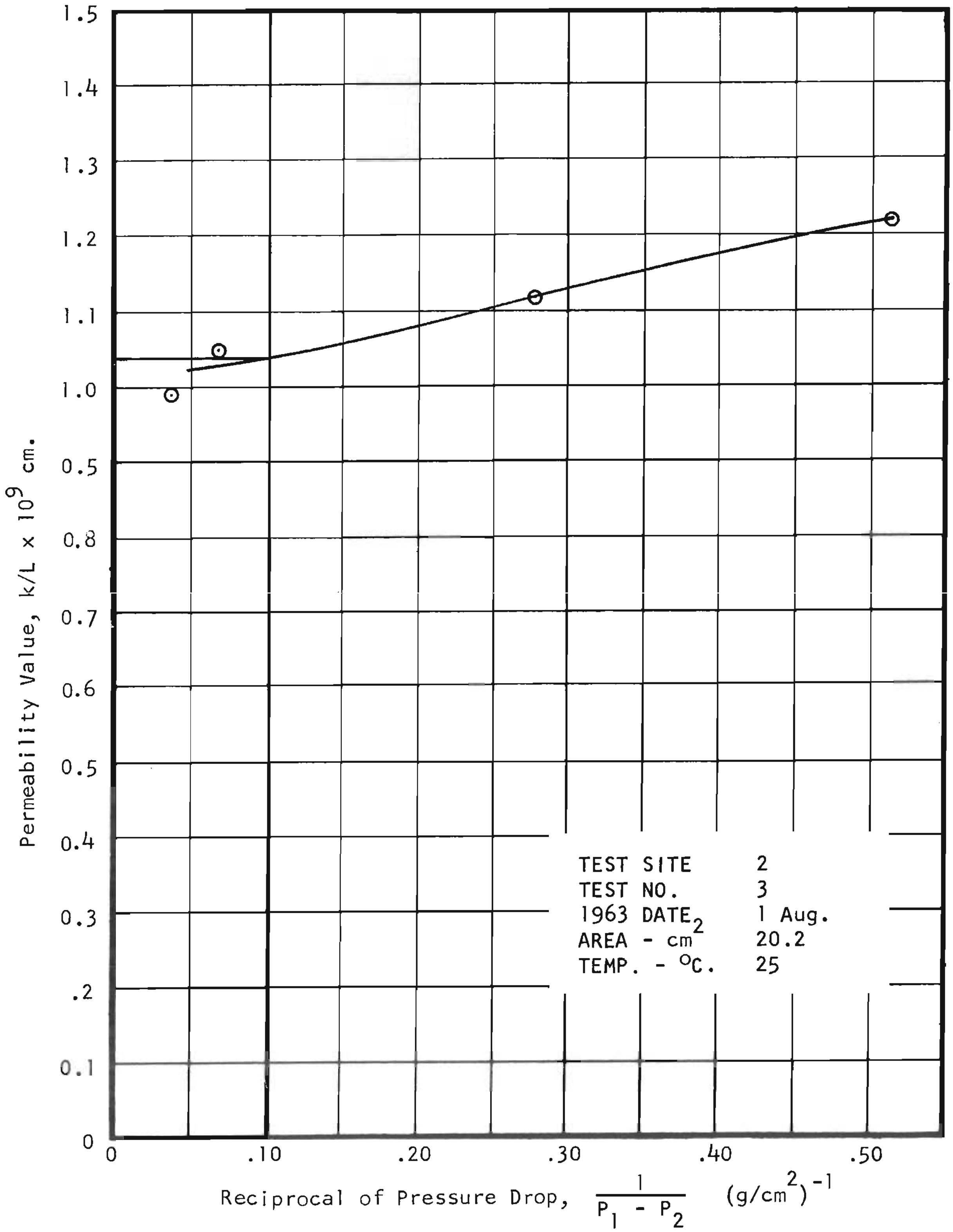


Figure C-9. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

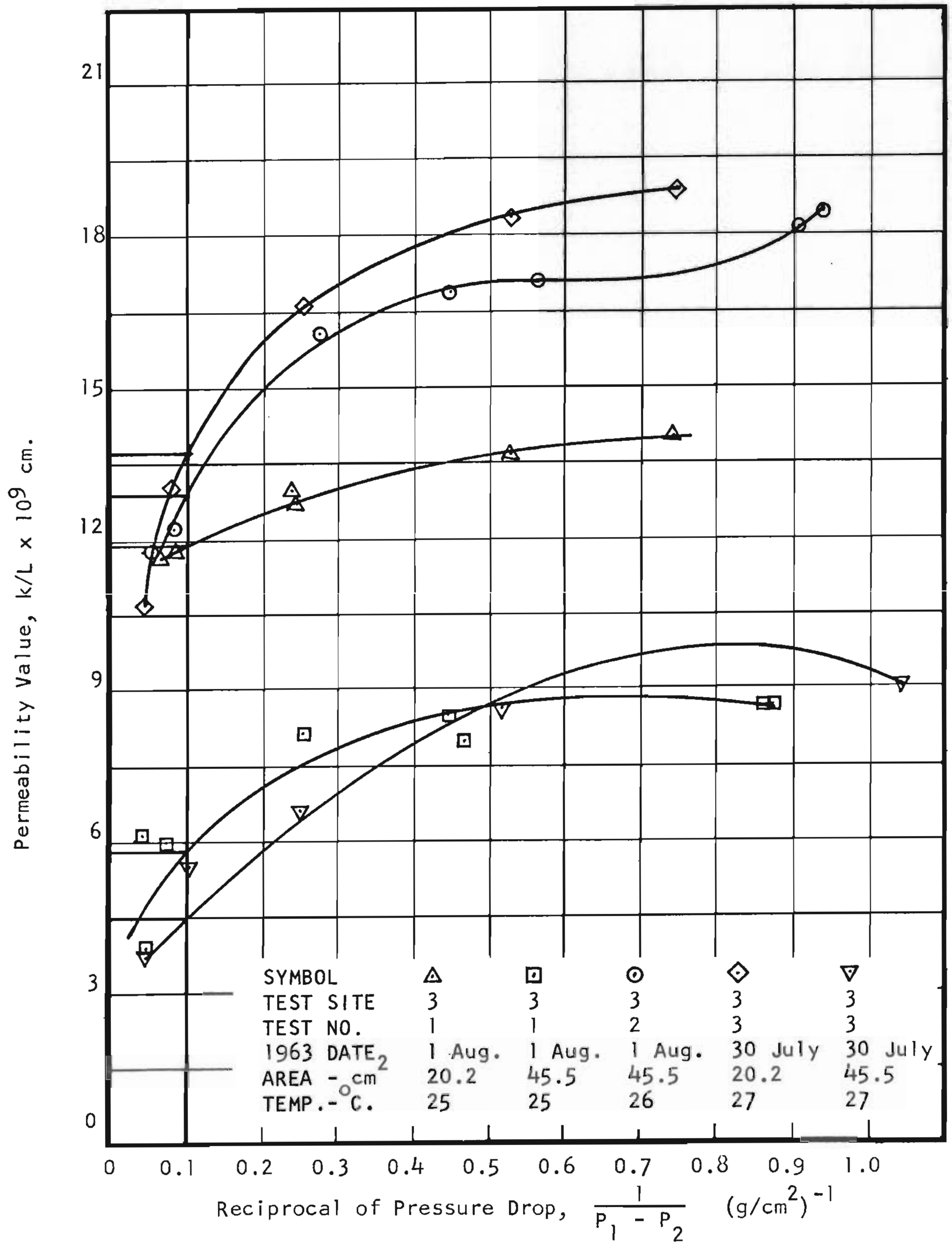


Figure C-10. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

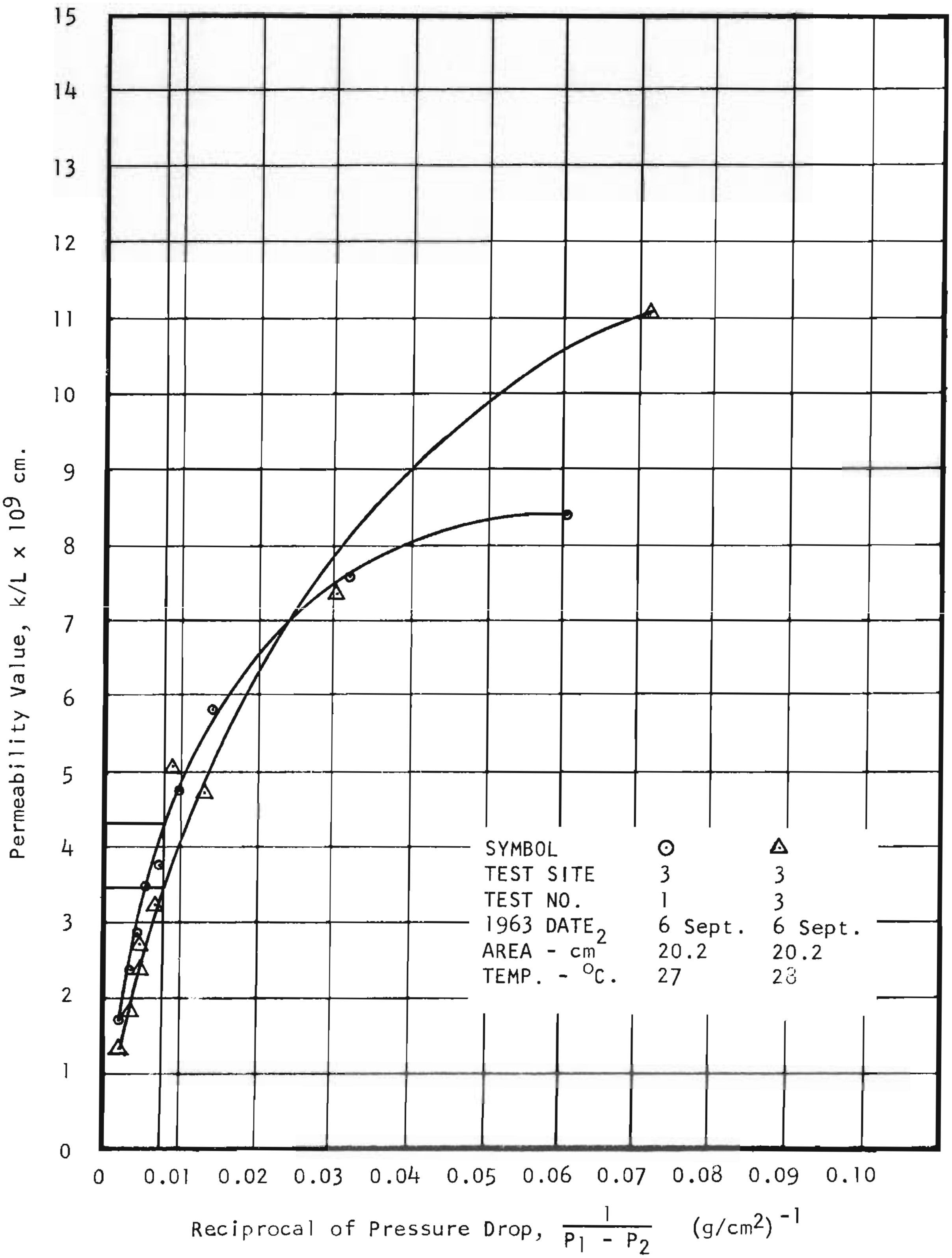


Figure C-11. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

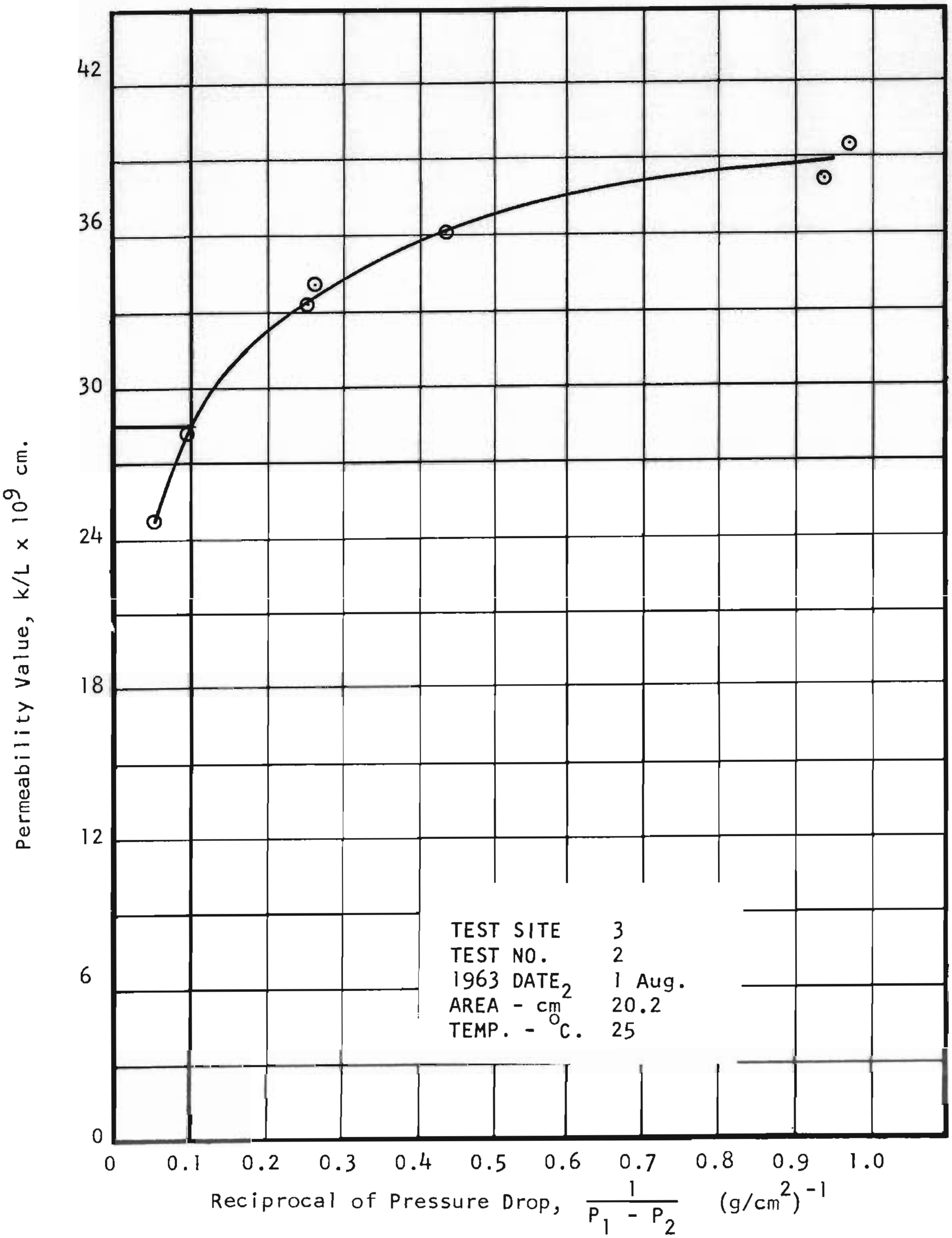


Figure C-12. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

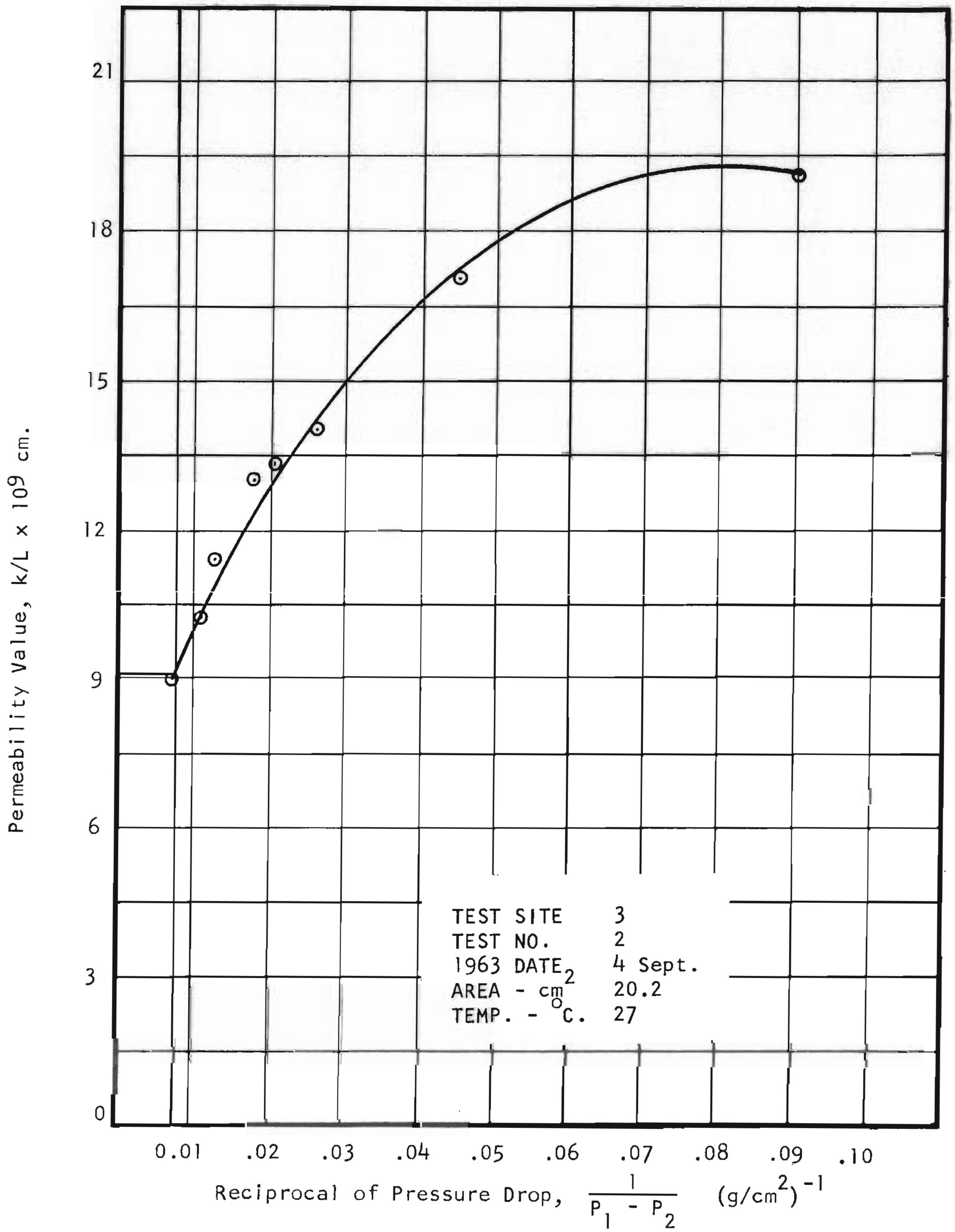


Figure C-13. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

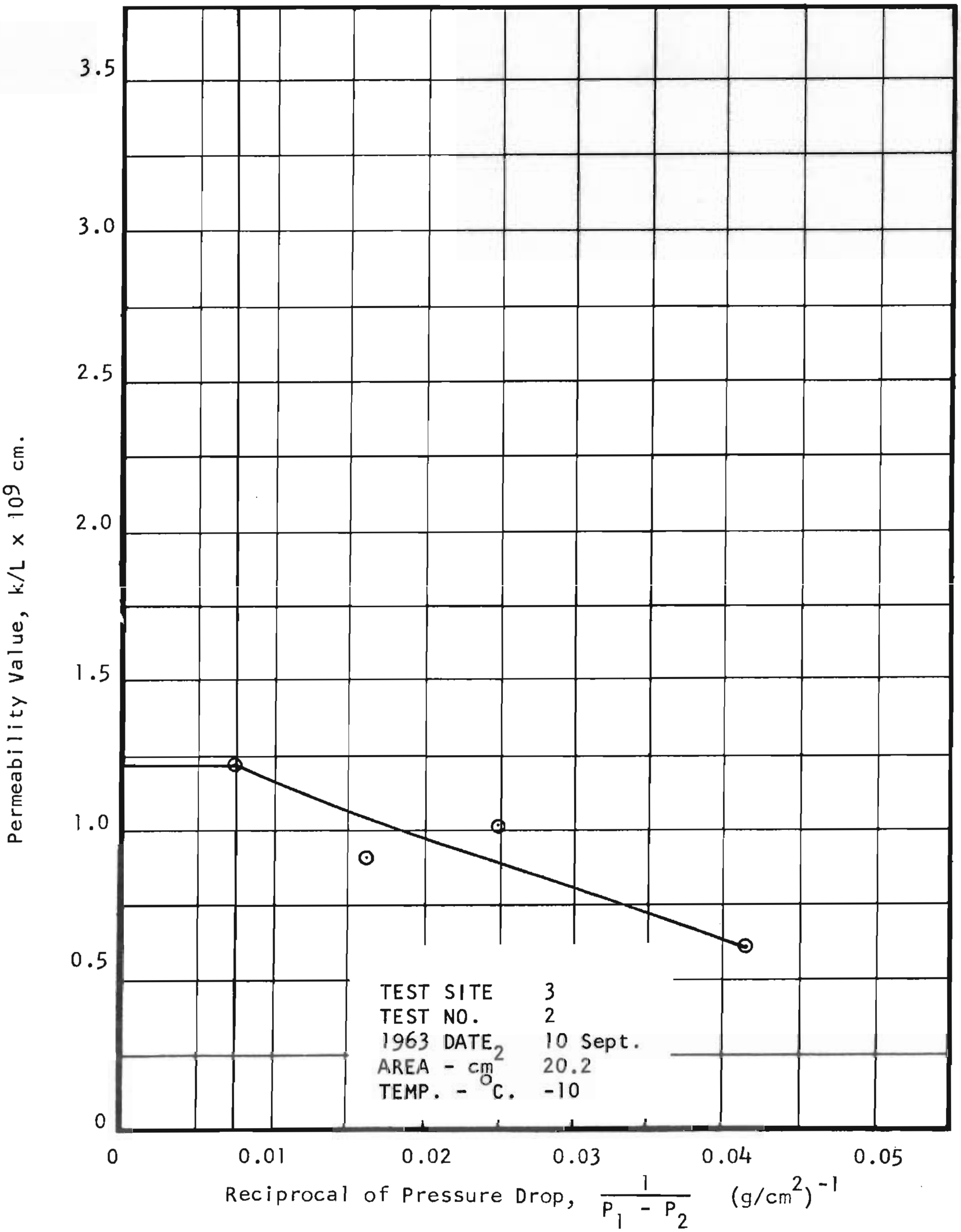


Figure C-14. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

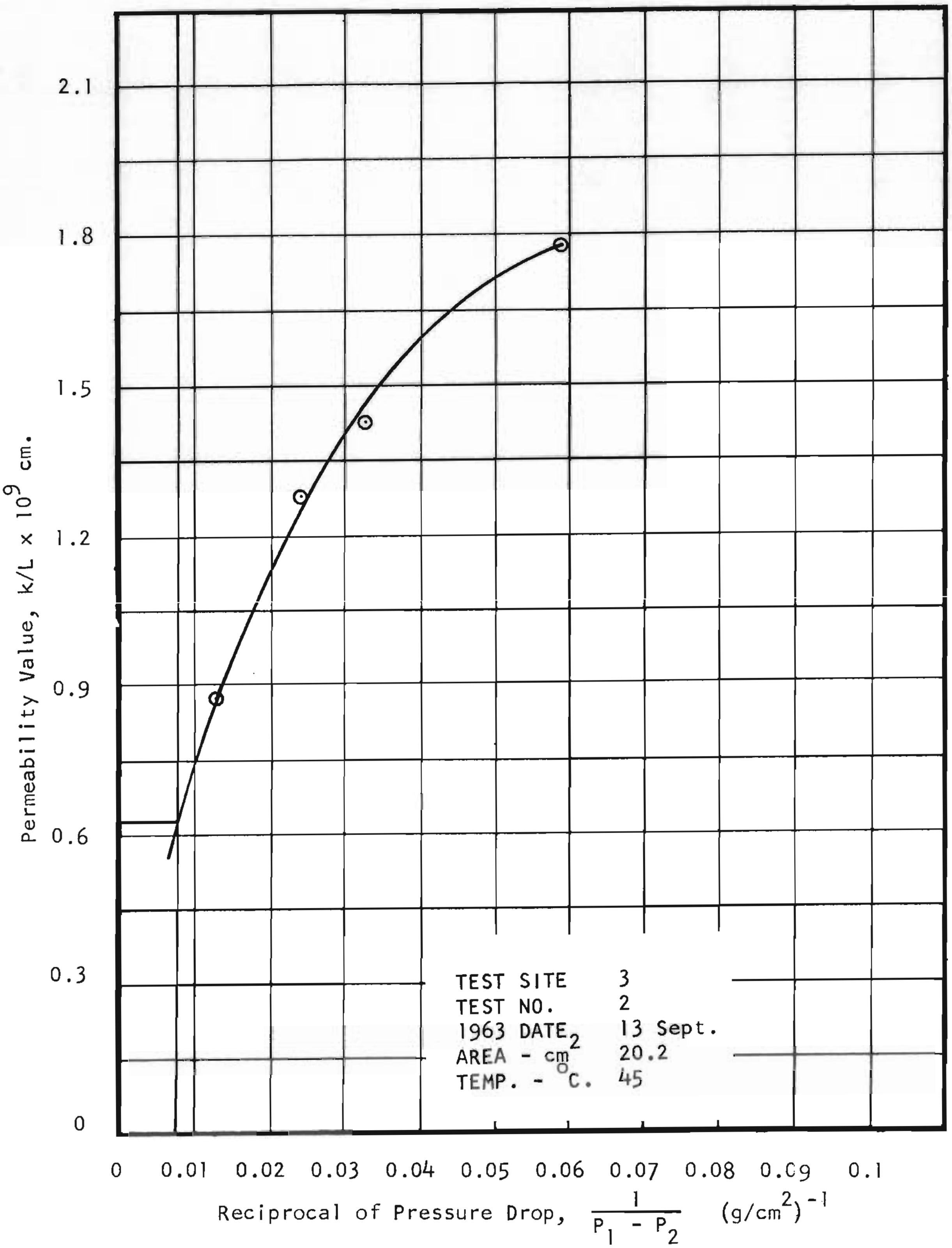


Figure C-15. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

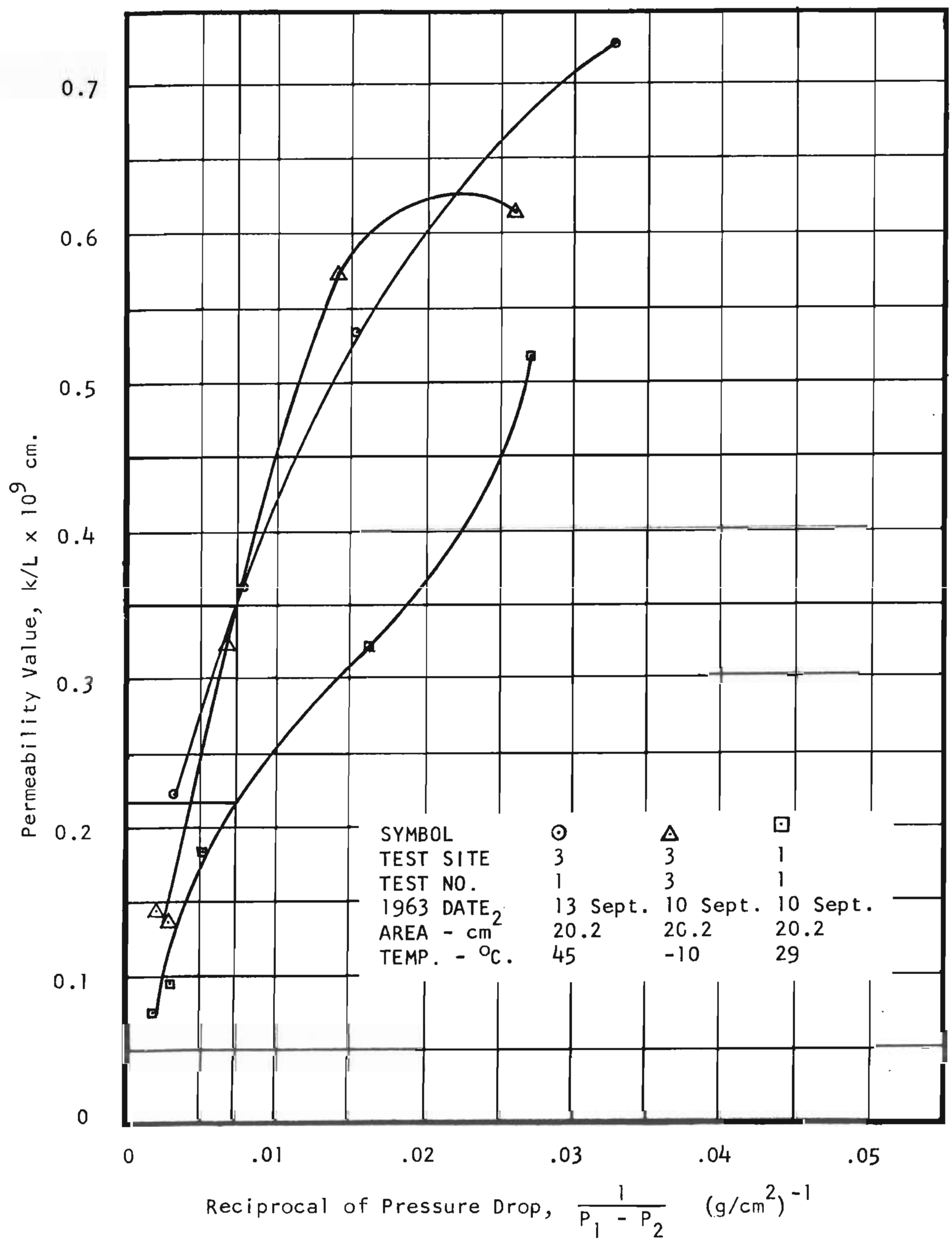


Figure C-16. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

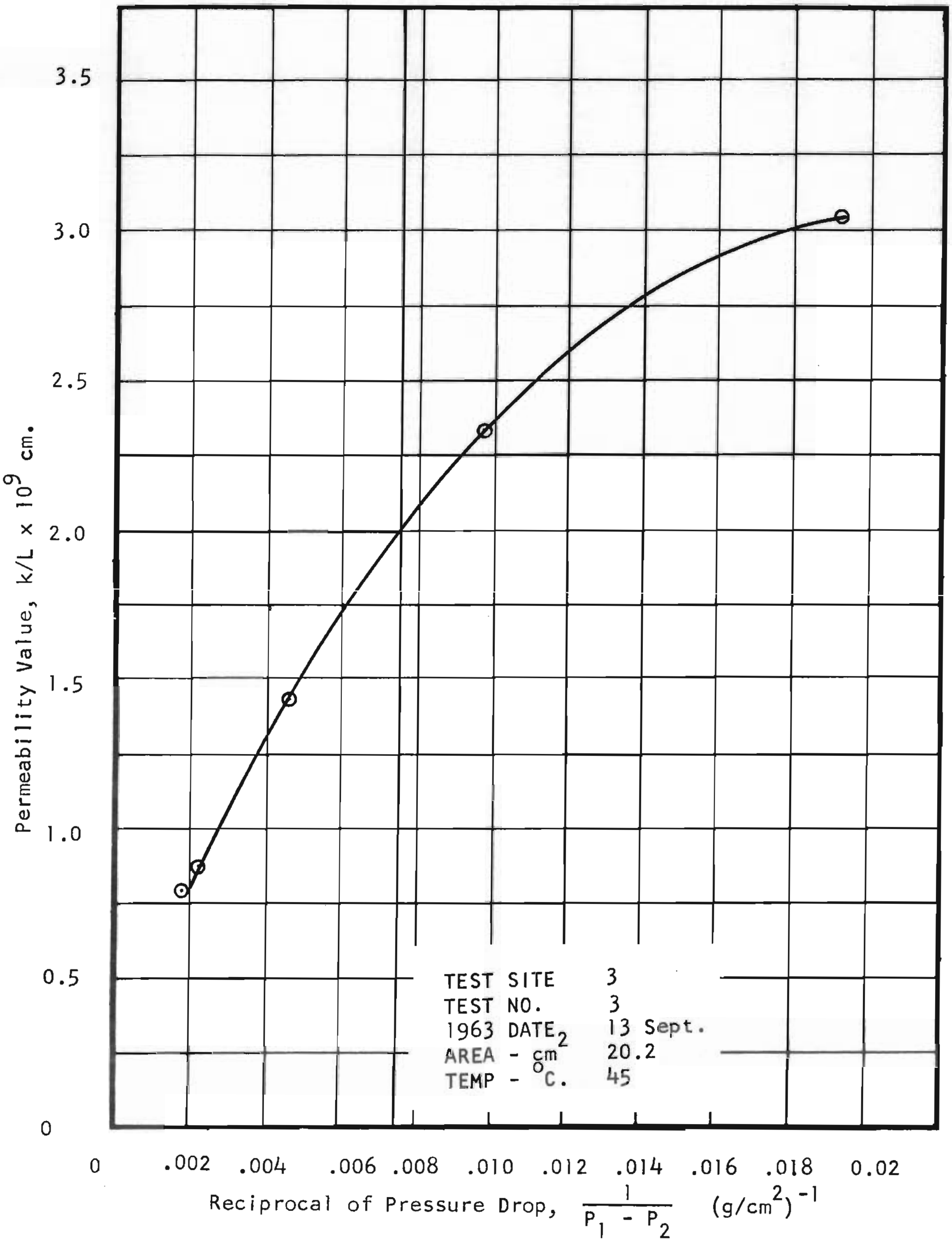


Figure C-17. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

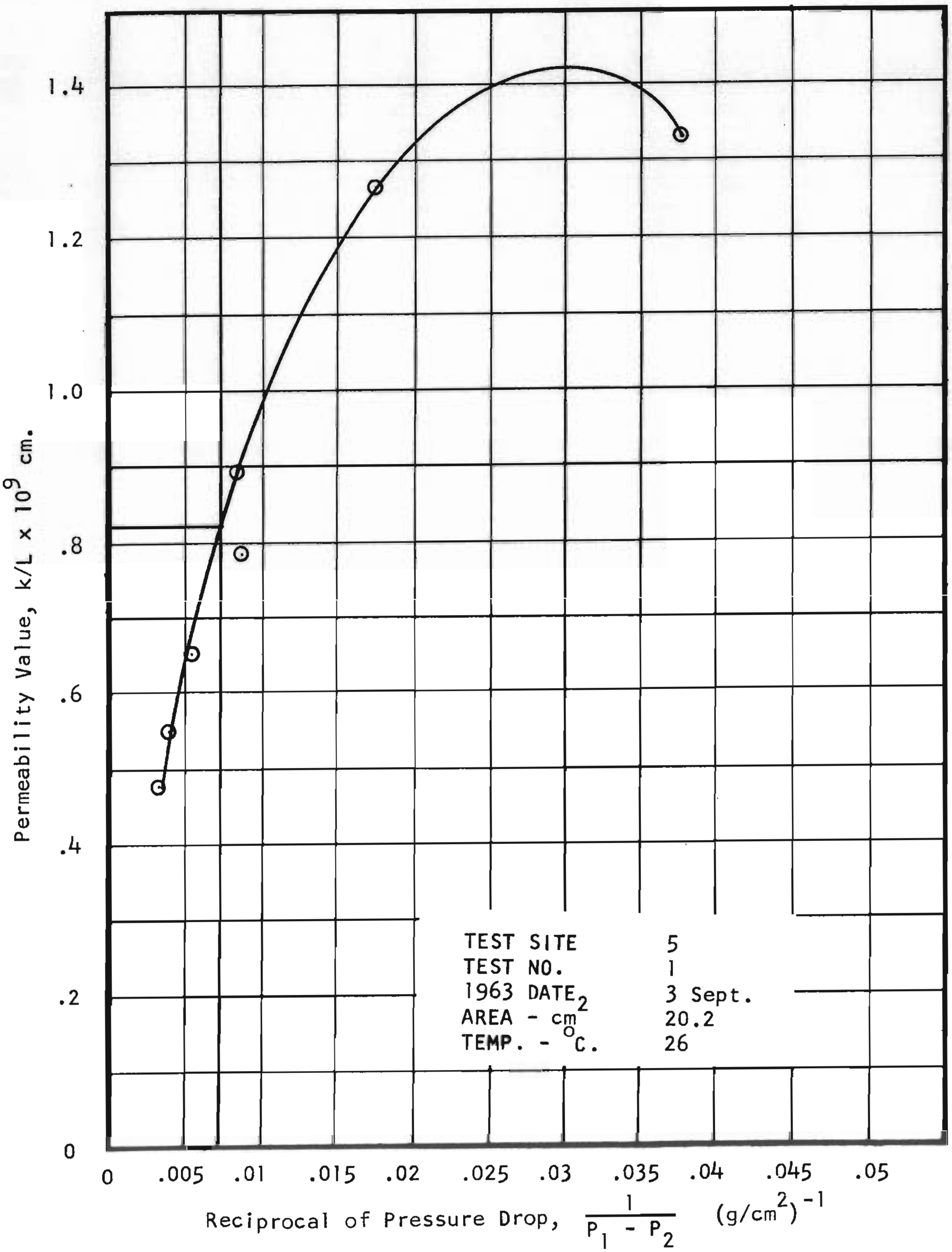


Figure C-18. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

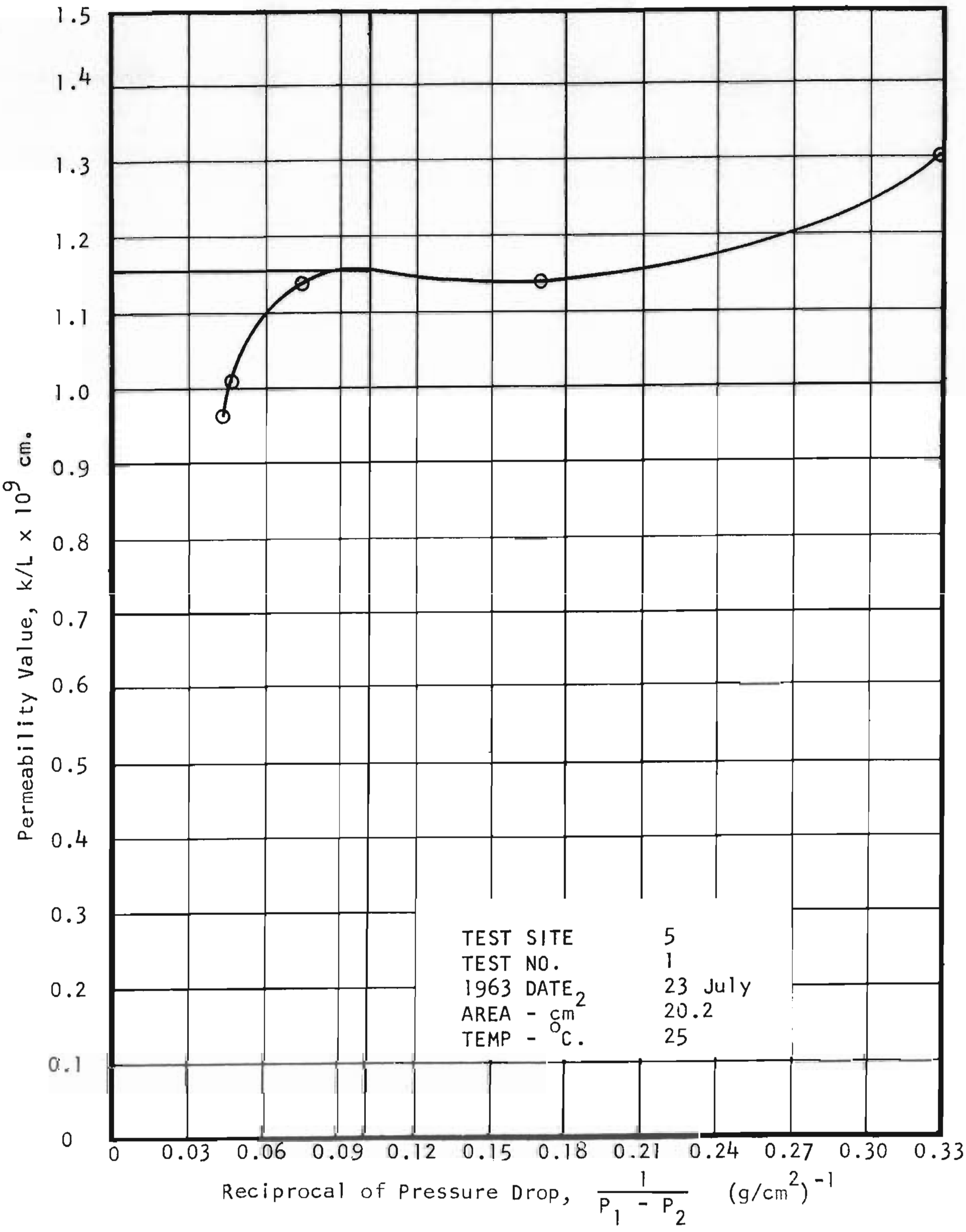


Figure C-19. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

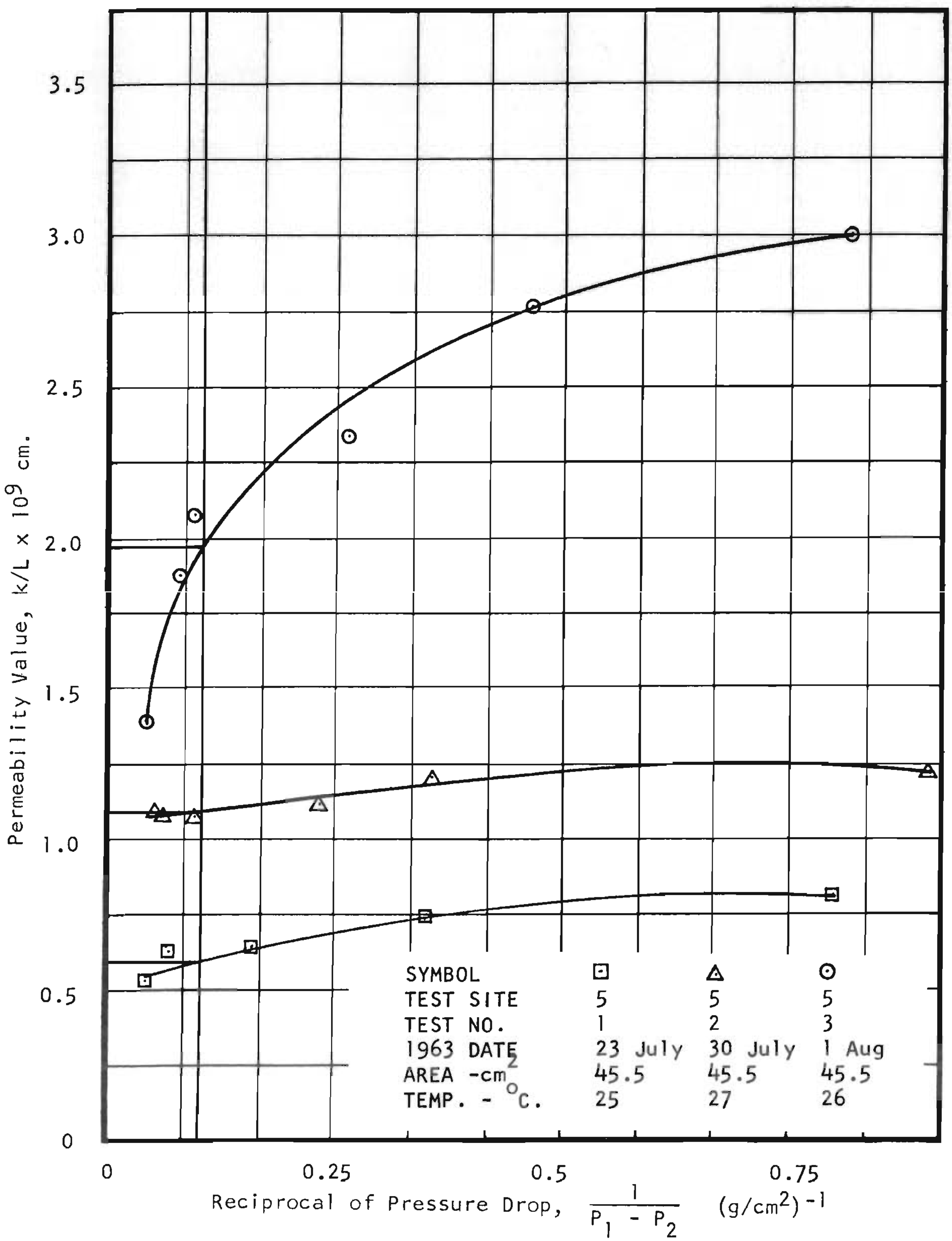


Figure C-20. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

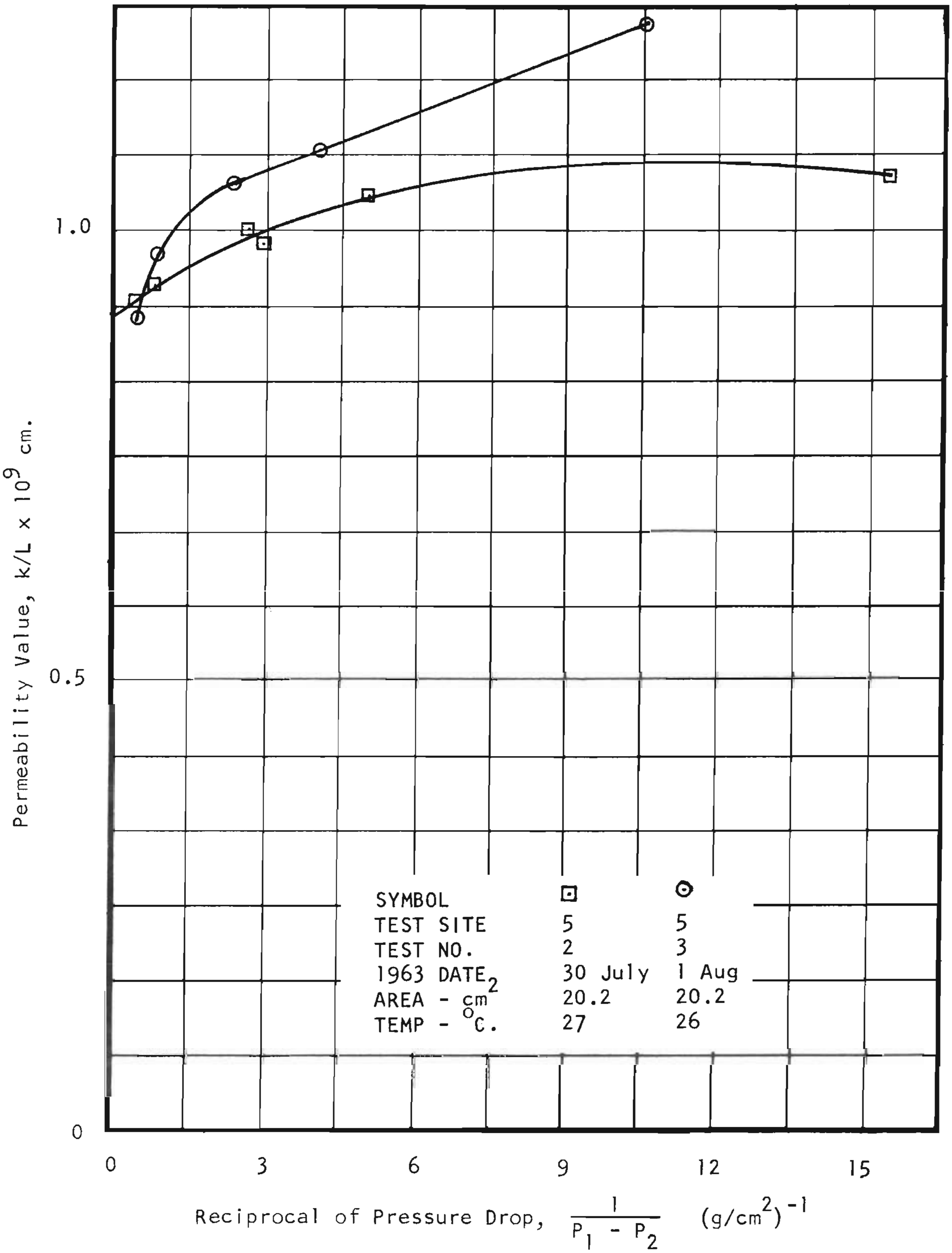


Figure C-21. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

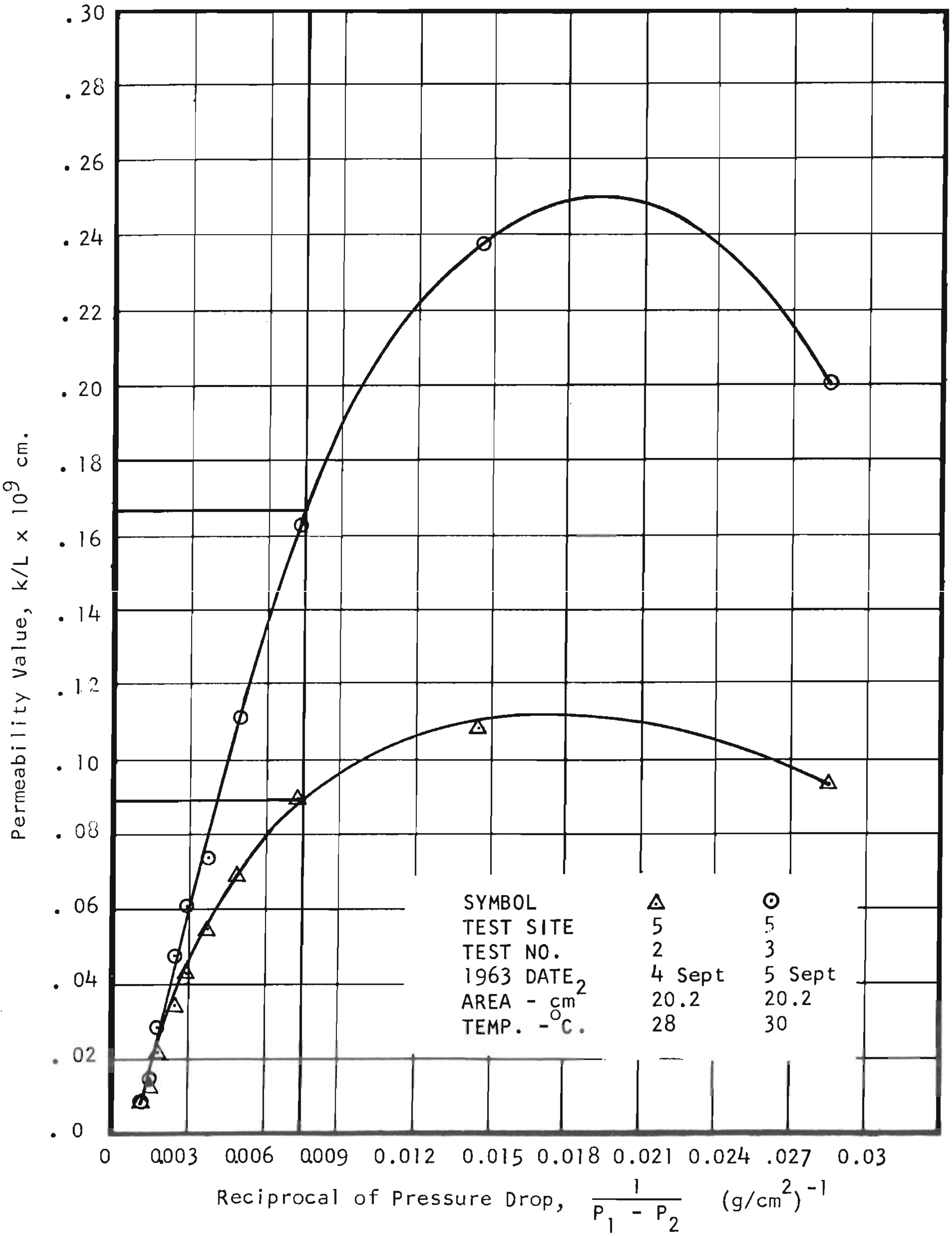


Figure C-22. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

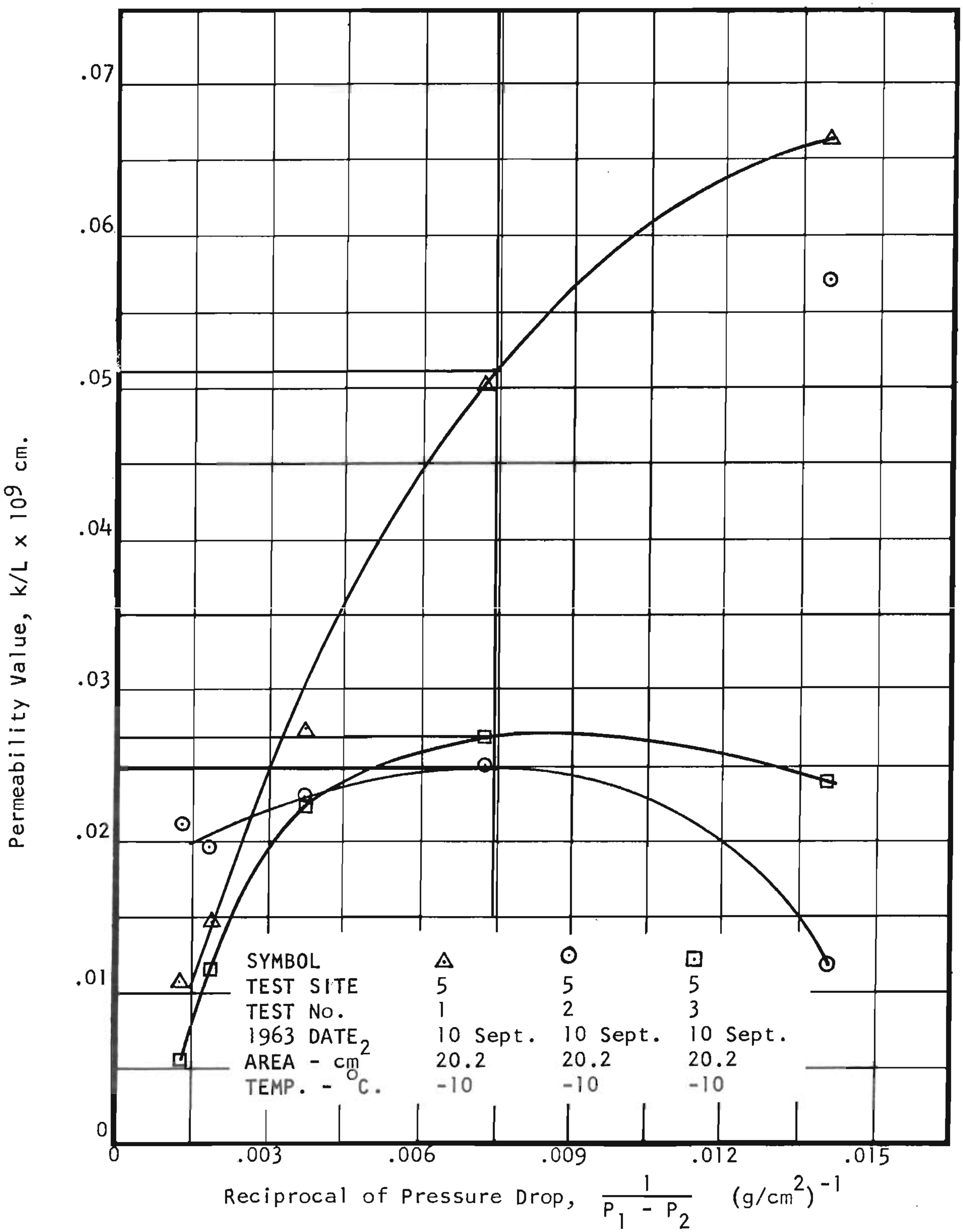


Figure C-23. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

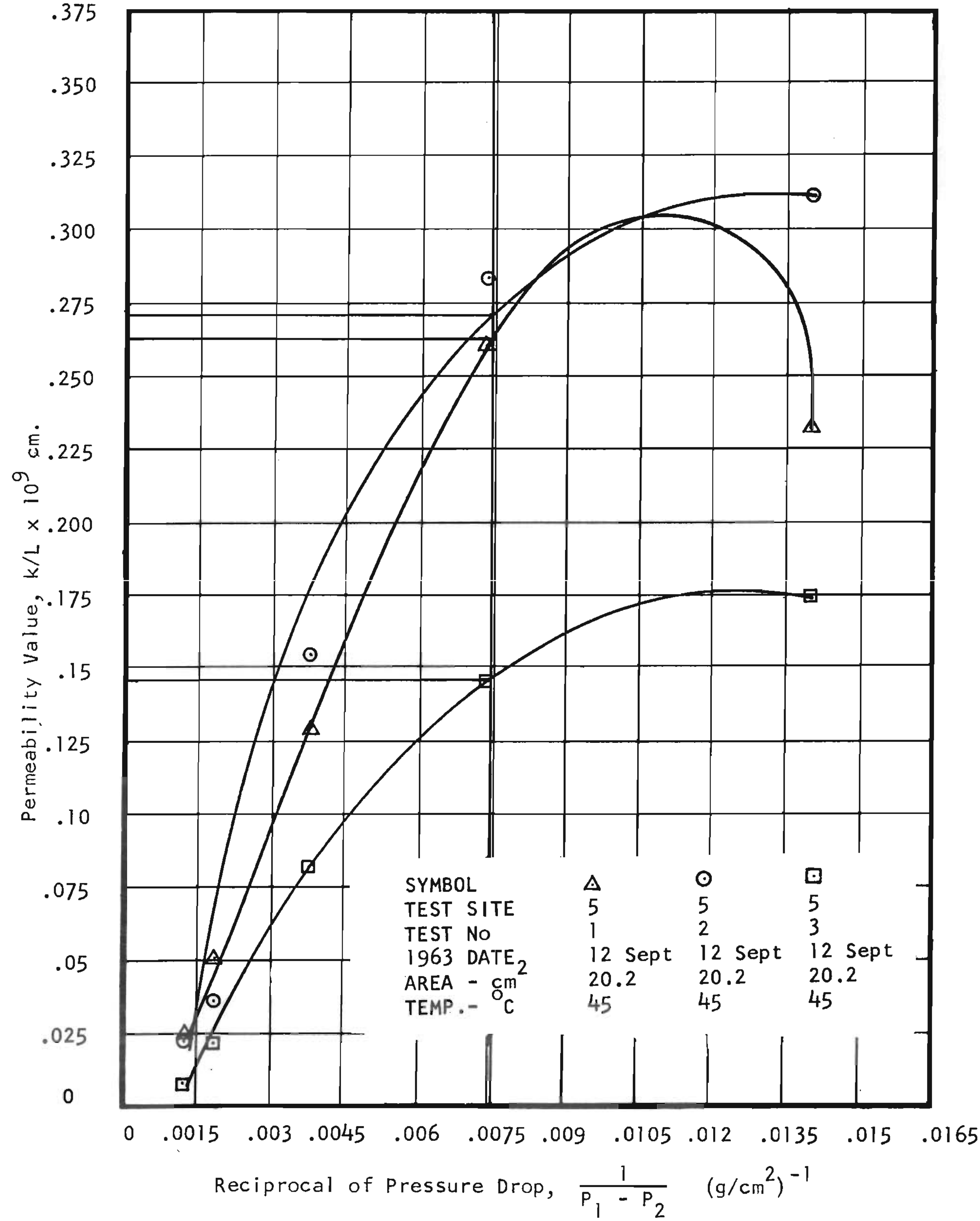


Figure C-24. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

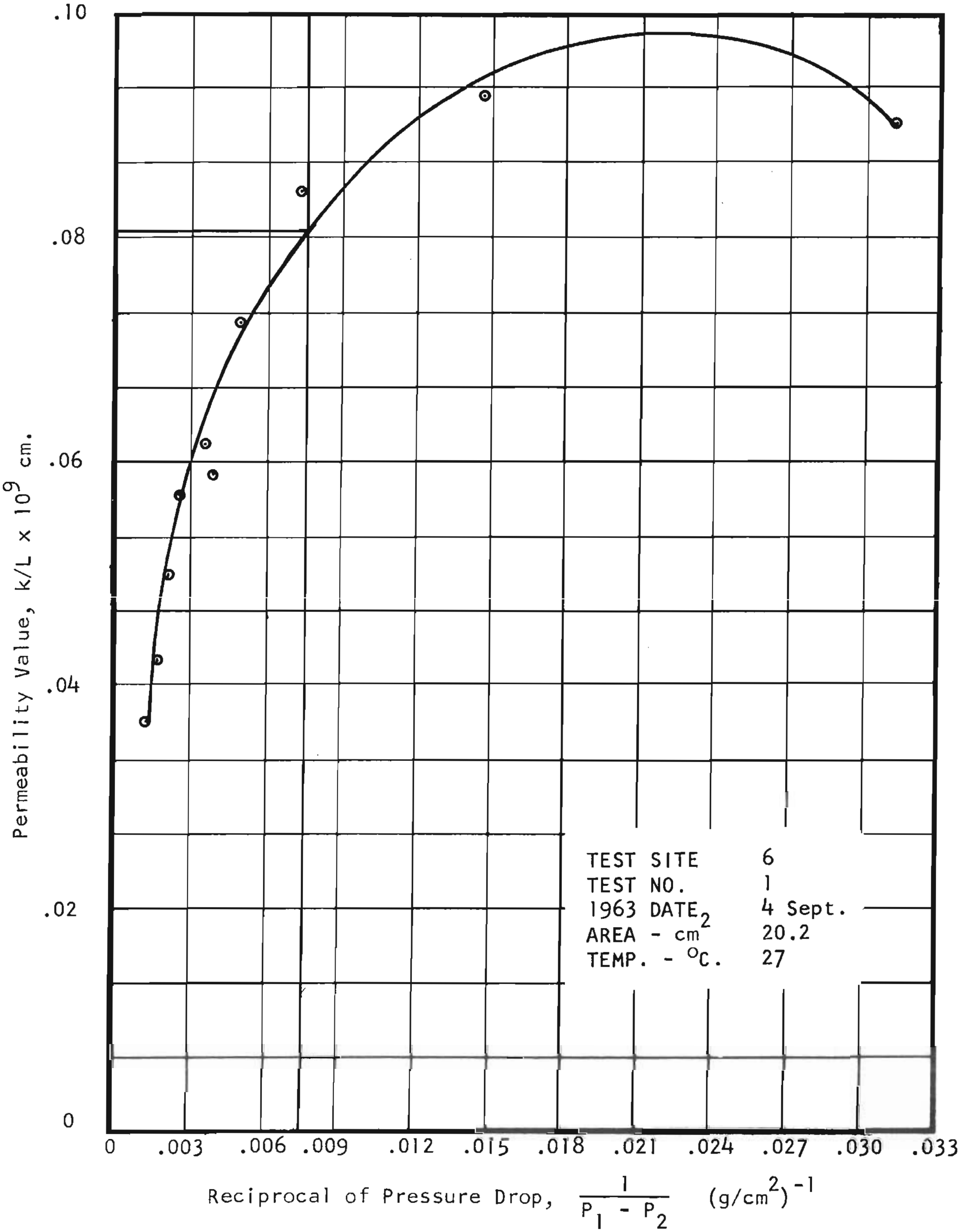


Figure C-25. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

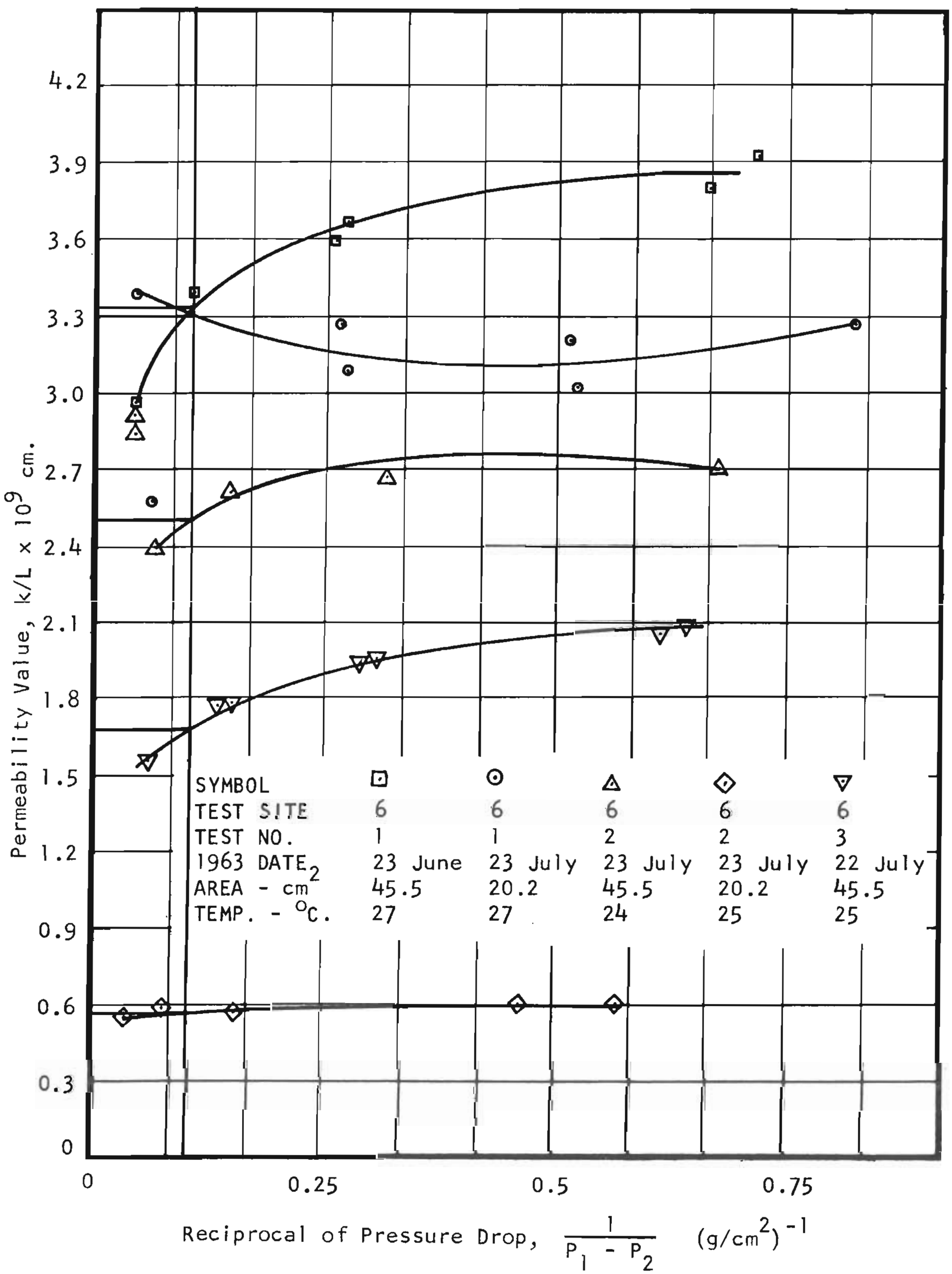


Figure C-26. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop

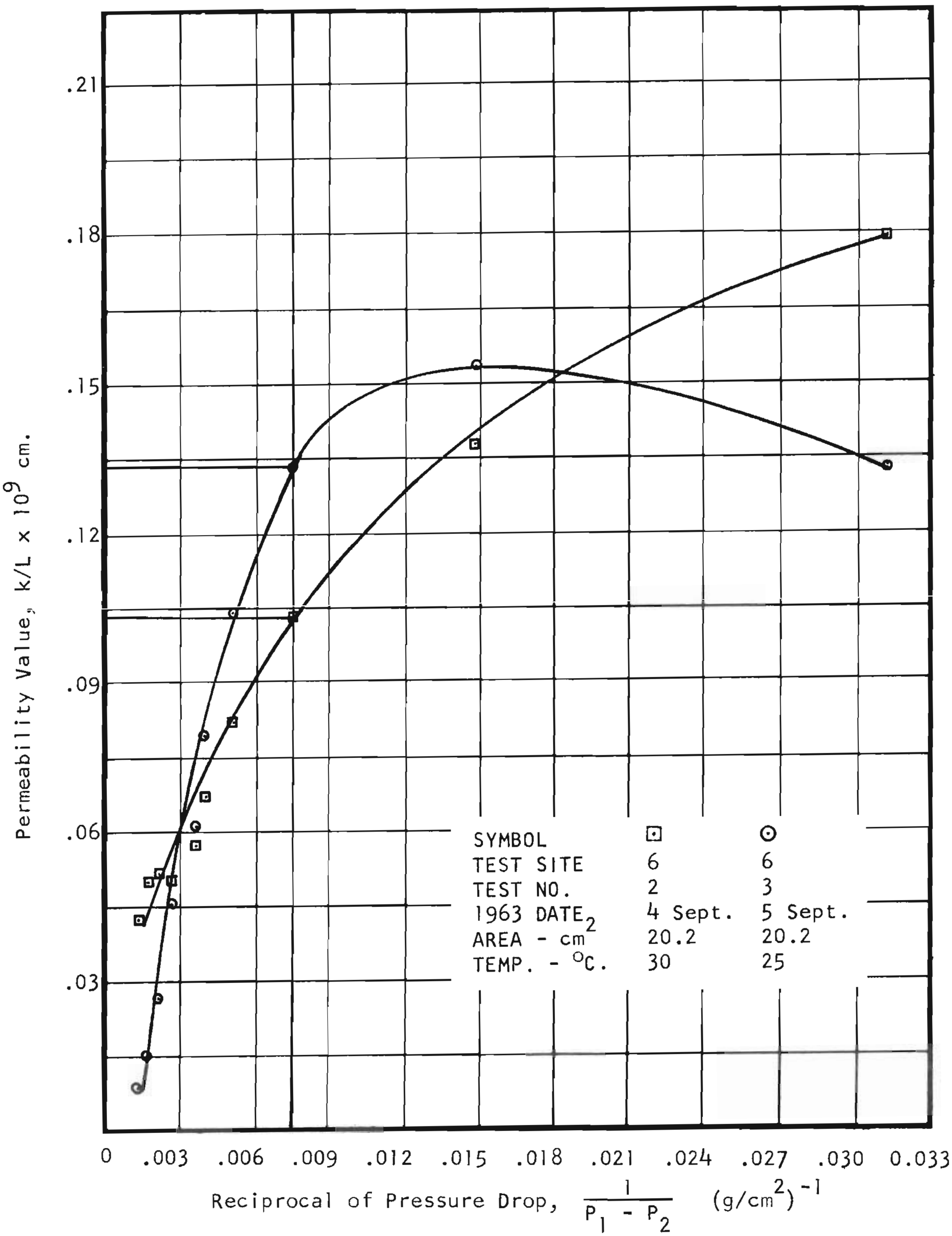


Figure C-27. Plot of Laboratory Permeability as a Function of the Reciprocal of Pressure Drop