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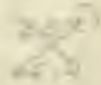
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F. H. COOK

THE UNIVERSITY OF OKLAHOMA
GRADUATE COLLEGE

A STUDY OF THE EFFECT OF VISCOSITY RATIO ON THE
DISPLACEMENT OF MIXED FLUIDS IN POROUS MEDIA

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

MASTER OF PETROLEUM ENGINEERING

BY

Floyd
F. H. COOK, JR.

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Norman, Oklahoma

1948

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THE NATIONAL BUREAU OF STANDARDS
WASHINGTON, D. C.

STANDARD SPECIFICATION FOR
STEEL WIRE RODS
FOR REINFORCING CONCRETE
ASTM A 675

1970
AMERICAN SOCIETY OF MECHANICAL ENGINEERS
NEW YORK, N. Y.

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Monterey, California

A STUDY OF THE EFFECT OF VISCOSITY RATIO ON THE
DISPLACEMENT OF ALCOHOL FUELS IN POROUS MEDIA

A THESIS

APPROVED FOR THE DEPARTMENT OF PETROLEUM ENGINEERING

BY _____

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Grateful acknowledgment is made to the U.S. Naval Postgraduate School for making possible this research.

TABLE OF CONTENTS

| | Page |
|---|------|
| LIST OF TABLES | v |
| LIST OF ILLUSTRATIONS | vi |
| Chapter | |
| I. INTRODUCTION | 1 |
| II. REVIEW OF PREVIOUS INVESTIGATIONS | 3 |
| III. STATEMENT OF PROBLEM | 6 |
| IV. MATERIALS | 8 |
| V. EXPERIMENTAL APPARATUS | 12 |
| VI. EXPERIMENTAL PROCEDURES | 15 |
| Permeability Determinations | 15 |
| Porosity Determinations | 16 |
| Index of Refraction Measurements | 17 |
| Experimental Tests | 17 |
| VII. ANALYSIS OF DATA | 43 |
| Theoretical Approach | 46 |
| Sample Calculations | 47 |
| Discussion of Experimental Results | 48 |
| Errors Involved | 50 |
| VIII. SUMMARY | 53 |
| IX. CONCLUSIONS | 60 |
| BIBLIOGRAPHY | 65 |

CONTENTS

| | | |
|-----|-------|-------|
| v | | |
| 10 | | |
| 11 | | |
| 12 | | |
| 13 | | |
| 14 | | |
| 15 | | |
| 16 | | |
| 17 | | |
| 18 | | |
| 19 | | |
| 20 | | |
| 21 | | |
| 22 | | |
| 23 | | |
| 24 | | |
| 25 | | |
| 26 | | |
| 27 | | |
| 28 | | |
| 29 | | |
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| 58 | | |
| 59 | | |
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| 71 | | |
| 72 | | |
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| 80 | | |
| 81 | | |
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| 83 | | |
| 84 | | |
| 85 | | |
| 86 | | |
| 87 | | |
| 88 | | |
| 89 | | |
| 90 | | |
| 91 | | |
| 92 | | |
| 93 | | |
| 94 | | |
| 95 | | |
| 96 | | |
| 97 | | |
| 98 | | |
| 99 | | |
| 100 | | |

LIST OF TABLES

| Table | Page |
|------------------------------|------|
| 1. Run Number 1 | 16 |
| 2. Run Number 2 | 20 |
| 3. Run Number 3 | 21 |
| 4. Run Number 4 | 22 |
| 5. Run Number 5 | 23 |
| 6. Run Number 6 | 24 |
| 7. Run Number 7 | 25 |
| 8. Run Number 8 | 26 |
| 9. Run Number 9 | 27 |
| 10. Run Number 10 | 28 |
| 11. Run Number 11 | 29 |
| 12. Composite Data | 30 |

LIST OF ILLUSTRATIONS

| Figure | Page |
|---|------|
| 1. A Glasser Sequestration System, after Washout | 31 |
| 2. Fluid Flow Diagram | 32 |
| 3. Effluent Composition vs Pore Volume Produced, (Horizontal Position) | 33 |
| 4. Effluent Composition vs Pore Volume Produced, (Vertical Position) | 34 |
| 5. The Effect of Pressure on Displacement | 35 |
| 6. The Effect of Gravity on Displacement | 36 |
| 7. Rate vs Pore Volume Produced | 37 |
| 8. Rate vs Pore Volume Produced | 38 |
| 9. Efficiency of Recovery at One Pore Volume as a Function of Viscosity Ratio | 39 |
| 10. Efficiency of Recovery at Break Through as a Function of Viscosity Ratio | 40 |
| 11. A Comparison to Leverett and Buckley Data on Efficiency of Initial Phase of Production | 41 |
| 12. Pore Volumes Produced at Complete Recovery vs Viscosity Ratio | 42 |
| 13. Semi-Log Plot of Pore Volumes Produced at Complete Recovery | 43 |
| 14. Viscosity Chart | 44 |

CONTENTS

| Page | Title | Page |
|------|-------|------|
| 1 | | 1 |
| 2 | | 2 |
| 3 | | 3 |
| 4 | | 4 |
| 5 | | 5 |
| 6 | | 6 |
| 7 | | 7 |
| 8 | | 8 |
| 9 | | 9 |
| 10 | | 10 |
| 11 | | 11 |
| 12 | | 12 |
| 13 | | 13 |
| 14 | | 14 |
| 15 | | 15 |
| 16 | | 16 |
| 17 | | 17 |
| 18 | | 18 |
| 19 | | 19 |
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| 22 | | 22 |
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| 25 | | 25 |
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| 27 | | 27 |
| 28 | | 28 |
| 29 | | 29 |
| 30 | | 30 |
| 31 | | 31 |
| 32 | | 32 |
| 33 | | 33 |
| 34 | | 34 |
| 35 | | 35 |
| 36 | | 36 |
| 37 | | 37 |
| 38 | | 38 |
| 39 | | 39 |
| 40 | | 40 |

A STUDY OF THE EFFECT OF VISCOSITY RATIO ON THE
DISPLACEMENT OF MISCIBLE FLUIDS IN POROUS MEDIA

CHAPTER I

INTRODUCTION

Within recent years the increasing demand for petroleum products and the realization that the supply of new sources of petroleum is not inexhaustible have focused attention on the fact that in most of our oil production in the past, only about one third of the oil originally present in the reservoir is recovered when the economic limit is reached. This figure applies only when the field is produced by conventional methods where the main source of energy is the gas dissolved in the oil.

With this in mind many investigators have sought to find ways both to remove the residual oil and to improve methods of production so that a much greater per cent of the oil is removed initially.

Two methods are in common use today to remove the residual oil after primary depletion. Both of these methods involve displacement of the residual oil by another fluid. In one method gas and the other method water is used as the

THE UNIVERSITY OF CHICAGO

DEPARTMENT OF CHEMISTRY

CHAPTER I

INTRODUCTION

The first part of this book is devoted to a general survey of the subject. It is intended to give the reader a broad view of the field and to point out the main lines of research. The second part is devoted to a more detailed study of the various methods used in the investigation of the subject. It is intended to give the reader a more complete knowledge of the techniques used in the laboratory. The third part is devoted to a study of the results obtained by the various investigators. It is intended to give the reader a more complete knowledge of the facts of the case. The fourth part is devoted to a study of the various theories proposed to explain the facts. It is intended to give the reader a more complete knowledge of the various hypotheses advanced to explain the facts. The fifth part is devoted to a study of the various applications of the subject. It is intended to give the reader a more complete knowledge of the various uses of the subject in the various branches of science.

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displacing fluid. Although both of these methods have been applied in the field for a number of years and much laboratory work has been done on the displacement of oil by another fluid in a porous media, there still remains a large number of problems to be solved before the mechanics of displacement of fluids in a porous media is completely worked out. Many investigators are now working on these problems with the idea of gaining more complete recovery of petroleum from the reservoir.

The first section of the report is devoted to a general survey of the situation in the country. It is followed by a detailed account of the work done during the year.

The second section contains a list of the names of the persons who have been employed during the year, together with a brief description of their duties.

The third section is devoted to a description of the various experiments which have been carried out during the year, and to a discussion of the results obtained.

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CHAPTER II

REVIEW OF PREVIOUS INVESTIGATIONS

The initial study of flow of liquids through sands dates back to 1806 when H. D'Arcy (1)* performed his experiments on the flow of water through sand. In 1892 King (2) measured the rate of flow of water and air through consolidated and unconsolidated sands and published the results. It was not until 1900, when the increasing demand for oil caused the U.S. Bureau of Mines to make a series of experiments on flow characteristics of oil and water, that additional work was done on flow of fluids in a porous media. By 1920 the importance of flow measurements to production of gas and oil was realized and in the ensuing years the investigations of Cloud (3), Wetting (4), Wyckoff, Motset and Mackat (5), and many others added materially to our knowledge of fluid flow in porous media.

In the last ten to fifteen years most of the work has been directed toward the development and improvement of methods of predicting petroleum reservoir performance. As a result there have been numerous investigations made of the behavior of immiscible fluids in porous media. Leverett (6),

*Numbers in parentheses refer to references in the bibliography.

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CHAPTER II

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Leverett and Lewis (7), and others have contributed much to the development of the theory and mechanics of the displacement of oil by water. Information concerning the displacement of oil by gas was reported by several investigators such as Reid and Huntington (8), Holset (9), and Buckley and Leverett (10). The latter worked out a satisfactory picture of the mechanics of the displacement of oil by both water and gas.

However, while the above work was being carried out with immiscible fluids, little work was done on the mechanics of displacement of two miscible fluids. Berts (11) and Dicker (12) investigated the effects of specific gravity, velocity and pressure on the amount of mixing taking place during the displacement of one gas by another in unconsolidated sand. They concluded that the amount of mixing was inversely proportional to the rate of flow and that it became less as the pressure was increased up to a certain point for any given linear velocity. Above this point an increase in pressure caused an increase in the amount of mixing. Their experiments also indicated that less mixing took place when the heavier gas was used as the displacing fluid.

Hesset, Morgan and Mahat (13) is studying the mobility of interstitial waters applied at some conclusions concerning the displacement of water by water in a consolidated sand. Their results in all cases showed that after injecting into the core a volume of displacing water equal to one core

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CHAPTER IV

DETAILS

The synthetic core that was used in this work consisted essentially of pure quartz grains partially consolidated by sinter. This core was contained in a cylindrical Lucite tube, 100 centimeters in length and 6.35 centimeters inside diameter.

To make this core Oil Creek sand, obtained from an outcrop near Sulphur, Oklahoma, was sieved and a fraction between 80 and 140 mesh retained. This sand was thoroughly washed with hot water then cleaned by agitation in hot hydrochloric acid. Following this it was again washed with water then agitated in a hot sodium hydroxide solution with a final wash with water until the solution was shown by litmus paper to be neutral. The sand was then placed in an oven to be dried. After drying was complete the sand was re-sieved with the 80 to 140 mesh fraction again retained.

Next the Lucite tube was fitted with square end plate cut from one inch sheet Lucite. A circular groove 3/16 inch deep, 6.35 centimeters inside diameter, and 7.75 centimeters outside diameter was machined in the face of each block and

a hole drilled and tapped for 3/8 inch threads in the center. Brass fittings and valves were threaded into these holes and a 130 mesh screen placed over the hole. The four corners of the two end plates were drilled to accommodate tie rods. Next a neoprene rubber gasket was put into the groove of one end plate and two tie rods were placed in opposite corners. This plate was fitted to one end of the Lucite tube, the two tie rods being secured at the other end in a wooden block placed on the Lucite tube. Prior to putting on this block a 3 inch extension of the same diameter tube was placed on the end of the long tube. The block left this end of the tube partially open. The tube was then placed on a vibrating table in a vertical position with the end plate down and a length of rubber hose run from the brass fitting to a large beaker.

With the valve at the lower end closed by hand,* a colloidal suspension of silica in water, was poured into the top of the tube until there was approximately 3 inches of Syton in the tube. The slanted stand was placed in a funnel which was slanted above the vertical tube. This allowed the sand to be fed slowly into the tube. Additional syton was added to maintain its level approximately 3 inches over the sand as it was deposited into the bottom of the tube. This method was used to get uniform porosity and porosity in the core.

When the sand had been deposited even with the top of the long tube, the vibrating table was stopped, the tie rods

*Obtainable from the Inorganic Chemical Co., Boston, Mass.

The first part of the report deals with the general situation of the country and the progress of the work done during the year. It is followed by a detailed account of the various projects and schemes which have been carried out, and a summary of the results achieved. The report concludes with a statement of the views of the Committee on the future of the work.

The Committee has been pleased to note the progress made during the year, and to see that the work has been carried out in accordance with the programme of work approved by the Council in 1954. It is particularly pleased to see that the work has been carried out in a most efficient and economical manner, and that the results achieved are of a high standard.

The Committee has also been pleased to see that the work has been carried out in a most efficient and economical manner, and that the results achieved are of a high standard. It is particularly pleased to see that the work has been carried out in a most efficient and economical manner, and that the results achieved are of a high standard.

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locked and the extension tube removed. The other end plate was put on and all four tie rods run through both end plates and pulled tight, thus sealing both ends of the tube. With the core still in the vertical position the valve on the lower end was opened and the liquid drained out. Then dry air was forced into the top and passed down through the sand and out the lower end of the tube thus displacing any remaining water and drying out the sand. After twenty-four hours of drying with air, the bottom valve was closed, a vacuum pump attached to the top of the tube and a vacuum placed on the tube for twenty-four hours. At the end of this time approximately 1300 cubic centimeters of alcohol ("Synusol") was forced into the core through the lower end. The core was again dried by passing dry air through it for a period of forty-eight hours and then maintaining a vacuum on it for twenty-four hours.

The above procedure resulted in a partially consolidated core of essentially pure silicon. At this time a series of permeability tests were run with air on the core. These indicated an average overall permeability of 3.4 darcies. However, upon installing pressure taps every 33.3 centimeters along the core it was found that one end of the core had a low permeability compared to the other two sections. A piece 6.3 centimeters long was removed from this end of the core and air permeabilities again run. The overall permeability was found to be 3.22 darcies and none of the sections deviated more than 5 per cent from this value. Since this gave a

The first part of the report deals with the general situation of the country and the progress of the work done during the year. It is followed by a detailed account of the various projects and schemes undertaken, and a summary of the results achieved. The report concludes with a statement of the financial position and a list of the members of the committee.

The committee has the pleasure to inform you that the work done during the year has been most satisfactory and that the various projects and schemes undertaken have all been carried out in accordance with the programme of work approved by the committee at its meeting on the 15th of January.

The financial position of the committee is also satisfactory and it is hoped that the work done during the year will have resulted in a further increase in the number of members of the committee.

The committee is grateful to you for the interest and assistance which you have given to the work of the committee and trusts that you will continue to do so in the future.

Yours faithfully,
 The Secretary

fairly uniform core it was deemed satisfactory for the experiments to be run on it.

The porosity of the core was determined next. The first method was to measure pressure at two different values and record the volume removed in going from the higher to the lower pressure. By using the perfect gas law the porosity was calculated to be .337. The other method was by the use of wet and dry weights. The fractional porosity in this case was calculated to be .307. This latter value was used in all calculations since it was felt that the method used in calculating this value was far more accurate.

The sugar solutions used in this work were made with distilled water and commercial cane sugar (sucrose). The index of refraction of the distilled water was checked before the addition of the sucrose, then after addition of sucrose the index of refraction was again taken and from this information the per cent of sucrose in the solution was calculated and thus the viscosity known.

CHAPTER V

EXPERIMENTAL APPARATUS

With the core partially consolidated and its permeability and porosity judged sufficiently homogeneous for this experiment, additional holes were drilled and tapped in the tops of the end plates and brass fittings were installed. With the core in the horizontal position, a copper spigot was installed at the outlet end, and a brass tee installed at the inlet end. With brass valves installed on both sides of the tee a means was provided for purging the fluid system before it entered the core. Manometer leads were connected to the fittings on both end plates.

Next a $2\frac{1}{2}$ liter pyrex bottle with a bottom outlet was set up with a rubber stopper that had a hole in the center through which a copper tube extended into the bottle to a point near the bottom of the bottle. The tube and stopper were held in place by a metal fitting fastened to the bottle by fine copper wire. A brass tee was connected to the tubing before it entered the bottle and from one side of this tee copper tubing was run to a source of air. Air originally under 100 psi pressure was first reduced by a pressure

CHAPTER V

THE UNIVERSITY OF TORONTO

The University of Toronto is one of the oldest and largest universities in Canada. It was founded in 1827 as King's College, a branch of the University of London. Over the years, it has grown into a major center of learning and research, offering a wide range of undergraduate and graduate programs. The university is known for its commitment to academic excellence and its diverse student body. It has a long history of producing leaders in various fields, and it continues to play a significant role in Canadian society.

regulator to 40 psi. It was further reduced and regulated by a Chilcote Pressure Regulator which allowed a fine accurate control of the pressure over a range of 2 psi to 50 psi.

From the other side of the tee a lead was run to a mercury manometer. This measured the pressure existing at the end of the copper tubing in the bottle. Therefore, differences in fluid level in the bottle at various times during the runs would not affect the pressures placed on the system and a constant pressure could be maintained.

Since the level of the outlet of the copper tube in the bottle was adjusted to the same level as that of the inlet to the core, with a fluid connection to this inlet, the pressure at the inlet was the same as that measured at the end of the tube in the bottle.

Figure II shows the flow system used in this experiment. The components of this system are:

- (A) High pressure regulator and reducer
- (B) Low pressure regulator and reducer
- (C) Mercury manometers
- (D) Pyrex bottle fluid reservoir
- (E) Valve for purging fluid system
- (F) Synthetic core
- (G) Valve and spigot at outlet
- (H) Manometer connections
- (I) Products
- (J) Screen type filter

The first part of the report deals with the general situation of the country and the progress of the work done during the year. It is followed by a detailed account of the various projects and schemes which have been carried out, and a summary of the results achieved. The report concludes with a statement of the views of the Committee on the future of the country and the steps which should be taken to improve the lot of the people.

The Committee is of the opinion that the country is in a state of transition, and that the people are beginning to realize their rights and demands. It is therefore necessary to take steps to meet these demands and to bring about a more just and equitable social order. The Committee recommends that the Government should take the following steps:

- (1) To provide for the basic needs of the people, such as food, clothing, and shelter.
- (2) To improve the educational system and to provide free education for all.
- (3) To create more employment opportunities for the unemployed.
- (4) To improve the health services and to provide free medical care for all.
- (5) To improve the housing conditions and to provide low-cost housing for the poor.
- (6) To improve the transport system and to provide better facilities for the people.
- (7) To improve the social services and to provide more facilities for the people.
- (8) To improve the judicial system and to provide free legal aid for the poor.
- (9) To improve the administrative system and to provide better services for the people.
- (10) To improve the financial system and to provide more facilities for the people.

The Committee believes that these steps are essential for the progress and development of the country, and it urges the Government to take prompt action thereon.

For the runs made in the vertical position essentially the same set up was maintained and a correction was made for the difference in height of the inlet to the core and the point where the pressure was measured in the bottle.

From Figure II it can be seen that the flow system consists only of applying air pressure to the bottle (b) which causes the fluid in the bottle to flow through the filter to the inlet of the core, then passing through the core to the outlet where it is caught and measured in the 200 cubic centimeter graduate (1).

The apparatus used to measure the per cent of sugar in the efflux stream was a Spencer Abbe-type Refractometer. This refractometer is accurate to the third decimal place. From the knowledge of the amount of sugar in the efflux stream the per cent of original fluid could be calculated.

CHAPTER VI

EXPERIMENTAL PROCEDURE

After completing the partial consolidation and drying of the core, a series of permeability tests were run with air. On the completion of the permeability tests porosity was obtained by two different methods. When the permeability and porosity were deemed satisfactory the core was saturated with water and connected to a fluid system that was under a controlled pressure. Thus the water in the core could be displaced by another fluid which in turn could be displaced by another fluid. During these displacements, rate and composition of the effluent stream were measured.

Permeability Determinations

Upon running initial permeability test it was found that one end section of the core had a very low permeability compared to the other two sections. Upon removing the end plate it could be seen that a small hard plug had been formed in the center of the core. This plug appeared to extend into the core for only a few centimeters. Using a diamond saw approximately 6 centimeters was cut from the end of the core which was then squared by the use of fine emery cloth. This

IV. CONCLUSION

REFERENCES

The first part of this paper is devoted to a study of the properties of the solutions of the system of equations (1) and (2) in the case of a homogeneous medium. It is shown that the solutions of this system are unique and that they depend continuously on the data of the problem. In the second part of the paper, the problem of the stability of the solutions of the system (1) and (2) with respect to the initial data is considered. It is shown that the solutions of this system are stable with respect to the initial data in the sense of Liapunov. In the third part of the paper, the problem of the stability of the solutions of the system (1) and (2) with respect to the boundary data is considered. It is shown that the solutions of this system are stable with respect to the boundary data in the sense of Liapunov. In the fourth part of the paper, the problem of the stability of the solutions of the system (1) and (2) with respect to the inhomogeneous terms is considered. It is shown that the solutions of this system are stable with respect to the inhomogeneous terms in the sense of Liapunov.

APPENDIX

The purpose of this appendix is to give a more detailed account of the proof of the uniqueness theorem. It is shown that the solutions of the system (1) and (2) are unique in the sense of Liapunov. It is also shown that the solutions of this system are stable with respect to the initial data in the sense of Liapunov. In the first part of the appendix, the problem of the stability of the solutions of the system (1) and (2) with respect to the initial data is considered. It is shown that the solutions of this system are stable with respect to the initial data in the sense of Liapunov. In the second part of the appendix, the problem of the stability of the solutions of the system (1) and (2) with respect to the boundary data is considered. It is shown that the solutions of this system are stable with respect to the boundary data in the sense of Liapunov. In the third part of the appendix, the problem of the stability of the solutions of the system (1) and (2) with respect to the inhomogeneous terms is considered. It is shown that the solutions of this system are stable with respect to the inhomogeneous terms in the sense of Liapunov.

resulted in a core 33.7 centimeters in length. When permeabilities were run on this core it was found to have an overall permeability of 3.72 darcies while the three sections had permeabilities of 3.31, 4.01, and 3.62 darcies. All of these permeabilities were determined in the usual manner using air. After the values were determined they were plotted against the reciprocal of the mean pressure at which they were obtained and extrapolated to an infinite pressure to correct for the Klinkenberg effect.

Porosity Determinations

Two methods were used to determine the porosity of the core. The first method was to build up a pressure in the core, record this pressure, then lower the pressure by metering out a known volume of air and again record the pressure. Applying the perfect gas law the volume of space the gas occupied in the core could be calculated. The total volume of the tube and fittings can be determined from their dimensions, thus the porosity determined. The average value found by this method was .337.

The second method used the difference in dry and wet weights of the core and was described in a previous section. The porosity by this method was found to be .307. This method was thought to be more accurate than the one using air, so it was used in all calculations.

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Section 10

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Index of Refraction Measurements

The solutions used in this experiment were transparent, thus using the proper instrument the index of refraction could easily be measured. Since the per cent of sucrose in an aqueous solution is directly related to its index of refraction a measurement of this value could be converted easily to per cent of sucrose present.

In this work the index of refraction of both the original fluid in the core and of the displacing fluid were measured before a run was started. At regular intervals during the run index of refraction of the efflux was measured and with these values the per cent of the original fluid in the efflux could be calculated.

Experimental Runs

After the permeability and porosity determinations had been made on the core it was left saturated with distilled water which was displaced by an aqueous sucrose solution of known index of refraction. The pressure bottle was filled with distilled water, then connected to the air system and to the core by means of plastic tubing. (See Figure II.)

Next a pressure was applied to the system through the regulators which maintained this pressure constant. A valve at the outflow end of the core was opened allowing the original fluid in the core to be displaced by the sucrose solution. The volume of the displaced fluid and the rate of flow

THE HISTORY OF THE UNITED STATES

The history of the United States is a story of a people who have grown from a small colony of English settlers to a great nation. The first step was the establishment of the thirteen original colonies. These colonies were founded by people who had come to America in search of a better life. They were not content with the conditions in England and sought a place where they could practice their own ideas of government and religion.

The colonies were not united at first. Each colony was governed by its own local authorities. It was not until the late 1700s that the colonies began to work together. They realized that they had common interests and that they needed to act in concert to protect those interests. This led to the signing of the Declaration of Independence in 1776, which declared the colonies to be free and independent states.

The next step was the creation of a new government. The Continental Congress drafted the Articles of Confederation and adopted them in 1777. This document established a loose confederation of thirteen states. However, the Articles proved to be weak and ineffective. They did not provide for a strong central government, and the states often acted in their own self-interest rather than for the good of the nation as a whole.

The need for a stronger government became apparent during the 1780s. The states were unable to raise a common army, and they often quarreled over trade and other issues. In 1787, delegates from twelve of the thirteen states met in Philadelphia to draft a new constitution. The result was the Constitution of the United States, which was signed on September 17, 1787.

THE CONSTITUTION

The Constitution is the supreme law of the United States. It sets out the structure of the federal government and the powers of each branch. The three branches are the Executive, the Legislative, and the Judicial. The Executive branch is headed by the President, who is elected by the people. The Legislative branch consists of the House of Representatives and the Senate. The Judicial branch is headed by the Supreme Court, which has the power to interpret the Constitution and to declare laws unconstitutional.

The Constitution also guarantees certain rights to the people. These rights are listed in the first ten amendments, known as the Bill of Rights. They include the right to free speech, the right to a fair trial, and the right to privacy. The Constitution is a living document, and it has been amended many times since it was first adopted. These amendments have added to the rights of the people and have changed the way the government operates.

The Constitution is the foundation of the United States. It is the document that has made it possible for this country to exist as a free and democratic nation. It is the source of our laws and the guide to our government. Without the Constitution, the United States would not be the country we know today.

of the effluent stream was measured and recorded at the same time the index of refraction of the effluent was obtained.

By referring to the tables in the Handbook of Chemistry and Physics (14), the per cent of sucrose by weight in the effluent was obtained. The temperature was measured and a correction applied to the above percentage. From another table in the handbook the amount of sucrose (grams per liter) was obtained. Since the spm values were obtained for the original sucrose solution the amount of the original fluid present in the effluent could be calculated. These measurements and calculations were made at regular intervals during the displacement process.

EXPERIMENTAL DATA

TABLE I
 RUN NUMBER 1

| | |
|----------------------------------|-----------------------------------|
| Temperature, 27° C | $F = 450 \text{ mm.Hg.}$ |
| Original Fluid (Distilled water) | Displacing Fluid (Sugar Solution) |
| $n = 1.3323$ | $n = 1.3710$ |
| Viscosity = .0040 cp | Viscosity = 1.00 cp |
| | $\% \text{ sugar} = 24.725$ |

| cu. cms. removed | $n =$ efflux | Fract. Pure Volume | % Sugar in eff. | wt. of sugar in eff. | % of Dis- placing fluid in efflux | % ori- ginal fluid in eff. |
|------------------|--------------|--------------------|-----------------|----------------------|-----------------------------------|----------------------------|
| 000 | 1.3323 | | | | | |
| 005 | 1.3331 | .968 | 1.4 | 14 | 5.17 | 94.8 |
| 025 | 1.3331 | 1.02 | 13.85 | 139 | 51.2 | 48.8 |
| 040 | 1.3338 | 1.03 | 21.00 | 205 | 55.2 | 44.8 |
| 075 | 1.3350 | 1.073 | 23.30 | 225 | 54 | 46.0 |
| 1000 | 1.3395 | 1.106 | 23.00 | 202 | 56.7 | 43.3 |
| 1080 | 1.3703 | 1.160 | 24.30 | 237 | 58.5 | 41.5 |
| 1120 | 1.3703 | 1.27 | 24.40 | 233 | 59.0 | 41.0 |
| 1200 | 1.3710 | 1.435 | 24.75 | 271 | 100 | 0 |

* $n_i =$ index of refraction.

TABLE 1

1. Summary of data

1.000 mm

1.000 mm

1.000 mm

1.000 mm

1.000 mm

1.000 mm

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1.000 mm

| 1.000 mm | 1.000 mm | 1.000 mm | 1.000 mm | 1.000 mm | 1.000 mm | 1.000 mm |
|----------|----------|----------|----------|----------|----------|----------|
| 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

1.000 mm

TABLE II

SUGAR NUMBER 2

Temperature = 25° C

P = 625 mm. Hg.

Original Fluid (Sugar
Solution)Displacing Fluid (Distilled
Water)

n = 1.3710

n = 1.3328

Viscosity = 8.00 cp

Viscosity = .0007 cp

S Sugar = 24.72%

| cu. cms. Produced | n = eff. liq. | Perct. Pure Volume | % Sugar in eff. | wt. of sugar in eff. | % Original Fluid in eff. |
|----------------------|------------------|--------------------------|--------------------|----------------------------|--------------------------------|
| 500 | 1.3710 | .882 | 24.72 | 270 | 1.00 |
| 600 | 1.3700 | .862 | 24.45 | 268 | .968 |
| 680 | 1.3692 | .792 | 23.40 | 236 | .950 |
| 700 | 1.3640 | .773 | 20.40 | 220.5 | .916 |
| 800 | 1.3540 | .683 | 14.67 | 154 | .81 |
| 850 | 1.3481 | .650 | 13.02 | 137 | .807 |
| 880 | 1.3472 | 1.048 | 10.02 | 104 | .808 |
| 1000 | 1.3462 | 1.108 | 8.27 | 83.0 | .817 |
| 1100 | 1.3410 | 1.318 | 6.52 | 64.2 | .832 |
| 1200 | 1.3400 | 1.343 | 5.23 | 50 | .807 |
| 1400 | 1.3351 | 1.245 | 2.40 | 28 | .863 |
| 1600 | 1.3332 | 1.970 | .45 | 6.0 | .884 |
| 1700 | 1.3327 | 1.878 | 0 | 0 | 0 |
| 1800 | 1.3328 | | | | |

TABLE III
SUCROSE COLUMN 3

Temperature = 20° C

$r = 220$ mm. Hg.

Original Fluid (sugar
solution)

Displacing Fluid (distilled
water)

$n = 1.4085$

$n = 1.3335$

Viscosity = 8.1 cp

Viscosity = .3537 cp

S Sugar = 45.035

| Co. amt. Produced | $n =$ efflux | Fract. Fore Volume | S Sugar in eff. | % of sugar in eff. | % of final fluid in eff. |
|----------------------|-----------------|--------------------------|--------------------|--------------------------|-----------------------------------|
| 0 | 1.4080 | | | | |
| 200 | 1.4020 | .811 | 45.03 | 241 | 1.00 |
| 400 | 1.4000 | .404 | 40.31 | 208 | .804 |
| 600 | 1.3900 | .130 | 35.30 | 152 | .704 |
| 800 | 1.3787 | | 29.50 | 130 | .614 |
| 900 | 1.3664 | .002 | 21.04 | 100 | .436 |
| 950 | 1.3534 | | 16.00 | 181 | .354 |
| 700 | 1.34 | .970 | 11.12 | 115 | .214 |
| 750 | 1.3472 | | 9.27 | 102 | .180 |
| 800 | 1.3151 | .863 | 12.30 | 130 | .240 |
| 850 | 1.3463 | .682 | 9.42 | 90 | .181 |
| 1000 | 1.3472 | 1.102 | 9.27 | 102 | .150 |
| 1050 | 1.3405 | 1.197 | 10.72 | 111 | .205 |
| 1350 | 1.3472 | 1.450 | 9.27 | 102 | .180 |
| 1725 | 1.3429 | 1.600 | 7.02 | 72 | .133 |
| 1875 | 1.3412 | | | | |
| 2000 | 1.3387 | 2.210 | 4.2 | 43 | .0784 |
| 2600 | 1.3383 | 2.670 | 1.9 | 19 | .035 |
| 3300 | 1.3349 | 3.640 | | | |
| 3750 | 1.3335 | 4.140 | | | |

Table 1
Summary of Data

Table 1 shows the results of the analysis of variance for the data presented in Table 1. The analysis was conducted using the method of least squares. The results are presented in Table 1. The analysis shows that the differences between the groups are significant at the 5% level of significance. The analysis also shows that the differences between the groups are significant at the 1% level of significance.

| Source of Variation | Sum of Squares | D.F. | Mean Square | F-Value | Significance |
|---------------------|----------------|------|-------------|---------|--------------|
| Between Groups | 10.5 | 2 | 5.25 | 10.5 | 0.01 |
| Within Groups | 10.5 | 18 | 0.58 | | |
| Total | 21.0 | 20 | | | |

TABLE IV
 AND FIGURE 4

Temperature = 25° C
 Original fluid (sugar
 solution)
 $n = 1.3910$
 Viscosity = 5.8 cp
 ρ sugar = 80.215

$r = 200$ cm. Hg.
 Dispersing fluid (distilled
 water)
 $n = 1.3333$
 Viscosity = .0137 cp

| St. cm. Produced | $n =$ eff. in | Rate st/min. | Fractions Pure Velocities | % Sugar in eff. | St. of sugar in eff. | Partial fluid in eff. in |
|---------------------|------------------|-----------------|---------------------------------|--------------------|----------------------------|--------------------------------|
| 0 | 1.3910 | 4.8 | | | | |
| 100 | 1.3910 | 4.8 | .11 | | | |
| 200 | 1.3910 | 5.7 | .221 | | | |
| 300 | 1.3910 | 6.02 | .331 | | | |
| 400 | 1.3910 | 6.3 | .442 | | | |
| 500 | 1.3910 | 6.4 | .552 | 35.01 | 413 | 1.00 |
| 600 | 1.3788 | 7.3 | .662 | 50.51 | 354 | .783 |
| 650 | 1.3758 | 8 | .717 | 57.51 | 305 | .734 |
| 800 | 1.3636 | 8.6 | .835 | 59.00 | 317 | .635 |
| 900 | 1.3524 | 9.5 | .953 | 13.22 | 138 | .334 |
| 950 | 1.3490 | | 1.000 | 10.37 | 113.5 | .274 |
| 1000 | 1.3469 | 9.7 | 1.103 | 9.63 | 98 | .239 |
| 1050 | 1.3457 | | 1.160 | 8.67 | 91.5 | .221 |
| 1120 | 1.3441 | 10 | 1.252 | 7.61 | 80 | .183 |
| 1200 | 1.339 | 10.3 | 1.325 | 3.7 | 37 | .0898 |
| 1300 | 1.339 | 10.3 | 1.435 | 3.7 | 37 | .0906 |
| 1500 | 1.3371 | 10.5 | 1.635 | 3.1 | 31 | .073 |
| 1600 | 1.3360 | 10.3 | 1.770 | 3.7 | 37 | .0896 |
| 1700 | 1.3360 | 10.6 | 1.975 | 2.4 | 24 | .0591 |
| 1800 | 1.3358 | 11.1 | 1.990 | 2.3 | 23 | .0537 |
| 2050 | 1.3355 | 12.5 | 2.24 | 2.00 | 20 | .0485 |
| 2300 | 1.3338 | 12.5 | 2.54 | .45 | 45 | .011 |

THE STATE OF TEXAS,
COUNTY OF _____

Know all men by these presents, that _____ of the County of _____ State of Texas, for and in consideration of the sum of _____ Dollars, to _____ in hand paid by _____ the receipt of which is hereby acknowledged, have granted, sold and conveyed, and by these presents do grant, sell and convey unto the said _____ of the County of _____ State of Texas, all that certain _____

| Acres | Section | Range | County | State | Original Grant | Original Grantee |
|-------|---------|-------|--------|-------|----------------|------------------|
| 1.00 | 11 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 12 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 13 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 14 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 15 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 16 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 17 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 18 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 19 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 20 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 21 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 22 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 23 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 24 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 25 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 26 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 27 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 28 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 29 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 30 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 31 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 32 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 33 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 34 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 35 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 36 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 37 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 38 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 39 | 10 | _____ | TX | _____ | _____ |
| 1.00 | 40 | 10 | _____ | TX | _____ | _____ |

WITNESSED my hand and seal of office this _____ day of _____ A.D. 19____, at the City of _____ State of Texas.

County Clerk

TABLE 7
 THE NUMBER 3

| Temperature = 20° C | | | P = 700 mm. Hg. | | | |
|---------------------------------|--------|--------------|------------------------------------|-----------------|----------------------|----------------------------|
| Original Fluid (Sugar solution) | | | Displacing Fluid (Distilled Water) | | | |
| n = 1.3721 | | | n = 1.3324 | | | |
| Viscosity = 2.06 cp | | | Viscosity = .737 cp | | | |
| S sugar = 24.73% | | | | | | |
| cu. cms. Produced | n = | Rate cc/min. | Fract. Pore Volume | % Sugar in eff. | Wt. of sugar in eff. | % Original fluid in efflux |
| 100 | 1.3713 | 37 | | | | |
| 200 | 1.3711 | 42 | | | | |
| 300 | 1.3710 | 52 | .525 | 24.71 | 272.5 | 100 |
| 400 | 1.3700 | | .640 | 24.13 | 205 | 77.3 |
| 500 | 1.3690 | | .685 | 22.93 | 250.5 | 92.0 |
| 710 | 1.3681 | 53 | .704 | 19.65 | 216 | 79.3 |
| 800 | 1.3618 | | .923 | 12.30 | 133.5 | 49.7 |
| 850 | 1.3493 | 61 | .933 | 10.99 | 114.3 | 42.0 |
| 900 | 1.3465 | 62 | .963 | 9.53 | 95.3 | 35.1 |
| 950 | 1.3450 | 62 | 1.042 | 8.30 | 59 | 22.3 |
| 1000 | 1.3456 | 61 | 1.105 | 8.50 | 52 | 22.7 |
| 1050 | 1.3454 | 61 | 1.160 | 5.6 | 31 | 15.4 |
| 1100 | 1.3435 | 61 | 1.31 | 7.5 | 77 | 28.3 |
| 1125 | 1.3430 | 60 | 1.37 | 7.15 | 73 | 26.8 |
| 1200 | 1.3413 | 61 | 1.323 | 3.96 | 61 | 22.4 |
| 1300 | 1.3394 | 60 | 1.435 | 4.70 | 49 | 18.0 |
| 1400 | 1.3377 | 64 | 1.545 | 3.30 | 36 | 13.2 |
| 1500 | 1.3344 | 68 | 1.635 | 1.34 | 13 | 4.8 |
| 1600 | 1.3320 | 66 | 1.779 | | | |
| 1700 | 1.3323 | 66 | 1.875 | | | |
| 1800 | 1.3323 | 64 | 1.910 | | | |

TABLE VI

Series 100000 C
(Vertical Pan - Upward)

Temperature = 30° K

P = 500 mm. Hg.

Original Fluid (Distilled
water)Displacement Yield (Sugar
solution)

n = 1.3384

n = 1.3002

Viscosity = .0737 cp

Viscosity = 3.7 cp

% Sugar = 30.615

| St. Ord. Produced | n = reflex | Rate cc/min. | Pres. Force Volume | % Sugar in off. | St. of Sugar in off. g/100g | % of fluid in offlux |
|----------------------|---------------|-----------------|--------------------------|--------------------|--------------------------------------|----------------------------|
| 0 | | 12 | | | | |
| 155 | 1.3384 | 5 | .130 | | | |
| 200 | | 6 | .221 | | | |
| 225 | | 7 | .303 | | | |
| 255 | 1.3384 | 5.7 | .470 | | | |
| 300 | | 5.1 | .553 | | | |
| 350 | | 4.6 | .663 | | | |
| 400 | | 4.3 | .771 | | | |
| 425 | 1.3384 | 4 | .893 | | | |
| 450 | 1.3324 | | .930 | | | 100 |
| 500 | 1.3330 | 3.7 | .993 | .50 | 4 | 89 |
| 510 | 1.3400 | | 1.003 | 5.23 | 55 | 87.5 |
| 520 | 1.3468 | | 1.014 | 6.71 | 102.5 | 75.3 |
| 530 | 1.3509 | | 1.025 | 15.30 | 201 | 51.6 |
| 540 | 1.3511 | | 1.042 | 33.50 | 344.5 | 17 |
| 555 | 1.3525 | | 1.055 | 33.95 | 393 | 7.7 |
| 565 | 1.3530 | | 1.064 | 34.05 | 401.5 | 3.5 |
| 585 | 1.3595 | | 1.066 | 35.15 | 404 | 3.6 |
| 1000 | 1.3500 | 3.3 | 1.103 | 35.40 | 408 | 1.5 |
| 1025 | 1.3502 | | | | | |
| 1050 | 1.3502 | | | | | |
| 1100 | 1.3504 | 3.3 | 1.21 | 35.59 | 415 | |

IV. 1900.

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2. 1900. 1900.

3. 1900. 1900.

4. 1900. 1900.

5. 1900. 1900.

6. 1900. 1900.

7. 1900. 1900.

8. 1900. 1900.

9. 1900. 1900.

10. 1900. 1900.

11. 1900. 1900.

12. 1900. 1900.

| No. | Name | Address | City | State | Profession | Age |
|-----|------|---------|------|-------|------------|-----|
|-----|------|---------|------|-------|------------|-----|

| | | | | | | |
|----|-----------------|-----------------|---------------|----|------------|----|
| 1 | John Doe | 123 Main St | New York | NY | Teacher | 35 |
| 2 | Jane Smith | 456 Elm St | Chicago | IL | Housewife | 28 |
| 3 | Robert Brown | 789 Oak St | Philadelphia | PA | Engineer | 42 |
| 4 | Mary White | 101 Pine St | Boston | MA | Doctor | 50 |
| 5 | James Black | 202 Cedar St | San Francisco | CA | Lawyer | 38 |
| 6 | Elizabeth Green | 303 Birch St | Washington | DC | Artist | 25 |
| 7 | William Grey | 404 Spruce St | Portland | ME | Farmer | 55 |
| 8 | Anna King | 505 Willow St | St. Louis | MO | Musician | 30 |
| 9 | Charles Lee | 606 Poplar St | Memphis | TN | Merchant | 45 |
| 10 | Sarah Hall | 707 Hickory St | Richmond | VA | Widow | 60 |
| 11 | George Young | 808 Sycamore St | Indianapolis | IN | Journalist | 33 |
| 12 | Frances Hill | 909 Chestnut St | Cincinnati | OH | Actress | 22 |

TABLE VII

WIND SYSTEM 7
(Vertical Run - Down)

Temperature = 20° C

P = 235 mm. Hg.

Original Fluid (Sugar
Solution)Displacing Fluid (Distilled
Water)

n = 1.3902

n = 1.3334

Viscosity = 3.7 cp

Viscosity = .0727 cp

Sugar = 35.21%

| cu. cm. Produced | n = afflux | Time | Fract. Fore Volume | % Sugar in eff. | Wt. of sugar in eff. | % Cris- tall fluid in efflux |
|---------------------|---------------|------|--------------------------|--------------------|----------------------------|---------------------------------------|
| 50 | 1.3902 | 3.6 | .0861 | | | |
| 100 | 1.3902 | 4.3 | .11 | | | |
| 200 | 1.3903 | 4.5 | .221 | | | |
| 300 | 1.3902 | 4.6 | .331 | | | |
| 400 | 1.3906 | 4.7 | .442 | | | |
| 500 | 1.3902 | 4.5 | .552 | 38.89 | 415 | 100 |
| 555 | 1.3943 | | .612 | 32.33 | 362 | 82.6 |
| 570 | 1.3799 | | .689 | 29.72 | 335.5 | 80.3 |
| 600 | 1.3767 | 5.7 | .682 | 27.63 | 311.5 | 78.0 |
| 660 | 1.3704 | | .722 | 24.31 | 265.0 | 64.6 |
| 700 | 1.3552 | 6.4 | .793 | 21.36 | 222 | 55.9 |
| 755 | 1.3520 | | .832 | 16.27 | 160 | 43.4 |
| 800 | 1.3500 | 6.7 | .893 | 16.01 | 193 | 46.5 |
| 850 | 1.3502 | | .952 | 13.14 | 134 | 40.0 |
| 900 | 1.3520 | 7.0 | .903 | 10.78 | 172 | 43.2 |
| 960 | 1.3520 | | 1.0556 | 12.89 | 168 | 39.8 |
| 1000 | 1.3522 | 7.0 | 1.106 | 12.14 | 132 | 33.3 |
| 1055 | 1.3499 | | 1.165 | 11.62 | 122.5 | 29.5 |
| 1100 | 1.3423 | 7.5 | 1.215 | 10.69 | 111.5 | 27.7 |
| 1150 | 1.3469 | | 1.275 | 8.69 | 100.3 | 24.1 |
| 1200 | 1.3400 | 7.8 | 1.325 | 8.14 | 84.3 | 22.3 |
| 1300 | 1.3437 | 8 | 1.385 | 7.63 | 79 | 19.0 |
| 1400 | 1.3411 | | 1.435 | 5.86 | 69 | 14.2 |
| 1500 | 1.3387 | 8.5 | 1.445 | 4.26 | 44 | 10.6 |
| 1600 | 1.3372 | | 1.685 | 3.26 | 32.5 | 7.2 |
| 1600 | 1.3343 | 9.2 | 1.770 | 1.46 | 13 | 3.6 |
| 1800 | 1.3330 | | 1.900 | .4 | 4 | .91 |
| 2000 | 1.3325 | 10.4 | 2.1 | .4 | 4 | .91 |
| 2000 | 1.3321 | 10.4 | 2.210 | | | |

TABLE VIII

Run Number 5
(vertical Run - upward)

Temperature = 27° C

P = 200 mm. Hg.

Original fluid (distilled
water)

Distilling fluid (sugar
solution)

n = 1.3325

n = 1.3700

Viscosity = .2045 cp

Viscosity = 1.75 cp

% Sugar = 24.75%

| cc. obs. produced | n = efflux | rate cc/min. | Fract. pure Vol. |
|----------------------|---------------|-----------------|---------------------|
| 0 | | 12 | |
| 100 | 1.3325 | 10.0 | .11 |
| 200 | | 9.3 | .221 |
| 300 | | 8.0 | .302 |
| 400 | | 8 | .442 |
| 500 | | 7.2 | .532 |
| 700 | | 5.8 | .773 |
| 800 | | 5.5 | .883 |
| 900 | 1.3345 | 4.2 | .963 |
| 925 | 1.3405 | | 1.05 |
| 950 | 1.3300 | 4.6 | 1.08 |
| 975 | 1.3200 | | |
| 1000 | | | |
| 1025 | 1.3700 | 4.5 | 1.13 |
| 1000 | 1.3700 | | |

TABLE 1

Summary of the results of the analysis of variance

| | | | | |
|---------------------|------|-------------|---------|-----------------|
| Source of variation | D.F. | Mean square | F-value | Probability > F |
| Between groups | 3 | 10.00 | 1.00 | 0.40 |
| Within groups | 12 | 10.00 | | |
| Total | 15 | | | |

| Group | Mean | S.D. | F-value | Probability > F |
|-------|-------|------|---------|-----------------|
| 1 | 10.00 | 1.00 | 1.00 | 0.40 |
| 2 | 10.00 | 1.00 | 1.00 | 0.40 |
| 3 | 10.00 | 1.00 | 1.00 | 0.40 |
| 4 | 10.00 | 1.00 | 1.00 | 0.40 |
| 5 | 10.00 | 1.00 | 1.00 | 0.40 |
| 6 | 10.00 | 1.00 | 1.00 | 0.40 |
| 7 | 10.00 | 1.00 | 1.00 | 0.40 |
| 8 | 10.00 | 1.00 | 1.00 | 0.40 |
| 9 | 10.00 | 1.00 | 1.00 | 0.40 |
| 10 | 10.00 | 1.00 | 1.00 | 0.40 |
| 11 | 10.00 | 1.00 | 1.00 | 0.40 |
| 12 | 10.00 | 1.00 | 1.00 | 0.40 |

TABLE IX

RUN NUMBER 2

Temperature = 27° C

P = 230 mm. Hg.

Original Fluid (Sugar

Displacing Fluid (Distilled

n = 1.3709 Solvent)

n = 1.3333

Viscosity = 1.00 cp

Viscosity = .3243 cp

Sugar = 24.00%

| cu. cm. Produced | n = | Note cc/min. | Fract. Pore Volume | % Sugar in off. | % Sugar in off. | % Original Fluid in off. |
|---------------------|---------|-----------------|--------------------------|--------------------|--------------------|--------------------------------|
| 100 | 1.3709 | 4.5 | | | | |
| 200 | 1.3709 | 4.5 | | | | |
| 300 | 1.3709 | 4.6 | | | | |
| 400 | 1.3709 | 4.6 | | | | |
| 500 | 1.3709 | 4.9 | | | | |
| 600 | 1.3709 | 5.0 | .662 | | | |
| 610 | 1.3709 | 5.0 | .675 | 24.00 | 272.5 | 100 |
| 625 | 1.3695 | 5.0 | .699 | 23.63 | 268 | 96 |
| 650 | 1.3679 | 5.1 | .717 | 22.63 | 250.4 | 92 |
| 700 | 1.3664 | 5.2 | .773 | 21.43 | 233 | 86.5 |
| 750 | 1.3659 | 5.2 | .827 | 19.65 | 201 | 73.9 |
| 800 | 1.3677 | 5.2 | .883 | 16.73 | 176 | 65.4 |
| 850 | 1.3643 | | .939 | 14.91 | 159 | 59.0 |
| 900 | 1.3607 | 5.4 | .993 | 12.26 | 126 | 47.0 |
| 950 | 1.3565- | | 1.045 | 11.16 | 116 | 42.6 |
| 1000 | 1.3566 | 5.6 | 1.103 | 9.61 | 99 | 36.3 |
| 1050 | 1.3537 | | 1.160 | 7.73 | 79.3 | 29.0 |
| 1100 | 1.3505 | 5.7 | 1.239 | 4.43 | 44 | 16.1 |
| 1200 | 1.3378 | 5.7 | 1.328 | 3.73 | 37.4 | 13.7 |
| 1600 | 1.3296 | 5.2 | 1.520 | | | |
| 1700 | 1.3295 | | 1.575 | | | |

Table 1

Summary of results

for the period 1950-1955

of the various types of ...

| Year | ... | ... | ... | ... | ... | ... |
|------|-----|-----|-----|-----|-----|-----|
| 1950 | ... | ... | ... | ... | ... | ... |
| 1951 | ... | ... | ... | ... | ... | ... |
| 1952 | ... | ... | ... | ... | ... | ... |
| 1953 | ... | ... | ... | ... | ... | ... |
| 1954 | ... | ... | ... | ... | ... | ... |
| 1955 | ... | ... | ... | ... | ... | ... |

TABLE X

NEW JERSEY 10

Temperature = 22° C

P = 230 mm. Hg.

Original fluid (Distilled
water)Displacing fluid (Sugar
distilled)

n = 1.3304

n = 1.3305

Viscosity = .0737 cp

Viscosity = 1.0 cp

Sugar = 4.1%

| cu. cm. Displaced | n = refractive | Rate cc/min. | Fract. Sugar Vol. |
|----------------------|-------------------|-----------------|----------------------|
| 100 | 1.3304 | 13 | .11 |
| 200 | 1.3304 | 13 | .321 |
| 300 | 1.3304 | 13 | .531 |
| 400 | 1.3304 | 11 | .443 |
| 500 | 1.3304 | 10.3 | .352 |
| 600 | 1.3304 | 10 | .663 |
| 700 | 1.3304 | 9.9 | .773 |
| 800 | 1.3304 | 9.5 | .883 |
| 950 | 1.3304 | 9.3 | .933 |
| 900 | 1.3370 | 9.3 | .793 |
| 960 | 1.3372 | | 1.060 |
| 1000 | 1.3370 | 7.9 | 1.105 |
| 1150 | 1.3302 | | 1.21 |
| 1400 | 1.3302 | | 1.345 |

Table 1
 (continued)

| Year | 1950-1959 | | 1960-1969 | |
|------|-----------------|------------------|-----------------|------------------|
| | Number of cases | Rate per 100,000 | Number of cases | Rate per 100,000 |
| 1950 | 11 | 0.1 | 10 | 0.1 |
| 1951 | 12 | 0.1 | 11 | 0.1 |
| 1952 | 13 | 0.1 | 12 | 0.1 |
| 1953 | 14 | 0.1 | 13 | 0.1 |
| 1954 | 15 | 0.1 | 14 | 0.1 |
| 1955 | 16 | 0.1 | 15 | 0.1 |
| 1956 | 17 | 0.1 | 16 | 0.1 |
| 1957 | 18 | 0.1 | 17 | 0.1 |
| 1958 | 19 | 0.1 | 18 | 0.1 |
| 1959 | 20 | 0.1 | 19 | 0.1 |
| 1960 | 21 | 0.1 | 20 | 0.1 |
| 1961 | 22 | 0.1 | 21 | 0.1 |
| 1962 | 23 | 0.1 | 22 | 0.1 |
| 1963 | 24 | 0.1 | 23 | 0.1 |
| 1964 | 25 | 0.1 | 24 | 0.1 |
| 1965 | 26 | 0.1 | 25 | 0.1 |
| 1966 | 27 | 0.1 | 26 | 0.1 |
| 1967 | 28 | 0.1 | 27 | 0.1 |
| 1968 | 29 | 0.1 | 28 | 0.1 |
| 1969 | 30 | 0.1 | 29 | 0.1 |

Source: [illegible]

[illegible]

TABLE XI
 RUN NUMBER 11

Temperature = 25° C

P = 220 cm. Hg.

Original Fluid (Sugar
 Solution)

Displacing Fluid (Distilled
 Water)

$n = 1.3335$

$n = 1.3334$

Viscosity = 1.0 cp

Viscosity = .6737 cp

S Sugar = 4.15

| Cap. nos. Specimen | $n =$ efflux | rate cc/min. | Pres. Pore Volume | Sugar in eff. | wt. of sugar in eff. | % orig. fluid in eff. |
|-----------------------|-----------------|-----------------|-------------------------|------------------|----------------------------|-----------------------------|
| 400 | 1.3335 | 10.5 | | | | |
| 700 | 1.3335 | | | | | |
| 800 | 1.3335 | 10.7 | .893 | 4.16 | 43 | 1.00 |
| 850 | 1.3335 | | .939 | 4.16 | 44 | 1.00 |
| 890 | 1.3335 | 10.7 | .972 | 2.00 | 22 | .67 |
| 900 | 1.3343 | | .995 | 1.50 | 15 | .31 |
| 925 | 1.3340 | | 1.02 | 1.00 | 11 | .26 |
| 975 | 1.3333 | | 1.075 | .71 | 7 | .17 |
| 1000 | 1.3335 | 10.7 | 1.105 | .35 | 3.6 | .090 |
| 1050 | 1.3336 | | 1.160 | | | |
| 1150 | 1.3334 | 10.7 | 1.210 | | | |

TABLE
 OF CONTENTS

| PART I - GENERAL INFORMATION | | PART II - STATISTICAL DATA | | PART III - ANALYSIS AND DISCUSSION | |
|------------------------------|------|-----------------------------|------|------------------------------------|------|
| Chapter | Page | Chapter | Page | Chapter | Page |
| 1. Introduction | 1 | 1. General Information | 1 | 1. General Information | 1 |
| 2. Objectives and Scope | 2 | 2. Statistical Data | 2 | 2. Statistical Data | 2 |
| 3. Methodology | 3 | 3. Analysis and Discussion | 3 | 3. Analysis and Discussion | 3 |
| 4. Data Collection | 4 | 4. General Information | 4 | 4. General Information | 4 |
| 5. Data Processing | 5 | 5. Statistical Data | 5 | 5. Statistical Data | 5 |
| 6. Data Analysis | 6 | 6. Analysis and Discussion | 6 | 6. Analysis and Discussion | 6 |
| 7. Results and Conclusions | 7 | 7. General Information | 7 | 7. General Information | 7 |
| 8. Recommendations | 8 | 8. Statistical Data | 8 | 8. Statistical Data | 8 |
| 9. Bibliography | 9 | 9. Analysis and Discussion | 9 | 9. Analysis and Discussion | 9 |
| 10. Appendix | 10 | 10. General Information | 10 | 10. General Information | 10 |
| 11. Index | 11 | 11. Statistical Data | 11 | 11. Statistical Data | 11 |
| 12. Glossary | 12 | 12. Analysis and Discussion | 12 | 12. Analysis and Discussion | 12 |
| 13. List of Figures | 13 | 13. General Information | 13 | 13. General Information | 13 |
| 14. List of Tables | 14 | 14. Statistical Data | 14 | 14. Statistical Data | 14 |
| 15. Summary | 15 | 15. Analysis and Discussion | 15 | 15. Analysis and Discussion | 15 |

TABLE III
COMPOSITE DATA

| Viscosity Ratio Displacing Fluid Original Fluid | Pore Volume Produced at Complete Recovery | Per cent of Orig. Fluid Recovered at one Pore Volume | Index of Refraction of Total Displaced Liquid |
|---|--|---|---|
| .110 | 4.1 | 72.7 | 1.3300 |
| .230 | 2.0 | 65.6 | 1.3326 |
| .435 | 1.37 | 63.7 | |
| .875 | 1.25 | 63.7 | 1.3361 |
| 4.35 | 1.3 | 63.0 | |

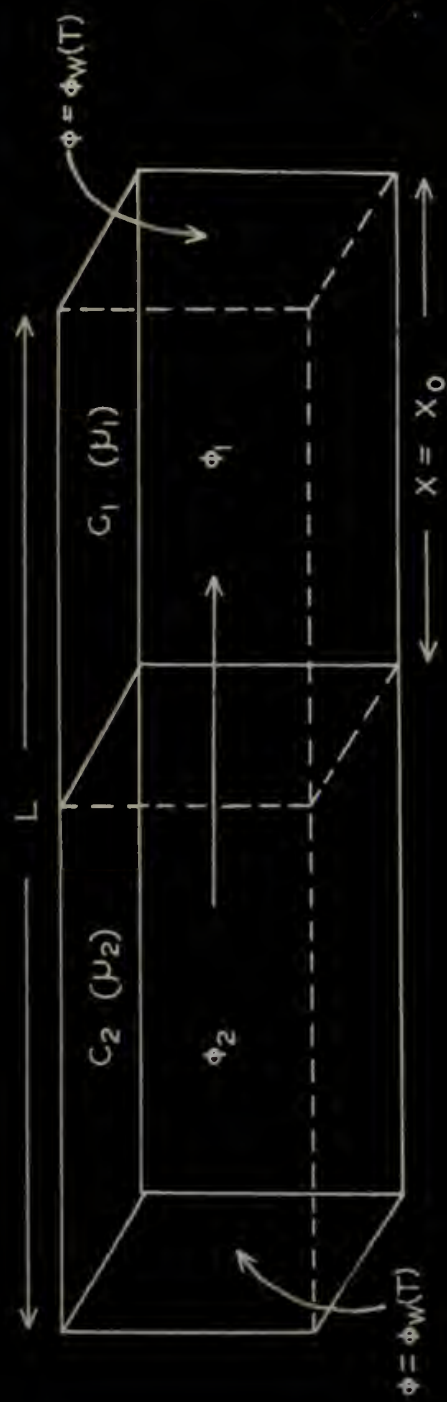
THE STATE

AND TERRITORIES

| To what territory does the land belong? | Area in square miles | Population in 1900 | Value of land in 1900 | Value of land in 1910 |
|--|----------------------------|-----------------------|-----------------------------|-----------------------------|
| Alaska | 588,000 | 0 | 0 | 0 |
| Arizona | 29,800 | 100,000 | 10,000,000 | 15,000,000 |
| California | 158,000 | 1,500,000 | 1,000,000,000 | 1,500,000,000 |
| Colorado | 104,000 | 500,000 | 500,000,000 | 700,000,000 |
| Idaho | 84,000 | 200,000 | 200,000,000 | 300,000,000 |
| Montana | 147,000 | 100,000 | 1,000,000,000 | 1,500,000,000 |
| New Mexico | 121,000 | 500,000 | 500,000,000 | 700,000,000 |
| North Dakota | 77,000 | 100,000 | 1,000,000,000 | 1,500,000,000 |
| South Dakota | 77,000 | 100,000 | 1,000,000,000 | 1,500,000,000 |
| Texas | 695,000 | 3,000,000 | 3,000,000,000 | 4,000,000,000 |
| Utah | 150,000 | 100,000 | 1,000,000,000 | 1,500,000,000 |
| Wyoming | 97,000 | 100,000 | 1,000,000,000 | 1,500,000,000 |

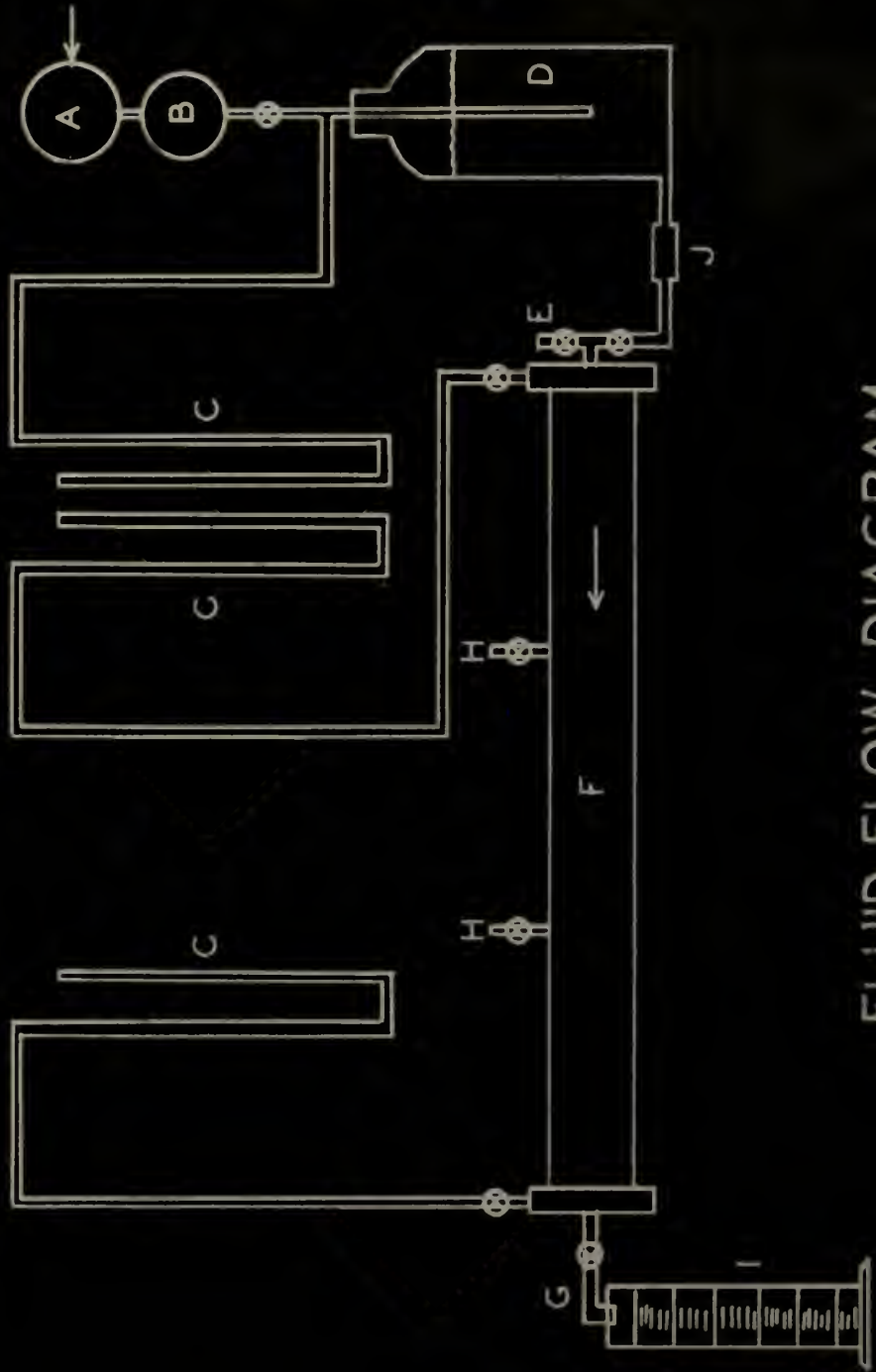
FIGURE

FIGURE I

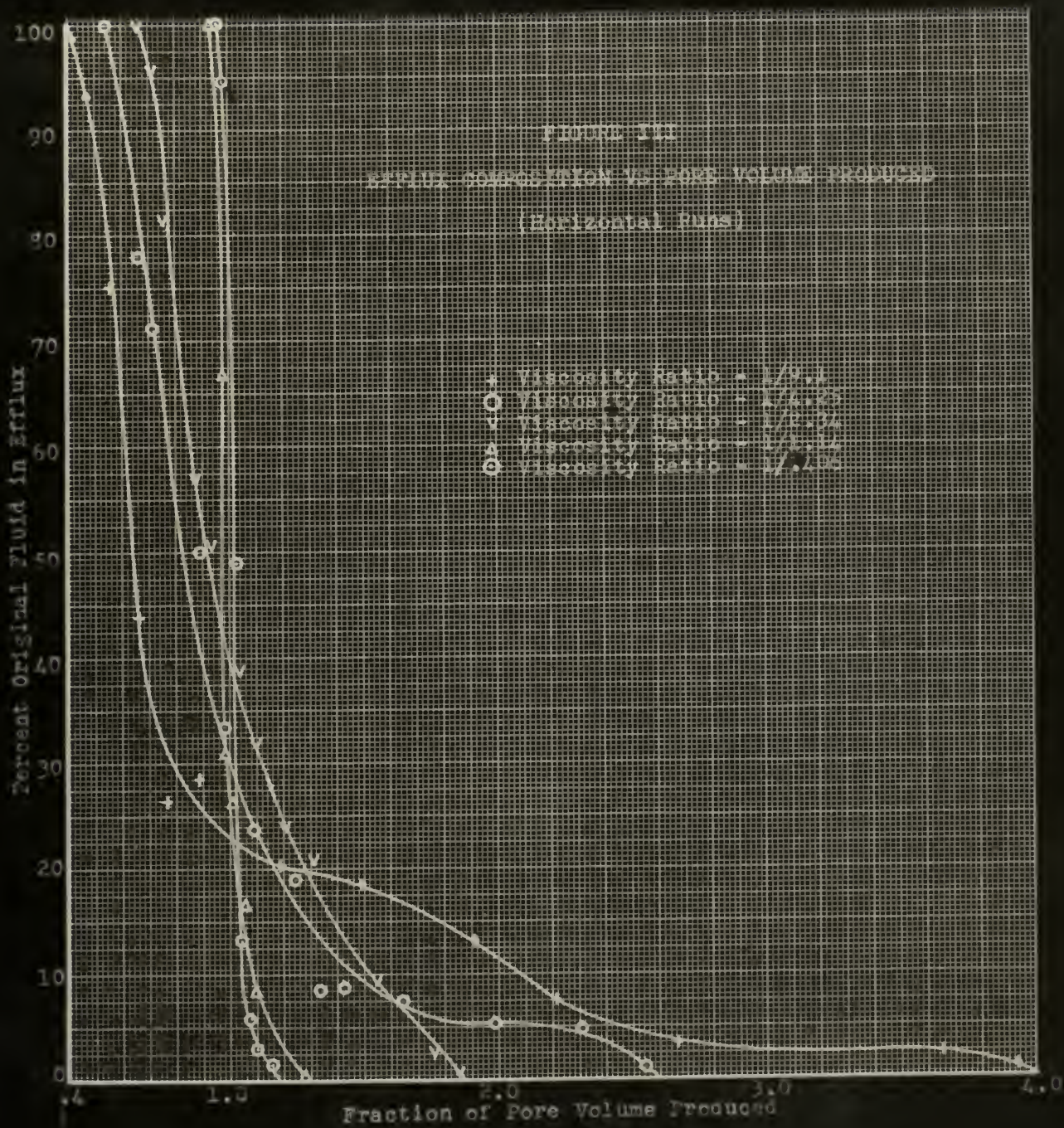


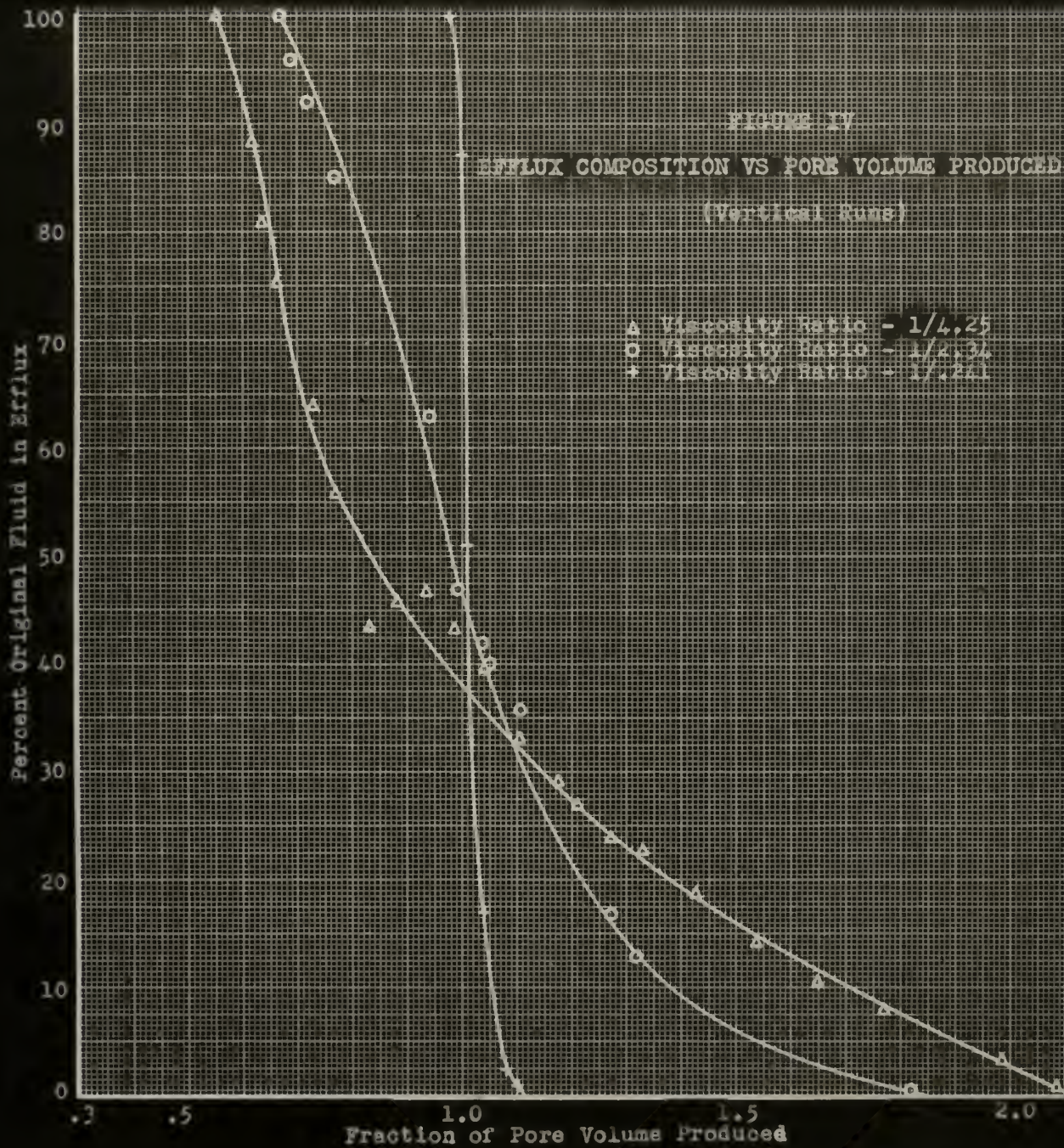
A LINEAR ENCROACHMENT SYSTEM
AFTER MUSKAT

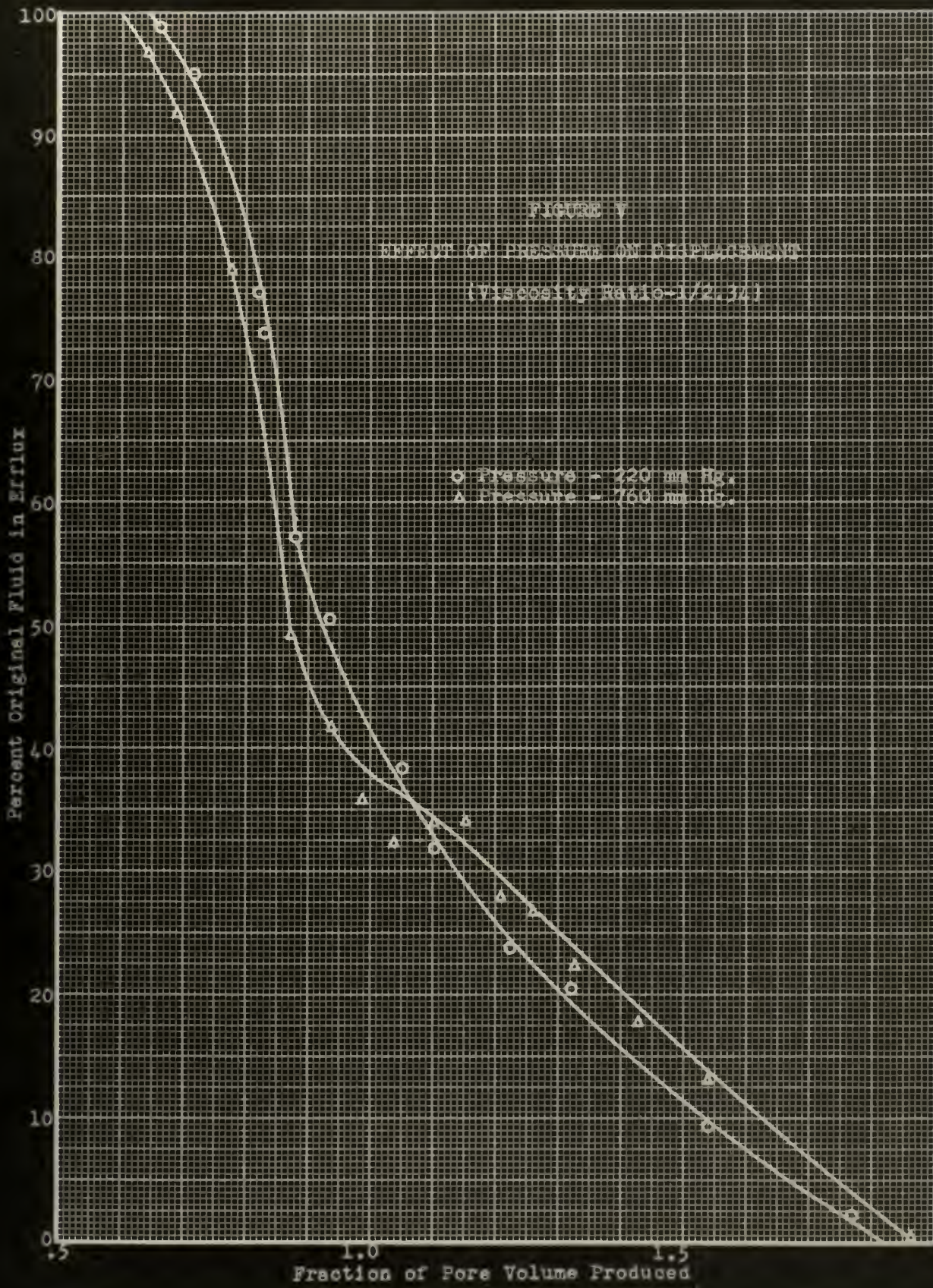
FIGURE II

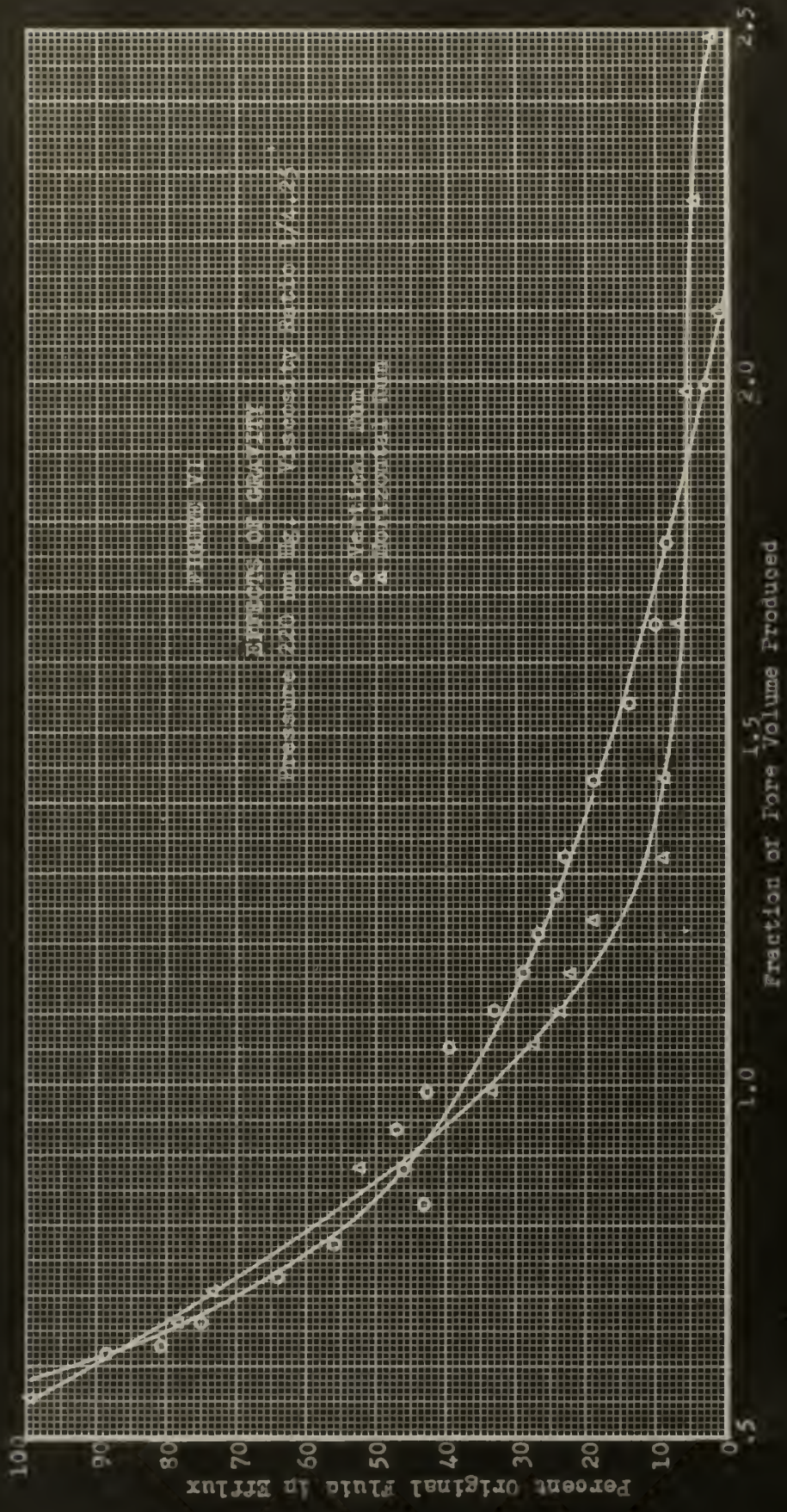


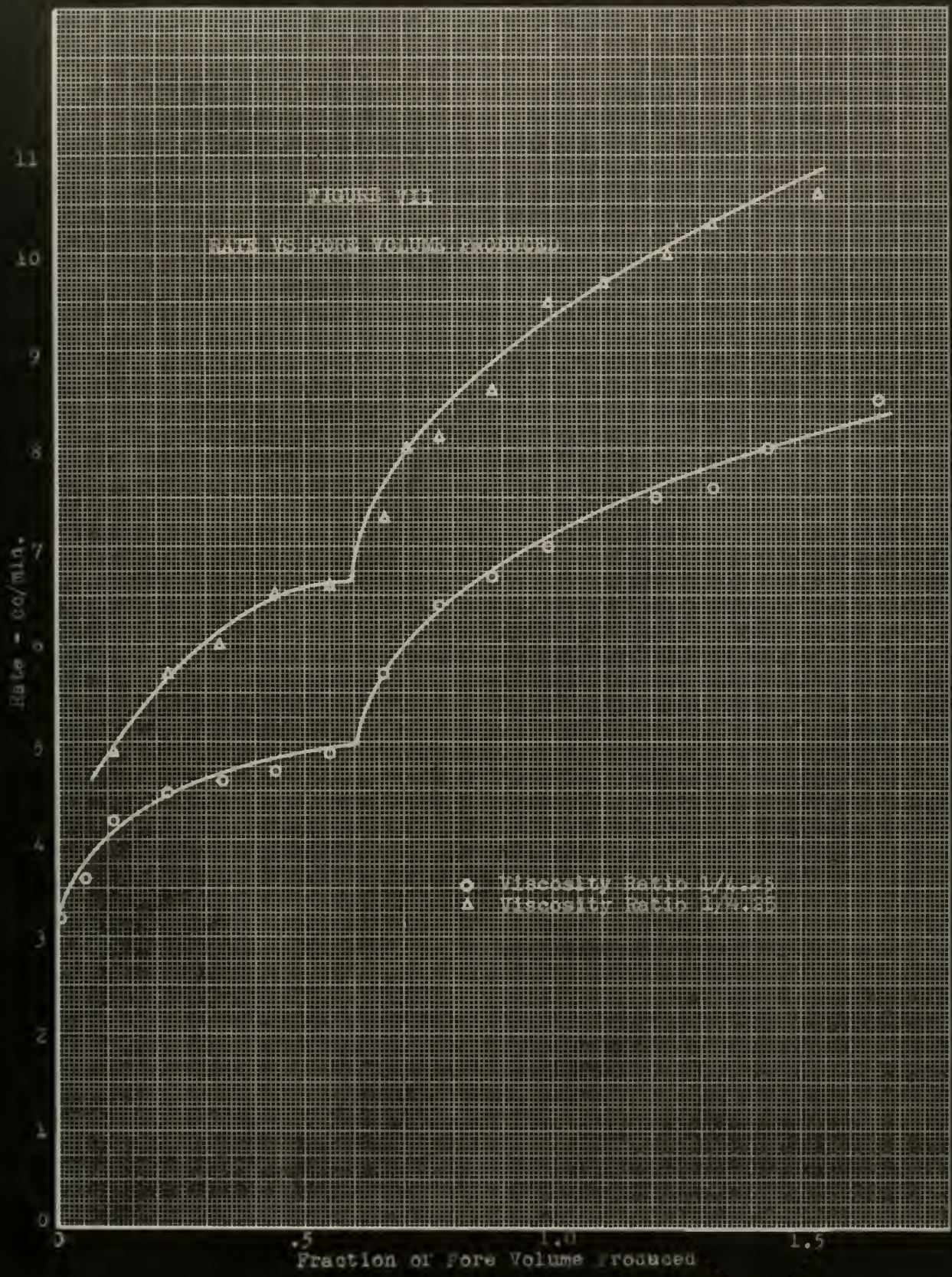
FLUID FLOW DIAGRAM

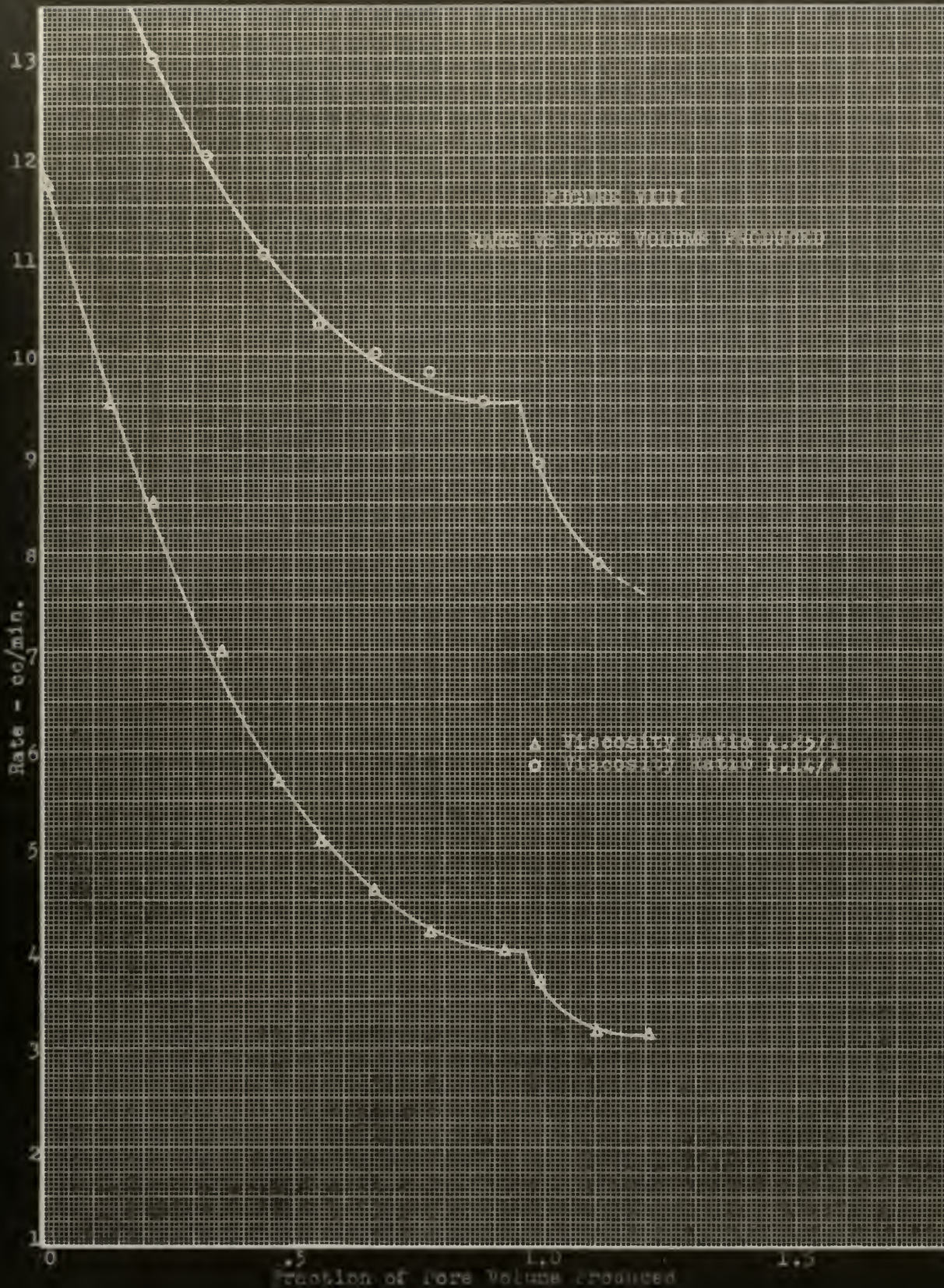


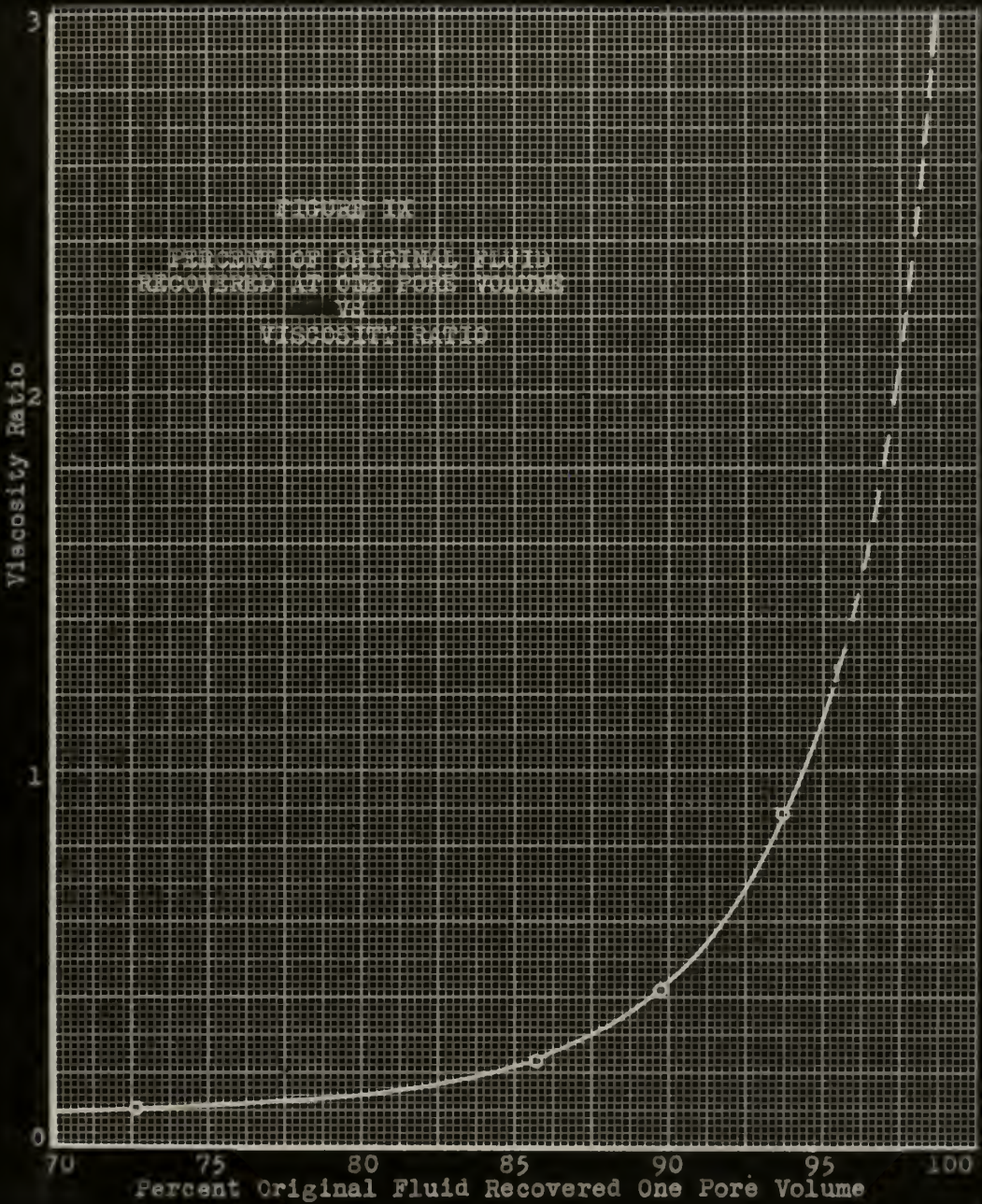












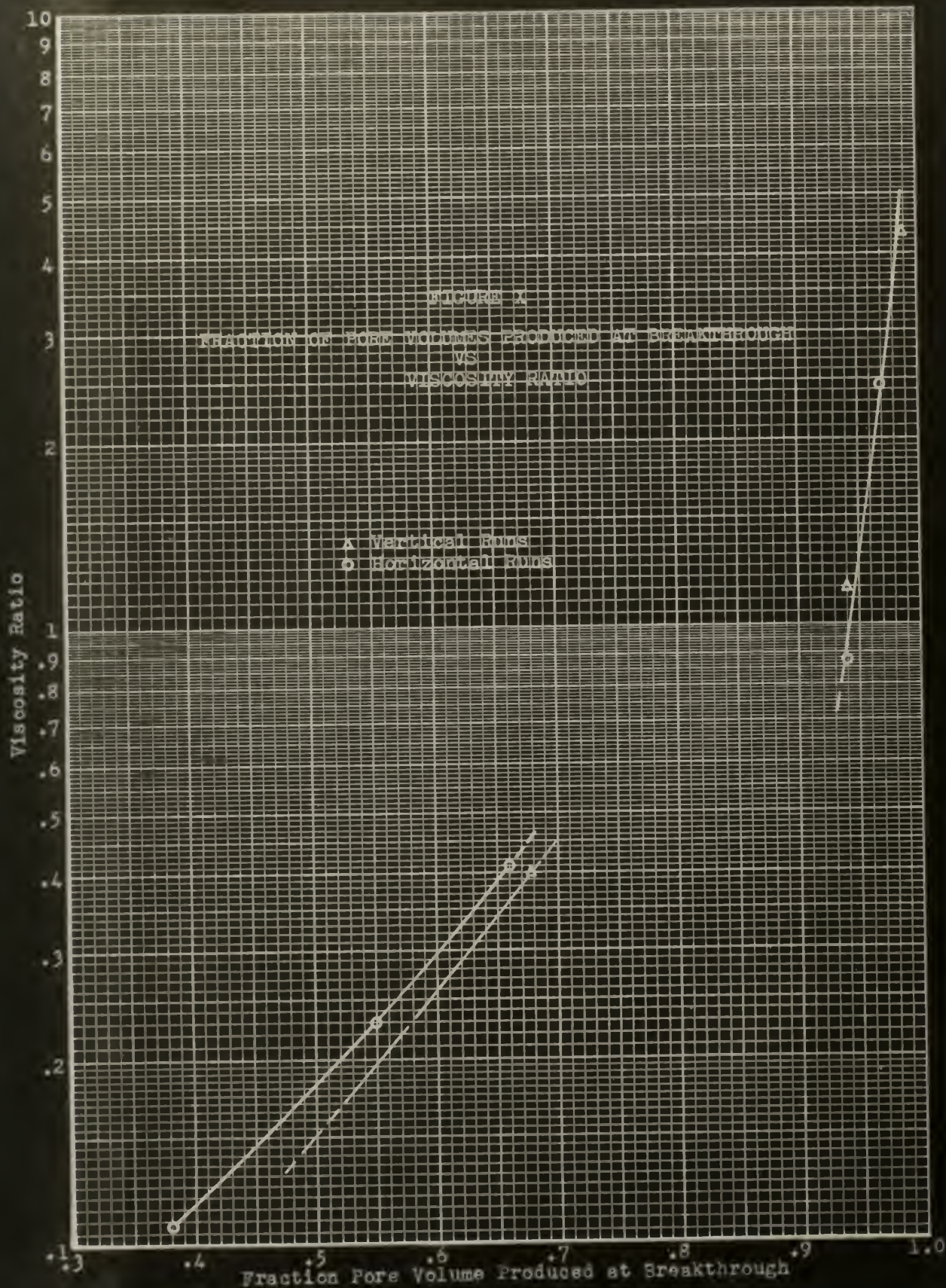
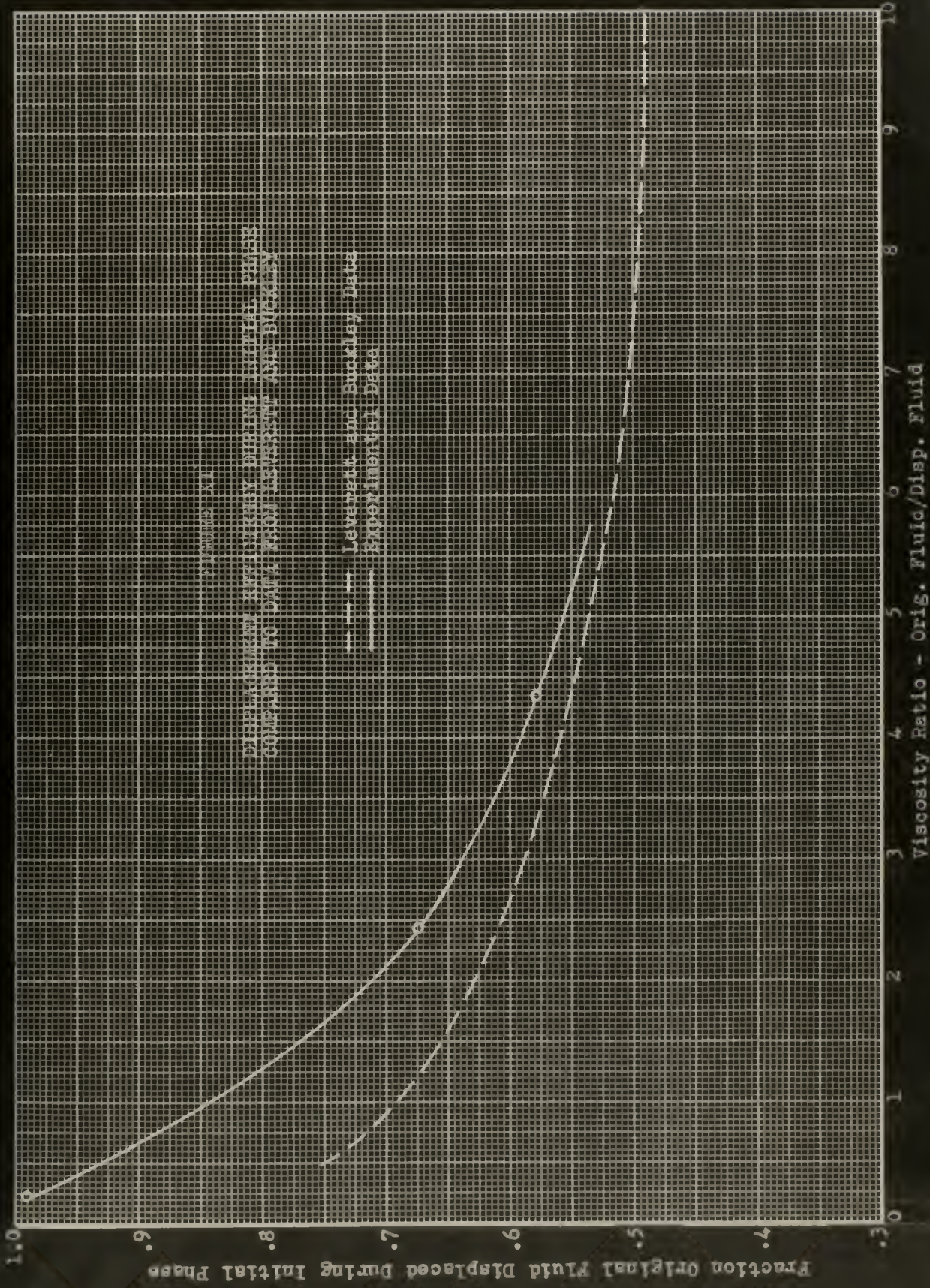


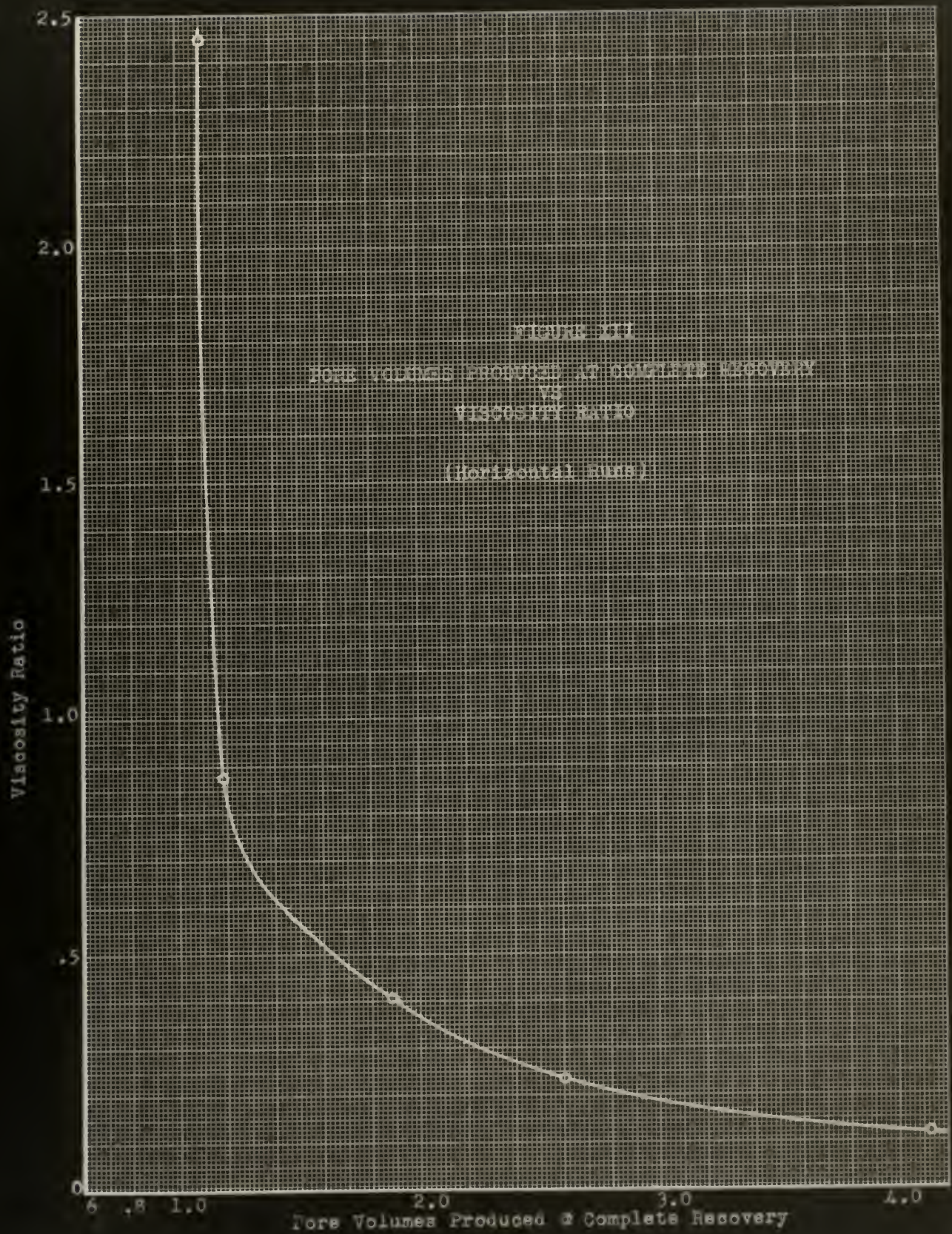
FIGURE X
 RELATIONSHIP OF PORE VOLUMES PRODUCED AT BREAKTHROUGH
 VS
 VISCOSITY RATIO

▲ Vertical Rods
 ● Horizontal Rods

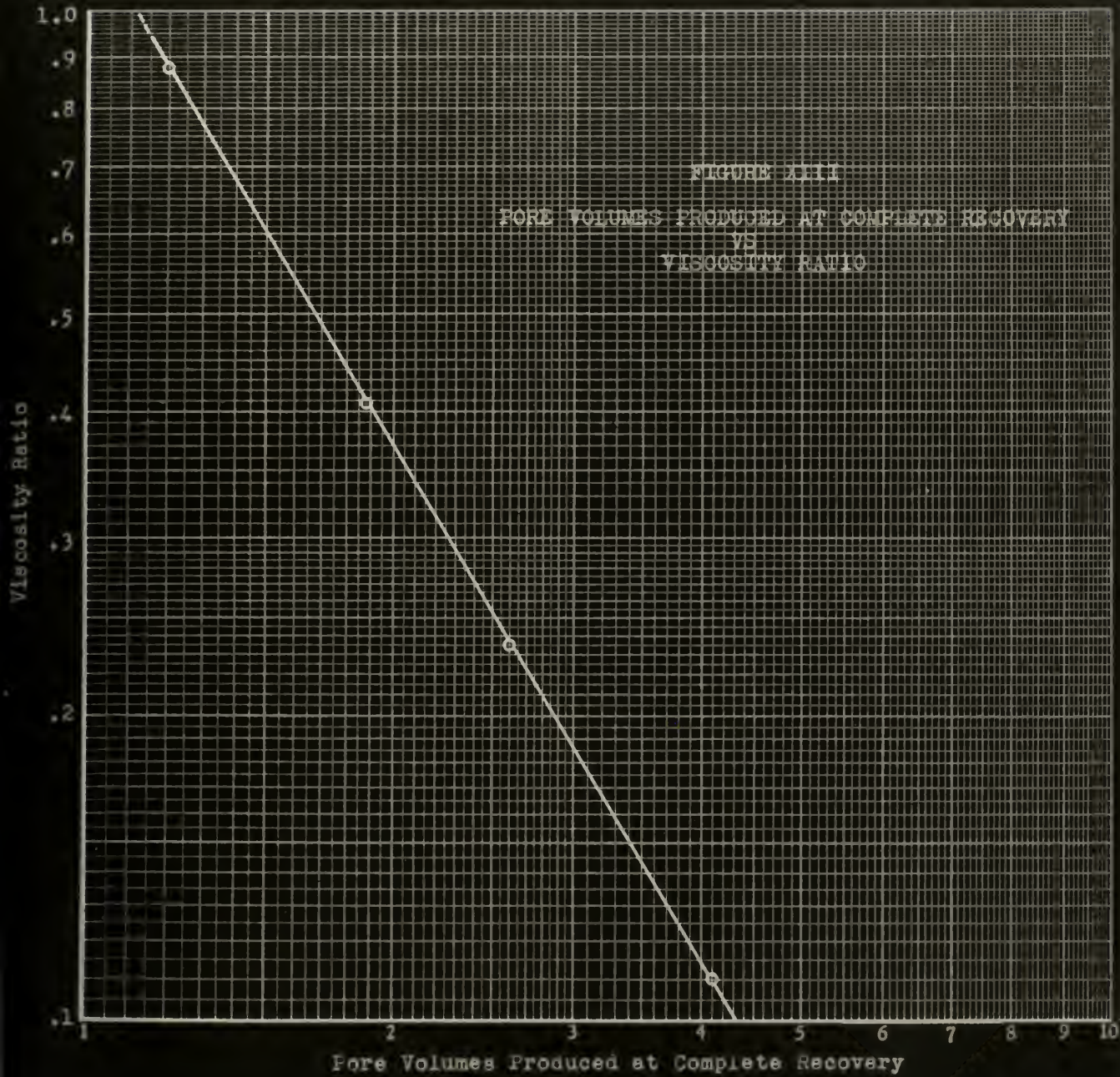
Viscosity Ratio

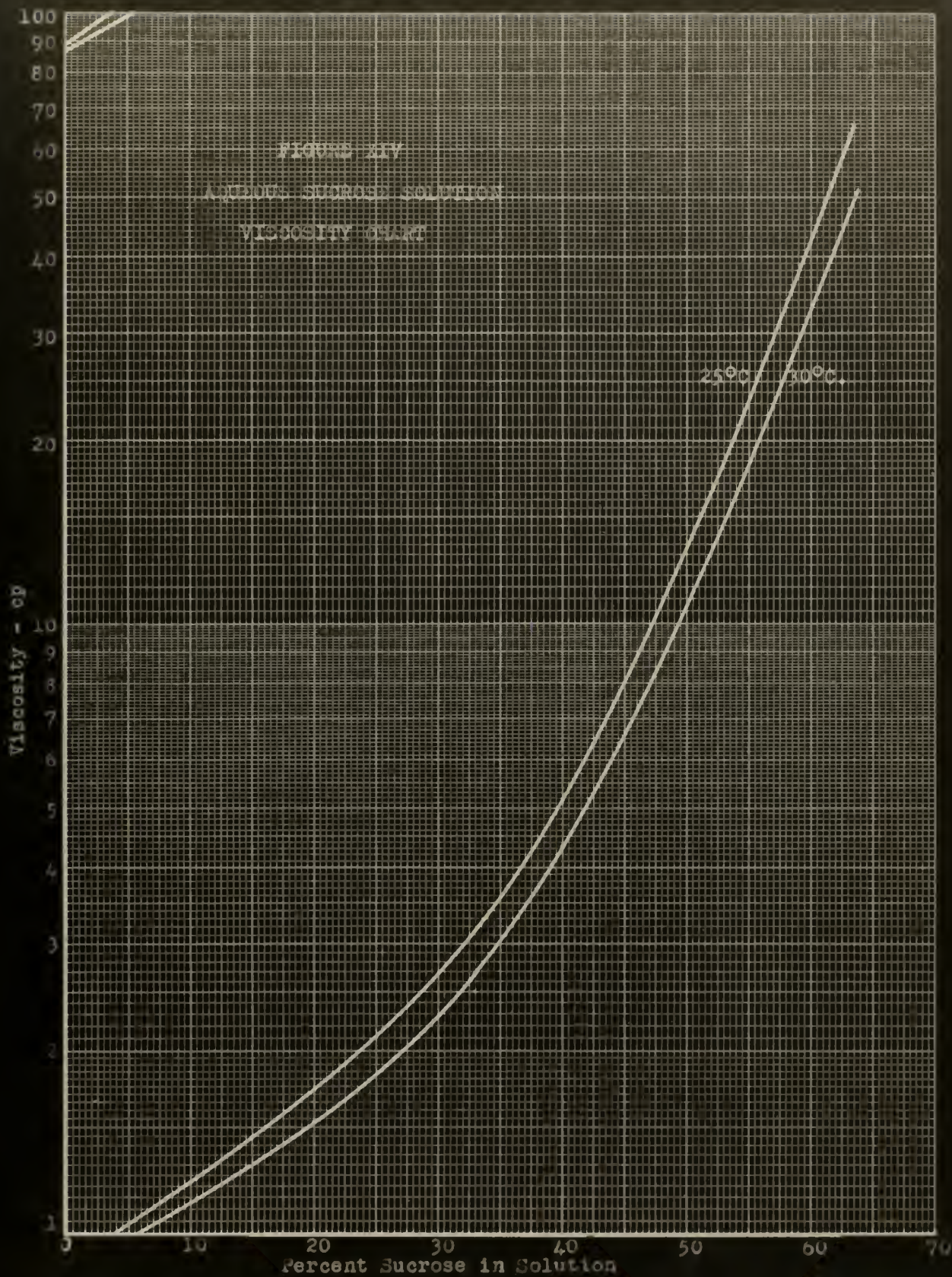
Fraction Pore Volume Produced at Breakthrough





REPORT NO. 481
 CORE VOLUMES PRODUCED AT COMPLETE RECOVERY
 AS A FUNCTION OF
 VISCOSITY RATIO
 (Flow Lines) (1958)





CHAPTER VII

ANALYSIS OF DATA

Theoretical Approach

An equation expressing the behavior of two miscible fluids of different viscosities, in the case of linear displacement, has been derived by Gassat (13). In developing this equation he simplified the system to one in which the two fluids are moving in a channel of great width but is small compared to its length. This could be approximated physically by a narrow channel of high permeability. Figure 1 illustrates such a linear system.

For a system as shown in Figure 1 Gassat arrives at the following equation:

$$\left(\frac{\rho_0}{\mu} - 1\right) \left[\frac{\rho_0}{\mu}(1 - \epsilon) + \epsilon + 1\right] \frac{2\Delta\phi C}{\mu^2} \epsilon = 0; \quad \text{Equation (1)}$$

where: k = permeability
 ρ = density
 ϕ = potential function = $h\phi$. If gravity is neglected
 μ = viscosity
 ϵ = fluidity = $1/\mu$
 Δ = length

The System

...

Thermodynamic Relations

...

$$p = \frac{1}{\beta} \left[\ln Z - \frac{1}{Z} \frac{\partial Z}{\partial V} \right]$$

...

...

...

...

...

...

$t = \text{time}$

$\Delta\phi =$ difference in potential function existing at the two boundaries.

$$\epsilon = \frac{c_1}{c_2} = \frac{\mu_2}{\mu_1}$$

$x = l$ minus distance fluid front has traveled.

Since t is included in the combined term $\frac{\partial \Delta\phi c_1 t}{L^2} = 0$, it shows that at any particular state of the displacement the time necessary to reach this state varies directly with the viscosity of the displaced fluid, directly as the total length of the system and inversely as the average potential gradient $\frac{\Delta\phi}{L}$. From this it is seen that as the interface advances its rate of advance is accelerated if the displacing fluid has the higher fluidity ($\epsilon < 1$) whereas it is retarded if the displacing fluid has the lower fluidity ($\epsilon > 1$).

The total time for the interface to travel the total length is given by setting x_0 equal to zero in equation one and solving for $t_{\max.}$

$$t_{\max.} = \mu_1 (1 + \mu_2/\mu_1) \frac{fL^2}{2\Delta\phi} \quad \text{Equation (2)}$$

where f is the porosity of the medium.

From this relation it is evident when $\mu_2 < \mu_1$ the displacement time is less than that for a single fluid.

$$t_{\max.}^0 = \frac{\mu_1 fL^2}{\Delta\phi} \quad \text{Equation (3)}$$

It may also be noted that when μ_2 is very much smaller than

$\Delta\phi = \text{difference in potential between points A and B}$

$$\frac{W}{q} = \frac{\Delta\phi}{1} = \Delta\phi$$

$$\Delta\phi = \int_a^b \vec{E} \cdot d\vec{s}$$

If there is an electric field \vec{E} in the region between points A and B, then the work done in moving a charge q from A to B is $W = q\Delta\phi$. The potential difference $\Delta\phi$ is defined as the work done per unit charge in moving a charge from A to B.

$$\frac{1}{\epsilon_0} \int_V \rho \, dV = \oint_S \vec{E} \cdot d\vec{S}$$

$$\mu > \mu_0$$

$$\frac{1}{\epsilon_0} \mu = \mu_0$$

$$\mu_0$$

μ_1 , a maximum decrease in t_{max} . is attained, then in this limiting case the drive by a displacing fluid of very low viscosity would cut by half the time required for the column of original fluid to pass through the system. When $\mu_2 > \mu_1$, it can be seen that t_{max} will always exceed t_{max}^0 , and will ultimately become infinite as μ_2 becomes infinitely large.

Sample Calculations

In all of the experiments the only physical properties of the solutions considered were temperature and index of refraction. From these two measurements could be calculated the amount of sucrose in the solution and thus the fraction of the original fluid in the effluent stream.

As an example one calculation is shown for converting the index of refraction to fraction of original fluid in the effluent. Data is taken from Run No. 5, Table III, when 900 cc of fluid had been displaced.

Taking the index of refraction 1.4003 at 20° C, for the original fluid in the case, and referring to the table, "Index of refraction of aqueous solutions of sucrose," in the Handbook of Chemistry and Physics, the per cent of sucrose was determined for a temperature of 20° C. to be 44.6. A temperature correction of + .43 was applied giving a per cent by weight of 45.03. From the table, "Specific Gravity of Aqueous Sucrose Solutions," in the same reference it was determined that this per cent of sucrose equals 541.3 grams per liter.

The first part of the report is devoted to a general survey of the situation in the country. It is followed by a detailed account of the work done during the year. The report concludes with a summary of the results and a list of the names of the members of the committee.

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The second part of the report is devoted to a detailed account of the work done during the year. It is followed by a summary of the results and a list of the names of the members of the committee.

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When 500 cc of fluid had been displaced from the core the index of refraction of the efflux was measured and found to be 1.3620 at a temperature of 25° C. From the Handbook of Chemistry and Physics the corrected per cent of sucrose was determined to be 14.35 and the weight of sucrose in grams per liter 130. To get the fraction of the original fluid present in the effluent stream the following relation is used:

$$\text{Fract. of Orig. Fluid in Eff.} = \frac{\text{g./litr. sucrose in efflux}}{\text{g./litr. sucrose in orig. fluid}}$$

Substituting the above values gives:

$$\text{Fract. of Orig. Fluid in Eff.} = \frac{130.0}{341.5} = .380$$

Discussion of Experimental Results

The results obtained in this series of experiments are tabulated in Tables I through XII. These tables have been simplified by including only the pertinent data. In addition the original data contained index of refraction of the total solution displaced and total elapsed time, which were not used in this work. In Runs 1 through 3 the rate of flow was not recorded and in Run 4 the screen at the inlet end of the core became plugged and thus the rates recorded during this run were of no benefit.

All runs were made with the core in a horizontal position except runs number 6, 7, 8, 9. The core was placed in a vertical position for these runs. When a heavy fluid was displaced by a lighter fluid, the lighter fluid was introduced at the upper end of the core; if a light fluid was being displaced

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by a heavier fluid it was introduced at the lower end of the core. Thus it was felt that the results of these drives were free from all effects of gravity.

Figures III and IV illustrate graphically the results of eight runs carried out at various viscosity ratios. Viscosity ratio as used in this paper will be the viscosity of the displacing fluid divided by the viscosity of the original fluid unless otherwise noted.

Figure III presents the results of the horizontal runs for various viscosity ratios. When the viscosity ratio is small as shown by the plot for a viscosity ratio of 1/3.2 the displacing fluid breaks through before half a pore volume has been produced. Following this break through there is a fairly constant decrease in the amount of original fluid in the effluent until approximately .8 of a pore volume is produced. From this point to a production of 1.6 pore volumes there appears to be unstable producing conditions as evidenced by the scattered points on the plot. The curve then tends to level off with very slight decrease in the amount of original fluid in the effluent. This appears to form a plateau on the plot. It is possible that this could be caused by gravity segregation since there was definite evidence of this when the progress of the flood front was followed visually as it moved along the core. The heavier fluid appeared to channel along the bottom of the core. When the core was rotated to check the possibility that the permeability was greater along

The first part of the report is devoted to a general
 description of the country and its resources. It
 is followed by a detailed account of the
 various industries and occupations of the
 people. The third part of the report
 contains a list of the principal towns and
 villages, with a description of each. The
 fourth part of the report is devoted to a
 description of the climate and the seasons.
 The fifth part of the report contains a
 list of the principal rivers and streams,
 with a description of each. The sixth
 part of the report is devoted to a
 description of the minerals and metals
 found in the country. The seventh part
 of the report contains a list of the
 principal plants and animals. The eighth
 part of the report is devoted to a
 description of the population and the
 government of the country. The ninth
 part of the report contains a list of the
 principal books and papers. The tenth
 part of the report is devoted to a
 description of the history of the country.
 The eleventh part of the report contains
 a list of the principal events of the
 country. The twelfth part of the report
 is devoted to a description of the
 present state of the country. The
 thirteenth part of the report contains
 a list of the principal persons of the
 country. The fourteenth part of the
 report is devoted to a description of the
 future prospects of the country. The
 fifteenth part of the report contains
 a list of the principal questions
 relating to the country. The sixteenth
 part of the report is devoted to a
 description of the country. The
 seventeenth part of the report contains
 a list of the principal questions
 relating to the country. The eighteenth
 part of the report is devoted to a
 description of the country. The
 nineteenth part of the report contains
 a list of the principal questions
 relating to the country. The twentieth
 part of the report is devoted to a
 description of the country.

one side of the tube, the channeling effect was still along the bottom indicating that it could be caused by gravity.

Referring again to Figure III when the viscosity ratio approached unity or larger, as illustrated by the plot for a ratio of 1/1.14, the displacing fluid does not break through until over .9 of a pore volume is produced. The amount of original fluid in the effluent drops off rapidly with no apparent plateau in the curve. This should follow if the plateau is due to gravity segregation.

Similar runs were made with the pore in a vertical position and the results plotted in Figure IV. From this it can be seen that the fraction of original fluid produced at break through is essentially the same as in the horizontal runs and this is not appreciably affected by gravity. There was no indication of a plateau with a viscosity ratio as low as 1/4.22 which bears out the supposition that this leveling off, in the cases illustrated in Figure III, was caused by gravity segregation.

From Figures III and IV it would appear that the mechanics of displacement involving two miscible fluids is similar to that of two immiscible liquids as described by Buckley and Leverett (10). The displacement can be divided into two phases. The initial phase occurs before the break through of the displacing fluid and is a piston like displacement. In the subordinate phase, which follows the break through, the original fluid is produced by a creeping action.

The first part of the report deals with the general situation of the country and the progress of the work done during the year.

The second part of the report deals with the details of the work done in each of the various departments.

The third part of the report deals with the financial statement and the balance sheet.

The fourth part of the report deals with the general remarks and conclusions.

The fifth part of the report deals with the appendixes.

The sixth part of the report deals with the index.

The seventh part of the report deals with the list of names.

The eighth part of the report deals with the list of subjects.

The ninth part of the report deals with the list of references.

The tenth part of the report deals with the list of illustrations.

The eleventh part of the report deals with the list of tables.

The twelfth part of the report deals with the list of figures.

The thirteenth part of the report deals with the list of maps.

The fourteenth part of the report deals with the list of plates.

This phase differs in the case of miscible fluids only in that 100 per cent of the original fluid can be produced which is not possible with immiscible fluids.

As a check on the accuracy of the plots and on the completeness of recovery of the original fluid from the core the area under each curve was measured. With 100 per cent recovery of the original fluid the area under each curve should be 100 units. In all cases the error was never more than 2 per cent.

The cause of the period of unstable production is not known, though it would seem possible that it could be due to streaks of variable permeability which would allow bypassing of small areas. At a later time the original fluid from these areas would reach the outlet end of the core and temporarily increase the amount of original fluid in the effluent.

To see what effect pressure would have on the displacement picture two runs were made using a viscosity ratio of 1/0.44. The pressure differential for one run was 320 mm. mercury and for the other run was 700 mm. mercury. The results plotted in Figure 7 show that an increase in pressure tends to cause a breakthrough to occur earlier and to require more pore volumes before complete displacement of the original fluid takes place.

To study the possible effects of gravity segregation, runs were made with the core both in the horizontal and

vertical position. Two runs with a viscosity ratio of 1/4.25 were plotted in Figure VI. From this plot it can be seen that in the horizontal run where it is possible for gravity aggregation to take place the curve is not as simple or smooth as the curve for the vertical run. However, the vertical run does break through earlier than the horizontal run, but the piston shows up in the horizontal run thus requiring more pore volumes through-put before complete displacement takes place.

Though it is not included herein, a similar plot for a viscosity ratio of 1/2.24 shows similar deviations between the two curves.

According to Sabet (15) the effect of viscosity ratio on the rate of flow of the efflux can be calculated by Equation (1). If the original fluid is being displaced by one of lower viscosity the overall resistance of the system will be lowered and the rate of efflux increased. If the original fluid is displaced by one of higher viscosity the overall resistance is increased and the rate of efflux decreased.

From Figure VII it is noted that there is an appreciable increase in efflux rate as soon as injection of the lower viscosity fluid commences. This increase in efflux rate tends to gradually drop off until the point is reached where the displacing fluid breaks through. Then there is a sharp increase in efflux rate with an immediate tapering off

The first part of the paper is devoted to a general discussion of the
 various methods which have been proposed for the determination of the
 constants of the system. It is shown that the method of least squares
 is the most reliable, and that the method of moments is only applicable
 in special cases. The method of moments is only applicable in special
 cases, and the method of least squares is the most reliable. The method
 of moments is only applicable in special cases, and the method of least
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 in special cases, and the method of least squares is the most reliable.

The second part of the paper is devoted to a detailed discussion of the
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of the rate until the point is reached where the original fluid is completely displaced and the efflux rate is constant.

This behavior is similar to the qualitative description given concerning the nature of the effects of the viscosity difference between encroaching and displaced liquids in the case of direct drive by Muskat (15). This should follow since the injection of the displacing fluid into a small opening in one end of a long cylindrical core and producing from a small opening in the other end would in many ways approximate the physical conditions of a direct drive between two wells.

The same pattern is shown by Figure VIII except in this case the original fluid is being displaced by one of higher viscosity, thus there is a decrease in efflux rates in place of an increase. The curve for a viscosity ratio of 1.34/1 was affected by a plugging of the screen at the inlet end of the core during the run. However, it was included since it illustrates the qualitative description given by Muskat.

To indicate a measure of the efficiency of the various drives as a function of the viscosity ratio, Figures IX, X, and XI were constructed. Figure IX illustrates the efficiency of recovery when one pore volume of fluid has been displaced from the core. From this it can be seen that as the viscosity ratio became smaller than .9 the per cent of original fluids displaced, when one pore volume has been produced, falls off

The first part of the report is devoted to a general
 description of the project and its objectives. It
 is followed by a detailed account of the work
 done during the period covered by the report.
 The results of the work are then presented and
 discussed. Finally, a conclusion is drawn from
 the work done and suggestions are made for
 further work.

rapidly. With the viscosity ratio unity or larger there is very little increase in the per cent of original fluid displaced. Thus it can be seen that as long as the viscosity ratio is .5 or greater 50 per cent or more of the original fluid will be displaced when one pore volume has been produced.

As another measure of the efficiency of displacement, the pore volume produced when the displacing fluid breaks through was plotted against the logarithm of the viscosity ratio in Figure 2. This plot appears to give a straight line up to a viscosity ratio of .4 with a break from this point to a viscosity ratio of approximately .6. At this point there was a return to linearity but at a new slope. Unfortunately runs were not made with viscosity ratios in the region of departure from linearity so that information on this region is missing. It would seem, as indicated by Figure 13, when the viscosity ratio is .5 or greater that the recovery efficiency would be very high.

Figure 21 shows a plot of pore volumes of original fluid produced during the initial phase versus viscosity ratio, where the viscosity ratio is equal to the viscosity of the original fluid divided by the viscosity of the displacing fluid. For comparison data given by Buckley and Leverett (10), concerning the effect of oil viscosity on the efficiency of the initial phase of a water flood in a typical sand, is also plotted in the same figure.

The shape of the two curves in the above plot is

similar; however, the effect of viscosity ratio is greater in the case of miscible fluids. This might be explained by the fact that in the case of immiscible fluids all of the original fluid is not active and is not moved at any time during the displacement; thus limiting the range of the fraction of original fluid that could be displaced during the initial phase.

Figures III and IIII give the number of pore volumes required before complete recovery of the original fluid is obtained. Figure III indicates that the number of pore volumes required for complete recovery, for a viscosity ratio of .2 or greater, would be slightly larger than one. The number of pore volumes required as the viscosity ratio gets smaller does not decrease rapidly until a viscosity ratio of .4 is reached. From here the increase is very great even with only slight reductions in viscosity ratio.

The same data plotted on log paper gives a straight line with viscosity ratios of .3 or lower.

Referring to the article, "Some Experiments on the Mobility of Interstitial Waters" (13), where data is contained on the displacement from a sandstone core of radio active water by non active water the following conclusions are given: the displacing fluid breaks through when between .6 and .9 of a pore volume has been produced, 50 to 60 per cent of the original fluid was recovered when one pore volume had been produced, and over 1.5 pore volumes were produced before complete recovery of the original fluid occurs.

The data obtained during the present series of experiments, for a viscosity ratio comparable to that used in arriving at the results described above, does not check the above conclusions. This data indicates that over 90 per cent of the original fluid is produced before the displacing fluid breaks through, approximately 95 per cent of the original fluid is displaced when one pore volume has been produced, and less than 1.5 pore volumes are required for complete recovery of the original fluid.

Thus even greater mobility of the interstitial water is indicated than was shown in the previous experiment. This could be due to the higher permeability that undoubtedly existed in this experiment but it would not seem that this alone would account for this difference.

It would appear that the shape of the displacement curves, Figures III and IV could be useful in studying the mechanism of displacement. Equation 2 indicates that the shape of the displacement curves might be an indication of the degree of permeability variation present in the porous media. However, work done by Fowler and Green (16) displacing one fluid by another in a pipe line indicates that the shape of the displacement curves is a result of the parabolic interface formed in each of the capillary openings.

It would seem possible that the shape of the displacement curves could be affected by both of the above factors.

Errors Involved

The use of a refractometer to measure index of

The first part of the report deals with the general situation in the country, and the second part with the results of the survey. The survey was conducted in the form of a questionnaire, and the results are given in the following tables.

The first table shows the results of the survey in the different districts. The second table shows the results of the survey in the different provinces. The third table shows the results of the survey in the different regions.

The fourth table shows the results of the survey in the different countries. The fifth table shows the results of the survey in the different continents. The sixth table shows the results of the survey in the different parts of the world.

The seventh table shows the results of the survey in the different parts of the world. The eighth table shows the results of the survey in the different parts of the world. The ninth table shows the results of the survey in the different parts of the world.

TABLE I

The results of the survey in the different parts of the world.

refraction which in turn is converted to per cent of sucrose in an aqueous solution limits the accuracy of the results to the accuracy of the instrument used. In this work a Spencer Abbe-type refractometer was used. The scale as it could be read directly to the wire Goniast glass and the fourth estimated with an accuracy of 0.0002. This gave an accuracy of 0.2 per cent in measuring the per cent of sucrose in solution.

The accuracy of the refractometer was checked before any runs were made by use of the glass test slab included with the instrument for which the index of refraction was known.

Index of refraction and viscosity of the solutions are both affected by changes in temperature. Since the temperature seldom changed more than a degree during a series of measurements it was felt that any temperature effects were within the experimental error. No appreciable effects on the data were observed that could be attributed to changes in temperature.

A small error was certainly introduced in the measurement of pressure differentials with a liquid manometer and volumes displaced with a graduated cylinder since there is some human error in reading fluid levels. These readings are considered to be well within the range of experimental error and sufficiently accurate for the computations necessary in this work. The degree of accuracy of these readings is indicated by graphical integration of the areas under the curves drawn in Figures III and IV. The majority of these areas were in error by less than one per cent and all were less than two per cent.

CHAPTER VIII

SUMMARY

A study was made of the displacement of one miscible fluid by another from a partially consolidated synthetic sandstone core. This core was composed of 80 to 140 mesh Mill Creek silica sand and colloidal silica. The porosity of the core was 30.7 per cent and the air permeability was 3.02 darcies. This core 0.55 centimeters in diameter and 13.7 centimeters in length was assembled with pressure taps in each end plate to permit determination of pressure drop across the core. The core was saturated with a fluid of known viscosity, then this fluid was displaced by another miscible fluid of different viscosity. The rate of efflux, total amount of fluid produced, and data to calculate the per cent of original fluid in the efflux was measured and recorded at regular intervals.

The solutions used in these experiments were made by dissolving various amounts of cane sugar (sucrose) in distilled water. The amount of sucrose in solution determined the viscosity of the fluid. Four solutions were used plus distilled water to get a range of viscosity ratios. The four

CHAPTER VIII

Summary

A study was made of the relationship between the

amount of rainfall and the amount of water

runoff from a catchment area. This was done by

measuring the rainfall and the runoff over a

period of ten years. The results showed that

the runoff was directly proportional to the

rainfall. This was true for all years except

one, when the runoff was less than expected.

This was due to a drought in the catchment

area. The results of this study are given

in the following table. The total rainfall

was 100 inches. The total runoff was 60

inches. The ratio of runoff to rainfall

was 0.6.

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the following table. The total rainfall

was 100 inches. The total runoff was 60

inches. The ratio of runoff to rainfall

was 0.6. This was due to a drought in the

solutions contained 4.1, 14.6, 35.1, and 45.05 per cent of sucrose by weight.

Since information of a fundamental nature was sought it was decided to vary only the viscosity ratio of the displacing fluid to the original fluid and to maintain all other factors as nearly constant as possible. The range of viscosity ratios examined in these experiments ran from .11 to 9.1.

The data gathered in this work was used to arrive at several conclusions regarding the effect of viscosity ratio on the mechanics and the efficiency of displacement of one miscible fluid by another.

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CHAPTER II

CONCLUSIONS

1. The mechanics of the displacement of one miscible fluid by another is similar to the mechanics of displacement where the two fluids are immiscible. The displacement can be divided into two phases, the initial phase where there is a piston like displacement and the subordinate phase where the fluid is displaced by a dragging action.

2. When the viscosity ratio is smaller than unity the rate will increase, if the viscosity ratio is larger than unity the rate will decrease.

3. Increasing pressure differential and maintaining the same viscosity ratio causes the break through of the displacing fluid to occur earlier and requires more pore volumes to obtain complete displacement of the original fluid.

4. If gravity segregation is present more pore volumes will be required to obtain complete recovery.

5. Efficient displacement in the initial phase is obtained with viscosity ratios of .8 or greater. More than 90 per cent of the original fluid is recovered when one pore volume has been produced.

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ARTICLE 1

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6. For the most efficient complete recovery of original fluid the viscosity ratio should be .3 or greater.

7. Viscosity ratios of .3 and lower do not produce efficiently in the initial phase and require 3 or more pore volumes for complete recovery.

8. There is very little increase in the efficiency of displacement when the viscosity ratio is increased beyond unity.

9. Further study to determine if a relation exists between the shape of the displacement curves and permeability variation is indicated in view of the importance of this factor in the production of petroleum.

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 various methods of determining the relative
 positions of the different parts of the
 system. It is shown that the relative
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 method of least squares.

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CONTENTS

1. Introduction
2. Chapter I
3. Chapter II
4. Chapter III
5. Chapter IV
6. Chapter V
7. Chapter VI
8. Chapter VII
9. Chapter VIII
10. Chapter IX
11. Chapter X

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101. The first part of the paper is devoted to a study of the
 properties of the function $f(x)$ defined by the equation

$$f(x) = \int_0^x f(t) dt + \int_0^x f(t) dt + \dots + \int_0^x f(t) dt + \dots$$

102. In the second part of the paper we shall study the
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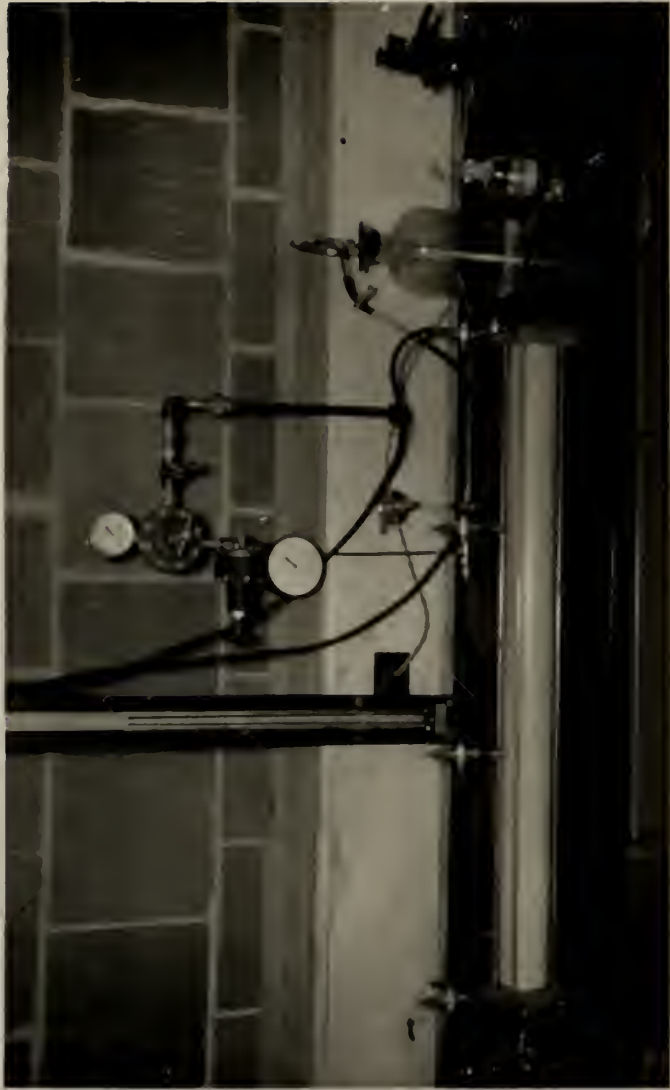
108. In the eighth part of the paper we shall study the
 properties of the function $f(x)$ defined by the equation

$$f(x) = \int_0^x f(t) dt + \int_0^x f(t) dt + \dots + \int_0^x f(t) dt + \dots$$

109. In the ninth part of the paper we shall study the
 properties of the function $f(x)$ defined by the equation

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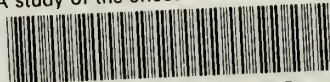
APPENDIX





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A study of the effect of viscosity ratio



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