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John Curtin Schratwieser

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INCREASED STRIPPER WELL RECOVERY
BY MEANS OF HIGH VOLTAGE ELECTRICAL HEATING

BY

JOHN CURTIN SCHRATWIESER

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

MASTER OF SCIENCE IN MINING ENGINEERING

PETROLEUM ENGINEERING OPTION

Rolla, Missouri

1951

Approved By - J. D. Forrester
Professor of Mining Engineering

ACKNOWLEDGEMENT

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The writer, also is indebted to Assistant Professors Rex I. Martin and Woodrow J. Latvala for their criticism of the manuscript.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure Page

LIST OF TABLES

INTRODUCTION

The purpose of this work is to investigate the possibility of using high voltage electrical heating to obtain increased stripper well production.

A substantial portion of the oil produced in the United States is obtained from stripper wells. These wells reach their economic limit when they can no longer produce sufficient oil to justify the cost of operation. In the majority of cases, however, there is still a high percentage of oil in the sand. If a production stimulus of sufficient magnitude is introduced into the formation, oil, otherwise nonproducible, may be recovered. It is the writer's thesis that high voltage electrical heating will prove to be such a stimulus.

REVIEW OF LITERATURE

There are two unpublished works treating with this method of high voltage electrical heating. They are:

1.) The Investigation of Possibilities of Underground Carbonization and Gasification of Fuels by means of Electric Current, A Thesis submitted to the Faculty of the School of Mines and Metallurgy of the University of Missouri, by Mr. Erich Sarapuu.

2.) Thermal Recovery of Petroleum by Electrical Heating, A Thesis submitted to the Faculty of the School of Mines and Metallurgy of the University of Missouri, by Mr. Harold Roy Coffer.

OTHER METHODS OF RESERVOIR HEATING

Steam(1)

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(1). Reistle, Jr., C. E., Paraffin and Congealing Oil Problems, U. S. B. M., Bulletin 348, pp. 74-80, 1932

One of the simplest methods of heating oil and paraffin in the production string is by the injection of steam into the space between the tubing and the casing. The condensed steam is allowed to accumulate in the well and be produced with the oil.

The successful application of this method will necessitate the following:

1.) The well must have tubing.
2.) The steam pressure must be greater than the reservoir pressure.
3.) The condensed steam must mot form an emulsion which is difficult to break.
4.) The steam must not cause damage to the sand face.

Steam coils often are used to prevent emulsification of the oil and water and damage to the sand face.

Plugging of the sand can occur easily if a steam coil is not used. The steam melts the paraffins at the well face and forces them into the formation. Upon cooling, these paraffins cause a greater clogging of the formation than occured during the first accumulation of wax at the sand face. Although the use of the steam coil will prevent clogging, it provides less heat due to the increased difficulty of heat exchange between the coil and sand.

Unless steam is available at low cost, this method is economically unsatisfactory.

Chemicals(2)

Chemicals having an exothermal reaction may be used to heat the oil and the sand face. An aluminum-lye compound is one having such a reaction.

Acidizing a formation will also produce a heating effect for a short distance into the formation.

Hot Gas(3)

In gas lift operations, it is often feasible to circulate hot gas in order to prevent paraffin solidification. Either steam heat exchangers or gas-fired heaters may be used to heat the gas.

The lose of heat by conduction to the surrounding formations and to the oil in the tubing may render this method ineffective.

Hot Oil(4)

Hot oil circulated back into the well, between the tubing and casing, has proved to be effective in the prevention of paraffin accumulation. A large quantity of oil must be used because of the rapid heat loss by conduction before the oil reaches the pay zone.

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(2) Reistle, op.cit., pp.81-83

(3) Reistle, op. cit., p. 84

(4) Reistle, op. cit., pp. 84-86

Flame.(5)

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(5) Reistle, op. cit., pp. 87-90

Wells have been cleaned of paraffin deposits and the formation heated by setting the sand face on fire. The air required for combustion is supplied to the face through tubing. The oil-bearing sand may be ignited by lowering burning waste into the well.

Increased recovery has been noted in many cases after the application of this method.

Electric Heaters(6)

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(6) Reistle, op. cit., pp. 89-97

Various types of electric heaters have been developed for oil well use. The heating element is usually of standard factory fabrication.

The element is placed near the bottom of the well. It has been found advisable to equip the heater with a circuit breaker and shield. The enclosing shield prevents the accumulation of sand around the heater, and the circuit breaker prevents burning out of the element due to overheating. Overheating occurs if the hot oil is not circulated away from the heater.

Hot Air

According to Gibbon,[7] Mr. E. W. Hartman demonstrated that

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(7) Gibbon, Anthony, Thermal Principle Applied to Seconaary Oil Recovery, The Oil Weekly, November 6, 1944, pp. 170-173

super-heated air can be used as a medium to obtain production from a formation which, otherwise, was nonproductive. The air is forced to the producing horizon through a well equipped with a heat exchanger. The heat thus induced yields a new production from nearby output wells.

The equipment consists of an air compressor of suitable capacity, a horizontal superheater, and a heat exchanger. The capacity of the air compressor used is determined by the depth of the formation.

The success attained in heating depleted formations, in two separate tests, shows the value of introducing energy to a formation by means of heat.

artman's thermal experiments were carried out during 1942 in the Mid-Continent area. Before thermal recovery was attempted both gas repressuring and water flooding had been applied.

Explosives

The use of nitroglycerin and 100 per cent blasting gelatin for shooting wells will produce an intensive fracture system and also considerable heat around the well bore. This practice of shooting wells has generally resulted in increased production, particularly if the sand had ecome plugged by paraffins.

THE PRINCIPLES OF ELECTRICAL HEATING(8)

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(8) Sarapuu, Erich, The investigation of Possibilities of Underground Carbonization and Gasification of Fuels by Means of Electric Current, A Thesis submitted to the Faculty of The School of Mines and Metallurgy of The University of Missouri, May, 1951

Three independent theoretical relationships have been determined for electrical behavior in an oil sand. Laboratory data have confirmed the curves depicted in Figure 1.

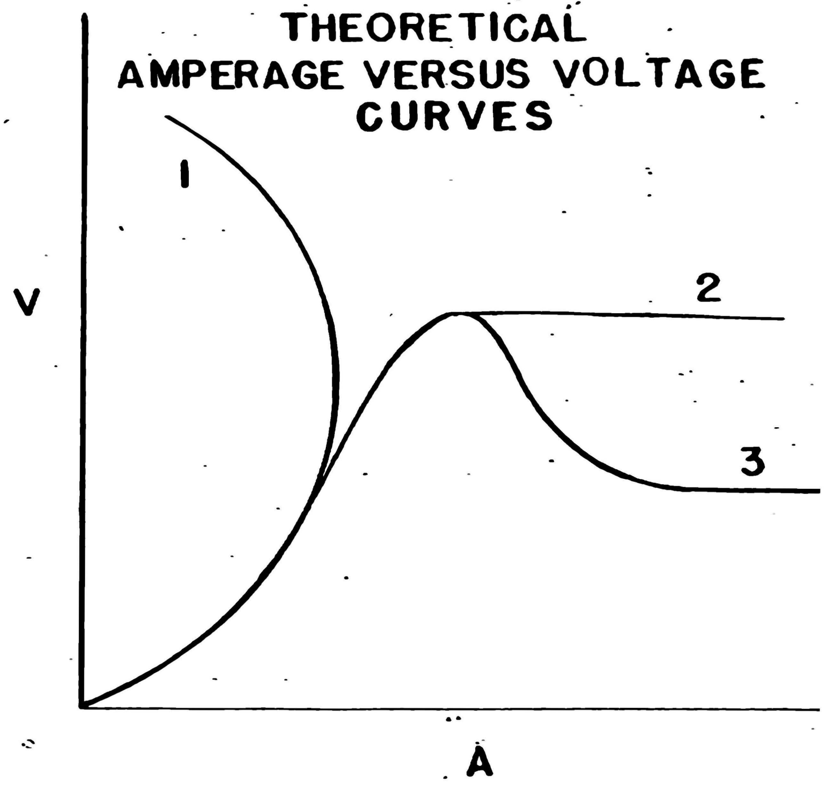
Curve 1 of Figure 1 shows amperage increasing as voltage is constantly increased; after reaching a maximum, the amperage declines. Impedence is shown as reducing with time until a minimum value is reached, thereafter, it begins to increase. The shape of the two curves is dependent upon the reservoir fluid.

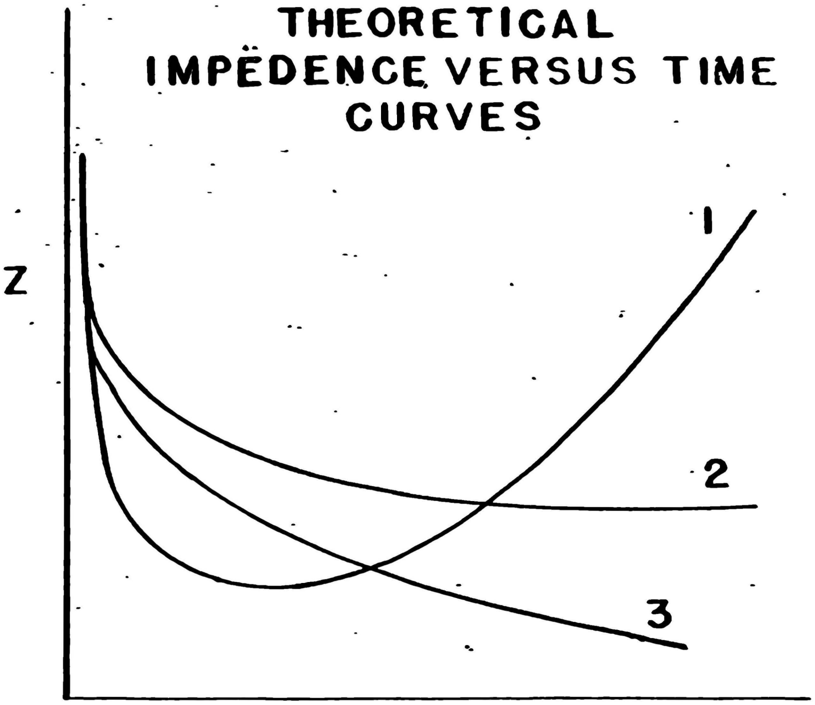
The impedence decrease and amperage increase are the result of a change in the conductivity of the connate water. Conductivity increases with temperature. The temperature increase is attributable to the resistance of the formation to current passage. Impedence drops with this temperature rise.

The fluid evaporates from the pore spaces of the rock as the maximum current and minimum impedence values are reached. The continued loss of conducting medium by evaporation results in the impedence rise and current reduction. This trend will continue until the sand has lost all of its contained fluid, after which further electrical heating is impossible. If reservoir fluid re-enters the sand, heating may be resumed.

The temperature which may be reached is limited by the degree of superheat of the steam under reservoir pressure. The length

FIGURE 1


THEORETICAL
AMPERAGE VERSUS VOLTAGE
CURVES
1
V
2
3
A


THEORETICAL
IMPEDENCE VERSUS TIME
CURVES
1
Z
2
3
T

of time required for vaporization of the reservoir fluid may be controlled by the voltage impressed.

An amperage and voltage rise and an impedence drop because of increasing conductivity are depicted in Curve 2. The conductivity of the reservoir fluid is replaced by a fixed carbon link which begins to form as the voltage reaches a maximum. The fixed carbon link is substantial enough to permit the maintenance of a constant voltage and impedence with increasing amperage. It may not extend completely between the electrodes. Conductivity is now constant and will remain so if the fixed carbon link fails to develop further. It is possible that this, as yet unstable, link may break causing the curve to revert to one similar to Curve 1, or it may grow and allow increased conductivity.

The impedence, voltage, and amperage values obtained when a carbon link connects and enlarges will allow a plot similar to Curve 3. In this curve impedence consistently declines. After fixed carbon linkage, or breakthrough, is effected amperage may be increased at a reduced voltage.

The creation of a carbon link, and therefore the shape of Curves 2 and 3, is dependent upon the presence of a plane of weakness in the formation along which breakthrough may occur. The nature of the plane will necessitate certain minimum power requirements for carbon linkage. If the power available is insufficient breakthrough will be impossible.

The factors controlling Curve 1 indicate that the temperature to be reached will not exceed that of superheated steam. Should the heating proceed under the conditions of Curve 3 very high temperature heating would be effected. These high temperatures would be sufficient to crack the oil in place thus the crude produced would have a very high A. P. I. gravity. The temperatures attainable when behavior is similar to that shown by Curve 2 will vary from, what may be called, middle temperature heating to high temperature heating. The temperature reached will depend upon whether or not the carbon link is extended across the formation.

Low temperature heating, however, is possible when the sand demonstrates the characteristics noted for Curve 3. After breakthrough the current input may be reduced allowing reduction of the temperature gradient throughout the reservoir and maintenance of low temperature heating.

Electrical experiments (9) have been carried out using a sand which contained a heavy asphaltic crude. Breakthrough was accomplished readily. The sand was then further heated using low voltages and amperages. The result was an 80 per cent recovery of oil by weight.

In an oil sand, conditions seem favorable for attempting what might be called a rapid electrical shock, that is, high voltage and amperage for a short period of time. The expected result of such a rapid electrical shock will be the creation of an effective radius of heating, rather than a carbon link. The term effective radius of heating refers to a radial temperature gradient with the well bore at the center.

Breakthrough may be economically impossible because of a large

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(9) Coffer, Harold R., Thermal Recovery of Petroleum by Electrical Heating, A Thesis submitted to the Faculty of the School of Mines and Metallurgy of the University of Missouri, May, 1950

power requirement. Should this be the case, a short duration, high voltage and amperage shock may prove to be a production stimulus within economic bounds.

The heat energy provided by high voltage electrical heating will cause vaporization of the reservoir fluids and will reduce, also, the viscosity of the crude. The interfacial tension between oil and water will likewise be lessened, greatly.

A graph(10) of viscosity against temperature, for six different crudes, shows a rapid reduction of viscosity with increased temperature. Similarity, a decrease in surface tension with increased temperature is illustrated by Muskat.

The data obtained by the writer from tests on several cores demonstrate that, though breakthrough was evidenced in some cases, conductivity primarily was due to the fluids in the core.

Experiments(11) performed in the electrocarbonigation and electrogasification of coal have demonstrated the possibility of breakthrough up to distances of from 60 to 70 feet. It was the purpose of these experiments to actually gasify the coal and produce a high B. T. U. gas. This end was attained successfully.

The experiments performed by Sarapuu also established the creation of an extensive fracture system. A somewhat similar result is expected in the electrical heating of an oil sand. The fractures will provide a system of flow channels, which will in-

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(10) Muskat, Morris, Physical Principles of Oil Production, p. 96, 1949

(11) Sarapuu, op. cit.

crease the permeability and, therefore, the production.

The anticipated results of electrical heating upon production may be summarized as follows:

1.) Additional driving force, due to the heat energy supplied. (Vaporization of fluid)

2.) Reduction of viscosity and interfacial tension of the crude.

3.) Creation of an extensive fracture system.

THEORECTICAL SATURATION DISTRIBUTION

The following illustrations of a water-wet formation depict the various relations of sand grains and saturating reservoir fluids resulting from water drive, gas drive, and electrical heating recovery processes.

FIGURE 2 represents a sand after production by water drive. Funicular saturation to water and insular saturation to oil are noted. The oil saturation will be of the order of 10 per cent of the available pore space.

FIGURE 3 illustrates a sand after gas drive. Pendular saturation to both water and oil is seen, with the gas occupying the funicular region. Dry gas, being passed through the reservoir, will come into contact with the oil. thus carrying off its lighter fractions. These lighter fractions may be recovered by separation at the surface.

A sand as it is believed to appear during high voltage electical heating is shown by FIGURE 4. The sand is one which had been originally produced by water drive.

Funicular saturation to water and insular saturation to oil are apparent. The arrows indicate the presence of additional driving forces resulting from the application of heat energy.

FIGURE 5 shows the consequence of electrical heating on a sand originally produced by water drive. The diagram demonstrates pendular saturation to water and oil. and funicular saturation to gas. Oil and water vapors are shown, also, in funicular saturation with the gas.

The energy supplied in the form of heat has caused the water

FIGURE 2(12)

Water-Wet Sand after Water Drive

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(12) after Pirson, Sylvain J., Elements of Oil Reservoir Engineering page 61, 1950

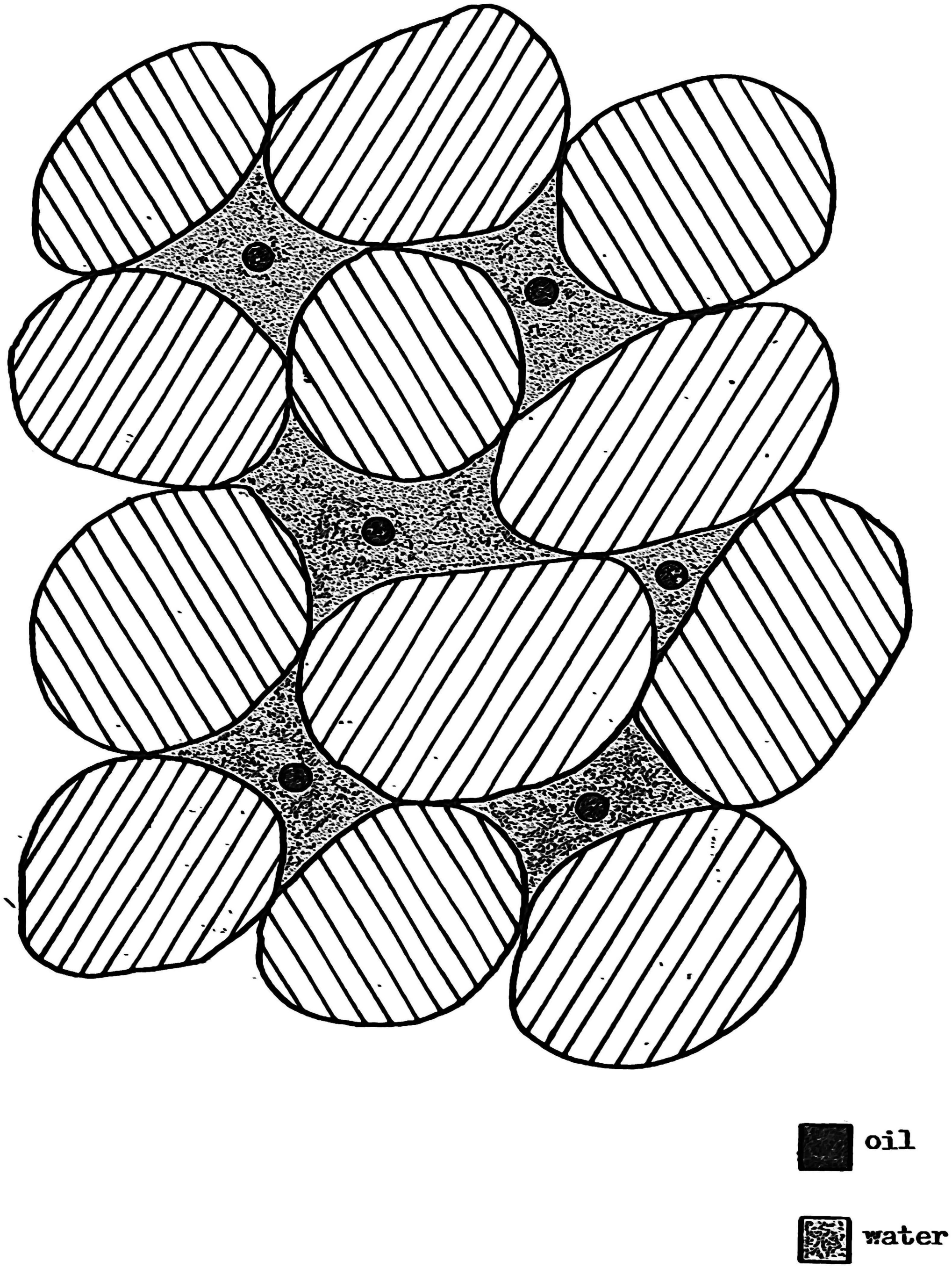


FIGURE 3

Water-Wet Sand after Gas Drive

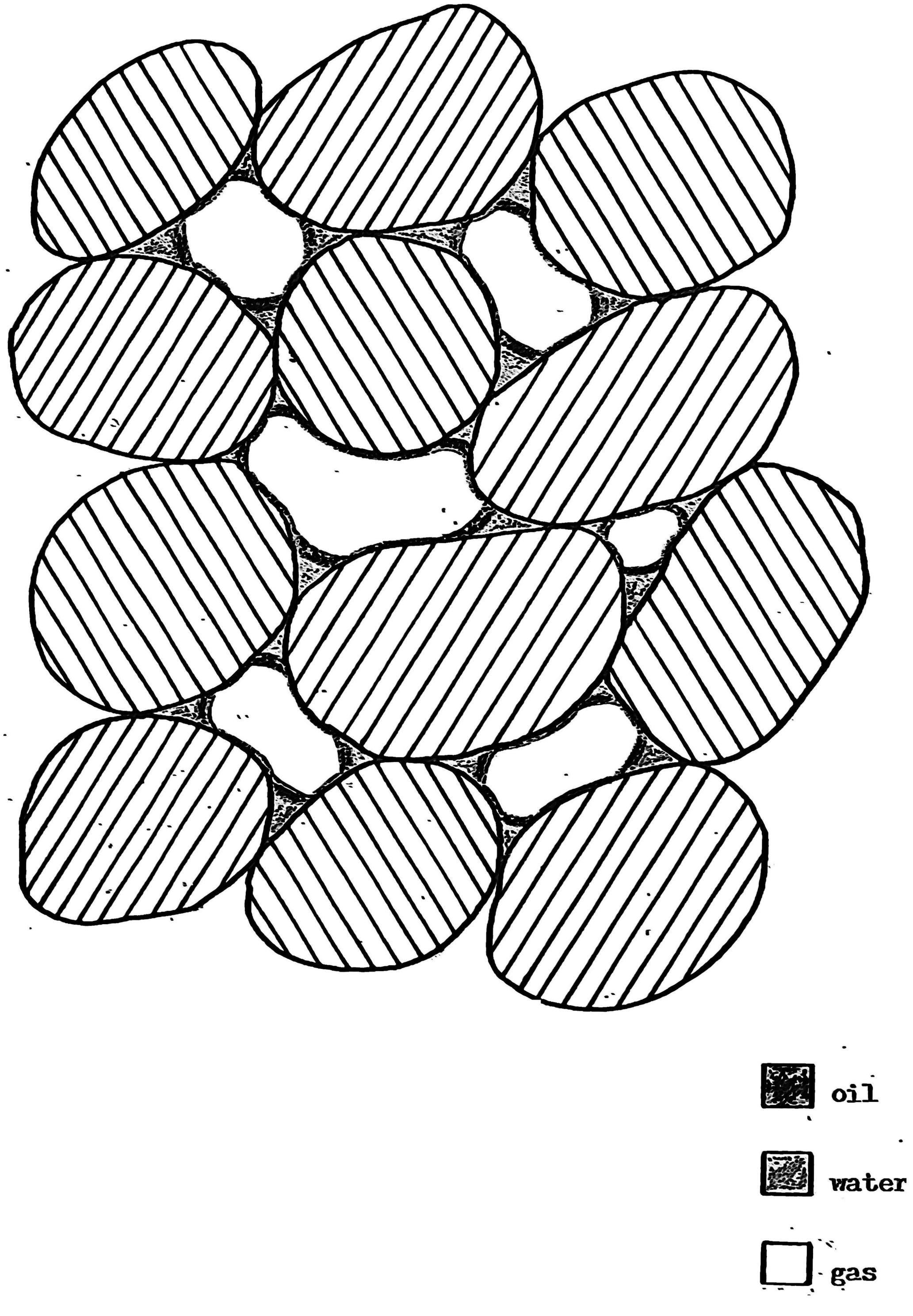


FIGURE 4

Water-Wet Sand During Electrical Heating

Water Drive Acted as Recovery Mechanism

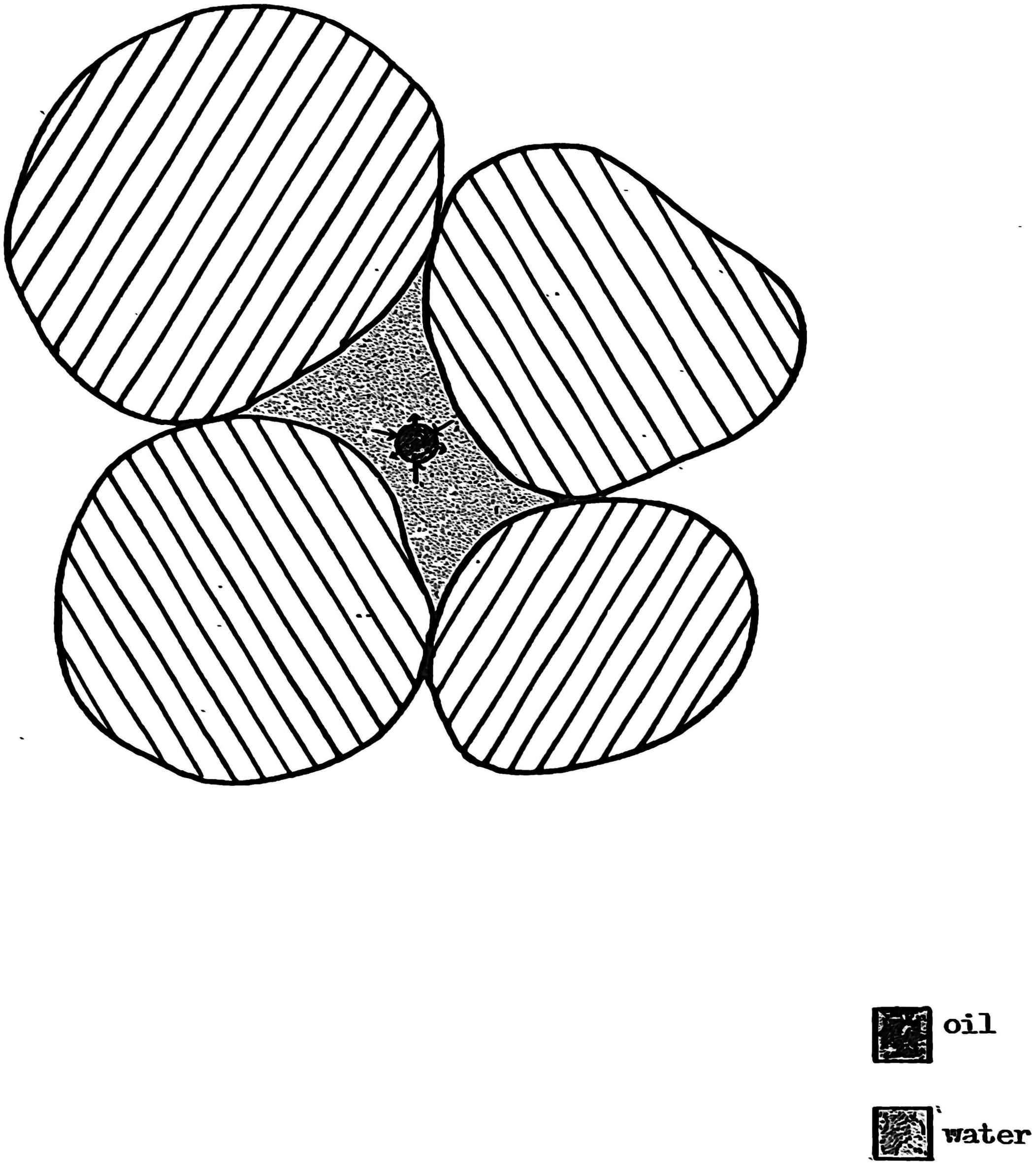
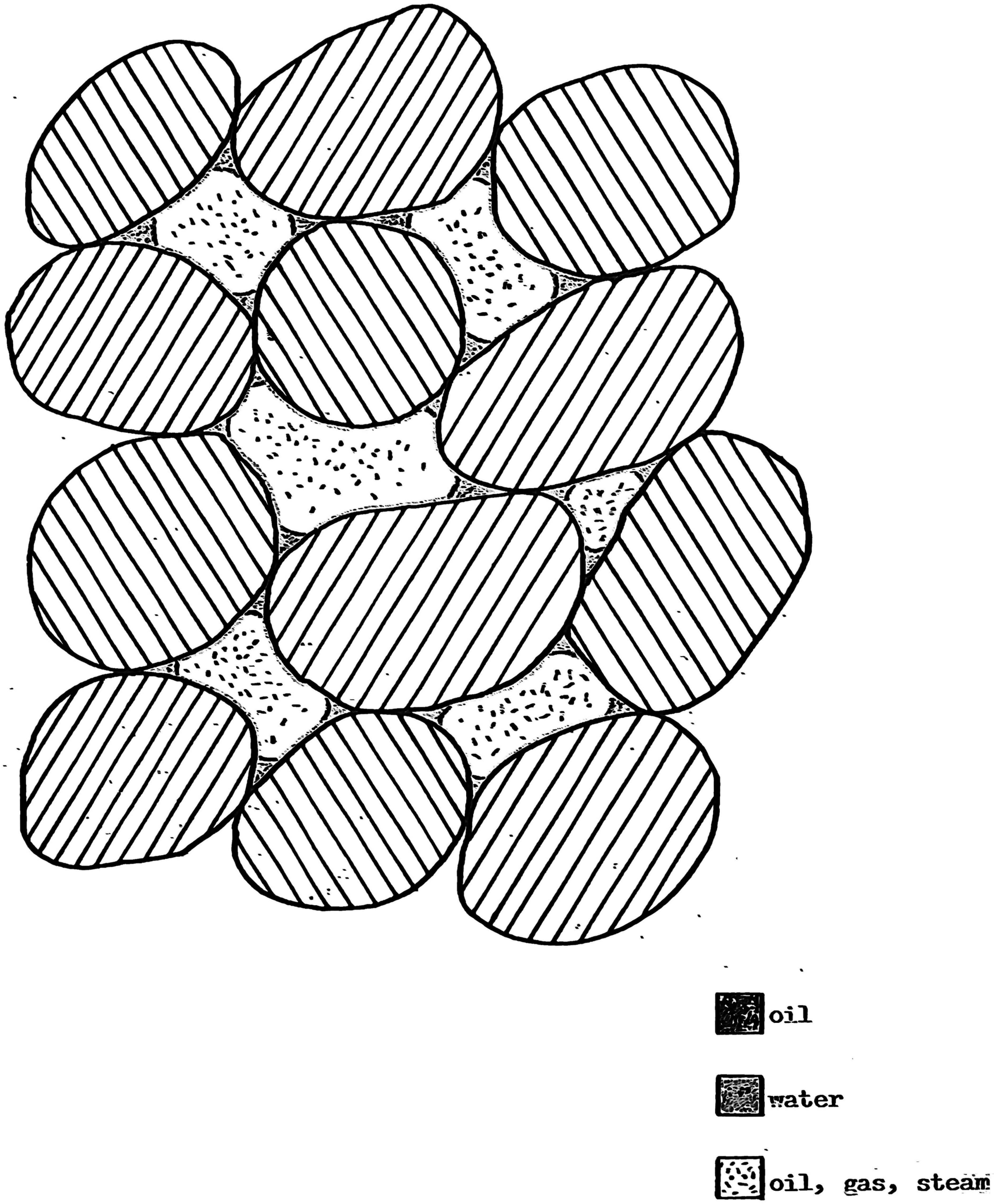


FIGURE 5

Water-Wet Sand After Electrical Heating

Water Drive Acted as Recovery Mechanism



to vaporize to a great degree. The oil originally in insular saturation has been disturbed and partially vaporized. Thus, a mixture of oil, steam, and gas will be produced. The amount of each recoverable constituent depends on the degree of heating.

A saturation distribution similar to FIGURE 6 is expected after gas has been used to produce an oil sand. The water and oil occur in pendular saturation with the gas occupying the funicular region. The arrows indicate the additional driving forces acting on the fluids, as a result of the heat energy being introduced into the formation.

FIGURE 7 represents the hypothetical saturation distribution in a sand after some production was induced by electrical heating. The sand had produced previously by gas drive. A lesser amount of pendular saturation, than would be the case with gas drive alone, is indicated for water and oil. Steam, gas, and oil vapor are shown in the funicular region.

The capillary forces holding the water and oil in the pendular region have been overcome, in part, allowing the two fluids to enter the funicular region. The reduced viscosity and surface tension of the oil will aid increased production.

FIGURE 6

Water-Wet Sand During Electrical Heating

Gas Drive Acted as Recovery Mechanism

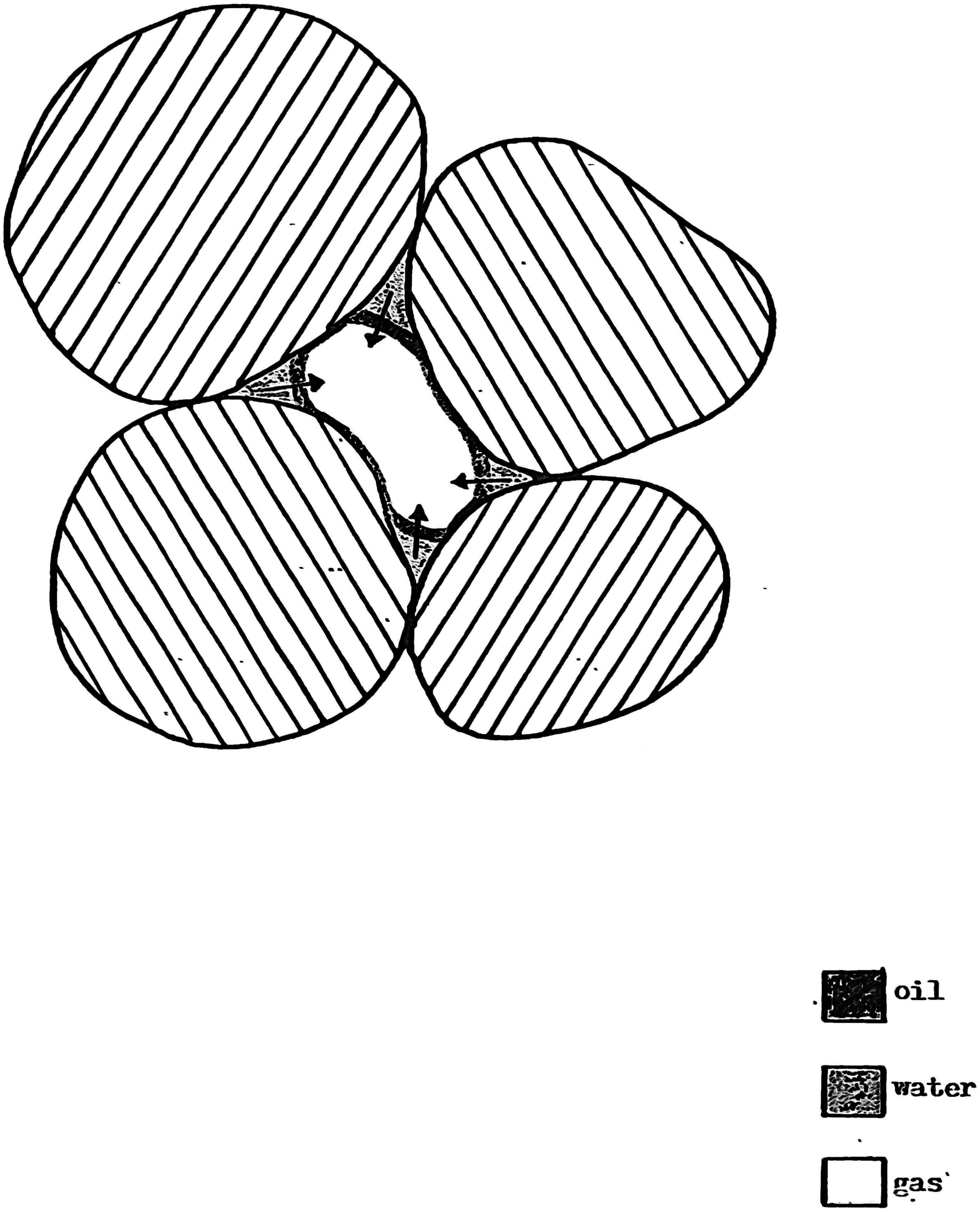
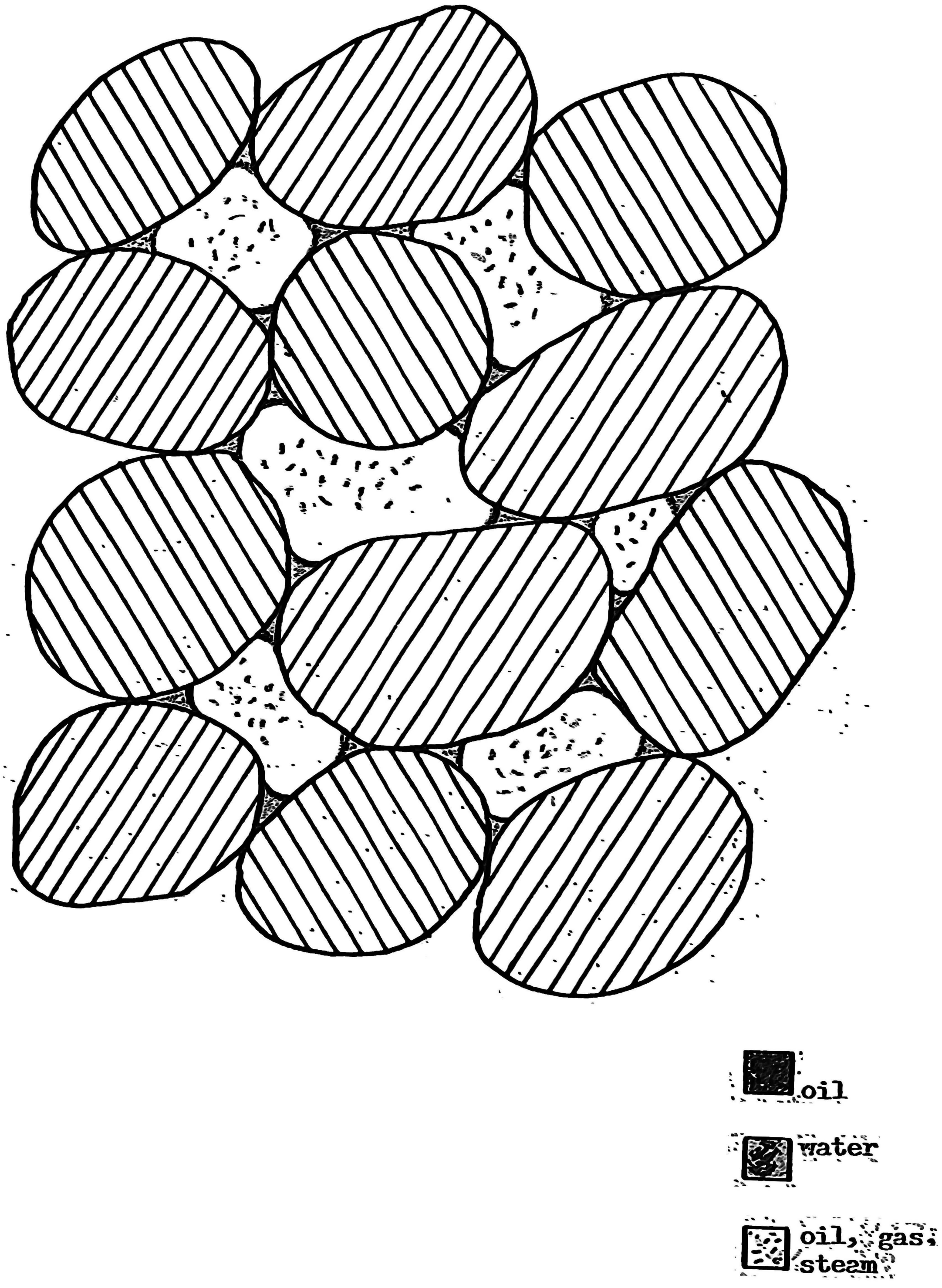


FIGURE 7

Water-Wet Sand after Electrical Heating

Gas Drive Acted as Recovery Mechanism



GEOLOGY OF THE SANDS

Bartlesville Sand

Bartlesville sand cores were obtained from Eastern Kansas. The material, occurring as a shoestring sand, is of Pennsylvanian Age. It is encountered by drilling to depths of approximately 7000 feet and varies between 100 and 200 feet in thickness.

W. B. Wilson(13) notes that closure is due to the pinching out of the sand body on the eastern or up-dip side of the field. The oil was trapped while migrating up-dip from the west.

Lalicker(14) reports an average porosity of 21 per cent for the sand. The United States Bureau of Mine (15) describe 340 cores as having average porosities varying between 17.7 and 26.2 per cent.

A core sample tested by the writer had a porosity of 16.5 per cent and a permeability of 0.215 millidarcys.

Bradford Sand

The cores tested from the Bradford sand were cut at depths varying between 1556 and 1562 feet on the Summitt lease of the Quaker State Oil Refining Company. The sand attains its greatest thickness in the northern part of the field. It is of uniform grain size, having a chocolate-brown color.

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(13) Wilson, W. B., Geology of Gleen Pool of Oklahoma, Structure of Typical American Oil Fields, Vol.I, p. 230, 1929

(14) Lalicker, Cecil G., Principles of Petroleum Geology, p. 107, 1949

(15) Ball, Cleo Griffith, and Taliaferro, D. B., Report of Investigations 4548, United States Bureau of Mines, p. 21, 1949

Clarence Ross(16) of the United States Geological Survey described the sand as follows:

> "The sand grains are quartz for the most part, but there are small amounts of feldspar mica and much chert-like material. The grains are angular and interlocking, and there may have been some enlargement of the quartz. The interstitial material is not abundant but is made up of a brown mica-like clay material."

Most of the Bradford sand, which is very hard with clay and silica being the cementing materials, has a thin calcareous cap rock.

It has been suggested(17) that the material had a bay origin. The source beds may have been the Portage and Chemun formations(18) which lie close to the Bradford sand.

The crude oil produced has an A. P. I. gravity of approximately 45°.

Fettke(19) gives the following concerning saturations:

> "In the case of the Bradford sand, eight cores, upon distillation, gave an average of 46.375 per cent total pore space occupied by oil while water occupied 46.625 per cent of the total openings."

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(16) Newby, Jerry B., Torrey, Paul D., Fettke, Charles R., Bradford Oil Field, McKean County, Penn., and Cattaraugus County, New York, Structure of Typical American Oil Fields, Vol. II, p. 425, 1929.

(17) Newby, Torrey, Fettke, op. cit., p. 429.

(18) Newby, Torrey, Fettke op. cit., p. 430.

(19) Fettke, Charles R., Core Studies of the Bradford Sand from the Bradford Field, Penn., Problems of Petroleum Geology, p. 285, 1934.

An average porosity of 13.1 per cent is reported by several authorities.(20)(21)

Lalicker(22) also reports the following experimental data:

Porosity per cent	Permeability millidarcys	Remarks
12	2.5	flow of water through sample
16.7	55.8	flow of air through sample

Laboratory determinations by the writer gave a permeability of 0.0334 millidarcys and a porosity of 14 per cent.

Bromide Sand

Cores of the Bromide sand were obtained from Garvin County, Oklahoma. The material part of the Simpson Series of Ordovician Age. The cores were procured from a depth of 9793 feet.

The Bromide Formation(23) is found below the Viola limestone. It is approximately 140 feet thick in Northern Oklahoma. The formation is composed of sandy, dolomitic limestones with some green shale and thin sandstones.

Lalicker(24) calls the Bromide formation the Simpson Group

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(20) Griffith, Cleo, Rall, and Taliaferro, D. B., op. cit., p. 21

(21) Lalicker, Cecil G., op. cit., p. 107.

(22) Lalicker, op. cit., p. 108.

(23) Ver Wiebe, Walter A., Oil Fields in the United States, p. 246, 1930.

(24) Lalicker, op. cit., p. 260.

with the Bromide sandstone being the main producing horizon of the group. The crude has an A. P. I. gravity of 23°.

The formation water(25) contains 63,000 parts per million chlorides, and 105,000 parts per million total solids.

Core analysis performed by the writer obtained a porosity of 8 per cent and a permeability of 0.444 millidarcys for the Bromide sand sample.

Lower Deese Sand

Samples of the Lower Deese sand come from a well in Garvin County, Oklahoma. The cores were obtained from depths of between 6455 feet to 5505 feet.

Fifty feet of this well was cored and a geological record made. Four sections of this cored material were made available to the writer. The geology of these samples is reported(26) as follows:

> "Can #6 - Sand, mottled grey-white, fine grained, friable on small chips; shows closely spaced alternating light and dark bands, horizontal, with paper thin partings of dark clay shale in basal 1 inch.
> Can #18 - Sand, grey to drab, fine to medium grained, friable, calcareous, fluorescent.
> Can #50 - Sand, grey, fine to medium grained, with clay filled pockets up to 3 mm., slightly friable, non calcareous, fluorescent.
> Can #68 - Sand, grey to white, very fine to fine grained, extremely dense and hard, flattened pockets of green-grey clay and much interstitial clay material."

Permeability and porosity measurements as recorde by The Carter Oil Company are as follows:

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(25) Phillips Petroleum Company, personal communication

(26) The Carter Oil Company, Personal communication.

Can No.	Permeability millidarcys	Porosity per cent
6	50 - 150	16
18	210	11
50	300	17
68	none given	none given

Misener Sand

Misener Sand cores were obtained from a well in Pottawatomie County, Oklahoma. Only a few wells are still producing in this nearly depleted area. Initially the wells were very prolific having had initial productions of several thousand barrels a day.

The Misener Sand is of Lower Mississippian Age. It was deposited probably as a near-shore sediment(27) in a marine sea. The crude(28) has a brownish green color, an A. P. I. gravity of 39.4°, and a sulfur content of between 17 and 18 per cent.

Electric log data give a water saturation of about 17 per cent.

The writer determined a permeability of 0.625 millidarcys and a porosity of 8.2 per cent for a Misener core sample.

Burbank Sand

Burbank Sand cores were cut from a well in the North Burbank Field, Osage County, Oklahoma. The sand is of Pennsylvanian Age.

The Burbank Sand is encountered at depths of 2,800 to 3,200 feet and varies between 50 and 80 feet in thickness. In some place,

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(27) Borden, J. L., and Brant, R. A., East Tuskegee Pool, Oklahoma, Stratigraphic Type Oil Fields, A Symposium, p. 446, 1941.

(28) Borden and Brant, op. cit., p. 452.

there is a parting of blue shale ranging in thickness from a few inches to 3 feet about 50 feet from the base of the sand. The sand is fine-grained and siliceous, having a calcareous cementing material.

J. M. Sands(29) reports the following concerning its productivity:

> "-----Through the lower 50 feet of the sand is generally a pure sand without any shale breaks, its porosity and content of calcareous material differ, so that the sand is probably not productive throughout its total thickness. The production comes from three or four different zones encountered at different depths, and it is quite probable that not more than two-thirds of the total thickness is productive."

The sand grades into an impervious sandy shale to the north and east of the field. This lithological change prevents further migration of the oil. The west and south extremities of the field are in contact with salt water. Structurally the field is an undulating monocline with a general westward dip of about 35 feet per mile.

Several sources(30)(31)(32) report average porosities of between 13 and 16 per cent for the sand.

The writer recorded a porosity of 8.2 per cent for the sample

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(29) Sands, J. M. Burbank Field, Osage County, Oklahoma, Structure of Typical American Oil Fields, Vol. I, p. 223, 1929.

(30) Melcher, A. F., Texture of Oil Sands with Relation to the Production of Oil, Bull. Amer. Assn. Pet. Geol., VIII, pp. 769-770, 1924.

(31) Sand , op. cit., p. 225.

(32) Rall and Taliaferro, op. cit., p. 21.

tested.

Weber Sand

The Weber Sandstone cores were from Rangely Field, Colorado. This sand is of Pennsylvanian Age.

The sand is found below a depth of 5,750 feet and is approximately 1,200 feet in thickness. The oil producing zones are, however, found only in the upper 500 feet to 700 feet of the formation.

Lalicker(33) reports an average porosity of 8.9 per cent and an average permeability of 3.8 millidarcys for a section of the Weber-sand cored near the east end of the producing area. The core also showed the sand to contain beds of shale and siltstone, with much of the sand being impermeable. Porosities of from 15 to 20 per cent, and a permeability of 50 millidarcys were encountered in a zone 40 feet thick.

A structure contour map(34) of the top of the Weber sandstone shows a large asymmetrical anticline. Dips of from 13° near the crest to 21° on the flank are encountered on the south side. The dips to the northeast average 6°.

The average gravity(35) of the oil from the Weber sandstone is 31° A. P. I.

The writer measured a porosity of 7.4 per cent for the core tested.

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(33) Lalicker, op. cit., p. 140.

(34) Lalicker, op. cit., p. 136.

(35) Lalicker, op. cit., p. 141.

CORING

The procurement of fresh cores has been one of the major difficulties in this laboratory study of attempting to attain increased recovery by using high voltage electrical current. The rapidity with which reservoir fluids are dissipated from the sand into the atmosphere, when the core is brought to the surface, is a situation which inhibits accurate laboratory interpretations.

The ability of the sand to conduct electricity is dependent upon these fluids, particularly the salt water. It is, therefore, obvious that the reservoir fluids must be present in any core used in the laboratory for electrical determinations.

The cores found most suitable were those sealed in cans immediately after being brought to the surface. It is the writer's belief that more accurate data will be gined from laboratory studies with the commercial development of a self-sealing pressure core barrel. Such an apparatus will keep the core at bottom hole conditions.

Plastic tubes or a coating of sodium silicate will keep cores quite fresh. It was found in this laboratory study that resaturated cores could be made to retain their fluids by immediately coating them with a solution of sodium silicate. When needed for further tests, the hardened water glass was chipped from the rock surface. Also, plastic tubes were used in the laboratory, but their detering feature was that the fluid from the sand could enter the air space between the rock and tube.

Immediate canning at the well site is at present the best known solution to the problem. This, in conjunction with the use of sodium silicate in the laboratory, yielded the best results.

LABORATORY PROCEDURE

Description of Equipment

The electrical equipment used in the experimentation, and illustrated in FIGURES 8 and 9, is described as follows:

1.) Induction Voltage Regulator; General Electric Company; Type HK; 6KVA; 120 to 240 volts; 0-5, 0-25 amps.

2.) Voltmeter; Westinghouse Co.; 0-300 volts; Type KA-25

3.) Ammeter; Westinhouse Co.; 0-5, 0-10 amps; Type KA-25

4.) Waltmeter; Westinghouse Co.; 120/240 volts; 5/10 amps; Type KY-25

5.) Transformer; General Electric Co., 7.5 KVA; 1987/2300/6900/11950 to 115/230 volts; Type H

6.) Overload Circuit Breaker; 25 amps.; 480 volts

The electrode used is shown by FIGURE 10.

Two different steel tips were used in the electrode. They were a flat circular disk and a pointed rod. The surface areas of these tips, used in calculating the current and load densities, are as follows:

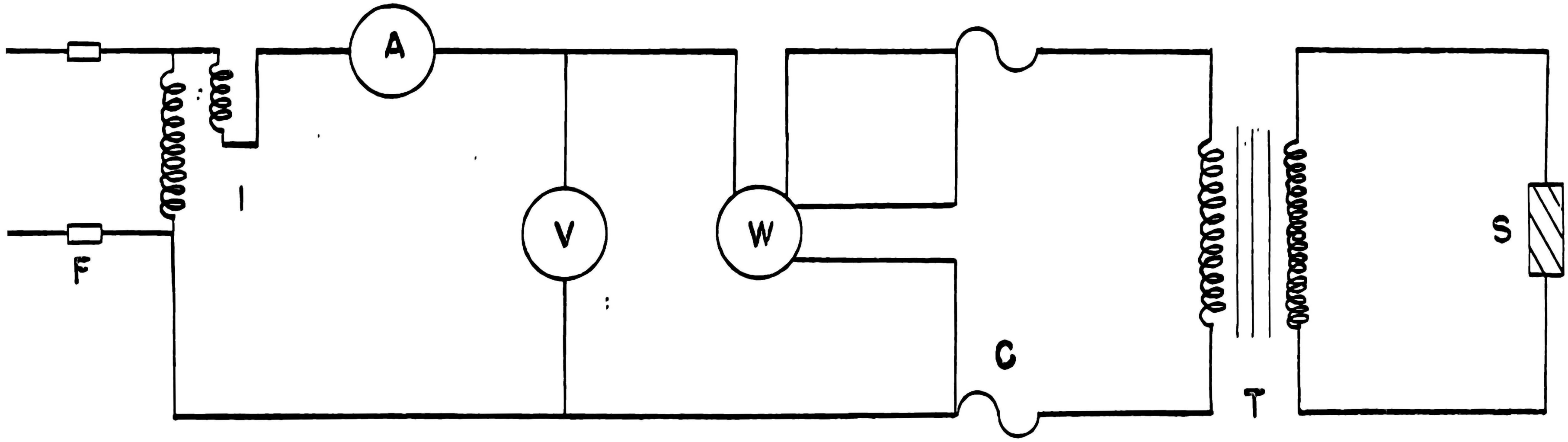
Area of circular plate electrode = 5.07 sq. cm.

Area of point electrode = 0.1585 sq. cm.

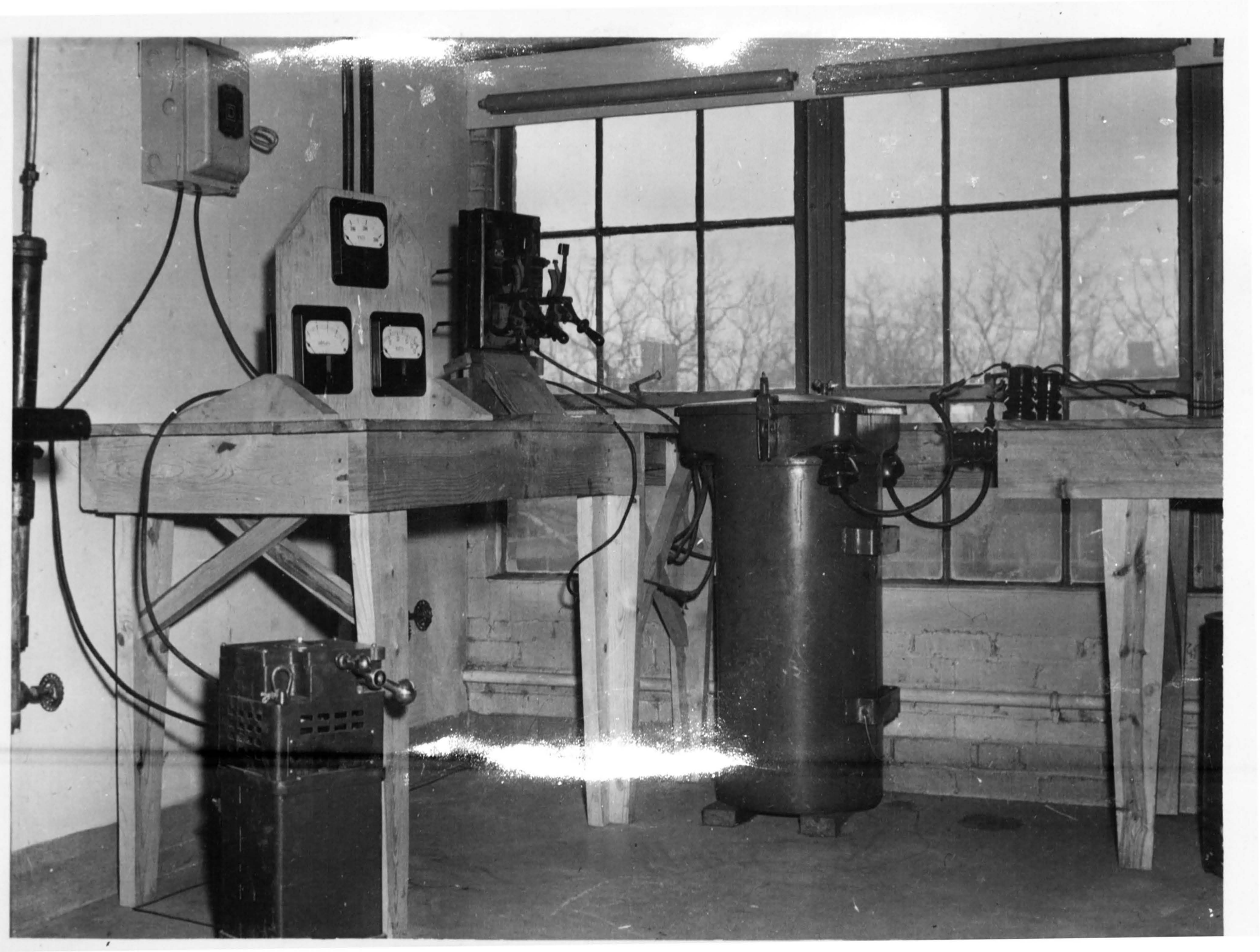
Sufficient contact was obtained with the point electrode by penetrating the core to a depth of 1/8 of an inch. The area of the point electrode was calculated on this basis.

DIAGRAM OF ELECTRICAL APPARATUS

FIGURE 8

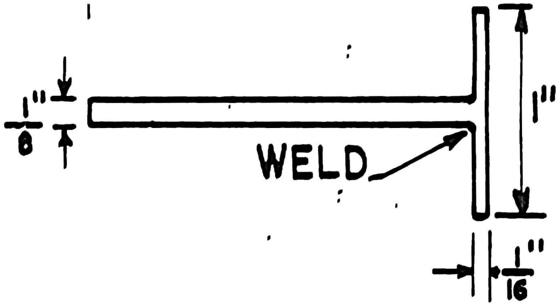


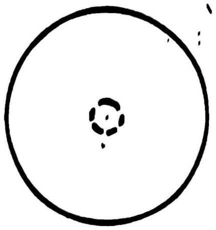
A = AMMETER
C = CIRCUIT BREAKER
F = FUSE
S = SAMPLE
I = INDUCTION REGULATOR
T = TRANSFORMER
V = VOLTMETER
W = WATTMETER

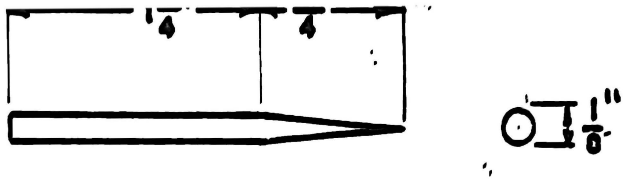


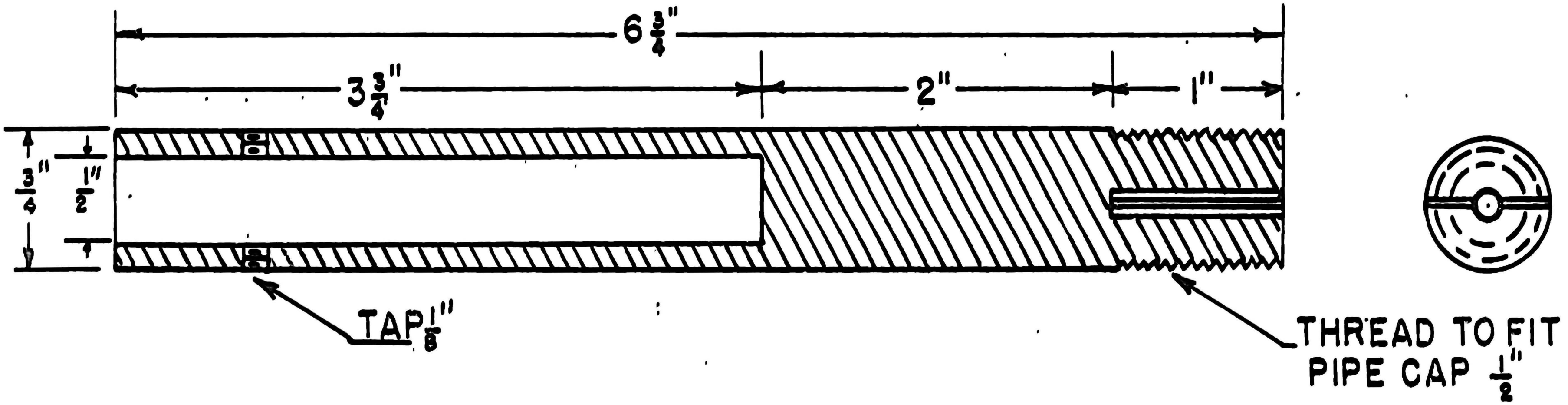
ELECTRICAL EQUIPMENT USED IN EXPERIMENTATION

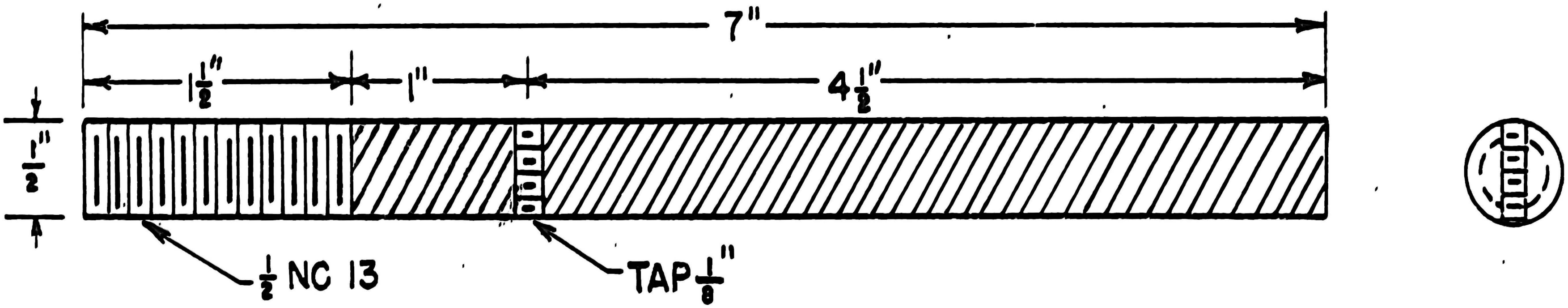
FIGURE 9

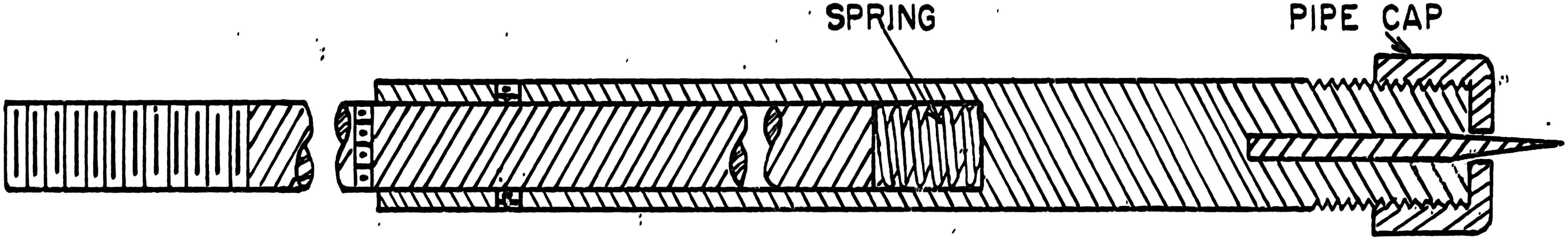

1"/8
1"
WELD
1"/16




1/4
4
1"/8


6 3/4
3 3/4"
2"
1"
3"/4
1"/2
TAP 1"/8
THREAD TO FIT
PIPE CAP 1"/2


7"
1 1"/2
1"
4 1"/2
1"/2
1/2 NC 13
TAP 1"/8


SPRING
PIPE CAP

Test Procedure

Use of the equipment described made it possible to develop 6600 volts in the secondary using a primary voltage of 220. Because of the rapid fluctuations of amperage and the limited scale on the available milliammeter, all readings were taken from the primary. This, although introducing an error, eliminated the possibility of burning out instruments on the secondary side.

Graphite was placed between the electrode and the sand sample to insure good contact. The circuit was closed and voltage constantly increased by means of the induction regulator. Voltage and amperage values were read and recorded as rapidly as possible.

As voltage built up, and the core heated, water vapor, gas, and oil were emitted from the sample.

An attempt was made to encase the electrodes and core in a large diameter pyrex tube for the purpose of collecting the fluids. The formation of a mist by the water vapor leaving the core caused the current to pass through the mist rather than the rock. The system behaved more satisfactorily when exposed to the air, although a short circuit could still occur if the vapors emporarily condensed on the surface of the core. Exposure to the atmosphere necessitated the determination of recovery on the basis of weight per cent.

A test was run by increasing the voltage until the impedence either failed to decrease or became constant with added voltage. Because of the rapid vaporization and limited amount of the saturating fluids, it would be futile to attempt, in the laboratory, to break down an increasing impedence by continued voltage incre ses.

It has been demonstrated,(36) however; that an increasing impedence may be broken down in the field by increasing the power applied. Field application is not restricted by a small amount of conducting media.

Resaturation of Cores

The dryness of the cores made artificial saturation necessary. The cores first were desaturated completely in a Soxlet extaction apparatus and original saturation data were procured. Permeability and porosity measurements were determined with Ruska instruments.

The cores were resaturated at pressures in excess of five hundred pounds per square inch by means of a Baker Hydraulic Hand Pump attached to a reducing pipe "L". The core was placed in a rubber stopper bored to the diameter of the sample. The stopper containing the core then was placed in a pipe nipple closed at one end by a pipe cap. The pipe cap prevented the rubber stopper from being blown out by the high pressure. A hole drilled in the cap allowed the passage of brine and oil. The pipe nipple was attached to the pipe "L" in a vertical position. Brine followed by crude oil was pumped through the core. FIGURE 11 illustrates the resaturation equipment.

A 34.5° A. P. I. gravity crude oil and a brine containing 30,350 parts per million chloride were used for all saturations. The brine and oil had respectively specific gravities at 60°F. of 1.04 and 0.8586.

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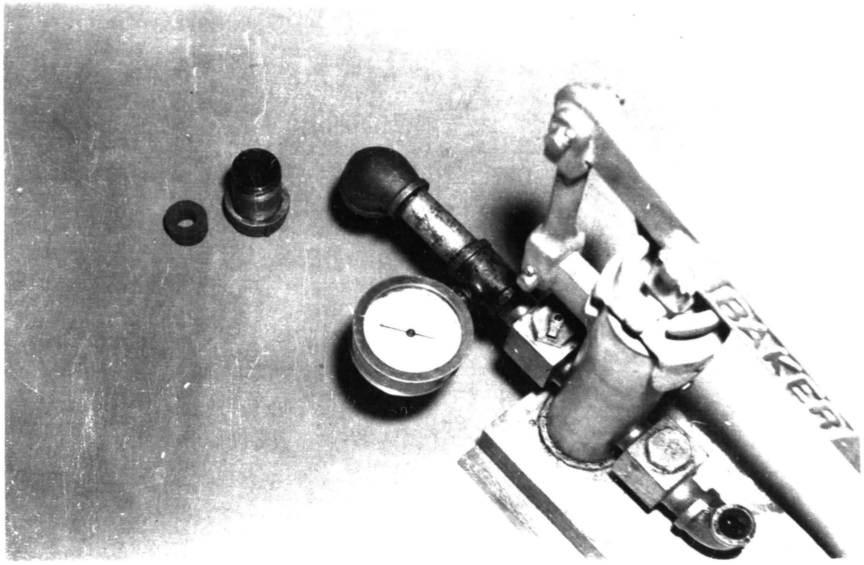
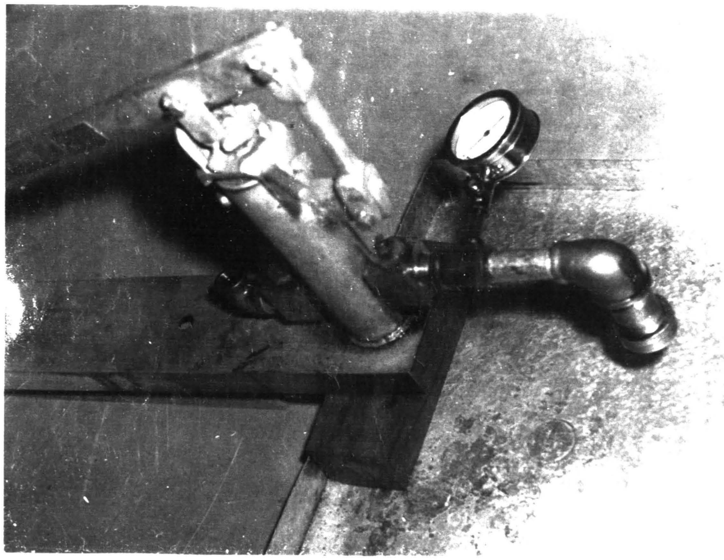
(36) Sarapuu, op. cit.



COMPONENT PARTS OF RESATURATION

APPARATUS



ASSEMBLED RESATURATION

APPARATUS

FIGURE 11

One hundred per cent total saturation was assumed for all cores and a mathematical relationship was established to determine the per cent saturation of each constituent.

The equation is as follows:

$$W_s = W_c + \rho_w V_w + \rho_o V_o = W_c + \rho_w V_w + \rho_o (V - V_w)$$

$$V_w = \frac{W_s - W_c - \rho_o V}{(\rho_w - \rho_o)}$$

W_c = dry weight of core (gms.)

W_s = saturated weight of core (100 per cent) (gms.)

V = total pore volume (cc.)

V_o = pore volume occupied by oil (cc.)

V_w = pore volume occupied by water (cc.)

ρ_o = density of oil (gms/cc.)

ρ_w = density of water (gms/cc.)

The equation, although valid for the assumptions made, failed to provide satisfactory per cent saturations. The writer believes that lack of accurate porosity data and failure to reach 100 per cent total saturation are responsible The low permeability of the sands prevented complete saturation. It is the author's belief that better results are possible for sands of higher permeability.

The sands which could be electrically heated, in all but one case were those resaturated in the manner described.

RESULTS OF EXPERIMENTS

Bartlesville Sand

The graphs of current versus voltage and impedence versus time for the Bartlesville sand were obtained by using an artificially saturated core. Attempts to use cores as they were received from the field failed completely because of their dryness.

The curve of current versus impressed voltage shows current increasing with increased voltage until a maximum of approximately 0.025 amps is reached at a voltage of nearly 1000. The amperage then begins a sharp decline to about 0.006 amps. With voltage still being increased the amperage again rises to a constant value of 0.0166 amps.

The curve of impedence versus time shows that impedence initially lessens to a low value of 32,100 ohms, at 30 seconds, and then rises steadily to a high of 630,000 ohms after two minutes, thirty seconds. The impedence then begins to decrease again.

The interpretation of these curves is that amperage increased and impedence decreased due to the increasing conductivity of the heating fluids. As the fluids began to evaporate, the impedence increased, reaching the maximum of 630,000 ohms when the core had dried. The amperage was reducing as the fluids evaporated. Carbon linkage is indicated by the final rise of amperage and fall of impedence.

The curves are similar to the theoretical Curve 1 of FIGURE 1 except for the final phase which indicates breakthrough.

Electrical heating resulted in 98.7 per cent recovery by weigh , after four minutes.

TABLE 1

RESATURATED BARTLESVILLE SAND

TIME MIN:SEC.	VOLTAGE	AMPERAGE	CURRENT DENSITY	LOAD VXA	IMPEDENCE	LOAD DENSITY	REMARKS
0:05	450	.00834	.0526	3.75	54,000	23.65	Point Electrodes Used
0:30	750	.02335	.1472	17.52	32,100	110.4	
1:00	1350	.05-.0834	.3155-.5260	67.5-112.5	27,000-16,200	425.5-710.0	Sparking on core surface
1:30	1500	.01666	.1050	25.0	90,000	157.6	Arcing around Electrodes
1:45	2250	.00834	.0526	18.75	270,000	118.2	Arcing around Electrodes
2:30	4200	.00667	.0421	28.0	630,000	176.6	Core Heating
3:00	5700	.01666	.1050	95.0	342,000	598.0	Arcing inside Core
3:30	6000	.01666	.1050	100.0	360,000	631.5	Arcing inside Core
4:00	6600	.0200	.1262	132.0	330,000	834.0	Arcing inside Core

Heating Stopped in order to Change Electrodes

TIME MIN:SEC.	VOLTAGE	AMPERAGE	CURRENT DENSITY	LOAD VXA	IMPEDENCE	LOAD DENSITY	REMARKS
0:30	2400	.00333	.000657	8.0	721,000	1.576	Plate Electrode Sodium Chloride and Water Used to Make Graphite Paste Providing Better Contact Between Core and Electrode Current Passed Over Surface of Core Causing Short after 30 Seconds.

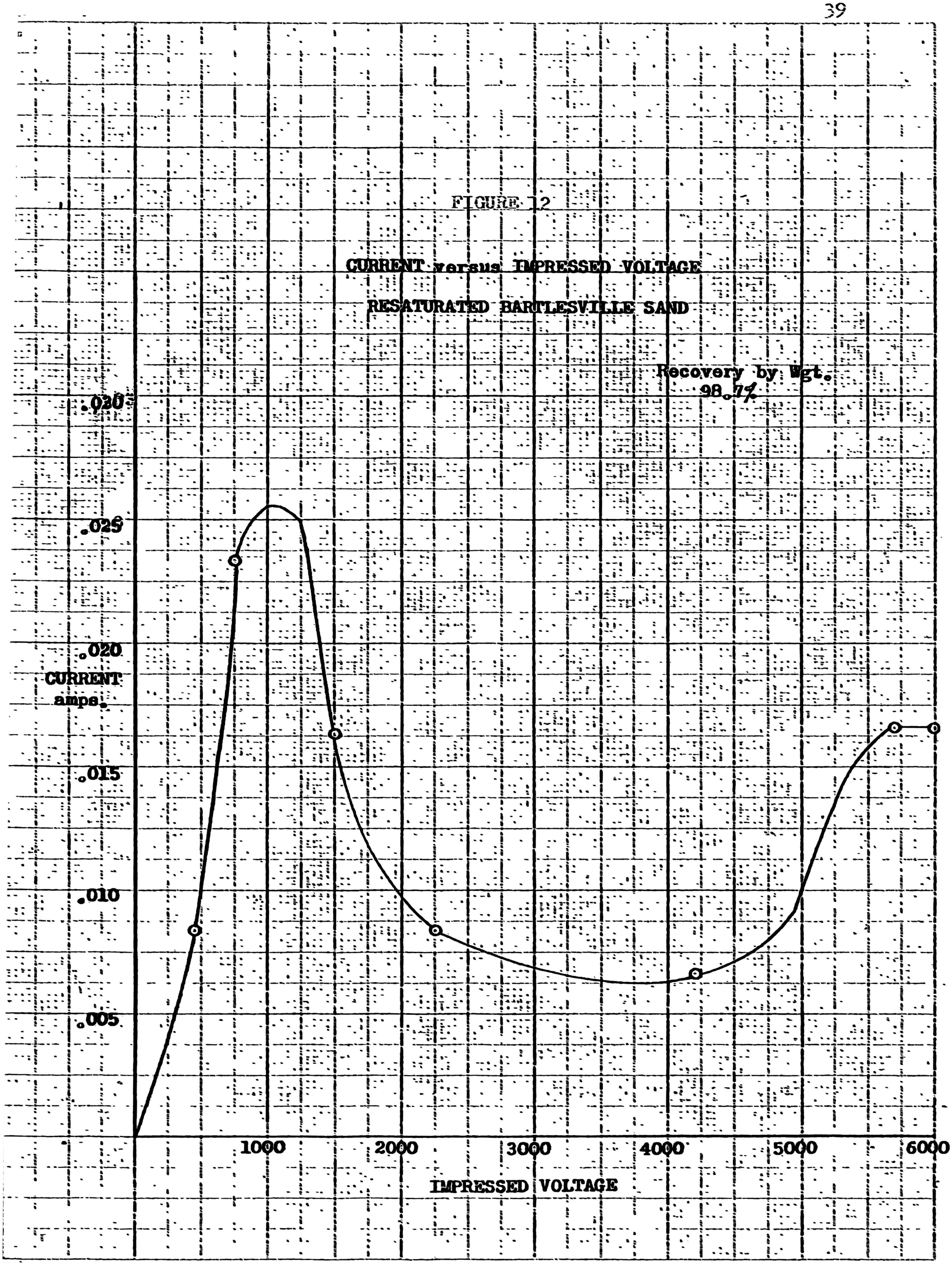
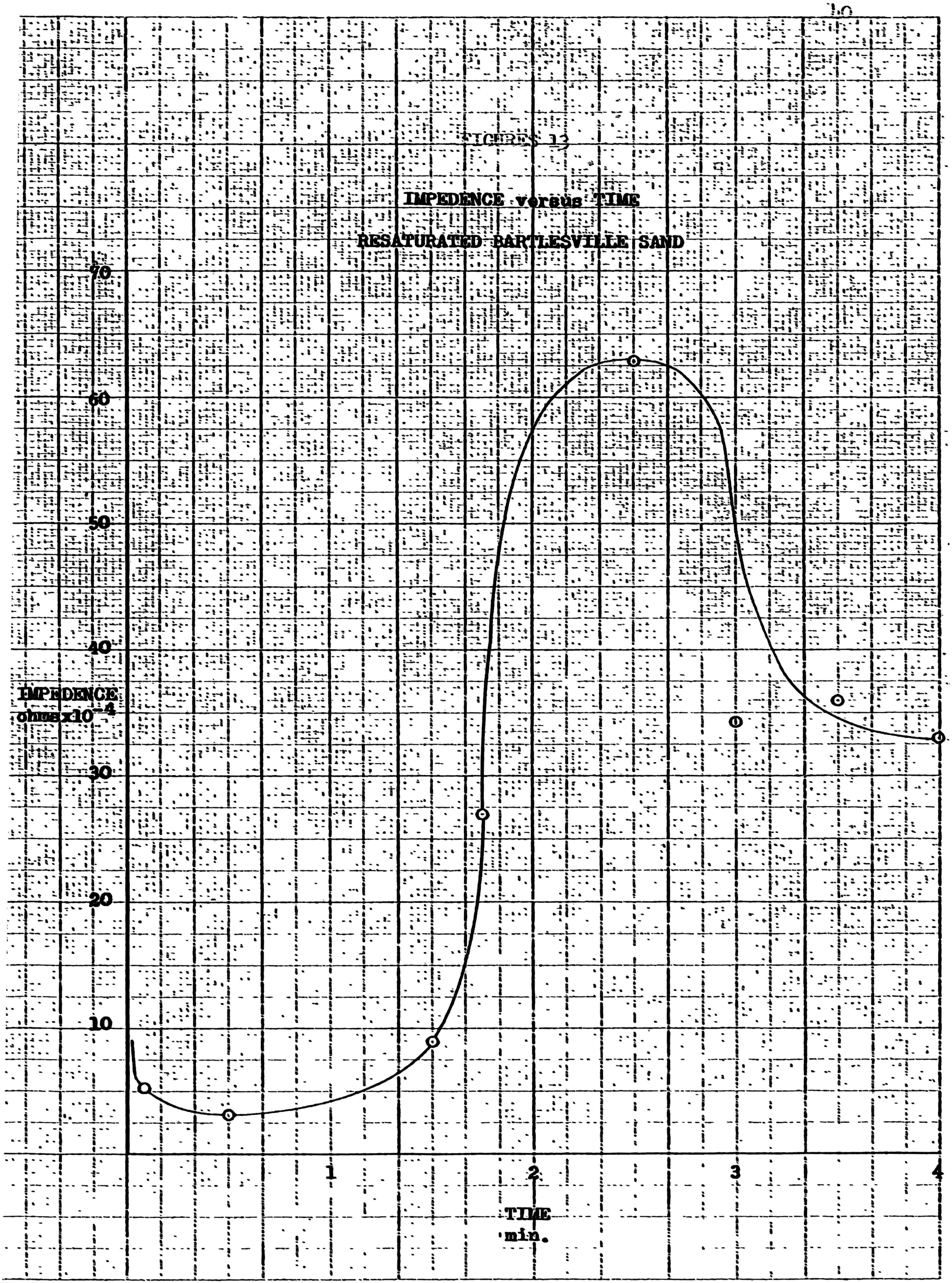


FIGURE 12

CURRENT versus IMPRESSED VOLTAGE

RESATURATED BARTLESVILLE SAND

Recovery by Wgt.
98.7%



FIGURES 13

IMPEDENCE versus TIME

RESATURATED BARTLESVILLE SAND

The current and load densities were somewhat variable and, under the conditions of the experiment, may not be dependable for making assumptions concerning field behavior.

Breakthrough occurred at 5000 volts and after three minutes.

Bradford Sand

The curve of amperage versus impressed voltage for the resaturated sample of Bradford sand shows an increasing amperage with a constantly increasing voltage. The amperage rise results from the heating of the conducting fluids. After a maximum of 0.0667 amps is reached, a rapid decline is noted to a constant value of 0.01333 amps. The decline is due to the loss of conducting fluids by evaporation. The constant amperage value of 0.01333 is reached at breakthrough.

The impedence versus time curve shows an impedence decrease caused by the heating core fluids. An impedence rise is noted as the fluids evaporate. After a maximum of 630,000 ohms, carbon linkage occurred and the impedence was reduced to 450,000 ohms.

Several values from Table 2 were not plotted on the graphs as they resulted from short circuits across the surface of the core.

A 98.0 per cent recovery, by weight, was realized after eleven minutes of heating.

Bromide Sand

The current versus impressed voltage curve for the resaturated Bromide sand exhibits a rapid increase of amperage to 0.030 amps followed by a decline to 0.00666 amps. The heating of the saturating fluids and the resultant vaporization caused this rise and fall.

The impedence versus time curve shows an impedence drop due

TABLE 2

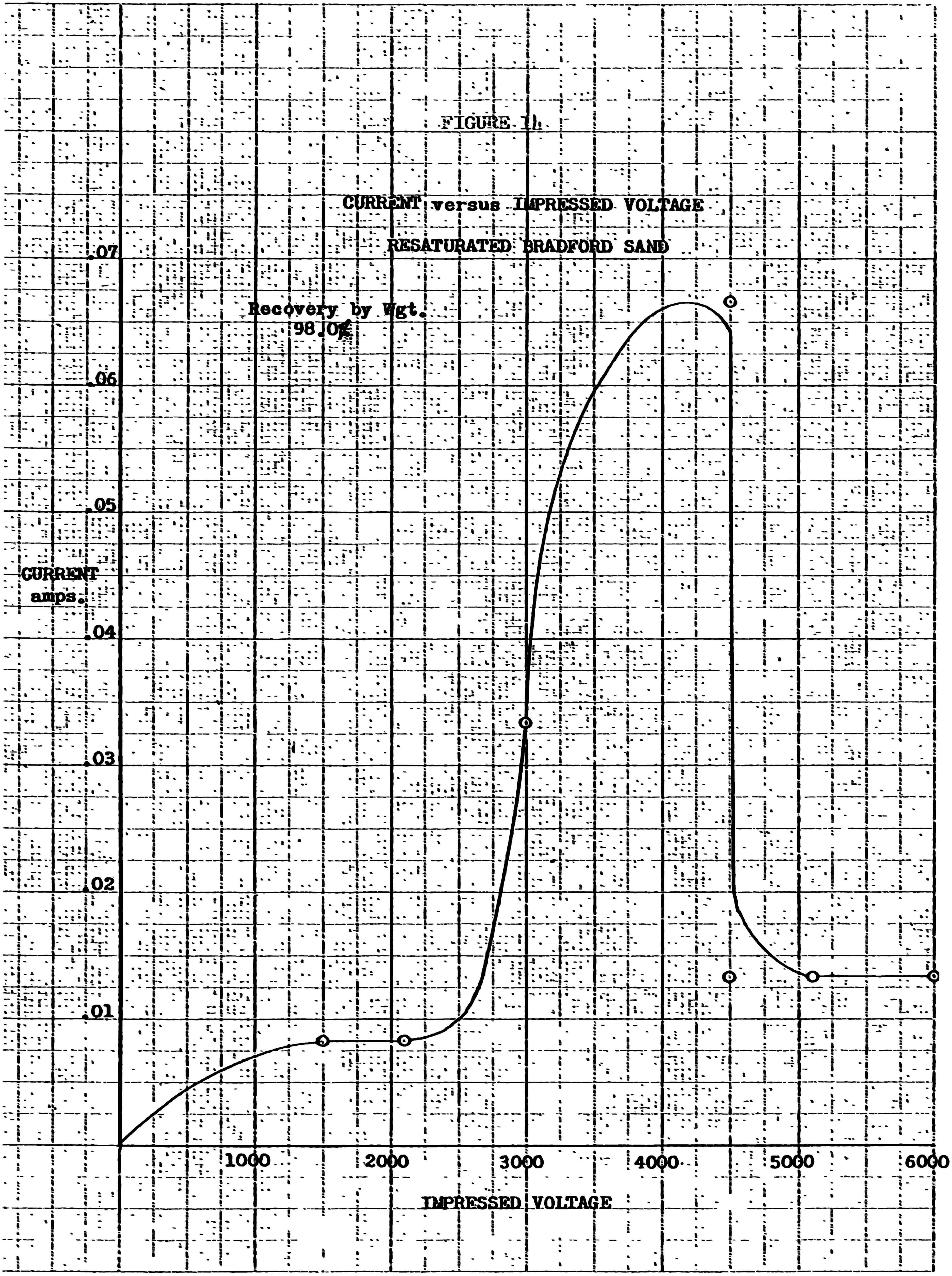
RESATURATED BRADFORD SAND

TIME MIN:SEC.	VOLTAGE	AMPERAGE	CURRENT DENSITY	LOAD VXA	IMPEDENCE	LOAD DENSITY	REMARKS
1:30	1500	.00834	.0525	12.5	180,000	78.9	Point Electrode Used
2:00	1500	.00834	.0525	12.5	180,000	78.9	
2:15	2100	.00834	.0525	17.5	252,000	110.5	
2:45	3000	.0334	.213	100.0	89,800	631.0	
3:00	4500	.0667	.421	300.0	67,500	1892.0	Sparking on Surface of Core
3:15	4500	.01333	.0841	60.0	337,000	378.5	Gas and Moisture Escaping Core
4:15	5100	.01333	.0841	68.0	382,000	429.0	
5:00	5400	.1000	.631	540.0	54,000	3405.0	Circuit Broken by Current Passing over Surface through Moisture leaving Core
6:00	4200	.0100	.0631	42.0	420,000	265.0	Resistance Increasing Due to Core Losing Moisture
7:00	4200	.00667	.0421	28.0	630,000	176.5	Shorting out Along Surface of Core. Circuit Broken
11:00	6000	.01333	.0841	80.0	450,000	505.0	Glass Tubing Removed Core Heating

FIGURE 14

CURRENT versus IMPRESSED VOLTAGE

RESATURATED BRADFORD SAND



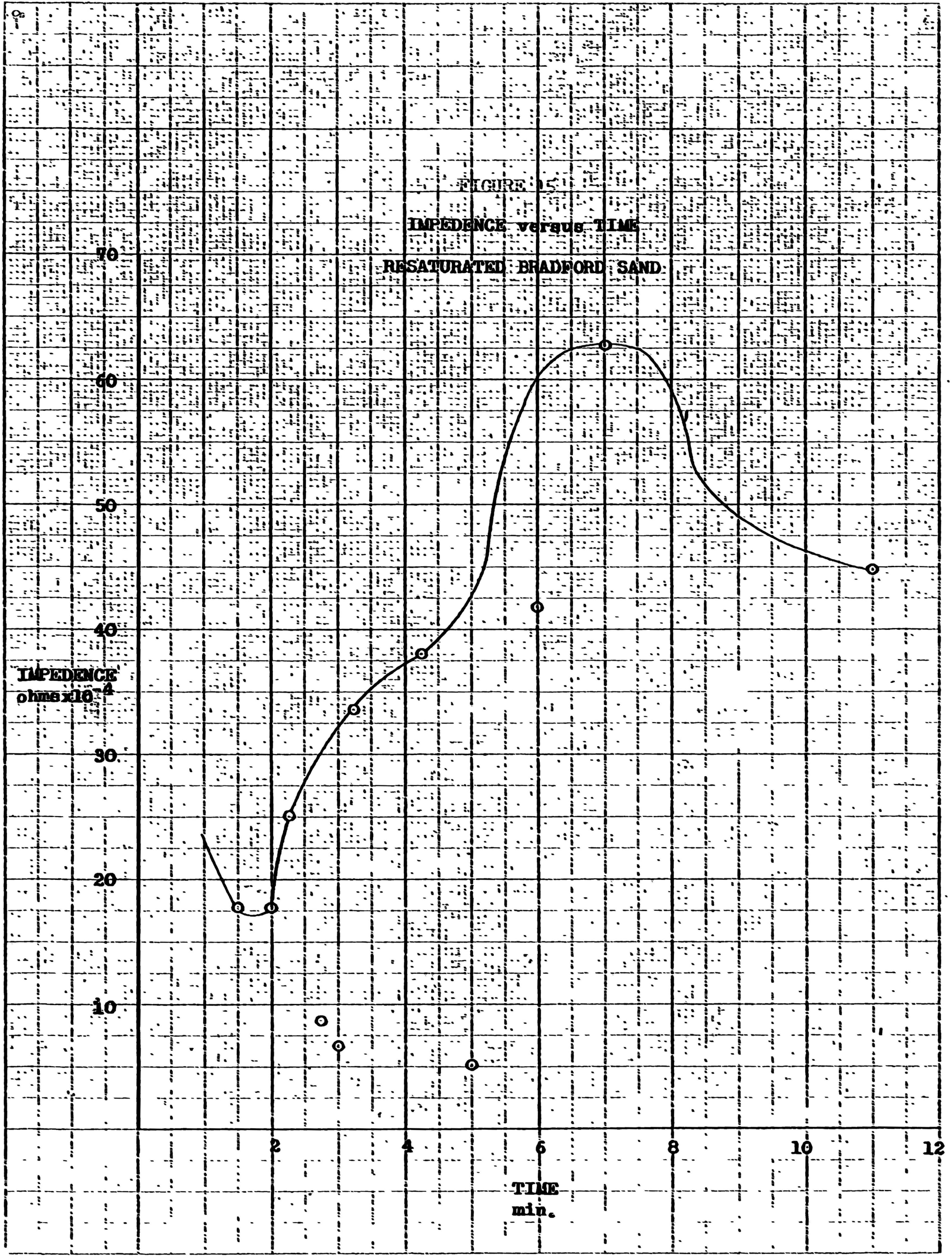


FIGURE 15

IMPEDENCE versus TIME

RESATURATED BRADFORD SAND

TABLE 3

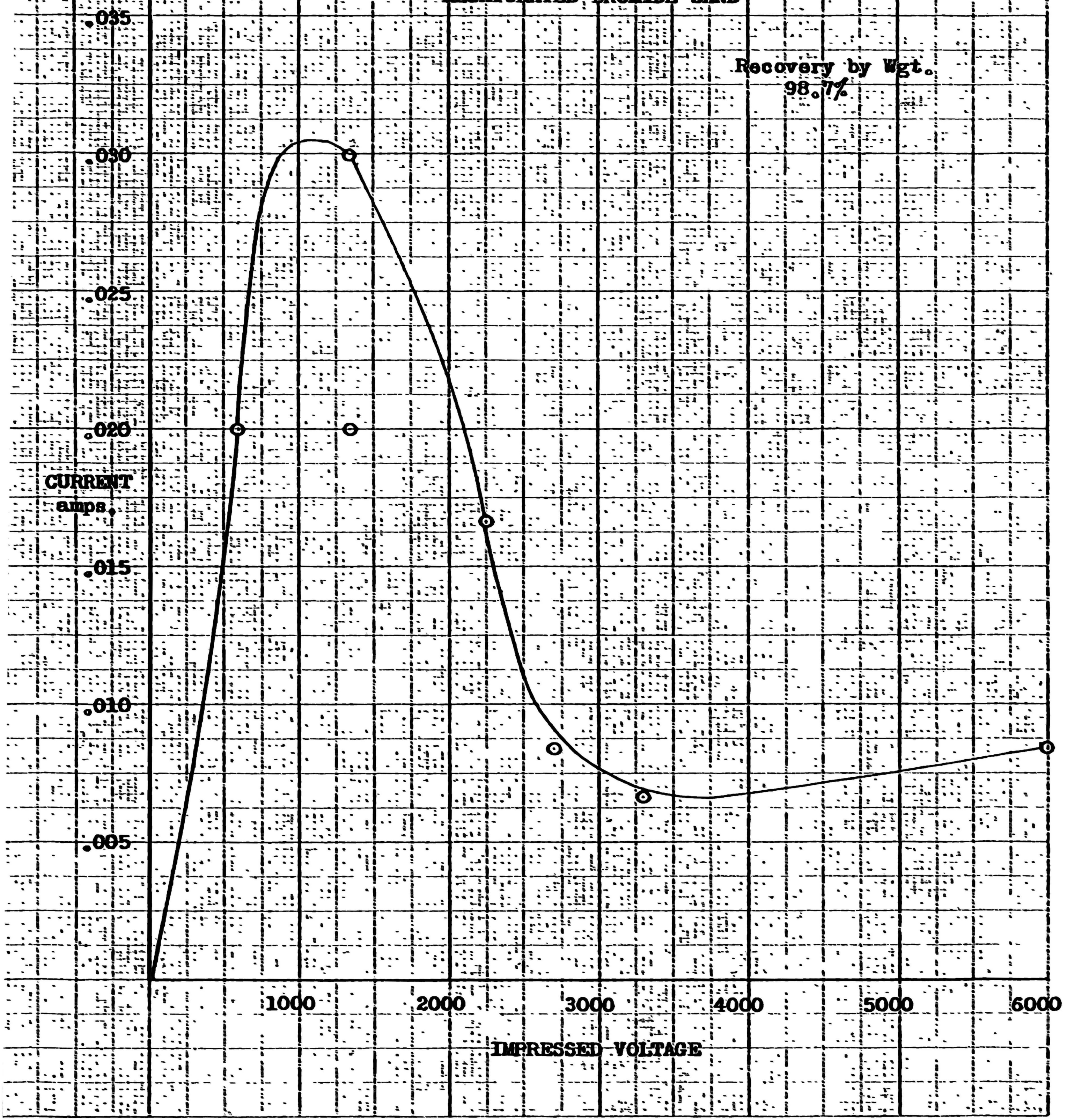
RESATURATED BROMIDE SAND

TIME MIN:SEC	VOLTAGE	AMPERAGE	CURRENT DENSITY	LOAD VXA	IMPEDENCE	LOAD DENSITY	REMARKS
0:30	1500	.1	.632	150.0	15,000	946.0	Circuit Broken; Current Arced over Surface
1:00	600	.02	.1262	12.0	30,000	76.8	
1:30	1350	.03	.1892	40.5	45,000	255.5	
1:40	1350	.02	.1262	27.0	67,500	170.5	
2:00	2250	.01666	.1050	37.4	135,000	236.0	
2:15	2700	.00834	.0525	22.5	324,000	142.0	
2:30	3000						Circuit Broken; Current Arced over Surface
3:00	2700	.00333	.0210	9.0	811,000	65.0	
3:15	3300	.00666	.0420	22.0	496,000	138.7	
3:45	3900	.00834	.0525	32.5	468,000	205.0	Core Heating Voltage Increased Amperage Constant
11:00	6000	.00834	.0525	50.0	720,000	315.0	Point Electrode Used

FIGURE 16

CURRENT versus IMPRESSED VOLTAGE

RESATURATED BROMIDE SAND



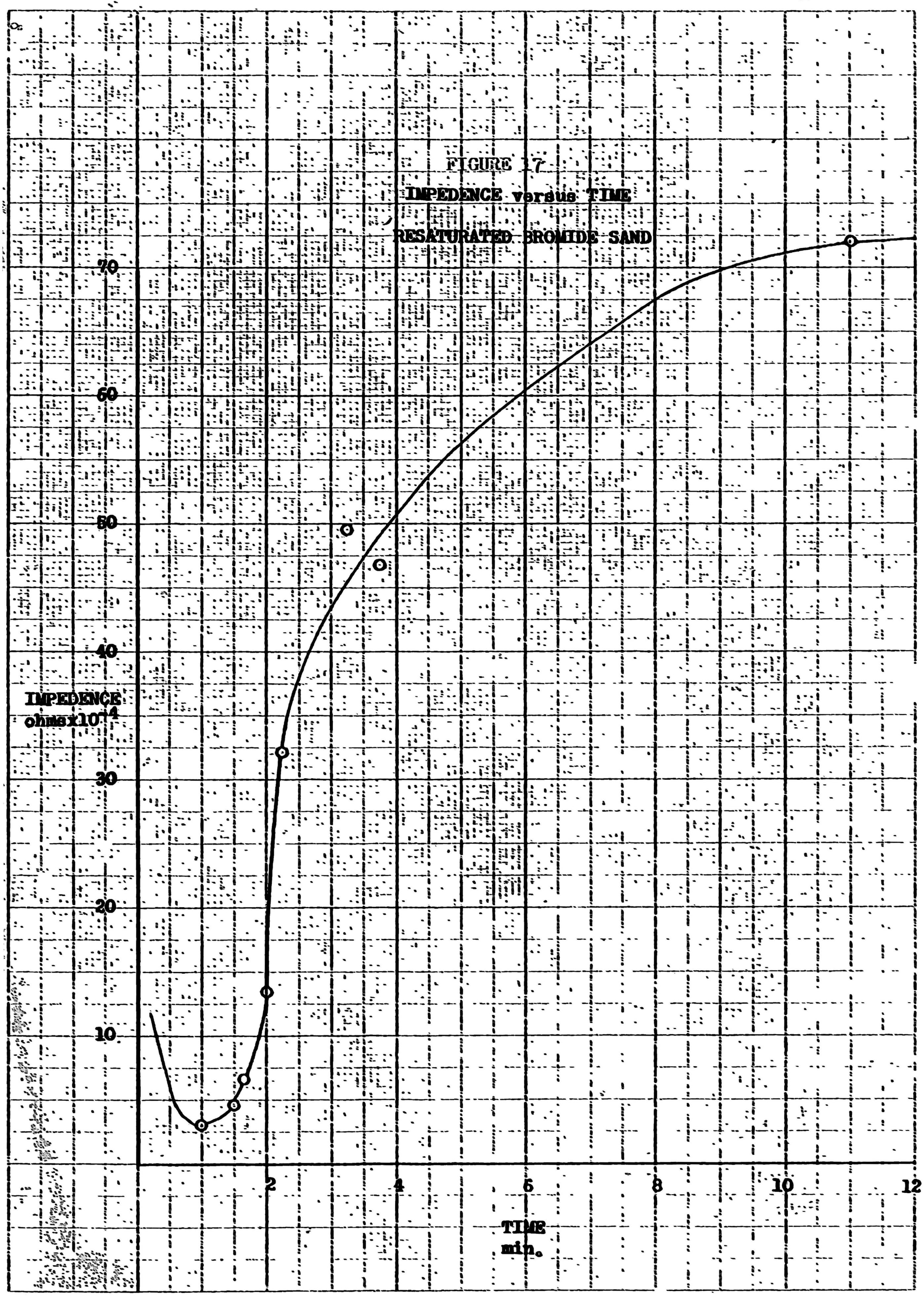


FIGURE 17
IMPEDENCE versus TIME
RESATURATED BROMIDE SAND
IMPEDENCE
ohmsx10^4
70
60
50
40
30
20
10
2
4
6
8
10
12
TIME
min.

to the heating fluids. Impedence increases as the fluids evaporate.

The final shape of both curves, depicting an amperage increase and impedence decrease, indicates the occurrence of breakthrough.

Eleven minutes of electrical heating resulted in 98.7 per cent recovery, by weight, of saturating fluids.

Lower Deese Sand

Data were obtained for the Lower Deese sand without resaturating the core. The experiment was carried out using both plate and point electrodes.

The current versus impressed voltage curve was plotted from the values recorded when the plate electrodes were used. The curve shows a constant increase of amperage with increasing voltage. After the values recorded in Table 4 had been determined, the heating was stopped, and the electrode tips changed. Heating was then resumed using the same core.

The impedence versus time curves for both the point and plate electrode tests demonstrate a decline in impedence with time. The values for the test made by using a point electrode show a slight rise at the end of the test.

The curves indicate an initial conductivity increase caused by the heating of the fluid in the core. Formation of a carbon link is interpreted from the failure of the amperage to reduce and the impedence to rise only slightly.

A recovery of 98.5 per cent, by weight, of the saturating fluids was obtained in one minute, thirty seconds.

Misener Sand

Plate electrodes were used to heat a resaturated sample of the

TABLE 4

LOWER DESSE SAND

TIME MIN:SEC.	VOLTAGE	AMPERAGE	CURRENT DENSITY	LOAD VXA	IMPEDENCE	LOAD DENSITY	REMARKS
							Plate Electrode Used
0.15	2250	.00333	.000657	7.5	676,000	1.48	
0.30	4500	.00666	.001313	30.0	676,000	5.91	
0:45	4950	.00834	.001645	41.2	587,000	8.125	
							Point Electrode Used
0:15	4500	.00666	.0421	30.0	676,000	189.1	
0:30	5400	.0100	.0632	54.0	540,000	341.0	
0:45	5550	.0100	.0632	55.5	555,000	350.0	Core Dry

FIGURE 18

CURRENT versus IMPRESSED VOLTAGE

LOWER DEESE SAND

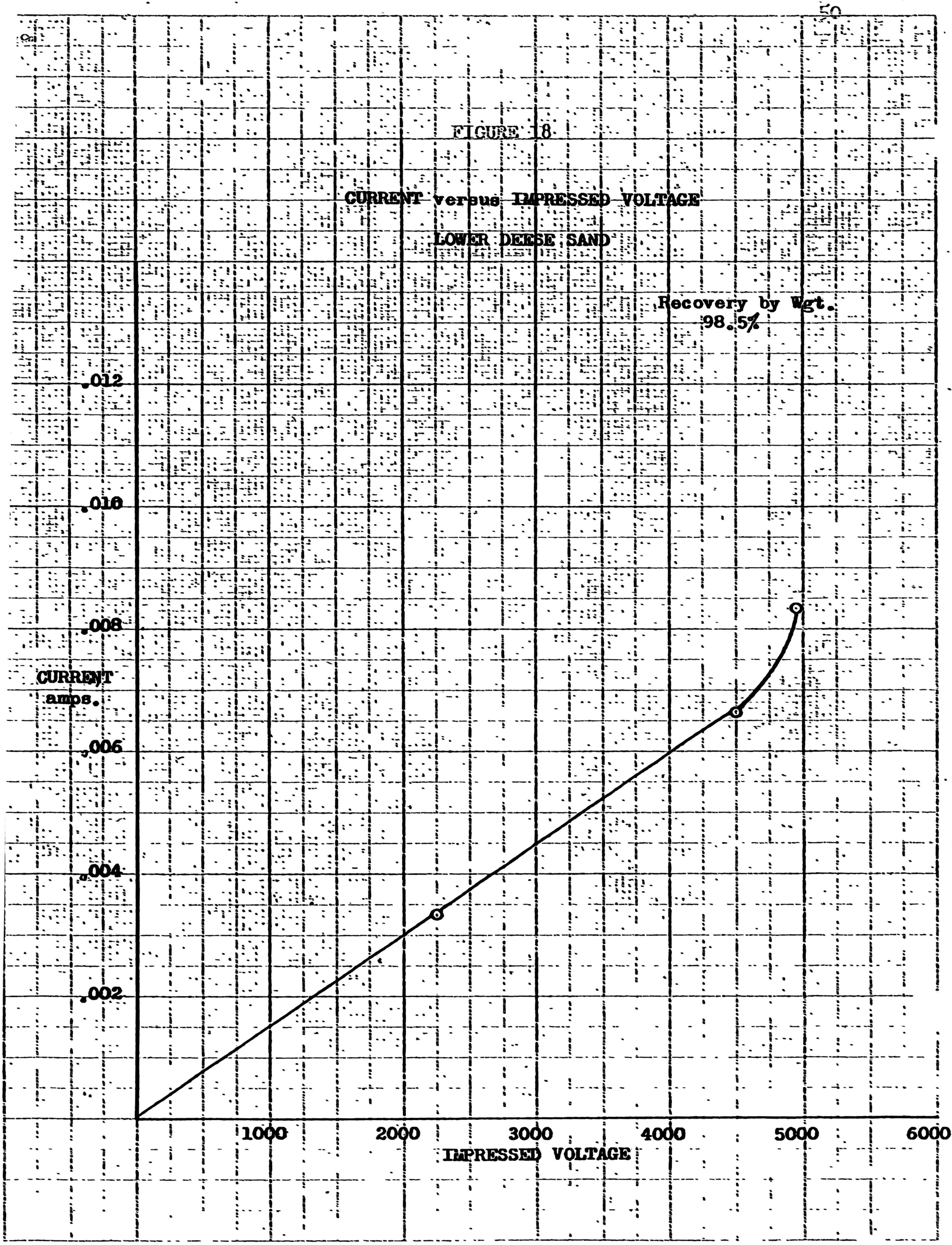
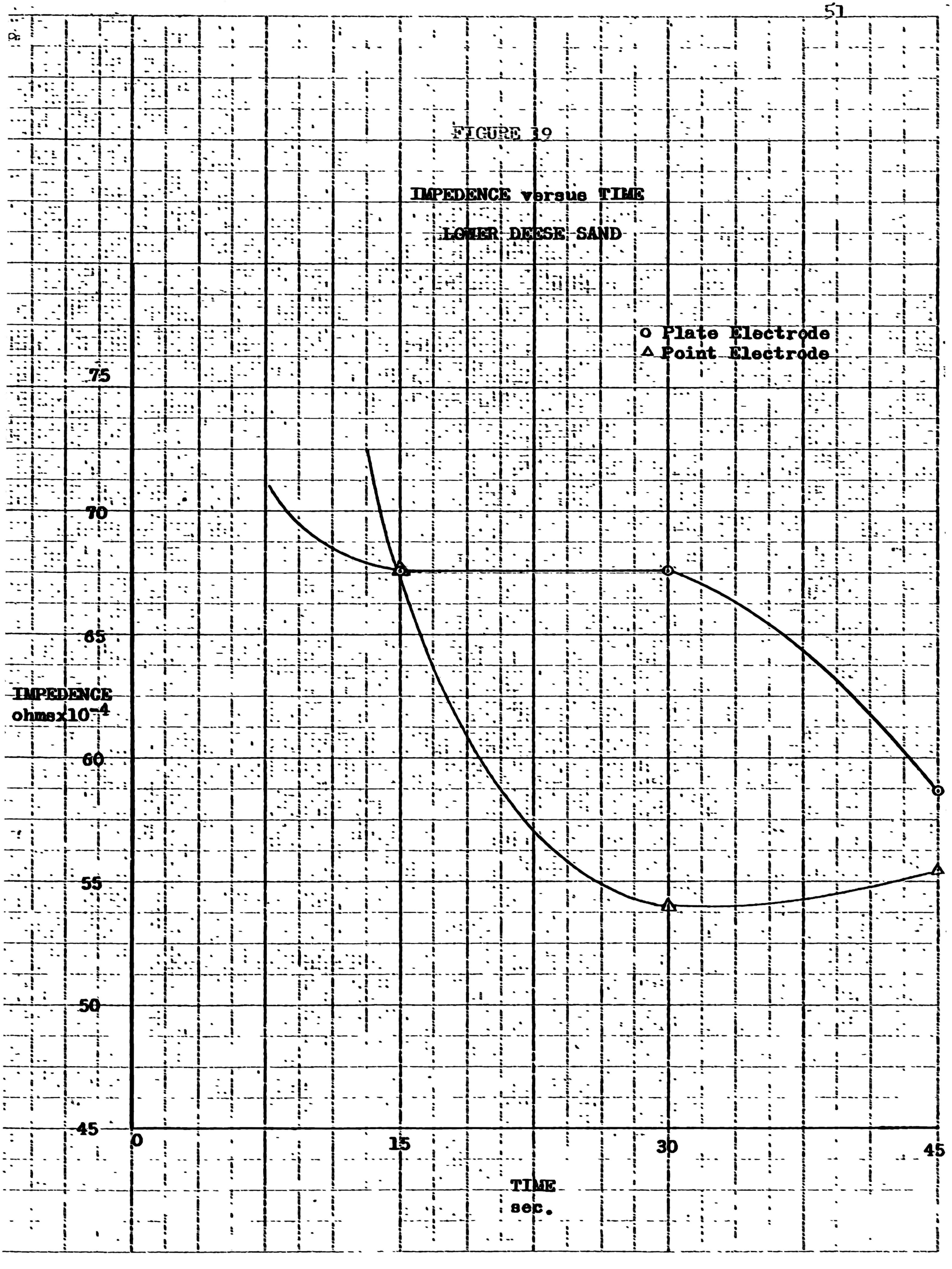


FIGURE 19

IMPEDENCE versus TIME

LOWER DEESE SAND



Misener sand to a high temperature in approximately forty-five seconds. A voltage of 3000 and an amperage of 0.05 were reached before the circuit broke as a result of current passing along the surface of the core. It was not possible to record values other than those immediately prior to the circuit break. Further testing of the core was impossible due to almost complete recovery (99.0 per cent, by weight) in the relatively short period of forty-five seconds.

The test showed that a high percentage of recovery is possible with short duration, high voltage and amperage shocks.

Burbank Sand

Voltage and amperage values were not recorded for the resaturated sample of the Burbank sand. Heating was possible but short circuiting occurred repeatedly.

Using plate electrodes 99.1 per cent recovery, by weight, was obtained with a high voltage and amperage shock.

Weber Sand

A maximum voltage of 4500 and amperage of 2 were reached while heating a resaturated core from the Weber sand. It was noted that the escaping fluids were responsible for conductivity being greater along the surface of the core rather than through the core. This resulted in frequent circuit breaks.

Oil began to flow from the core at 3000 volts yielding 99.3 per cent recovery by weight.

TABLE 5

PER CENT RECOVERY

SAND	ORIGINAL WGT. OF CORE, GRAMS	WGT.AFTER SOLVENT EXTRACTION, GRAMS	RESATURATED WGT.,GRAMS	WGT.AFTER ELECTRICAL HEATING, GRAMS	WGT.AFTER FISHER RETORTING, GRAMS	% RECOVERY BY SOLVENT EXTRACTION	% RECOVERY BY ELECTRICAL HEATING
Bartlesville	29.850	29.750	30.7640	29.394	28.9546	97.3	98.7
Bradford	34.0095	33.7378	35.4384	33.9500	33.2706	98.6	98.0
Bromide	17,7090	17.6657	18.4150	17.572	17.3353	98.2	98.7
Lower Deese				22.6574	22.3393		98.5
Misener	27.1262	27.0654	27.9120	27.2035	26.9640	99.5	99.0
Burbank	33.600	33.3242	34.1580	33.6295	33.3098	100.0	99.1
Weber	33.6021	33.5464	34.1410	33.5693	33.2511	99.2	99.3

CONCLUSIONS

The experiments show that high voltage electrical heating of stripper sands is scientifically sound.

Rapid evaporation of the oil and water from the cores resulted in a high percentage of recovery after a few minutes of heating. The creation of a carbon link was possible for each of the cores tested. This linkage would have been more pronounced if the oil contained by the sand had been of a lower A. P. I. gravity.

The current and load densities measured in the laboratory under true saturation conditions may be of the same order as those required in the field. This point will require further investigation.

The technique to be used for oil sand heating, with high voltage electricity, must be expanded greatly, in order to apply the method to field use.

The economic considerations for practical application of recovery by high voltage electrical heating have not been studied. Complete reservoir studies will be necessary in order to determine if additional oil to be gained is sufficient to justify the capital expenditure. A cheap source of electric power obviously must be available if the method is to be an economic possibility.

The creation of an effective radius of heating about the well, by means of a short duration high voltage and high amperage shock, seems at present to be the most economical application of this method. Technically and economically it would be more favorable to attempt any future field experimentation on a shallow sand. The sands studied occur at depths between 2000 and 7000 feet; such depth will present additional difficulties.

The curves of impedence versus time and of amperage versus impressed voltage for a resaturated core will be similar in shape to those plotted for a sample having the true reservoir saturation. The magnitude of the values recorded will, however, differ.

Summary

Cores from seven oil bearing sands, presently under stripper production, were obtained for the purpose of determining their behavior during high voltage electrical heating.

A sample of each sand first was desaturated to determine its original oil and water saturation. The permeability and porosity of each was measured.

The cores were found to be dry, due to exposure to the atmosphere, and were resaturated.

The resaturated cores were then subjected to electrical heating and their behavior was noted.

Percentage recovery by weight was found to be of the order of 98 to 99 per cent.

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VITA

John Curtin Schratwieser was born February 21, 1927, at East Rockaway, Long Island, New York. He received his secondary education at the East Rockaway High School. He served in the United States Army from 1944 to 1947; from June, 1944 to March, 1945, he attended Princeton University under the Army Specialized Training Reserve Program. He received a B. S. in Chemistry from St. Francis College, Brooklyn, New York in 1949. From June 1949 to the present, he was enrolled as a graduate student in Petroleum Engineering at the University of Missouri School of Mines and Metallurgy.