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East Mereenie No. 4

Waterflood Susceptibility and Water-Oil Relative Permeability Tests on Samples from the Pacoota Sandstone Reservoir

by

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BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS
MINERAL RESOURCES BRANCH
PETROLEUM TECHNOLOGY SECTION

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WATERFLOOD SUSCEPTIBILITY AND WATER-OIL RELATIVE PERMEABILITY TESTS ON SAMPLES FROM THE PACOOTA SANDSTONE RESERVOIR

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INTRODUCTION :

East Mereenie No. 4 is the sixth successive well drilled on the Mereenie Anticline lying across Oil Permits 43 and 56 in the Northern Territory. This well was put down to further test the hydrocarbon potential of this structure, which has been found to contain both oil and gas.

Special core analysis including determination of porosity, permeability, capillary pressure, fluid imbibition and electrical resistivity was carried out in 1967, on core samples from the East Mereenie No. 4 well in the Petroleum Technology Laboratory of the Bureau of Mineral Resources.

On completion of this analysis Magellan Petroleum Corporation, the holder of Permit 43, requested additional studies on cores from this well. These comprised waterflood susceptibility, water-oil relative permeability and gas-oil relative permeability tests. The results of the waterflood and water-oil relative permeability investigations are included in this report. Gas-oil relative permeability studies will be conducted at a later date when the required equipment becomes available.

PROCEDURE AND APPARATUS :

The tests were conducted on ten samples selected from three cores. These samples were initially subjected to waterflood susceptibility tests. Subsequently, additional investigations involving waterflooding at much higher oil-water viscosity ratio were conducted in order to evaluate the water-oil relative permeability relationships over a much wider saturation interval.

The samples selected for testing were drilled parallel to bedding, using a 1½-inch diamond core bit. These core plugs, 1½ inches in diameter and approximately 1½ inches in length, were drilled, parallel to bedding, out of core samples selected for testing. They were then extracted with toluene for approximately 16 hours in a soxhlet-type apparatus and dried in an oven at 110°C for 24 hours.

Subsequent to measurement of porosity in a mercury porosimeter, and of permeability to nitrogen in a Hassler cell, the samples were prepared for waterflooding tests, by initially saturating them with a 5% NaCl brine, approximating the salinity of the formation water in the Pacoota reservoir. The samples were then separately placed in a Hassler cell, and residual water saturation was established in each by dynamic displacement with viscous mineral oil (approximately 130 cp. @ 20°C). The resultant oil and water saturations in the samples were determined by comparing the original (single phase) brine saturation with the total volume of the aqueous effluent.

After establishing residual water saturations in the samples, the viscous oil was displaced from each plug by extensive flushing with a light refined oil. In the absence of reliable data on fluid viscosities at reservoir conditions in this well, soltrol-C oil was chosen to approximate the reservoir oil giving an oil water viscosity ratio of 1.4:1.

Prior to the waterflood tests, permeability with respect to soltrol-C was determined in each of the samples at residual water saturation. Then using a 0.2% NaCl brine (with 25 p.p.m. $HgCl_2$ as preservative) to represent the Mereenie formation injection water, the plugs were water-flooded to residual oil saturation. Incremental volumes of oil and water were collected at selected time intervals throughout the tests. Permeability to the injection water was determined at residual oil saturation on completion of each of the flood tests.

The incremental volumes of water and oil produced during the waterflood tests were utilized in compiling an oil recovery curve for each sample. This was done as follows : oil recovery readings taken at, and subsequent to water breakthrough, were expressed as a percentage of sample pore volume, and were plotted as a function of the brine injected at the same increment expressed in pore volumes. A water "cut" curve of the oil recovery as a function of the percentage water in the total production was also calculated for each of the samples.

The water-oil relative permeability tests were initiated by the re-extraction and drying of the waterflood test samples. The same procedure was followed as that preceding the water flood tests to establish residual water saturation. However, this time a mixed oil composed of soltrol-C and mineral oil having a resultant viscosity of approximately 30 cp. was used. Permeability was measured in each of the samples with respect to this oil at residual water saturation.

Flooding tests were again conducted using 0.2% NaCl brine as the injection water giving an oil-water viscosity ratio of 30.8:1 at 20°C. These tests were again carried to the point of residual oil saturation, and results were calculated from the measurement of oil and water volumes at water breakthrough and at selected time intervals thereafter.

The water-oil relative permeability calculations were based on a method by Johnson, Bossler and Nauman.(2) Relative permeability to the oil and water phases produced throughout the tests were expressed in terms of the percentage of the oil permeability determined prior to the Kw/Ko test. The resultant values were plotted as a function of the average water saturation (including residual) in the samples. A curve of the water-oil relative permeability ratio as a function of the average water saturation was also developed for each sample.

DISCUSSION OF RESULTS :

The results of the foregoing tests are listed as follows :

(1) The waterflood and water-oil relative permeability test data are included in Table 1.

(2) Results of the water flood susceptibility tests are shown in Figures 1-9.

(3) Figures 10-18 show the water-oil relative permeability relationship.

(4) Figures 19-27 present the relative permeability ratios.

The initial preparation of these samples for waterflooding tests revealed characteristics which compared favourably with those obtained in tests on a previous report (1) on cores from this well. Residual water/permeability relationships established by dynamic displacement with oil in these tests were in the same range as those evaluated previously by mercury injection. The corresponding relationship between the oil and dry nitrogen permeability established in the two sets of investigations also appears favourable.

The waterflood susceptibility test results indicated a reasonably good oil recovery; the average recovery for all samples at water breakthrough (see Note 1) being 37% of pore volume, and 44% of pore volume at residual oil saturation. The small oil recovery subsequent to water breakthrough is probably an expression of the fairly uniform pore distribution, as shown in adjacent samples (1).

However, due to the low oil-water viscosity ratio, and the small oil recovery subsequent to water breakthrough in these tests, conditions were not satisfactory for evaluation of water-oil relative permeability. Only a very small portion of the relative permeability curves could be evaluated subsequent to water breakthrough during which two-phase flow existed. This necessitated further tests to try and extend the interval of two-phase production.

Investigations (3) have shown that relative permeability is independant of the viscosity of the non-wetting (oil) phase, provided no saturation gradient caused by capillary "end effects" (see Note 2) exists at the effluent core face. It follows therefore, that the saturation interval over which a relative permeability relationship may be evaluated can be considerably increased by using a higher viscosity non-wetting (oil) phase to initiate earlier water breakthrough.

Accordingly, flooding tests were conducted at a 30.8:1 oil-water viscosity ratio (20°C). This resulted in a much earlier water breakthrough than the previous flooding tests conducted at a 1.4:1 ratio, and the saturation range over which two phase production could be determined was more than doubled.

Relative permeability to water at residual oil saturation was generally higher than expected in most samples during these latter floods. The initial waterflood tests conducted at an oil-water viscosity ratio of 1.4:1 and formation damage tests reported in B.M.R. Record No. 1967/121 indicated water permeability at residual oil saturation to be lower in these and adjacent samples.

The waterflood tests conducted at the higher oil-water viscosity ratio required a relatively high displacement pressure (noted in Table 1) as compared to the initial low viscosity floods. Residual oil saturations obtained in both sets of flooding tests were generally comparable within the range of experimental error. Therefore, the discrepancies in water permeability results between the two tests were probably caused by capillary "end effects" with resultant variations in the saturation gradient at the outlet end face in the initial flooding tests. This in turn would create some holdup or "drag" in the flow capacity, but would not be expected to materially effect the waterflood oil recovery.

However, because of the apparent effect of rate in the water-oil relative permeability results, additional tests to investigate this phenomenon whereby relative permeability to oil and water was measured at several different flowing rates (in separate tests), to evaluate any possible variation in the relative permeability curves, would be warranted.

CONCLUSIONS :

Special core analysis tests comprising waterflood susceptibility and water-oil relative permeability investigations on selected core samples from the

East Mereenie No. 4 well have shown the following :

(1) Residual water saturations established by dynamic displacement with viscous oil compare favourably with water saturations evaluated by mercury injection on adjacent samples (of similar permeability range) as previously reported (1).

(2) Oil recovery by waterflooding averaged 37% of pore volume at water breakthrough, and 44% of pore volume at residual oil saturation. The small additional oil recovered subsequent to water breakthrough is probably the expression of a uniform pore distribution.

(3) A generally moderate permeability to water was indicated at residual oil saturation by the relative permeability tests. This was not in complete agreement with the (lower) water permeability results in the initial flooding tests. Since the initial floods were conducted at a lower rate than the latter because of a much lower oil-water viscosity ratio, it is assumed the difference in flow capacity may have been due to capillary "end effects" during the initial flood tests.

<u>Note 1</u> : <u>Water Breakthrough</u> - the point at which water injected at the input face of the sample first appears at the outlet (effluent) face. In the reservoir, this corresponds to the first production of water at an oil producing well from some water injection well source.

<u>Note 2</u> : <u>Capillary End Effects</u> - A buildup of the wetting phase at the effluent core face due to capillary discontinuity between the core sample and the end plug. The effect may be minimized by maintaining relatively high rates of flow during laboratory testing.

REFERENCES :

1. McKAY, B.A. "East Mereenie No. 4 - Special Core Analysis Tests On Samples From the Ordovician (Pacoota) Sandstone Reservoir". Bureau of Mineral Resources; Record 1967/121.

2. JOHNSON, E.F., BOSSLER, D.P., NAUMAN, V.O. "Calculations of Relative Permeability From Displacement Experiments". Journal of Petroleum Technology; January, 1959.

3. SANDBERG, C.R., GOURNAY, L.S., SIPPEL, R.F. "The Effect of Fluid-Flow Rate and Viscosity on Laboratory Determinations of Water-Oil Relative Permeabilities". Petroleum Transactions - AIME; Volume 213, 1958.

TABLE 1

Sample Depth (feet)	WATER FLOOD TEST DATA: Permeability (md.) To Dry Nitrogen	To 1.4 cp. oil at Residual Water Saturation	To water at Residual Oil Saturation	Porosity (% bulk volume)	Residual water saturation before waterflood test (% pore volume)	Residual oil saturation after water flood (% pore volume)	Oil Recovery (% pore volume) At water break through	At 10 pore volumes water throughput	Test Pressure Used (PSI)	RELATIVE PERMEABILITY TEST DATA: Permeability to 30 cp. oil at residual water saturation (md.)	Residual water saturation before Kw/Ko test (% pore volume)	Test Pressure Used (PSI)
4615	2.3	1.2	>0.1	8.5	20.2	47.8	32	32	120	1.1	20.2	120
4618	34	31	1.9	12.3	11.5	40.2	45.5	48.3	20	25	11.5	120
4631	31	21	4.1	8.2	12.2	46.6	31.3	41.2	30	18	12.2	68
4632	20	14	3.2	9.5	12.5	41.0	28.4	46.5	40	14	12.5	120
4633	13	8.4	1.0	8.4	17.4	39.6	33.3	43	50	6.9	17.4	100
4708	0.12	N.D.	N.D.	5.3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
4710	34	25	1.9	9.6	9.4	39.1	43.3	51.5	20	26	9.4	100
4711	26	18	1.3	10.4	15.7	37.3	36	47.0	62	17	15.7	118
4712	15	11	0.4	10.4	12.6	44.9	41.2	42.5	50	11	12.6	140
4713	32	19	0.9	10.1	11.1	44.9	40.2	44	30	19	11.1	120
AVERAGES	- - -	- - -	- - -	9.3	13.6	42.4	36.8	44.0			13.6	

N.D. : Not Determined

FIGURE 1

WATER FLOOD SUSCEPTIBILITY

WELL NAME AND NUMBER – E.MEREENIE No.4

DEPTH INTERVAL – 4615

POROSITY – 8.5 %

PERMEABILITY TO OIL – 1.2 Md.

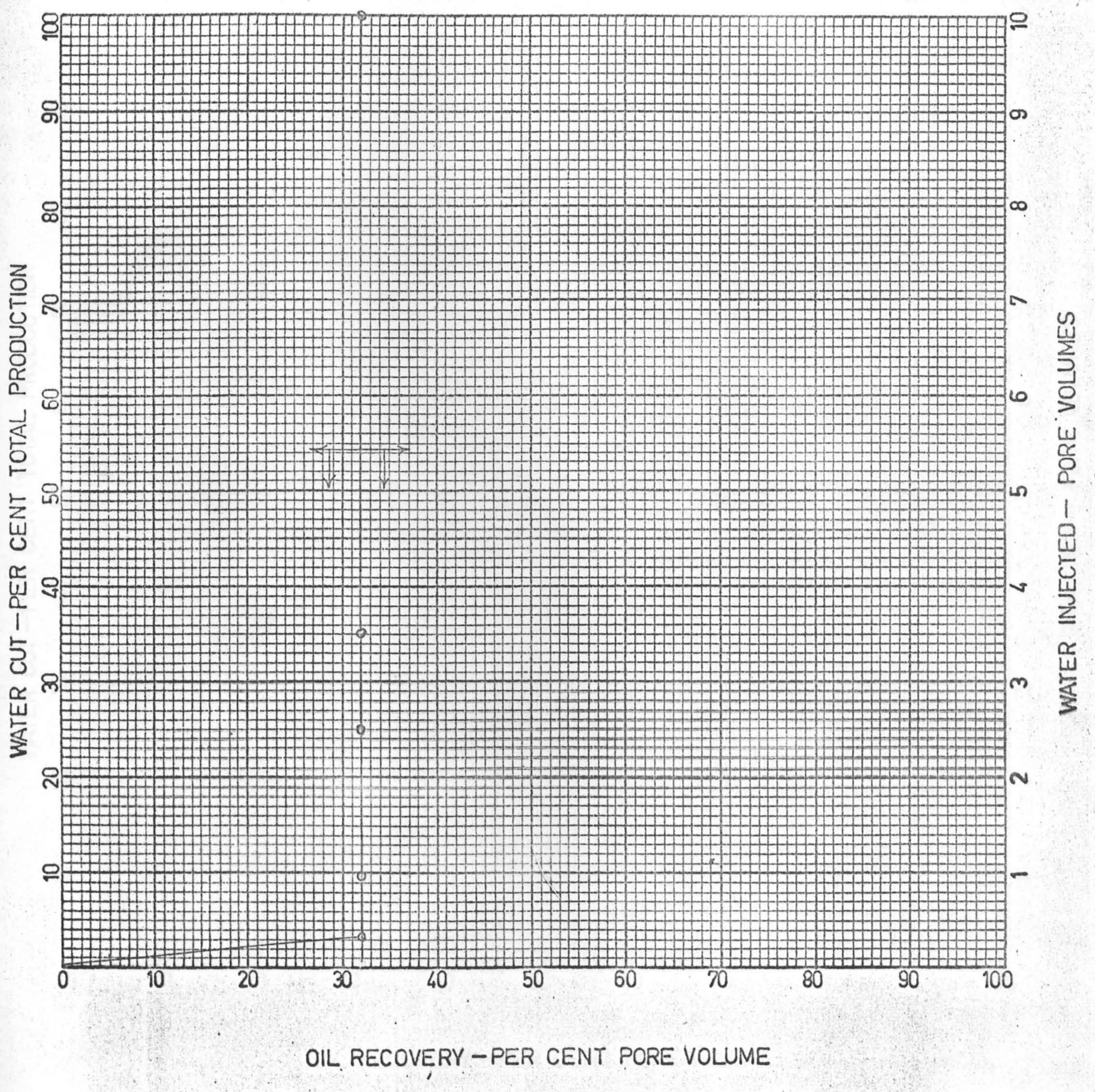

FIGURE 2

WATER FLOOD SUSCEPTIBILITY

WELL NAME AND NUMBER – E.MEREENIE No.4

DEPTH INTERVAL – 4618

POROSITY – 12.3 %

PERMEABILITY TO OIL – 31 Md.

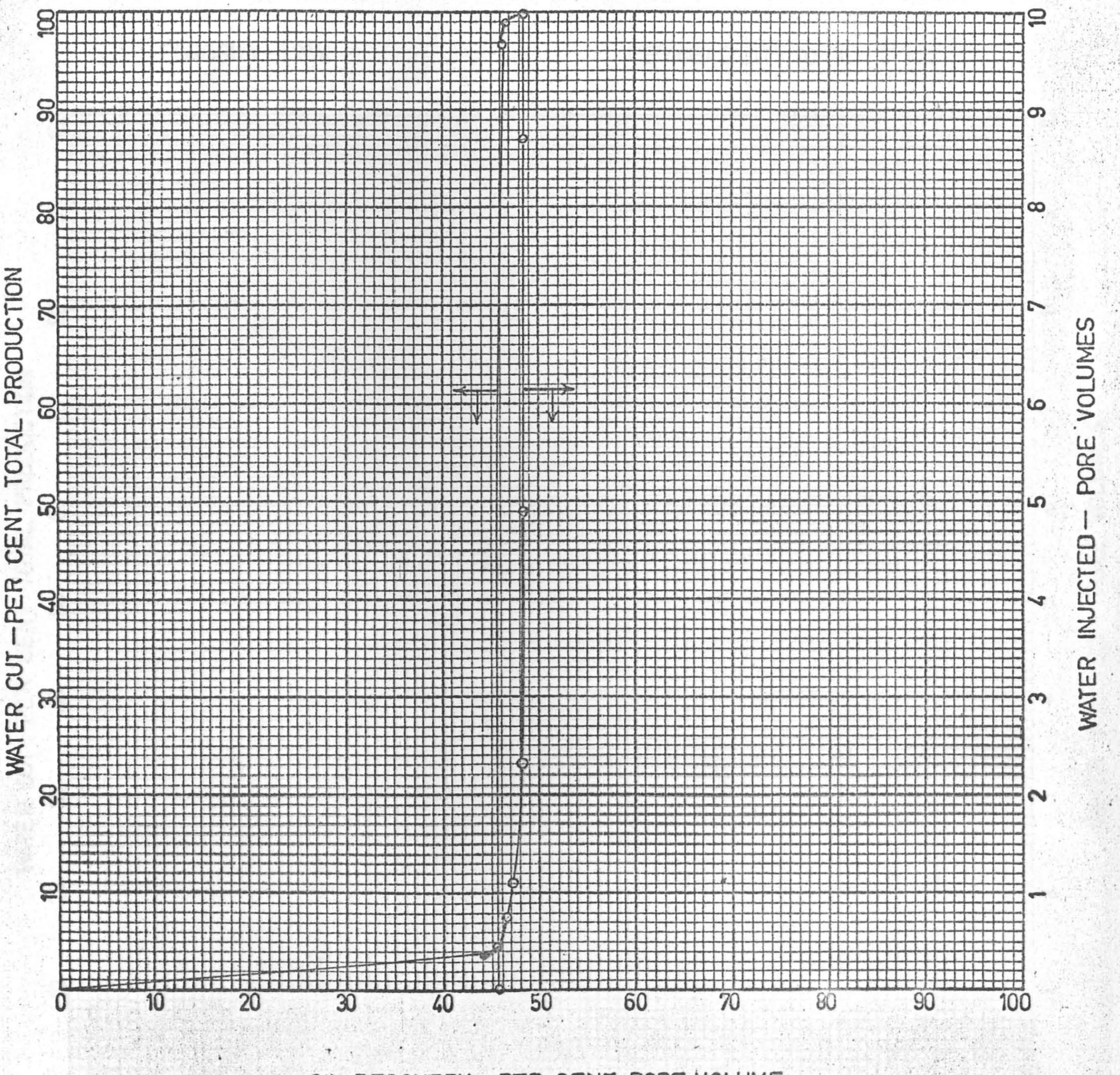

FIGURE 3

WATER FLOOD SUSCEPTIBILITY

WELL NAME AND NUMBER - E.MEREENIE No. 4

DEPTH INTERVAL - 4631

POROSITY - 8.2%

PERMEABILITY TO OIL - 21 Md.

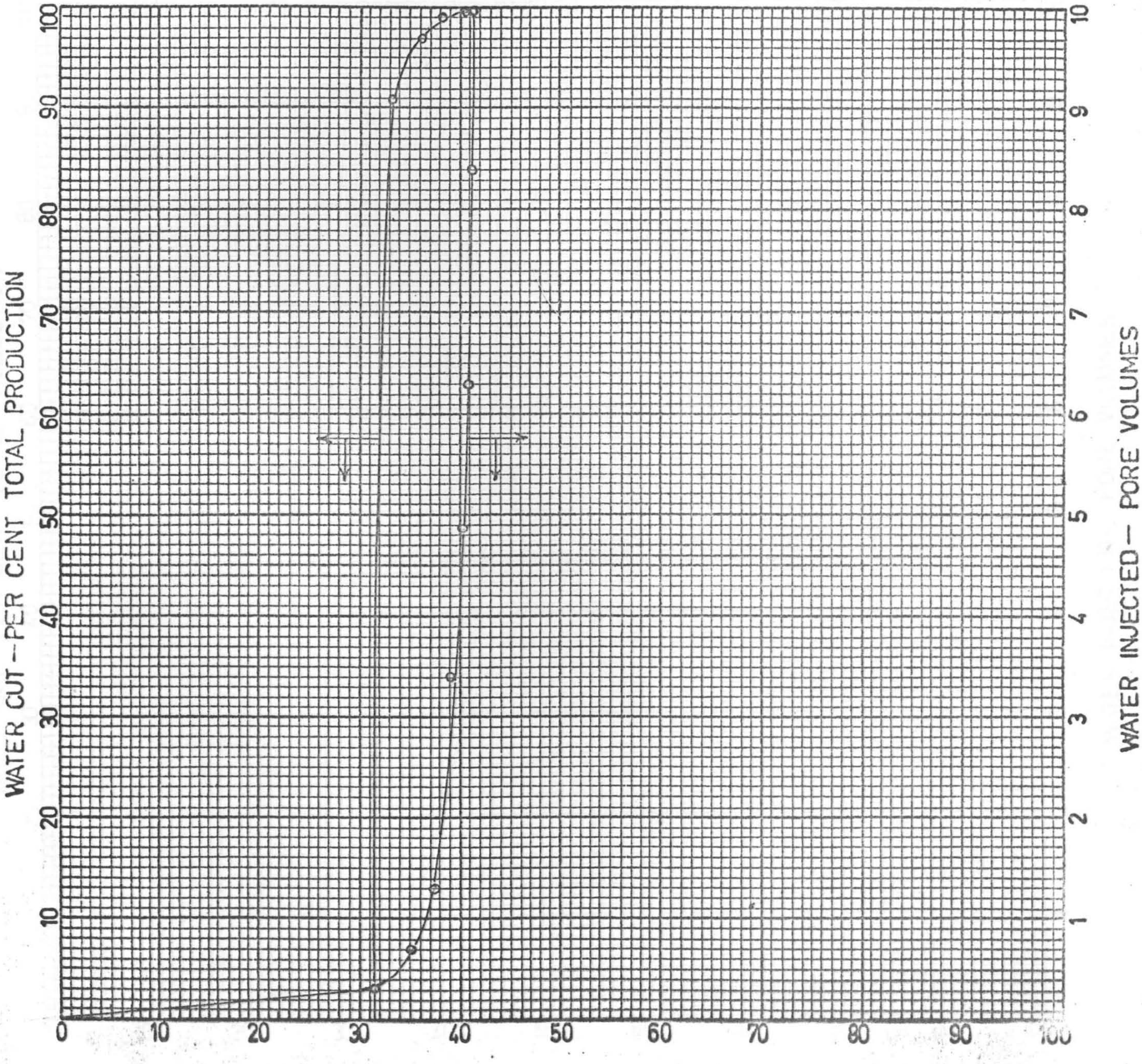

FIGURE 4

WATER FLOOD SUSCEPTIBILITY

WELL NAME AND NUMBER - E.MEREENIE No. 4

DEPTH INTERVAL - 4632

POROSITY - 9.5%

PERMEABILITY TO OIL - 14 Md.

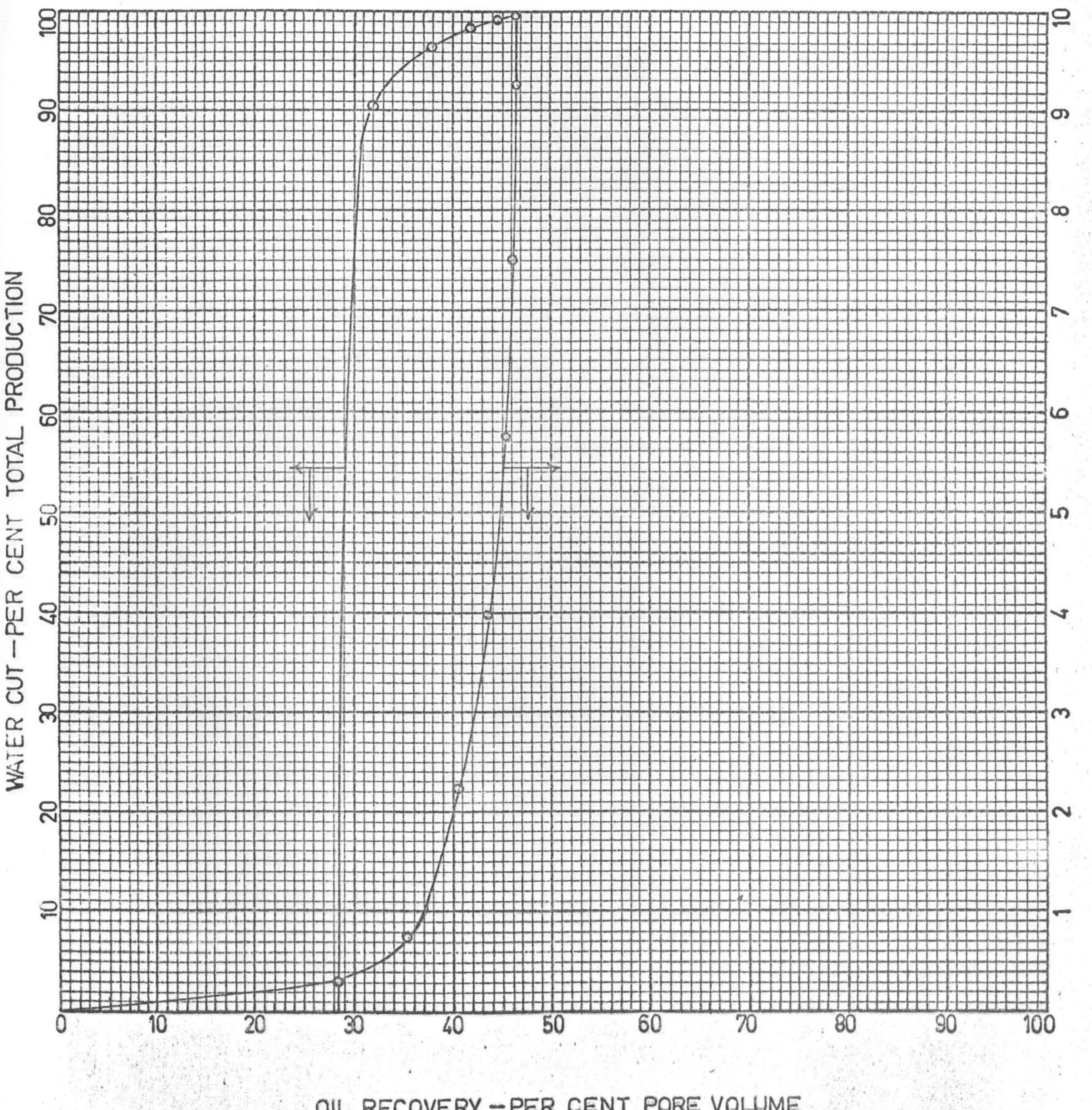

FIGURE 5

WATER FLOOD SUSCEPTIBILITY

WELL NAME AND NUMBER - E. MEREENIE No. 4

DEPTH INTERVAL - 4633

POROSITY - 8.4%

PERMEABILITY TO OIL - 8.4 Md.

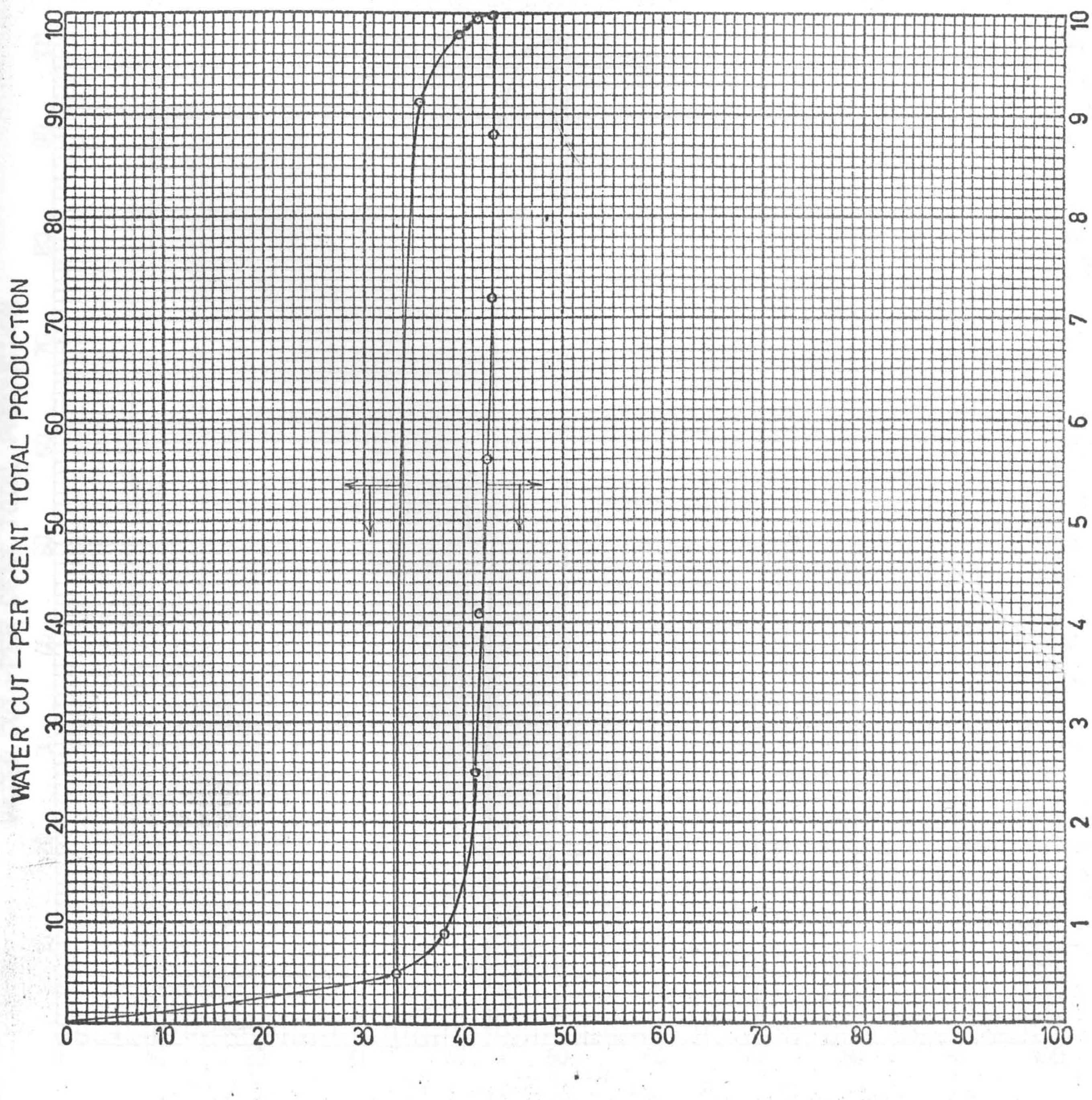

FIGURE 6

WATER FLOOD SUSCEPTIBILITY

WELL NAME AND NUMBER-E.MEREENIE No.4

DEPTH INTERVAL-4710

POROSITY-9.6%

PERMEABILITY TO OIL- 25 Md.

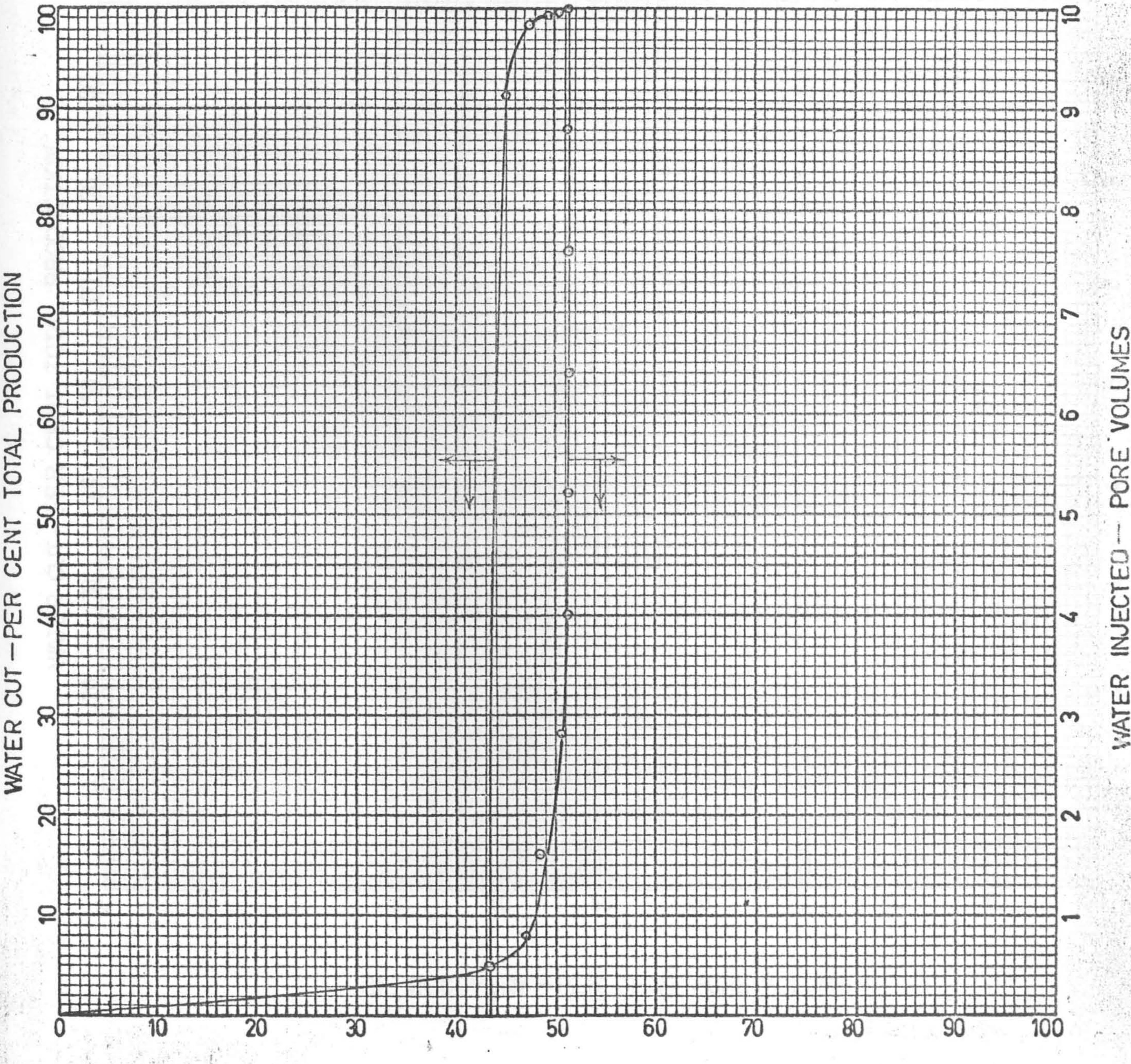

FIGURE 7

WATER FLOOD SUSCEPTIBILITY

WELL NAME AND NUMBER – E. MEREENIE No. 4

DEPTH INTERVAL – 4711

POROSITY – 10.4

PERMEABILITY TO OIL – 18 Md.

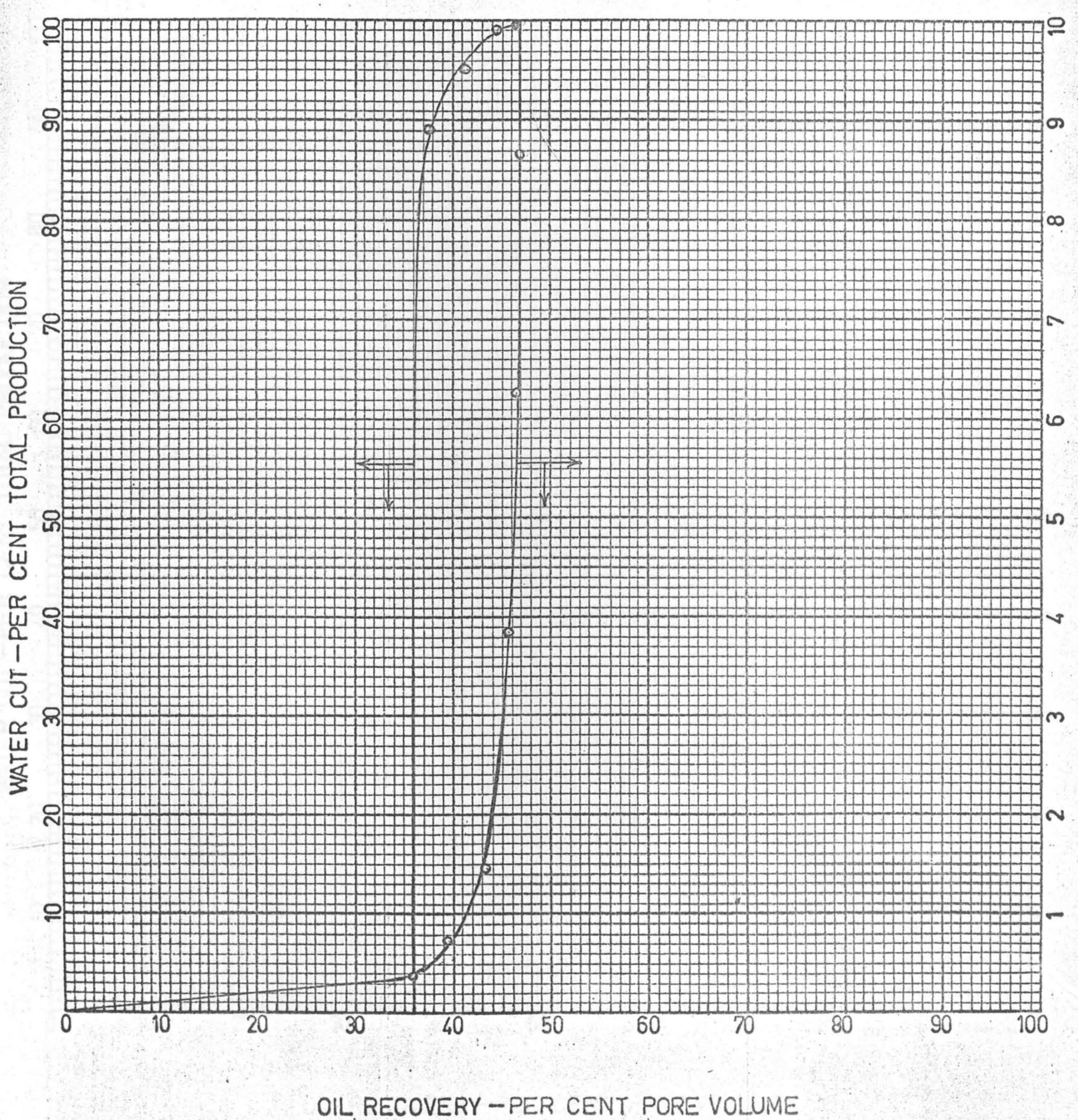

FIGURE 8

WATER FLOOD SUSCEPTIBILITY

WELL NAME AND NUMBER–E.MEREENIE No. 4

DEPTH INTERVAL–4712

POROSITY–10.4

PERMEABILITY TO OIL–11 Md.

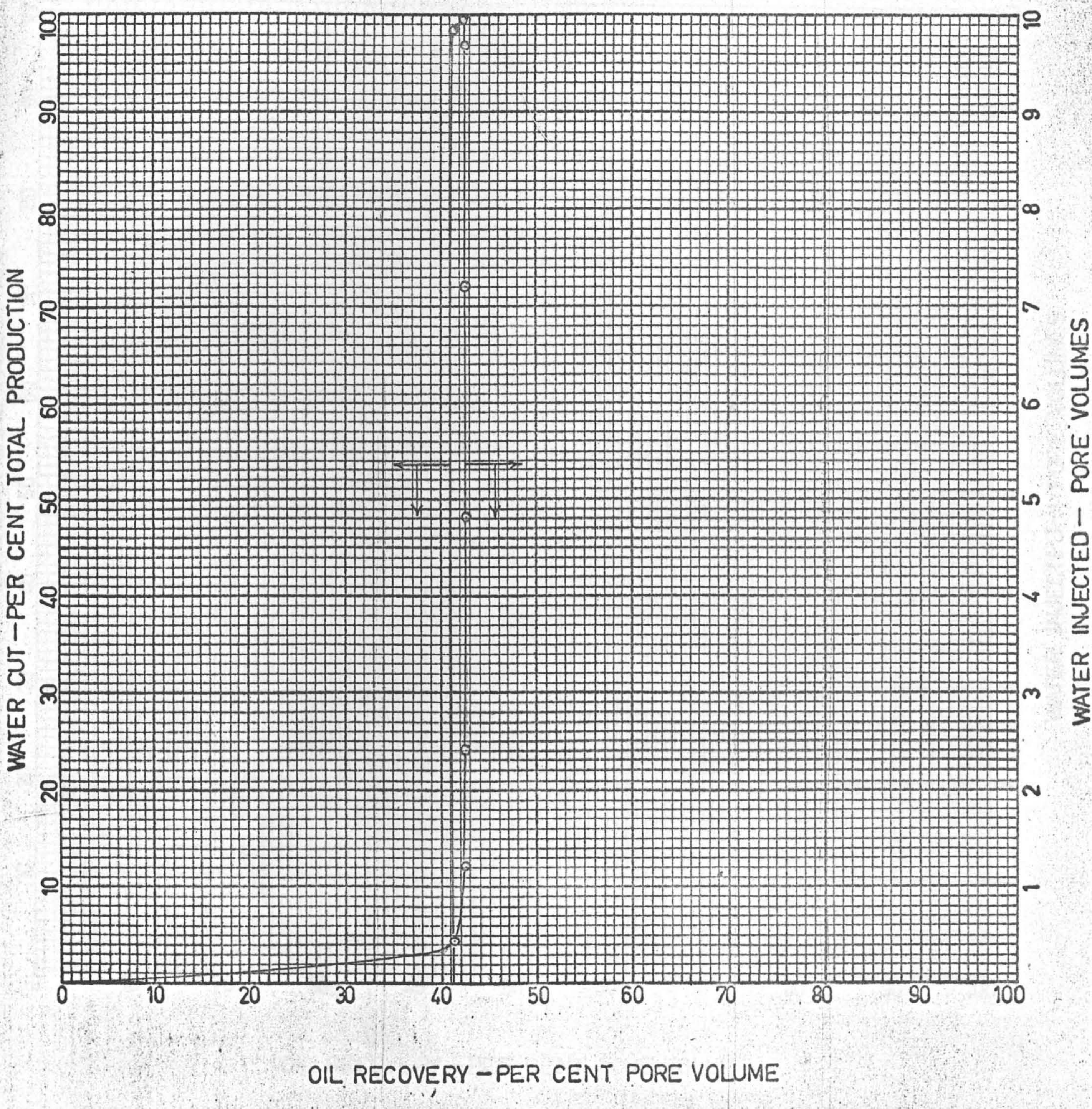

FIGURE 9

WATER FLOOD SUSCEPTIBILITY

WELL NAME AND NUMBER–E.MEREENIE No. 4

DEPTH INTERVAL–4713

POROSITY–10.1 PERMEABILITY TO OIL–19 Md.

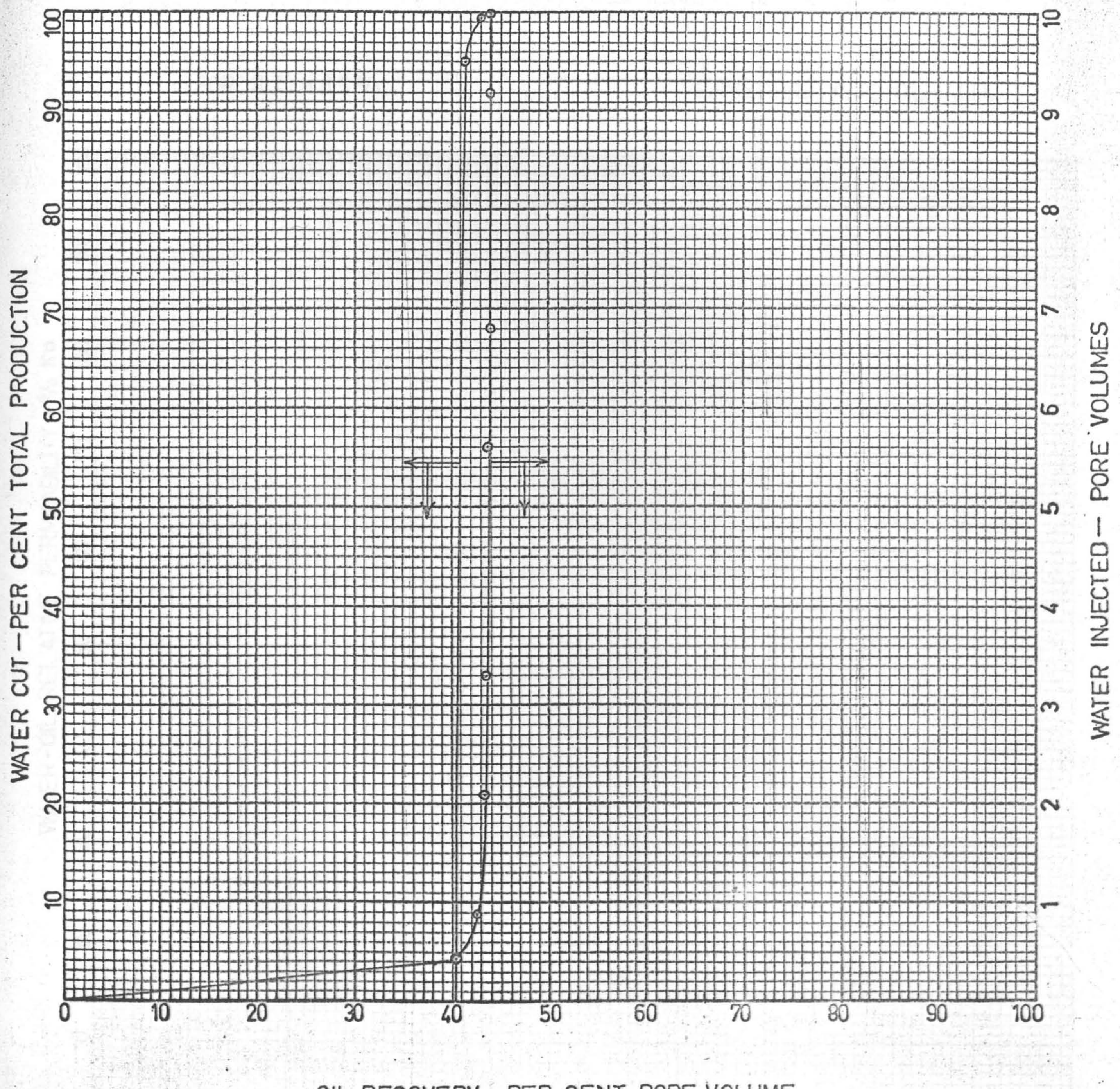

FIGURE 10

WATER-OIL RELATIVE PERMEABILITY

WELL NAME AND NUMBER - E.MEREENIE No. 4

DEPTH INTERVAL - 4615

POROSITY - 8.5 %

PERMEABILITY TO OIL - 1.1 Md.

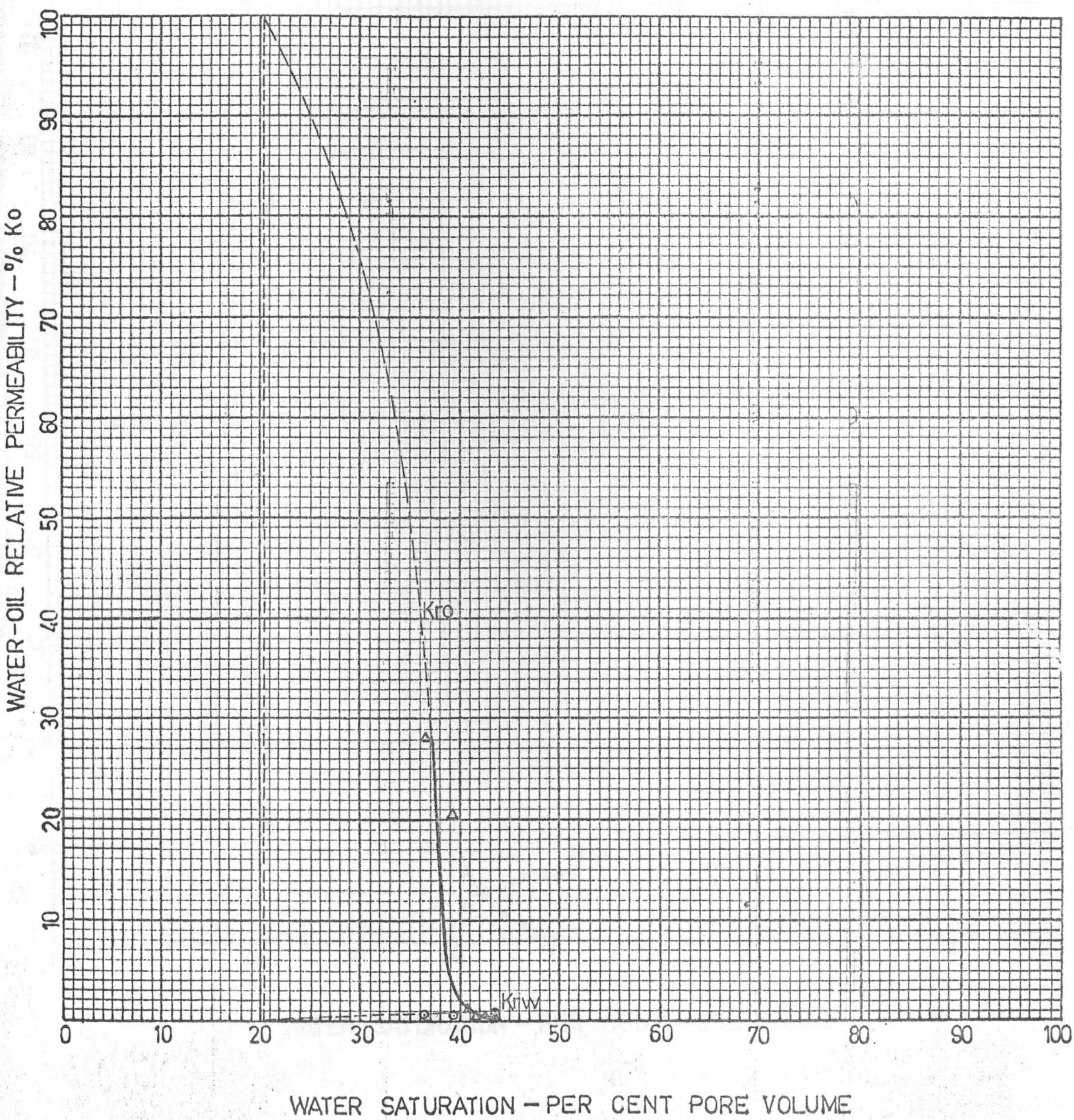

FIGURE 11

WATER-OIL RELATIVE PERMEABILITY

WELL NAME AND NUMBER - E. MEREENIE No. 4

DEPTH INTERVAL - 4618

POROSITY - 12.3%

PERMEABILITY TO OIL - 25 Md.

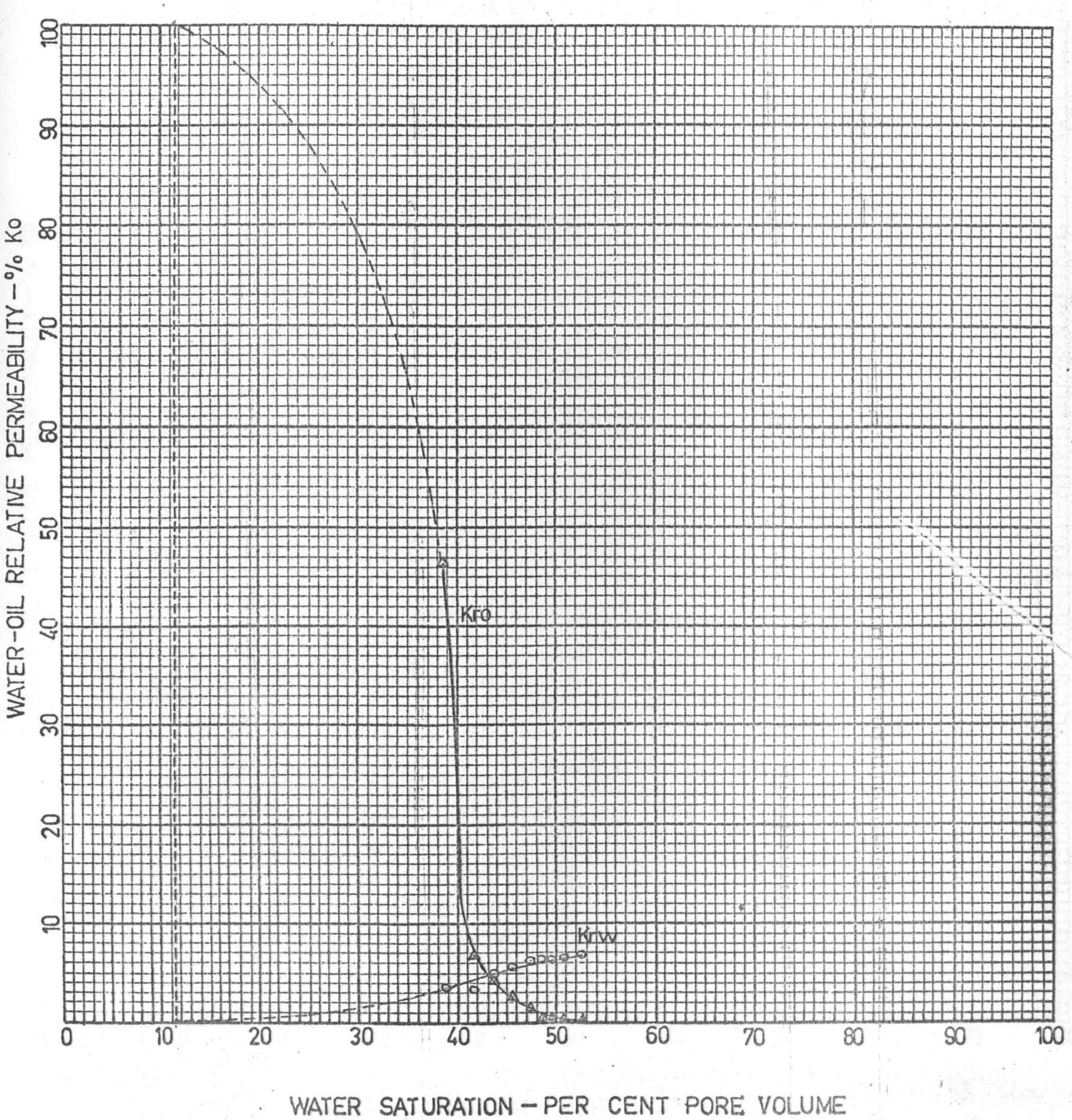

FIGURE 12

WATER-OIL RELATIVE PERMEABILITY

WELL NAME AND NUMBER-E. MEREENIE No. 4

DEPTH INTERVAL- 4631

POROSITY - 8.2% PERMEABILITY TO OIL - 18 Md.

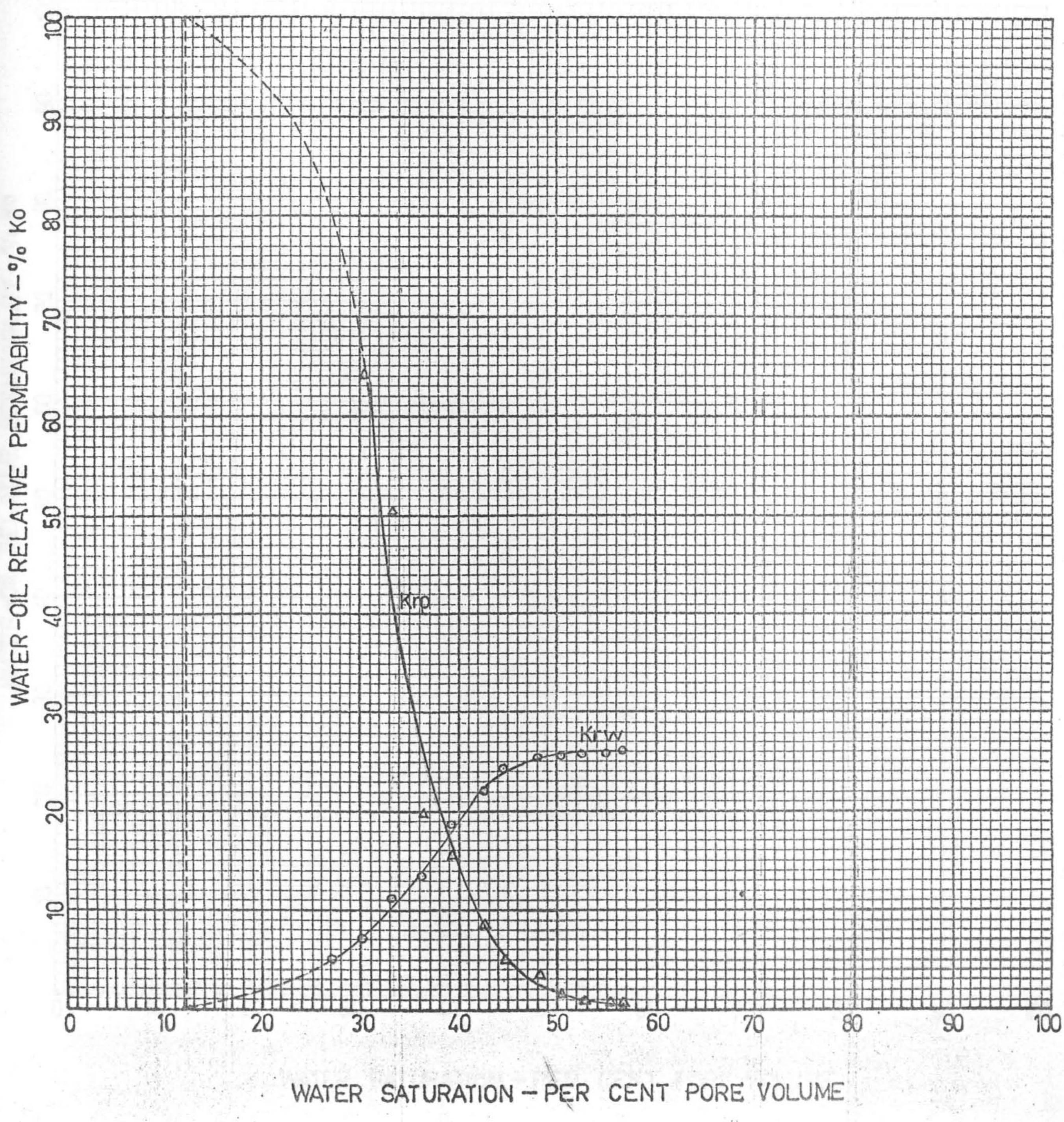

FIGURE 13

WATER-OIL RELATIVE PERMEABILITY

WELL NAME AND NUMBER - E. MEREENIE No. 4

DEPTH INTERVAL - 4632

POROSITY - 9.5 %

PERMEABILITY TO OIL - 14 Md.

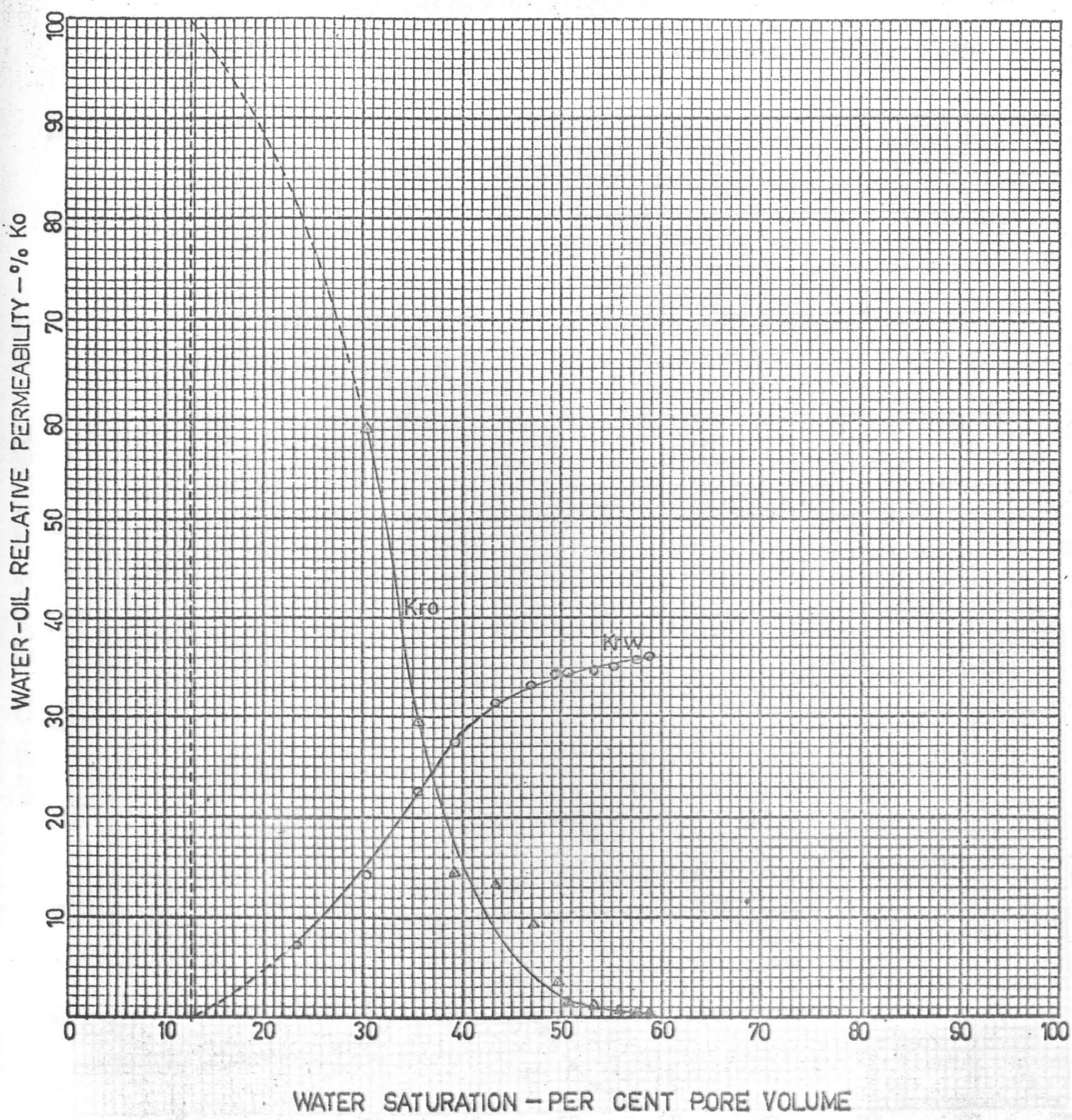

FIGURE 14

WATER-OIL RELATIVE PERMEABILITY

WELL NAME AND NUMBER - E.MEREENIE No. 4

DEPTH INTERVAL - 4633

POROSITY - 8.4 %

PERMEABILITY TO OIL - 6.9 Md.

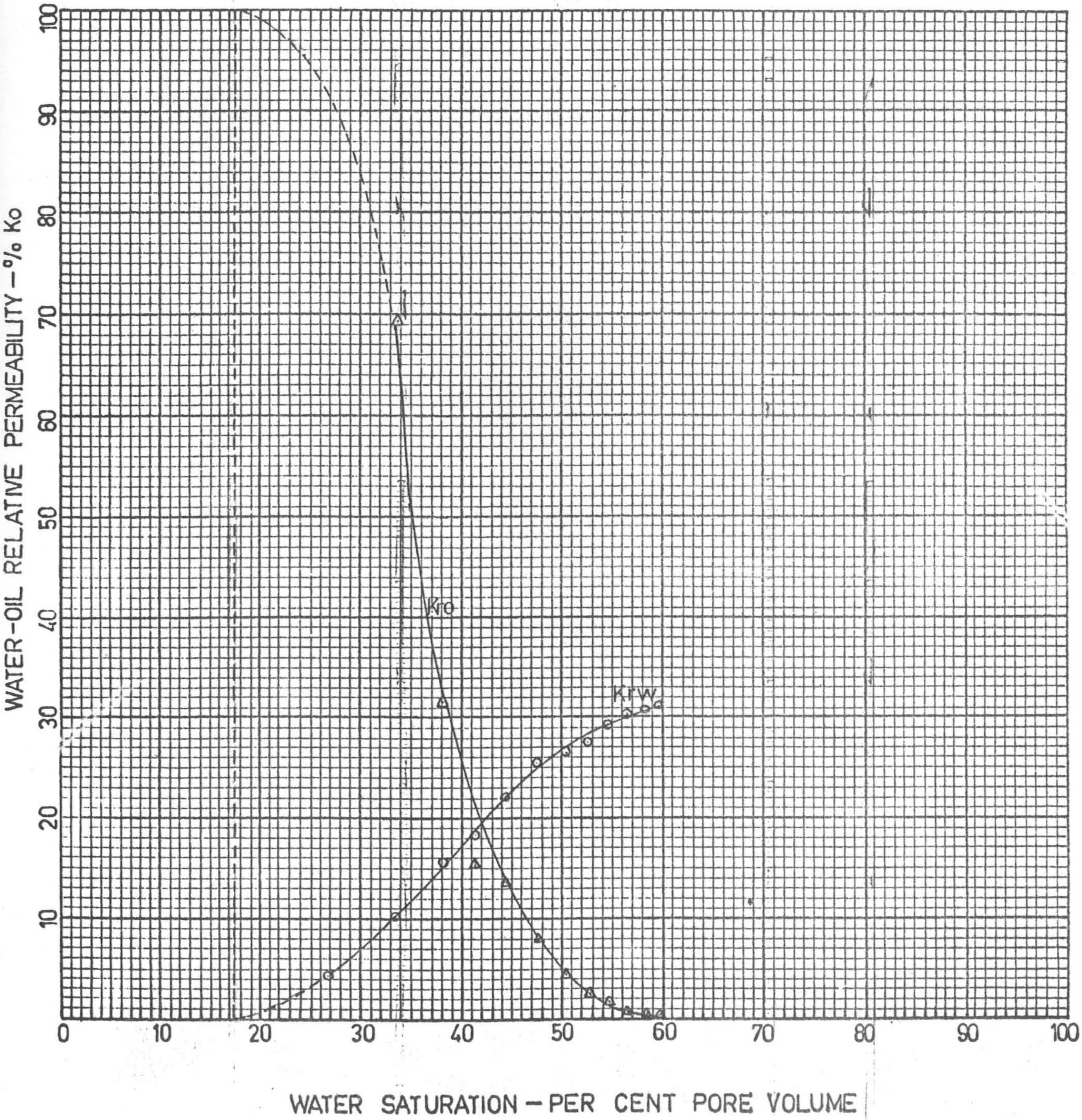

FIGURE 15

WATER-OIL RELATIVE PERMEABILITY

WELL NAME AND NUMBER - E. MEREENIE No. 4

DEPTH INTERVAL - 4710

POROSITY - 9.6 %

PERMEABILITY TO OIL - 26 Md.

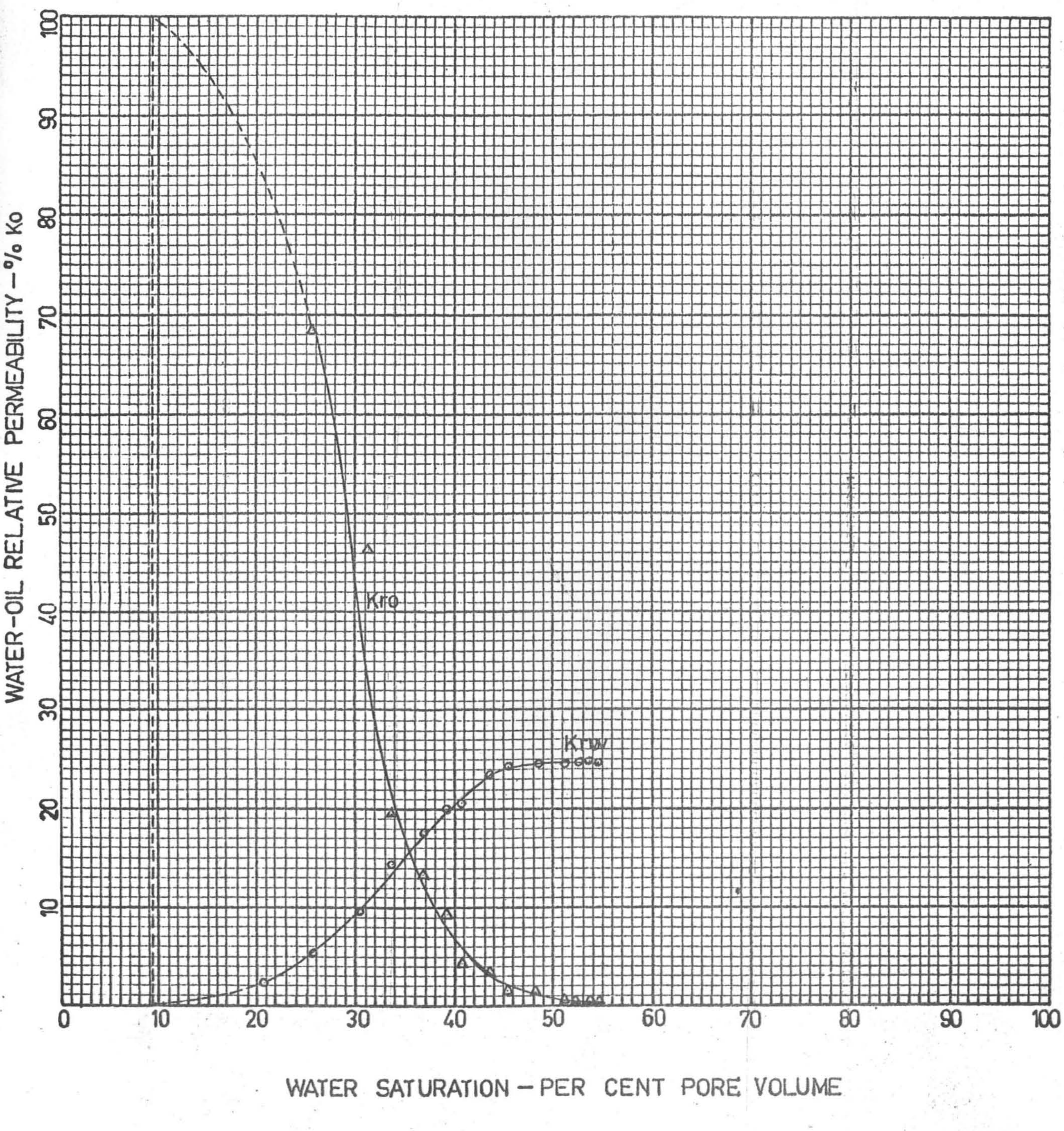

FIGURE 16

WATER-OIL RELATIVE PERMEABILITY

WELL NAME AND NUMBER - E.MEREENIE No. 4

DEPTH INTERVAL - 4711

POROSITY - 10.4 %

PERMEABILITY TO OIL - 17 Md.

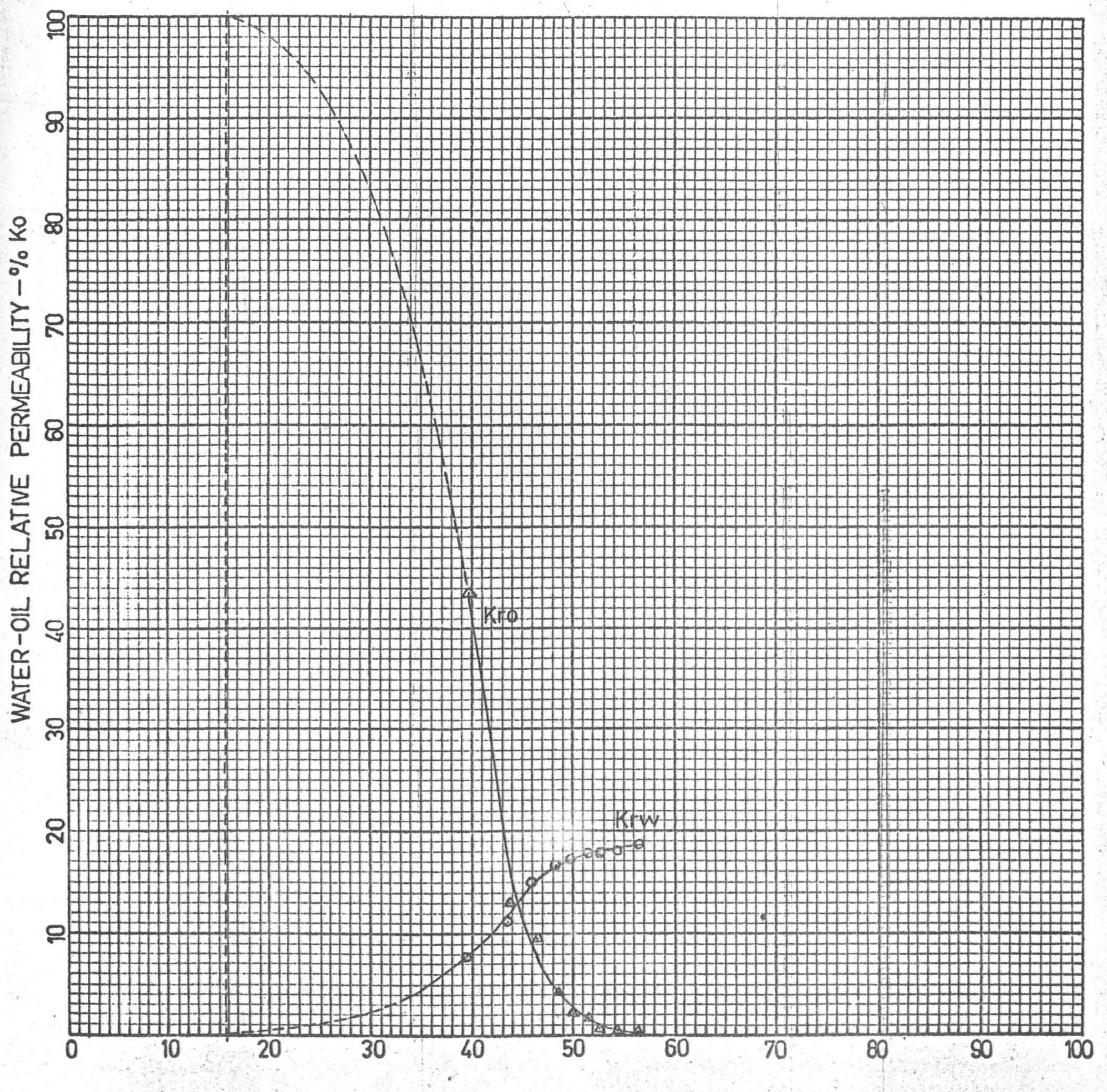

FIGURE 17

WATER-OIL RELATIVE PERMEABILITY

WELL NAME AND NUMBER - E. MEREENIE No. 4

DEPTH INTERVAL - 4712

POROSITY - 10.4%

PERMEABILITY TO OIL - 11 Md.

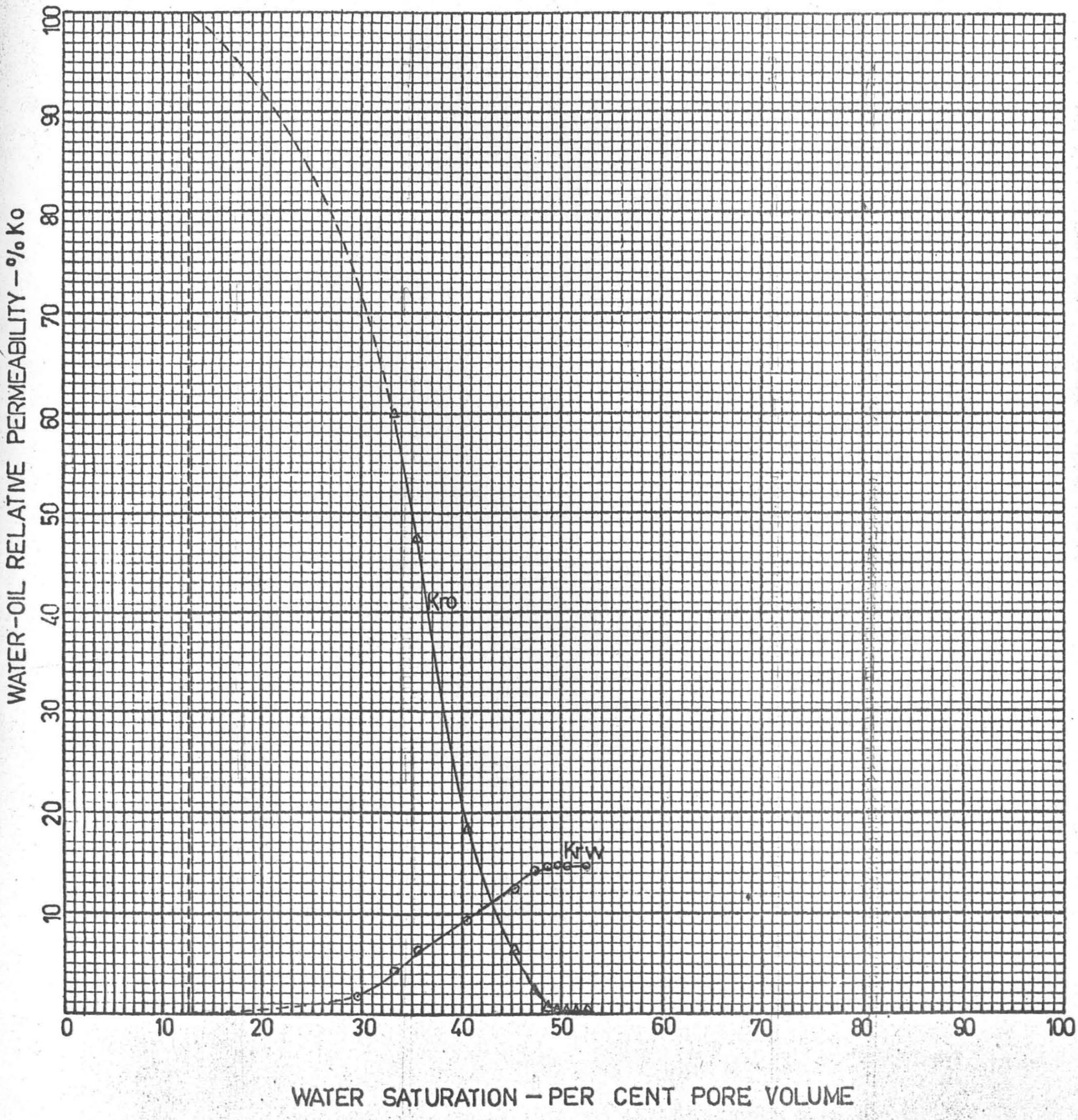

FIGURE 18

WATER-OIL RELATIVE PERMEABILITY

WELL NAME AND NUMBER-E.MEREENIE No. 4

DEPTH INTERVAL-4713

POROSITY-10.1%

PERMEABILITY TO OIL-19 Md.

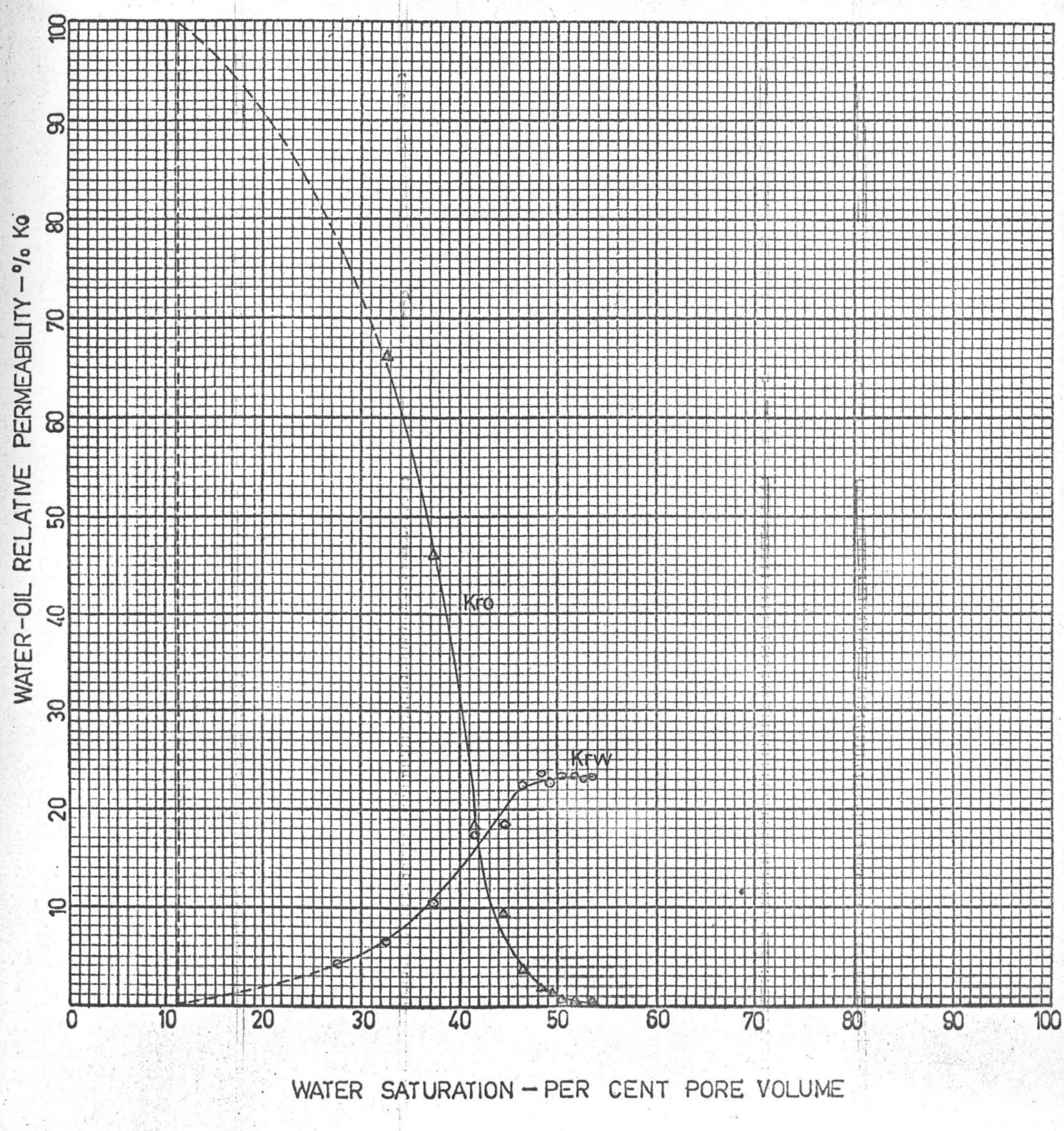

FIGURE 19

WATER-OIL RELATIVE PERMEABILITY RATIO

WELL NAME AND NUMBER - E. MEREENIE No. 4

DEPTH INTERVAL - 4615

POROSITY - 8.5%

PERMEABILITY TO OIL - 1.1 Md.

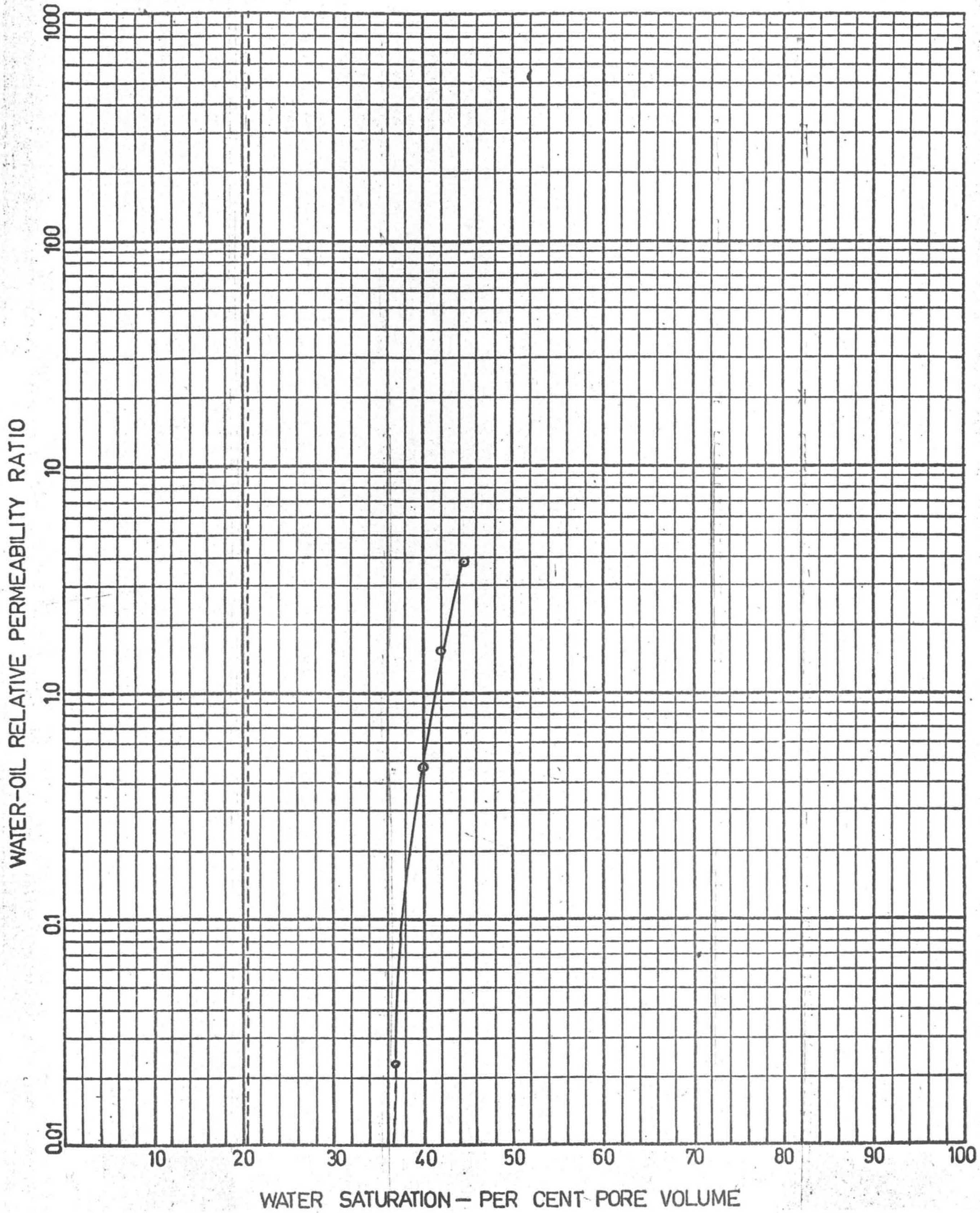

FIGURE 20

WATER-OIL RELATIVE PERMEABILITY RATIO

WELL NAME AND NUMBER-E.MEREENIE No. 4

DEPTH INTERVAL-4618

POROSITY-12.3 %

PERMEABILITY TO OIL-25 Md.

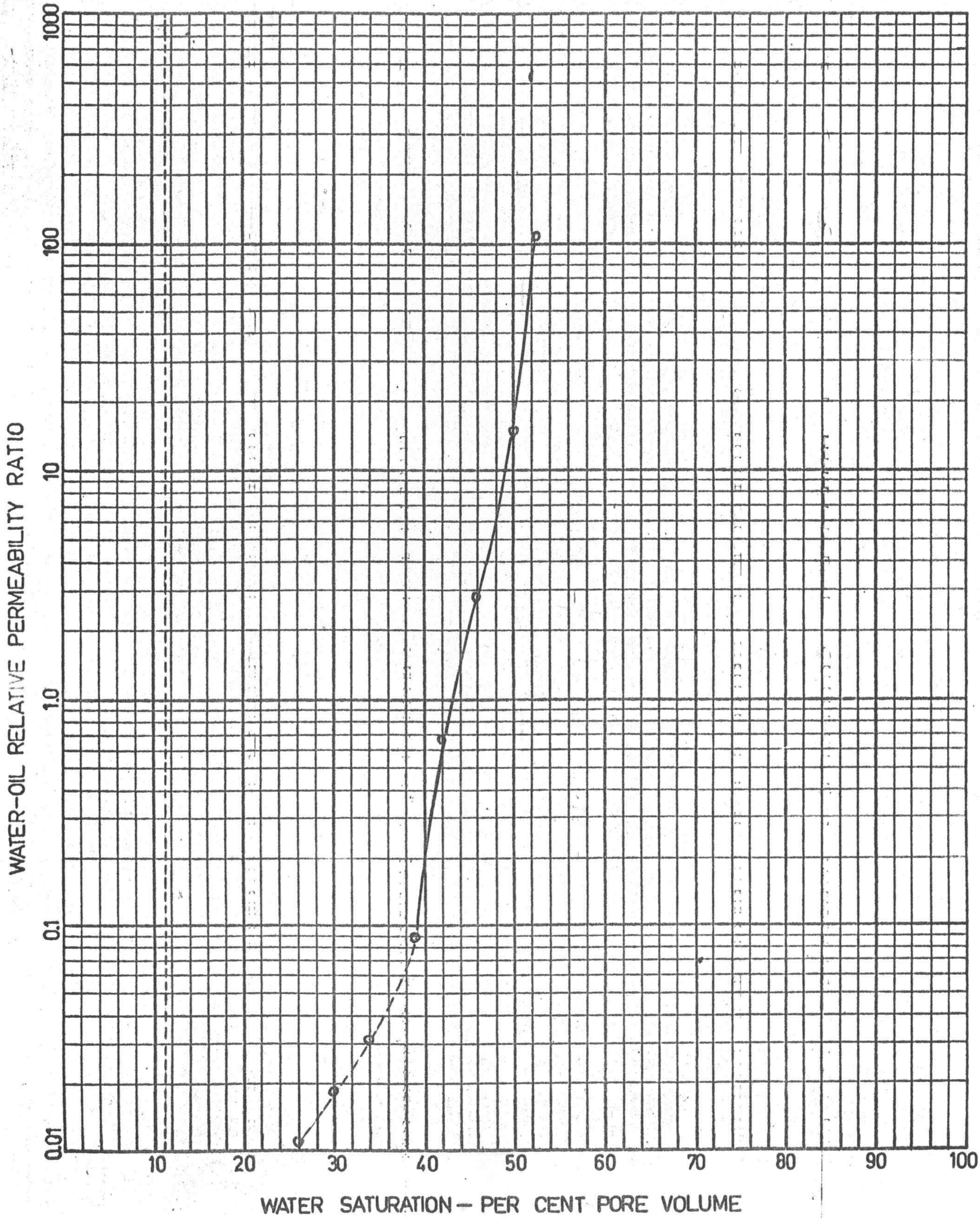

FIGURE 21

WATER-OIL RELATIVE PERMEABILITY RATIO

WELL NAME AND NUMBER - E. MEREENIE No. 4

DEPTH INTERVAL - 4631

POROSITY - 8.2 %

PERMEABILITY TO OIL - 18 Md.

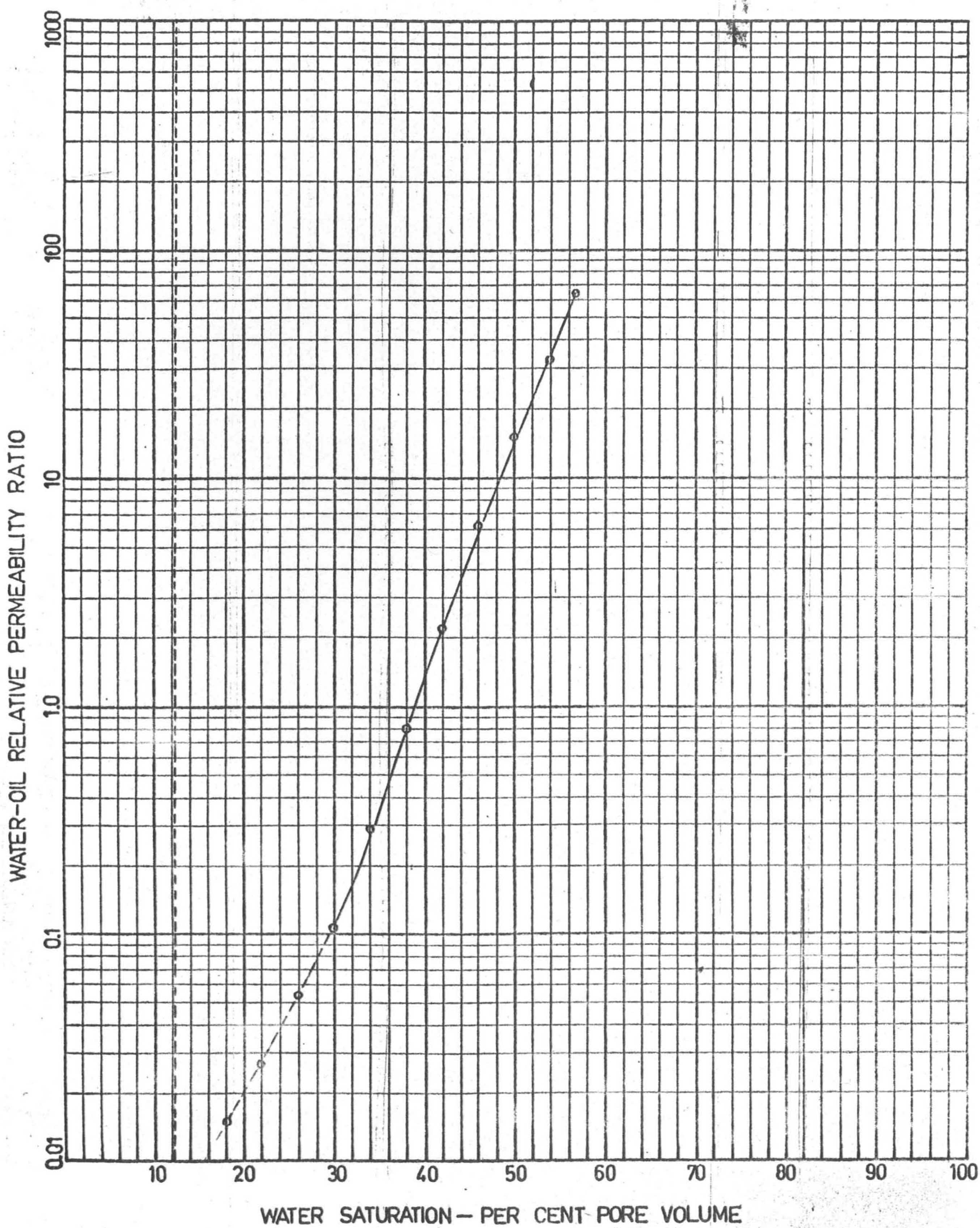

FIGURE 22

WATER-OIL RELATIVE PERMEABILITY RATIO

WELL NAME AND NUMBER-E.MEREENIE No. 4

DEPTH INTERVAL-4632

POROSITY-9.5%

PERMEABILITY TO OIL-14 Md.

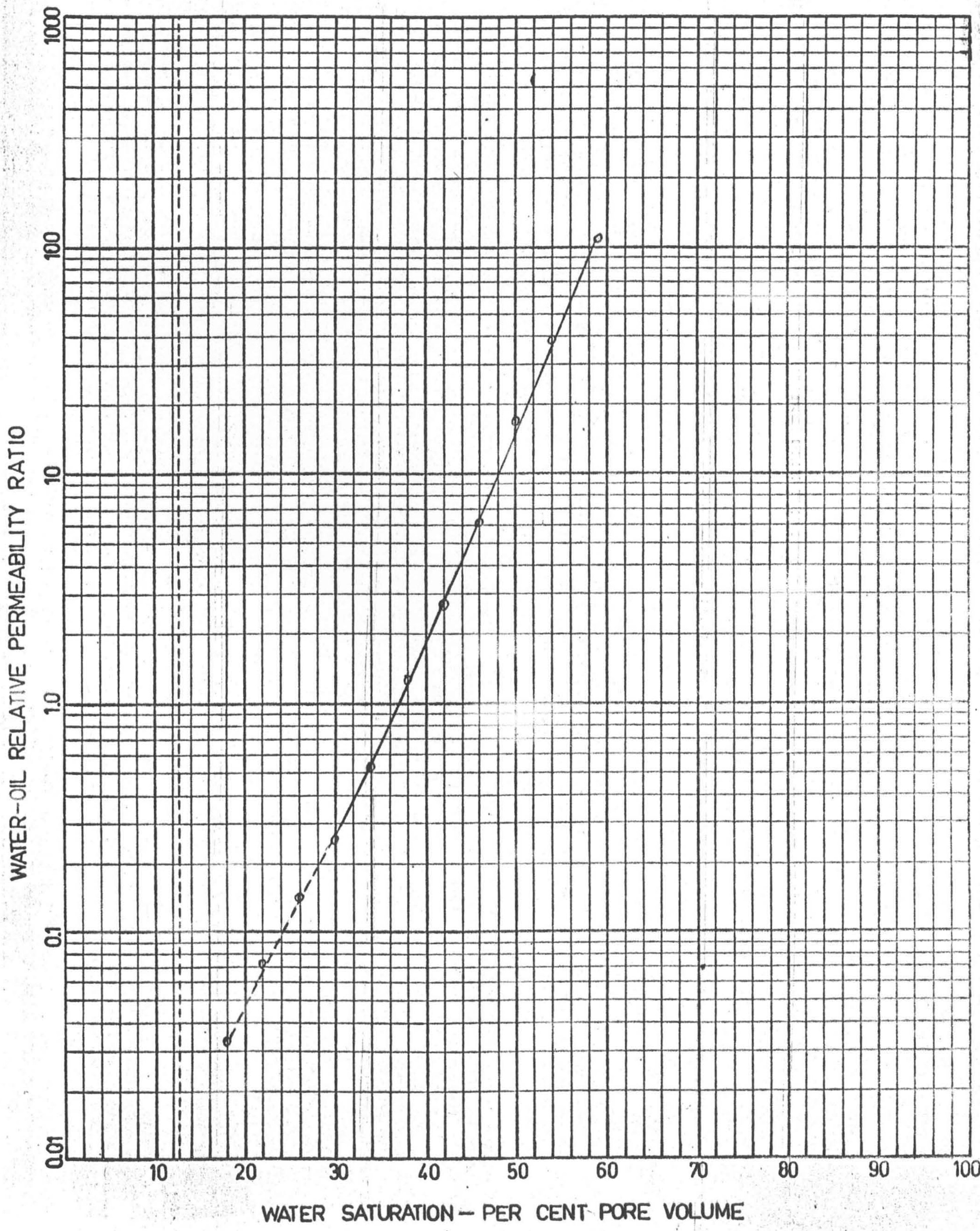

FIGURE 23

WATER-OIL RELATIVE PERMEABILITY RATIO

WELL NAME AND NUMBER-E.MEREENIE No. 4

DEPTH INTERVAL-4633

POROSITY-8.4%

PERMEABILITY TO OIL-6.9 Md.

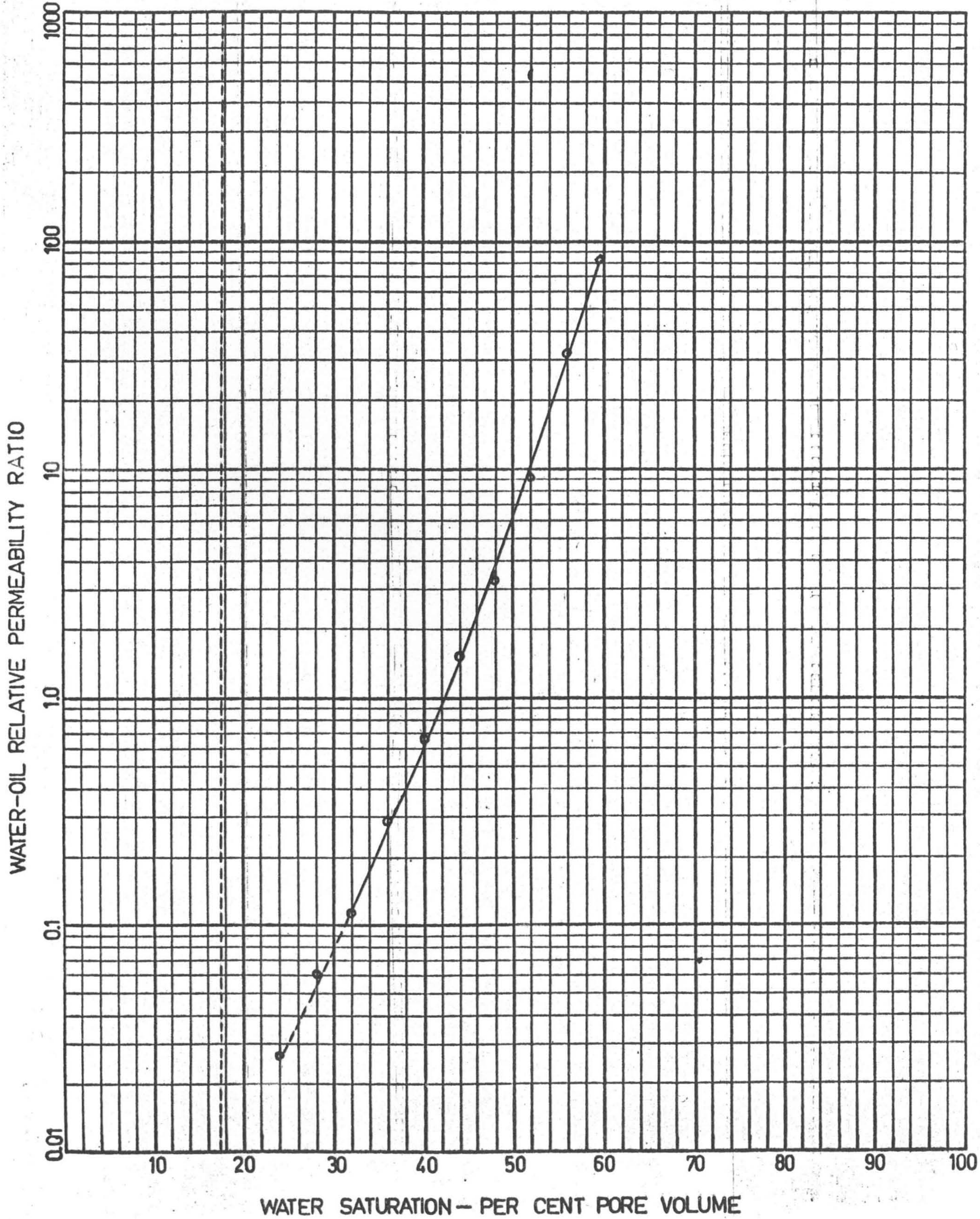

FIGURE 24

WATER - OIL RELATIVE PERMEABILITY RATIO

WELL NAME AND NUMBER - E. MEREENIE No. 4

DEPTH INTERVAL - 4710

POROSITY - 9.6 %

PERMEABILITY TO OIL - 26 Md.

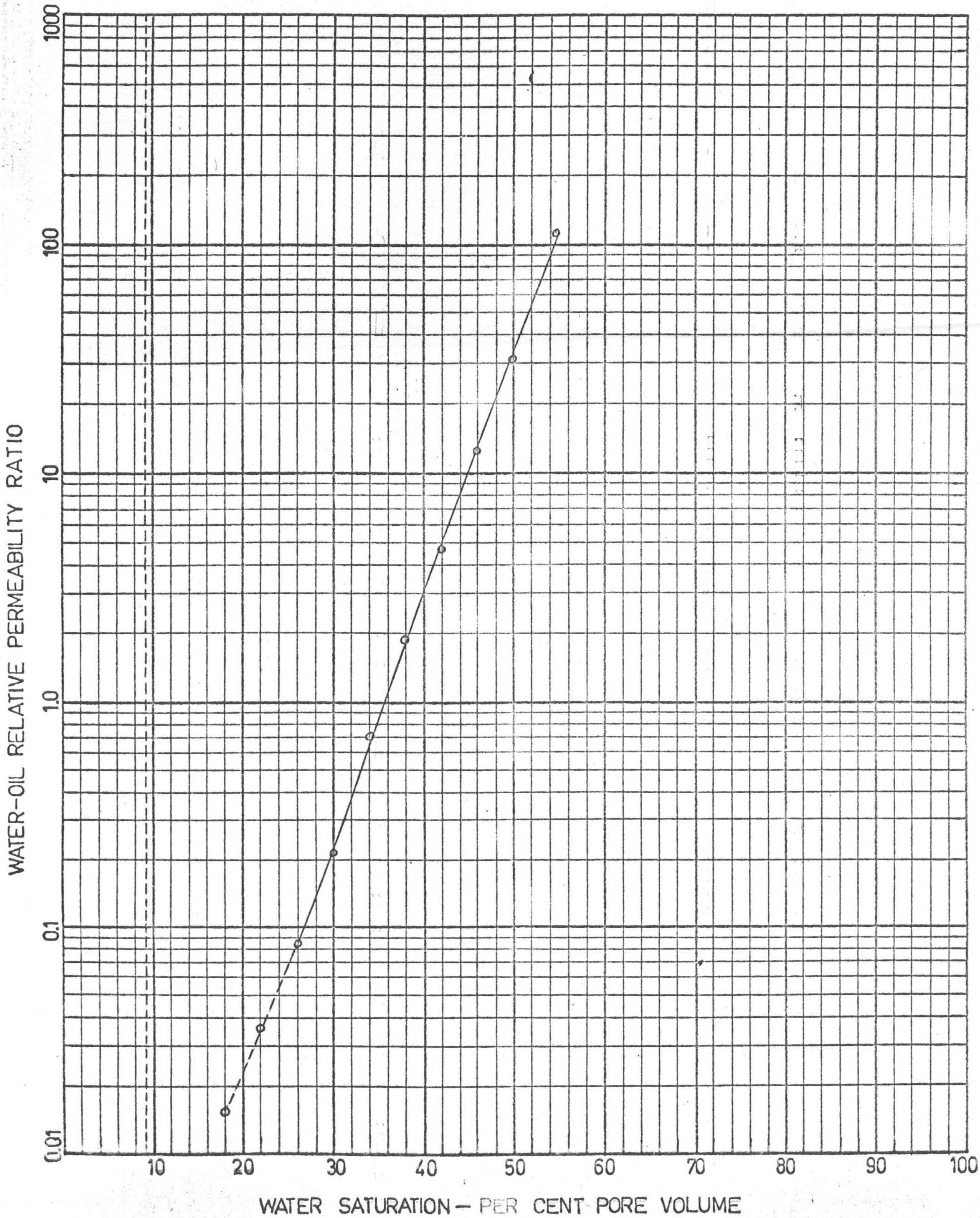

FIGURE 25

WATER-OIL RELATIVE PERMEABILITY RATIO

WELL NAME AND NUMBER - E. MEREENIE No. 4

DEPTH INTERVAL - 4711

POROSITY - 10.4%

PERMEABILITY TO OIL - 17 Md.

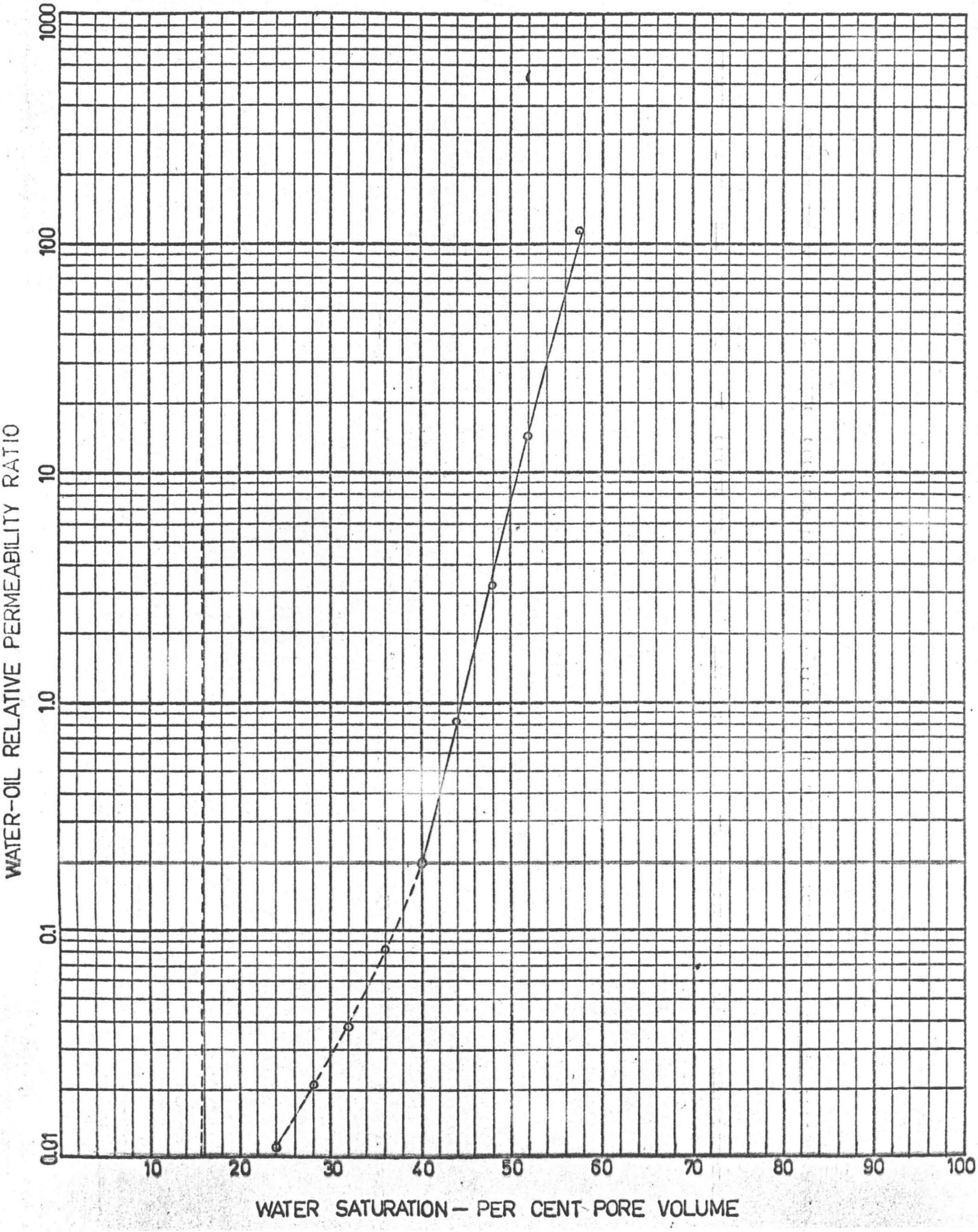

FIGURE 26

WATER-OIL RELATIVE PERMEABILITY RATIO

WELL NAME AND NUMBER-E.MEREENIE No.4

DEPTH INTERVAL-4712

POROSITY-10.4%

PERMEABILITY TO OIL-11 Md.

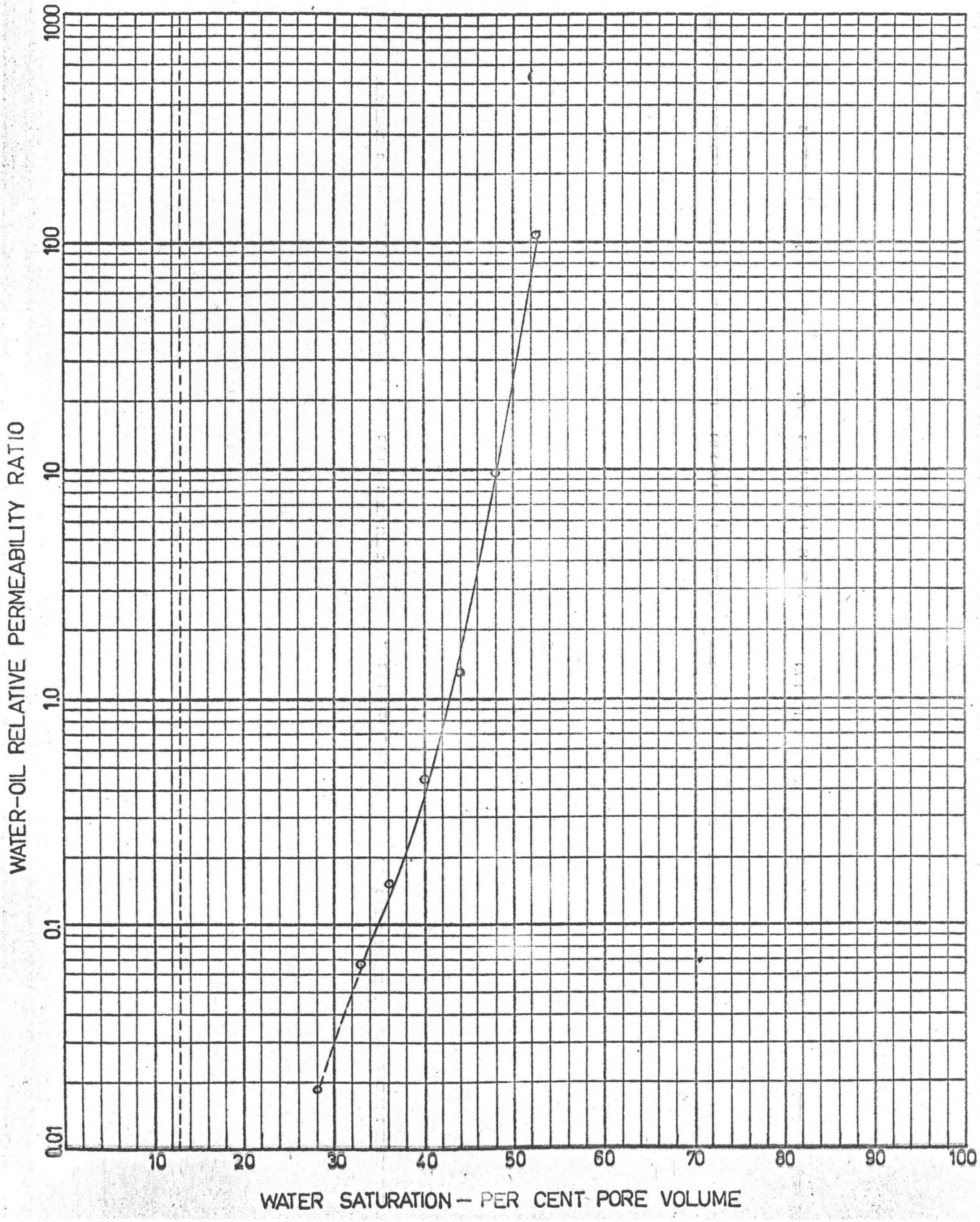

FIGURE 27

WATER-OIL RELATIVE PERMEABILITY RATIO

WELL NAME AND NUMBER-E.MEREENIE No. 4

DEPTH INTERVAL-4713

POROSITY-10.1%

PERMEABILITY TO OIL-19 Md.