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East Mereenie No. 4 Gas-Oil Relative Permeability and Waterflood Susceptibility Tests on Core Samples from the Oil Column of the Pacoota Sandstone Reservoir

by

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PETROLEUM TECHNOLOGY SECTION

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SUMMARY

The Mereenie oil and gas field, a long narrow anticline in the Amadeus Basin, Northern Territory, is covered by the production licences L3 and L4. The first well, Mereenie No. 1, located on the crest of the structure, discovered natural gas in a sandstone reservoir of Ordovician age. Subsequently, six additional wells were drilled on the structure and established both gas and oil accumulations in a thick Pacoota Sandstone sequence.

A study is presented of the gas-oil relative permeability characteristics in the oil column on this Pacoota Sandstone reservoir and compared to waterflood tests of the same zone. The results indicate that a favourable oil recovery can be expected from the reservoir by gas drive.

EAST MEREENIE NO. 4

GAS-OIL RELATIVE PERMEABILITY AND WATERFLOOD SUSCEPTIBILITY TESTS ON CORE SAMPLES FROM THE OIL COLUMN OF THE PACOOTA SANDSTONE RESERVOIR.

Introduction

East Mereenie No. 4 is one of the six wells which have now been completed in the Mereenie oil and gas field, in the Amadeus Basin, Northern Territory.

The possibility of hydrocarbon production from the Pacoota reservoir has been under consideration for some time, and the Petroleum Technology Laboratory of the Bureau of Mineral Resources has assisted in these investigations by performing some laboratory reservoir engineering studies (1,2).

This report deals with gas-oil relative permeability and waterflooding tests performed on eight samples from the oil column of the Pacoota reservoir, intersected by the No. 4 well. The gas-oil relative permeability tests were requested by the owners of the Mereenie field some time ago, but could not be performed until the required laboratory equipment was obtained from overseas.

Procedure and Apparatus

The eight samples used in these tests were drilled parallel to bedding from whole cores taken from the Pacoota reservoir. The samples, 1 1/8 inches in diameter, were then trimmed to approximately 1¼ inches in length, cleaned with toluene in a centrifugal extractor, and dried in an oven at 110°C for 48 hours.

Effective porosity was then determined for each of the samples in a Ruska-type mercury porometer, and absolute permeability with respect to nitrogen in a Hassler-cell with a flexible rubber sleeve.

Subsequently, the samples were prepared for gas-oil relative permeability tests by initially saturating them with a 5% NaCl brine, displacing the brine to a residual saturation by extensive flushing with a refined oil (Soltrol-C) and measuring the permeability to Soltrol-C at residual brine saturation. The 5% NaCl brine and the 1.4 cp oil used in the tests respectively simulate the connate water salinity and the crude oil viscosity in the Pacoota oil reservoir.

Gas-oil relative permeability tests were then conducted in an apparatus which is schematically shown in Fig. 25. It consists of a Hassler-cell with gas inlet and gas-oil outlet end plugs, connected by short flexible tubing to an oil and gas measuring system. The outlet end plug is so designed that on leaving the sample the displacing gas (nitrogen) and the displaced oil are separated by a capillary membrane, and are individually measured. Timed readings of the produced gas are taken at predetermined volumes with simultaneous readings of the volume of displaced oil. From these values, gas-oil relative permeability curves are derived by applying the calculation method of Johnson, Bossler and Nauman (3). The values of relative permeability to gas and oil produced during the test, expressed as percentages of the oil permeability determined prior to the test, are plotted as a function of the average gas saturation (Figs. 1-16).

Immediately upon completion of the gas drive tests, a waterflood of the samples, simulating water injection subsequent to depletion gas drive was carried out. Approximately 10 to 15 pore volumes of water containing 0.2% NaCl, were injected into the samples, and the amount of displaced oil, combined with the oil recovery from the gas drive tests was measured.

In order to compare these combined gas and water drive oil recovery results with those derived solely by water flooding additional waterflood tests were carried out on the core samples. The tests were preceded by extraction and drying of the samples, and followed by saturation with a 5% NaCl brine and subsequent flushing with Soltrol-C to residual water saturation.

These waterflood tests were conducted using a 0.2% NaCl brine as the displacing phase. The samples were flooded to a water cut greater than 99% in the effluent stream. Incremental readings of the oil and water production were taken throughout the tests from water breakthrough to residual oil saturation. The water injected (in pore volumes) was plotted against the oil recovery readings. By plotting the oil recovery values versus the percentage values of water in the total production stream, a water "cut" curve was also obtained (Fig. 17-24).

Discussion of Results

(1) Gas-oil relative permeability and waterflood information are listed in Table 1.

(2) Gas-oil relative permeability and relative permeability ratio curves are shown in Figures 1 to 16. A schematic diagram of the relative permeability apparatus is shown in Figure 25.

(3) Waterflood susceptibility curves are shown in Figures 16 to 24.

The gas-oil relative permeability results show very favourable recovery characteristics under gas drive for this section of the Pacoota reservoir. The average oil recovery of eight samples by gas drive at depletion was 53.8 percent of the effective pore volume, and additional 5 percent recovery was obtained by waterflooding the samples immediately after the relative permeability tests.

This recovery compared favourably with the results of subsequent recovery tests by waterflooding the samples from initial production to depletion. As shown in Table 1, oil recovery obtained solely by waterflooding averaged 42.4 percent of pore volume at water breakthrough, and 58.5 percent at 99 percent water cut for the eight samples, the latter value of 58.5 percent being almost identical with the recovery value by the combined gas drive and subsequent waterflood tests.

In a previous study (2), six samples from adjacent intervals from this well gave an average oil recovery of 37.5 percent pore volume at water breakthrough, and 44.8 percent pore volume at floodout (99 percent water cut). These values are considerably below those obtained in the current testing of similar samples.

There are reasons for believing this difference is due to the influence of capillarity in (these) displacement experiments. Investigators like Perkins (4) and Leverett (5) to name two only, have shown how capillarity controls waterflood performance, and how this is particularly important because of "boundary effects" in samples used in laboratory displacement experiments.

Boundary effects are a peculiarity of two-phase laboratory flow tests, and may be explained as follows:- Within core samples, a high capillary pressure between two non-miscible phases (oil and water) exists; outside the core, (at the end face), the magnitude of pressure difference between the two phases is negligible, as no porous medium is present.

In the case of laboratory waterflood tests, oil is the only phase flowing across the outflow face during the initial stages of production. As water injection continues, and reaches the outflow face, it encounters a capillary pressure barrier which initially prevents it from flowing out of the core. With a build-up of water saturation at the outflow face, the capillary pressure and the oil/saturation are both reduced at that location, and water starts flowing from the core. This of course constitutes a saturation gradient across the core length, the magnitude of which is controlled by the fluid velocity and the core length.

At the time of carrying out the previous study, sample equipment for waterflood tests was limited to plugs 1½ inches in diameter and approximately 1¼ inches long; samples used in the current tests were 1 1/8 inches in diameter and 1¼ inches long. As the pressure differentials used in both tests were approximately similar, it is apparent that the main difference in the two sets of test results is in the fluid flow rate; the 1½-inch diameter samples used in the original tests had a lower rate of flow per unit of cross sectional area when compared to the current samples. In brief, the pressure differential used in the larger diameter plugs was too low to minimize boundary effects, which in turn resulted in a more irregular saturation distribution and a greater "back-up" of water saturation at the out flow face of the larger plugs, thereby reducing oil saturation.

Conclusions

Gas-oil relative permeability tests of Pacoota reservoir samples show very favourable oil recovery characteristics by gas drive. At residual oil saturation $\left(\frac{Kg}{Ko} \cong 100\right)$, oil recovery by gas drive was in the order of 54 percent of the effective pore volume. This was increased to an ultimate oil recovery of 58.7 percent pore volume by waterflooding the gas drive depleted samples.

5

The combined gas and water drive oil recovery tests compared favourably with the total oil displacement tests by waterflooding alone, which averaged 42.4 percent of pore volume at water breakthrough, and 58.5 percent of pore volume at residual oil saturation (99 percent water-cut in the outflow stream).

References

1.	McKay, B.A.	"East Mereenie No. 4 - Special Core Analyses tests on samples from the Ordovician Pacoota Sandstone Reservoir". Bureau of Mineral Resources Record 1967/121.
2.	McKay, B.A.	East Mereenie No. 4 - Waterflood Susceptibility and Water-Oil Relative Permeability Tests on Samples from the Pacoota Sandstone Reservoir." Bureau of Mineral Resources Record 1968/50.
3.	Johnson, E.F. Bossler, D.P. Nauman, V.O.	Calculations of Relative Permeability from Displacement Experiments". Journal of Petroleum Technology; January 1959.
4.	Perkins, F.M.	"An Investigation of the Role of Capillary Forces in Laboratory Water Floods". Journal of Petroleum Technology, November 1957.
5.	Leverett, M.C.	"Capillary Behaviour in Porous Solids". Transactions, AIME 1941.

TABLE I

Sample Depth (feet)	GAS-OIL RELATIVE PERMEABILITY TEST DATA: Permeability to 1.4 cp. oil at residual water saturation (md.)	Residual water saturation before $\frac{Kg}{Ko}$ test (per cent pore volume)	Oil recovery (per cent pore volume): At Depletion	$\frac{Kg}{Ko}$ ratio	Water injected (p.v.)	After combined $\frac{Kg}{Ko}$ and waterflood test	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 (per cent bulk volume)	Residual water saturation before waterflood test (per cent pore volume)	Residual oil saturation after waterflood test (per cent pore volume)	Oil recovery (per cent pore volume): At Water break-through	At 10 pore-volumes water throughput
4631	30	13.3	50.6	132	17.6	59.4	31	30	11.6	8.4	16.0	30.5	37.4	53.5
4633	11	15.2	55.4	104	17.5	61.2	13	9.5	1.2	8.5	15.2	33.8	42.2	61.0
4710	30	9.5	52.3	77	14.2	57.5	34	31	7.1	10.4	9.5	29.3	43.4	61.2
4711	22	11.5	55.9	90	14.6	60.7	26	21	3.8	10.0	11.5	29.7	43.2	58.8
4712	16	15.5	58.7	56	13.8	63.7	15	16	5.6	10.1	13.2	26.9	44.5	60.9
4713	29	13.5	51.6	140	13.5	55.6	32	29	7.3	10.5	13.7	30.1	39.6	56.2
4742	53	13.8	53.9	107	19.3	58.0	55	53	13.6	11.3	13.8	24.4	44.3	61.8
4752	4.5	18	52.5	147	12.3	53.8	6.3	4.0	0.42	9.7	20.0	25.0	44.5	55.0
AVERAGES			53.8			58.7							42.4	58.5

FIGURE 1

GAS-OIL RELATIVE PERMEABILITY

WELL NAME AND NUMBER - E.MEREENIE No. 4

DEPTH INTERVAL - 4631'

POROSITY 8.4%

PERMEABILITY 30 Md.

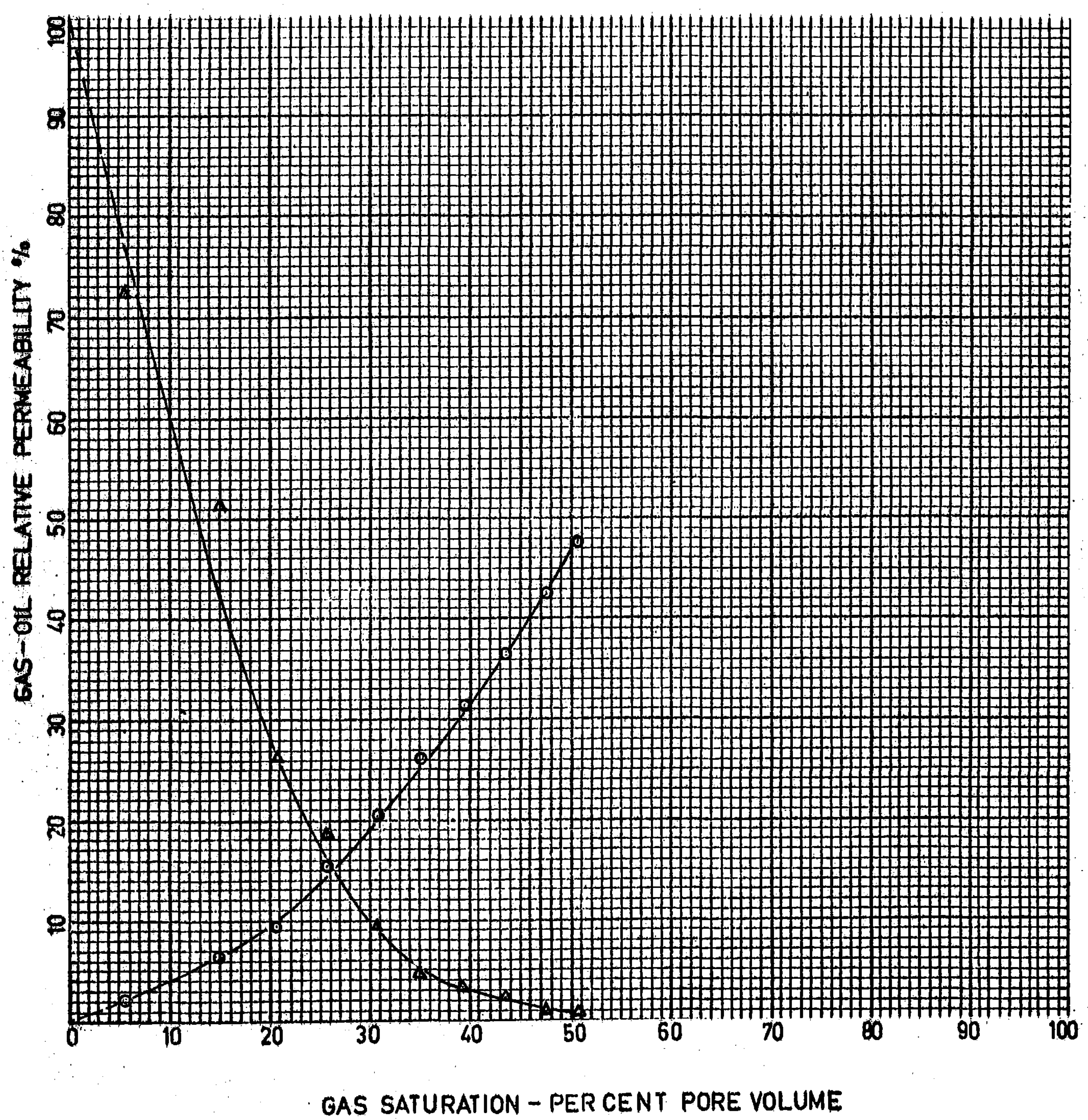


FIGURE 2

GAS - OIL RELATIVE PERMEABILITY

WELL NAME AND NUMBER - E. MEREENIE No. 4

DEPTH INTERVAL - 4633'

POROSITY 8.5 %   PERMEABILITY 11 Md.

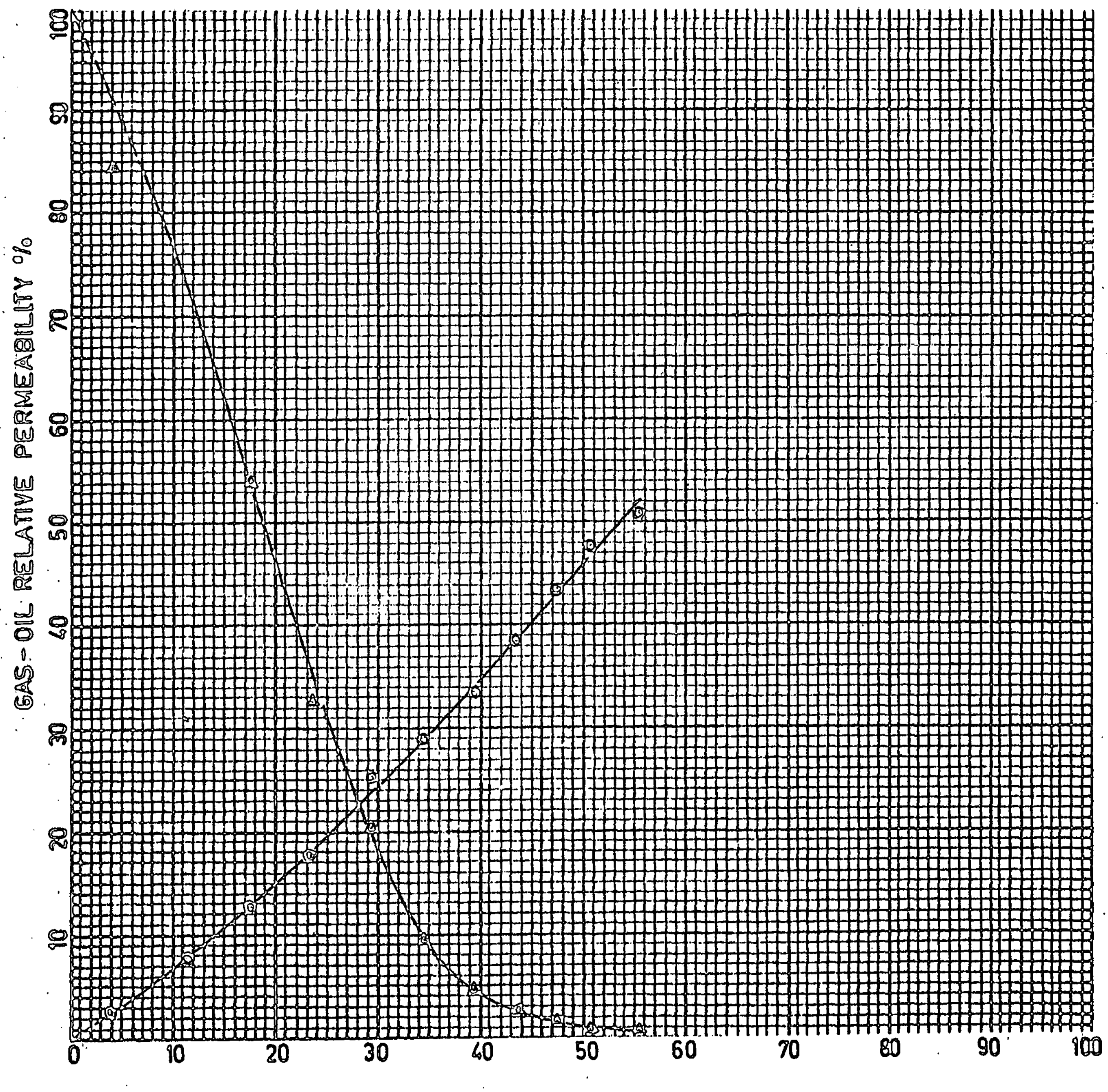


FIGURE 3

GAS-OIL RELATIVE PERMEABILITY

WELL NAME AND NUMBER-E.MEREENIE No. 4

DEPTH INTERVAL-4710'

POROSITY-10.4%

PERMEABILITY-30 Md.

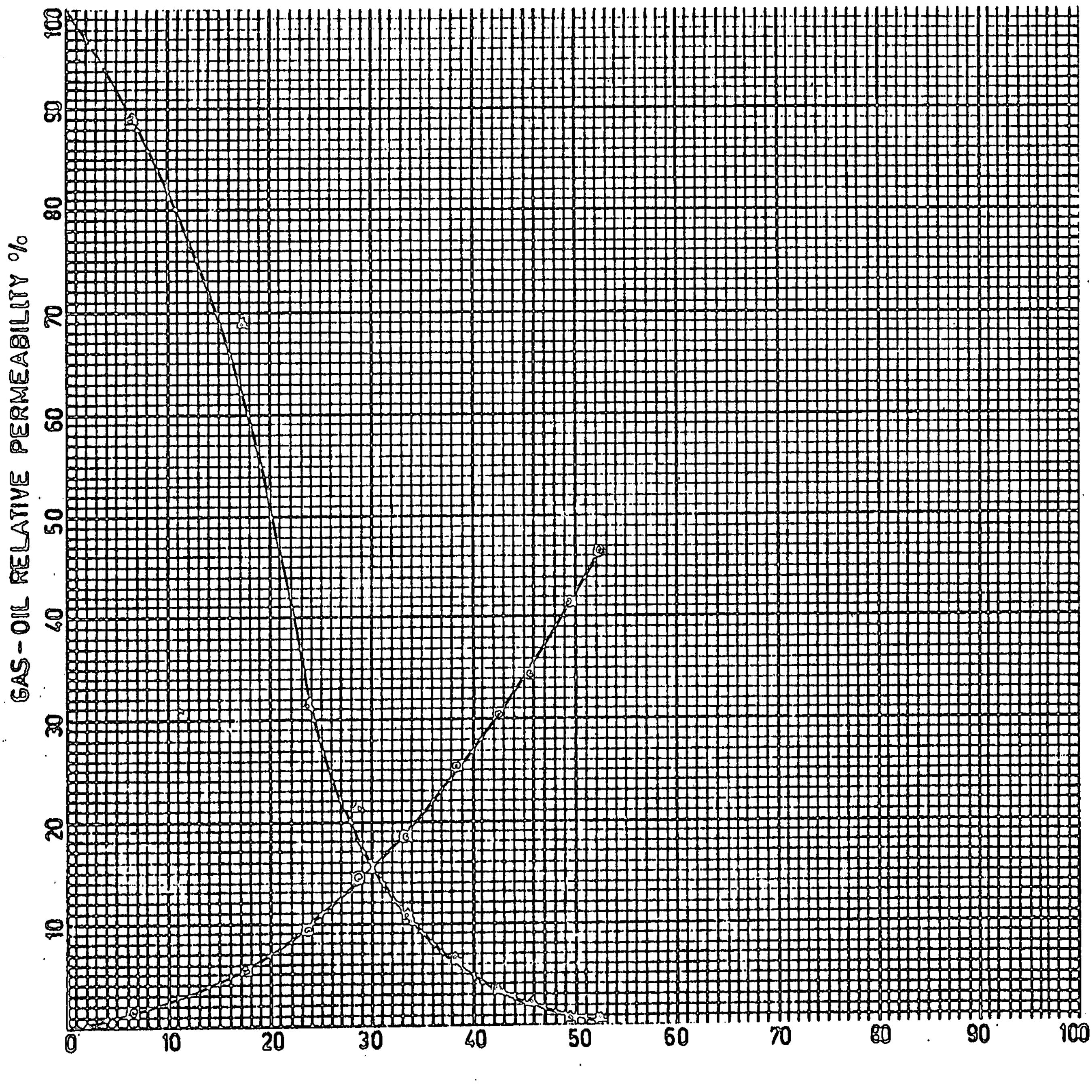


FIGURE 4

GAS-OIL RELATIVE PERMEABILITY

WELL NAME AND NUMBER-E.MEREENIE No 4

DEPTH INTERVAL-4711'

POROSITY - 10.0 %

PERMEABILITY-22 Md.

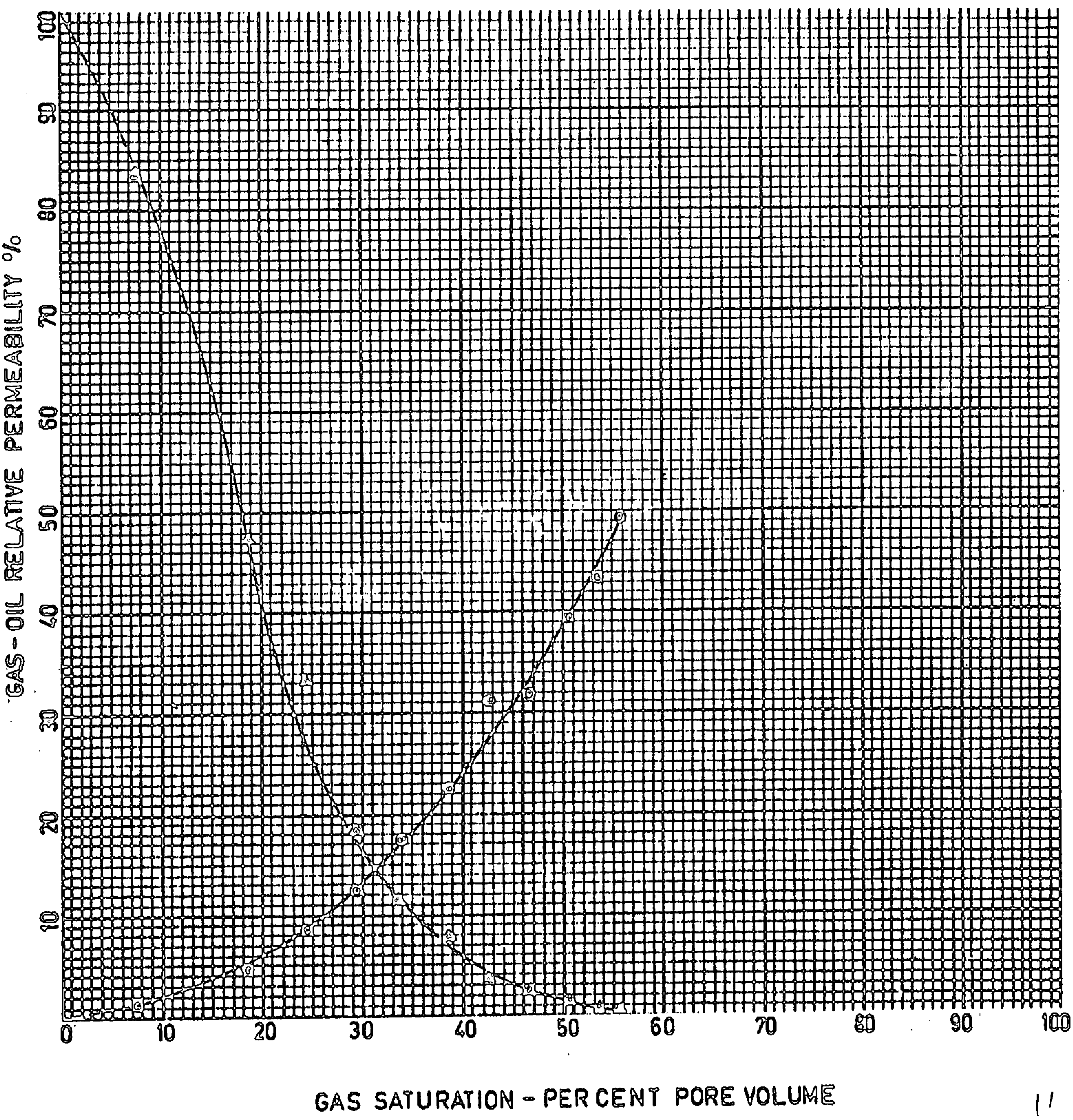


FIGURE 5

GAS-OIL RELATIVE PERMEABILITY

WELL NAME AND NUMBER-E.MEREENIE No.4

DEPTH INTERVAL-4712'

POROSITY-10.1%

PERMEABILITY-16 Md.

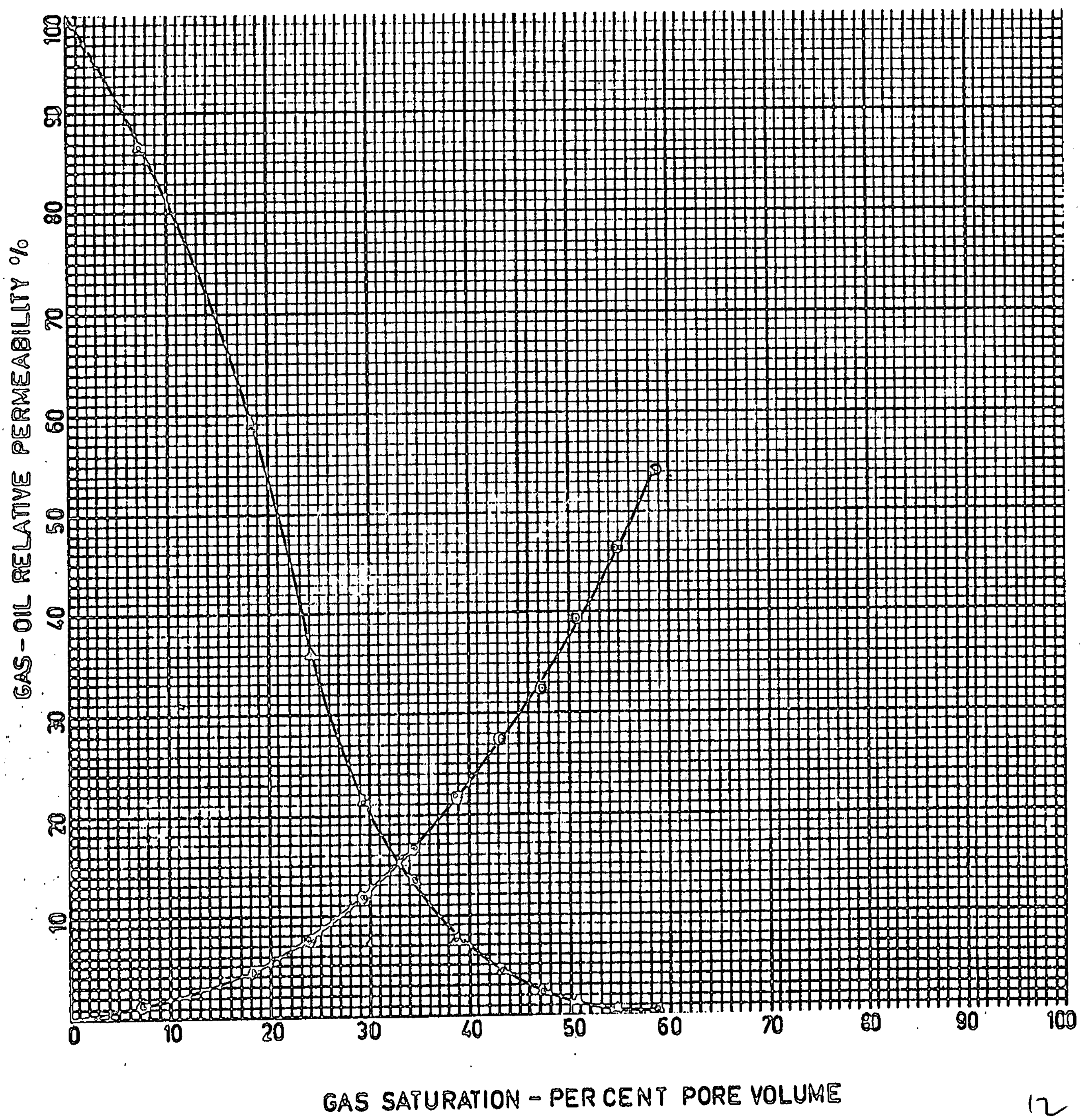


FIGURE 6

GAS-OIL RELATIVE PERMEABILITY

WELL NAME AND NUMBER - E. MEREENIE No. 4

DEPTH INTERVAL - 4713'

POROSITY - 10.5%

PERMEABILITY - 29 Md.

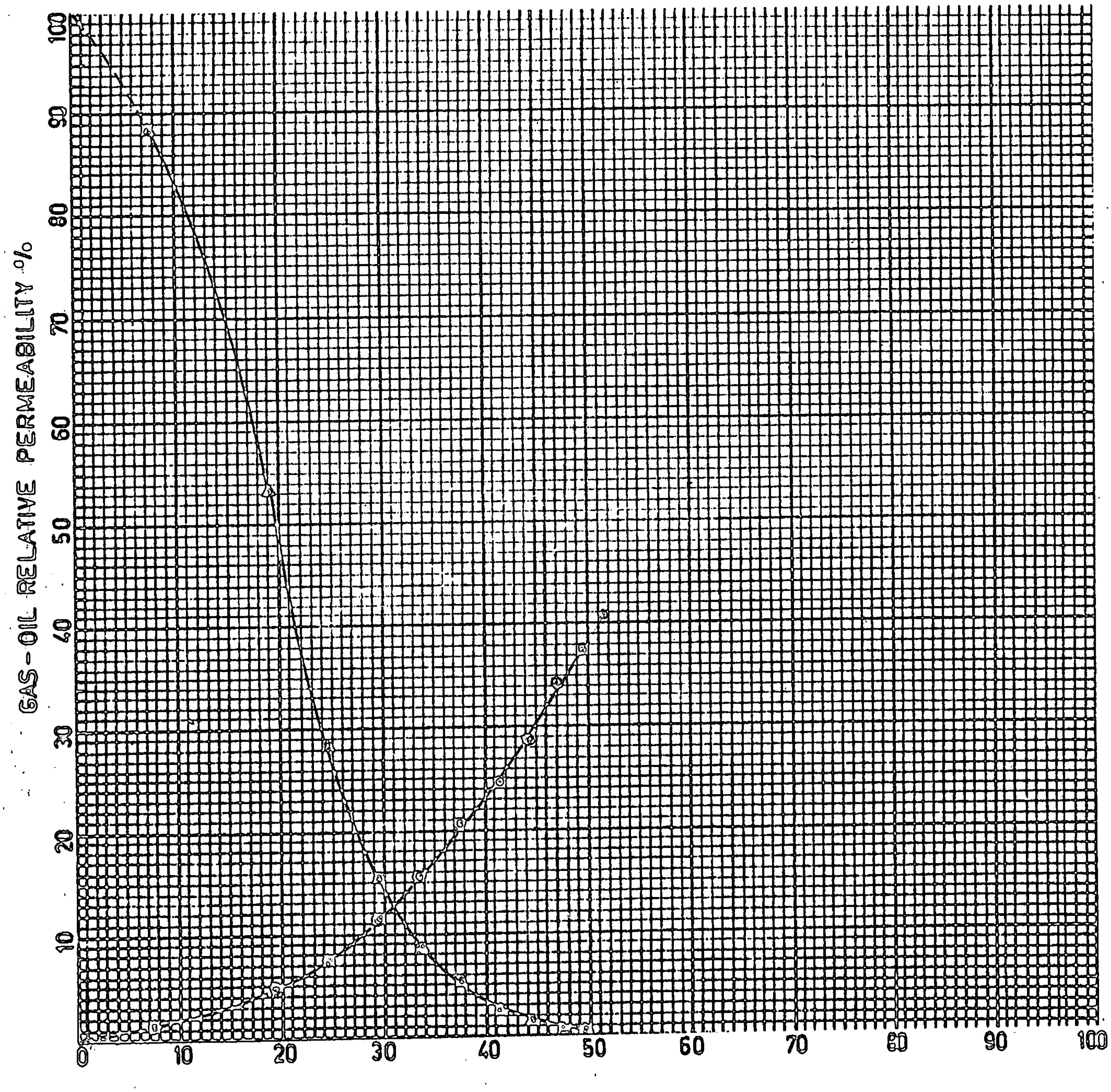


FIGURE 7

GAS-OIL RELATIVE PERMEABILITY

WELL NAME AND NUMBER-E.MEREENIE No. 4

DEPTH INTERVAL-4742'

POROSITY-11.3 %

PERMEABILITY-53 Md.

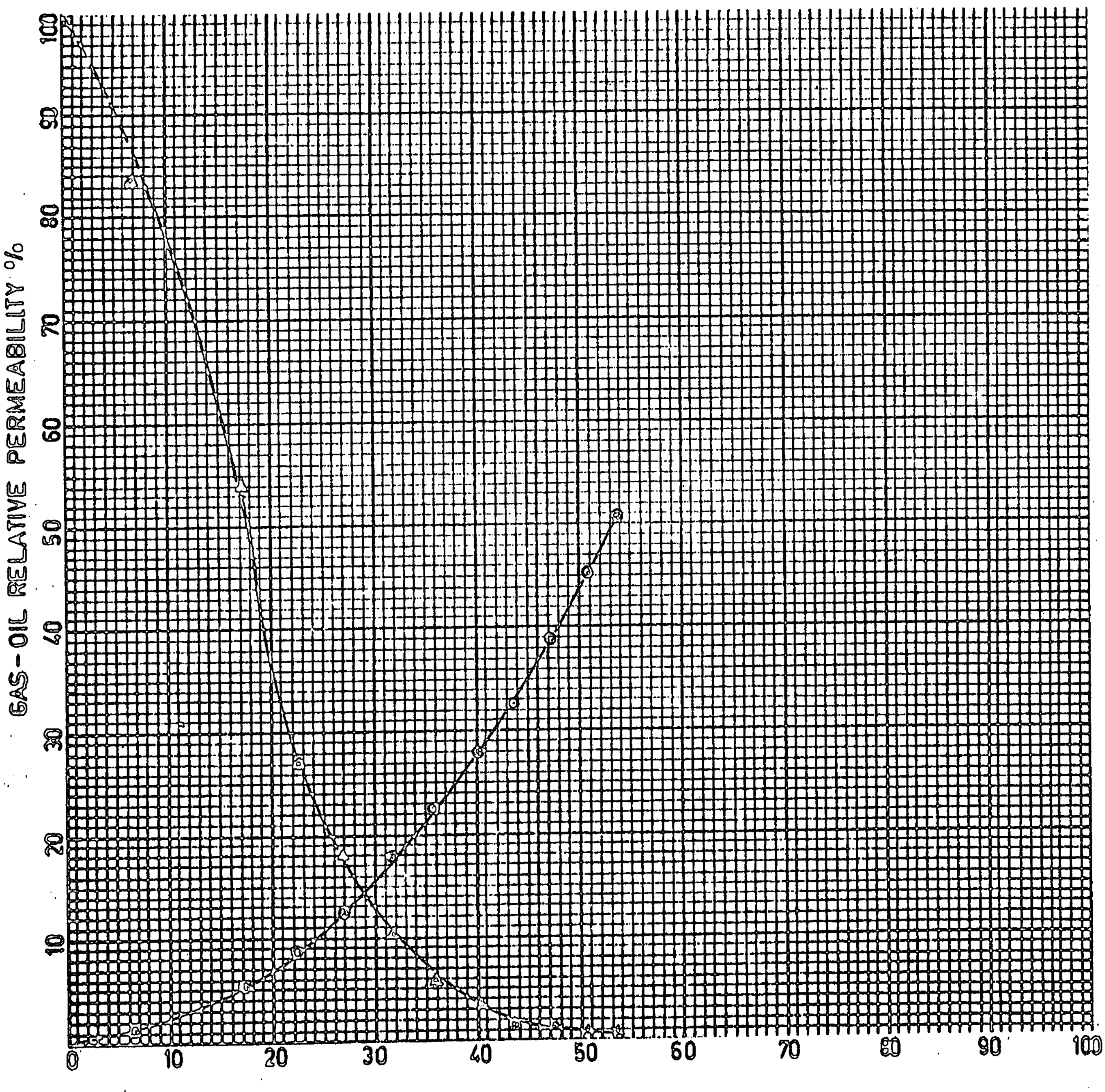


FIGURE 8

GAS-OIL RELATIVE PERMEABILITY

WELL NAME AND NUMBER - E.MEREENIE No. 4

DEPTH INTERVAL - 4752'

POROSITY - 9.7 %

PERMEABILITY - 4.5 Md.

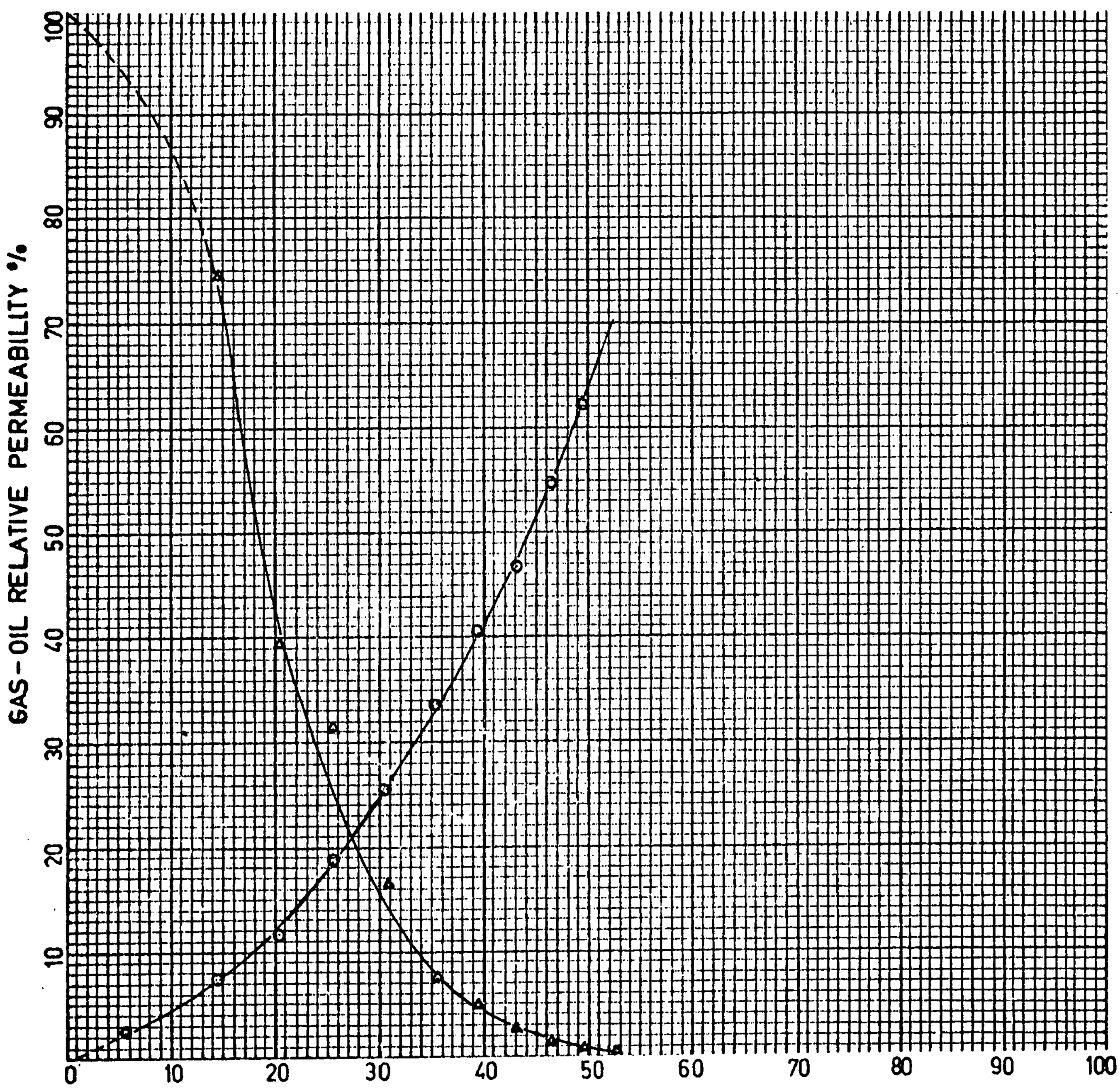


FIGURE 9

GAS-OIL RELATIVE PERMEABILITY RATIO

WELL NAME AND NUMBER – E. MEREENIE No. 4

DEPTH INTERVAL – 4631′

POROSITY – 8.4 %

PERMEABILITY – 30 Md.

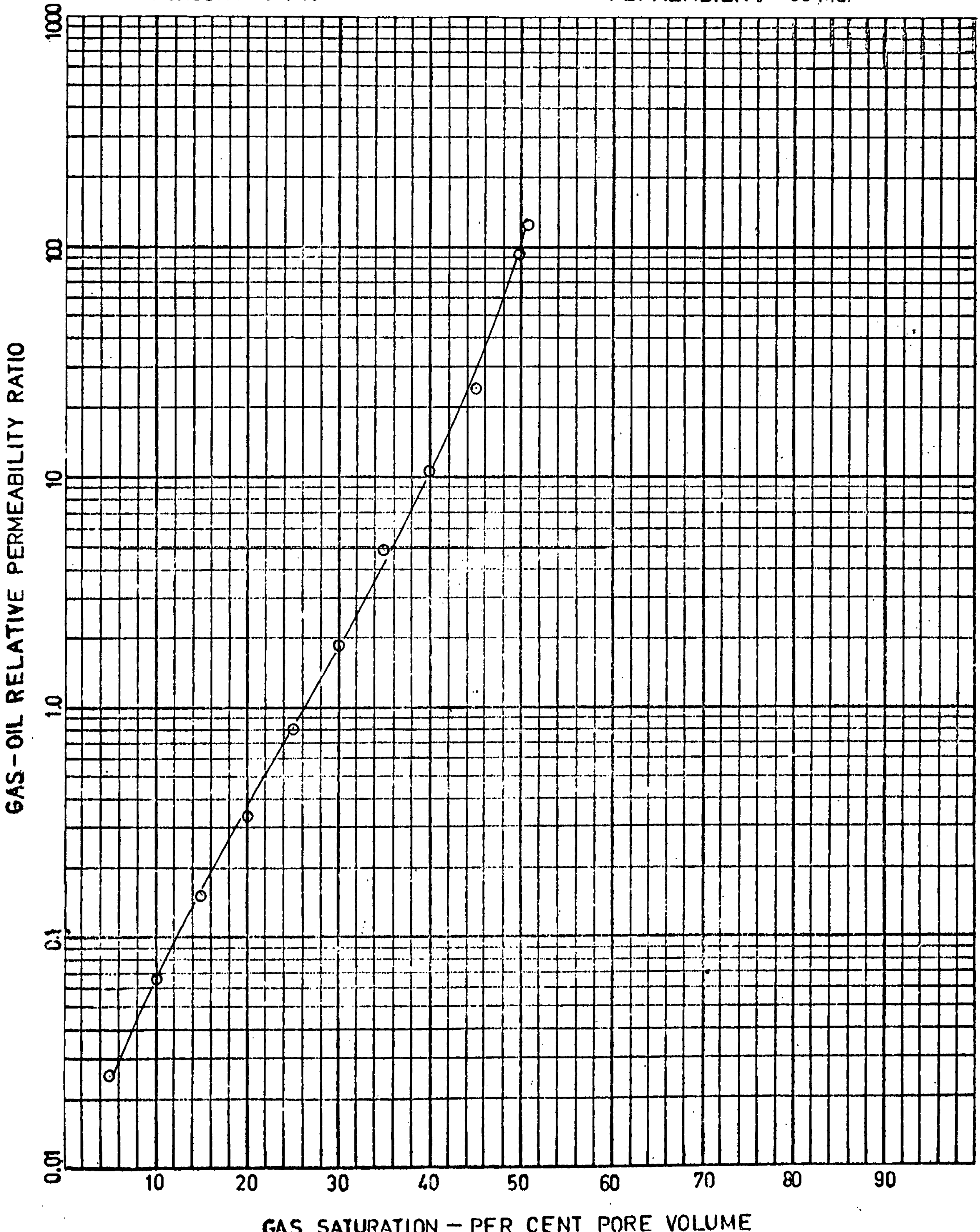


FIGURE 10

GAS-OIL RELATIVE PERMEABILITY RATIO

WELL NAME AND NUMBER - E.MEREENIE No.4

DEPTH INTERVAL - 4633'

POROSITY - 8.5%

PERMEABILITY - 11 Md.

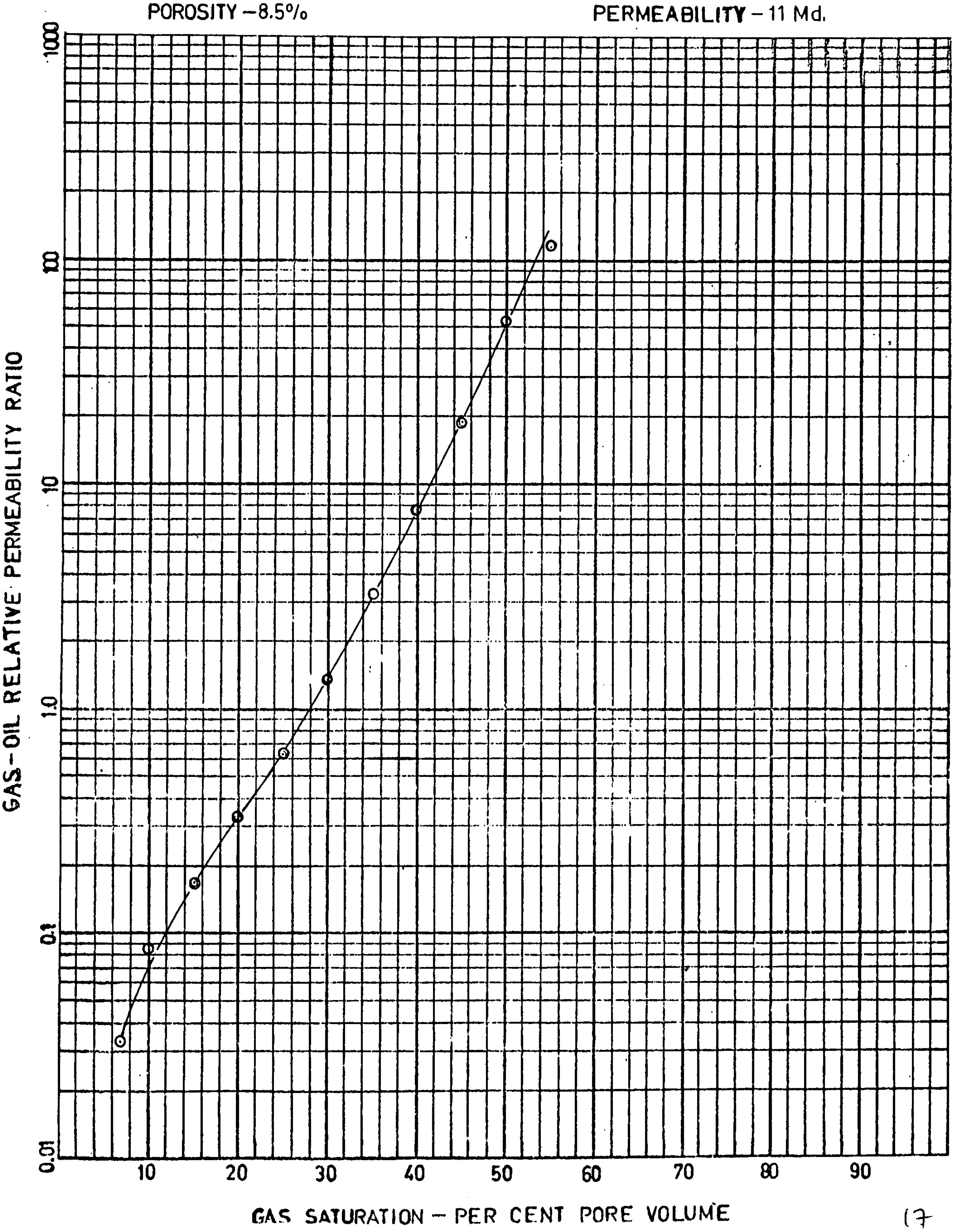


FIGURE 11

GAS-OIL RELATIVE PERMEABILITY RATIO

WELL NAME AND NUMBER - E.MEREENIE No. 4

DEPTH INTERVAL - 4710'

POROSITY - 10.4% PERMEABILITY - 30 Md.

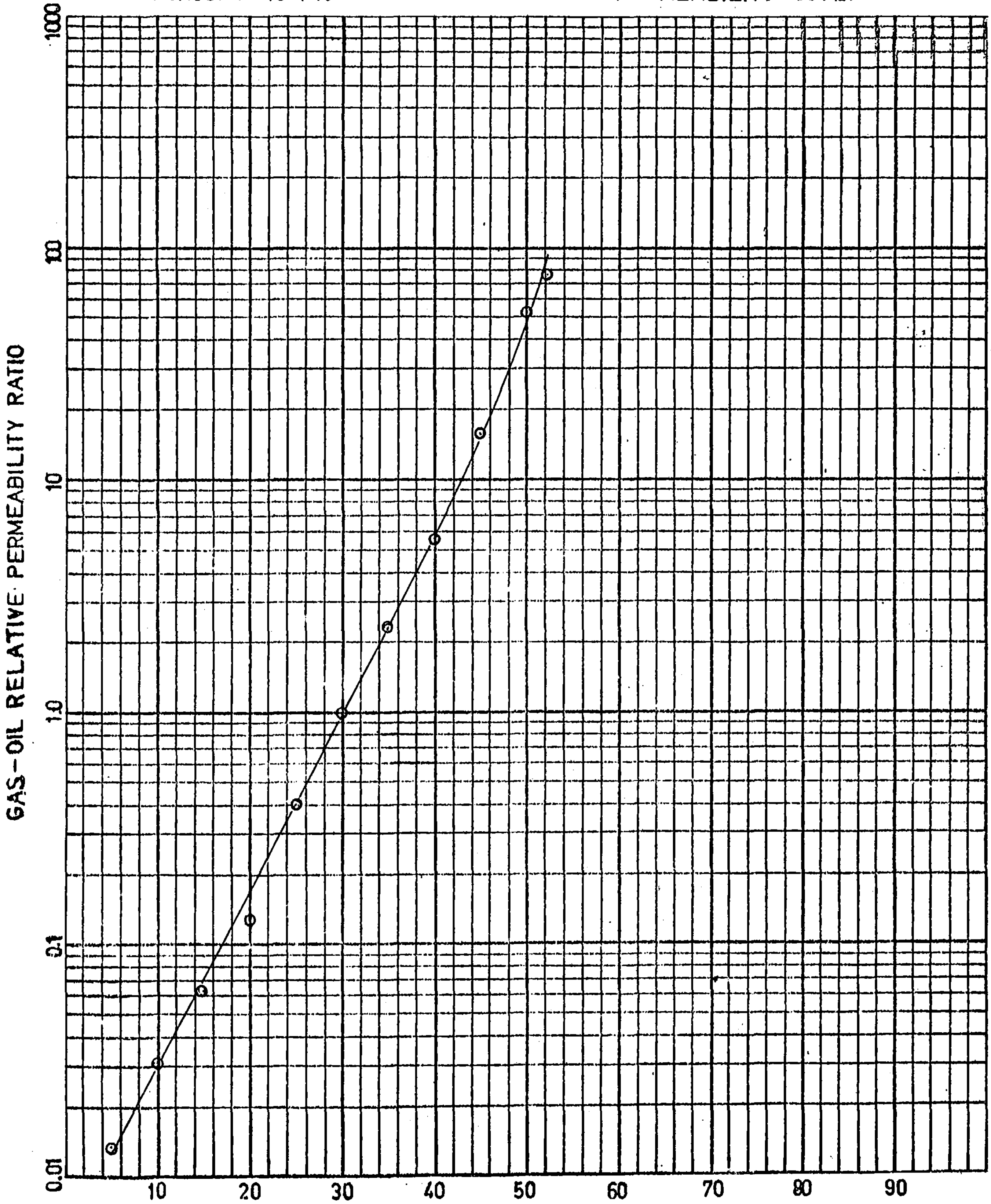


FIGURE 12

GAS-OIL RELATIVE PERMEABILITY RATIO

WELL NAME AND NUMBER – E.MEREENIE No. 4

DEPTH INTERVAL – 4711'

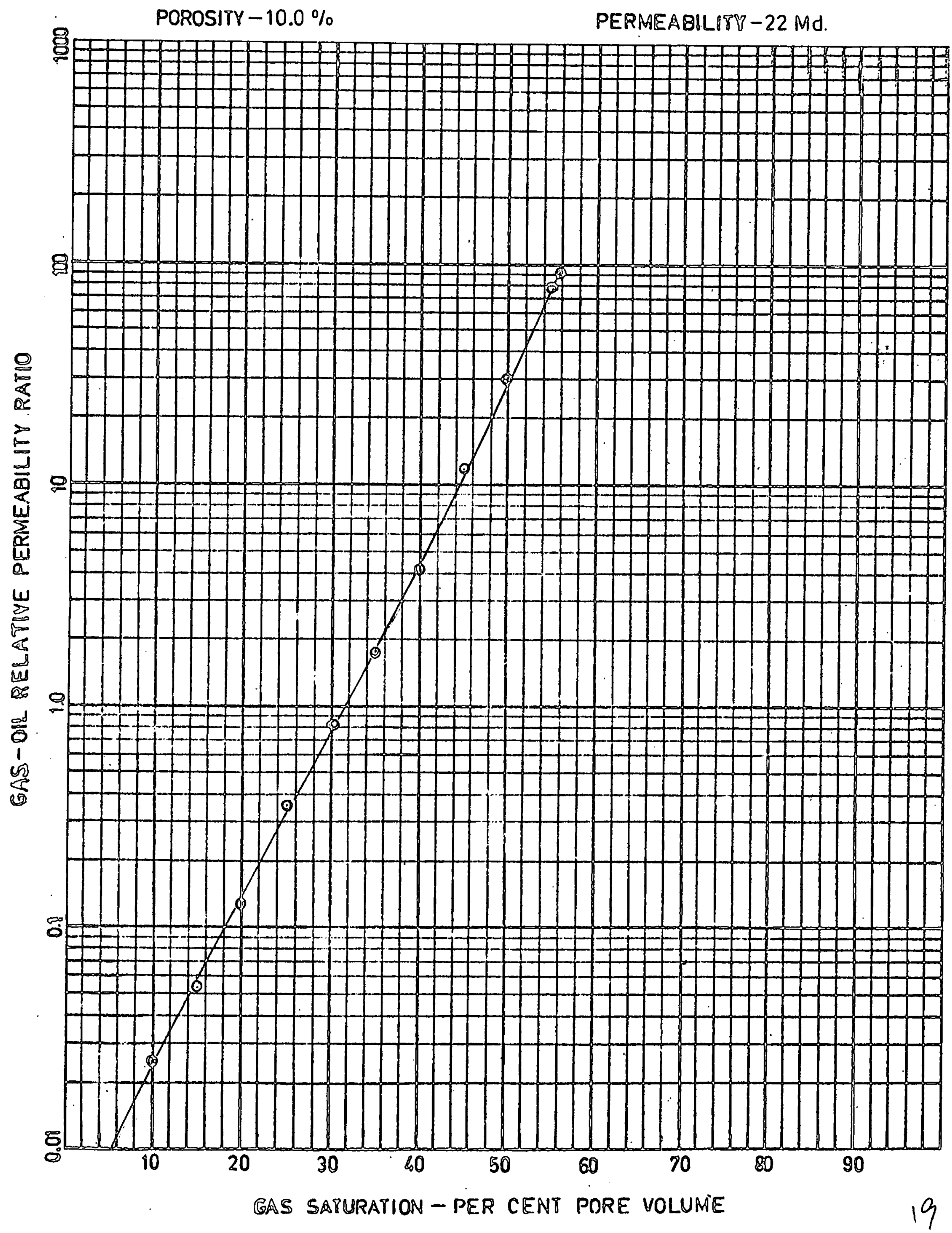


FIGURE 13

GAS-OIL RELATIVE PERMEABILITY RATIO

WELL NAME AND NUMBER-E.MEREENIE No. 4

DEPTH INTERVAL-4712'

POROSITY-10.1%

PERMEABILITY-16 Md.

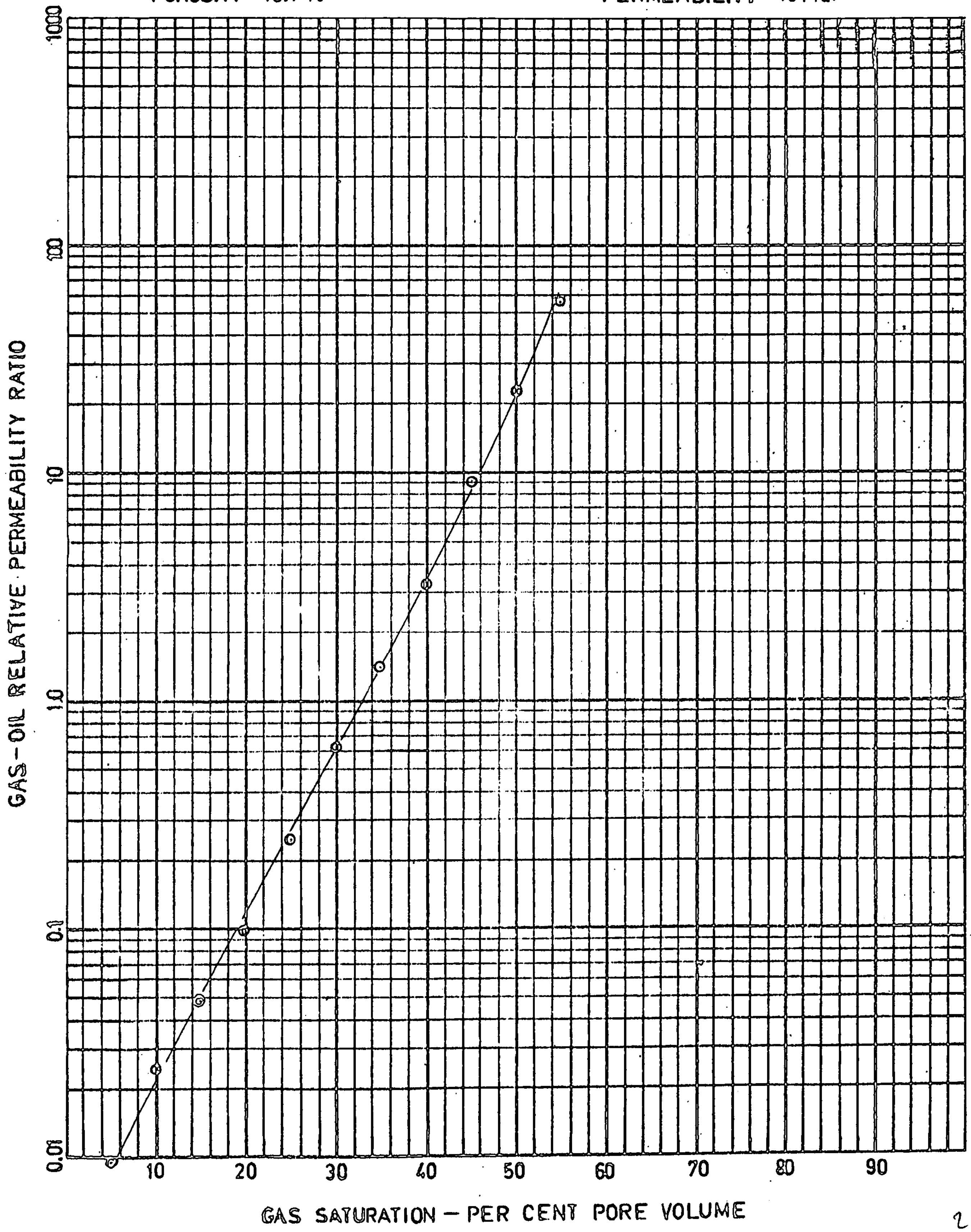


FIGURE 14

GAS-OIL RELATIVE PERMEABILITY RATIO

WELL NAME AND NUMBER-E.MEREENIE No.4

DEPTH INTERVAL-4713'

POROSITY - 10.5 %

PERMEABILITY-29 Md.

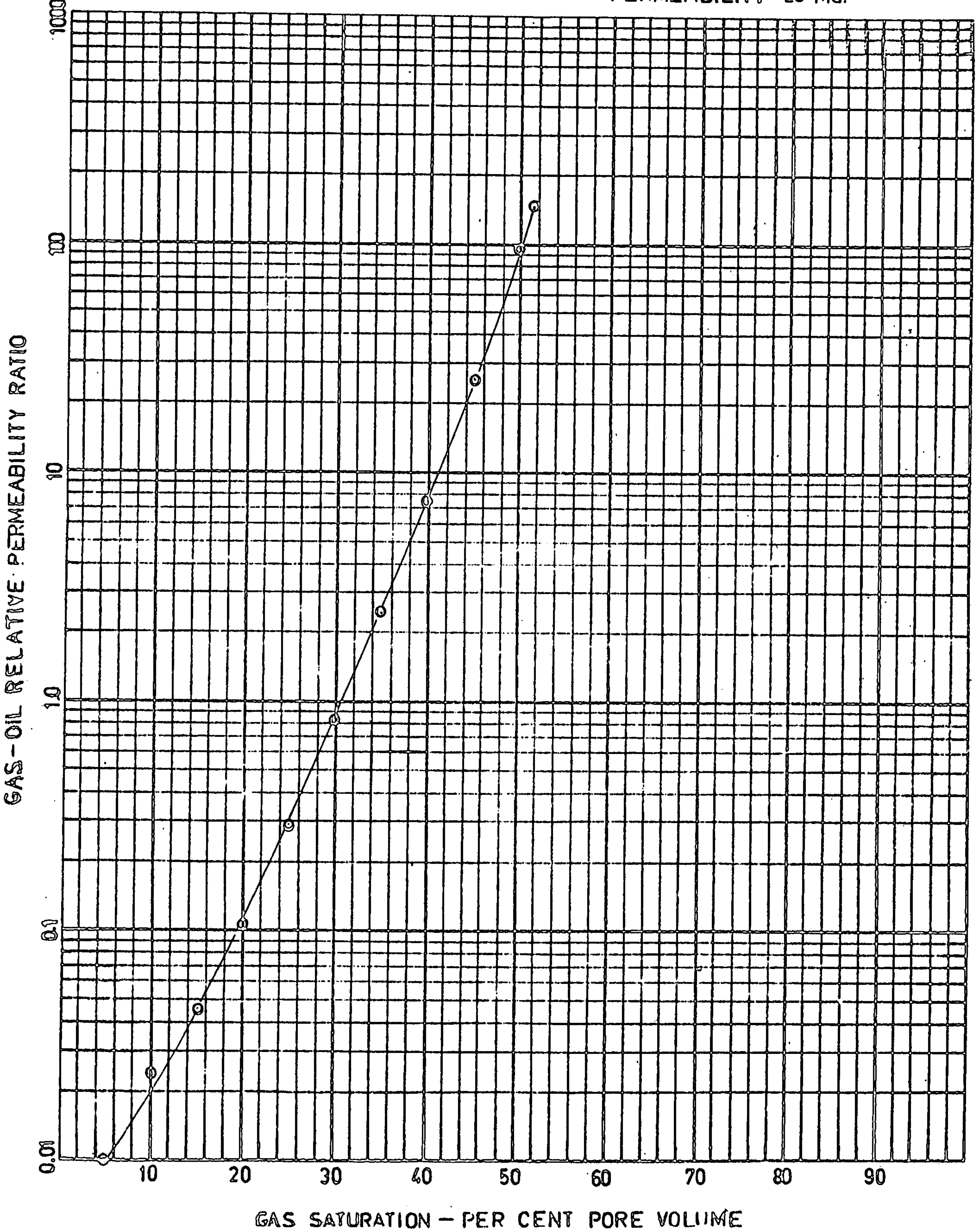


FIGURE 15

GAS-OIL RELATIVE PERMEABILITY RATIO

WELL NAME AND NUMBER – E. MEREENIE No. 4

DEPTH INTERVAL – 4742′

POROSITY – 11.3%　　　　PERMEABILITY – 53 Md.

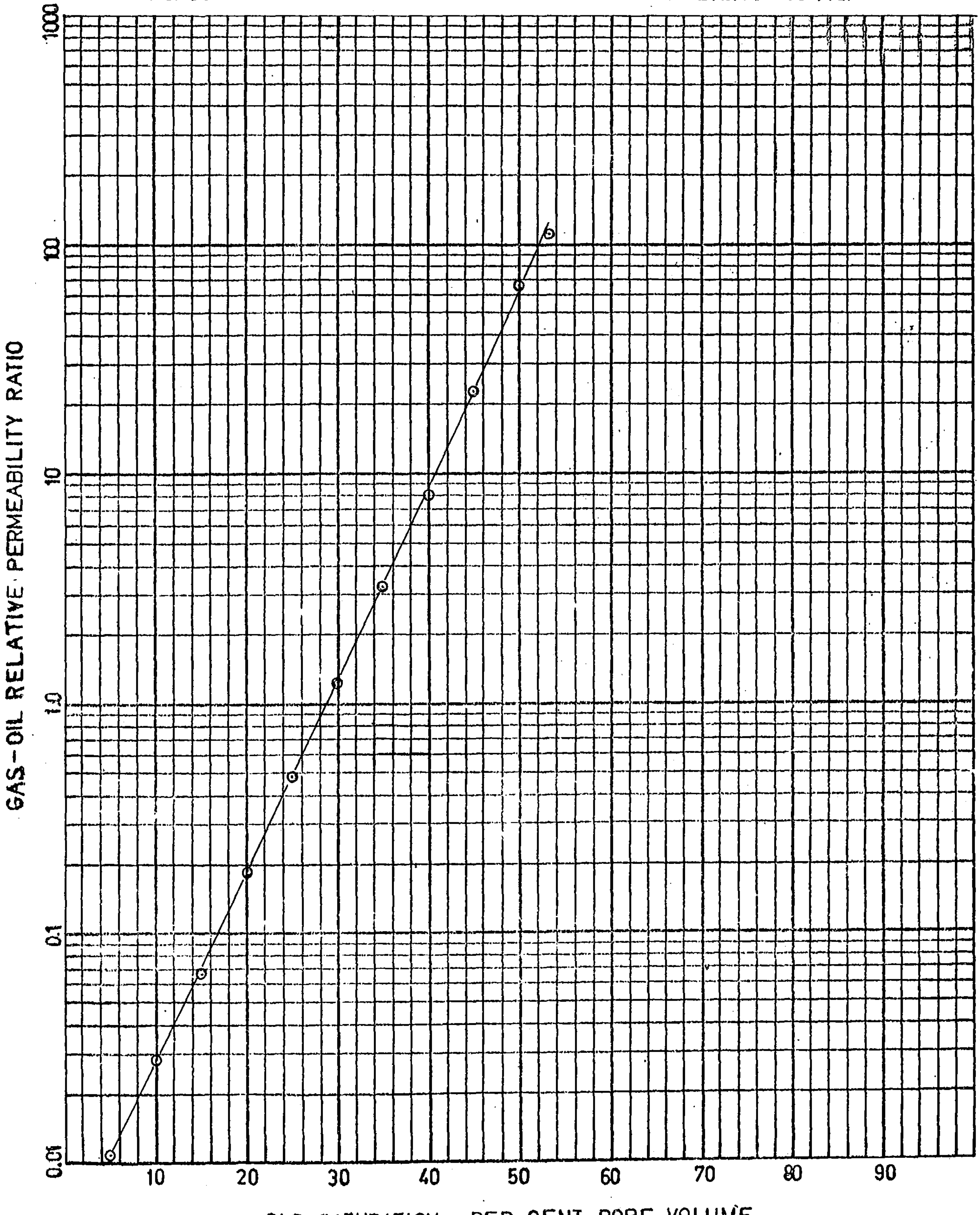


FIGURE 16

GAS-OIL RELATIVE PERMEABILITY RATIO

WELL NAME AND NUMBER - E. MEREENIE No. 4

DEPTH INTERVAL - 4752'

POROSITY - 9.7 %

PERMEABILITY - 4.5 Md.

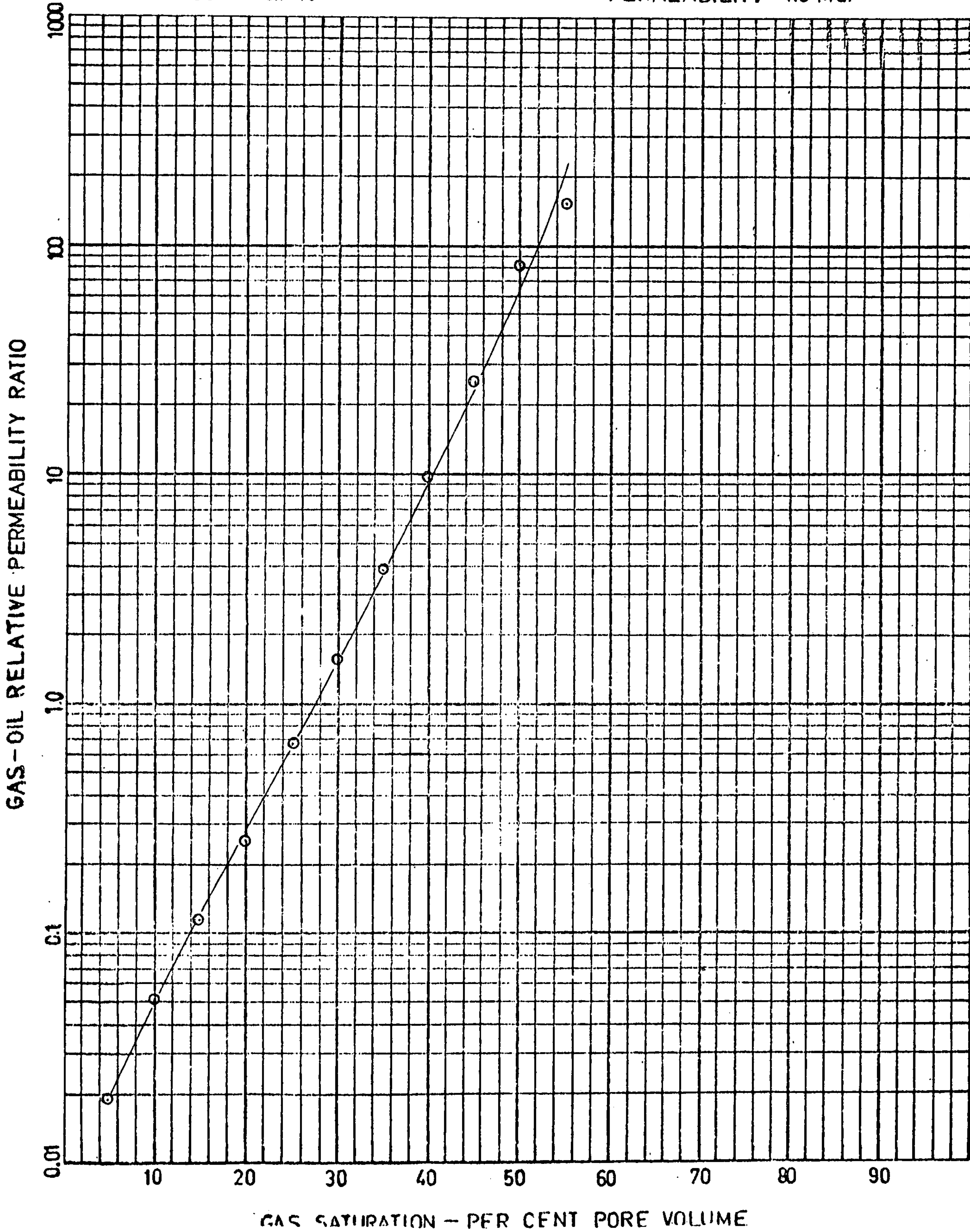


FIGURE 17

WATER FLOOD SUSCEPTIBILITY

WELL NAME AND NUMBER - E. MEREENIE No 4

DEPTH INTERVAL - 4631'

POROSITY - 8.4%

PERMEABILITY - 30 Md.

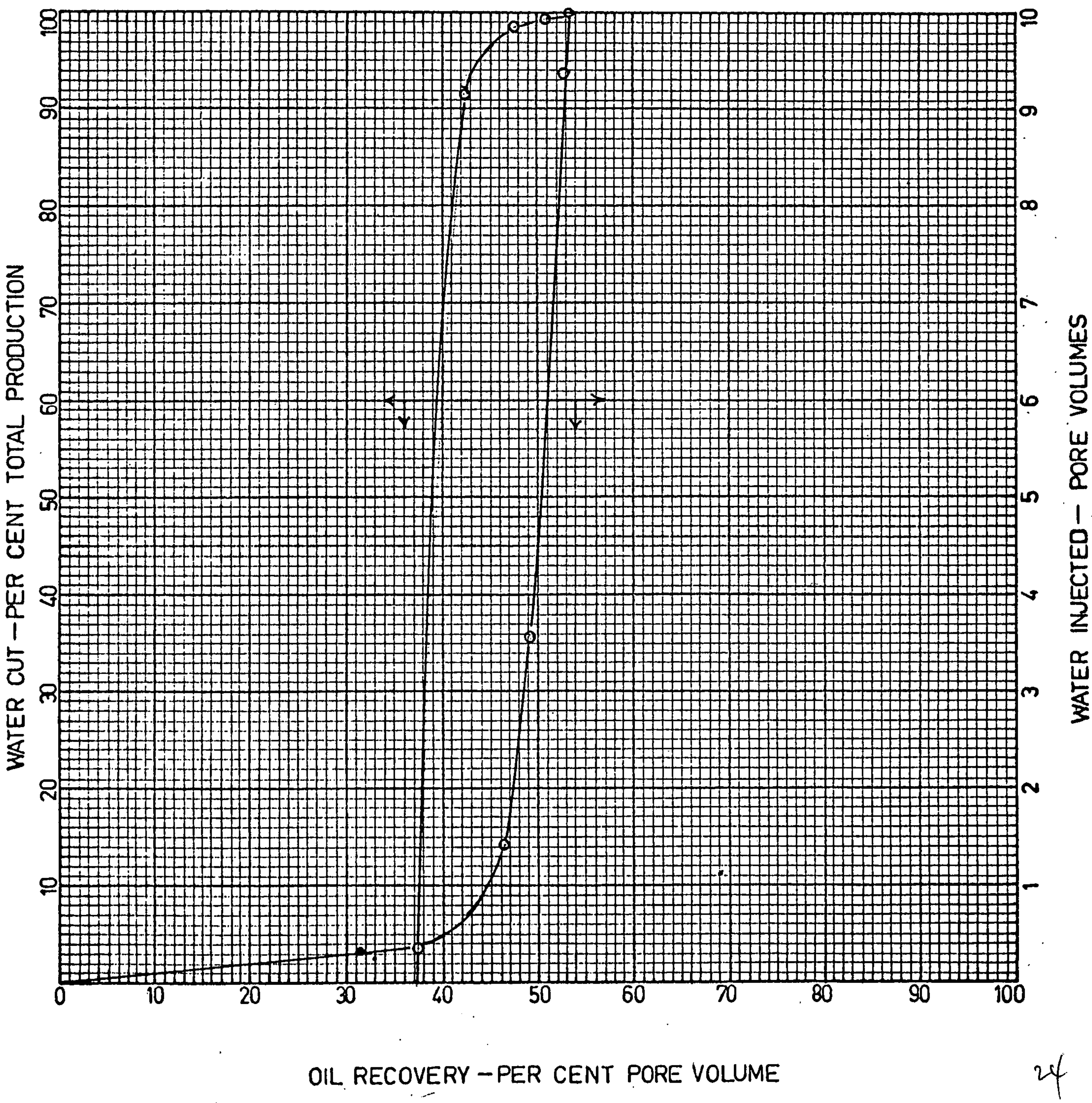


FIGURE 18

WATER FLOOD SUSCEPTIBILITY

WELL NAME AND NUMBER - E. MEREENIE No. 4

DEPTH INTERVAL - 4633'

POROSITY - 8.5 %

PERMEABILITY - 9.5 Md.

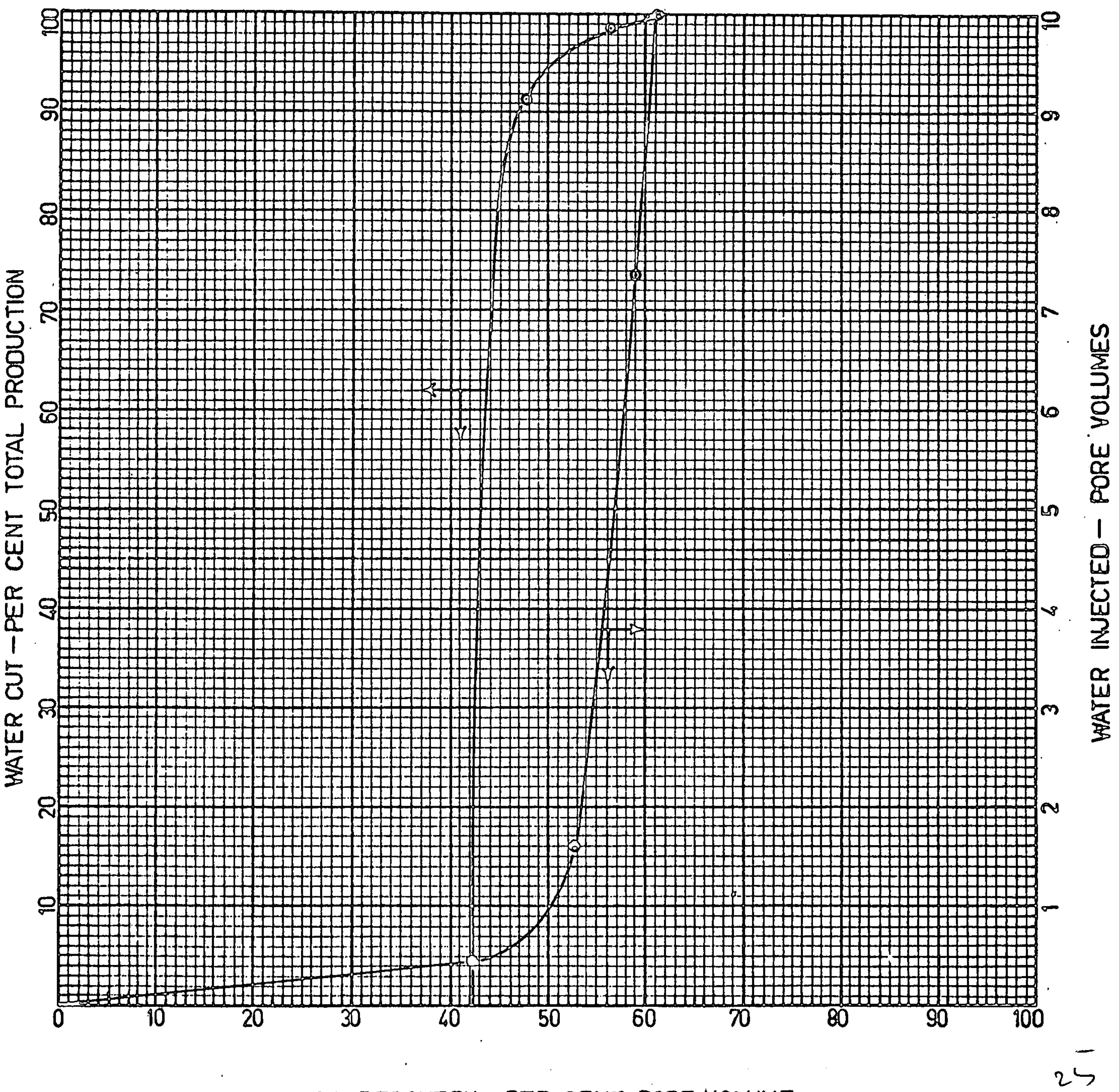


FIGURE 19

WATER FLOOD SUSCEPTIBILITY

WELL NAME AND NUMBER – E. MEREENIE No. 4

DEPTH INTERVAL – 4710'

POROSITY – 10.4 %

PERMEABILITY – 31 Md.

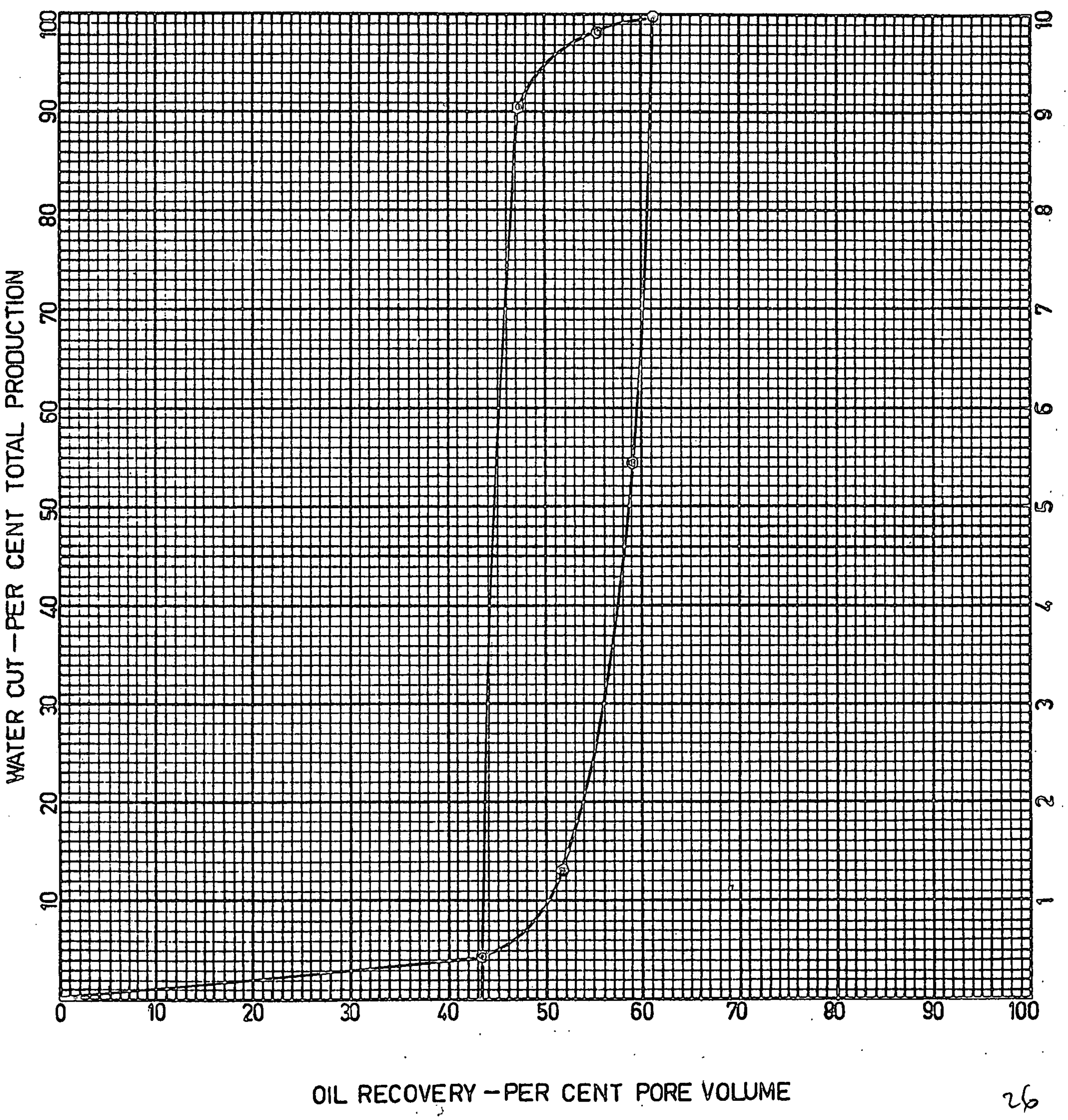


FIGURE 20

WATER FLOOD SUSCEPTIBILITY

WELL NAME AND NUMBER – E. MEREENIE No. 4

DEPTH INTERVAL – 4711

POROSITY – 10%

PERMEABILITY – 21 Md.

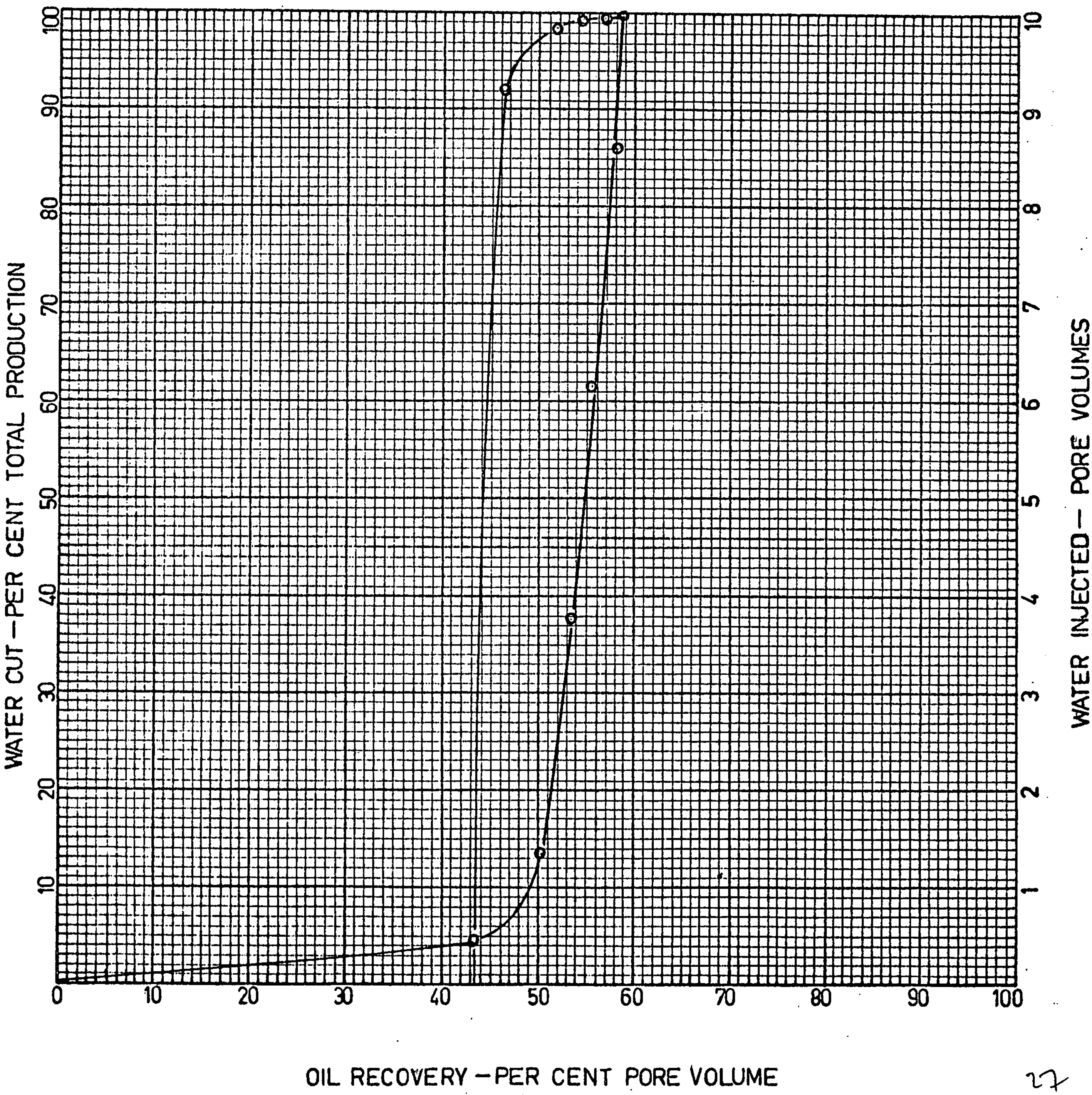


FIGURE 21

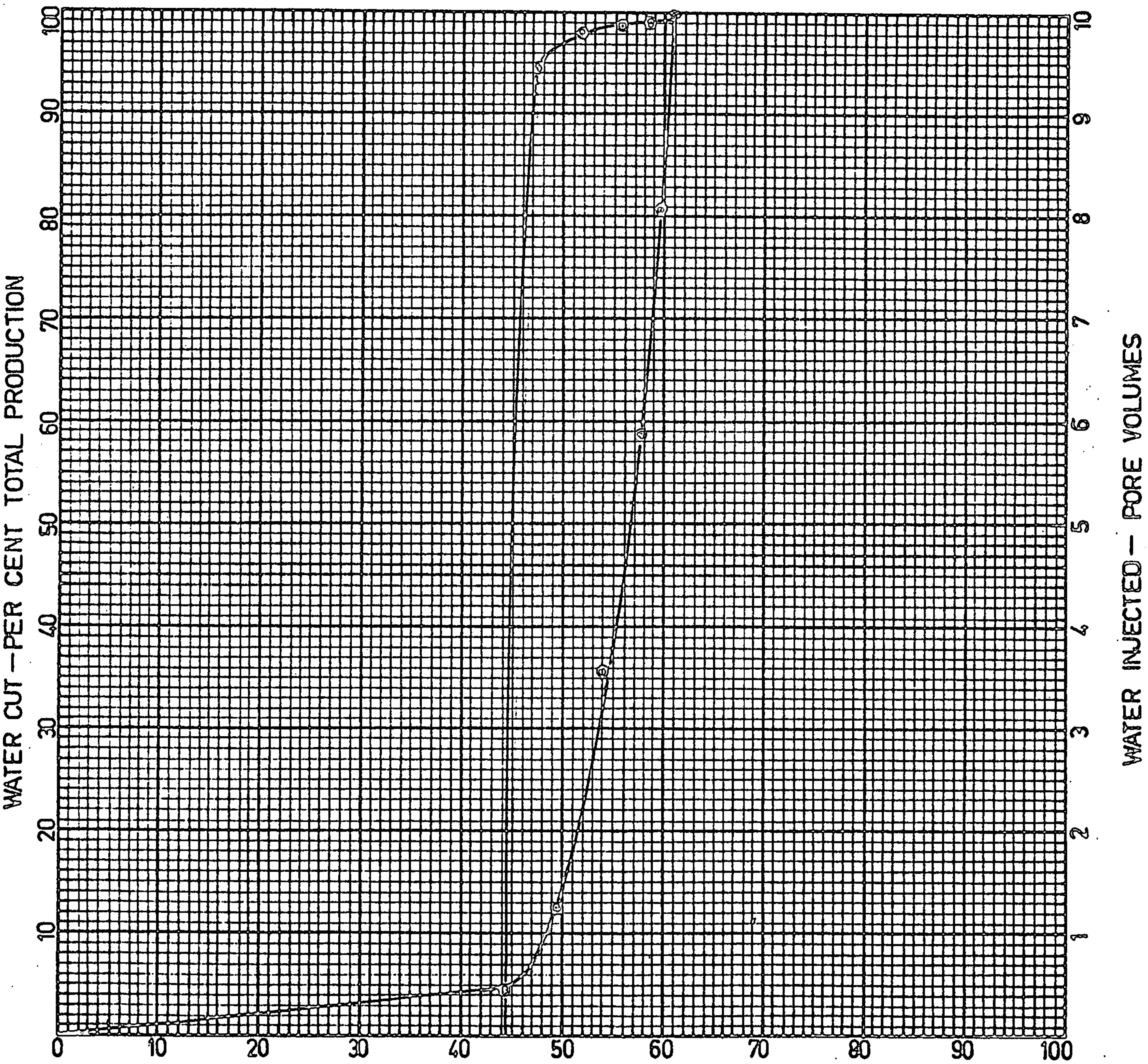
WATER FLOOD SUSCEPTIBILITY

WELL NAME AND NUMBER - E. MEREENIE No. 4

DEPTH INTERVAL - 4712'

POROSITY - 10 %

PERMEABILITY - 16 Md.



OIL RECOVERY - PER CENT PORE VOLUME

FIGURE 22

WATER FLOOD SUSCEPTIBILITY

WELL NAME AND NUMBER – E. MEREENIE No. 4

DEPTH INTERVAL – 4713'

POROSITY – 10.5 %

PERMEABILITY – 28.7 Md.

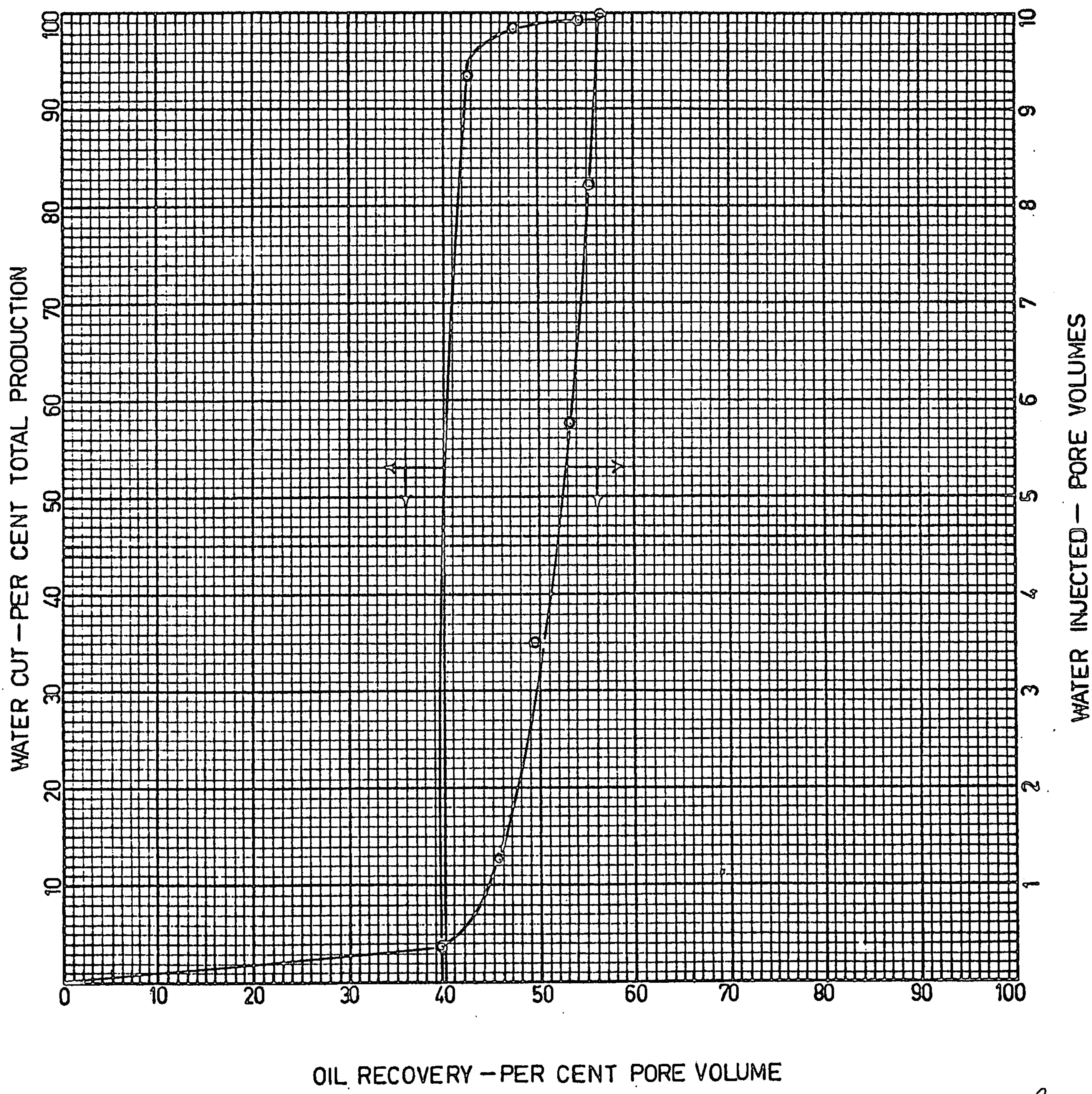


FIGURE 23

WATER FLOOD SUSCEPTIBILITY

WELL NAME AND NUMBER - E.MEREENIE No 4

DEPTH INTERVAL - 4742'

POROSITY - 11 %

PERMEABILITY - 53 Md.

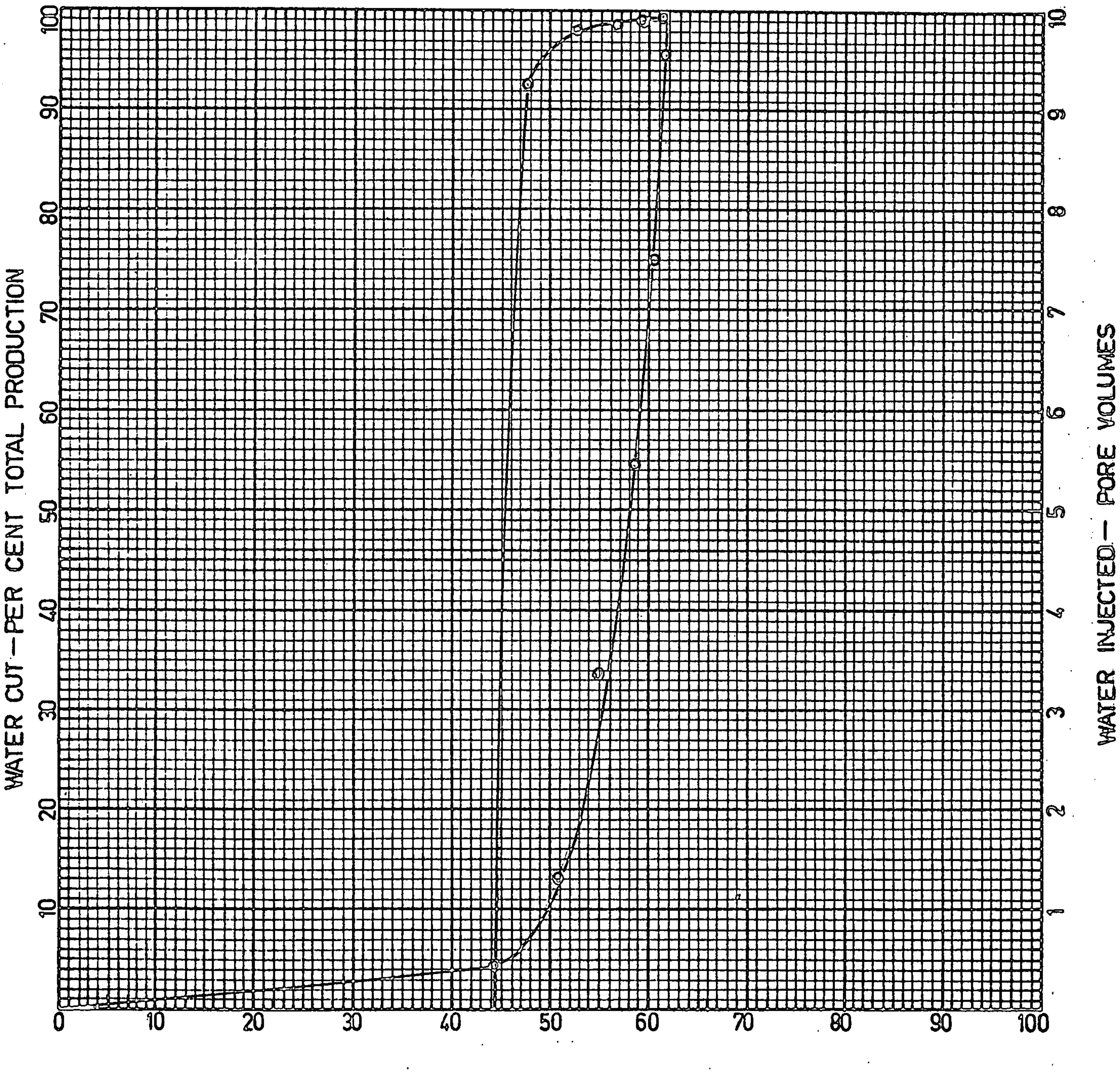


FIGURE 24

WATER FLOOD SUSCEPTIBILITY

WELL NAME AND NUMBER - E.MEREENIE No.4

DEPTH INTERVAL - 4752'

POROSITY - 9.7 %

PERMEABILITY - 4.0 Md.

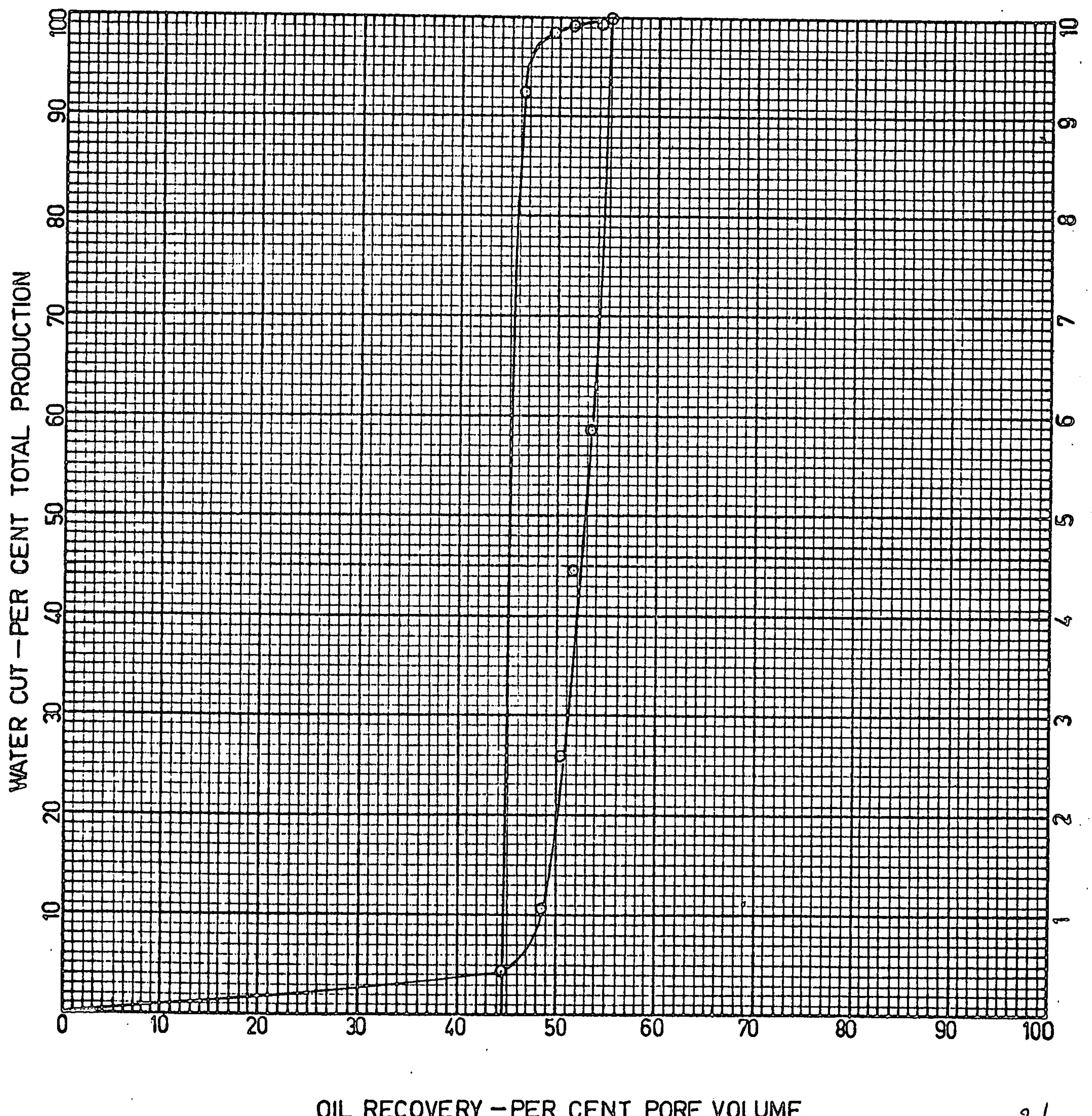
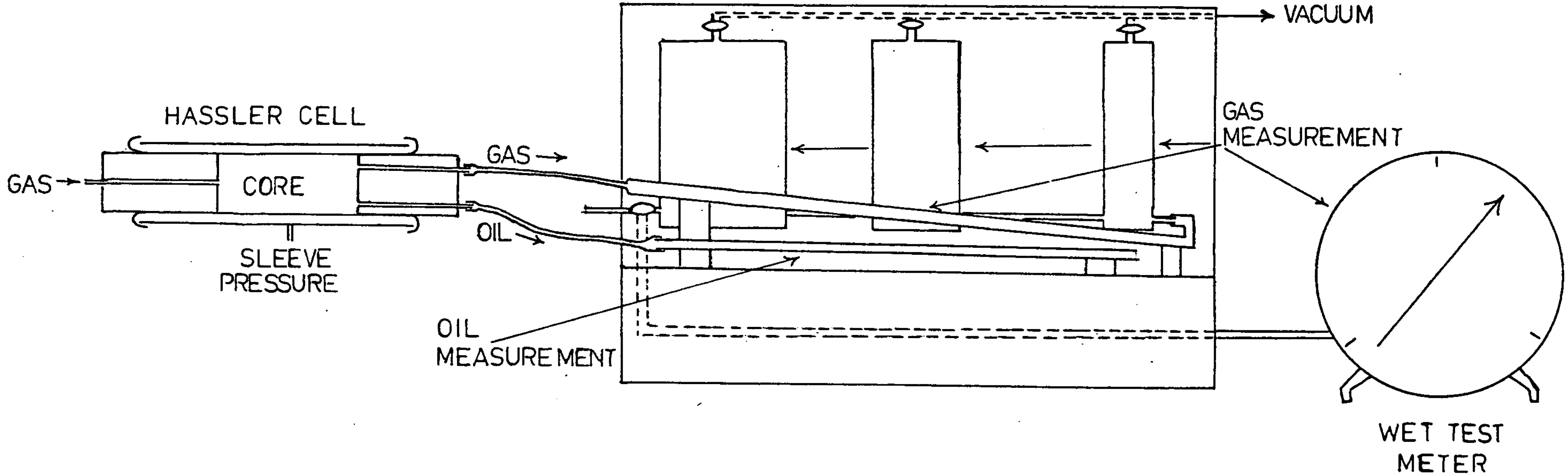


FIGURE 25

GAS–OIL RELATIVE PERMEABILITY APPARATUS



OUTLET END PLUG ASSEMBLY