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CORE LAB

SPECIAL CORE ANALYSIS STUDY

FOR

STATOIL

Well: 34/10-8

CORE LABORATORIES UK LTD.

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Stavanger
Norway

18th June 1982

Attention: Peter Read

Subject: Special Core Analysis Study
Well: 34/10-8
Area: North Sea, Norway
File: UKSCAL 311-80061

Gentlemen,

In a letter dated 11th July 1980, ref PAR/GEB from Statoil, Core Laboratories UK Limited was requested to perform a series of special core analysis measurements, as listed below, on samples from the subject well.

1. Specific Water Permeability
2. Gas-Oil Relative Permeability
3. Waterflood Susceptibility
4. Calculation of Water-Oil Relative Permeability
5. Wettability by Imbibition and Dynamic Displacement
6. Cation Exchange Capacity
7. Rock Compressibility

The results of these analyses are presented herein as a final report and serve to confirm all previous preliminary data. A table of contents immediately follows this letter.

It has been a pleasure working with Statoil on this study. Should you have any questions please do not hesitate to contact us.

Yours faithfully,
CORE LABORATORIES UK LIMITED

Jon Roberts
Laboratory Manager - Special Core Analysis

JCR/MBH/hsb
10 cc - Addressee

REGISTERED IN ENGLAND NO. 1331818 VAT NUMBER 219 8700 49
Registered Office:— 75 Greenfield Road, London, E1 1EJ.

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Special Core Analysis Study

Sample Preparation

A total of five, preserved, full diameter core pieces as listed below were received for use in this study.

Sample Number	Depth Metres
A	1847.59 - 1847.80
B	1856.68 - 1857.05
C	1902.53 - 1902.78
D	1920.82 - 1921.18
E	1974.75 - 1975.00

From each core piece, four one and a half inch diameter core plug samples were air drilled, due to the poorly consolidated nature of the core. Cut offs were also taken for use in cation exchange capacity measurements.

One sample from each core piece was sent, as requested, to Dr. Kohlaas of the Colorado School of Mines.

Five of the samples were scheduled to undergo fresh-state wettability analysis, and these were stored under synthetic formation brine, prior to analysis.

The remaining samples were leached in cool methanol and then cleaned in cool xylene. Sample number C_2 fractured and could not undergo further analysis.

The remaining nine samples were dried in a humidity controlled oven and had air permeability and helium injection porosity measured, however due to the extremely friable nature of the samples, samples numbered A_2, A_3, B_2, C_3, D_2, E_2 and E_3 were unsuitable for further analysis. All samples used are described with respect to depth and lithology on page 1 of this report.

Specific Water Permeability Data (Page 3)

Of the five samples originally scheduled to undergo this analysis, only samples numbered B_3 and D_3 were suitable.

The clean, dry samples were evacuated and pressure saturated with simulated formation brine. This brine consisted of approximately 43,000 mg/l total dissolved solids which was synthesised according to information furnished for use in this study. A copy of this brine analysis is presented on page 2.

The samples were each mounted in a hydraulic core holder and were flushed with this brine for a few pore volumes until a stable permeability was obtained. Results are presented in tabular form on page 3.

Cont'd.......

Gas-Oil Relative Permeability Data (Page 4)

Samples B_3 and D_3 were also scheduled for this analysis, however sample B_3 has a water permeability below 0.08 millidarcies, the recommended minimum liquid permeability for floods and was therefore unable to undergo further analysis.

The remaining fully saturated sample was placed in a high pressure porous plate cell and desaturated using humidified nitrogen as the displacing phase, an initial water saturation was calculated gravimetrically with the sample removed from the cell.

The sample was then mounted in a hydraulic core holder and was flushed with a refined mineral oil having a viscosity of approximately 20 centipoise at room conditions to ensure the removal of all trapped gas and mobile water. Effective permeability to this oil was then measured.

Gas-oil relative permeability measurements were performed using humidified nitrogen as the displacing phase. Incremental productions of oil and gas produced were recorded against time and the flood was terminated at a relative permeability ratio in excess of 30.

Relative permeability data were calculated using a digital computer and results are presented in tabular form on page 4 and in graphical form on pages 5 and 6.

Waterflood Susceptibility Data (Page 7)

Following gas-oil relative permeability measurements, sample D_3 was restored under vacuum with a refined mineral oil having a viscosity of approximately 2.6 centipoise this gives an oil:water viscosity ratio in the laboratory similar to the oil:water viscosity ratio in the reservoir. The sample was then mounted in a hydraulic core holder and flushed with this oil to ensure the removal of all trapped gas and 20 centipoise oil. Effective permeability to this oil was then measured.

Waterflood susceptibility measurements were performed using synthetic formation brine as the displacing phase at a flow rate of approximately 400 cc/hr. Incremental productions of oil and water were recorded against time and the flood was terminated after a throughput of approximately 200 pore volumes.

Results are summarised on page 7 and are presented in tabular form on page 8 and in graphical form on page 10.

The sample was then flushed with the matched viscosity oil, water displaced was recorded and when the initial water saturation had been achieved, effective permeability to this oil was remeasured.

Cont'd......

Waterfloods were performed as before but at a flow rate of 4 cc/hr, and after a throughput of 5 pore volumes, when the watercut was in excess of 95% the flood was terminated.

Results are summarised on page 7 and are presented in tabular form on page 9 and in graphical form on page 11.

Relative permeability data were to be calculated from the results of both the fast and slow rate floods, however this was only possible for the fast rate flood, due to the narrow saturation range obtained during the slow rate flood. Results are presented in tabular form on page 12 and in graphical form on pages 13 and 14.

Wettability by Imbibition and Dynamic Displacement (Page 15)

Five samples were scheduled to undergo this analysis.

The fresh-state samples were each mounted in a hydraulic core holder and flushed with synthetic formation brine to ensure the removal of any trapped gas. Effective permeability to this brine was then measured. Samples numbered A_1, C_1, D_1 and E_1 fractured and no further analysis was possible.

The remaining sample was immersed in treated, degassed kerosene for a period of weeks until static imbibition of the kerosene ceased. The volume of oil imbibed, indicated by the volume of water displaced was recorded. The sample was then flushed with kerosene and the volume of brine displaced indicating the volume of kerosene imbibed recorded. Effective permeability to the kerosene was then measured.

The procedure was repeated using synthetic formation brine as the imbibing fluid. Wettability indices were calculated using the volumes of fluid dynamically and statically imbibed.

The sample was then cleaned in a Dean-Stark type distillation apparatus, leached in methanol and dried in a humidity controlled oven.

Air permeability and helium injection porosity were then measured and fluid saturations calculated using material balance equations. Results are presented in tabular form on page 15 and the sample is water wet.

In a meeting between Core Laboratories and Statoil on the 19th December 1980, it was requested that further samples of one inch diameter be drilled.

Cont'd......

Four further samples were drilled and were labelled A_5, C_5, D_5 and E_5, these were to undergo wettability analysis as before but prior to the dynamic displacement phase, when the samples were to be placed in a hydraulic core holder, they were mounted in thin metal sleeves to maintain their coherence. For the static imbibition phase these sleeves were removed. However samples numbered A_5, C_5 and E_5 collapsed during analysis and no further analysis was possible. A further two samples labelled A_6 and E_6 were drilled, but these also collapsed during analysis . Results for sample D_5 are presented in tabular form on page 15 and the sample is oil wet.

<u>Cation Exchange Capacity Data (Page 16)</u>

Cut offs of five samples were used in this analysis.

An ammonium acetate titration technique was used in determining the cation exchange capacity of the samples. Results are presented in tabular form on page 16.

<u>Rock Compressibility Data (Page 17)</u>

Sample D_5 was scheduled to undergo this analysis.

The clean, dry sample was mounted in heat shrinkable plastic tubing, placed in a hydraulic core holder and was then saturated with a brine consisting of approximately 30,000 mg/l sodium chloride. The external and internal sleeve pressures were raised simultaneously to approximately 357 bars and 344 bars respectively. Having reached pressure stabilisation, the internal pore pressure was reduced incrementally to simulate reservoir depletion and corresponding pore volume reductions recorded.

Compressibilities were calculated from a plot of pore volume versus effective overburden pressure and, from the curve, the instantaneous change in pore volume per unit overburden pressure was determined. The resulting compressibilities were corrected for uniaxial loading as per Teeuw [1]. The results are presented in tabular form on page 17.

[1] Uniaxial loading conditions, transformed from hydrostatic data as per Teeuw, Dirk, "Prediction of Formation Compaction from Laboratory Compressibility Data". <u>Trans</u> AIME (1971) 251, 263-271.

COMPANY: STATOIL
WELL: 34/10-8
FIELD:

FORMATION:
COUNTRY: NORTH SEA
STATE: NORWAY

IDENTIFICATION AND DESCRIPTION OF SAMPLES

Sample Number	Depth Metres	Lithological Description
B1	1856.74	Sst, gy, fgn, mod hd, wcmt, w srtd, tr calc mtrx, mod abund mic, fin dk gy shly lams.
B3	1856.83	As above.
D3	1920.99	Sst, lt brn, med/crs gn, mod hd, wcmtd, m srtd, calc cmt, fe stning, mod abund mica, tr carb.
D5	1921.02	As above.

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Petroleum Reservoir Engineering

LONDON—ABERDEEN

File: UKSCAL 311-80061

Water Analysis Data

Constituents

Cations:	mg/l	meq/l
SODIUM	14,000	609
CALCIUM	1,275	63.6
MAGNESIUM	335	27.6
BARIUM	50	0.73
LITHIUM	7.6	1.10
POTASSIUM	209	5.35

Anions	mg/l	meq/l
CHLORIDE	26,200	739
BICARBONATE	415	6.80
SULPHATE	30.8	0.64
BROMIDE	62	0.78

Ph = 7.05

Resistivity Ohms/Metres at 21.6^{o}C = 0.168

Water Permeability Data

Sample Number	Depth Metres	Air Permeability, Md	Porosity Percent	Water Permeability, Md
B3	1856.83	0.16	3.5	0.06
D3	1920.99	115	30.0	89

GAS-OIL RELATIVE PERMEABILITY DATA

Sample Number: D3

Air Permeability, Md: 115

Oil Permeability with Initial Water Present, Md: 92

Initial Water Saturation Per Cent Pore Space: 25.7

Porosity, Per Cent: 30.0

Liquid Saturation Per Cent Pore Space	Gas-Oil Relative Permeability Ratio	Relative Permeability To Gas*, Fraction	Relative Permeability To Oil*, Fraction
100	0.000	0.000	1.000
94.5	0.050	0.028	0.543
93.1	0.077	0.036	0.467
90.7	0.146	0.053	0.365
88.0	0.291	0.078	0.265
86.7	0.402	0.091	0.226
84.5	0.673	0.116	0.173
82.2	1.05	0.142	0.135
77.0	3.16	0.228	0.072
73.6	6.55	0.286	0.043
70.3	13.9	0.358	0.026
66.7	35.8	0.441	0.012

* Relative to Oil Permeability

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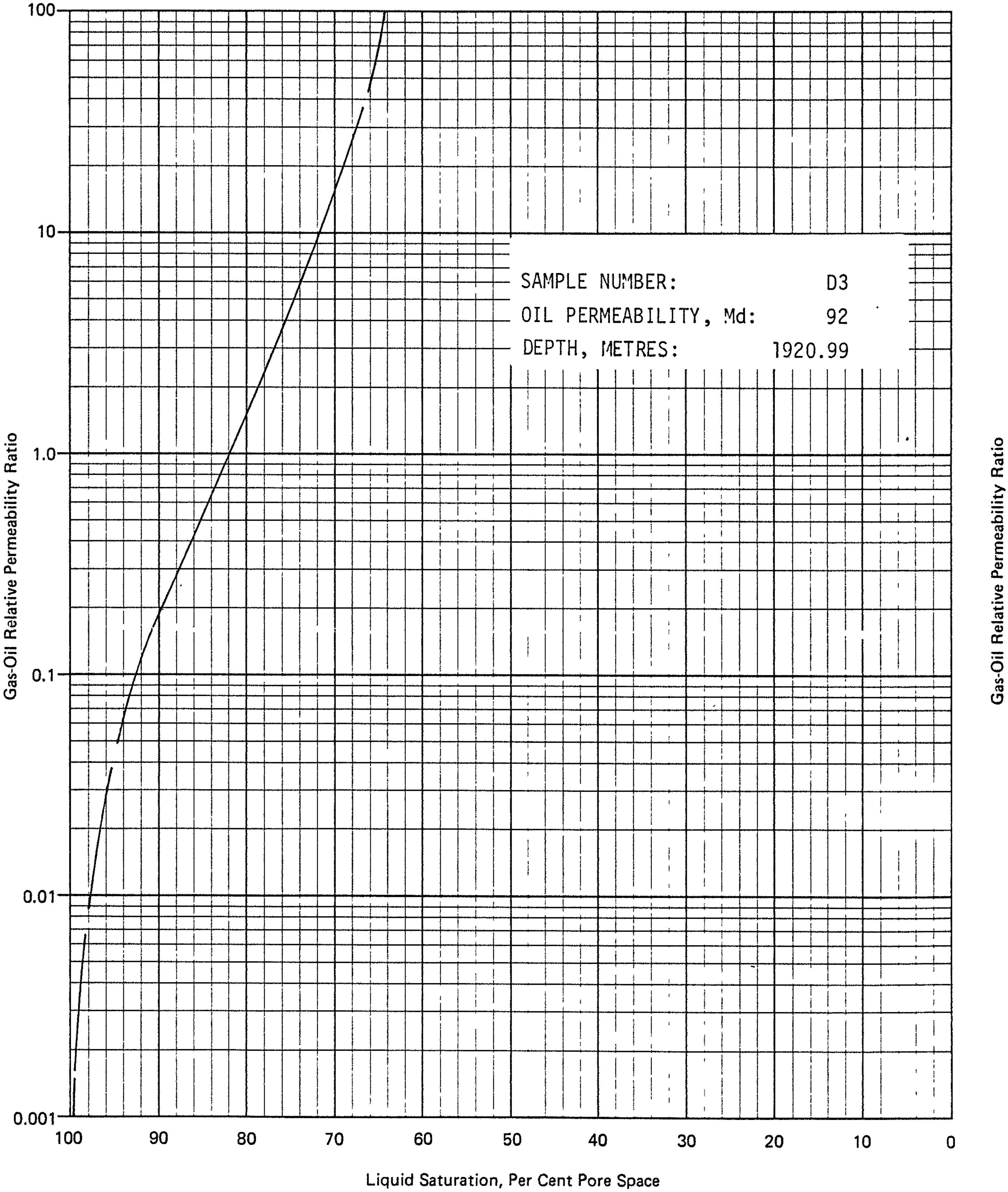
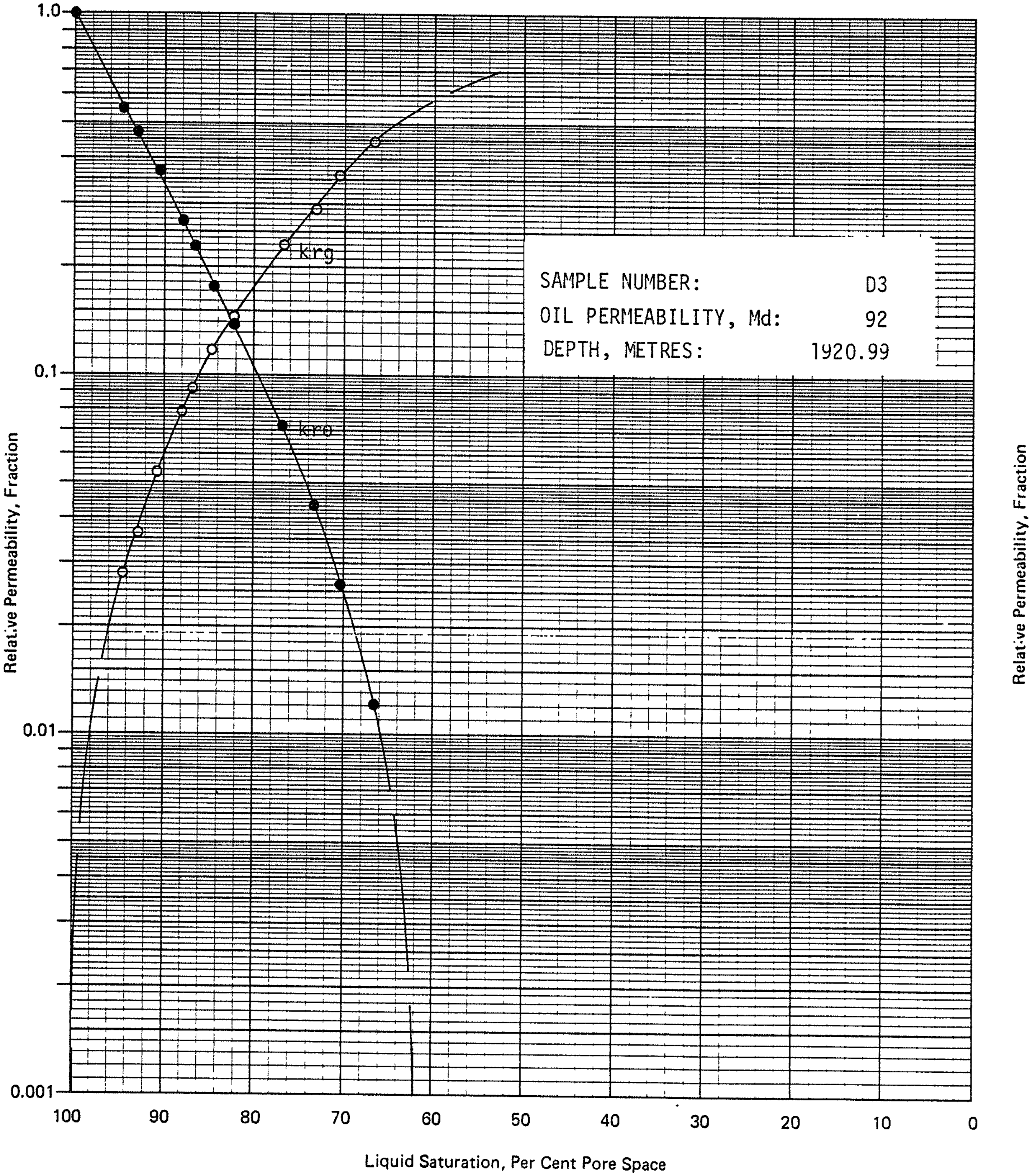


Company STATOIL
Well 34/10-8
Field

Formation
Country NORTH SEA
NORWAY



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SUMMARY OF WATERFLOOD TEST RESULTS

			Initial Conditions		Terminal Conditions		Oil Recovered	
Sample Number	Air Permeability Millidarcys	Porosity Per Cent	Water Saturation Per Cent Pore Space	Oil Permeability Millidarcys	Oil Saturation Per Cent Pore Space	Water Permeability Millidarcys	Per Cent Pore Space	Per Cent Oil in Place
				Flow Rate: 400 cc/hr				
D3	115	30.0	25.7	88	20.6	39	53.7	72.2
				Flow Rate: 4 cc/hr				
D3	115	30.0	26.5	88	39.3	17	34.2	46.5

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Waterflood Susceptibility Data

Sample Number: D3

Permeability to Air, Md: 115

Permeability to Oil with Initial Water Present, Md: 88

Initial Water Saturation Per Cent Pore Space: 25.7

Porosity, Per Cent: 30.0

Flooding Pressure, Bars: 2.59

Flow Rate 400 cc/hr

Water Input Pore volumes	Cumulative Oil Recovery, Per Cent Pore Space	Average Oil Recovery, *Per Cent Pore Space	Average Water Cut** Per Cent
0.229	22.9 ***	-	-
0.341	27.0	25.0	54.87
0.428	29.7	28.4	68.62
0.612	33.2	31.5	81.36
0.882	35.5	34.4	91.41
1.16	36.9	36.2	94.92
1.70	38.8	37.9	96.95
2.19	39.8	39.3	97.92
3.89	42.1	41.0	98.80
5.09	43.2	42.7	99.07
8.63	45.3	44.3	99.47
11.0	46.2	45.8	99.61
13.3	47.0	46.6	99.68
22.7	48.8	47.9	99.81
36.6	50.2	49.5	99.92
55.2	51.5	50.9	99.94
73.8	52.2	51.9	99.98
129.7	53.1	52.7	99.99
148.3	53.3	53.2	99.99
167.0	53.5	53.4	99.99
185.5	53.6	53.6	99.99
204.1	53.7	53.7	99.99

* Calculated for mid-point of incremental throughput
** Calculated from incremental throughput volumes
*** Break through recovery

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Waterflood Susceptibility Data

Sample Number: D3

Permeability to Air, Md: 115

Permeability to Oil with Initial Water Present, Md: 88

Initial Water Saturation Per Cent Pore Space: 26.5

Porosity, Per Cent: 30.0

Flooding Pressure, Bars: 0.056

Flow Rate 4 cc/hr

Water Input Pore volumes	Cumulative Oil Recovery, Per Cent Pore Space	Average Oil Recovery, *Per Cent Pore Space	Average Water Cut** Per Cent
0.243	24.3 ***	-	-
0.336	26.8	25.6	72.36
0.430	28.6	27.7	86.00
0.612	29.8	29.2	93.64
0.901	30.8	30.3	96.31
1.38	31.8	31.3	98.08
2.57	32.6	32.2	99.25
3.77	33.3	33.0	99.42
5.91	34.2	33.8	99.61

* Calculated for mid-point of incremental throughput
** Calculated from incremental throughput volumes
*** Break through recovery

"Flow Rate: 400cc/hr"

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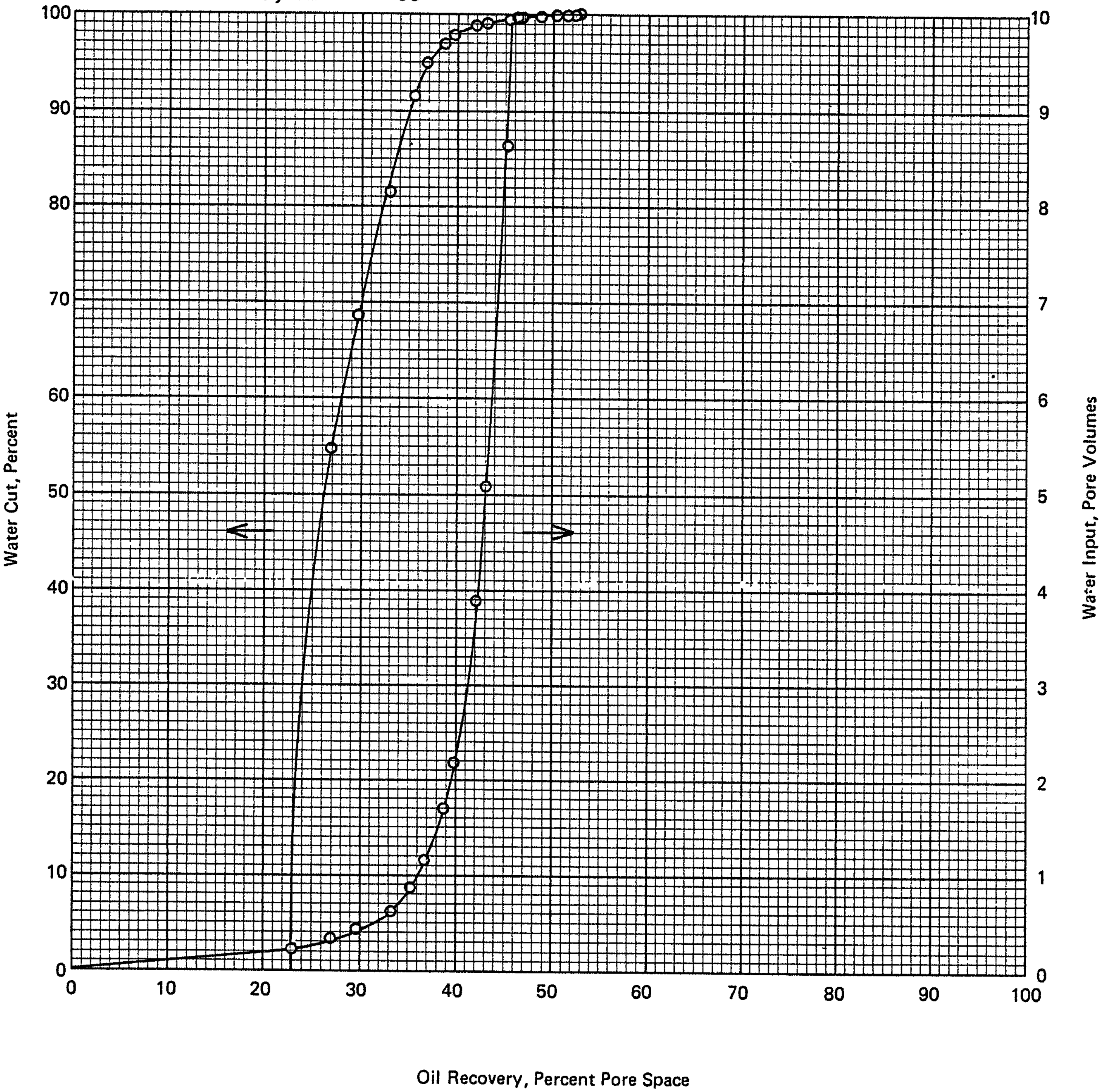
SAMPLE NUMBER D3

DEPTH, METRES: 1920.99

OIL PERMEABILITY, MD 88



"Flow Rate: 4cc/hr"

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Company STATOIL
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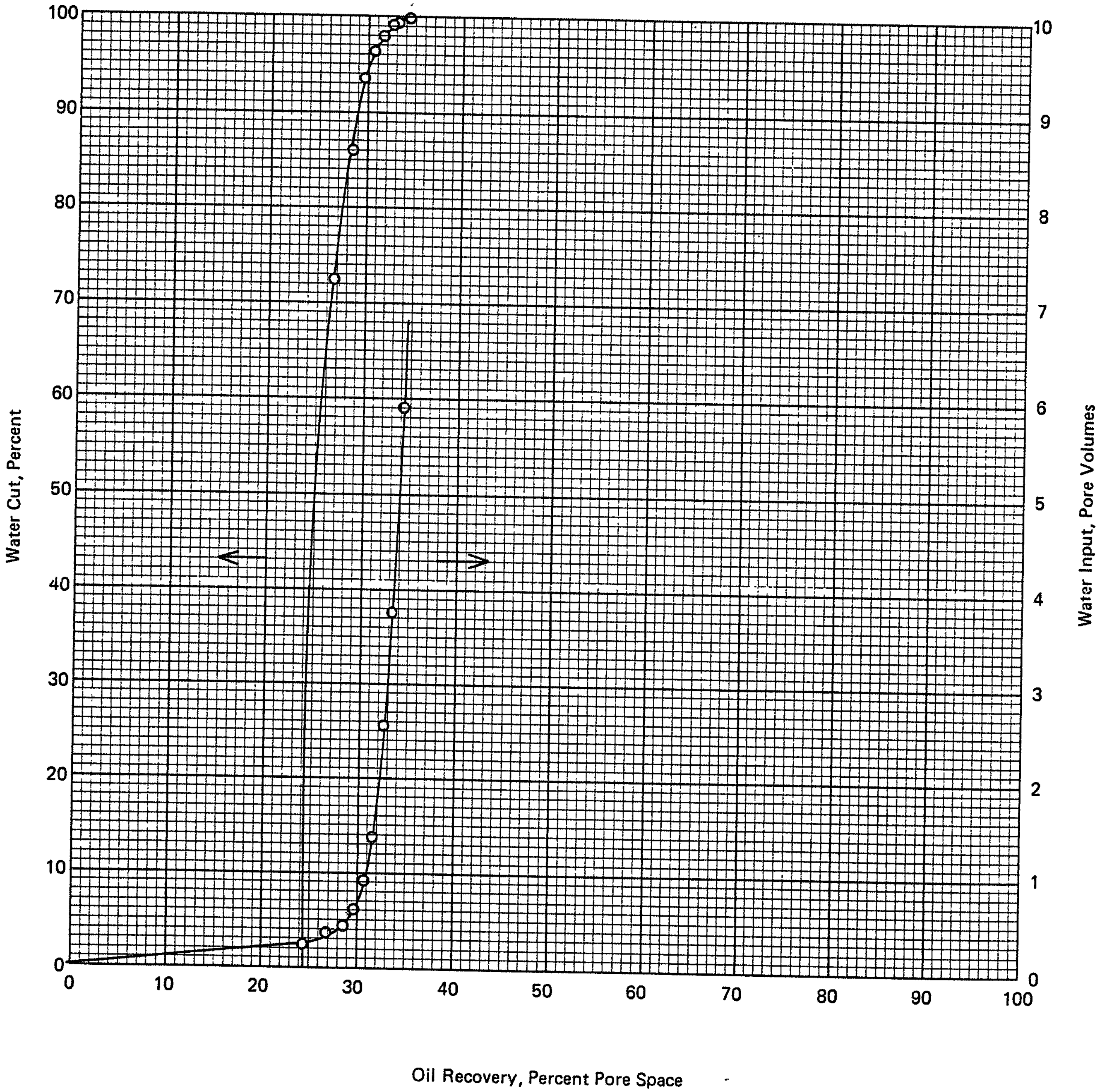
NORWAY

SAMPLE NUMBER D3

DEPTH, METRES: 1920.99

OIL PERMEABILITY, MD 88



Water-Oil Relative Permeability Data

Sample Number: D3

Air Permeability, Md: 115

Oil Permeability with
Initial Water Present, Md: 88

Initial Water Saturation
Per Cent Pore Space: 25.7

Porosity, Per Cent: 30.0

Water Saturation, Per Cent Pore Space	Water-Oil Relative Permeability Ratio	Relative Permeability To Water*, Fraction	Relative Permeability To Oil*, Fraction
25.7	0.000	0.000	1.000
60.7	18.3	0.268	0.015
62.3	26.3	0.282	0.011
63.3	33.4	0.292	0.0088
64.0	39.5	0.302	0.0076
64.6	45.5	0.309	0.0068
65.7	60.1	0.322	0.0054
66.3	68.7	0.328	0.0048
67.1	86.0	0.337	0.0039
67.5	93.7	0.341	0.0036
68.0	107	0.348	0.0032
68.3	117	0.351	0.0030
69.3	154	0.357	0.0023
70.4	214	0.378	0.0018
72.8	463	0.397	0.00086
73.8	628	0.409	0.00065
76.4	1918	0.417	0.00022
77.1	2895	0.428	0.00015
77.8	4707	0.430	0.000091
78.0	5352	0.431	0.000081
78.2	6628	0.432	0.000065
78.4	7940	0.433	0.000055
79.4	-	0.440	0.000000

* Relative to Oil Permeability

Company STATOIL
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Field

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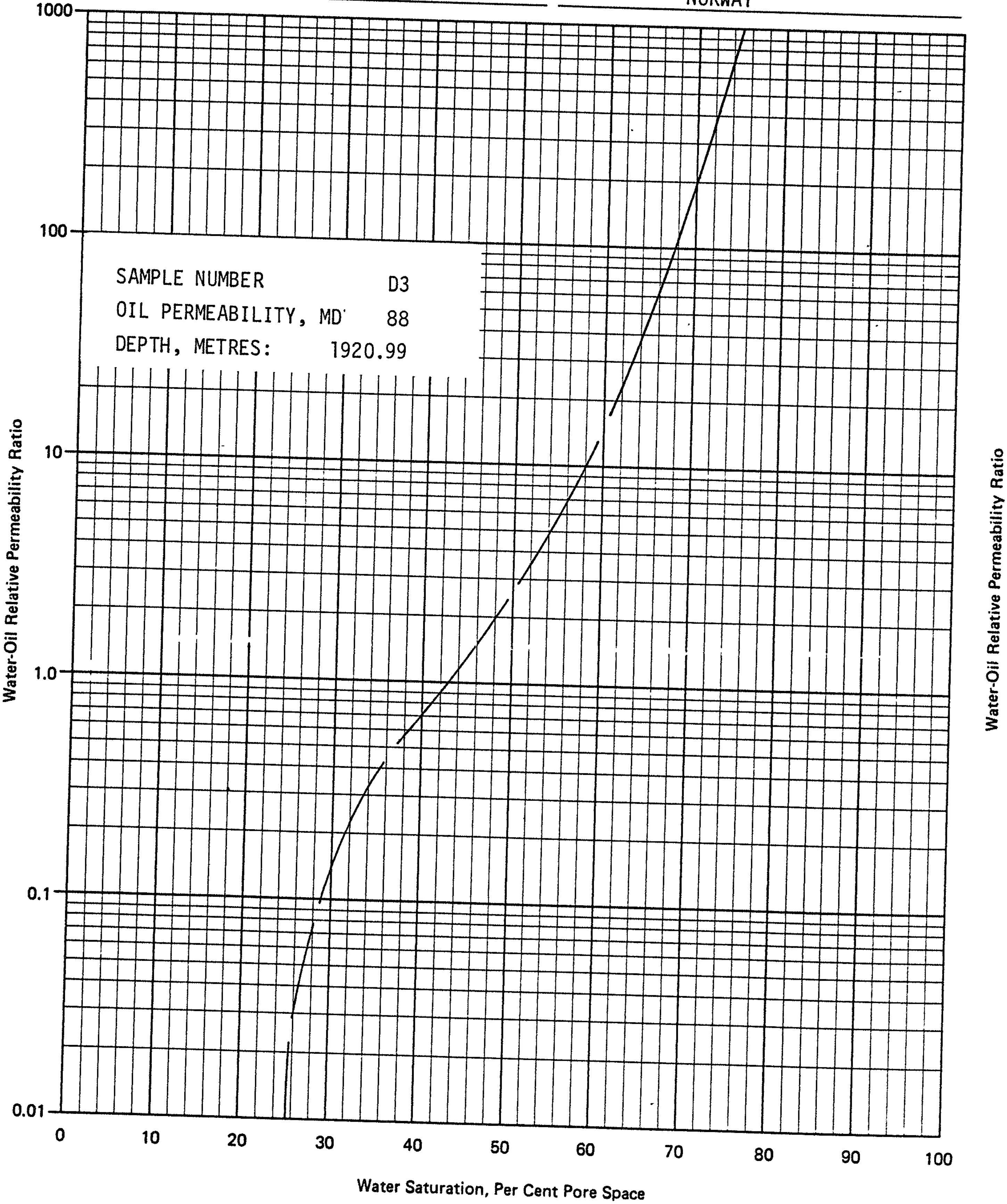
Country NORTH SEA
NORWAY



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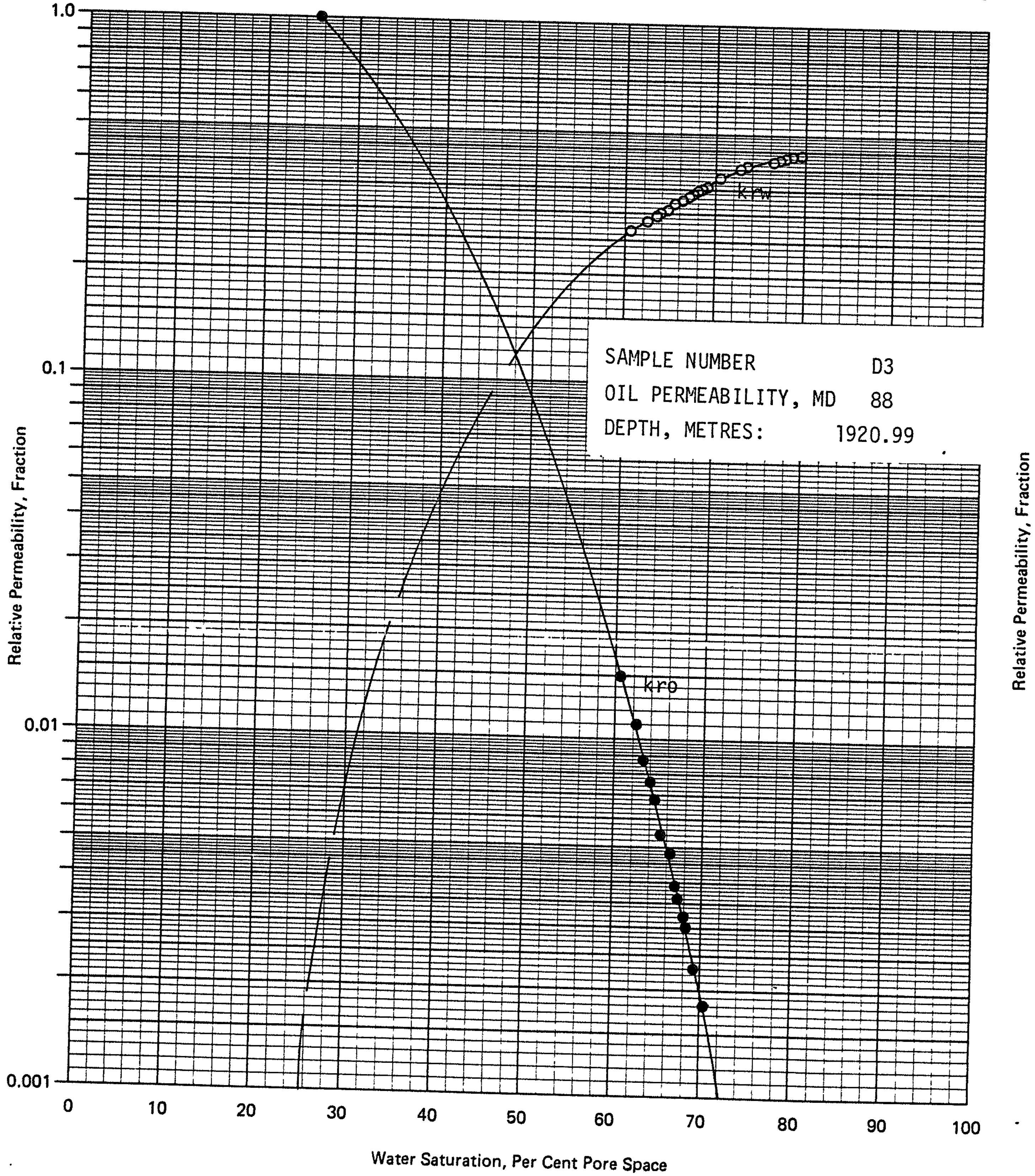

Summary of Fresh-State Imbibition & Dynamic Displacement

Initial Fluid Imbibed is Oil

Sample Number	B1	D5
Air Permeability, Md	< 0.01	30
Porosity, Per Cent	3.8	28.3
Immobile Water Saturation,* Per Cent Pore Space	45.0	42.3
Oil Permeability, Md at Immobile Water Saturation	< 0.01	35
Water Imbibed Statically Per Cent Pore Space	1.1	2.5
Water Imbibed Dynamically, Per Cent Pore Space	1.6	37.4
Total Water Imbibed, Per Cent Pore Space	2.7	39.9
Immobile Oil Saturation,** Per Cent Pore Space	55.0	27.9
Water Permeability, Md at Immobile Oil Saturation	< 0.01	30
Oil Imbibed Statically, Per Cent Pore Space	0	29.7
Oil Imbibed Dynamically, Per Cent Pore Space	0	0.45
Total Oil Imbibed, Per Cent Pore Space	0	30.2
Wettability Index to Water	0.407	0.063
Wettability Index to Oil	0	0.985

* Water present just prior to water imbibition
** Oil present just prior to oil imbibition

$$\text{Wettability Index} = \frac{\text{Fluid Imbibed Statically}}{\text{Total Fluid Imbibed}}$$

CATION EXCHANGE CAPACITY DATA

Sample Number	Depth Metres	Porosity Per Cent	Cation Exchange Capacity m eq/ 100 g	Pore Volume cc/100 g
A4	1847.77	33.3	0.23	18.9
B4	1856.85	3.7	0.25	1.2
C4	1902.72	21.7	0.72	13.2
D4	1921.02	24.3	0.24	16.6
E4	1974.91	33.9	0.11	19.5

ROCK COMPRESSIBILITY DATA

Sample Number	Pressure, BARS Initial External	Effective Overburden	Pore Volume, cc	Bulk Volume, cc	Porosity, Per Cent	Compressibility, PV/PV/PSIX10^{-6} (1)	(2)
D5	357	13.6	4.40	15.67	28.1	-	-
		34.0	4.15	15.42	26.9	186.2	115.3
		51.0	3.96	15.23	26.0	177.0	109.6
		68.0	3.78	15.05	25.1	169.0	104.6
		102.0	3.45	14.72	23.4	153.5	95.0
		136.1	3.16	14.43	21.9	140.3	86.8
		170.1	2.88	14.15	20.4	128.7	79.7
		204.1	2.61	13.88	18.8	118.0	73.0
		238.1	2.40	13.67	17.6	108.6	67.2
		272.1	2.20	13.47	16.3	100.4	62.1
		306.1	2.08	13.35	15.6	93.0	57.6
		343.5	1.97	13.24	14.9	86.2	53.4

(1) Measured in laboratory under hydrostatic Loading conditions.
(2) Uniaxial loading conditions, transformed from hydrostatic data as per Teeuw, Dirk: "Prediction of Formation Compaction from Laboratory Compressibility Data," Trans., AIME (1971) 251, 263-271.