rtson Research International Limited

SPECIAL CORE ANALYSIS STUDY FOR
STATOIL DEN NORSKE STATS OLJESELSKAP a.s.
WELL: 31/3 - 1, TROLL FIELD
NORWEGIAN SECTOR, NORTH SEA.

CONTENTS

APPENDICES

1 INTRODUCTION

This report presents the results of Special Core Analysis tests performed on a suite of samples from the Well 31/3-1 of the Troll field in the Norwegian sector of the North Sea.

The original specifications for the project were outlined in discussions between representatives of Robertson Research and Mr. Jon Ringen of Statoil during March 1984, and the final programme for tests was detailed in a letter from Messers Didrik Malthe Sorenssen and Jon Ringen of Statoil dated 26th March 1984.

2 SAMPLE AND TEST SUMMARY TABLE

SAMPLE NUMBER	DEPTH (metres)	FORMATION	K + Ø	Klinkenberg Permeability	Kw	Klinkenberg Permeability SW_{ir}	L.R. Waterflood	Kg/Kw	L.R. and L.R. Oilflood Waterflood	Kw/Ko
53.1	1375.75	SET A	x							
57.1	1376.75	SET A	x	x	x	x	x	F		
81.1	1384.00	SET A	x							
89.1	1386.00	SET A	x							
99.1	1389.00	SET A	x							
350.1	1470.00	SET A	x		x	x	x	x		
426.1	1494.20	SET A	x		x	x	x	F		
432.1	1500.00	SET B	x	x	x	x	x	x		
435.1	1500.75	SET B	x	x	x	x	x	F		
444.1	1503.00	SET B	x							
445.1	1504.00	SET B	x	x	F					
455.1	1507.00	SET B	x	x	x	x	x	x		
587.1	1546.50	SET C	x							
593.1	1548.00	SET C	x	x	x	x			x	
599.1	1550.00	SET C	x							
603.1	1551.00	SET C	x	x	x	x			x	
605.1	1552.00	SET C	x	x	x	x			x	
647.1	1564.30	SET D	x							
654.1	1566.00	SET D	x							
665.1	1569.00	SET D	x	x	x	x				x
667.1	1570.00	SET D	x	x	x	x				x
671.1	1571.00	SET D	x	x	x	x				x

3 AIR PERMEABILITY, POROSITY AND GRAIN DENSITY SUMMARY TABLE

SAMPLE NUMBER	DEPTH (metres)	FORMATION	AIR PERMEABILITY Ka (mD)	POROSITY* (per cent)	GRAIN DENSITY (g/c.c.)
53.1	1375.75	SET A	1574	Sample not suitable for grain volume measurement	
57.1	1376.75	SET A	194		
57.1	1376.75	SET A	149	36.7*	2.66
81.1	1384.00	SET A	Sample failed during cleaning		
89.1	1386.00	SET A	Sample failed during cleaning		
99.1	1389.25	SET A	615	Sample not suitable for grain volume measurement	
350.1	1470.00	SET A	1229	31.5*	2.71
426.1	1494.00	SET A	439	33.6*	2.68
432.1	1500.00	SET B	37		2.66
432.1	1500.00	SET B	34	28.9*	
435.1	1500.75	SET B	62		2.65
435.1	1500.75	SET B	55	32.8*	
444.1	1503.00	SET B	11.8	25.8	2.64
445.1	1504.00	SET B	17		2.63
445.1	1504.00	SET B	13.9	26.0	
455.1	1507.00	SET B	16		2.65
455.1	1507.00	SET B	14.7	27.2*	
587.1	1546.50	SET C	1102	32.8	2.67
593.1	1548.00	SET C	215		2.67
593.1	1548.00	SET C	194	32.1*	
599.1	1550.00	SET C	695	36.0	2.65
603.1	1551.00	SET C	123		2.68
603.1	1551.00	SET C	103	37.1*	
605.1	1552.00	SET C	249		2.66
605.1	1552.00	SET C	210	32.1*	
647.1	1564.30	SET D	168	31.9	2.67
654.1	1566.00	SET D	1.05	13.4	2.69
665.1	1569.00	SET D	742		2.67
665.1	1569.00	SET D	672	31.8*	
667.1	1570.00	SET D	591		2.66
667.1	1570.00	SET D	509	32.0*	
671.1	1571.00	SET D	290		2.66
671.1	1571.00	SET D	244	31.6*	

* Calculated from saturated bulk volumes, all other porosities are screening values using the product of length and area as the sample bulk volume.

4 SAMPLE PREPARATION

4 SAMPLE PREPARATION

4.1 TEST PROCEDURES

Sample cleaning

The test suite for this study comprised 20 plug samples of one and one half inches diameter. Upon receipt at Robertson Research an examination of the samples indicated that several of the samples, particularly those from Set A were friable and as a precautionary measure the samples were wrapped with PTFE tape prior to being trimmed into right cylinders. The samples were trimmed into right cylinders using a diamond tipped saw with brine as the coolant/lubricant.

All of the samples were cleaned of residual mobile reservoir and drilling fluids by solvent extraction. This was achieved by Soxhlet retorting of the samples using methanol, toluene and methanol again. The samples were deemed to be clean when the refluxing solvent showed no discolouration and tests for salt proved negative. The samples were then dried in a humidity controlled oven.

Permeability and porosity measurement techniques

A 'base' screening test for air permeability and porosity were attempted on all twenty samples, these data were reported to Statoil. Ten samples were then selected for gas permeability measurements with 4 point Klinkenberg correction. These measurements were made by flowing nitrogen gas through the samples after they had been loaded in Hassler core holders with an overburden stress of 200 psi applied. Differential pressure across the sample was measured with a manometer and back pressure was monitored with either a manometer or an electronic pressure transducer.

From these data a graph of gas permeability versus the reciprocal of mean pressure was plotted for each sample and Klinkenberg permeability was determined by extrapolation. A plot of Klinkenberg permeability versus porosity is presented on page 12.

Porosity values were determined indirectly. The grain volume of each sample was measured by the expansion of helium gas from standard volumes into the sample loaded in a matrix cup. Pressures in the system were monitored by electronic transducer and the grain volume was calculated by applying Boyle's law to the data. Pore volume and subsequently porosity were calculated after saturating and immersing the samples in brine to derive the bulk volume.

At this stage two replacement samples from Set A were incorporated into the test schedule. Upon completion of the air permeability and grain volume measurements the samples were saturated with simulated formation brine. The process was achieved in two stages. Firstly the samples were carefully positioned in an air tight vessel and this vessel was then evacuated. De-aired simulated formation brine was then introduced and the system was pressured up to approximately 70 bars. This pressure was maintained overnight for approximately 16 hours.

The saturated pore volume of each sample was calculated by material balance and sample bulk volume was determined by immersing the samples in brine and applying Archimedes' principle. The helium pore volumes and the saturated pore volumes were compared and in all cases the levels of saturation were considered suitable for testing to continue.

Brine Permeabilities

The brine permeability of each sample was then determined. Measurements were performed by flowing brine at three different flow rates and a graph of flow rate versus brine permeability was plotted for each sample. The data was taken to be valid if a straight line could be drawn through the data points and the co-ordinate 0.00, 0.00.

During the measurement of brine permeability the following observations were made:

1. The brine volume expelled from the cores whilst the overburden was being applied was greater than is usually seen during this stage of testing. Unfortunately at this time no attempt had been made to measure the volume, however, later on in the test schedule volumes of the order of 2.5 c.c. were recorded as squeeze out.

2. Upon unloading the samples from the overburden cell after the brine permeability measurements the sample weight had decreased.

From the data above it was concluded that the sample porosity had decreased although the saturation remained at 100 per cent. The samples were then immersed in brine and the system was evacuated. Although the sample weights increased they did not reach the original 100 per cent saturated weight before the overburden had been applied.

The above information was telexed to Statoil ref telex 4853/DG on 10th June 1984. In reply Statoil requested us to proceed using the recalculated pore volume as the base value.

All of the samples were then loaded onto a brine saturated porous plate and desaturated in a single desaturation stage using humidified air at 200 psi. The time taken to reach SWir was approximately seven days, the desaturation profile of the sample being monitored periodically throughout this stage. Once irreducible brine saturation had been attained gas permeability measurements were performed using the techniques previously described. Air permeability (SWir) and Klinkenberg Permeability (SWir) were then calculated from these data.

4 SAMPLE PREPARATION

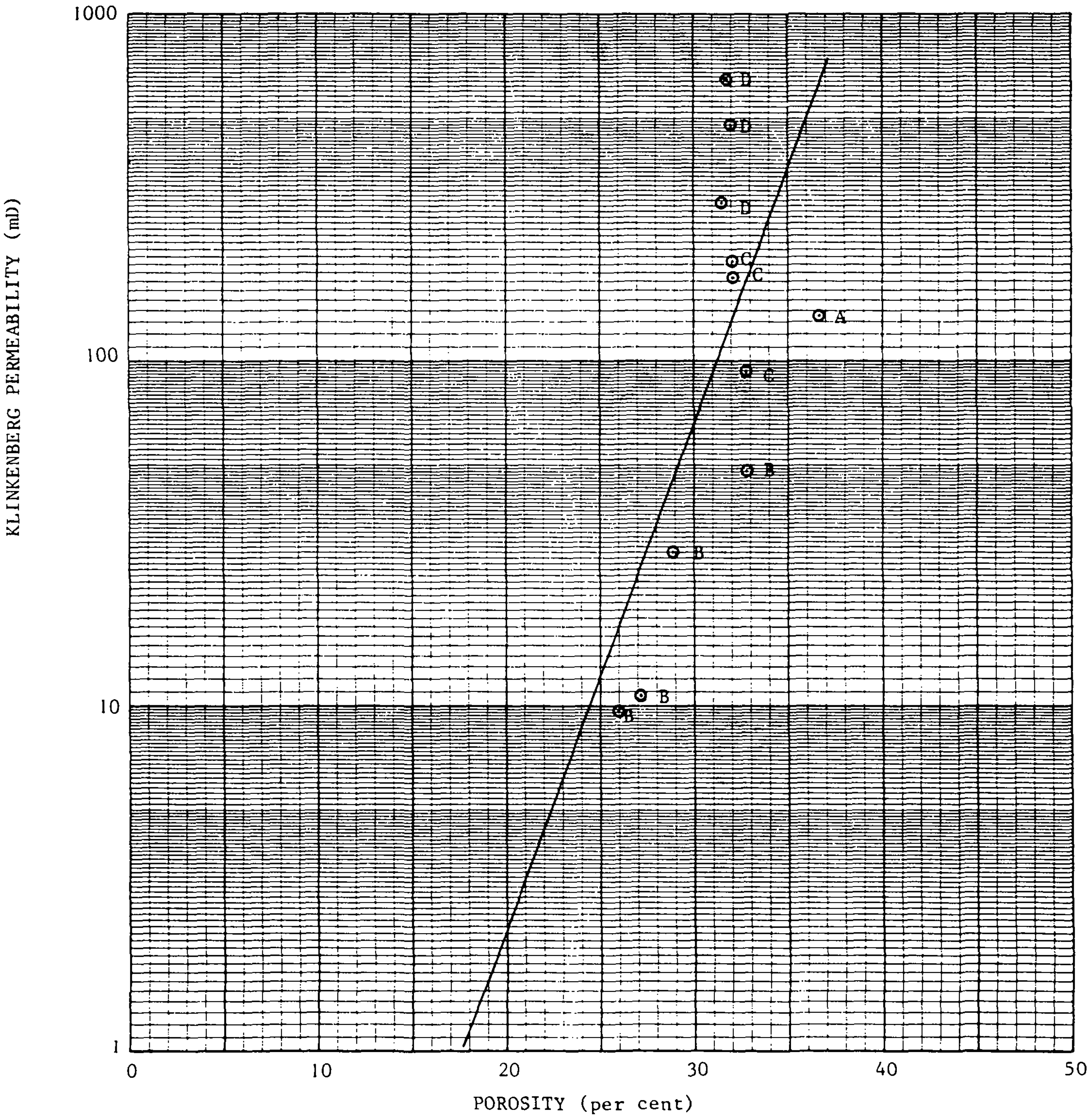
4.2 KLINKENBERG PERMEABILITY DATA

SAMPLE NUMBER	DEPTH (metres)	FORMATION	POROSITY (per cent)	GAS PERMEABILITY (mD)	MEAN PRESSURE (bars)	KLINKENBERG PERMEABILITY (mD)
57.1	1376.75	SET A	36.7	149		135
				146	1.28	
				144	1.58	
				143	1.78	
				142	2.05	
432.1	1500.00	SET B	28.9	34		28
				30.9	1.73	
				30.1	2.36	
				29.5	3.02	
				29.2	3.72	
435.1	1500.75	SET B	32.8	55		48
				52	1.72	
				51	2.42	
				50	3.73	
				49	4.62	
445.1	1504.00	SET B	26.0	13.9		9.7
				12.0	1.77	
				11.3	2.55	
				11.0	3.21	
				10.8	3.87	
455.1	1507.00	SET B	27.2	14.7		10.7
				12.8	1.82	
				12.2	2.47	
				11.9	3.15	
				11.6	4.56	
593.1	1548.00	SET C	32.1	194		175
				190	1.23	
				187	1.51	
				184	2.03	
				183	2.52	
603.1	1551.00	SET C	32.7	103		94
				101	1.26	
				100	1.50	
				99	1.76	
				99.5	2.03	

SAMPLE NUMBER	DEPTH (metres)	FORMATION	POROSITY (per cent)	GAS PERMEABILITY (mD)	MEAN PRESSURE (bars)	KLINKENBERG PERMEABILITY (mD)
605.1	1552.00	SET C	32.1	210		196
				207	1.27	
				205	1.51	
				204	1.77	
				203	2.25	
665.1	1569.00	SET D	31.8	672		643
				666	1.23	
				662	1.49	
				659	1.74	
				657	2.01	
667.1	1570.00	SET D	32.0	509		480
				503	1.24	
				499	1.49	
				496	1.75	
				494	2.01	
671.1	1571.00	SET D	31.6	244		285
				240	1.23	
				237	1.49	
				235	1.76	
				234	2.01	

COMPANY: STATOIL
WELL: 31/3-1
FIELD: TROLL
FORMATION: SETS A,B,C, AND D
LOCATION: NORWEGIAN NORTH SEA
COUNTRY: NORWAY

KLINKENBERG PERMEABILITY
Versus
POROSITY



4 SAMPLE PREPARATION

4.3 BRINE PERMEABILITIES

SAMPLE NUMBER	DEPTH (metres)	FORMATION	KLINKENBERG PERMEABILITY (mD)	BRINE PERMEABILITY (mD)
57.1	1376.75	SET A	135	46
350.1	1470.00	SET A	1179*	953
426.1	1494.20	SET A	409*	174
432.1	1500.00	SET B	28	9.8
435.1	1500.75	SET B	48	7.6
455.1	1507.00	SET B	10.7	4.1
593.1	1548.00	SET C	175	144
603.1	1551.00	SET C	94	19
605.1	1552.00	SET C	196	67
665.1	1569.00	SET D	643	402
667.1	1570.00	SET D	480	299
671.1	1571.00	SET D	225	63

Samples 350.1 and 426.1 were replacement samples and the 4 point Klinkenberg Permeability test was not performed. Klinkenberg Permeability taken from standard graphs.

4 SAMPLE PREPARATION

4.4 IRREDUCIBLE BRINE SATURATIONS AND KLINKENBERG PERMEABILITIES AT SWir

SAMPLE NUMBER	DEPTH (metres)	FORMATION	IRREDUCIBLE BRINE SATURATION (per cent)	GAS PERMEABILITY SWir (mD)	MEAN PRESSURE (bars)	KLINKENBERG PERMEABILITY SWir (mD)
57.1	1376.75	SET A	16.6	120		109
				117	1.40	
				116	1.64	
				115	1.91	
				114	2.21	
350.1	1470.00	SET A	8.7	1092		1059
				1086	1.16	
				1078	1.68	
				1075	1.97	
				1072	2.25	
426.1	1494.20	SET A	8.5	309		297
				307	1.17	
				305	1.45	
				304	1.72	
				302	2.22	
432.1	1500.00	SET B	39.8	15		12.9
				14.3	1.50	
				13.9	2.11	
				13.7	2.80	
				13.5	3.49	
435.1	1500.75	SET B	24.3	15		13
				14.5	1.37	
				14.1	1.94	
				13.8	2.64	
				13.7	3.25	
455.1	1507.00	SET B	43.8	6.4		5.0
				5.8	1.73	
				5.6	2.32	
				5.5	3.02	
				5.4	3.61	
593.1	1548.00	SET C	26.1	183		167
				178	1.40	
				176	1.66	
				175	1.92	
				174	2.21	

SAMPLE NUMBER	DEPTH (metres)	FORMATION	IRREDUCIBLE BRINE SATURATION (per cent)	GAS PERMEABILITY SWir (mD)	MEAN PRESSURE (bars)	KLINKENBERG PERMEABILITY SWir (mD)
603.1	1551.00	SET C	31.8	54		49
				53	1.13	
				52	1.54	
				51	2.28	
				50	4.85	
605.1	1552.00	SET C	23.0	194		178
				189	1.42	
				187	1.68	
				186	1.94	
				185	2.22	
665.1	1569.00	SET D	16.9	623		589
				618	1.15	
				613	1.39	
				609	1.64	
				607	1.90	
667.1	1570.00	SET D	16.6	449		422
				445	1.15	
				441	1.39	
				438	1.65	
				434	2.19	
671.1	1571.00	SET D	23.4	213		201
				211	1.17	
				210	1.40	
				209	1.67	
				208	3.38	

5 RESIDUAL GAS SATURATION BY LOW RATE WATERFLOOD

5 RESIDUAL GAS SATURATION BY LOW RATE WATERFLOOD

5.1 Test and Calculation Procedures

The samples scheduled for this test had been driven to irreducible brine saturation in a single desaturating phase as described in Section 4.1. Each sample was then individually loaded into a specially prepared overburden cell. The cell containing the sample and the gas collection system were then pressurised until the core was sustaining approximately 20 bars pore pressure and 20 bars net overburden pressure.

The residual gas saturation of the samples was established by performing a low rate 4 c.c./hr constant rate waterflood. The differential pressure across the sample and downstream back pressure were monitored using electronic transducers.

The floods were continued until there was no more removal of gas and then the permeability to brine was measured.

Upon unloading the samples it was discovered that three of the samples had fractured during the test. The three samples 57.1 and 426.1 from Set A and 435.1 from Set B were excluded from further testing.

As previously mentioned in Section 4.1 these samples were subject to a reduction in pore volume when under overburden conditions. The data from these tests have therefore been calculated using the saturated pore volume calculated from the sample weights after the brine permeabilities, this pore volume although not determined at 20 bars would be more appropriate than the value determined before desaturation to SWir.

5 RESIDUAL GAS SATURATION BY LOW RATE WATERFLOOD

5.2 SUMMARY OF RESULTS

SAMPLE NUMBER	DEPTH (metres)	FORMATION	KLINKENBERG PERMEABILITY (mD)	POROSITY (per cent)	SW_{ir} (per cent)	Kg SW_{ir} (mD)	Kw (mD)	Sgr(W) (per cent)	Kw(Sgr) (mD)
57.1	1376.75	SET A	135	34.5	18.7	120	46	52.0	8.3
350.1	1470.00	SET A	1229*	29.1	14.5	1092	847	34.8	32
426.1	1494.00	SET A	439*	29.6	16.6	309	174	46.8	16
432.1	1500.00	SET B	28	27.8	40.8	15	9.8	43.2	0.6
435.1	1500.75	SET B	48	30.2**	24.3	15	7.6	52.9	0.45
455.1	1507.00	SET B	10.7	26.4	44.6	6.3	4.1	38.9	0.58

* Data not derived from 4 point Klinkenberg test

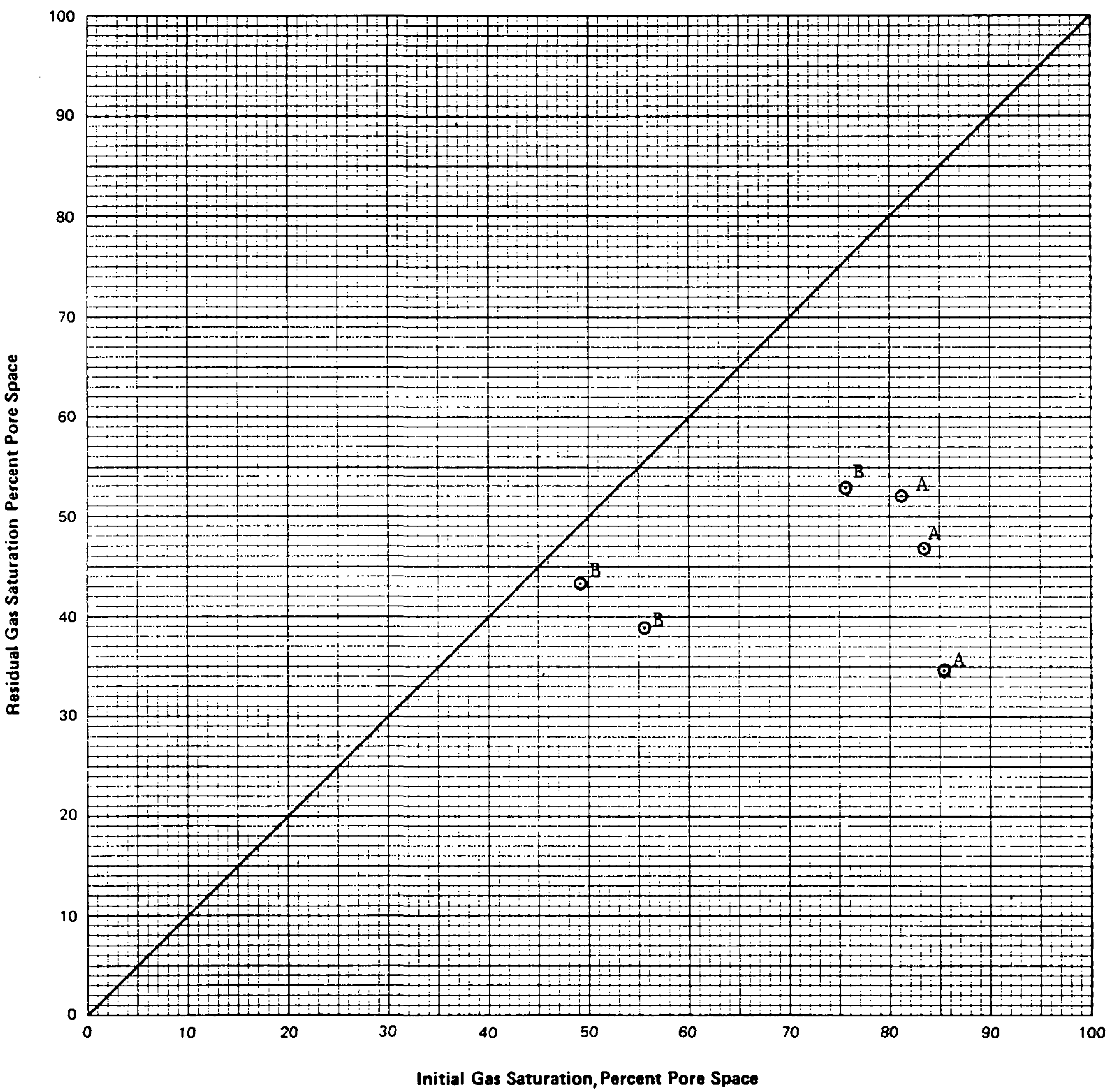
** Sample had fractured during Kw. Statoil advised that testing should proceed, but porosity is only calculated from a bulk volume that is the product of length and area, and assuming that the original sample was homogeneous.

File No. SCAL-0211

COMPANY: STATOIL
WELL: 31/3-1
FIELD: TROLL
FORMATION: SETS A AND B
LOCATION: NORWEGIAN NORTH SEA
COUNTRY: NORWAY

RESIDUAL GAS SATURATION versus INITIAL GAS SATURATION

LOW RATE WATERFLOOD



ROBERTSON RESEARCH

6 GAS - BRINE, RELATIVE PERMEABILITY, UNSTEADY-STATE

6 GAS - BRINE, RELATIVE PERMEABILITY, UNSTEADY-STATE

6.1 Test and Calculation Procedures

The samples scheduled for testing had previously been used for residual gas saturation determination. The samples were restored for further testing by immersion in brine and evacuating, and then by flooding with brine. Brine permeability was then measured. At this stage it was noticed the brine permeabilities were lower than those previously determined after the initial saturation. From these data, plots of flow rate versus differential pressure were drawn. The graph indicated that the test was performed at laminar flow conditions and the presence of residual gas was not suspected. These conclusions were duly reported to Statoil. The sample permeability to brine was then remeasured whilst flowing against back pressure, again graphs of flow rate versus differential pressure indicated laminar flow and no gas was seen in the effluent. However, in all cases the brine permeability had decreased further, as had the sample weight. We concluded that the samples must have been subject to a further reduction in pore volume and therefore the recalculated saturated pore volume and the brine permeability determined directly prior to the flood were used as the base data for the relative permeability calculations.

The gas floods were performed using a constant differential pressure against a back pressure of approximately 20 bars. The tests were continued until approximately 1000 pore volumes of gas had been flooded through each sample. Throughout the test gas volume was monitored by the displacement of oil in a pressurised, calibrated 'sight glass' cell and as the flow rate increased the gas was flowed through a wet test meter. The brine recovered was also monitored within the 'sight glass' system. Elapsed time, differential and back pressure were recorded at each salient point. From these data, the change in sample saturation and individual gas and brine relative permeabilities were calculated.

6 GAS - BRINE, RELATIVE PERMEABILITY, UNSTEADY-STATE

6.2 Gas - Brine Production Data

GAS - BRINE PRODUCTION DATA

SAMPLE NUMBER	DEPTH (metres)	FORMATION	BRINE PERMEABILITY Kw (mD)	PORE VOLUME (c.c.)
350.1	1470.00	SET A	315	18.68

CUMULATIVE TIME (seconds)	CUMULATIVE BRINE RECOVERED (c.c.)	CUMULATIVE GAS RECOVERED (c.c.)	DIFFERENTIAL PRESSURE (bars)	BACK PRESSURE (bars)
204.6	5.71	40.2	0.186	20.47
311.4	6.51	104.9	0.192	20.46
882.3	8.16	678.2	0.209	20.46
1495	8.72	1459	0.209	20.46
2519	9.03	2871	0.187	20.46
3087	9.14	3702	0.179	20.47
3739	9.21	4686	0.187	20.46
4633	9.27	6073	0.188	20.48
5660	9.33	7686	0.189	20.47
6857	9.37	9603	0.187	20.45
8350	9.39	12023	0.187	20.50
9967	9.41	14645	0.187	20.52
11778	9.42	17621	0.187	20.53
15317	9.44	23470	0.187	20.58

GAS - BRINE PRODUCTION DATA

SAMPLE NUMBER	DEPTH (metres)	FORMATION	BRINE PERMEABILITY Kw (mD)	PORE VOLUME (c.c.)
432.1	1500.00	SET B	3.9	19.72

CUMULATIVE TIME (seconds)	CUMULATIVE BRINE RECOVERED (c.c.)	CUMULATIVE GAS RECOVERED (c.c.)	DIFFERENTIAL PRESSURE (bars)	BACK PRESSURE (bars)
187.2	1.40	9.01	4.52	20.74
306.8	2.25	37.6	4.51	20.74
762.0	3.48	188	4.52	20.74
1214	4.23	512	4.39	20.74
2115	4.76	1351	4.40	20.74
2683	5.06	1905	4.52	20.75
3204	5.24	2491	4.55	20.77
3995	5.47	3431	4.63	20.77
4878	5.66	4732	4.49	20.78
6127	5.90	6152	4.49	20.78
7508	6.03	8067	4.38	20.78
9415	6.17	10757	4.46	20.83
11340	6.29	13545	4.53	20.83
13279	6.37	16404	4.82	20.86
15477	6.45	19777	4.55	20.86
17109	6.50	22306	4.51	20.86

GAS - BRINE PRODUCTION DATA

SAMPLE NUMBER	DEPTH (metres)	FORMATION	BRINE PERMEABILITY Kw (mD)	PORE VOLUME (c.c.)
455.1	1507.00	SET B	22	21.49

CUMULATIVE TIME (seconds)	CUMULATIVE BRINE RECOVERED (c.c.)	CUMULATIVE GAS RECOVERED (c.c.)	DIFFERENTIAL PRESSURE (bars)	BACK PRESSURE (bars)
441	4.38	3.62	7.28	13.66
651	6.18	6.01	7.42	13.74
837	6.73	53.3	7.28	13.76
931	7.01	91.7	7.21	13.66
2065	8.35	786	7.28	13.64
2824	8.91	1403	7.28	13.67
3782	9.33	2292	7.21	13.72
6179	9.92	4880	7.21	13.69
7502	10.16	6464	7.21	13.74
9035	10.36	8396	7.21	13.74
10531	10.53	10366	7.21	13.69
12260	10.69	12723	7.21	13.73
14100	10.84	15312	7.21	13.74
16083	10.96	18171	7.21	13.72
17814	11.05	20720	7.21	13.74
18721	11.09	22074	7.21	13.72

6 GAS - BRINE, RELATIVE PERMEABILITY, UNSTEADY-STATE

6.3 SUMMARY OF RESULTS

			Initial Conditions			Terminal Conditions		
SAMPLE NUMBER	DEPTH (metres)	FORMATION	KLINKENBERG PERMEABILITY (mD)	POROSITY** (per cent)	BRINE PERMEABILITY (mD)	BRINE SATURATION (per cent)	GAS PERMEABILITY (mD)	BRINE RECOVERED (per cent)
350.1	1470.00	SET A	1179*	25.7	315	49.5	106	50.5
432.1	1500.00	SET B	28	25.8	3.9	67.0	1.22	33.0
455.1	1507.00	SET B	10.7	26.0	2.2	48.4	0.53	51.6

* Sample 350.1 was a replacement sample and the 4 point Klinkenberg Permeability test was not performed. Klinkenberg Permeability taken from standard graph.

** Saturated porosity calculated prior to Kg/Kw

6 GAS - BRINE, RELATIVE PERMEABILITY, UNSTEADY-STATE

6.4 Gas - Brine Relative Permeability Data

GAS-BRINE RELATIVE PERMEABILITY DATA

SAMPLE NUMBER	DEPTH (metres)	FORMATION	POROSITY (per cent)	BRINE PERMEABILITY Kw (mD)
350.1	1470.00	SET A	25.7	315

BRINE SATURATION (per cent)	GAS-BRINE RELATIVE PERMEABILITY RATIO	* RELATIVE PERMEABILITY TO GAS, FRACTION	* RELATIVE PERMEABILITY TO BRINE, FRACTION
100			1.00
67.3	1.38	0.134	0.098
60.7	5.89	0.222	0.038
54.8	23.7	0.282	0.011
52.5	77.2	0.306	0.004
51.4	128	0.324	0.003
50.9	239	0.334	0.001
50.6	391	0.344	0.0009
50.2	485	0.348	0.0008
50.0	807	0.355	0.0004
49.8	1997	0.359	0.0002
49.7	2248	0.359	0.0002
49.6	5207	0.364	$<10^{-4}$
49.5	5237	0.366	$<10^{-4}$

* Relative to brine permeability determined prior to the test.

GAS-BRINE RELATIVE PERMEABILITY DATA

SAMPLE NUMBER	DEPTH (metres)	FORMATION	POROSITY (per cent)	BRINE PERMEABILITY Kw (mD)
432.1	1500.00	SET B	25.8	3.9

BRINE SATURATION (per cent)	GAS-BRINE RELATIVE PERMEABILITY RATIO	* RELATIVE PERMEABILITY TO GAS, FRACTION	* RELATIVE PERMEABILITY TO BRINE, FRACTION
100			1.00
90.8	0.528	0.146	0.276
85.5	1.91	0.201	0.104
80.5	6.78	0.436	0.064
77.2	24.9	0.567	0.023
75.1	29.0	0.594	0.021
73.9	51.1	0.686	0.013
72.8	64.2	0.724	0.011
71.8	90.9	0.760	0.008
70.7	106	0.791	0.007
69.8	231	0.845	0.004
69.1	302	0.860	0.003
68.4	365	0.882	0.002
67.9	562	0.899	0.002
67.5	935	0.935	0.001
67.2	794	0.945	0.001

* Relative to brine permeability determined prior to the test.

GAS-BRINE RELATIVE PERMEABILITY DATA

SAMPLE NUMBER	DEPTH (metres)	FORMATION	POROSITY (per cent)	BRINE PERMEABILITY Kw (mD)
455.1	1507.00	SET B	26.0	2.2

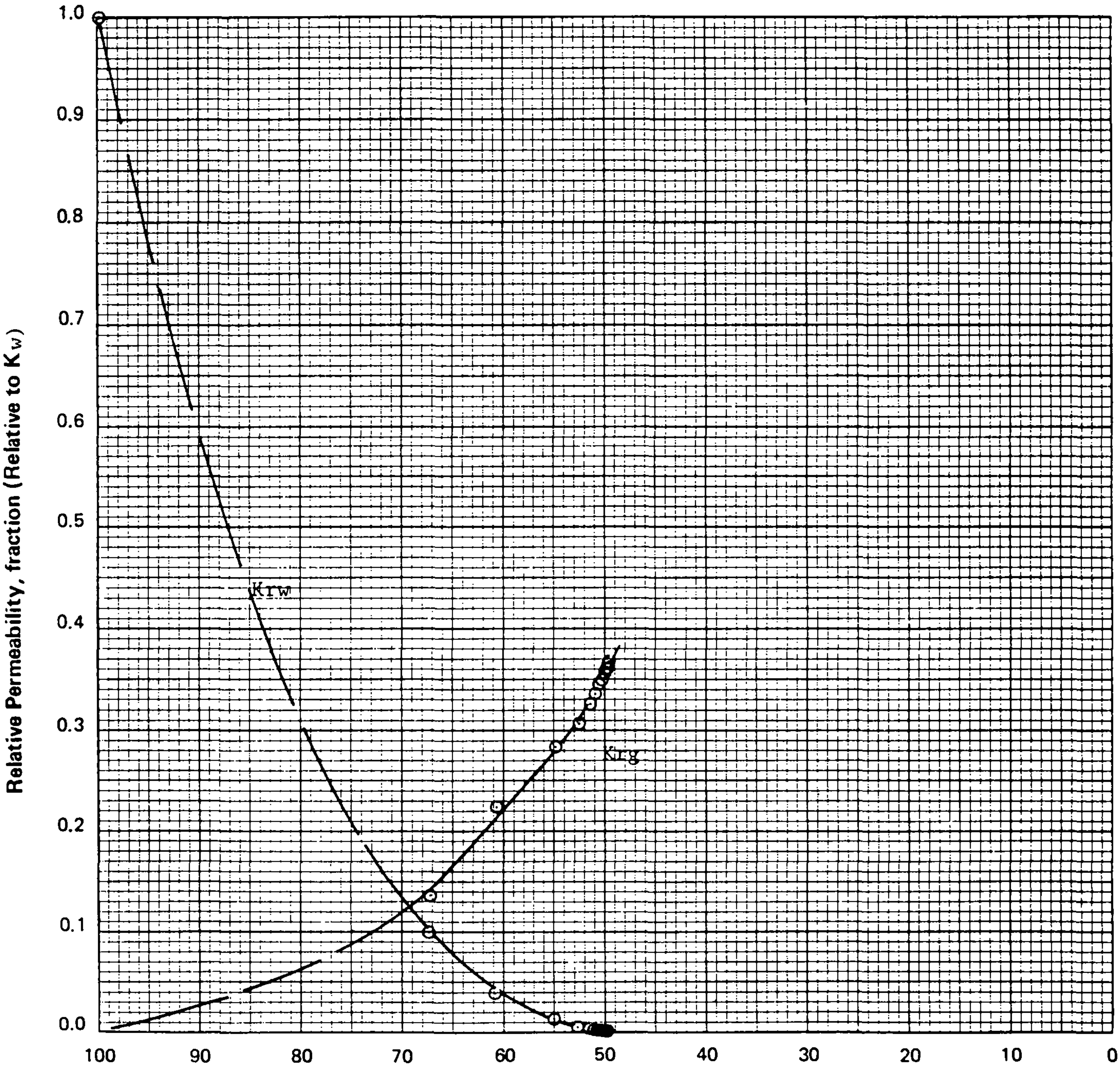
BRINE SATURATION (per cent)	GAS-BRINE RELATIVE PERMEABILITY RATIO	* RELATIVE PERMEABILITY TO GAS, FRACTION	* RELATIVE PERMEABILITY TO BRINE, FRACTION
100			1.00
75.4	0.018	0.006	0.374
70.0	1.17	0.151	0.129
68.0	1.86	0.242	0.122
64.3	7.04	0.363	0.051
59.8	15.0	0.482	0.032
57.6	28.8	0.550	0.019
55.2	36.0	0.640	0.011
53.3	89.7	0.710	0.007
52.3	131	0.748	0.006
51.4	157	0.781	0.005
50.6	200	0.808	0.004
49.9	234	0.834	0.004
49.3	324	0.855	0.003
48.8	385	0.873	0.002
48.5	461	0.886	0.002

* Relative to brine permeability determined prior to the test.

File No SCAL-0211

COMPANY: STATOIL
FORMATION: SET A
WELL: 31/3-1
LOCATION: NORWEGIAN NORTH SEA
FIELD: TROLL
COUNTRY: NORWAY
SAMPLE No.: 350.1
PERMEABILITY md: 315Kw
SAMPLE DEPTH: 1470.00 m

GAS-BRINE RELATIVE PERMEABILITY
Unsteady State, Restored State, Increasing Gas Saturation



File No. SCAL-0211

COMPANY: STATOIL

WELL: 31/3-1

FIELD: TROLL

SAMPLE NUMBER: 350.1

FORMATION: SET A

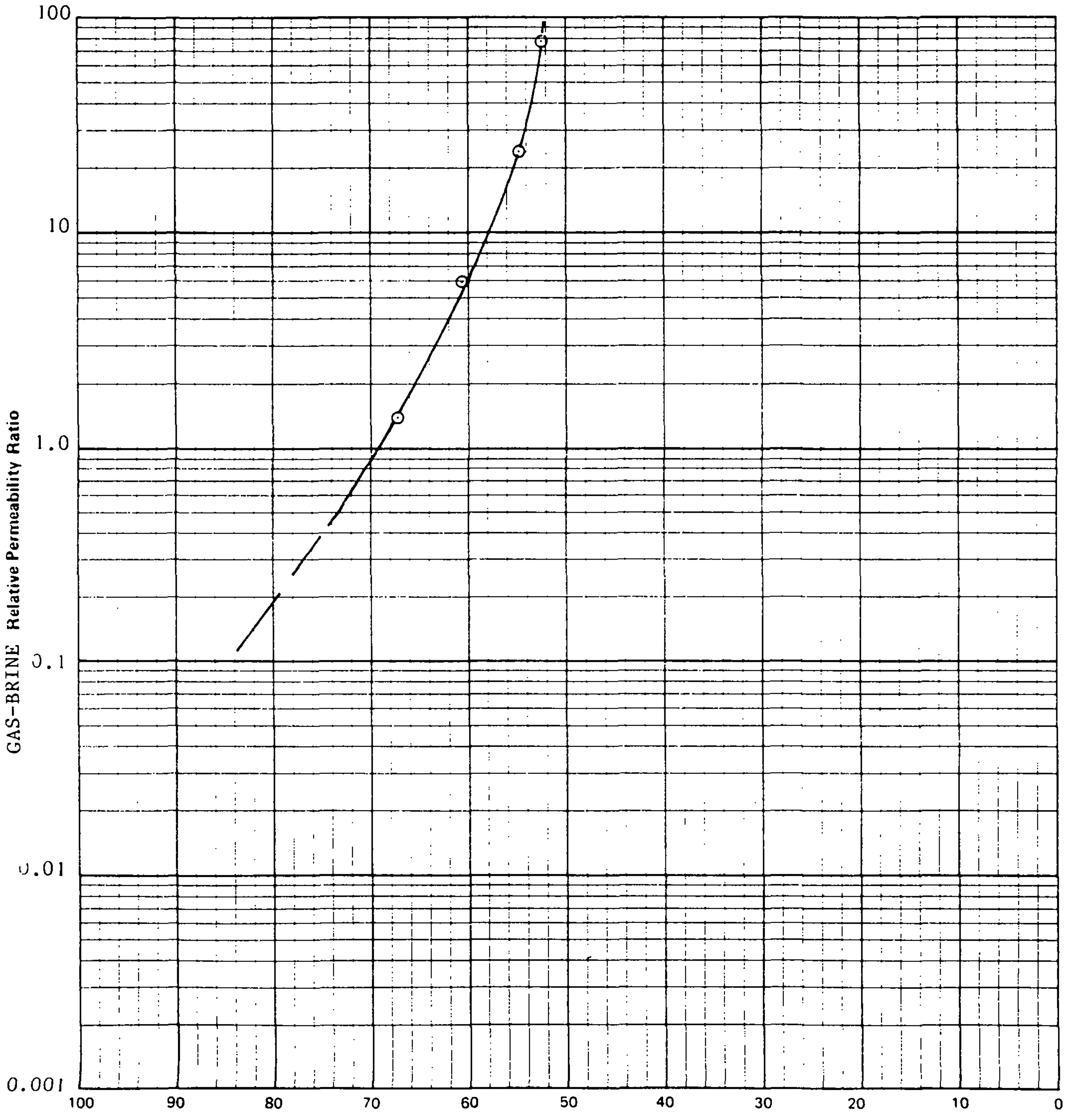
LOCATION: NORWEGIAN NORTH SEA

COUNTRY: NORWAY

PERMEABILITY md : 315 Kw

SAMPLE DEPTH: 1470.00 m

GAS-BRINE RELATIVE PERMEABILITY
Unsteady-State, Restored-State, Increasing Gas Saturation

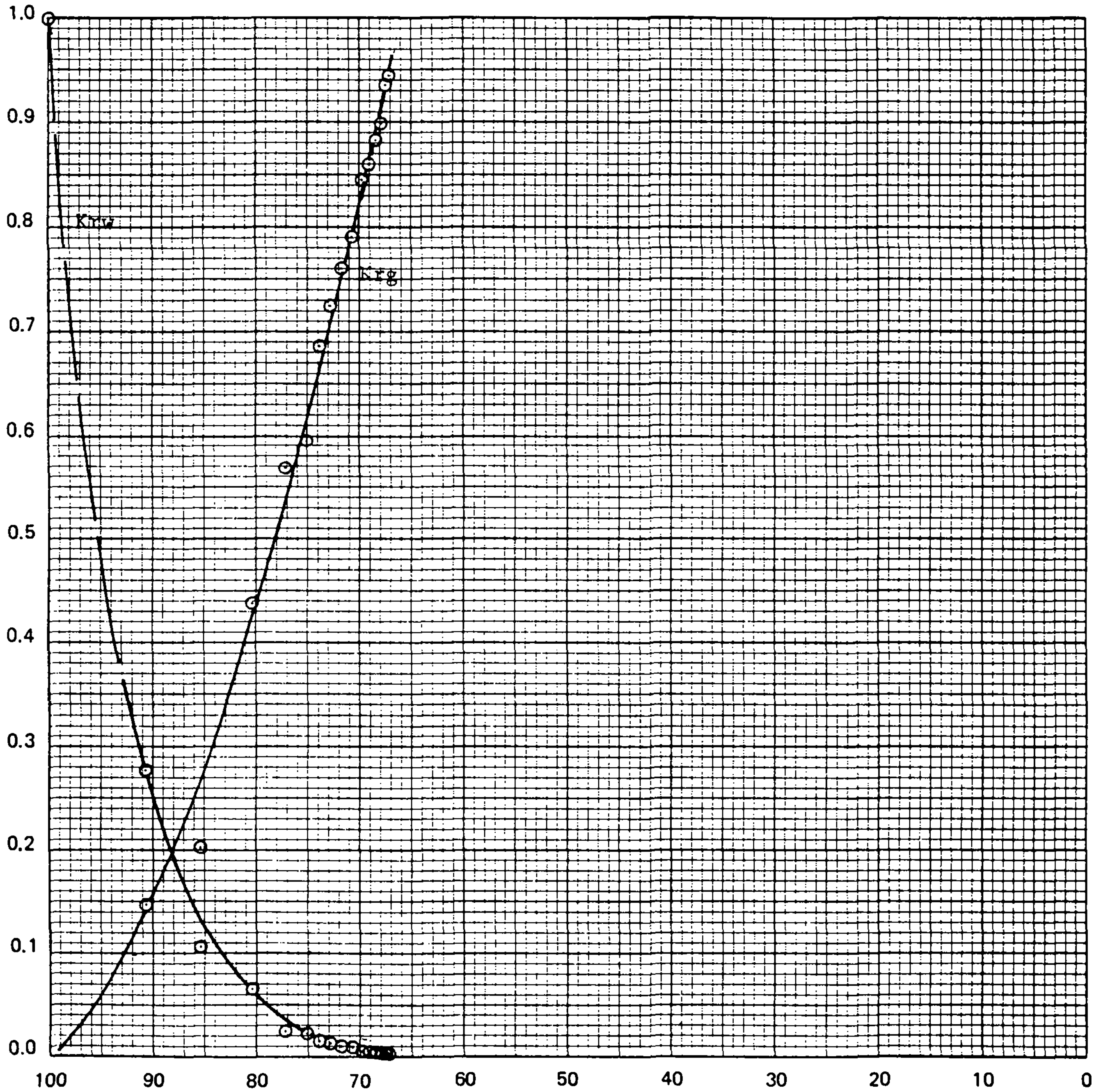


ROBERTSON RESEARCH

COMPANY: STATOIL
WELL: 31/3-1
FIELD: TROLL
SAMPLE No.: 432.1

FORMATION: SET B
LOCATION: NORWEGIAN NORTH SEA
COUNTRY: NORWAY
PERMEABILITY md: 3.25 Kw
SAMPLE DEPTH: 1500.00 m

GAS-BRINE RELATIVE PERMEABILITY
Unsteady State, Restored State, Increasing Gas Saturation



COMPANY: STATOIL

FORMATION: SET B

WELL: 31/3-1

LOCATION: NORWEGIAN NORTH SEA

FIELD: TROLL

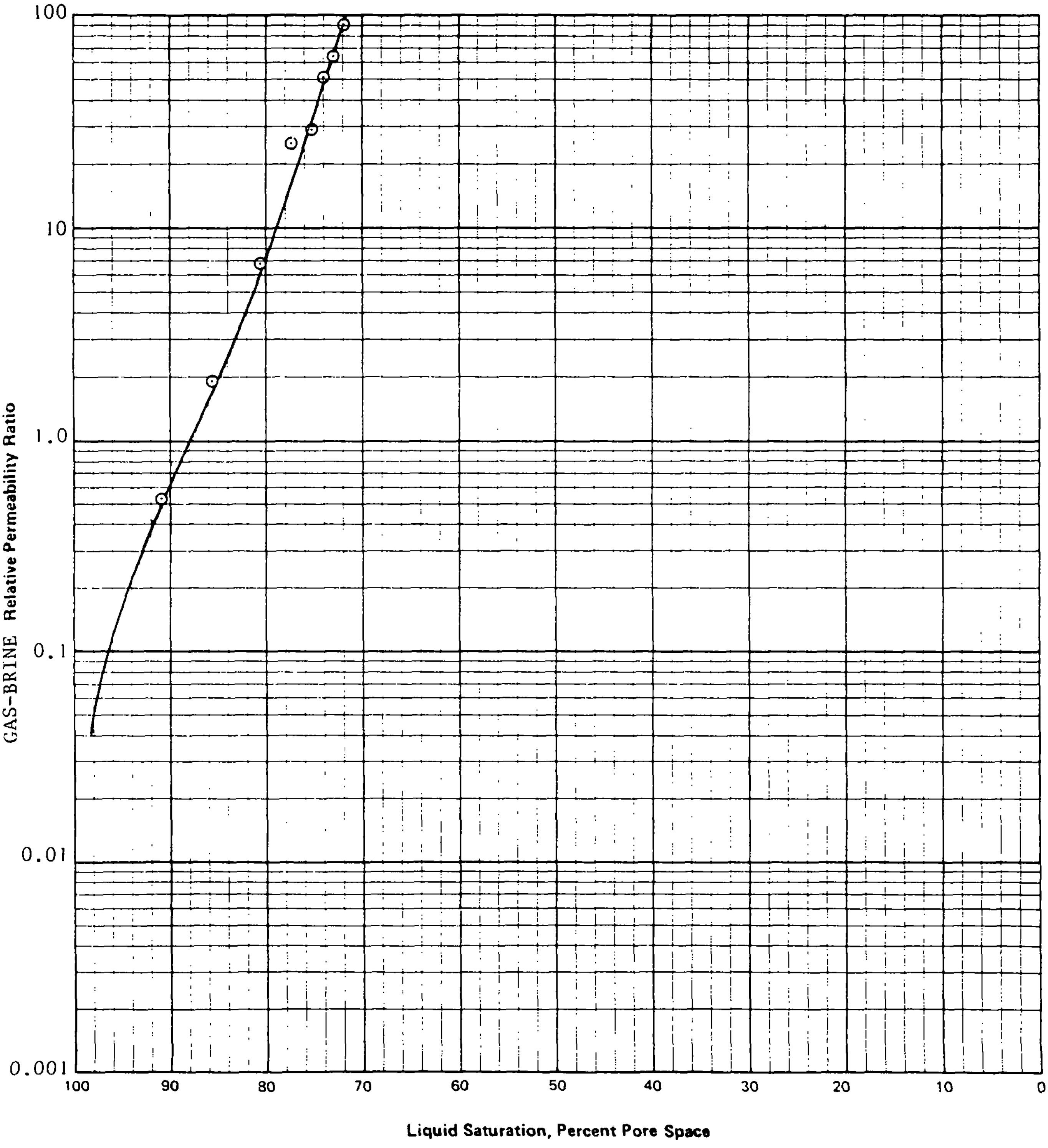
COUNTRY: NORWAY

SAMPLE NUMBER: 432.1

PERMEABILITY md : 3.25

SAMPLE DEPTH: 1500.00 m

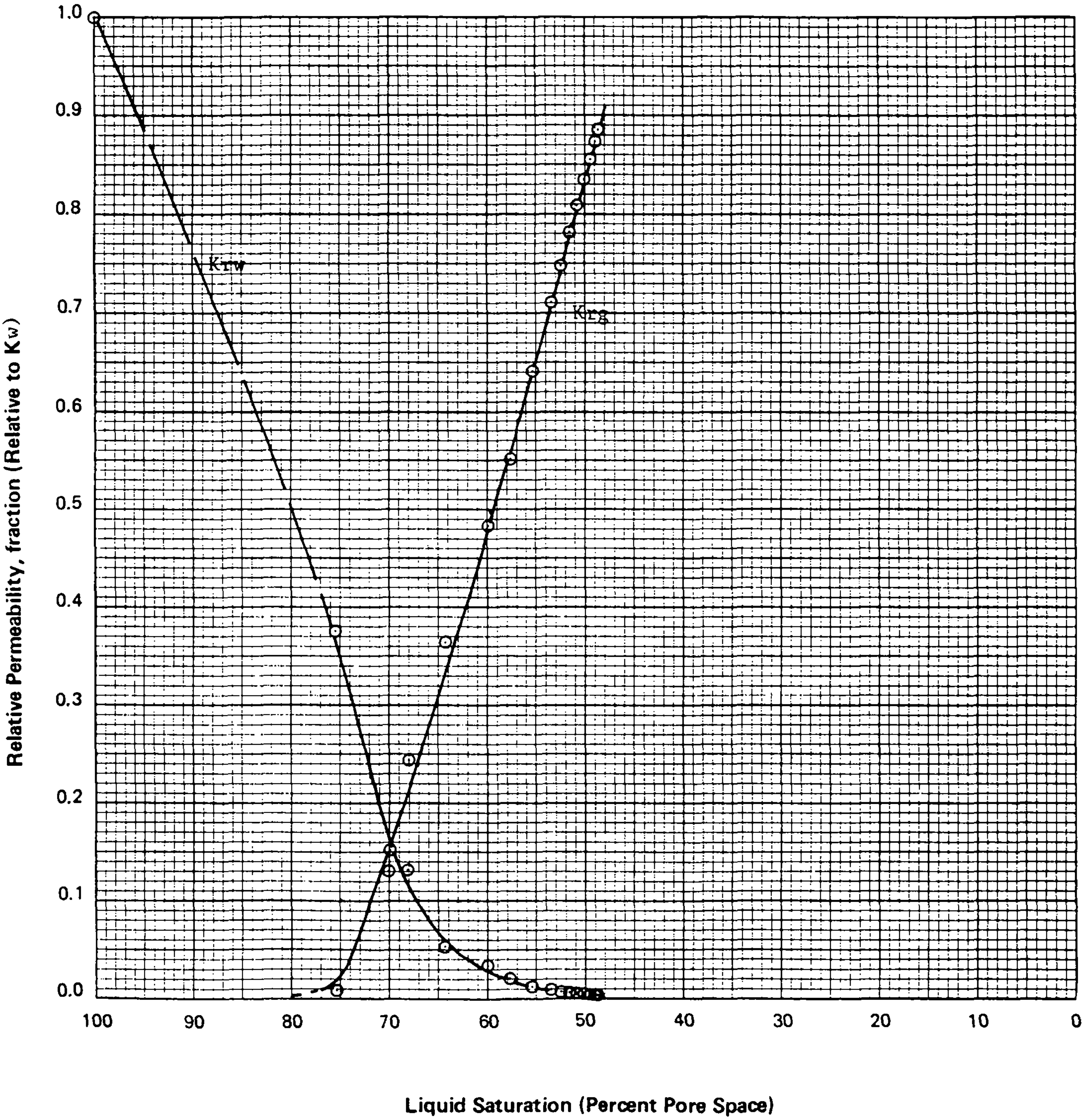
GAS-BRINE RELATIVE PERMEABILITY
Unsteady-State, Restored-State, Increasing Gas Saturation



File No SCAL-0211

COMPANY: STATOIL
FORMATION: SET B
WELL: 31/3-1
LOCATION: NORWEGIAN NORTH SEA
FIELD: TROLL
COUNTRY: NORWAY
SAMPLE No.: 455.1
PERMEABILITY md: 2.2 Kw
SAMPLE DEPTH: 1507.00 m

GAS-BRINE RELATIVE PERMEABILITY
Unsteady State, Restored State, Increasing Gas Saturation

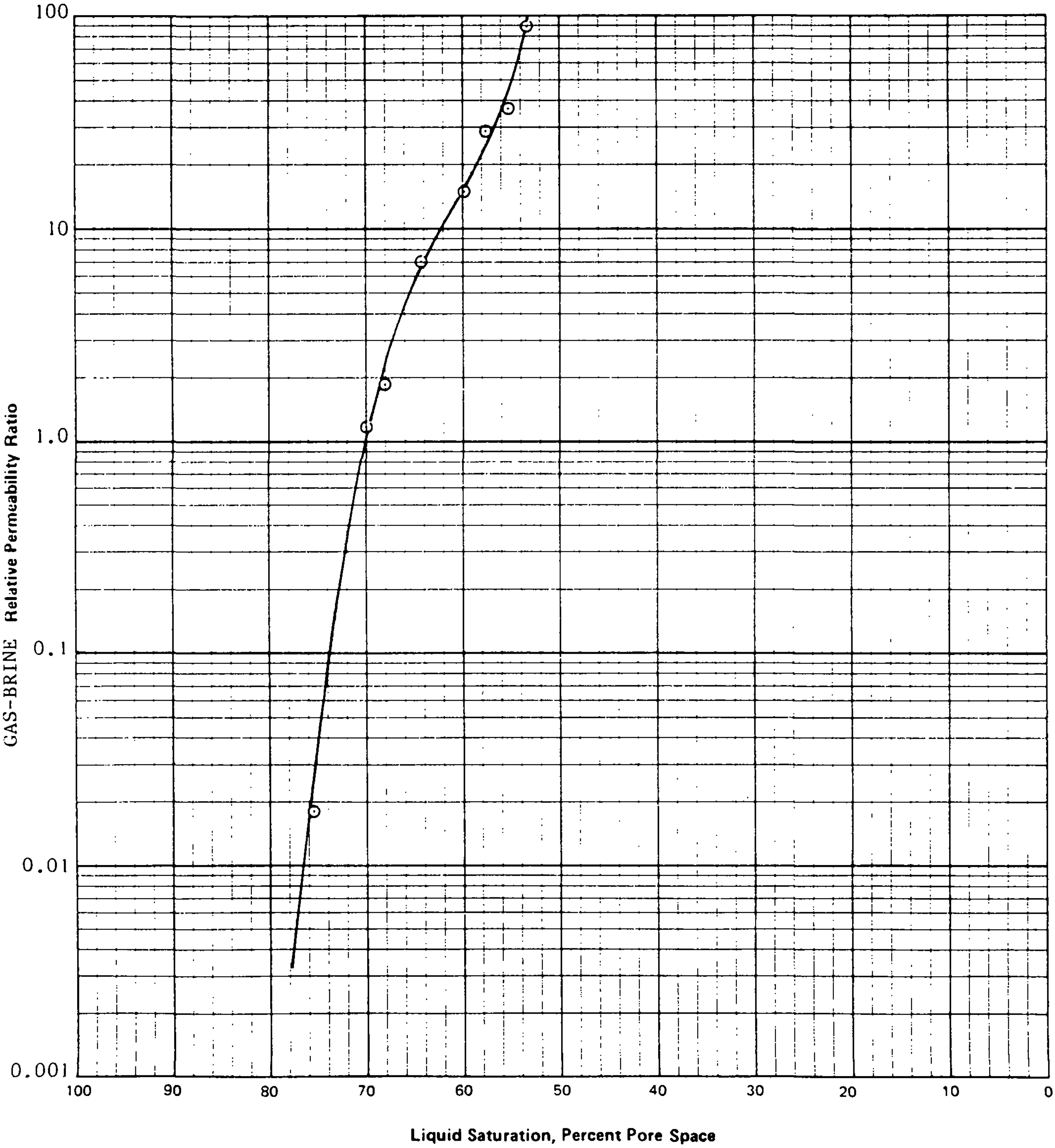


File No. SCAL-0211

COMPANY: STATOIL
WELL: 31/3-1
FIELD: TROLL
SAMPLE NUMBER: 455.1

FORMATION: SET B
LOCATION: NORWEGIAN NORTH SEA
COUNTRY: NORWAY
PERMEABILITY md : 2.2 Kw
SAMPLE DEPTH: 1507.00 m

GAS-BRINE RELATIVE PERMEABILITY
Unsteady-State, Restored-State, Increasing Gas Saturation



ROBERTSON RESEARCH

7 RESIDUAL GAS SATURATION BY LOW RATE OILFLOOD AND RESIDUAL OIL SATURATION BY LOW RATE WATERFLOOD (in the presence of residual gas saturation)

7.1 Test Procedures

The samples had been preconditioned for this test as outlined in Section 4.1. At the start of the test the samples were at irreducible brine saturation as determined during single point desaturation achieved using the porous plate method.

The low rate oilflood was performed at a constant rate of 4 c.c./hr whilst the sample was mounted in an overburden cell/'sight glass' system similar to that used during the low rate waterflood described in Section 5.1. The floods were continued until no gas was produced and permeability to oil was then measured.

Without unloading the sample or altering the pressure of the collection system the flood was continued using brine as the injection fluid. The flow rate was maintained at 4 c.c./hr and the flood was continued until there was no more production of oil. At this point the permeability to brine was determined.

All of the changes in saturation have been based on the recalculated pore volume measured after the initial Kw measurement.

SUMMARY OF RESULTS

7.2a. RESIDUAL GAS SATURATION BY LOW RATE OILFLOOD

			Initial Conditions			Terminal Conditions	
SAMPLE NUMBER	DEPTH (metres)	FORMATION	POROSITY (per cent)	Kg SW_{ir} (mD)	Sw_{ir} (per cent)	Sgr(O) (per cent)	Ko(Sgr) (mD)
593.1	1548.00	SET C	31.9	183	27.6	27.2	41
603.1	1551.00	SET C	31.0	54	33.0	35.6	8.4
605.1	1552.00	SET C	31.6	194	22.9	32.0	33

SUMMARY OF RESULTS

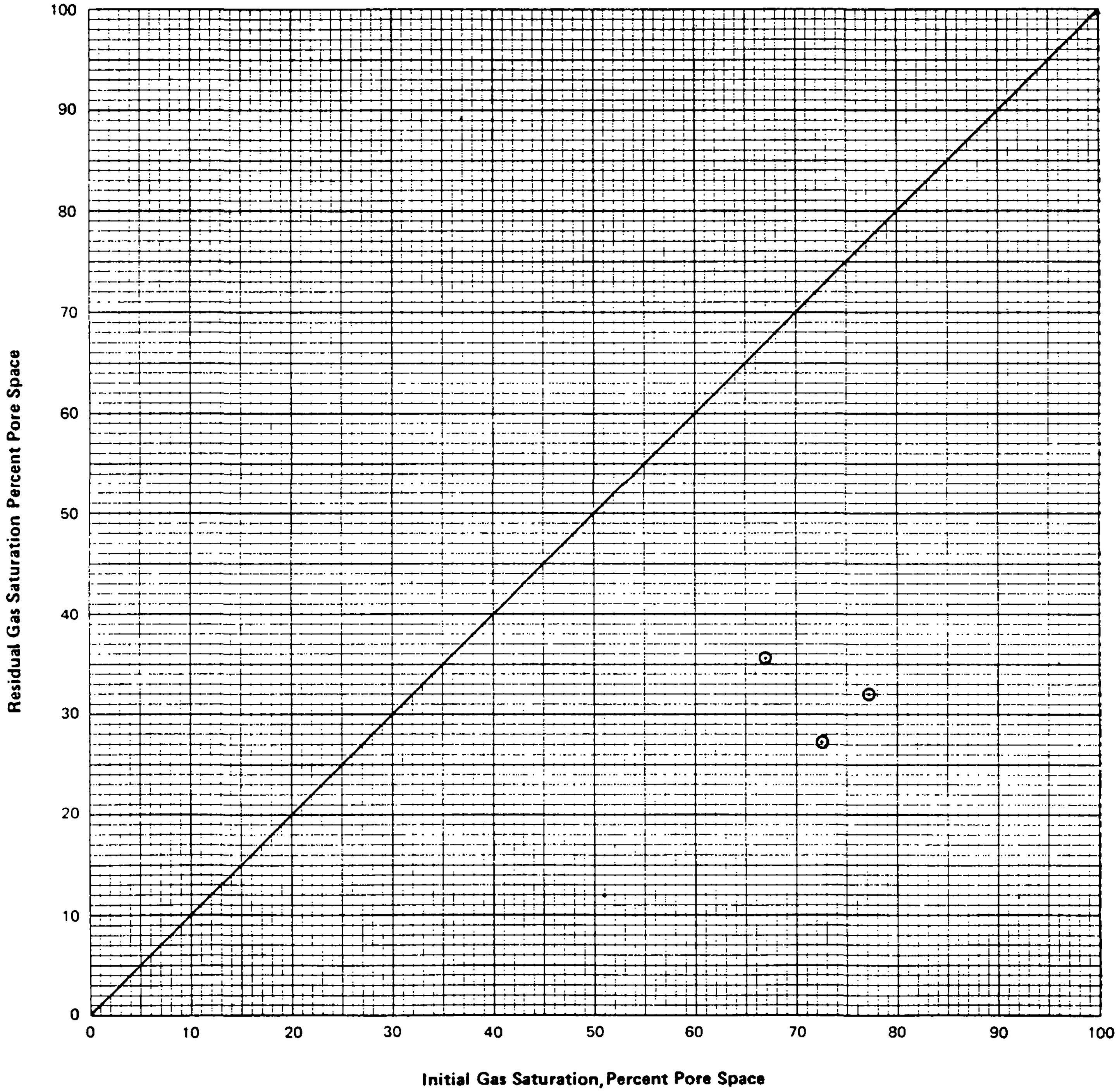
7.2b. RESIDUAL OIL SATURATION BY LOW RATE WATERFLOOD
(in the presence of residual gas saturation)

SAMPLE NUMBER	DEPTH (metres)	FORMATION	Initial Conditions Sgr(O) (per cent)	Initial Conditions Ko(Sgr) (mD)	Terminal Conditions Sgr(O-W) (per cent)	Terminal Conditions Sor (per cent)	Terminal Conditions Kw(Sor-Sgr) (mD)
543.1	1548.00	SET C	27.2	41	27.2	6.3	2.7
603.1	1551.00	SET C	35.6	8.4	34.7	7.0	4.5
605.1	1552.00	SET C	32.0	33	31.6	5.9	11.7

COMPANY: STATOIL
WELL: 31/3-1
FIELD: TROLL
SAMPLE NUMBER:
FORMATION: SET C
LOCATION: NORWEGIAN NORTH SEA
COUNTRY: NORWAY
PERMEABILITY md :

RESIDUAL GAS SATURATION versus INITIAL GAS SATURATION

LOW RATE OILFLOOD

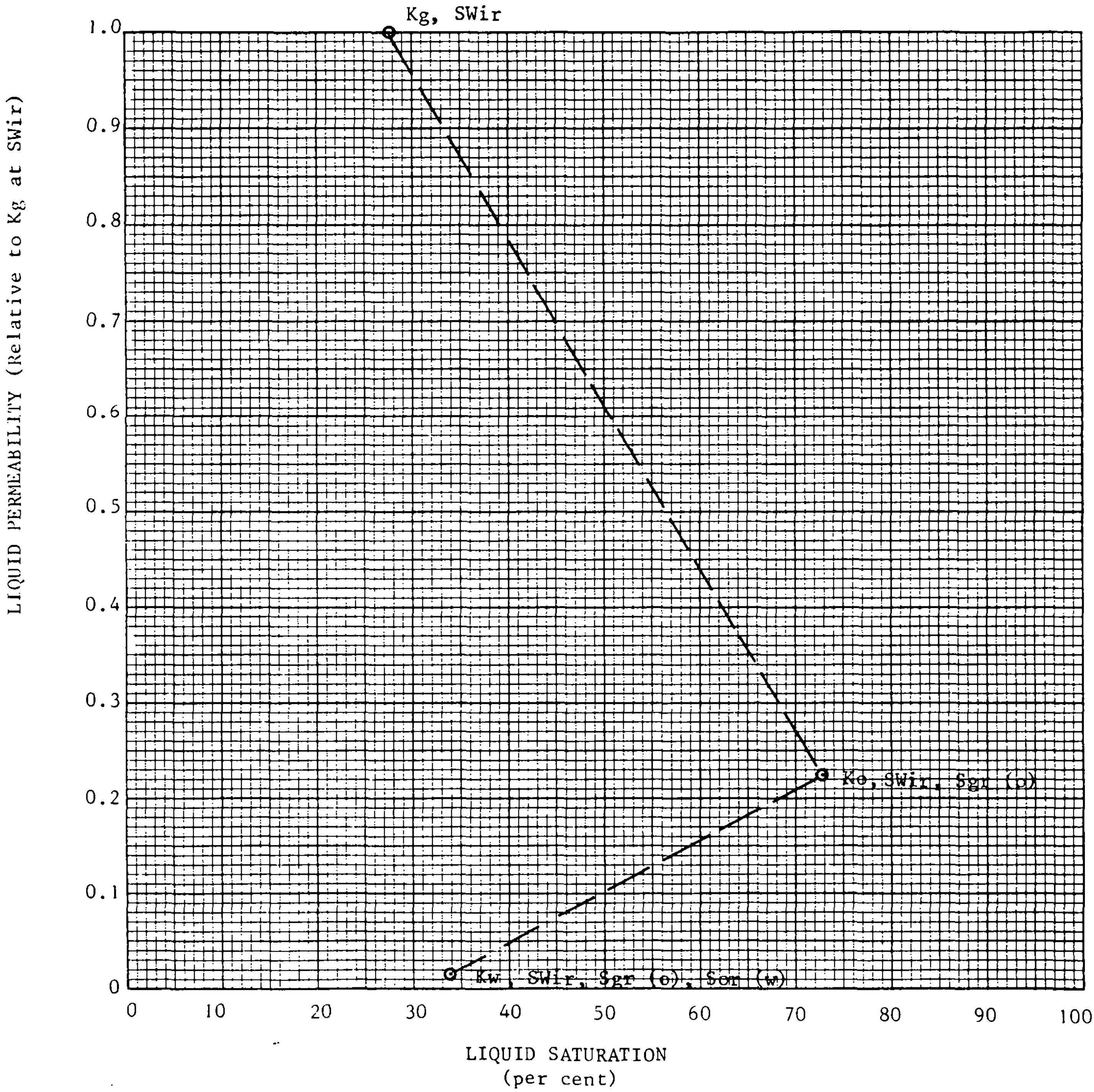


RESIDUAL GAS SATURATION BY LOW RATE OILFLOOD
and
RESIDUAL OIL SATURATION BY LOW RATE WATERFLOOD
(in the presence of residual gas saturation)

File No. SCAL-0211

COMPANY: STATOIL
WELL: 31/3-1
FIELD: TROLL
SAMPLE No.: 593.1

FORMATION: SET C
LOCATION: NORWEGIAN NORTH SEA
COUNTRY: NORWAY
PERMEABILITY md: 133 (Kg at SWir)
SAMPLE DEPTH: 1548.00 m



RESIDUAL GAS SATURATION BY LOW RATE OILFLOOD
and
RESIDUAL OIL SATURATION BY LOW RATE WATERFLOOD
(in the presence of residual gas saturation)

File No. SCAL-0211

COMPANY: STATOIL

FORMATION: SET C.

WELL: 31/3-1

LOCATION: NORWEGIAN NORTH SEA

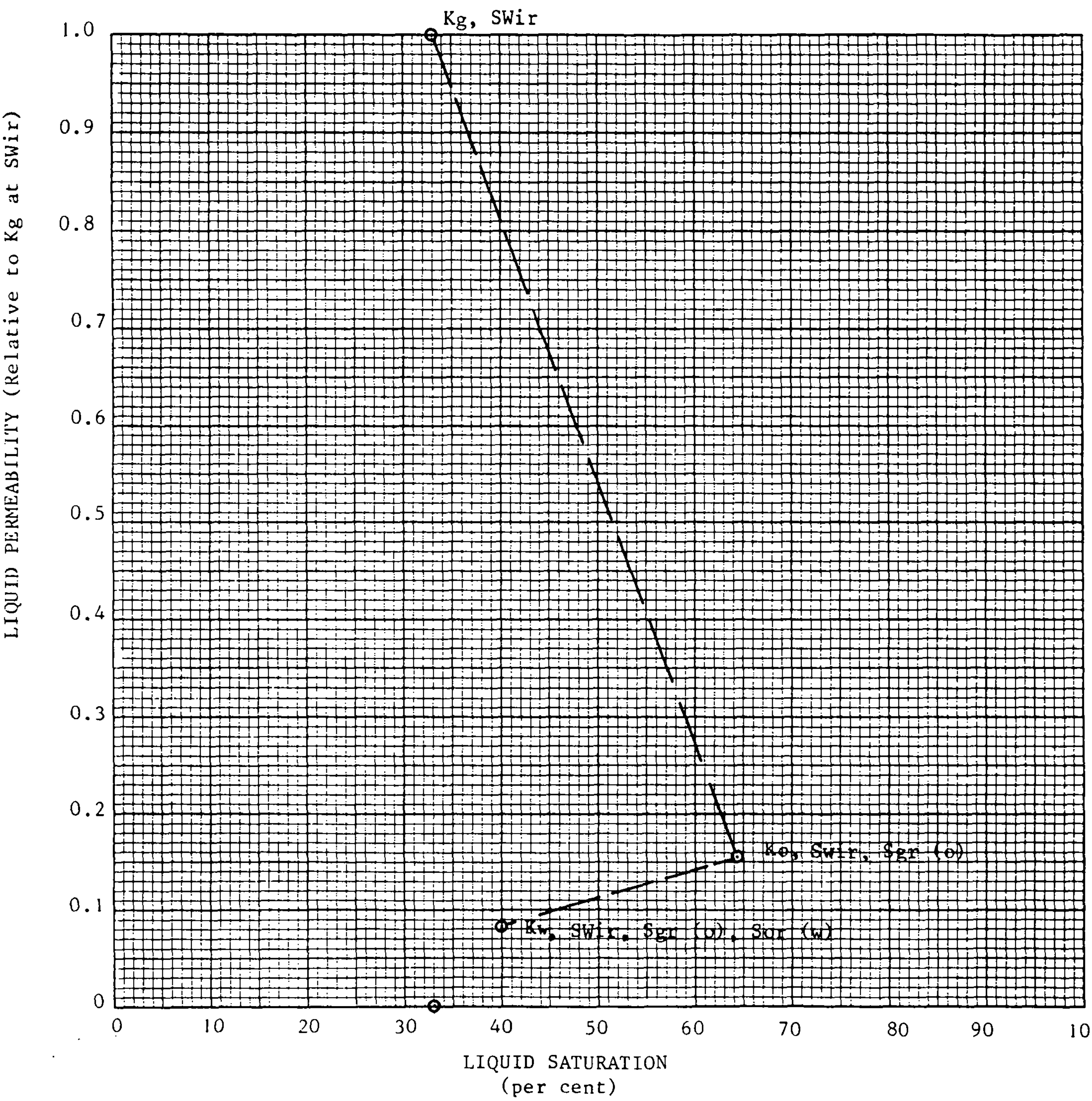
FIELD: TROLL

COUNTRY: NORWAY

SAMPLE No.: 603.1

PERMEABILITY md: 54 (Kg at SWir)

SAMPLE DEPTH: 1551.00 m

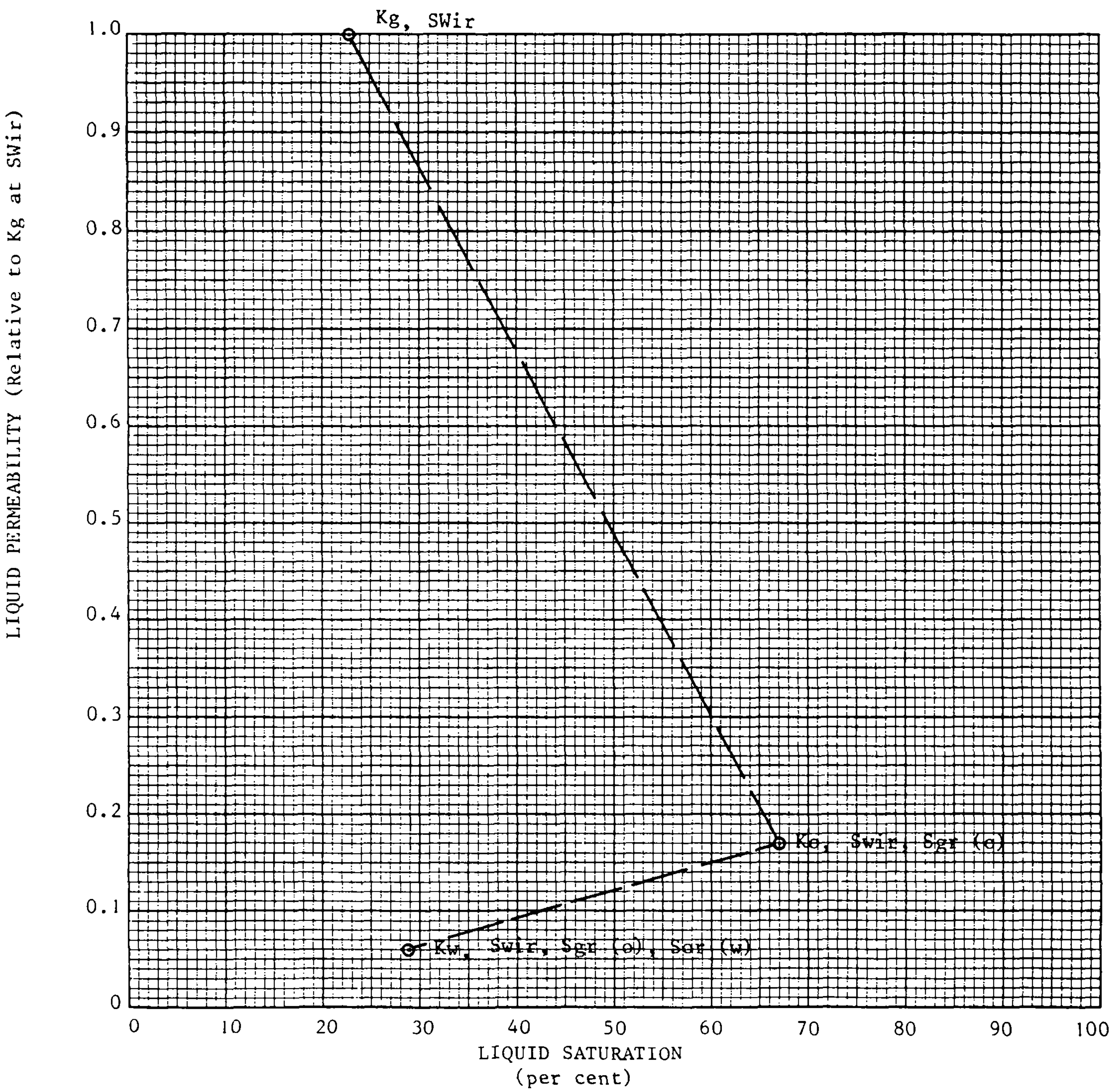


RESIDUAL GAS SATURATION BY LOW RATE OILFLOOD
and
RESIDUAL OIL SATURATION BY LOW RATE WATERFLOOD
(in the presence of residual gas saturation)

File No. SCAL-0211

COMPANY: STATOIL
WELL: 31/3-1
FIELD: TROLL
SAMPLE No.: 605.1

FORMATION: SET C
LOCATION: NORWEGIAN NORTH SEA
COUNTRY: NORWAY
PERMEABILITY md: 194 (Kg at SWir)
SAMPLE DEPTH: 1552.00 m



8 WATER - OIL, RELATIVE PERMEABILITY, UNSTEADY-STATE

8 WATER - OIL, RELATIVE PERMEABILITY, UNSTEADY-STATE

8.1 Test Procedures

The three samples from Set D that were specified for Kw/Ko were cleaned and restored for the test as described in Section 4.1. After the irreducible brine saturation had been established the voided pore space was filled with a light mineral oil of approximately 4 cP viscosity. This process was acheived in two stages. Firstly the sample was chilled to a few degress above the freezing point of the brine and then immersed in the oil and evacuated. Complete saturation was then achieved by pressuring the sample and leaving the system overnight. The sample saturation was then calculated by mass balance.

The oil permeability of each sample was then measured, this data was to be used as the base value for the relative permeability ccalculations. It was noticable at this point that the weight of the samples before and after the Ko remained constant (except for a small change in sample 5D). Therefore the pore volume calculated prior to the single point resaturation was used as base value for the saturation calculations performed on data from the Kw/Ko's.

The brine floods were performed using a constant flow rate of 4 c.c./hr. The flow rate being maintained using positive displacement metering pumps. Throughout the test the effluent was collected in precision graduated glassware and the two phases were allowed to separate. The time interval over which each increment was collected was recorded and differential pressure was recorded at each salient point.

The floods were continued until approximately 10 pore volumes of brine had been pumped through each sample. At this point the permeability to brine was determined.

The three tests performed during this phase of the study were characterised by piston like displacement of the oil and consequently the calculation of relative permeability characteristics was not possible.

8 WATER - OIL, RELATIVE PERMEABILITY, UNSTEADY-STATE

8.2 Water - Oil, Production Data

WATER - OIL PRODUCTION DATA

SAMPLE NUMBER	DEPTH (metres)	FORMATION	OIL PERMEABILITY Ko (mD)	PORE VOLUME c.c.
665.1	1564.00	SET D	620	23.14

CUMULATIVE TIME (seconds)	CUMULATIVE OIL (c.c.)	CUMULATIVE BRINE (c.c.)	DIFFERENTIAL PRESSURE (bars)
9899	10.78	-	0.0249
11690	10.80	2.02	0.0244
17058	10.82	7.92	0.0239
26044	10.85	17.2	0.0235
49074	10.88	41.5	0.0189
93283	10.90	92.6	0.0182
178701	10.95	189	0.0152
267315	10.96	291	0.0171

WATER - OIL PRODUCTION DATA

SAMPLE NUMBER	DEPTH (metres)	FORMATION	OIL PERMEABILITY Ko (mD)	PORE VOLUME c.c.
667.1	1570.00	SET D	470	20.73

CUMULATIVE TIME (seconds)	CUMULATIVE OIL (c.c.)	CUMULATIVE BRINE (c.c.)	DIFFERENTIAL PRESSURE (bars)
7963	8.52	--	--
9540	8.52	1.76	0.0407 -
14910	8.56	7.67	0.0390
23382	8.57	17.0	0.0295
46787	8.59	41.3	0.0362
92108	8.62	90.6	0.0361
181842	8.70	188	0.0306
191838	8.70	199	0.0300

WATER - OIL PRODUCTION DATA

SAMPLE NUMBER	DEPTH (metres)	FORMATION	OIL PERMEABILITY Ko (mD)	PORE VOLUME c.c.
671.1	1571.00	SET D	207	25.08

CUMULATIVE TIME (seconds)	CUMULATIVE OIL (c.c.)	CUMULATIVE BRINE (c.c.)	DIFFERENTIAL PRESSURE (bars)
8344	8.69	-	0.070
8748	8.86	0.25	0.073
9764	8.90	1.33	0.067
11175	8.94	2.80	0.064
13261	8.97	5.07	0.064
16076	9.00	8.09	0.064
22361	9.02	14.0	0.064
29888	9.06	24.1	0.069
50847	9.13	50.0	0.056
93932	9.20	101	0.053
179794	9.24	202	0.039
262351	9.25	308	0.049

4 c.c./hr CONSTANT FLOW RATE

8.3 SUMMARY OF WATERFLOOD TEST RESULTS

WATER - OIL, RELATIVE PERMEABILITY, UNSTEADY-STATE

				INITIAL CONDITIONS		TERMINAL CONDITIONS		OIL RECOVERED	
SAMPLE NUMBER	DEPTH (metres)	AIR PERMEABILITY (mD)	POROSITY per cent	WATER SATURATION per cent pore space	OIL PERMEABILITY (mD)	OIL SATURATION per cent pore space	WATER PERMEABILITY (mD)	per cent pore space	per cent oil in place
665.1	1569.00	732	31.9	16.9	620	36.8	49.6	46.3	55.7
667.1	1570.00	580	31.7	16.6	470	41.8	21.5	41.6	49.9
671.1	1571.00	291	31.2	23.8	207	39.3	21.1	36.9	48.4

APPENDICES

Appendix I

Composition and Specification Summary for the fluids used during the analyses

1. Simulated Formation Brine

Salt	g/litre	
NaCl	47	
KCl	0.9	
$CaCl_2.6H_2O$	10.6	
$MgCl_2.6H_2O$	4	
Density at 20°C	1.0385	g/c.c.
Viscosity at 20°C	1.094	cP

2. Oil used during Water - Oil, Relative Permeability tests

Density at 20°C	0.8089	g/c.c.
Viscosity at 20°C	4.214	cP

3. Oil used during low rate oilflood

Density at 20°C	0.7882	g/c.c.
Viscosity at 20°C	1.920	cP

Appendix II

SAMPLE DIMENSIONS

SAMPLE NUMBER	DEPTH (metres)	FORMATION	SAMPLE LENGTH (cm)	SAMPLE AREA (cm^2)
53.1	1375.75	SET A	4.106	9.842
57.1	1376.75	SET A	6.364	10.406
99.1	1389.25	SET A	4.960	10.179
350.1	1470.00	SET A	7.526	10.492
426.1	1494.00	SET A	7.962	11.074
432.1	1500.00	SET B	7.064	11.222
435.1	1500.75	SET B	7.756	11.341
444.1	1503.00	SET B	7.170	11.163
445.1	1504.00	SET B	7.330	11.282
455.1	1507.00	SET B	7.448	11.252
987.1	1546.50	SET C	7.464	10.521
593.1	1548.00	SET C	7.158	10.839
599.1	1550.00	SET C	6.974	10.752
603.1	1551.00	SET C	7.000	11.045
605.1	1552.00	SET C	7.440	10.927
647.1	1564.30	SET D	7.352	10.810
654.1	1566.00	SET D	7.242	10.986
665.1	1569.00	SET D	6.944	10.810
667.1	1570.00	SET D	6.156	10.839
671.1	1571.00	SET D	7.440	10.927

Appendix III

Summary of Pore Volume Data

SAMPLE NUMBER	DEPTH (metres)	FORMATION	Pore Volume calculated after initial saturation (c.c.)	Pore Volume calculated after brine permeability test (c.c.)	Pore Volume calculated prior to desaturation to SWir (c.c.)	Pore Volume calculated prior to Kg/Kw (c.c.)
57.1	1376.75	SET A	24.81	22.09	24.37	
350.1	1470.00	SET A	22.91	22.09	22.1	18.68
426.1	1494.00	SET A	27.37	25.67	26.11	
432.1	1500.00	SET B	23.58	21.88	22.2	19.72
435.1	1500.75	SET B	29.6*	15.10	14.2	
455.1	1507.00	SET B	23.46	22.08	22.29	21.49
593.1	1548.00	SET C	25.03	24.44	24.70	
603.1	1551.00	SET C	25.28	22.48	24.03	
605.1	1552.00	SET C	24.33	23.27	23.58	
665.1	1569.00	SET D	24.15	23.19	23.64	
667.1	1570.00	SET D	21.40	20.73	20.89	
671.1	1571.00	SET D	26.08	25.08	25.08	

Appendix IV

Abbreviations

K + Ø	Base Air Permeability and Porosity
Ka	Air Permeability
Kg	Gas Permeability
Krg	Gas Permeability relative to Brine Permeability
Kw	Brine Permeability
Krw	Brine Permeability relative to Brine Permeability at 100% brine saturation
Ko	Oil Permeability
Kw/Ko	Water - Oil, Relative Permeability
Kg/Kw	Gas - Brine, Relative Permeability
mD	Millidarcies
SW_{ir}	Irreducible Brine Saturation
Sgr	Residual Gas Saturation
Sor	Residual Gas Saturation
L.R.	Low Rate
g	grams
c.c.	cubic centimetres
cm	centimetres
cP	Centipoise
hr	hour