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RELATIVE PERMEABILITY MEASUREMENTS ON CORE SAMPLES FROM WELL 31/2-7, NORWAY

by

A.E. van Aperen

Sponsor: Shell Forus

KONINKLIJKE/SHELL EXPLORATIE EN PRODUKTIE LABORATORIUM

RIJSWIJK, THE NETHERLANDS

(Shell Research B.V.)

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CONTENTS

KEYWORDS

Well 31/2-7, Norway, relative permeability, imbibition, drainage.

RELATIVE PERMEABILITY MEASUREMENTS ON CORE SAMPLES FROM WELL 31/2-7, NORWAY

Ref. Telex FOR 110809 dated 23-2-1982, from Shell Forus, Norway to KSEPL, Rijswijk.

1. INTRODUCTION

At the request of Shell Forus, the following relative permeability measurements were caried out on core samples from well 31/2-7:

- Measurement of oil/water end-point relative permeabilities, including determination of irreducible water and residual oil saturation (see Appendix A).
- Measurement of (drainage) gas/oil relative permeability curves by the 'modified' Welge displacement method as described in Appendix B.
- Measurement of gas/water end-point relative permeabilities, including determination of irreducible water and residual gas saturation (see Appendix C).

2. RESULTS AND CONCLUSIONS

The relative permeability measurements were carried out on cylindrical one-inch diameter core plugs approximately 3 cm long. These plugs were drilled from the frozen core material (submitted by Shell Forus) using liquid nitrogen as a coolant. The request involved measurements on ten plug samples. The limited amount of core material, however, permitted a selection of only seven plugs. After mounting in the core holder, in which a radial stress of 50 bar was applied to the sample, the plugs were allowed to thaw and were subsequently cleaned by flooding with toluene and chlorotene. Finally, the samples were dried by purging with nitrogen, after which they were saturated with brine. For all measurements this brine contained 60 g NaCl per litre.

2.1 Oil/water end-point relative permeabilities

Oil/water end-point relative permeability measurements were carried out on four samples (R1, R2, R5 and R6). The results are summarised in Table I. The irreducible water saturation, Scw, ranged from 13-46 % PV, averaging 30 % PV. The residual oil saturation, S_{or}, varied from 21-29 % PV, averaging 25 % PV. Hence the movable oil volume amounts to 45 % PV.

2.2 Gas/oil drainage curves

Three samples (G1, G3 and G4) were subjected to the measurement of gas/oil drainage curves. During the actual gas/oil displacement the abslolute viscosity of the applied oil was 15.8 cP. The irreducible water saturation varied from 12-23 % PV, averaging 17 %. The results are summarised in Table II. Figures 1-3 present oil and gas relative permeability as a function of wetting phase saturation.

2.3 Gas/water end-point relative permeabilities

Gas/water end-point relative permeability measurements were carried out on the same three samples discussed in section 2.2, after they had been cleaned. The results are presented in Table III. The irreducible water saturation, S_{wi}, varied from 31-42 % PV, averaging 40 % PV. The measured S_{gr} values (residual gas saturation) varied from 3-12 % PV, averaging 6 % PV, which is very low and probably not realistic. Similar results were obtained when core samples from well 31/2-6 were subjected to this type of measurement[1].

2.4 Permeability correlations

Figure 4 shows the correlation between air permeability and water permeability. Figures 5 and 6 represent the correlation between water permeability and effective oil permeability at S_{cw} and between water permeability and effective water permeability (at S_{or}). The straight lines were obtained by the least square fit method.

REFERENCE

1. van Aperen, A.E., Relative permeability measurements on core samples from well 31/2-6, Norway RKER.83.217.

TABLE I

RESULTS OF OIL/WATER END-POINT RELATIVE PERMEABILITY MEASUREMENTS ON CORE SAMPLES FROM WELL 31/2-7

Sample no.	R1	R2	R5	R6
Depth, m	1548.2	1566.5	1605.6	1620.5
Porosity, % of bulk volume	25.6	29.3	24.0	23.1
Grain density, g/ml	2.70	2.68	2.66	2.69
Air permeability, k_a, mD	1200	1400	6.3	1.9
Water permeability, k_w, mD	980	880	3.4	1.5
Irreducible water saturation, S_{cw}, % of pore volume	22	13	40	46
Effective oil permeability at S_{cw}, k_{ocw}, mD	1140	1380	3.8	1.8
Residual oil saturation, S_{or}, % of pore volume	26	29	21	25
Effective water permeability at S_{or}, k_{wor}, mD	185	230	1.3	0.4
Applied oil/water-viscosity ratio	37	105	1.3	1.3

Note: Air permeability, k_a, not corrected for the Klinkenberg effect.

TABLE II

RESULTS OF GAS/OIL RELATIVE PERMEABILITY MEASUREMENTS BY WELGE-DISPLACEMENT METHOD ON CORE SAMPLES FROM WELL 31/2-7

Sample no.	G1	G3	G4
Depth, m	1548.2	1576.5	1588.2
Porosity, % of bulk volume	27.6	32.9	31.8
Grain density, g/ml	2.65	2.64	2.65
Air permeability, k_a, mD	1100	5000	7000[1]
Irreducible water saturation, S_{cw}, % of pore volume	16	12	23
Effective oil permeability at S_{cw}, k_{ocw}, mD	630	3700	6900
"Residual oil"[2] saturation at the end of the experiment, S_{or}, % of pore volume	28	39	42

1. Because of production of some fines during measurement of k_{ocw}, the air permeability, k_a, was measured after determination of the curve.
2. "Residual oil" saturation is partly due to hold up by capillary forces and partly due to the limited duration of the experiment. In gas drive experiments at connate water the entire oil phase has to be considered mobile next to the immobile water phase. This means that the curves end theoretically at S_{cw} with an effective gas permeability equalling k_{ocw}.

TABLE III

RESULTS OF GAS/WATER END-POINT RELATIVE PERMEABILITY MEASUREMENTS ON CORE SAMPLES FROM WELL 31/2-7

Sample no.	G1	G3	G4
Depth, m	1548.2	1576.5	1588.2
Porosity, % of bulk volume	27.6	32.9	31.8
Air permeability, k_a, mD	1100	5000	7000[1]
Grain density, g/ml	2.65	2.64	2.65
Absolute water permeability, k_w, mD	600	3400	6500
Irreducible water saturation, S_{wi}[2], % of pore volume	48	31	42
Effective gas permeability at S_{wi}, k_{giw}, mD	460	2600	5800
Effective water permeability at "residual gas" saturation, k_{wgr}[3], mD	370	1500	4400
Residual gas saturation [4], S_{gr}, % of pore volume	12	3	3

Note: water salinity= 60 g NaCl/litre

1. See remark under 1 in Table II.
2. S_{wi} is probably too high because of capillary forces and also because of the limited duration of the displacement experiment at unfavourable mobility ratio.
3. The values of k_{wgr} as presented in this table are to be considered as being too high because of the very low S_{gr} values achieved.
4. The measured S_{gr} values are very low and probably not realistic.

GAS-OIL DISPLACEMENT METHOD

RELATIVE PERMEABILITIES IN DRAINAGE MODE AT SCW-.16

CC	OPCO	FIELD	WELL	SAMP	DEPTH	POR	PERM
2030	55	9100	7	G1	1548.2	.276	1100.

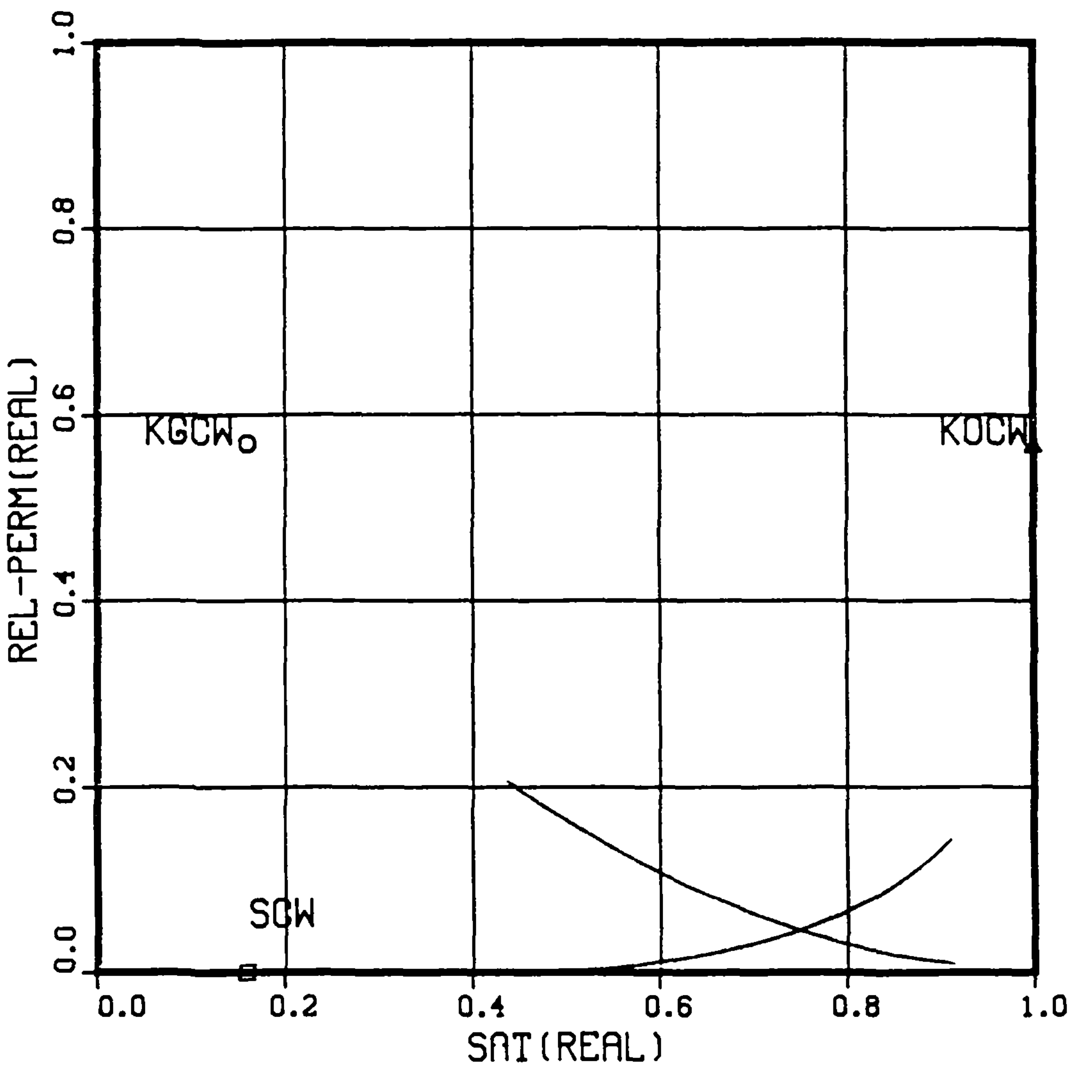

fig. 1

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GAS-OIL DISPLACEMENT METHOD

RELATIVE PERMEABILTIES IN DRAINAGE MODE AT SCW-.12

CC	OPCO	FIELD	WELL	SAMP	DEPTH	POR	PERM
2030	55	9100	7	G3	1576.5	.329	5000.

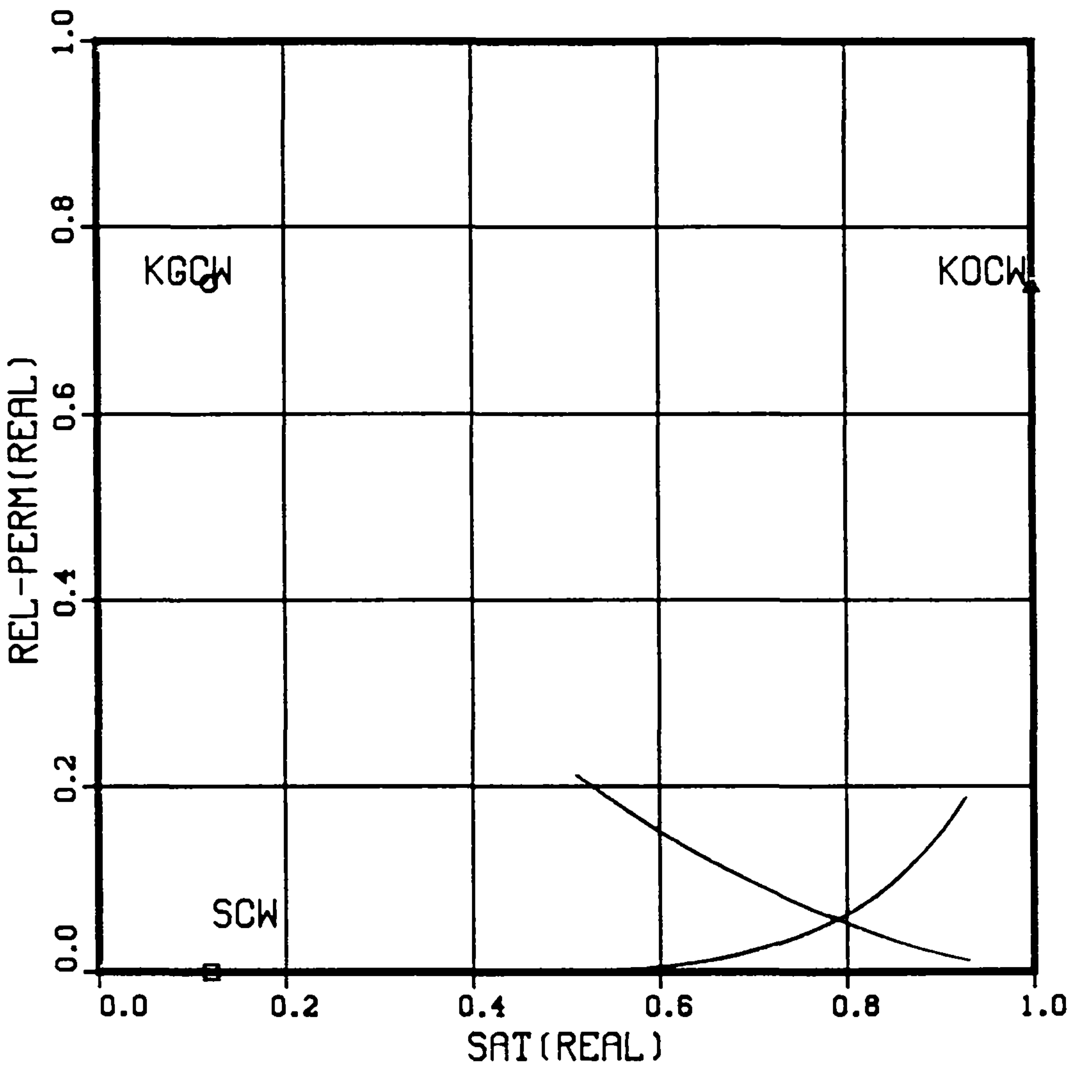


fig. 2

GAS-OIL DISPLACEMENT METHOD

RELATIVE PERMEABILITIES IN DRAINAGE MODE AT SCW-.23

CC	OPCO	FIELD	WELL	SAMP	DEPTH	POR	PERM
2030	55	9100	7	G4	1588.2	.318	7000.

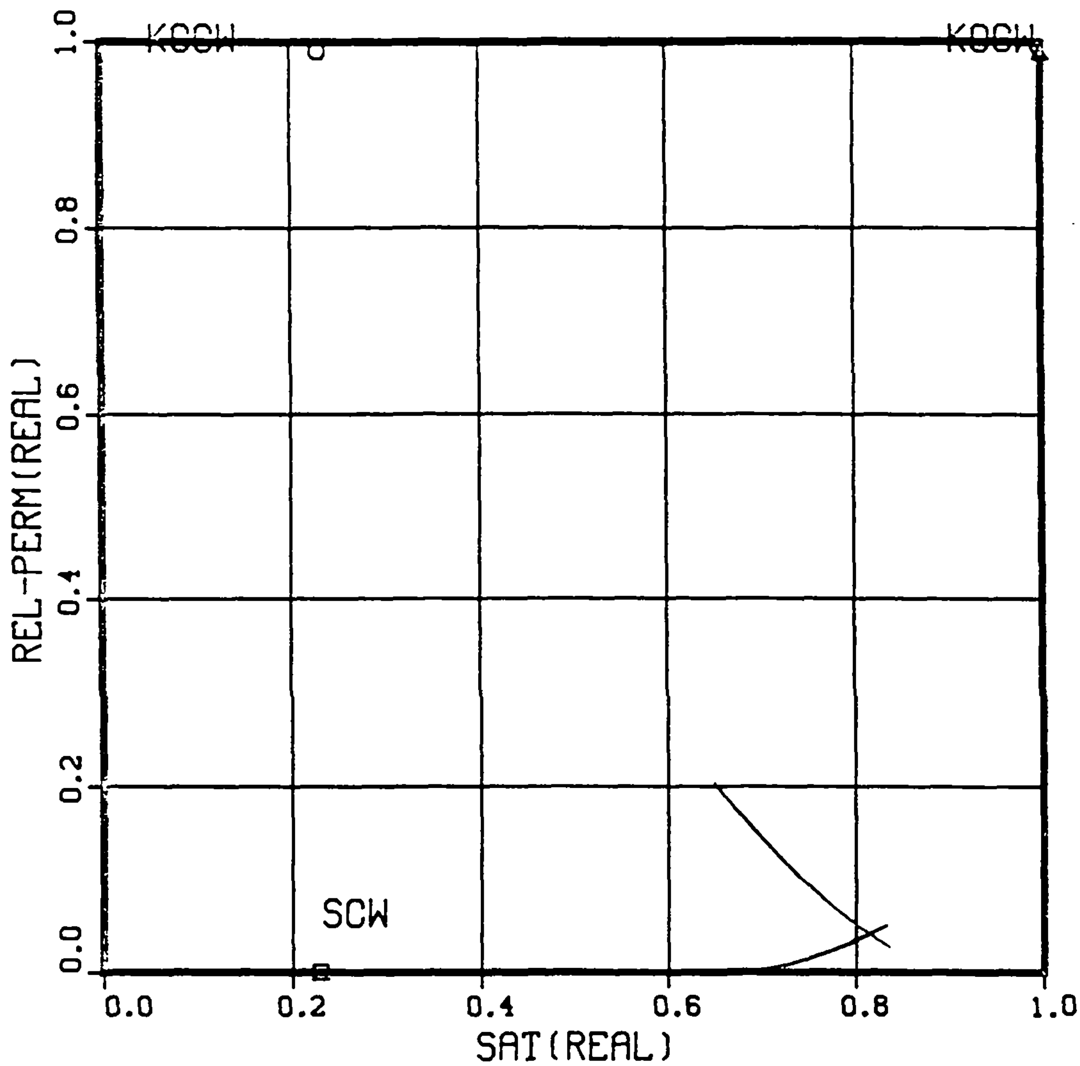
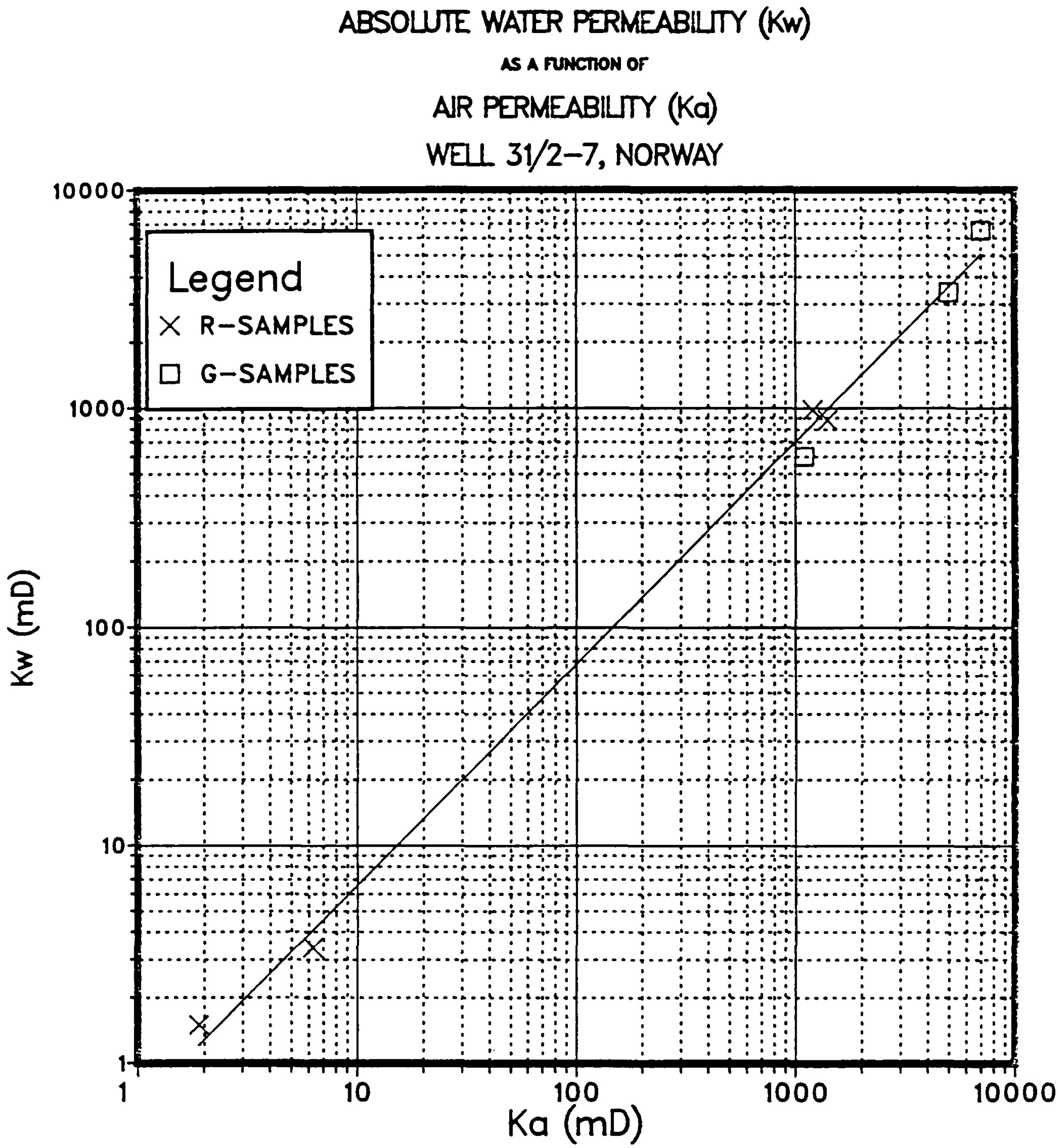


fig. 3

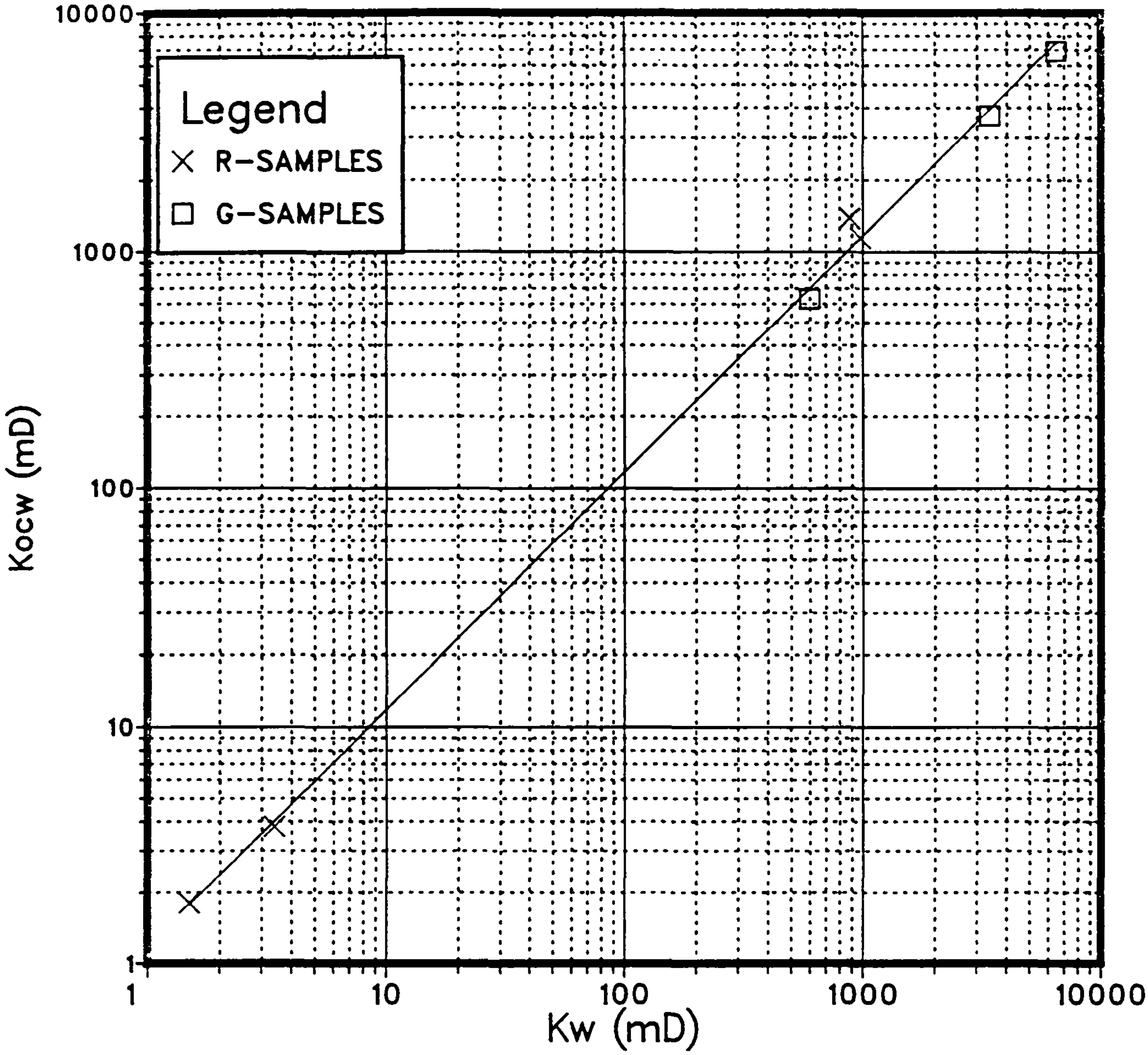

ABSOLUTE WATER PERMEABILITY (Kw)
AS A FUNCTION OF
AIR PERMEABILITY (Ka)
WELL 31/2-7, NORWAY
Legend
R-SAMPLES
G-SAMPLES
Kw (mD)
Ka (mD)
10000
1000
100
10
1
1
10
100
1000
10000

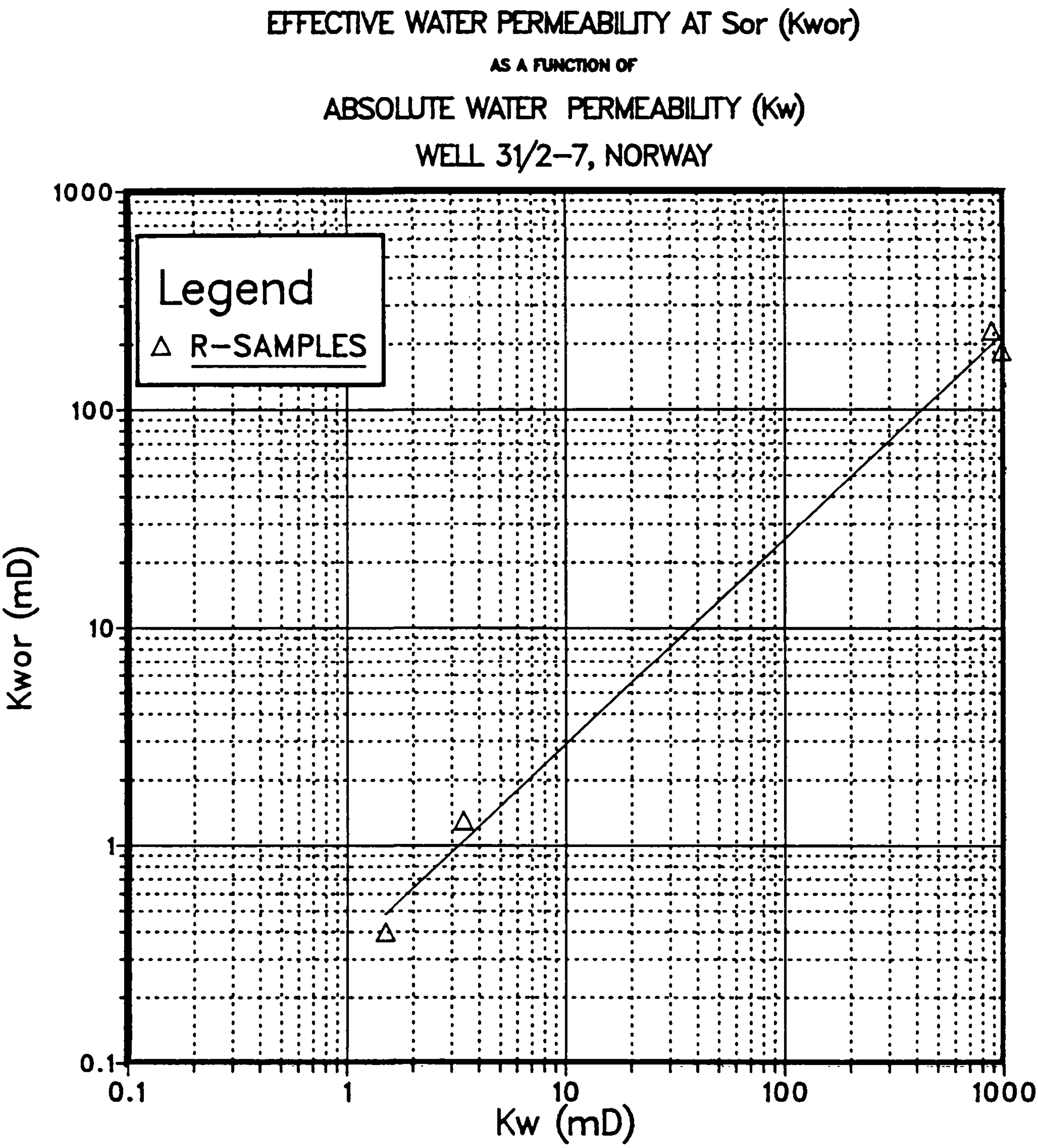
EFFECTIVE OIL PERMEABILITY AT Scw (Kocw)

AS A FUNCTION OF

ABSOLUTE WATER PERMEABILITY (Kw)

WELL 31/2-7, NORWAY




EFFECTIVE WATER PERMEABILITY AT Sor (Kwor)
AS A FUNCTION OF
ABSOLUTE WATER PERMEABILITY (Kw)
WELL 31/2-7, NORWAY
Legend
△ R-SAMPLES
Kwor (mD)
Kw (mD)
1000
100
10
1
0.1
0.1
1
10
100
1000

APPENDIX A

OIL/WATER END-POINT RELATIVE PERMEABILITY MEASUREMENTS

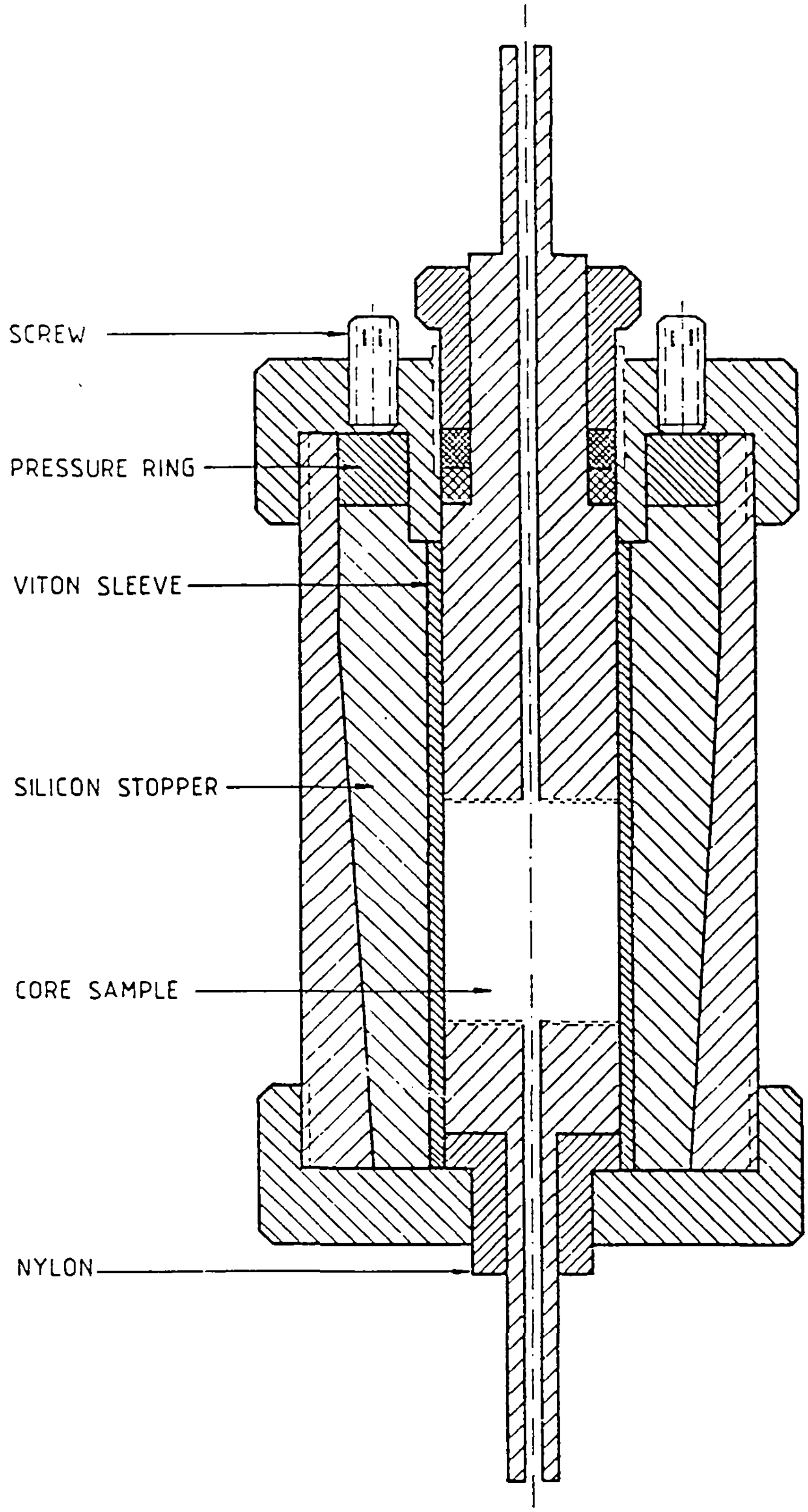
Procedure

Selected plugs are mounted in a special core holder (Fig. A1) and a radial stress of 50 kg/cm^2 is applied to the sample by means of a rubber stopper. After the air permeability (k_a) has been determined, the sample is saturated with (artificial) formation water and the absolute water permeability (k_w) is measured.

Subsequently, the sample is flooded with oil ($\Delta P/Pc > 20$) until water is no longer produced and the effective oil permeability (k_{ocw}) can be determined.

The sample is flooded with formation water again, and when oil production has ceased the effective water permeability is measured.

End-point saturations are calculated from the volumetric balance and the pore volume of the sample.


SCREW
PRESSURE RING
VITON SLEEVE
SILICON STOPPER
CORE SAMPLE
NYLON

CORE HOLDER

APPENDIX B

GAS-DRIVE DRAINAGE METHOD[B1]

Oil is displaced from an oil-saturated core sample (if required at connate water saturation) by gas drive. The displacement occurs at a constant pressure differential and during the experiment the production of oil and gas is recorded as a function of time (see Fig. B1). Both gas and liquid relative permeabilities are calculated as a function of total liquid saturation, derived from defined fractional flows, saturation and pressure gradient at the outflow end of the core plug.

Remarks (disturbing effects)

I. Capillary end-effect

As a result of capillary forces, the wetting fluid is held up at the outflow end of the core sample, thus affecting the saturation of that part of the sample.

Therefore, proper test conditions have to be selected to reduce the end-effect as much as possible (e.g. $\frac{\Delta P}{Pc} > 10$).

II. Gas expansion

The experiment is based on the Welge[B2] type displacement technique, in which the use of incompressible "fluids" is assumed.

Therefore, gas compressibility has to be reduced by elevation of the average pressure level (by applying an appropriate back pressure) in combination with the smallest allowable pressure differential across the core sample.

REFERENCES

B1. Owens, W.W., Parrish, D.R. & Lamoreaux, W.E., An Evaluation of a Gas Drive Method for Determining Relative Relationships.
Petroleum Transactions, AIME vol. 207 (1956), p. 275.

B2. Welge, H.G., Simplified Method for computing oil recovery by gas or water drive.
Trans AIME 195 (1952), p. 91.

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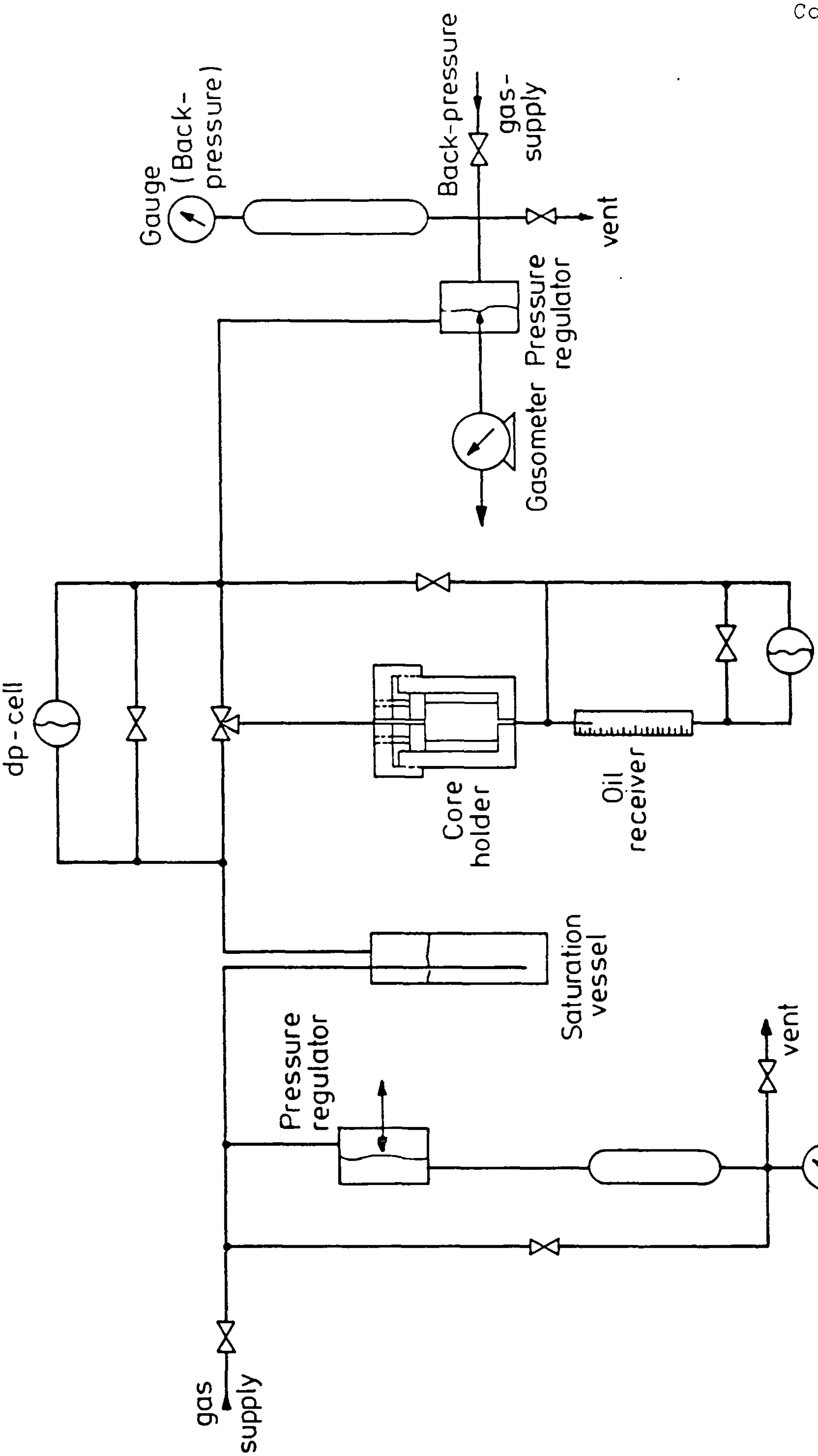

FLOW SCHEDULE OF GAS-DRIVE DRAINAGE EXPERIMENTS

FIG. B1

APPENDIX C

GAS/WATER END-POINT PERMEABILITY MEASUREMENTS

Procedure

Selected plugs are mounted in a special core holder (Fig. A1) in which a radial stress of 50 kg/cm^2 is applied on the sample by means of a rubber stopper. After the sample has been cleaned and dried, the air permeability (k_a) is determined, after which the sample is saturated with (artificial) formation water and the pore volume (porosity) is determined. Subsequently, the absolute water permeability is measured and the sample is then flushed with water-saturated gas ($\Delta P/Pc > 10$) until water is no longer produced and the effective gas permeability can be determined.

After this, the sample is flooded with gas-saturated water to establish residual gas saturation. This has to be done at a very small pressure difference, because otherwise solution of gas into the water phase will cause too low gas saturations. The effective water permeability at residual gas saturation is determined upon flooding approx. 5 - 10 pore volumes.

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