THE EFFECT OF RESERVOIR CONDITIONS AND WETTABILITY ON THE CAPILLARY PRESSURE CURVE

by

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ABSTRACT

Capillary pressure curves have been determined on sandstone core plugs from three North Sea reservoirs using the porous plate method.

Traditionally, restored or native state samples are compared with cleaned samples in studies of the effect of wettability on capillary pressure. In this study cleaned samples were restored during a capillary pressure drainage test. This is supposed to be more similar to the process taking place during migration of the oil in the reservoir.

Capillary pressure curves, refined oil displacing brine, at reservoir and ambient temperature, both with ambient pressure and reservoir conditions, (reservoir temperature and pressure), are presented.

Next capillary pressure curves, crude oil displacing brine, at reservoir and ambient temperature both with ambient pressure are presented.

Finally capillary pressure curves, live crude oil displacing brine, at reservoir conditions are presented.

The wettability preference of the samples was determined both prior to and after the capillary pressure tests.

The capillary pressure curves were displaced toward a lower wetting-phase saturation when the temperature was increased to reservoir temperature, for the refined oil/brine system.

For the samples which remain water-wet throughout the capillary pressure measurements, it is found that the difference between the capillary pressure curve at reservoir conditions and at ambient conditions is due to temperature effects rather than to pressure effects. The pressure effects the capillary pressure curve only in the transition zone lying immediately above the water table.

The crude oil/brine capillary pressure curves are different from the refined oil/brine capillary pressure curves when both measurements were performed with cleaned samples. At high capillary pressure the reduced crude oil/brine capillary pressure curves (P_c/γ) are above the reduced refined oil/brine capillary pressure curves, (P_c/γ), *i.e.* for a given capillary pressure, the brine saturation from crude oil measurements are higher than brine saturations from refined oil measurements. This difference in brine saturation is related to a wettability change for the samples displaced with crude oil. The greatest difference in brine saturation is found for the samples with the largest wettability change.

INTRODUCTION

Capillary pressure (P_c) is an important petrophysical property. The capillary pressure as a function of brine saturation, capillary pressure curve, is used to evaluate the brine saturation in oil reservoirs.

Capillary pressure data are usually obtained at ambient conditions which differ greatly from full reservoir conditions (reservoir pore pressure, temperature, overburden pressure and fluid properties). Capillary pressure measurements are usually performed with fluids not representative of the reservoir to be studied. One may assume that in the capillary pressure test the core samples are representative for the reservoir to be studied with respect to most rock characteristics, but the wettability preference of the samples in the test can differ from the wettability of the reservoir.

Longeron *et al.* (1986) have compared capillary pressure data at reservoir conditions with refined oil displacing brine and at ambient conditions with gas displacing brine. The samples were water-wet. For brine saturations lower than 0.5, the P_c/γ curves at reservoir conditions were below the P_c/γ curves at ambient conditions for both the limestone and the sandstone sample.

In a previous paper, (Søndenå *et al.*, 1990) we compared capillary pressure measurements on water-wet samples at ambient conditions; refined oil displacing brine and nitrogen displacing brine, with measurements at reservoir conditions; refined oil displacing brine. At the same capillary pressure the brine saturations obtained at reservoir conditions were lower than the brine saturations obtained at ambient conditions.

Anderson (1987) made a literature survey of the effect of wettability on capillary pressure. He found that in uniformly wetted porous media the drainage capillary pressure is insensitive to the wettability when the contact angle is less than 50^{o}. The insensitivity is due to pore geometry effects and the extremely rough surfaces of the porous media, which makes the effective contact angle zero.

Sample with wettability index lower than 0.3, (contact angle equal to 75^{o}), is defined as uniformly water-wet sample, while sample with wettability index lower than -0.3 (contact angle equal to 105^{o}), is defined as uniformly oil-wet sample. Sample with wettability index between 0.3 and -0.3 is defined as intermediate wettability preference.

In a fractional-wet or mixed-wet core it is possible for either fluid to imbibe freely when the core is initially at the irreducible saturation for that fluid. Fractional wettability is nonuniform wettability where portions of the surface are strongly water-wet, while the remainder are strongly oil-wet. Mixed-wettability, which was first introduced by Salathiel, (1973), is a special type of fractional wettability in which the oil-wet surfaces form continuous paths through the larger pores. The smaller pores remain water-wet, containing no oil.

Anderson pointed out that if the reservoir is intermediate or oil-wet and a clean water-wet core is used, the shape of the capillary pressure curve will not be representative of the reservoir.

Longeron *et al.* (1989) compared capillary pressure curves obtained at reservoir conditions first with refined oil displacing brine, then with crude oil displacing brine. The samples were restored with crude oil between the capillary pressure measurements. The difference between the reduced capillary pressure curves (P_c/γ) was significant when the wettability preference changed from intermediate to oil-wet for a carbonate sample. The curve obtained with crude oil was below the one obtained with refined oil in the S_w interval between 0.7 and 0.3. The sample had a slight fractional wettability nature, since both oil and brine were spontaneously displaced by imbibition of brine and oil respectively.

In a previous paper, (Søndenå *et al.*, 1989), we compared capillary pressure measurements on samples of intermediate and slightly water-wet wettability preference at ambient conditions with samples of intermediate and slightly water-wet wettability preference which changed to oil-wet (mixed-wet) preference during the capillary pressure measurement at reservoir conditions. The brine saturated samples used at ambient conditions were displaced with refined oil and the twin samples used at reservoir conditions were displaced with live crude oil. At low capillary pressures the live crude oil P_c/γ curves obtained at reservoir conditions are equal to the refined oil P_c/γ curves at ambient conditions. At higher capillary pressures the live crude oil P_c/γ curves are above the refined oil P_c/γ curves, *i.e.* for a given capillary pressure, the brine saturations from live crude oil measurements are higher than brine saturations from refined oil measurements. They related the differences in the capillary pressure curves to a change in the wettability preference.

The main object of the present study is to see if the difference between the capillary pressure curve obtained at ambient conditions and those obtained at reservoir conditions could be related to a temperature effect and/or wettability effect.

The porous plate method was chosen to drain the samples for brine to simulate the saturation distribution in the reservoir which is established by capillary forces only. The porous plate method used in this study is unlike the porous plate method described by de Waal *et al.*, (1989), but similar to the equilibrium technique described by de Waal *et al.*, (1989).

DESCRIPTION OF THE TESTS

Prior to the tests, all samples were gently flushed alternately with methanol and toluene, then dried with a lenient air flow and finally saturated with synthetic formation brine. 100% brine saturation at the start of the measurement was checked by comparing the pore volume with the difference in weight between brine saturated and dry samples.

Ambient Condition Test

The brine saturated samples were placed on a brine saturated porous plate in a Hassler- type coreholder. Clay powder was used between the sample and the porous plate to keep hydraulic contact during the test. The samples were exposed to a net confining sleeve pressure of 20 bar. The samples were drained for brine using refined oil and crude oil, increasing the pressure in 6 steps. The highest capillary pressure was 1.6 bar.

The test proceeded to the next pressure step when the production in a three days interval was less than 1% of the pore volume.

The different brine saturations were determined by measuring the volume of brine produced from each sample. In addition, the endpoint brine saturations were controlled with the results from a Dean and Stark extraction..

Two samples from each reservoir were tested for wettability preference according to the USBM method (Donaldson *et al.*, 1969; Sharma and Wunderlich, 1985) and the Amott method, (Amott, 1959; Sharma and Wunderlich, 1985).

Tests at Reservoir Temperature and at Ambient Pressure.

The procedure was identical to the one used at ambient conditions but the pore pressure was set to 1 barg in order to increase the boiling point of the brine at reservoir temperature, (Table 1). Brine was displaced with refined oil and crude oil.

The samples from each reservoir were tested for wettability preference according to the USBM method and the Amott method.

Resevoir Condition test

The equipment and the experimental procedure used in the capillary pressure measurements at reservoir conditions are described in the previous papers by the same authors, (Søndenå *et al.*, 1989 and Søndenå *et al.*, 1990) and in the Ph.D. thesis, (Søndenå, 1991). The reservoir conditions applied are listed in Table 1.

RESULTS AND DISCUSSION

The properties of the fluids and the rocks used in the experiments are listed in Table 2-5. The summary of the capillary pressure tests are presented in Table 6.

Effect of Reservoir Conditions.

In Figure 1 capillary pressure curves at reservoir temperature and ambient pressure are compared with data from a previous paper by the same authors, (Søndenå *et al.*, 1990) at reservoir conditions and at ambient conditions, (reservoir B), with the same samples; refined oil displacing brine.

The capillary pressure data have not been corrected for interfacial tension, (IFT).

At the same capillary pressure, the brine saturations obtained at reservoir temperature are lower than the brine saturations obtained at ambient temperature for the refined oil/brine measurement, Figure 1.

At low capillary pressure, (reservoir B), the brine saturations obtained at reservoir temperature are lower than the brine saturations obtained at reservoir conditions. At high capillary pressures, the brine saturations at reservoir temperature are equal to the brine saturations at reservoir conditions, Figure 1. The difference at low capillary pressures is probably due to pore compression of the biggest pores. Pore compression will cause higher water saturations at reservoir pressure than at ambient pressure at the same capillary pressure. The equality of the capillary pressure curves at high capillary pressures is probably due to non pore compression of the smaller pores.

Similar results were observed by Chierici et. al., (1967) for 20 samples at ambient temperature. They compared capillary pressure curves with confining pressure of 0 bar and 400 bar.

For the reservoir-B samples, which remain water-wet throughout the capillary pressure measurements, Table 7, it is found that the difference between the capillary pressure curve obtained at reservoir conditions and at ambient conditions is due to temperature effects rather than to pressure effects. The pressure effect the capillary pressure curve only in the transition zone lying immediately above the water table.

Effect of Wettability

In Figure 2 refined oil/brine P_c/γ curves from reservoir A are compared to crude oil/brine P_c/γ curves at ambient temperature and at reservoir temperature. The samples are the same samples used in a previous paper by the same authors, (Søndenå *et al.*, 1989).

In Figure 3 live crude oil/brine P_c/γ curves at reservoir conditions are compared to refined oil/brine P_c/γ curves at ambient conditions. The interfacial tension (IFT) between live crude oil and brine is not tested at reservoir conditions. Instead the crude oil/brine IFT at ambient conditions (24 mN/m) is used in Figure 3. However the difference between the capillary pressure curve obtained at ambient conditions and at reservoir conditions with live crude oil displacing water can not be related to a possible discrepancy in the interfacial tension. Munkerud *et al.*, (1984) studied the effect of temperature on the crude oil/brine IFT and found that the difference between IFT at 20°C and 80°C was less than 1 mN/m for stock tank oil system from four North Sea reservoirs.

The crude oil/brine P_c/γ curves are different to the refined oil/brine P_c/γ curves at ambient conditions, (Figure 3, sample A-1b and A-5b). At low capillary pressures the crude oil/brine P_c/γ curves from the samples A-1b and A-5b are equal to the refined oil/brine P_c/γ curves. At higher capillary pressure the crude oil/brine P_c/γ curves are above the refined oil/brine P_c/γ curves, *i.e.* for a given capillary pressure, the brine saturation from crude oil measurements are higher than brine saturations from refined oil measurements. The greatest differences were found for the samples with the largest wettability change. During the measurement with crude oil the wettability index decreased from 0.40 to -0.27. and from 0.27 to -0.11, for sample A-5b and A-1b respectively. This represent a wettability change from water-wet to slightly oil-wet.

The same results are obtained for the measurements at reservoir temperature and ambient pressure (Figure 3). At low capillary pressures the crude oil/brine P_c/γ curve from the sample A-8b is equal to the refined oil/brine P_c/γ curve. At higher capillary pressure the crude oil/brine P_c/γ curves are above the refined oil/brine P_c/γ curves, *i.e.* for a given capillary pressure, the brine saturation from crude oil measurements are higher than the brine saturations from refined oil measurements. During the measurement the wettability index decreased from 0.30 to -0.42. On sample 3-b, the crude oil/brine P_c/γ curve is almost equal to the refined oil/brine P_c/γ curve for all measured capillary pressure. In this measurement with crude oil the wettability index decreased from 0.05 to -0.09.

The results confirm a study by the same authors (Søndenå *et al.*, 1989), (Figure 3). At low capillary pressures the live crude oil/brine P_c/γ curves obtained at reservoir conditions are equal to the refined oil/brine P_c/γ curves at ambient conditions. At higher capillary pressures the live crude oil/brine P_c/γ curves are above the refined oil/brine P_c/γ curves, *i.e.* for a given capillary pressure, the brine saturations from crude oil measurements are higher than brine saturations from refined oil measurements. Two of the samples were tested for wettability preference according to the USBM method. The wettability index decreased from 0.27 to -0.18. and from 0.14 to -0.30, respectively during the measurement; live crude oil displacing brine.

For uniformly wetted systems Morrow (1976) found that changes in drainage and imbibition capillary pressure were approximately proportional, respectively to the cosines of the receding and advancing contact angles observed at rough surfaces. In uniformly wetted systems brine and oil only imbibe spontaneously in water-wet and oil-wet samples respectively. For intermediate wetted samples, either of the fluids imbibe spontaneously.

In this study and in a previous study by the same authors (Søndenå *et al.*, 1989) both the brine and oil imbibe spontaneously and thus the samples have a slight fractional wettability nature after the capillary pressure measurement with crude oil and live crude oil, (Table 7).

Longeron *et al.*, (1989) compared capillary pressure curves obtained at reservoir conditions first with refined oil displacing brine then with crude oil displacing brine. The samples were restored with crude oil between the capillary pressure measurements. The difference between the P_c/γ curves was significant when the wettability preference changed from intermediate to oil-wet for a carbonate sample. The curve obtained with crude oil was below the one obtained with refined oil in the S_w interval between 0.7 and 0.3. The sample has a slight fractional wettability nature, since both oil and brine were spontaneously displaced by imbibition of brine and oil respectively.

Several authors have compared cleaned and native state capillary pressure curve (Anderson, 1987; Richardson *et al.*, 1955; Luffel and Randall, 1960; Schmid, 1964; Salathiel, 1973; Hirasaki *et al.*, 1990). At low capillary pressures they found that the native state capillary pressure curve is lower than the cleaned capillary pressure curve. It then shifted over and has a higher irreducible brine saturation for the native state samples.

Schmid (1964), (Anderson, 1987), pointed out that mixed wettability is responsible for the capillary pressure behaviour of these cores. At the beginning of the capillary pressure measurement in the mixed-wettability (native state) plug, oil enters the large, oil-wet pores. A lower capillary pressure is required to displace the brine from large pores when they are oil-wet versus water-wet, so the capillary pressure curve is initially below that of a cleaned, water-wet core. During this time, some of the brine in the smaller pores is bypassed and trapped. Eventually, most of the brine in the large, oil-wet pores is displaced, and oil begins to enter the remaining smaller pores, which are water-wet and filled with brine. At this point, the capillary pressure for the mixed wettability core crosses over the cleaned curve and begins to rise rapidly. There may be two likely reasons to this behaviour. First, a higher pressure is required to force oil into the smaller, water-wet pores. Second, the irreducible brine saturation will be relatively high, since some of the brine in the smaller water-wet pores will have a tendency to be bypassed and trapped as oil flows in the larger pores.

In all the capillary measurements with crude oil displacing brine reported (Anderson, 1987; Richardson *et al.*, 1955; Luffel and Randall, 1960; Schmid, 1964; Salathiel, 1973; and Longeron; 1989) restored or native state samples were used. In this study and in a previous study by the same authors (Søndenå *et al.*, 1989) cleaned samples were used. The water-wet samples were aged stepwise through the capillary pressure test by crude oil. Since the pores first were aged after the brine drainage, the crude oil P_c/γ curve and the refined oil P_c/γ curve should be superposable for low capillary pressure, (Figure 4). Due to the aging of the large pores some of the brine in the small pores is bypassed and trapped. As a consequence the crude oil P_c/γ curve is above the refined oil P_c/γ curve at higher capillary pressure, *i.e.* the S_{wi} from the crude oil/brine measurement is higher than S_{wi} from the refined oil/brine measurement, (Figure 4).

This is the same process taking place in the migration of oil in the reservoir. Except of the reservoirs where portion of the mineral surface are initially oil-wet, the reservoirs are initially water-wet. The eventually wettability change in the reservoir takes therefore place through the oil-migration. In the generally accepted theory, the reservoirs are saturated with water prior to the oil migration, (Tissot and Welte, 1978; Hawkins and Bouchard, 1989). The brine saturation distribution in the reservoir is then established by capillary pressure during the primary drainage of brine. If the reservoir is water-wet prior the tests with crude and live crude oil, the smallest pores which are not entered by oil are still water-wet forming continues paths. Due to this, the reservoir probably have a mixed wettability preference.

In the capillary pressure measurements using native state and restored samples the oil-wet pores are spontaneously imbibed or imbibed with low capillary pressure, *i.e.* the capillary pressure curve are below the capillary pressure curve from the cleaned samples at low capillary pressure, (Figure 4). Then the capillary pressure curve crosses over and has a higher irreducible brine saturation.

Since there is no comparable study of the difference between capillary pressures on native state samples and capillary pressure curves obtained by aging during the test, it is difficult to point out any difference between the irreducible brine saturations obtained. But if native state or restored state samples at residual oil saturation are used in capillary pressure measurements (secondary drainage), it can cause errors in the calculation of oil in place in the reservoir, especially if the samples have mixed wettability preference, (Batycky *et al.*, 1981). Several authors have studied the effect of hysteresis of capillary pressure curves, (Evrenos and Comer, 1969; Sanyal *et al.*, 1973; Batycky *et al.*, 1981; Longeron *et al.*, 1986 and Hawkins and Bouchard, 1989). They showed that the primary and secondary capillary pressure curves were different due to hysteresis.

CONCLUSION

The capillary pressure curves were shifted toward a lower wetting-phase saturation when the temperature was increased to reservoir temperature, for both a refined oil/brine system and a crude oil/brine system.

For a water-wet reservoir it is found that the difference between the capillary pressure curve obtained at reservoir conditions and at ambient conditions is due to temperature effects rather than to pressure effects. The pressure effects the capillary pressure curve only in the transition zone lying immediately above the water table.

The crude oil/brine capillary pressure curves are different from the refined oil/brine capillary pressure curves when both measurements were performed with cleaned samples. At higher capillary pressure the crude oil P_c/γ curves are above the refined oil P_c/γ curves, *i.e.* for a given capillary pressure, the brine saturation from crude oil measurements are higher than brine saturations from refined oil measurements. This difference in brine saturation were related to a wettability change for the samples displaced with crude oil. The greatest difference in brine saturation were found for the samples with the largest wettability change.

NOMENCLATURE

K	Permeability [mD]
P_c	Capillary pressure.
r	Pore radius
S_w	Brine saturation (fraction of pore volume)
WI	Wettability Index
$\gamma_{o/w}$	Interfacial Tension between oil and brine, (IFT), [mN/m]
θ	Contact angle through wetting phase
ϕ	Porosity [%]

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TABLES

TABLE 1 Reservoir Conditions

Reservoir	*A*	*B*
Temperature [°C]	104	98
Pore Pressure [Bar]	359	414
Overburden Pressure [Bar]	684	594
Effective Stress	325	180

TABLE 2 Physical Properties of the Formation Brine.

Reservoir	*Density (20°C), [g/cm^3]*	*Viscosity (20°C), [cp]*
A	1.040	1.12
B	1.135	1.54

TABLE 3 Chemical Composition of the Formation Brine.

Reservoir	*A*	*B*
Na^+ [mg/l]	16 034	41 600
Ca^{2+} [mg/l]	5 300	26 000
Mg^{2+} [mg/l]	360	1 925
Sr^{2+} [mg/l]	1 120	735
K^+ [mg/l]	0	1 235
Cl^- [mg/l]	36 092	119 500

TABLE 4 Physical Properties of the Oils.

Oil	*Density (20°C), [g/cm³]*	*Viscosity (20°C),[cp]*	*IFT Brine/Oil [mN/m], (20°C)*
Isopar-M	0.780	2.45	48.75
Marcol 82	0.844	22.05	50.25
Crude A	0.841		23.90

TABLE 5 Rock Properties.

Sample	*K [mD]*	*ϕ [%]*	*Geological Desciption*
A-1b	899	21.7	F/M grain, W-cmt, W-srt, W/O Matrix, Ltl. Mica, With Calcite.
A-3b	832	18.0	M-grain, W-cmt, W-srt, W/O Matrix, Ltl. Mica, With Calcite, Coal.
A-5b	452	17.9	F-grain, W-cmt, W-srt, W/Matrix, Mica, Calcite, Ltl. Clay, Coal.
A-8b	65	16.6	F-grain, W-cmt, W-srt W/Matrix, Mica, Ltl. Calcite, Ltl Clay, Ltl. Coal.
B-1	226	27.9	F-grain, W-cmt, W-srt, Ltl. fracture, with Coal, Clay, Mica.
B-2	74	25.5	Vf/F grain, W-cmt, W-srt, With Mica, Ltl. Clay.
B-4	190	24.5	M/C grain, F-cmt, F-srt, Ltl. Coal, Clay, Mica.
B-5	23	23.1	F-grain, W-cmt, W-srt, Ltl. Clay, Mica.

C-grain:	*Coarse grain*	*M-grain:*	*Medium grain*
F-grain:	*Fine grain*	*Vf-grain:*	*Very fine grain*
W-Cmt:	*Well cemented*	*F-Cmt:*	*Fair cemented*
W-Srt:	*Well sorted*	*F-Srt:*	*Fair sorted*
W/O Matrix:	*With out Matrix*	*W/Matrix:*	*With Matrix*
ltl:	*Litle*		

TABLE 6 Summary of Capillary Pressure Tests

Sample	*Oil*	*Temp. [°C]*	*Pore pressure [Bar]*	*Purpose*
A-1b	Crude	21	0	Effect of wettability on P_c.*
A-3b	Crude	104	1	Effect of wettability on P_c.*
A-5b	Crude	21	0	Effect of wettability on P_c.*
A-8b	Crude	104	1	Effect of wettability on P_c.
B-1	Isopar	98	1	Effect of temperature on P_c.**
B-2	Isopar	98	1	Effect of temperature on P_c.**
B-4	Isopar	98	1	Effect of temperature on P_c.**
B-5	Isopar	98	1	Effect of temperature on P_c.**

* *The capillary pressure curve is compared with capillary pressure curve with a previous paper by the same authors at ambient conditions, (Søndenå et al., 1989).*

** *The capillary pressure curve is compared with capillary pressure curve with a previous paper by the same authors at ambient conditions and reservoir conditions, (Søndenå et al., 1990).*

TABLE 7 Brine Saturations, obtained with a Capillary Pressure of 1 bar, Versus Wettability Index According to the USBM Method.

Sample	*Oil*	*Temp. [°C]*	*S.B.I. % PV*	*S.O.I. % PV*	*WI*	S_w
A-1a*	Live Crude	104	3.3	4.2	-0.18	0.103
A-1b	Marcol	21	31.0	0.0	0.27	0.060
	Crude	21	4.8	0.8	-0.11	0.061
A-3a*	Live Crude	104	4.1	6.0	-0.30	0.091
A-3b	Marcol	104	4.2	5.3	0.05	0.040
	Crude	104	1.6	3.7	-0.09	0.043
A-5b	Marcol	21	44.0	0.0	0.40	0.121
	Crude	21	3.0	6.5	-0.27	0.140
A-8b	Marcol	104	33.0	0.0	0.30	0.136
	Crude	104	3.0	11.0	-0.42	0.144
B-3**	Isopar	21			0.93	
	Isopar	98			0.73	

S.O.I:	*Spontaneous Oil Imbibition*
S.B.I:	*Spontaneous Brine Imbibition*

* *Søndenå et al. (1989)*

** *Søndenå et al. (1990) according to Amott Wettability Test.*

FIGURES

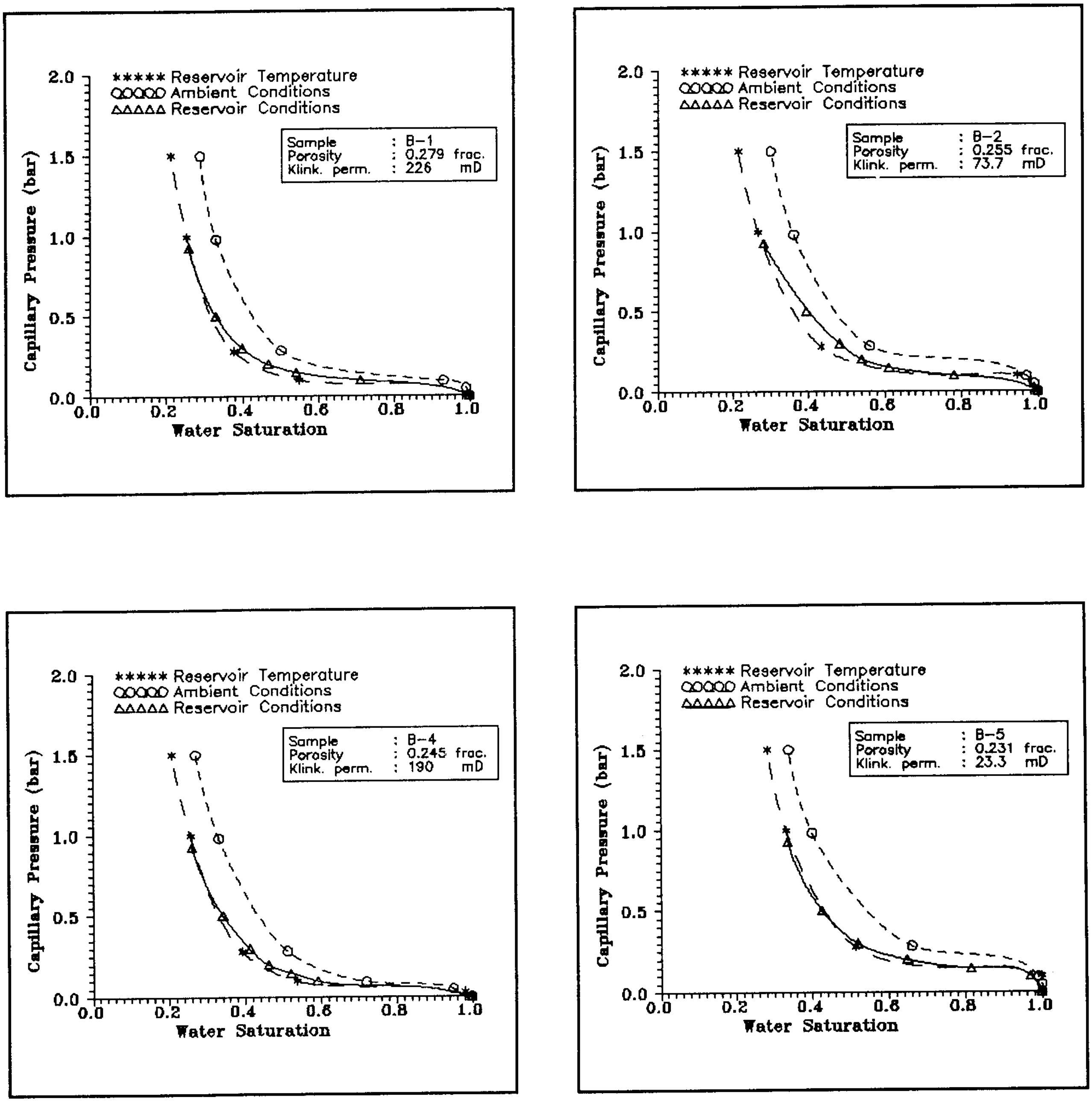

FIGURE 1 Capillary pressure curve at reservoir temperature and ambient pressure for the Reservoir B samples compared to capillary pressure curves from a previous paper by the same authors at ambient conditions and at reservoir conditions (reservoir temperature and pressure), (Søndenå *et al.*, 1990).

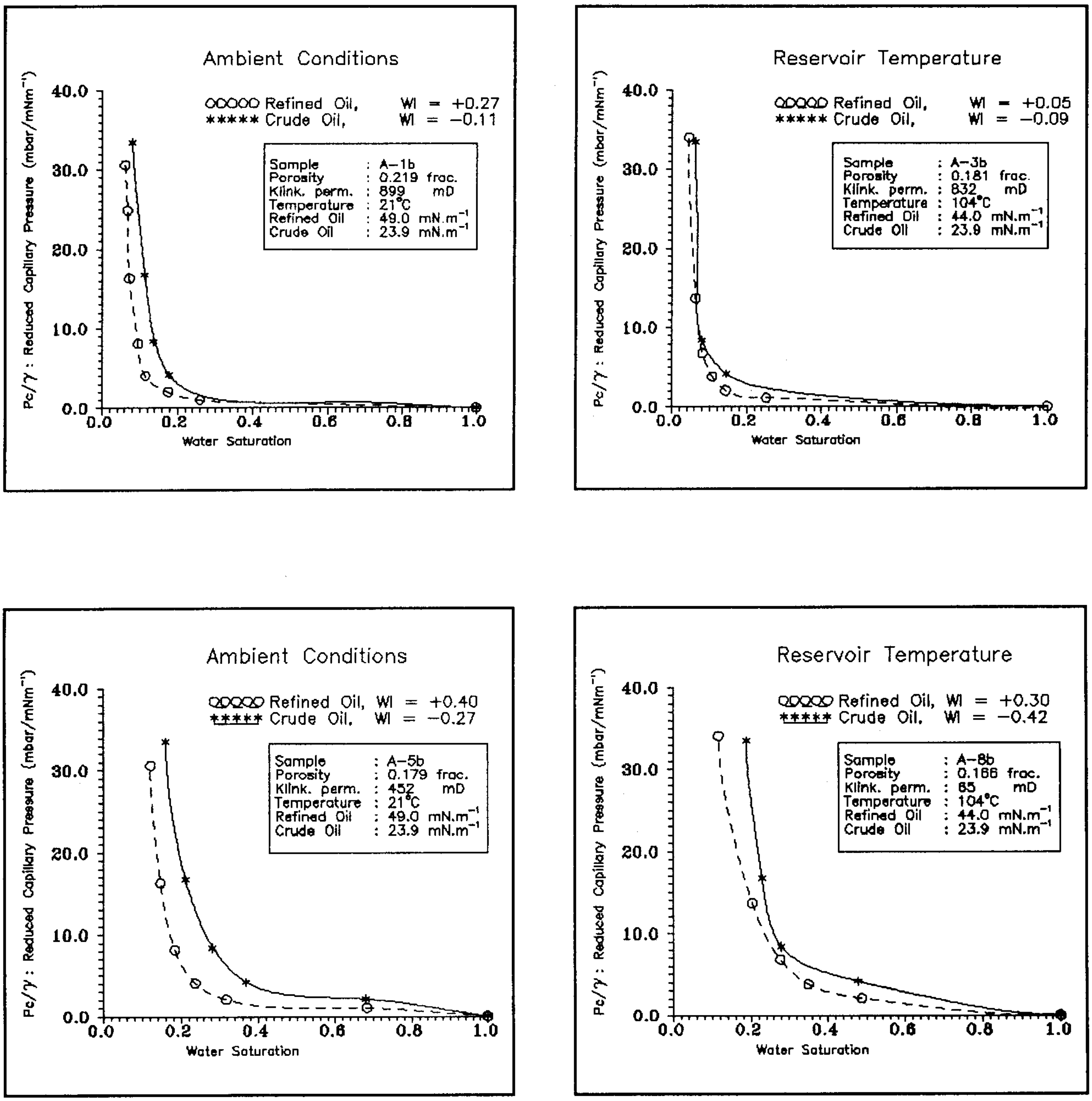

FIGURE 2 Reduced capillary pressure (Pc/γ) curves; crude oil displacing brine compared to reduced capillary pressure curves; refined oil displacing brine, both at ambient conditions. The samples are the same used in a previous paper by the same authors, (Søndenå *et al.* 1989).

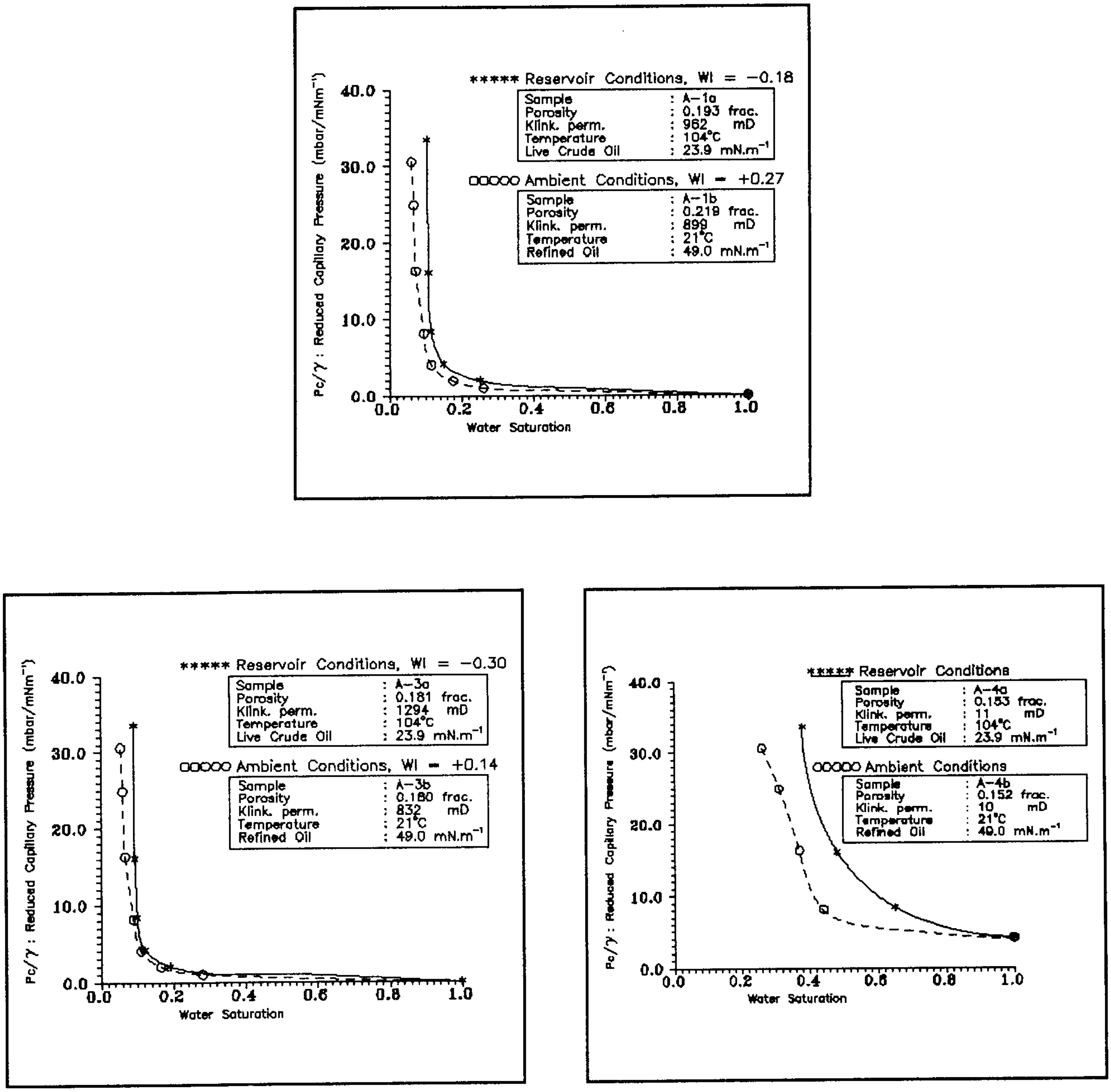

FIGURE 3 **Reduced capillary pressure (Pc/γ) curves from a previous paper by the same authors obtained at reservoir conditions; live crude oil displacing brine compared to reduced capillary pressure curves obtained at ambient conditions; refined oil displacing brine, (Søndenå *et al.*, 1989).**

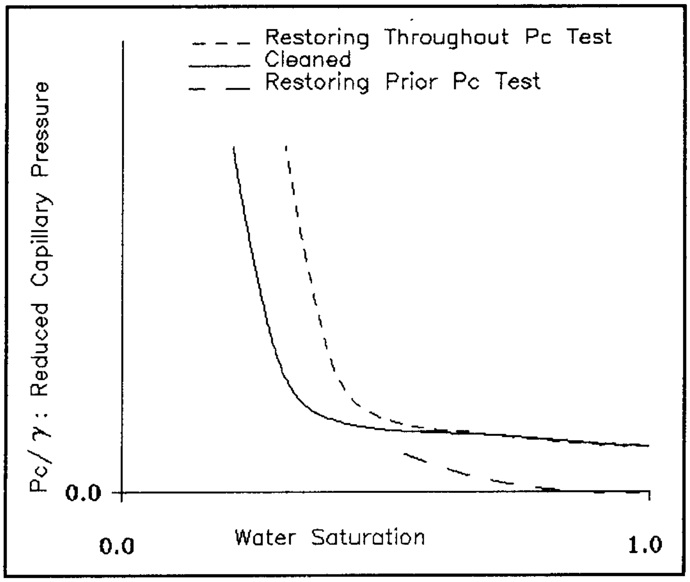

FIGURE 4 A model of a capillary pressure curve of a cleaned sample, a sample restored prior the test and a sample restored throughout the test.