EFFECT OF PROCEDURE ON WETTABILITY INDEX TO WATER

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ABSTRACT

The wettability index to water (Iw) is the ratio of the quantity of water spontaneously imbibed to the total quantity of mobile water. This index is largely used to characterize the wettability of rock reservoirs which is an important factor for the understanding and design of the recovery processes.

This paper presents the results of measurements of Iw on different samples taken at different levels in a limestone reservoir : water zone, transition zone and oil zone. Iw was determined on preserved and cleaned samples at different initial water saturation (Swi). No restoration was conducted. Swi was established by different ways : flooding, centrifugation and porous plate.

When considering a series of determination conducted under identical experimental conditions, Iw's show a consistent variation of wettability from more water-wet to less water-wet when moving up in the reservoir. But Iw is different from one series to another.

This is explained by a decrease of both residual oil saturation (Sor) and quantity of water spontaneously imbibed when Swi increases. These decreases are dependent on wettability and rock structure.

INTRODUCTION

One of the standard procedure for the determination of wettability is derived from the Amott test[1] as proposed by Cuiec[2]. After establishment of an initial water saturation (Swi), the core is immersed in brine and the volume of oil displaced by spontaneous imbibition of water is measured (Qo1). The core is then either flushed with brine or centrifuged in brine and the volume of oil displaced by forced imbibition of water is determined (Qo2). The wettability index to water is defined by :

$$Iw = \frac{Qo1}{Qo1 + Qo2}$$

The core being at residual oil saturation (Sor), it is immersed in oil and the volume of water displaced by the spontaneous imbibition of oil is measured (Qw1). The final step is a forced displacement by flushing or centrifugation with oil which gives a volume of displaced water (Qw2). The wettability index to oil is computed as follows :

$$Io = \frac{Qw1}{Qw1 + Qw2}$$

In the present study, the above described procedure was applied to preserved samples from a limestone reservoir. The results show a consistent variation of wettability : water-wet samples in the transition zone and samples of mixed wettability in the oil zone.

This initial study was carried out at low Swi values which appear to be unlikely in actual reservoirs considering small oil columns height. Therefore we decided to determine the effect of Swi on the wettability index to water. Twin plugs were used and Swi was established either by porous plate technique or by centrifugation.

In view of the discrepancy of the results obtained with dead crude oil, additional testing was carried out using refined oil for comparison purposes.

The paper presents the whole set of results which display the effect of the procedure, and thus of Swi on the wettability index to water, although this study was not a systematic approach.

EXPERIMENTAL TECHNIQUES

Preserved samples

Nine plugs were sampled at different levels, on preserved cores taken with bland water-base mud in a limestone reservoir. These samples were selected in the oil zone, in the transition zone and below the water-oil contact inaccurately defined at the time of the selection.

The plugs were flushed with synthesized formation brine in order to remove the mud filtrate. Swi was then established by flushing the plugs with dead crude oil at an equivalent flow rate of 10 ft/day.

The wettability test was then carried out, the spontaneous imbibition steps being performed at 80°C. Dead crude oil was used for water displacement steps (spontaneous and forced) and Swi and Sor were reached by flushing, at a flow rate equivalent of 10-20 ft/day.

At the end of the wettability test, samples were flooded with isopropanol ; the water content of each plug was determined by Karl Fisher titration in the alcoholic effluent ; then Swi, at which test began, was deduced knowing the displaced volumes in the previous steps.

The Swi were found very low in view of the reservoir configuration.

Additional tests

In order to measure Iw at more representative Swi, some of the previous samples were cleaned by Soxhlet extraction (chloroform and toluene) followed by flooding with a solution of low content in calcium chloride. After drying, they were saturated with brine and centrifuged in dead crude oil at a low capillary pressure about 2 bar (30 psi). Without knowing the correction to be applied to average saturations, capillary pressure was chosen as corresponding approximately to the top of the reservoir. But the obtained average water saturation was actually too high for samples with low permeability, and only the spontaneous imbibition in brine at 80°C was performed on these samples.

Thus, afterwards, the samples were centrifuged again in dead crude oil at higher capillary pressures, up to about 5.5 bar (80 psi) and the wettability index to water was determined, using centrifugation for oil displacement.

Iw was also determined on twin samples at different values of Swi obtained by the porous plate technique used for the determination of the water-oil capillary pressure curves using dead crude oil, up to 3 bar (43.5 psi). The Sor was obtained by flushing with brine at an equivalent flow rate as that used for the tests on preserved samples.

Cleaned samples

Since Iw were different when using preserved samples and cleaned samples, some variation of wettability during laboratory tests was suspected and additional measurements of the wettability index to water were performed on samples on which Swi was established with refined oil after Soxhlet cleaning (chloroform, toluene and ethanol). Either flushing at two different flow rates equivalent to 1 and 10 ft/day respectively or centrifugation were used. The spontaneous imbibition in brine was carried out at 80°C and the Sor was obtained by flushing with brine at an equivalent flow rate as that used in previous tests.

RESULTS

▪ Wettability of the samples

The wettability indexes measured on preserved samples are shown in Figure 1. The results are presented as a function of distance to the water-oil contact. Samples taken near or below the water-oil contact are actually water-wet, with a wettability index to water above 0.9. It should be noted that wettability indexes to oil never reached zero. As sampling moved up from the water-oil contact, an increase of the wettability index to oil and a decrease of the wettability index to water was observed.

These measurements are in agreement with existing values measured on samples located in higher zones of the reservoir which show negative global wettability index (Iw-Io) due to low Iw values. In that case the variation of Iw is more significant than the variation of Io. This is the reason why this parameter was closely examined.

Because of their consistency, these results appeared valid. All along the analysis presented below, samples are classified in the water-zone samples, transition-zone samples and the oil-zone samples. Samples from the water-zone are assumed to be water-wet. It was not tried to compare the results with those that would have been obtained on restored samples because according to our experience and that of others^5 on rocks of close origin, results are generally similar.

Figure 2 compares the values of Iw obtained on preserved samples to those obtained on samples where Swi was established by centrifugation (Iw calculated with average saturations). All the Iw are shifted towards lower values according to a constant value. This constant value appears to vary from one type of test to another. The latter results are in contradiction with the assumption that water-zone samples are water-wet : low Iw were obtained.

In order to clarify this point the differences between the three kind of tests were examined. In the three cases, oil was dead crude oil and spontaneous imbibition step was conducted under identical conditions. The two major differences are the method of establishment of Swi and the initial state of the samples (i.e-preserved and cleaned). Two reasons might explain the observed phenomenon : either wettability of the samples has changed as a consequence of the different treatments for the establishment of Swi or the value of Swi itself has a significant effect on Iw.

▪ Swi establishment

According to the procedure and the structure of the porous network, different values of Swi may be obtained as shown on Figure 3. The reservoir rocks may be classified in one of two very large classes characterized by their schematised capillary pressure curves : type I of relative low permeability (1-5 mD) and type II of higher permeability.

If Swi is established by centrifugation at low capillary pressure, Swi will be very high for type I samples and fair for type II. At higher capillary pressure Swi will be lower for samples of type I than those of type II ; at the same capillary pressure, the average values of Swi for both types will be higher using the centrifuge than those obtained by the porous plate technique. When using flushing at the same constant flow rate for all the samples, Swi for type I samples will be lower because pressure gradient is higher and microporosity content lower.

For example the following values were obtained for two samples :

	Swi, % PV	
	Type I	Type II
Preserved-Flushing (10 ft/day)	13.0	20.2
Porous plate (3 bar)	24.0	34.7
Centrifugation (≃ 2 bar)	62.3	39.4
Centrifugation (≃ 5.5 bar)	38.5	37.7

These considerations establish that wettability tests may be performed with samples of very different Swi values, which result in different Iw as it will be eluted to below.

▪ Centrifugation technique

It appears reasonable to assume that the distribution of Swi is homogeneous inside the sample when established either by flushing or by the porous plate technique. However it is not the case when centrifugation is used. In that case, what happens during the spontaneous imbibition step? Is oil displaced in the low water saturation zone of the sample, even if the average water saturation is high ? This situation may occur if wettability has to be determined on samples from transition zones at the same Swi as they are in the reservoir. The four samples of type I, belonging to the water zone exhibit the following results, when centrifuged at low capillary pressure :

Swi, % PV (average)	Oil displaced by spontaneous imbibiton % PV
77.3	2.7
62.3	12.8
83.9	3.0
93.3	0.0

The forced displacement of oil was not carried out and may be the displaced oil volumes would have been nil, leading to Iw around 1. But these extreme values show that Sor is very low and that it might depends on Swi, thus changing the Iw.

Possible modification of wettability

A possible explanation for the results shown in Figure 2 is a modification of the initial wettability during establishment of Swi, by centrifugation or by the porous plate technique, the samples being immersed for a long time in dead crude oil. This procedure is a kind of wettability restoration process without temperature.

In Figure 4, are reported all the values of Iw as a function of Swi, including those obtained on preserved samples and on samples tested with refined oil which never had been in contact with crude oil, in the laboratory. Results are shown separating out samples of the water zone from samples of the oil zone.

If the assumption of modification of the initial wettability was true, initial water-wet samples from the water zone would have reached the same level of Iw as the one of samples from the oil zone. But this is not the case, as shown in Figure 4, Iw remains higher than 0.5 for samples from the water zone and lower than 0.5 for samples from the oil zone, whatever the value of Swi and the way to establish it. Furthermore, samples issued from the porous plate technique would have been found less water-wet than samples issued from centrifugation since time of contact is several months compared to several days. But as shown in Figure 2, samples issued from the porous plate technique present intermediate Iw between those of preserved samples and those of centrifuged samples. And, as an additional proof of no wettability change, samples tested with refined oil, that were not submitted to cold ageing in crude oil, have the same behaviour as the other samples : according to Swi, Iw vary between 0.6 and 0.9 on samples from water zone, while they remain between 0.15 and 0.4 on samples from the oil zone.

So, it appeared that variation of Iw could not be attributed to a modification of wettability. On the other hand, results reported in Figure 4 clearly show that Iw decreases when Swi increases, for all kind of samples and whatever their treatment. Particularly, samples tested with refined oil present the same variation of Iw with Swi : they are neither more water-wet nor less water-wet than the others. This incidentally demonstrates that cleaning by a Soxhlet procedure is a mild cleaning.

In conclusion, the observed variations of Iw seem to be better explained by an effect of Swi.

Additionally, it should be noted that changing a water-wet sample to an oil-wet sample, at least in this case and without temperature has been unsuccessful.

- ## Effect of the Swi values

All the results, even those obtained by centrifugation but taking into account only average saturations are presented in Figure 5. Shown is the increase of water saturation during spontaneous imbibition and the Sor as a function of Swi for a) three type I samples from the water zone, b) two type I sample from the transition zone, c) one type II sample from the oil zone, d) two type II samples from the oil zone but with permeability six times higher than c) sample.

For all samples, Sor decreases when Swi increases. This was reported by G.W. Davies et al.[3] when they analyze a set of data, in the same range of Swi, on a reservoir of intermediate wettability.

It should be noted that the decrease is different from one sample to another according to wettability and type of rock. The variation of water saturation during spontaneous imbibition decreases when Swi increases but in a lesser extent than the total variation of water saturation, especially for samples from the oil zone. The variation is from 20% down to 10% of pore volume when it decreases from around 35% down to 10% of pore volume for samples from the water zone.

It results from both variation of water spontaneously imbibed and of total mobile water with Swi that Iw varies with Swi. This is schematically presented in figure 6 where gross trend of each case are reported. As a first approximation, Iw will vary with Swi as follows :

Swi, % PV	14	20	30	40	50
Type I water zone	0.98	0.89	0.76	0.67	0.62
Type I transition zone	0.67	0.66	0.61	0.61	0.61
Type II oil zone		0.42	0.30	0.26	
Type II, high permeability, oil zone	0.50	0.42	0.29	0.17	

These results may appear inconsistent with those of Jia et al,[4]. They observed an increase of oil wettability with decreasing Swi values. However there was, between the establishment of Swi and the wettability test, a step of ageing which was proved absent in our case because our purpose was not to change water-wet samples from the water zone to oil-wet samples but to determine the wettability and to explain the observed variations.

In conclusion, the absolute value of Iw is not significant, since it depends largely on the Swi. But its variation is such that, whatever the procedure, water-wet samples still remain recognizable from oil-wet samples. It results that Iw is a strong index of wettability when comparing samples, even if results come from different sources, provided tests are conducted with same-range Swi values, and it is generally the case.

From these results it appears that the best conditions to perform the tests on preserved or mildy cleaned samples is probably at the lowest Swi possible. Perhaps, this is a way to be investigated, in trying to explain why after cleaning, and whatever the cleaning, limestone rocks are generally not found water-wet [5,6]. Obviously, if tests are carried out on restored samples, ageing after strong cleaning has to be done at Swi as close as possible to the Swi in the reservoirs.

CONCLUSIONS

For the type of studied reservoir, limestone of mixed wettability :

1. The absolute value of Iw is not by itself a significant measure of wettability because it depends not only on wettability but also on Swi and rock-type.
2. Despite the above point, Iw remains a strong index of comparison of wettability, provided Swi are not too different.
3. It seems that wettability is better defined at low Swi. In fact, only under these conditions, are samples from water zone found, purely water-wet.
4. Centrifugation is an acceptable method for establishing Swi, but Iw has to be derived only from average saturations.
5. Sor decreases when Swi increases but slopes vary with wettability and rock-type.
6. Changing a water-wet sample to an oil wet sample without increasing the temperature, at least on this type of rock, is unsuccessful.

REFERENCES

1. Amott, E. : "Observations Relating to the Wettability of Porous Rock," Trans. AIME, 216 (1959) 156-62.
2. Cuiec, L.E. : "Evaluation of Reservoir Wettability and Its Effect on Oil Recovery," Chapter 9, in Interfacial Phenomena in Oil Recovery, N.R. Morrow, ed., Marcel Dekker, 1990.
3. Davies, G.W., Gamble, I.J.A. and Heaviside, J.: "Field-Wide Variations in Residual Oil Saturation in a North Sea Sandstone Reservoir," SPE 19851 (1989).
4. Jia, D. Buckley, J.S. and Morrow, N.R.: "Control of Core Wettability With Crude Oil," SPE 21041 (1991).
5. Cuiec, L.E. and Yahya, F.A.: "Wettability of Asab Reservoir Rock : Comparison of Various Evaluation Methods, Role of Lithology," SCA Conference Paper Number 9109 (1991).
6. Lichaa, P.M., Alpustun, H., Abdul, J.H., Wasef, A.N. and Fuseni, A.B.: "Wettability Evaluation of Carbonate Reservoir Rock," in Advances in Core Evaluation III, Gordon and Breach Science Publishers (1993), 327-358.

Figure 1. Wettability as a function of distance to the water-oil contact

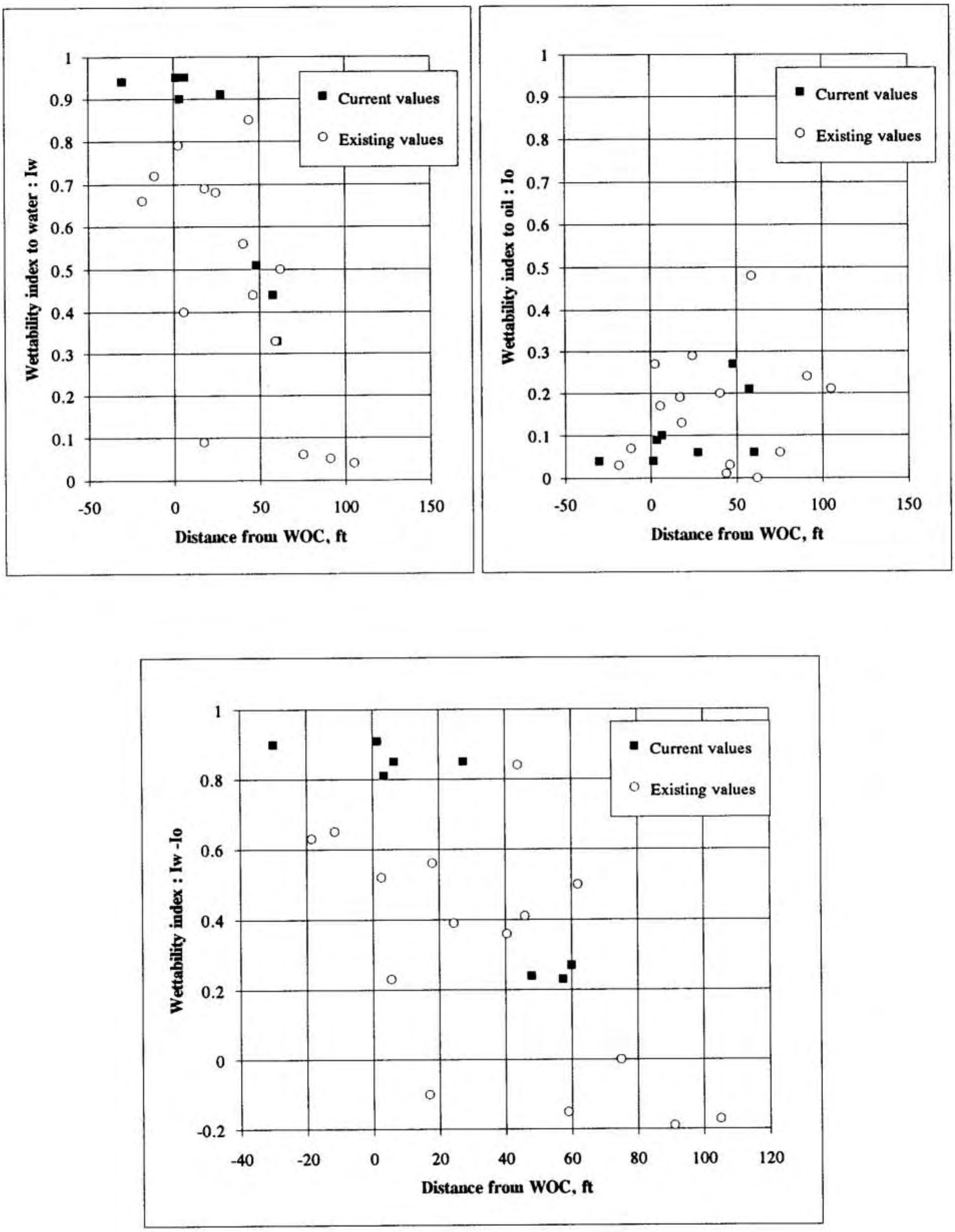


Figure 2. Wettability index to water. Different procedures of Swi establishment.

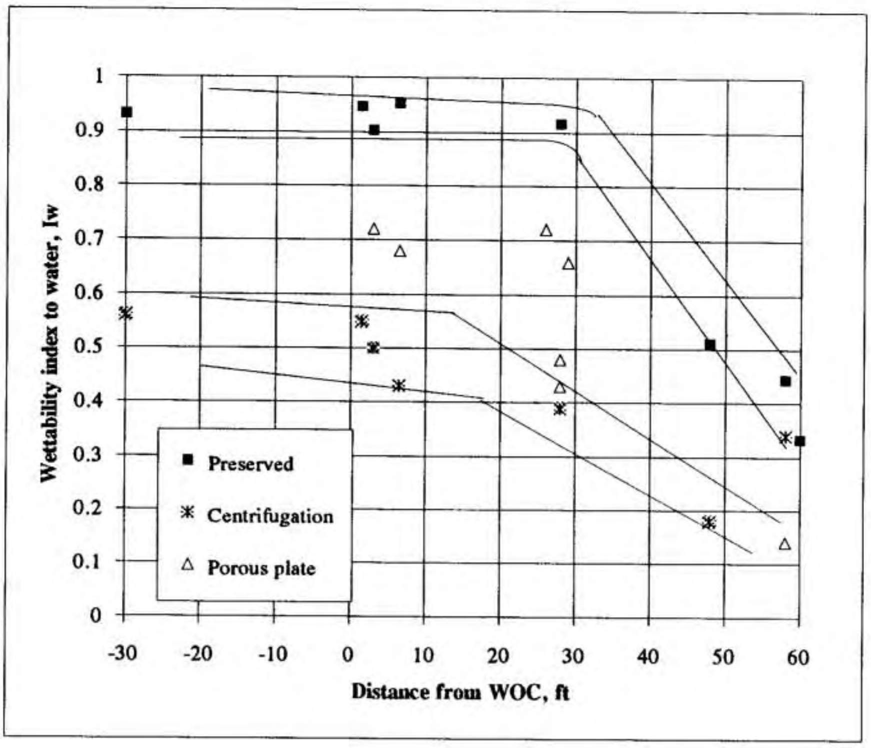
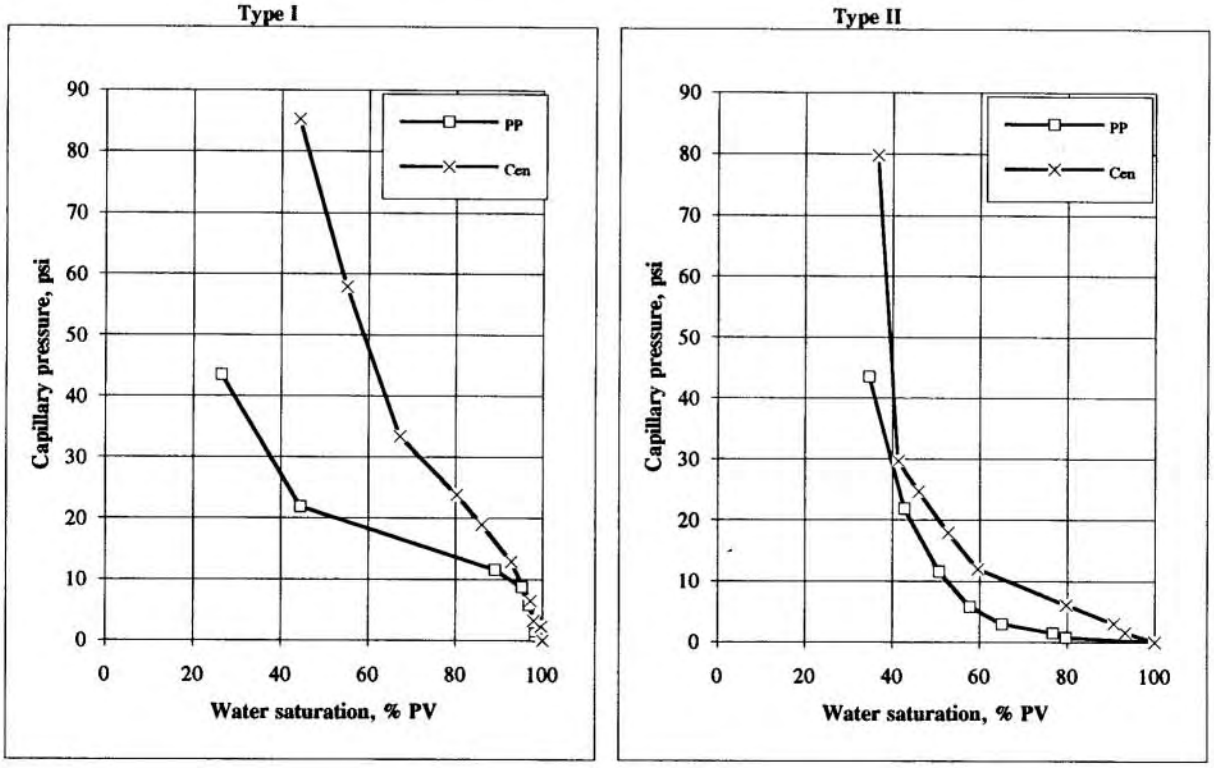
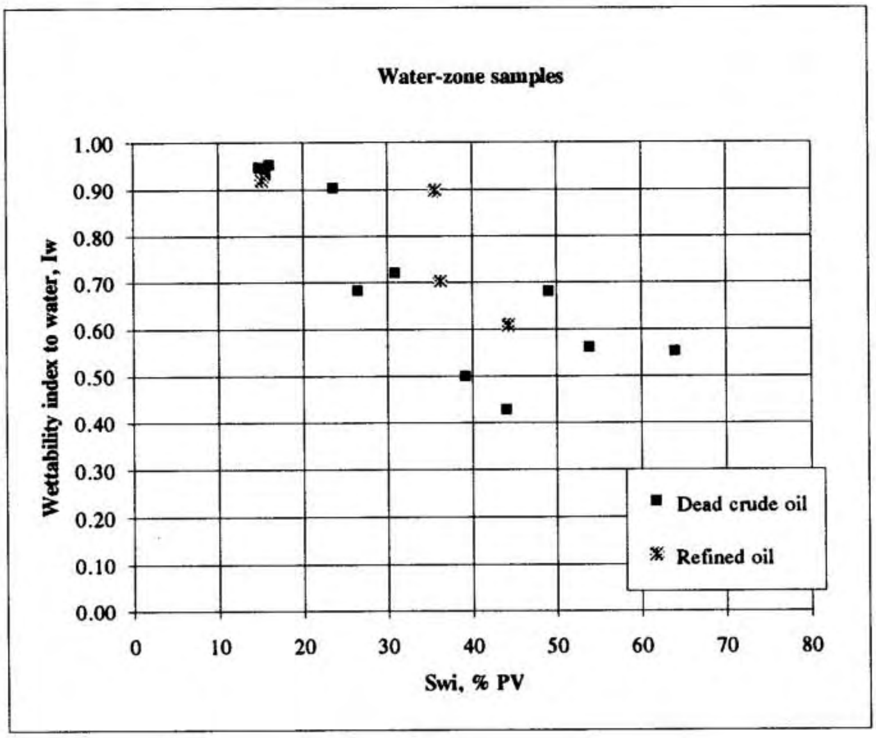


Figure 3. Capillary pressure curves.


Type I

Type II

Figure 4. Wettability index to water as a function of Swi.



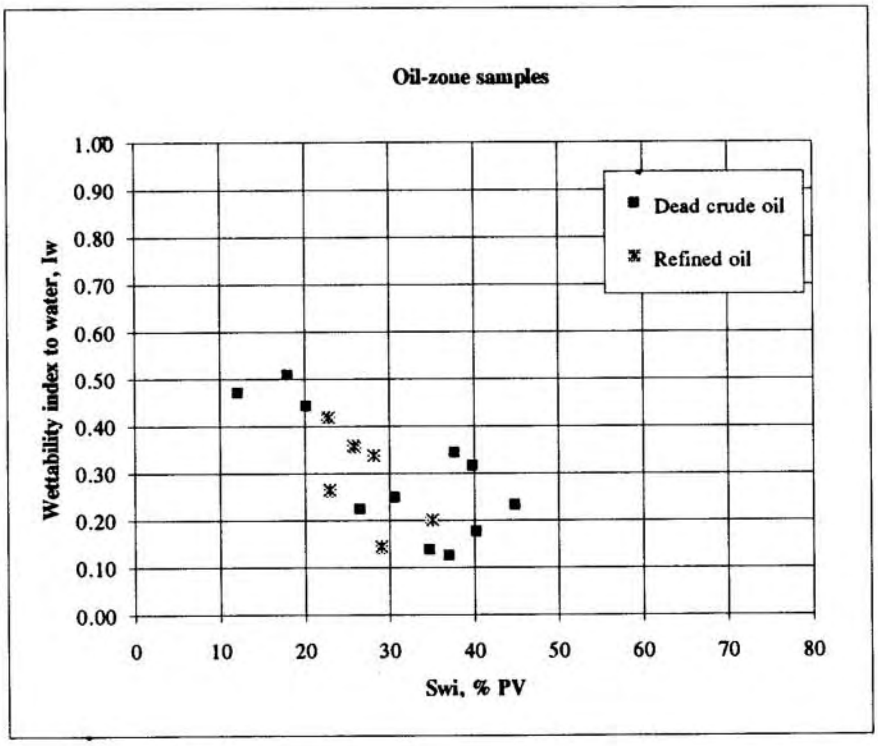
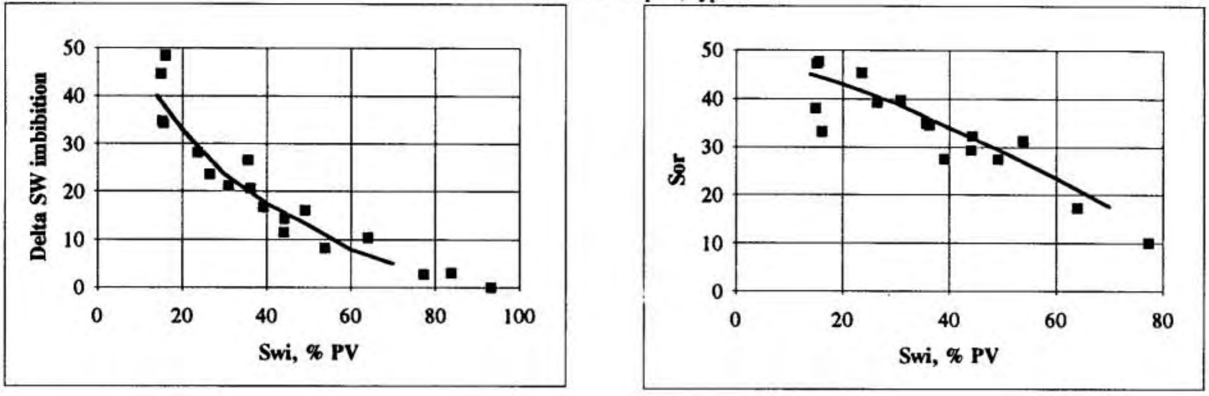
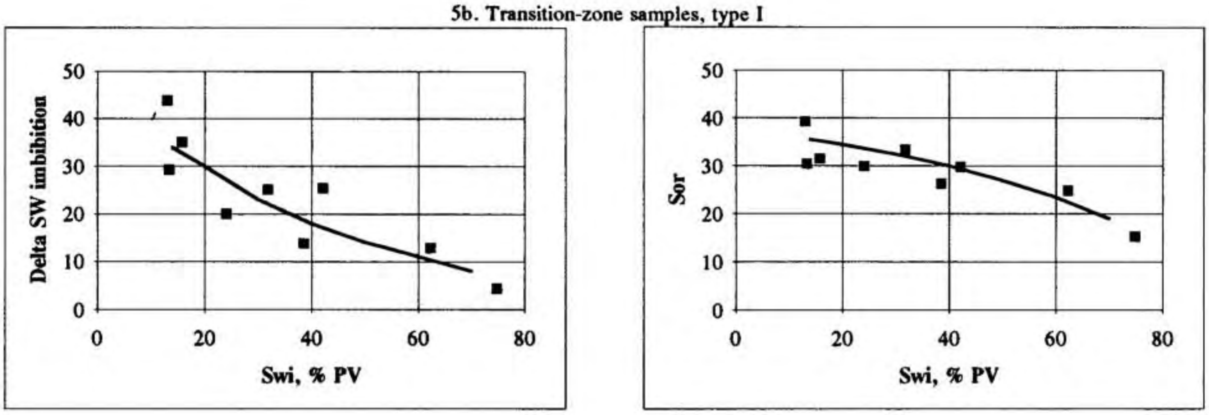


Figure 5. Imbibition water saturation variation and Sor as a function of Swi.

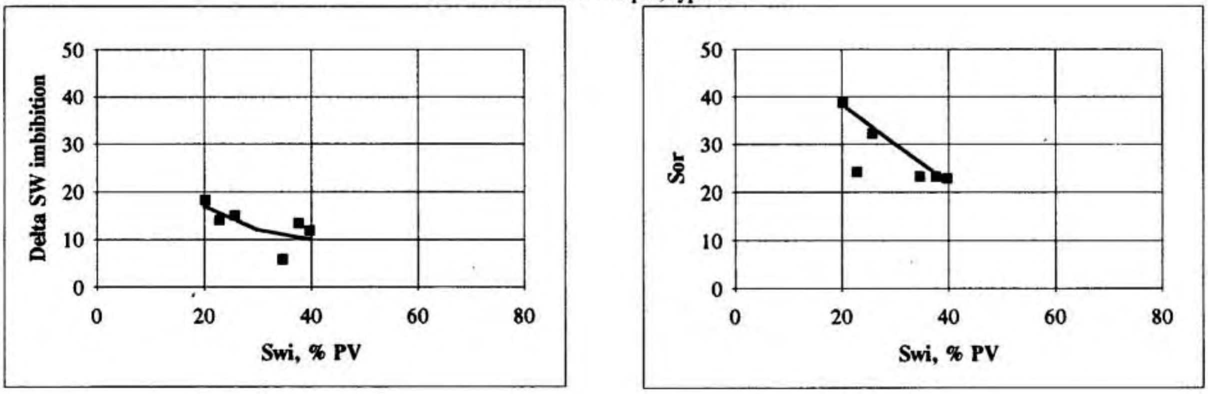
5a. Water-zone samples, type I



5b. Transition-zone samples, type I



5c. Oil-zone sample, type II



5d. Oil-zone samples, type II, high permeabiliy

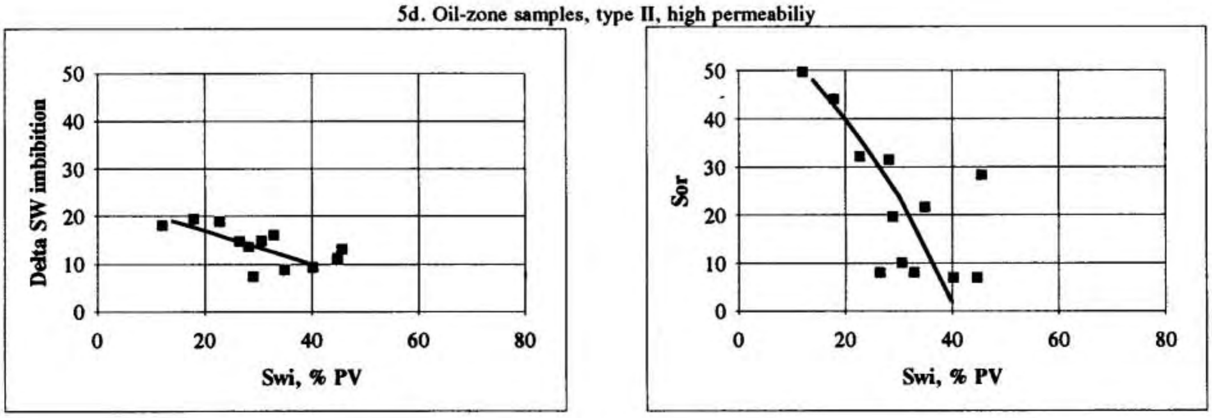


Figure 6. Schematic variation of wettability index to water with Swi.