WETTABILITY STUDY OF IRANIAN CARBONATE ROCKS

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ABSTRACT

Wettability studies have been done on carbonate rock samples from an Iranian oil reservoir using relative permeability curves and Amott tests. The samples were aged at reservoir temperature for 40 days using reservoir fluids in order to achieve the original reservoir wettability. Both Amott and relative permeability tests have been carried out in reservoir temperature. The results for Amott method showed oil-wet behavior for these carbonate samples. Also it is found that relative permeability values cannot be used to predict the wettability of the carbonate samples used in this study due to some discrepancy between end-point values and crossover point saturations.

INTRODUCTION

Wettability is defined as “the tendency of one fluid to spread on or adhere to a solid surface in the presence of other immiscible fluids” [1]. Another definition is based on the contact angle phenomena. It is defined as the contact angle at which a droplet of a liquid in thermal equilibrium meets a horizontal surface. In general, at least one of the two immiscible fluids in a porous medium will be the wetting phase. When the system is in equilibrium, the wetting fluid will completely occupy the smallest pores and be in contact with the majority of the rock surface. The nonwetting fluid will occupy the center of the large pores and form globules that extend over several pores. When the rock is water wet, there is a tendency for water to occupy the small pores and to contact the majority of the rock surface. The term “oil wet” is referred to the rock, which is preferentially in contact with the oil, and oil will occupy the small pores and contact the majority of the rock surface.

Knowledge of the wettability of reservoir rock is important to petroleum engineers and geologists. For example, a waterflood on a strongly oil-wet rock is much less efficient than one in water-wet rock [2]. Until 3 decades ago many engineers assumed that most of the reservoir rocks are water-wet. The reason was the work of Leverett [3] and methodology for determination of the wettability. Treiber et al. [4] states that 64% of carbonate rocks were intermediate-wet, 28% were oil-wet and 8% were water-wet.
Chilingar and Yen [5] evaluated the wettability on 161 carbonate rocks and concluded that

15% of these rocks were strongly oil-wet (contact angle 160-180°), 65% oil-wet (contact angle 100- 160°), 12% intermediate wettability (contact angle 80- 100°) and 8% were water-wet (contact angle 0-80°). Hamon [6] performed some capillary pressure measurements at reservoir conditions, using reservoir fluids and both water-wet and oil-wet semi-permeable membranes. He obtained trends between the amounts of spontaneous imbibition and wettability index to water. Esfahani et al. [7] evaluated wettability for samples of some Iranian carbonate formations using Amott and USBM method. Their experiments were run at 90° C with crude oil and formation water and restored samples. He concluded most of the carbonate samples had intermediate wettability at restored state.

Many different methods have been proposed for measuring the wettability of a system including both quantitative and qualitative methods. Quantitative methods consist of contact angle, Amott and USBM method while qualitative methods include relative permeability curves, reservoir logs, etc. Several factors may cause changes in wettability, so the most reliable results will be achieved while the wettability of the system is similar to that one in the reservoir.

For use in reservoir evaluation wettability measurements performed on native and restored state cores are considered to be most relevant.
Wettability has been determined by quantitative and qualitative methods in the present study. Crude oil and formation water were used and initial water saturation was established in the core before the experiments started. Wettability evaluation was performed using Amott and relative permeability techniques. The samples were restored using crude oil and formation brine at reservoir temperature (83° C).

SAMPLE PREPARATION

Wettability experiments were performed on 5 carbonate samples from one of the Iranian oil wells in which Asmari is the main producing formation. Average porosity is 8% and permeability average 18 md. Core plugs were drilled with brine identical to the formation brine. The first three samples were mostly calcite with only 1-2 % dissolution porosity while samples 4 and 5 were more than 95% dolomite with both inter-granular and dissolution porosity is evident in thin sections. Experiments have been performed on "restored cores" which had a diameter of 3.7 cm and length around 5 cm using reservoir oil and brine while the temperature was kept constant during the experiments by an air bath. After initial preparation a helium porosimeter and an air permeameter were used for porosity and absolute permeability measurements, respectively. Table 1 shows the measured porosity and permeability of each sample.

The following steps have been performed in order to restore the samples:

1) The plugs were saturated with formation water and were aged for 10 days in order to obtain an ionic equilibrium between rock and formation water.

2) The plugs were then flooded with formation water at reservoir temperature in order to measure the absolute water permeability.
3) Plugs were then put in a centrifuge and rotated at constant rpm at reservoir temperature in order to reach to S_{wi}.
4) Plugs were submerged in oil and allowed to age for 40 days at reservoir temperature to achieve the restored state conditions.

Amott test were performed on the samples after preparing them. In addition we used relative permeability curves for qualitative evaluation of wettability as well.

RESULTS

The Amott test is often used for evaluation of oil recovery by spontaneous imbibition from fractured reservoirs. The test is based on the fact that some of the oil is produced under spontaneous imbibition while the core initially is at connate water saturation. Some additional oil could be recovered by forced imbibiton either by centrifuging or by waterflooding. A wettability index to water, I_w, is defined by the ratio of spontaneous increase in water saturation to the total increase. After reaching to residual oil saturation by forced displacement, the cores were tested for spontaneous imbibition of oil followed by measurement of additional oil recovery by forced displacement. The ratio of spontaneously uptake of oil to the total oil displaced gives a wettability index to oil, I_o. Using these two ratios the Amott-Harvey wettability index is calculated as: $WI = I_w - I_o$. A strongly water-wet rock/fluid system would thus have an index of 1 while a strongly oil-wet system would have an index of –1. For the purpose of classification discussion, the wettability index ranging from +1 to –1 was subdivided as follows: water wet (+1 to +0.3), slightly water wet (+0.3 to +0.1), neutral or mixed wet (-0.1 to +0.1), slightly oil wet (-0.1 to –0.3), and oil-wet (-0.3 to –1) [10]. Calculated Amott indices for samples are shown in Table 2. As we can see in Table 2, samples are showing oil-wet behavior. The end-point values and the crossover point saturation of relative permeability curves where $K_{rw} = K_{ro}$ are measures of wettability [8]. For example, in water-oil system, if the crossover saturation is more than 0.5 the system is water-wet and is oil-wet if it is less than 0.5. Also the wetting phase end-point relative permeability will be less than the non-wetting phase end-point. The rules of end point values and crossover saturation are based on the fact that the non-wetting phase occupies the centers of the pores as globules several pore diameter in length, while the wetting phase moves through the small pores. In the present study, relative permeability curves were obtained at reservoir temperature and by using the unsteady state method. Jones and Roszelle [9] graphical technique was used for calculating the relative permeability values. The core holder was placed in a hot air bath where the temperature was controlled during the experiments. Several pore volumes of the reservoir oil were injected to the core in order to measure the relative permeability to oil at the presence of connate water. Relative permeability curves are shown in Figure 1-5. All end points and cross over saturations were shown in Table 3. It is clear that the cross over points are less than 0.5 for all samples which is an indication of oil-wet behavior. However, there is a discrepancy in the end point relative permeabilities where the end points of K_{rw} at S_{or} is less than K_{ro} at S_{wi}.

Cuiec [10] reported similar wettability results based on the Amott procedure where the centrifuging is replaced with forced displacement and measurements of end point relative permeabilities. The relative permeability values can give additional informations about wettability, but it is risky to evaluate the wettability of a reservoir solely from such data [10].

CONCLUSIONS

1. The carbonate samples in this study had oil-wet behavior at reservoir temperature by Amott test.

2. The relative permeability crossover saturations show values less than 0.5 which confirm the results by the Amott test. The end-point relative permeability values show some discrepancy with the Amott test results. Therefore the relative permeability curves alone cannot be used to evaluate the wettability behavior in these carbonates samples.

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Table 1- Petrophysical properties of the samples

Sample no.	Lithology	Porosity %	Permeability (md)
1	Limestone	9.9	23.1
2	Limestone	16.9	32.0
3	Limestone	12.0	17.3
4	Dolomite	24.9	130.2
5	Dolomite	8.16	1.5

Table 2-Amott wettability indices

Sample No.	WWI	OWI	Amott-Harvey index
1	0.26	0.92	-0.66
2	0.3	0.87	-0.57
3	0.25	0.78	-0.53
4	0.34	0.82	-0.48
5	0.25	0.75	-0.5

Table 3- End point values and cross over saturation.

Sample No.	S_{wi}	S_{or}	K_{ro} @ S_{wi}	K_{rw} @ S_{or}	S_w % at $K_{rw} = K_{ro}$
1	15.7	24.3	0.69	0.11	31
2	25.8	31.7	0.95	0.51	39
3	22.7	12.4	0.62	0.39	40
4	18.9	32.7	0.22	0.11	40
5	20.4	31.8	0.82	0.1	39

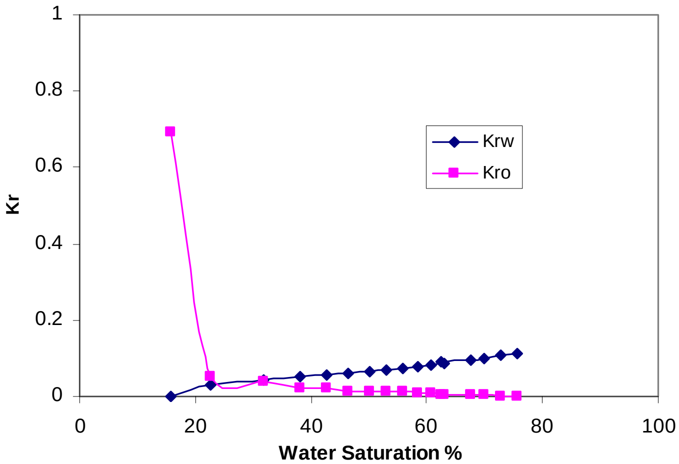

Figure 1- Relative permeability curves for sample No.1

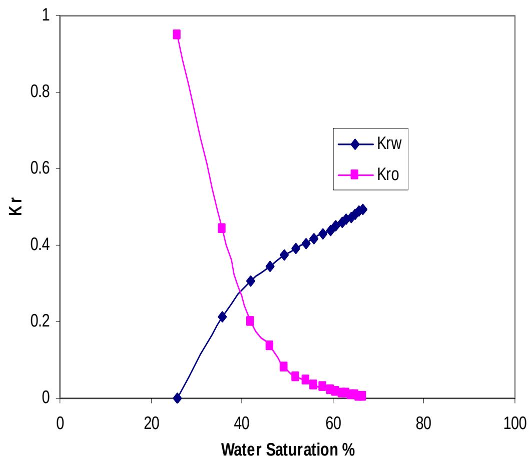

Figure 2- Relative permeability curves for sample No.2

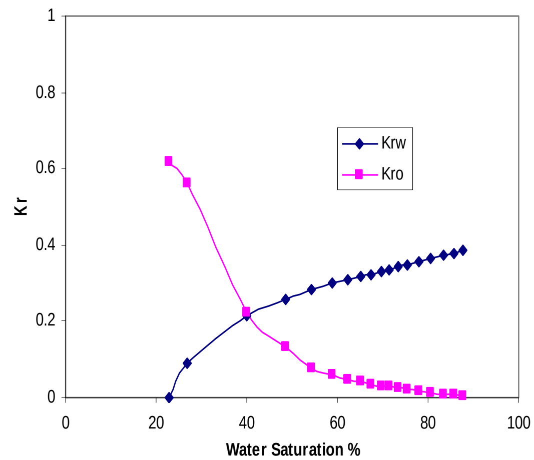

Figure 3- Relative permeability curves for sample No.3

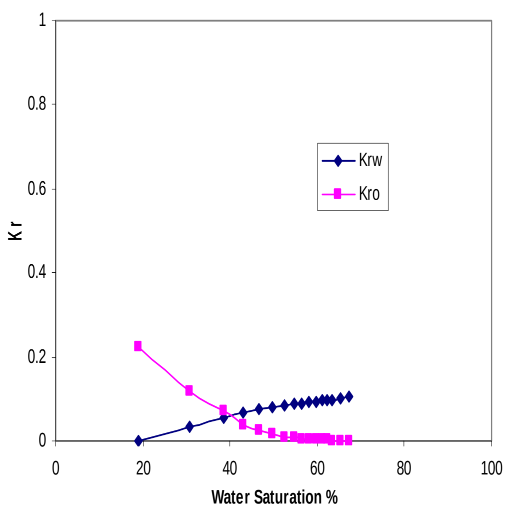

Figure 4- Relative permeability curves for sample No.4

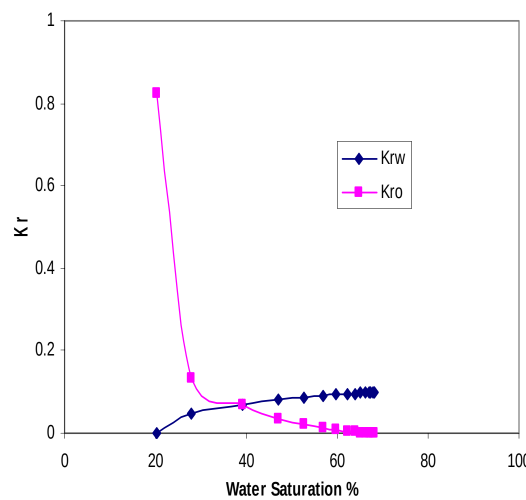

Figure 5- Relative permeability curves for sample No.5