EFFECT OF WETTABILITY ALTERATION ON RELATIVE PERMEABILITY CURVES FOR LOW PERMEABILITY OIL-WET RESERVOIR ROCKS

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ABSTRACT

Wettability conditions control the location, distribution and flow properties of oil and brine through porous media. It is widely recognized that the efficiency increases as the wettability of the uniformly wetted porous medium is varied from oil wet to water wet. A series experiments were conducted for investigating the effect of wettability alteration on relative permeability for oil-wet reservoir sandstones rock with air permeability range from 0.1 millidarcy to 2.0 millidarcy. The unsteady state method with constant pressure was adopted in test, while the brine with different concentration of the thin film spreading agent were injected into reservoir core plugs with 1.0 inch diameter. It is also proved by the measurements of interfacial tension that the thin film spreading agent lower oil water interfacial tension, but not by the three orders of magnitude needed to increase the capillary number sufficiently to recover a substantial amount of incremental oil. The study results indicate that both water and oil relative permeability curves are dependent strongly on wettability alteration. In particular, water relative permeability curves are found to lower as wettability were altered from oil wet to intermediate wet. In addition, the recovery efficiency was improved and the water cut were lowered by injection of thin film spreading agent solution.

INTRODUCTION

The development of low permeability reservoirs (air permeability<10md) is a crucial challenge due to the high injection pressure and low oil production. Many methods had been used for low permeability reservoirs to improve the performance, such as hydrofracturing, surfactant flooding, cycle injection, etc.. It was found that the pores with small radius ($r_a < 1.0 \mu m$) have major fraction in pore volume from pore structure study such as mercury injection. It can be speculated that the small pores dominate the fluid flow and displacement in low permeability porous media, so the capillary forces plays primary role in water oil displacement. It should be remembered that in water-wet systems capillary forces assist water to enter pores, whereas in the oil wet case they tend to prevent water entering pores. So the wettability alteration from oil wet to water wet or to intermediate plays a beneficial role to lower the injection pressure and enhance oil recovery. Although there had many works on the chemicals synthesis and wettability alteration experiments, there is little work on the relative permeability before and after wettability alteration.

The major goal of this work is to study the relative permeability of the water and oil phase before and after wettability alteration from oil wet to water wet or intermediate wet by the addition of DBA, a thin film spreading agents. For this purpose, in addition to relative permeability measurements, we also conducted interfacial tension tests and Amott wettability test to demonstrate the effect of wettability alteration. In this paper, we first present the experimental procedures. Then the results of relative permeability tests were discussed.

EXPERIMENTS

Reservoir sandstone core samples from Changqing Oilfield in west of China with air permeability range from 0.1 to 1.2 millidarcy were used in all tests. The diameter of cores were 1.0 in. and the length about 3.0 in.. It was found that these core samples were oil wet by Amott test previously. The properties of core samples were listed in Table 1.

Table 1. Summary of Sample Properties

Well No.	Sample No.	DBA Concentration	ϕ (%)	k_a (md)	S_{iw} (%)	η_f (%)	S_{or} (%)	S_c (%)	Amott Index
Xi119	3-9		14.5	1.06	31.3	10.9	37.3	31.5	-0.71
	3-11	100mg/L	14.8	1.11	26.3	15.2	28.5	45.2	-0.38
Xi129	1-13		11.0	0.352	31.9	28.1	16.2	51.9	-0.52
	1-14	300mg/L	11.0	0.256	27.9	37.8	15.2	56.9	-0.16

The oil used in these studies were light crude oil from Changqing Oilfield with viscosity of 2.1~2.3mPa.s. Synthetic brines were prepared to approximate the corresponding native brines. The brine compositions and characteristics are listed in Table 2.

Table 2. Summary of Formation Brine

Brine Composition（mg/L）								Salinity
$Na^{+}+K^{+}$	Ca^{2+}	Mg^{2+}	Ba^{2+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	CO_3^{2-}	g/L
19249	2460	317	876	35220	0	308	0	58.43

DBA, a thin film spreading agents, manufactured by EOR Department, RIPED (Research Institute of Petroleum Exploration and Development, PetroChina), were used in all tests. Interfacial tension measurements were made on the crude oil to synthetic brine with different DBA concentration by the spinning drop technique. The values of interfacial tension were listed in Table 3. It was found that the interfacial tension were reduced from 34mN/m to 1.14mN/m by the adding of DBA chemicals, but the reduction magnitude was not as significant as in surfactant flooding or Alkaline-Surfactant-Polymer compositional flooding, where the interfacial tension decreased several orders of magnitude to as low as 10^{-3}mN/m. Increasing the DBA concentration from 100mg/L to 400mg/L had some effect on interfacial tension reduction.

Table 3. Result of interfacial tension test

DBA Concentration (mg/L)	0	100	200	300	400
Interfacial Tension (mN/m)	34	3	1.8	1.6	1.14

The cores were evacuated with vacuum pump to less than 5 mmHg and saturated with brine. Crude oil was injected to establish the irreducible water saturation until no more brine was produced. Typical irreducible water saturation were 25% to 35%. Then the cores were aged for two weeks at simulated reservoir temperature 65^{o}C for wettability restoration.

The relative permeabilities were measured with unsteady state method under constant injection pressure equal to 15 MPa. For original relative permeability tests, synthetic brine was injected into core plugs. For compared test, synthetic brine with different DBA concentration was injected into core plugs. The relative permeability curves were calculated by JBN method. The schematic of the apparatus for coreflooding tests were neglected for simplicity.

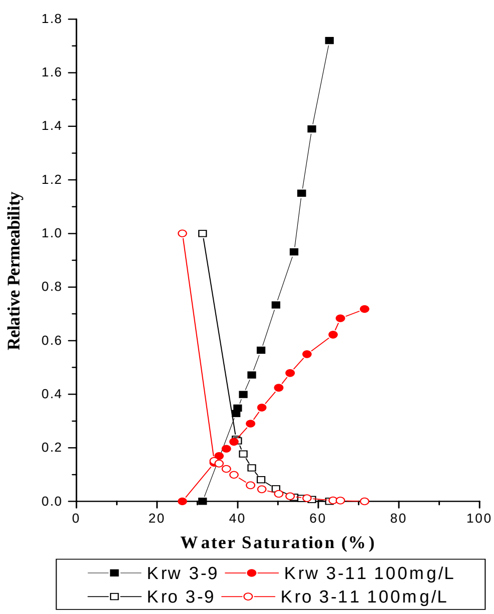
RESULTS

The summary of relative permeability test was listed in Table 1. The symbols S_{iw}, η_f and S_{or} denote the irreducible water saturation, water-free oil recovery and residual oil saturation respectively. The water oil mobilization saturation S_c were defined as

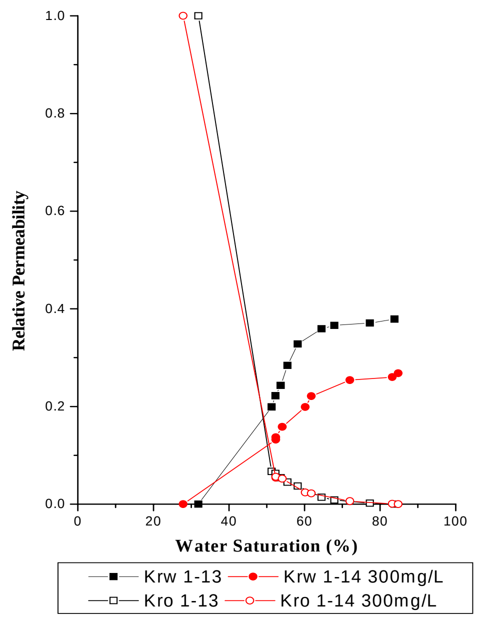
$$S_c = 1 - S_{iw} - S_{or} \tag{1}$$

It is well understood that high water oil mobilization saturation S_c means both phase had well flow capacity at wide water saturation. This is much preferable especially for low permeability sandstones.

It is well known that unsteady state method is very sensitive to viscous fingering and heterogeneity especially for very low permeable plugs. The drawbacks of unsteady state method for low permeable oil wet core plugs is a great challenge and remain controversial. In this work, we present only four representative results from more than 20 relative permeability tests. These four relative permeability curves were presented in two groups. The samples in one group were from same layer and same well, one for original relative permeability test and another for test by wetttability alteration agents.



a. Well Xi-119

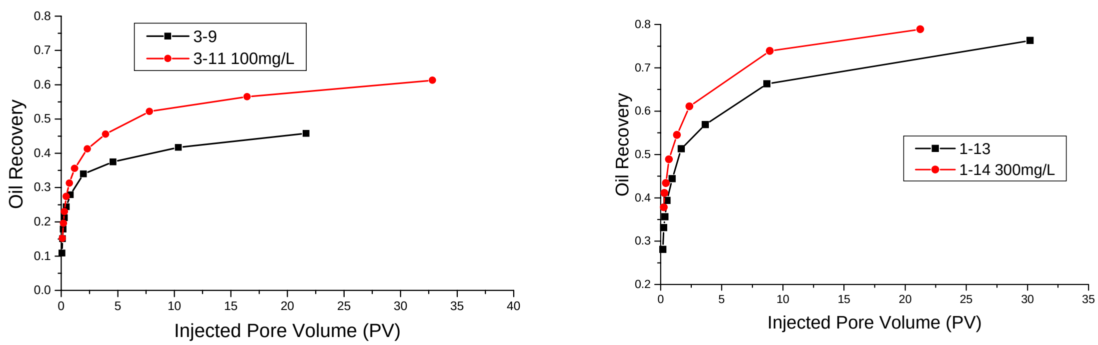


b. Well Xi-129

Figure 1. Relative permeability result for Well Xi-119 and Xi-129

The results from Well Xi-119 and Well Xi-129 were depicted in Figure 1.. Core plugs of 3-9 and 1-13 were flooded by brine, while core plugs of 3-11 and 1-14 were flooded by DBA solution. For Well Xi 119, it is surprise to see that the relative permeability to water at residual oil saturation was greater than 1, i.e., the permeability to water at residual oil saturation was greater than the permeability to oil at irreducible water saturation. It was well accepted that the relative permeability to water at residual oil saturation for oil wet systems was greater than for water wet systems, even approach to unity. But the phenomenon where the relative permeability to water at residual oil saturation was greater than unity was very rare.

It was found that after wettability alteration, the relative permeability to both water and oil were reduced with different extent. The relative permeability to water phase were lowered much than for oil phase. For core plugs 3-11 in Well Xi-119, the relative permeability to water at residual oil saturation was lowered to less unity.



a. Well Xi-119 b. Well Xi-129

Figure 2. Oil Recovery versus Injected Volume

Figure 2. show the comparisons of runs made with and without DBA solution added to the injection brine. In all test more than 20 PV brine were injected into plugs. For both well Xi-119 and well Xi-129, the oil recovery for samples with DBA was much higher than for samples without DBA at same injected volume.

The Amott wettability test results were presented in Table 1. According to the definition of Amott wettability index, the system was oil wet when wettability index range from -1.0 to -0.3. When the wettability lies between -0.3 to 0.3, the system was neutral wet or intermediate wet. The results indicate that the wettability were altered from oil wet to neutral wet by injection of DBA solutions. But the wettability alteration was not as strong as supposed to water wet.

Although the wettability were alter only to intermediate wet, it is still interesting to find some consistent changes in overall properties from the coreflooding tests, listed in Table 1. It can be concluded as below:

1. The water-free oil recovery was enhanced by wettability alteration. For example, in well Xi-119, η_f was improved from 10.9% to 15.2%.
2. The residual oil saturation was decreased by wettability alteration. The results indicate that the residual oil saturation will be decreased with the range from 1% to 9%.
3. The water oil mobilization saturation was extended with the range from 4.4% to 14%. This modification is very important for low permeability reservoirs.

CONCLUSION

The work presented in this paper has established that in low permeability oil wet systems, the alteration of wettability from oil wet to intermediate wet by addition of some thin film spreading agents may modify the relative permeability distinctly. The integrated modifications were promising for improved oil recovery especially for low permeability reservoirs.

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