IMPACT OF A NOVEL SCALE INHIBITOR SYSTEM ON THE WETTABILITY OF PALEOZOIC UNAYZAH SANDSTONE RESERVOIR, SAUDI ARABIA

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ABSTRACT

Central Arabia oil field was developed and oil production started in August 1994. The main producing reservoir is Paleozoic Unayzah sandstone reservoir. Water injection started in early 1995, using peripheral water injection pattern to maintain reservoir pressure. A decline in oil production was noted in some wells and attributed to the formation of calcium carbonate scale. The scale was covering gravel pack screens, pump intake and the impellers of submersible pumps.

A novel scale inhibitor treatment was developed to mitigate the scale in this field. An emulsified-type scale inhibitor (phosphonate-type) treatment was developed and successfully applied in more than 35 wells.

The objective of this work is to assess the impact of the emulsified scale inhibitor on the wettability of the sandstone reservoir. Extensive laboratory studies were conducted to evaluate wettability behavior before and after scale treatment. The effect of the scale inhibitor on oil/brine interfacial tension (IFT) was also investigated. Preserved core plugs from Unayzah reservoir were used in Amott wettability tests. Natural rock plates and pure quartz crystals were used as solid substrates in contact angle measurements to evaluate wettability at reservoir conditions (T = 90 ^{o}C and P = 2,500 psi).

Amott results revealed no significant changes in wettability indices/state before and after the addition of the scale inhibitor. Amott-Harvey wettability index ranged from 0.19 to 0.5 for samples tested without inhibitor and from 0.12 to 0.49 for those tested with the scale inhibitor. These indices reflect slightly to water-wet characteristics of tested core plugs. Contact angle data showed that rock plate and quartz crystal surfaces become more water-wet (positive alteration) by addition of the scale inhibitor. Results of IFT for both oil-brine and oil-scale inhibitor systems indicated that addition of scale inhibitor leads to 20% decrease in IFT values at reservoir conditions. Positive wettability alterations and reduction in IFT highlighted an unexpected benefit of using scale inhibitors (phosphonate-type) to mitigate scale in sandstone reservoirs. This paper will discuss various techniques used to measure wettability and relate lab data with field results.

INTRODUCTION AND BACKGROUND

Wettability of hydrocarbon reservoirs has a profound effect on oil production in oil fields, which are being produced by waterflood and water-drive mechanisms. Therefore, it is necessary to determine the preferential wettability of the reservoir, whether this be to water, or oil or somewhere between two extremes i.e. intermediate. The importance of wettability has been realized by a number of researches when water-driven systems were evaluated (Amott, 1959; and Donaldson et al., 1969). Due to this importance, many reviews of wettability and its effect on oil recovery have been published (Cuiec, 1991, and Buckley, 1998).

In Saudi Arabia, oil production from Unayzah sandstone reservoir started in August 1994 and shortly thereafter in 1995 a peripheral water injection was started to maintain reservoir pressure (2,500 psi). Many of the oil wells started producing wet crude shortly after oil production started. In 1998, decline in oil production of some wet wells was noted. This decline was attributed to scale formation, which was found covering the producing gravel pack screens, pump intake, and on the impellers of the electrical submersible pumps. R&D scientists introduced the most effective scale inhibitor (diethylene triamine pentamethylene phosphonic acid or DTPMP) to prevent scale formation and more than 35 wells were successfully treated (Nasr-El-Din et al., 2003).

This study was conducted to assess the impact of the emulsified scale inhibitor on the wettability of the Unayzaah sandstone reservoir. Extensive laboratory tests were conducted on preserved core materials recovered from Unayzah reservoir evaluate wettability behavior before and after scale treatment. The effect of the scale inhibitor on oil/brine interfacial tension (IFT) was also investigated.

EXPERIMENTAL APPROACH

Fluids and Material

The scale inhibitor used is DTPMP. The recipe consists of 30 vol% diesel phase (water-in-oil) and 70 vol% aqueous phase. The aqueous phase consist of 47 vol% of calcium chloride (8 wt% $CaCl_2$), 47 vol% scale inhibitor (penta-phosphonate as received) and 6 vol% HCl (31 wt%). Stock tank crude oil samples produced from Unayzah reservoir represented the oleic phase. Synthetic brine was prepared based on geochemical analysis of the produced water, and filtered through 0.2 μm filter paper. Chemical analysis of synthetic brine and scale inhibitor mix with brine are shown in Table 1.

Preserved core plugs from Unayzah reservoir were used in Amott wettability test. Pure quartz plates and natural rock plates were used as solid substrates in contact angle measurements to evaluate wettability using contact angle method.

Amott Wettability Test

Wettabilities of preserved core plugs were measured by modified Amott method (Amott, 1959). The samples were flushed with brine to establish immobile oil saturation. The Amott test compares the quantity of oil or brine that spontaneously enters the core (spontaneous imbibition) with the amount of oil or brine that can be forced into the core (dynamic imbibition). The displacement volumes (both spontaneous and total) are measured for both oil and water. The ratio of the spontaneously displaced volume to the total displaced volume is calculated for both the oil and water phases. The Amott-Harvey wettability index is the displacement-by-water ratio minus the displacement-by-oil ratio.

Contact Angle Test

The contact angle measurements were made with Unayzah reservoir oil-brine/rock and oil-brine/rock quartz systems at reservoir conditions (90 ^{o}C and pressure of 2500 psig). Contact angles were measured on a smooth substrate using pendent drop apparatus. The system permitted measurements of the angle made by an oil drop pending on the brine-solid interface. Quartz was chosen since it represented the major component of Unayzah reservoir.

Interfacial Tension Test

The pendent-drop tensiometer was used to determine the IFT of oil/brine interface. Detailed procedure of IFT measurement could be obtained in work published by Okasha, T. M. (2004).

RESULTS AND DISCUSSION

Amott Wettability Results

Samples selected for the Amott tests were flushed with synthetic brine (200-300 cm^3) to remove drilling fluid contaminants and to establish residual oil saturations. Wettabilities of preserved core plugs were measured by a modified Amott method using dynamic flow-through displacement (Amott, 1959). The method combines spontaneous imbibition and dynamic displacement performed under ambient conditions with simulated formation brine or scale inhibitor and stock tank oil. If a sample spontaneously imbibes only brine, it is considered water wet. Similarly, if it imbibes only oil, it is considered oil wet. If the sample imbibes neither, it is described as neutrally wet. The modified Amott-Harvey index combines oil and water indices into a single wettability index that varies from +1 for strongly water wet to –1 for strongly oil wet.

Amott wettability data and wettability state for samples tested with synthetic brine only and with scale inhibitor are listed in Tables 2 and 3, respectively. The wettability results, in Tables 2 and 3, indicated that samples tested with brine were slightly to water-wet in character Amott varied between 0.19 to 0.5. The Amott index for samples tested with scale inhibitor changed from 0.19 to 0.49 which reflect slightly to water-wet characteristics. The distribution of wettability index with depth is shown in Figure 1. The figure indicates that Unayzah core material tended to be water-wet in character with a tendency for increasing water-wet characteristics with depth. It also shows that in most cases samples tested with scale inhibitor reflected less water-wet characteristic than those tested with brine only.

Contact Angle Results

The contact angle is a measure of the relative strength of adhesion of fluids to solid. It is commonly used to measure the wetting properties of the solid surface with respect to two immiscible fluids. It has a major influence on the hydrocarbon distribution as well as water within reservoir rock. The range of contact angles has been rather arbitrarily divided into three regions. From 0 to 75^o is termed water-wet, 75 to 105^o neutrally-wet, and 105 to 180^o oil-wet.

In this study both pure quartz plate and natural rock plate were used as substrates in contact angle measurements. The plots in Figure 2 showed the effect of temperature and scale inhibitor on contact angle values for both systems. Plots in Figure 3 indicate a general trend of little increase in contact angle values with increase of temperature for both systems. It is seen that addition of scale inhibitor decreases contact angle values for both systems. The range contact angle (79 – 82^o) for Unayzah oil-brine/rock system reflects neutral wetting behavior. Addition of scale inhibitor decreases the range of contact angle (64 – 70^o), which alters wettability positively to water wet behavior.

The results obtained from Amott and contact angle methods are in agreement. Both methods indicated that no significant changes in wetting conditions after adding scale inhibitor (DTPMP). Moreover, there is a positive wettability alteration due to change of wetting character from neutral state to water-wet behavior as could be observed from contact angle values (Figure 3). The insignificant changes of the contact angle after addition of scale inhibitor is due to low adsorption of scale inhibitor chemicals on sandstone surface. Also control of pH values higher than 8 helps in stability of wetting conditions. These findings are in agreement with results and observation published by Guan et el., 2003. They examined changes in surface wettability in a series of static scale inhibitor (DETPMP) adsorption tests using environmental scanning electron microscopy (ESEM) and they reported insignificant change of wetting characteristic on micro-scale.

Interfacial Tension Results

The interfacial tension (IFT) between Unayzah oil and synthetic brine was measured at various temperatures (up to 90^{o}C) and reservoir pressures (2,500 psia). Figure 2 shows plots of IFT versus temperature for oil/brine system and oil/scale inhibitor system, respectively. The plots indicate a general trend of increasing IFT with increase of temperature. Comparing plots in Figure 3 indicates that adding scale inhibitor to brine reduces IFT values oil/scale inhibitor system. For example, at temperature of 75 ^{o}C the IFT value of oil/brine system was 20.5 dyne/cm at 2,500 psia; while for oil/scale Inhibitor system decreased to 16.4 dyne/cm at the same pressure. The reduction of IFT as a result of adding scale inhibitor will lead to improvement in oil relative permeability and consequently in oil recovery. The decrease of IFT values at higher temperature can be attributed to the weakening of intermolecular forces at the oil/brine interface. These results are, in general, consistent with results published by Hjemeland and Larrondo, 1983.

It can be stated that the developed emulsified scale inhibitor system by R&D Center to mitigate scale in Unayzah reservoir leads to more water-wet conditions, which may help to explain successful field treatments in more than 35 wells.

SUMMARY

1. Amott wettability results showed that ranges of Amott indices for samples (Unayzah reservoir) tested with brine and samples interacted with scale inhibitor varied from 0.19 to 0.5 and from 0.12 to 0.49, respectively. This indicates no significant changes in wettability conditions for samples interacted with scale inhibitor. The wettability conditions of core plugs were slightly to strongly water-wet.
2. Contact angle data showed that rock plate and quartz crystal surfaces become more water-wet (positive alteration) by addition of the scale inhibitor.
3. Contact angle values for both oil-brine and oil-scale inhibitor systems increased with increasing temperature.
4. Interfacial tension (IFT) results indicated that addition of scale inhibitor leads to a considerable decrease in IFT values at reservoir conditions.

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Table 1- Chemical analysis of synthetic brine and scale inhibitor solutions.

Variable	Synthetic Brine (mg/l)	Scale Inhibitor (mg/l)
Sodium	2579	2714
Chloride	4266	4469
Sulfate	1620	1740
Bicarbonate	178	113
Magnesium	89	92
Calcium	750	771
Total Dissolved Solids	9482	9899

Table 2- Amott wettability indices and wettability state for samples tested with brine.

Sample No	Amott Wettability Index		Amott-Harvey Index	Wettability State
	To Oil OWI	To Brine WWI		
1	0.00	0.19	0.19	Slightly water-wet
2	0.00	0.50	0.50	Water-wet
3	0.00	0.35	0.35	Water-wet
4	0.00	0.20	0.20	Slightly water-wet

Table 3. Amott wettability indices and wettability state for samples tested with scale inhibitor.

Sample No	Amott Wettability Index		Amott-Harvey Index	Wettability State
	To Oil OWI	To Brine WWI		
5	0.00	0.49	0.49	Water-wet
6	0.00	0.32	0.32	Water-wet
7	0.00	0.19	0.19	Slightly water-wet
8	0.01	0.13	0.12	Slightly water-wet

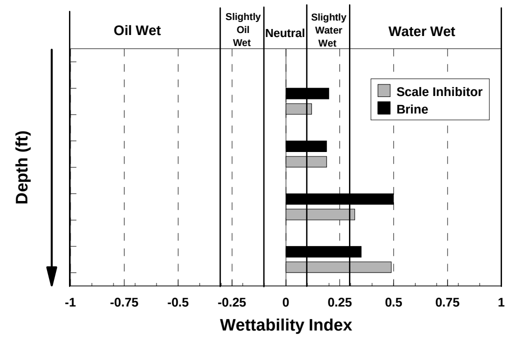

Figure 1- Amott wettability indices distribution.

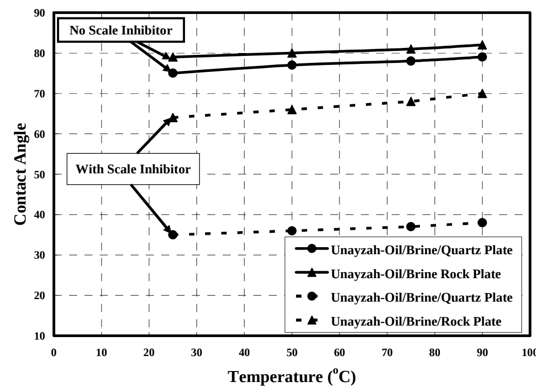

Figure 2- Effect of temperature and scale inhibitor on contact angle at reservoir pressure (2500 psi).

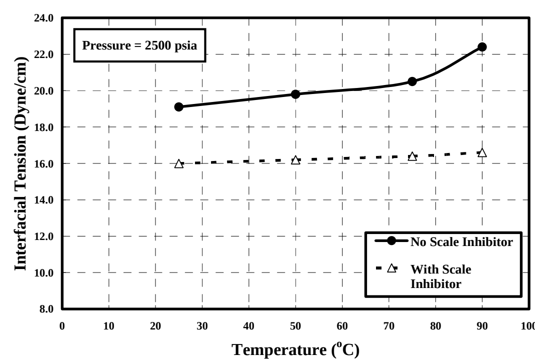

Figure 3: Effect of temperature and scale Inhibitor on IFT for oil/brine system.