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Study on interfacial tension of surfactant and its oil displacement performance

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Abstract. Tuha oil field is located at the Turpan basin in China. Currently, the water content of the main reservoir of the section Y-6 of the Tuha oil field is more than 93% and the recovery rate is less than 20%. At present, an efficient oil displacing agent must be selected for this oil field, which can be used in reservoirs with a high degree of mineralization. Based on the results of experiments measuring the interfacial tension of the surfactant solution and oil, a non-ionic surfactant was selected. Non-ionic surfactant can reduce interfacial tension to the ultra-low level (10^{-3} mN/m), and when the amount of adsorption by oil sand is 3, interfacial tension also can maintain at the level of 10^{-2} mN/m, so the solution of non-ionic surfactant has good anti-adsorption ability. The results of the oil displacement experiments show that the solution of a non-ionic surfactant can increase the efficiency of oil displacement. But under condition of high water cut, the dominant flow channel in the core is formed, and the surfactant solution flows into the main channel preferentially and reduces the residual oil saturation in the main channel, which leads to a decrease in the resistance coefficient and injection pressure. Therefore, after water flooding, take measures to control the fluid profiles firstly so that the following surfactant solutions change direction in areas not exposed to water in order to achieve the best effect of the increase in oil recovery.

1. Introduction

Oil displacement agent refers to the chemical substances used to improve oil recovery, mainly refers to the functional compounds that can reduce residual oil saturation through chemical reaction, namely surfactants [1, 2]. The surfactant molecule has two functional groups, the hydrophilic (water soluble) and hydrophobic (oil soluble) group [3, 4]. Two functional groups are easily absorbed at the liquid-liquid or gas-liquid interface and form a single-molecular film. Therefore, surfactant can reduce surface tension and change the surface condition, as a result, change the wetting angle, emulsification increase and others [5–7]. Depending on the characteristics of the hydrophilic group, the surfactants are divided into four (anionic, cationic, zwitterionic and non-ionic) groups. The commonly used surfactants for oil displacement are anionic, non-ionic and zwitterionic surfactants [8–11].

Tuha oil field is located at the Turpan Basin in China. Section Y-6 is the main water injection development area in the oilfield. The degree of mineralization of the formation water ranges from 115.5 to 191.8 g/l, and the concentration of Ca^{2+} and Mg^{2+} exceed 7 g/l. Currently, the water content of the main reservoir of the section Y-6 of the Tuha oil field is more than 93% and the recovery rate is less than 20%, so it is essential to use the enhance oil recovery technology to increase the oil recovery rate. At present, an efficient oil displacing agent must be selected for this oil field, which can be used in reservoirs with a high degree of mineralization. In this paper, based on the geological characteristics and fluid properties of the oil reservoir of the Y-6 section of the Tuha oil field, the suitable surfactant

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solution was selected, the interfacial tension of the solution with oil was measured, the adsorption characteristics and the oil displacement ability of the surfactant solution were evaluated.

2. Experiment description

2.1. Experimental materials
Surfactants include petroleum sulfonate produced by Daqing Refinery and Chemical Company (effective content 50%), heavy alkylbenzene sulfonate produced by Donghao Company of Daqing Oilfield (effective content 50%) and non-ionic surfactant (DWS), produced by Dalian Davis Technology Co., Ltd. (effective content 35%). Alkali include weak alkali sodium carbonate (Na_2CO_3, effective content 98%) and strong alkali sodium hydroxide (NaOH, effective content 96%). The experimental water is simulated injection water of the target oilfield, mass concentrations of ions (K^++ Na^+), Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, CO_3^{2-} and HCO^{3-} are 51.433, 6.915, 0.393, 92.524, 0.129 and 0.059 g/l respectively. The overall degree of salinity of simulated injection water is 151.453 g/l. The oil used in the experiment is the crude oil of the Tuha oil field. Oil sands are obtained by crushing and sieving the natural cores of the target reservoir, and their particle size range from 40 meshes to 80 meshes. Cores are natural cores from the Tuha oil field.

2.2. Instruments and equipment for experiments
Interfacial tension between the displacing agent and oil was tested using the Spinning Drop Interfacial Tensiometer Model 500. Experiments were performed at a reservoir temperature of 55 °C. The main equipment used for the experiment for the oil displacement in heterogeneous cores includes a core holder, an advection pump, a hand pump for generating rock pressure, a pressure sensor and two intermediate containers. With the exception of the advection pump and the hand pump, the remaining parts were placed in a thermostat oven at 55 °C. Figure 1 shows the experiment-process diagram.

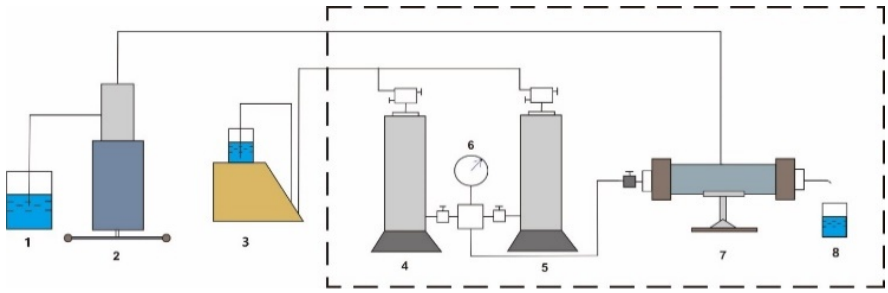

Figure 1. Experiment-process diagram: 1 – beaker, 2 – hand pump, 3 – advection pump, 4 – the container of water, 5 – the container with surfactant, 6 – sensor, 7 – core holder, 8 – measuring cup.

3. Results and discussion

3.1. Interfacial tension and adsorption characteristics of the solution of non-ionic surfactant and oil
The solution of strong alkali and heavy alkylbenzene petroleum sulfonate (1.2% NaOH + 0.3% heavy alkylbenzene petroleum sulfonate), weak alkali and petroleum sulfonate (1.2% Na_2CO_3 + 0.3% petroleum sulfonate) and non-ionic surfactant solution (0.3%) were prepared with 100 ml simulated injection water. The interfacial tension between the oil displacement agent and crude oil in different solution was measured by interfacial tensiometer. The results of measurement of interfacial tension are presented in table 1.

It can be seen from table 1 that the solution of strong alkali + heavy alkylbenzene sulfone and the solution of weak alkali + petroleum sulfonate can slightly reduce the interfacial tension of the solution and oil, comparing simulated injection water and oil. The non-ionic surfactant can reduce interfacial tension to the very low level of 0.0021 mN/m. In conjunction with this, the non-ionic surfactant (DWS) was selected for the next study.

Table 1. The results of measuring the interfacial tension (mN/m).

Composition	Interfacial tension
simulated injection water	2.95
1.2% NaOH + 0.3% heavy alkylbenzene petroleum sulfonate	2.91
1.2% Na_2CO_3 + 0.3% petroleum sulfonate	1.50
non-ionic surfactant (0.3%)	0.0021

Different concentrations of non-ionic surfactant (DWS) solutions were prepared with simulated injection water. The experimental data of the relationship between interfacial tension and concentration and time of DWS are shown in table 2.

Table 2. Relation between DWS concentration and interfacial tension (mN/m).

Concentration (%)	Time（min）0	4	8	12	16
0.025	2.470	0.55000	0.1400	0.0590	0.04600
0.05	1.900	0.30000	0.0260	0.0044	0.00023
0.1	0.950	0.20000	0.0026	0.0012	0.00260
0.2	0.730	0.01400	0.0016	0.0050	0.00690
0.3	0.037	0.00036	0.0090	0.0036	0.00110
0.4	0.050	0.00160	0.0029	0.0021	0.00290

From table 2, it can be seen that the interfacial tension shows a downward trend as the test time prolongs, and some samples show the "downward, upward and downward" trend. The interfacial tension decreases with the increase of surfactant concentration. When the surfactant concentration reaches or exceeds 0.05%, the interfacial tension reaches ultra-low interfacial tension (10^{-3} mN/m).

Under the condition of 0.3% DWS concentration, the surfactant solution was contacted with fresh oil sand for many times, and the interfacial tension was measured 24 hours after each contact. The experimental data of interfacial tension are shown in table 3.

Table 3. The results of measurement of interfacial tension after adsorption (mN/m).

Parameters t	The amount of adsorption initial	1	2	3
Non-ionic surfactant (0.3%)	0.0011	0.0021	0.0130	0.0240

It can be seen from table 3 that with the increase of the amount of contact between the solution of non-ionic surfactant and fresh oil sand, the interfacial tension increases. When the amount of adsorption is 3, the interfacial tension can be maintained at level 10-2 mN/m, which indicates that the solution of non-ionic surfactant has good anti-adsorption ability.

3.2. Oil displacement efficiency of nonionic surfactant solution.

The experimental results of the effect of surfactant solution concentration and injection timing on oil displacement efficiency (oil recovery) are shown in table 4. The dynamic characteristics of injection pressure, water cut and oil recovery during core displacement experiments are shown in from Figure 2 to Figure 4.

Table 4 shows that surfactant solution can effectively reduce the interfacial tension between oil and water and improve the oil washing efficiency. Compared with experiment No.1 and No.2, experiment No.3 and No.4 have greater increase in recovery and higher final recovery. It can be seen that the earlier the injection time of surfactant solution, the higher the oil saturation of core, the higher the seepage resistance and the injection pressure, so the area affected by surfactant larger, and the increase of the recovery greater.

Table 4. Experimental data of oil recovery.

Experiment number	The content of the experiment	Core length (cm)	Permeability Kg （10^{-3} μm^2）	Recovery （%）	
				Water flooding	Final
1	Water flooding to water cut 98% + 0.2PV (pore volume of the core) DWS + subsequent water flooding to water cut 98%	6.9	110	39.47	43.86
2	Water flooding to water cut 98% + 0.4PV DWS + subsequent water flooding to water cut 98%	7.1	117	38.88	49.48
3	Water flooding to water cut 60% + 0.4PV DWS + subsequent water flooding to water cut 98%	6.2	131	27.23	56.68
4	Water flooding to water cut 0% + 0.4PV DWS + subsequent water flooding to water cut 98%	6.3	143	-	68.74

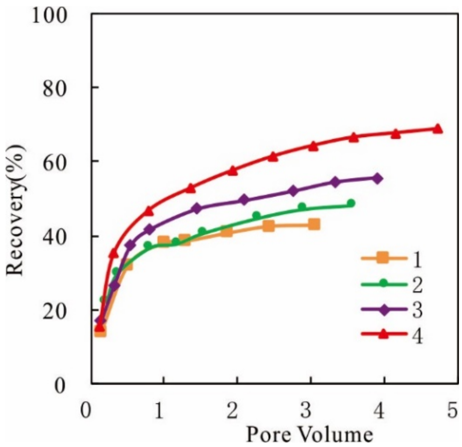

Figure 2. The relationship between injection pressure and pore volume.

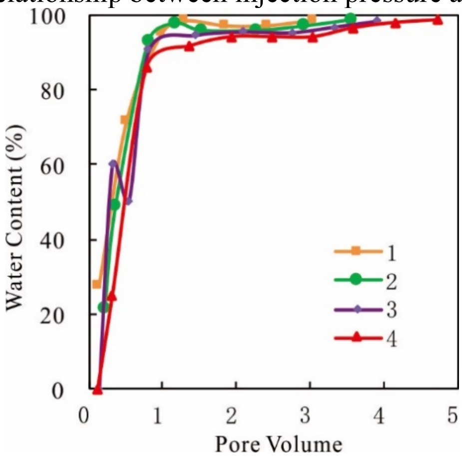

Figure 3. The relationship between water content and pore volume.

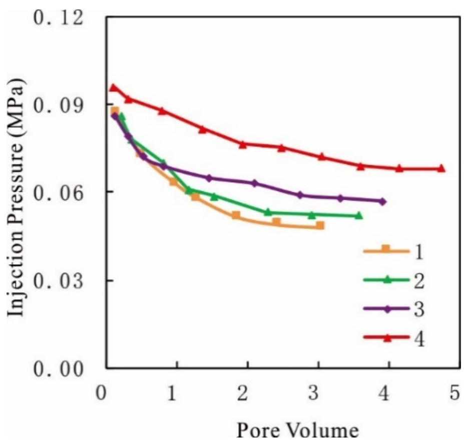

Figure 4. The relationship between oil recovery and pore volume.

From Figure 2 to Figure 4, it can be seen that the injection pressure of surfactant solution in displacement process decreases due to the poor retention ability of surfactant itself in core pore. Compared with experiment No. 1 and No. 2, injection pressure of experiment No. 3 and No. 4 is obviously higher, which indicates that displacement pressure gradient is larger, capillary diameter of the pore that surfactant solution can enter is smaller, so the effect of sweep volume enlargement and recovery increase is better. Thus, under the condition of high water cut, the dominant channel of flow has been formed in the core, and the surfactant solution will enter the dominant channel preferentially, further reduce the remaining oil saturation in the dominant channel, resulting in the decrease of seepage resistance and injection pressure. Therefore, after water flooding, profile control measures should be taken first to make the following surfactant solutions divert into areas not affected by water, so as to achieve better oil recovery increase effect.

4. Conclusion

The solution of strong alkali +heavy alkylbenzene sulfonate and the solution of weak alkali +petroleum sulfonate can slightly reduce the interfacial tension of the solution and oil compared with formation water and oil. The non-ionic surfactant DWS can reduce interfacial tension to the ultra-low level (10^{-3} mN/m), and when the amount of adsorption is 3, interfacial tension can be maintained at 10^{-2} mN/m level, so the solution of non-ionic surfactant has good anti-adsorption ability. The solution of non-ionic surfactants can effectively reduce the interfacial tension between the oil and the solution, and increase the efficiency of oil displacement. But under conditions of high water cut, the dominant flow channel in the core is formed, so the surfactant solution flows into the dominant channel preferentially and reduces the residual oil saturation in the dominant channel, which leads to a decrease in the seepage resistance and injection pressure. Therefore, profile control measures should be taken first after water flooding to make the following surfactant solutions divert into areas not affected by water, so as to achieve better oil recovery increase effect.

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