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The Effect of Emulsifying Capacity of ASP Flooding on Oil Displacement Efficiency for Jing-11 Fault Block Reservoir in Huabei Oil Field

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Abstract

Although started late, the development of ASP flooding technology in China was rapid. With the spread of the field test of ASP flooding, the effect of the emulsifying property of the composite system during the process of seepage on the oil displacement efficiency has gradually become the problem that people are concerning. In this paper, taking Jing-11 fault block reservoir in Huabei Oil Field as the research object, the influence rule of alkali, surfactant and polymer on the stability of the crude oil emulsion was inspected through indoor experiment. Besides, on the basis of the controlling variables method and under the circumstance of other conditions remains unchanged, the simulated displacement experiment was conducted using the physical model for ASP system of emulsion type and non-emulsion type surfactant respectively. It is proved that the emulsifying capacity of ASP flooding has significant effect on improving the oil displacement efficiency.

Keywords*: ASP flooding; emulsification; stability; recovery efficiency*

1. Introduction

ASP flooding (ASP) refers to the composite flooding system consisting of alkali-surfactant-polymer, which is also a tertiary oil recovery technology developed on the basis of the alkaline-water flooding and polymer flooding method [1]. Due to its remarkable effect on enhancing the recovery efficiency, ASP flooding has obtained more and more attention. It is generally believed that the reduction in the oil-water interface tension by the surfactant is the main factor for the improvement in the oil recovery efficiency by the surfactant flooding [2]. In recent years, some researchers found that the emulsification is the key factor for the improvement of oil recovery efficiency through research on the ASP flooding and the field tests [3-6], but there are little research on the influence of the emulsification on the recovery efficiency. For this purpose, the author took the reservoir of Jing-11 in Huabei Oil Field as the research object, the effect of alkali, surfactant and polymer of different concentrations on the stability of crude oil emulsion were measured through experiment. Also, the indoor simulated displacement experiment was conducted by compounding the three constituent and the oil displacement efficiency was evaluated according to the obtained best performance parameters. The temperature of oil reservoir in the researching area is 53 ℃, the embedded depth is 1217-1810 m, the shale content of sandstone reservoir is high (12.4 %), the reservoir oil viscosity is low (1-3 mPa·s), the acid value is low (0.28 mg/L), and the total mineralization of formation water is higher (7-11 g/L). The fault block was developed since July 1979, experiencing the development process of water cut going up from low to high and the production rate from low, high, stabilization and declining. Now it has entered into the high water cut development stage and the average water cut has reached up to 90 %.

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2. The Effect of the Concentration of ASP System on the Stability of Emulsion

The stability of the emulsion is a relative concept in theory. If the performance of the emulsion doesn't change with time basically, the emulsion can be thought to be stable based on the needs of the actual situation. There are many factors affecting the stability of the emulsion and the mechanism is also very complicated. Here we mainly consider the effect of the concentration of added chemical reagents in the ASP flooding on the stability of the emulsion.

2.1. Experimental Reagent and Instrument

2.1.1. Experimental Reagent: Crude oil of the Jing-11 reservoir in Huabei Oil Field; simulated water of the Jing-11 reservoir in Huabei Oil Field (Table 1); weak base NaAc; emulsion-type surfactant A (sulphobetaine); surfactant B reducing the interfacial tension (SHY-1); polyacrylamide; NaCl、KCl、$CaCl_2$、$MgCl_2$、Na_2CO_3、Na_2SO_4、$NaHCO_3$.

Table 1. The Indicators of the Formation Water Quality in North J11

Project	Na^++K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	Total salinity
Content mg/L	3609.14	59.17	52.62	3914.12	117.65	1997.72	9750.44

2.1.2. Experimental Instrument: Constant temperature oven, type UFE500; high-speed emulsifying dispersion instrument, type UITRA-TURRA; mixer, type DW-3, Henan; emulsification machine, type RHY-3; Magnetic heating stirrer, type F15-6A; electronic balance, type MGL6HT; particle-size analyzer; Zetasizer nano potentiostat *etc*.

2.2. The Effect of the Concentration of Surfactant on the Stability of the Emulsion

2.2.1. Experimental Method: Heat the crude oil to the flow state using the constant temperature oven, prepare the solution by mixing different mass percent of surfactant A with formation water of the Jing-11 reservoir in Huabei Oil Field, then emulsify with crude oil of the Jing-11 reservoir in Huabei Oil Field according to the oil-water ratio of 1:1, conduct the measurement of the molecular particle size of the emulsion for prepared emulsion with Zetasizer nano potentiostat.

Table 2. The Experimental Design Table for the Effect of Surfactant Concentration on the Emulsion Stability

The concentration of surfactant wt/%	0.05	0.1	0.2	0.3	0.4	0.5	0.6
The concentration of alkali wt/%	-	-	-	-	-	-	-
The concentration of polymer /ppm	-	-	-	-	-	-	-

2.2.2. Analysis of the Results:

Table 3. Particle Size of the Emulsion Molecular at Different Surfactant Concentration

Surfactant concentration wt/%	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.05
Molecular particle size/nm	1168	1030	955	940	931	925	921	1168

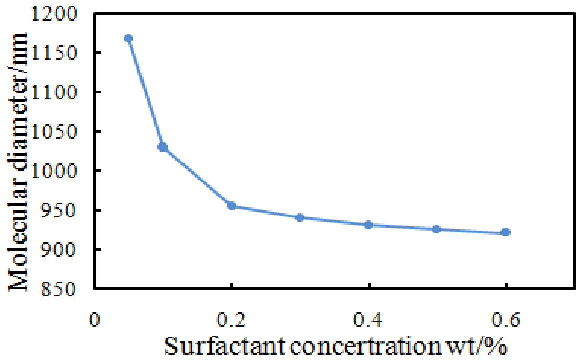


Figure 1. The Diagram of the Surfactant Concentration and Particle Size of the Emulsion Molecular

With the increase in the concentration of surfactant, the particle size of the formed emulsion gradually decreased and the stability of the emulsion was enhanced. Thus the emulsion could be stabilized with the increasing surfactant concentration. As can be seen from Figure 1, when the concentration of surfactant was greater than 0.3 wt%, the change in the molecular particle size of the emulsion tended to be stable, then the concentration of surfactant will no longer be the main factor influencing the stability of the emulsion.

2.3. The Effect of the Concentration of Alkali on the Stability of the Emulsion

2.3.1. Experimental Method: Heat the crude oil to the flow state using the constant temperature oven, prepare the solution by mixing the weak base NaAc at different mass percent with 0.3 wt% surfactant A, formation water of the Jing-11 reservoir in Huabei Oil Field, then emulsify with crude oil of the Jing-11 reservoir in Huabei Oil Field according to the oil-water ratio of 1:1, emulsify the prepared emulsion with high-speed emulsifying dispersion instrument for 1 min. After completing the emulsion, place it in the oven at 50 ℃(constant temperature) for 5 h, and then observe the water distribution efficiency.

Table 4. The Experimental Design Table for the Effect of Alkali Concentration on the Emulsion Stability

The concentration of surfactant wt/%	0.3	0.3	0.3	0.3	0.3	0.3	0.3
The concentration of alkali wt/%	0.1	0.2	0.4	0.6	0.8	1.0	1.2
The concentration of polymer /ppm	-	-	-	-	-	-	-

2.3.2. Analysis of the Results:

Table 5. Emulsion Stability at Different Alkali Concentrations

Time /min	Emulsion stability rate %						
	Alkali concentration wt/%						
	0.1	0.2	0.4	0.6	0.8	1.0	1.2
15	98.25	99.04	99.88	99.90	99.96	98.31	96.82
30	97.86	98.13	98.52	98.85	99.28	97.79	95.01
60	96.59	96.95	97.28	97.78	98.42	96.69	94.22
120	96.32	96.44	96.58	97.21	97.79	96.48	93.05
180	96.10	96.22	96.35	96.83	97.52	95.45	92.12
300	95.48	95.88	96.02	96.23	96.48	93.78	90.85

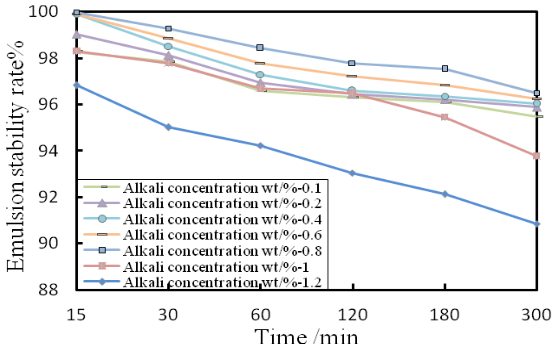


Figure 2. The Diagram of the Alkali Concentration and Emulsion Stability Rate

With the increase in the content of NaAc in the emulgator, NaAc reacted with the active ingredients in the crude oil and generated the surfactant-type emulsified crude oil, making the crude oil's emulsification time shorten and enhancing the emulsion's stability. However, with further increase in the content of NaAc, the generated surfactant from reaction preformed a competitive adsorption with surfactant A on the oil-water interface, making the emulsion's stability become poorer, which is basically consistent with the conclusion drawn from experiments in Daqing oil field in 2010 by Fenglan Zhao [7]. Therefore, when the concentration of NaAc is 0.8 %, the formed emulsion is the most stable.

2.4. The Effect of the Concentration of Polymer on the Stability of the Emulsion

2.4.1. Experimental Method: Heat the crude oil to the flow state using the constant temperature oven, prepare the solution by mixing the polyacrylamide at different mass percent with 0.3 wt% surfactant A, formation water of the Jing-11 reservoir in Huabei Oil Field, then emulsify with crude oil of the Jing-11 reservoir in Huabei Oil Field according to the oil-water ratio of 1:1, emulsify the prepared emulsion with high-speed emulsifying dispersion instrument for 1 min. After completing the emulsion, place it in the oven at 50 ℃(constant temperature) for 5 h, and then observe the water distribution efficiency.

Table 6. The Experimental Design Table for the Effect of Polymer Concentration on Emulsion Stability

The concentration of surfactant wt/%	0.3	0.3	0.3	0.3	0.3	0.3	0.3
The concentration of alkali wt/%	-	-	-	-	-	-	-
The concentration of polymer /ppm	100	200	400	600	800	1000	1200

2.4.2. Analysis of the Results:

Table 7. Emulsion Stability under Different Polymer Concentrations

Time /min	Emulsion stability rate %						
	Polymer concentration /ppm						
	100	200	400	600	800	1000	1200
15	98.25	99.52	100	100	100	100	100
30	97.86	98.84	99.86	100	100	100	100
60	96.59	97.60	99.21	99.65	100	100	100
120	96.31	97.19	98.38	98.82	100	100	100
180	96.12	96.78	97.51	98.23	98.62	99.58	100
300	95.86	96.05	96.48	97.13	97.82	98.18	98.61

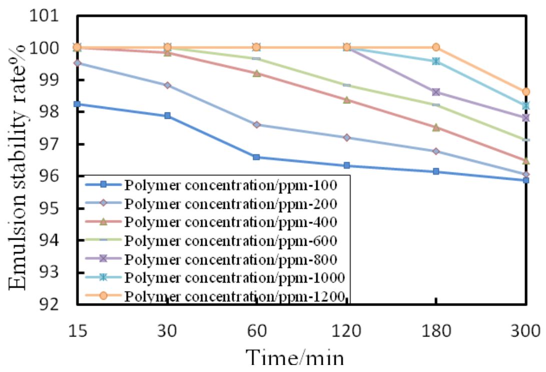


Figure 3. The diagram of Polymer Concentration and Emulsion Stability Rate

With the increase in the concentration of polymer, the water-soluble polymer chain segment fully extended in the continuous phase (water), formed a thick adsorption layer on the surface of the oil droplet, and prevented oil droplets from coalescing, thus slowing the bleeding speed of the emulsion and enhancing the stability. When the mass percentage content of the polymer was greater than 800 ppm, the desorpted water was not seen in the first two hours and the performance of the emulsion was stable, meeting the requirements of the experiment.

3. The Assessment of the Oil Displacement Efficiency of Physical Simulation

In order to compare the effect of the emulsification capacity of the ASP flooding on the oil displacement efficiency, we specially selected a type of surfactant B which can reduce the oil-water interfacial tension (which does not occur emulsion after contacting with the crude oil), conducted the combination of chemical agents in the case that other conditions were the same and performed the displacement experiment using the simulated core.

3.1. Experimental Reagent and Instrument

3.1.1. Experimental Reagent: Crude oil of the Jing-11 reservoir in Huabei Oil Field; simulated water of the Jing-11 reservoir in Huabei Oil Field; weak base NaAc; emulsion-type surfactant A (sulphobetaine); surfactant B reducing the interfacial tension (SHY-1); polyacrylamide.

3.1.2. Experimental Instrument: Domestic Berea core; constant temperature oven; core holding unit; constant speed and constant pressure pump; precise pressure sensor; electronic balance; vernier caliper; measuring cylinder; interface tensiometry, type TX-500C.

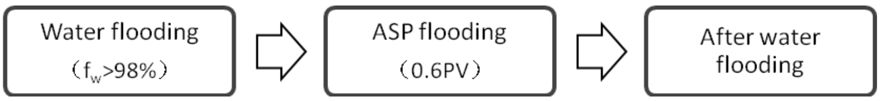
3.2. Experiment Method

Conduct the combination of chemical agents of ASP system using surfactant A and surfactant B respectively and measure the stability of the emulsion (at 1 h) and the interfacial tension. The specific parameters are as follows:

Table 8. The Basic Parameters of ASP Flooding

Chemical composition			S_{te}/%	σ/mN·m^{-1}
Type A-0.3%,	Polyacrylamide -800ppm,	NaAc-0.8%	96.28	5.072
Type B-0.3%,	Polyacrylamide -800ppm,	NaAc-0.8%	21.32	1.96×10^{-3}

Choose two domestic Berea cores with the same model and conduct the displacement experiment respectively after making a series of conventional preparation including drying, saturating oil, aging etc. The experimental procedures are as follows:



3.3. Analysis of the Results

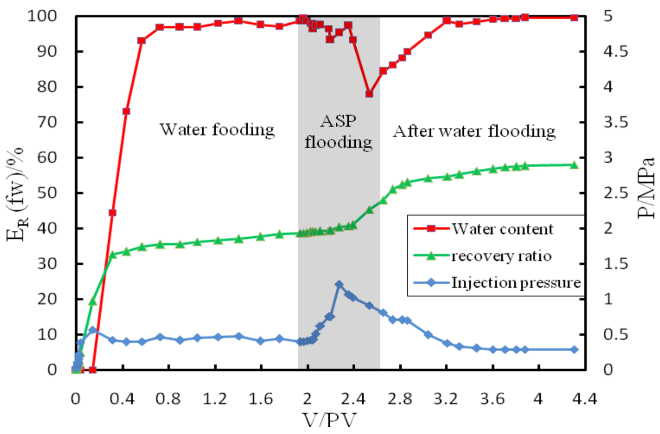


Figure 4. Flooding Effect of Ultralow Interfacial Tension System

After driving the water cut to more than 98 % by water and shifting to the chemical flooding, the pressure of the injection side increased obviously, the oil on the outlet end had obvious emulsion phenomenon (the oil droplets was brown), the water cut of extracted oil decreased, which was because that after the injection of the chemical agent, the residual oil was emulsified into emulsion and coalesced into "oil wall", leading to an increase in the pressure of the injection side, meanwhile, the emulsion blocked the high permeability zone, thus improving the sweep efficiency of the crude oil.

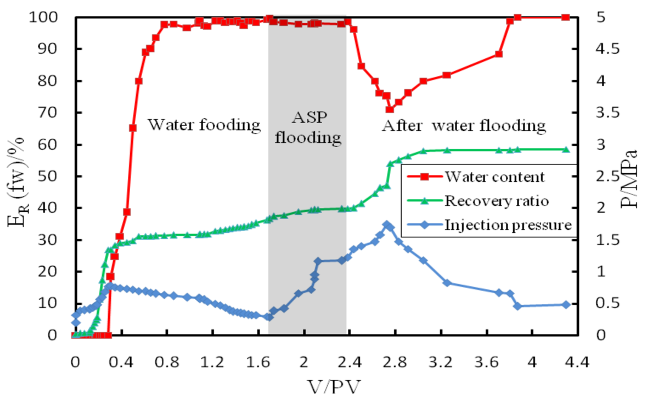


Figure 5. Flooding Effect of Emulsifying System

After driving the water cut to more than 98 % by water and shifting to the chemical flooding, the water cut of the crude oil decreased significantly, and the recovery efficiency increased, which was because that the injection of the chemical agent reduced the oil-water interfacial tension, increased the number of capillary, meanwhile, reduced the work of adhesion and made the water easy to wash the crude oil down from the rock, thus enhancing the oil recovery.

Table 9. Comparison of the Displacement Results for the Two Systems

Flooding system	Recovery ratio E_R/%			
	Water flooding	ASP flooding	After water flooding	Increase rate
Emulsifying surfactant system-type A	36.68	46.29	58.45	21.77
Low interfacial tension surfactant system-type B	39.02	48.02	58.03	19.01

On the premise that the basic parameters of the core, the basic parameters of the displacement and the water flooding's recovery efficiency, the injecting PV value of the chemical flooding are basically consistent, we can see from the table that both displacement solutions can improve the recovery efficiency by about 20 %, and the improvement in the oil recovery efficiency by the chemical flooding system with emulsifying ability is 2 % higher than that of the chemical flooding system with ultralow interfacial tension.

4. Conclusion

For the reservoir of Jing-11 in Huabei Oil Field, the concentration of surfactant, alkali, polymer in the ASP flooding had an important influence on the stability of the formed crude oil emulsion. And it is found that the higher concentration doesn't mean more stable crude oil emulsion. While the concentration of surfactant is 3 wt%, the concentration of alkali is 0.8 wt% and the concentration of polymer is 800 ppm, the stability of the emulsion is quite strong.

The results of indoor core displacement experiment showed that the ASP flooding system with the emulsifying performance and the ASP flooding system with ultralow interfacial tension could make great contribution to improve the recovery efficiency, among which the ASP flooding system with emulsifying ability had a better oil displacement efficiency. It is thus suggested that the emulsification capacity of the ASP flooding of the Jing-11 reservoir in Huabei Oil Field has significant effect on the oil displacement efficiency and has a good development prospect.

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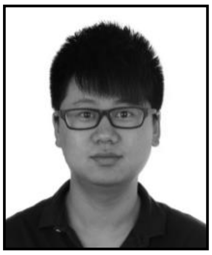

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