Analysis on the Formation of Water/Oil Emulsion System of High Water-cut Crude Oil and Its Profile and Flooding Effect

Hongjiang Ge, Jing Cheng*, Dangke Ge, Weihua Yang, Zhiqiang Guo, Lihua Ren, Jianjun Bao, Qian Li, Xiaoyan Ma and Xiaoliang Liang

Oil Production Technology Institute, Dagang Oil field Company, Tianjin Binhai New Area

Abstract: In view of the limitations of modulated flooding technology in low permeability high temperature reservoirs, the water/oil emulsion with the effect of expanding sweep volume and its influence on the effect of modulated flooding were studied. Under the condition of high water content (80% water content), the dispersion system formed by emulsifier 55# and crude oil is mainly water/oil emulsion. At the same time, the influence of surfactant type, water content, temperature and other factors on the formation of water/oil emulsion system was investigated, and the influence of emulsion properties on the effect of displacement was analyzed. The low permeability core experiment shows that the emulsifier with the effect of expanding sweep volume can improve the oil recovery by 17.93% on the basis of water flooding, which is obviously higher than that of polymer flooding. At the same time, emulsifier has good temperature resistance, which is of great significance for enhancing oil recovery in high temperature and low permeability water drive reservoirs.

1. Overview

At present, most of my country's water flooding development reservoirs have entered a period of high water cut. As a technical means of enhancing oil recovery, with the change of the properties of underground reservoirs, the effective period and effect of control flooding are also decreasing. The existing modulate flooding (profile) systems [1-2] mainly include polymers, gels, bulk swellable particles and precipitation agents, which cannot be effectively expanded the effect of expanding sweep volume due to the adsorption and retention of formation porous media and the dilution of formation water, low permeability reservoirs and high temperature conditions also limit the application of organic modulate flooding systems [3]. Therefore, there is an urgent need to find new oil displacement methods to greatly enhance oil recovery. Emulsion flooding has become a hot research topics of chemical flooding in recent years [4-9]. Under different water-oil ratios, emulsifiers can form water-in-oil (W/O) or oil-in-water (O/W) emulsions with crude oil. When the O/W type emulsion is formed, the crude oil molecules are solubilized in the active agent micelles; When the W/O type emulsion is formed, the emulsion has a higher viscosity, which reduces the mobility ratio of waterflooding oil, increases the swept volume of the subsequent injected water, and improves the heterogeneous formation profile. At the same time, there is a low interfacial tension between oil and water, which plays the role of oil displacement. Wanfen Pu, et al [10] developed a W/O emulsifier OB-2 when the volume ratio of oil to water is 7:3, and the viscosity increase rate of OB-2 emulsion with a concentration of 0.3 wt% reaches 370%. Studies have shown that viscous W/O emulsions are used as a very promising oil displacement system [11-12]. We have developed a water-in-oil emulsion system with good water solubility that can easily form a high water content after mixing with crude oil, Taking the S reservoir of Dagang Oilfield as the research object, the causes and influencing factors of the water-in-oil system of high water-cut crude oil were investigated, and the emulsification, viscosity increase and oil displacement were realized, which is expected to be applied to the high-water-cut crude oil reservoir for enhanced oil recovery [13-14].

2. Experiment part

2.1 Materials and Instruments

Cocamidopropyl betaine (effective content 35%), fatty alcohol polyvinyl ether sulfate (effective content 70%), industrial products, provided by Linyi Yiqun Chemical Co., Ltd.; polyoxyethylene sorbitan monostearate, polyoxyethylene fatty alcohol ether, alkanolamide, oleic acid diethanolamide, industrial products, provided by Nantong Chenrun Chemical Co., Ltd. Emulsifier 55# is self-made in the laboratory, and the main component is non-ionic surfactant mixed in proportion; The oil used in the experiment is the crude oil from the S reservoir of Dagang Oilfield, and the viscosity of the crude oil is 80 mPa·s (laboratory test at 90°C); The experimental water is the formation water of S reservoir in Dagang Oilfield, the salinity is 28630 mg/L, and the ion content is as follows: Cl-, 15267 mg/L; HCO3-, 251 mg/L, SO42-, 368
mg/L; Ca²⁺, 340 mg/L; Mg²⁺, 48 mg/L; Na⁺, K⁺, 9540 mg/L.
The experimental instruments mainly include TX500C full rotation drop meter/interfacial tension meter, Brookfield DV-III+Pro viscometer, magnetic stirrer, DGM-III core displacement device, etc.

2.2 Experimental Method

2.2.1 Preparation of Water-in-oil Emulsion System.

Formation water was used to prepare 55# aqueous solution of emulsifier with different concentrations and crude oil of S reservoir according to different water-oil ratios. The total volume was 50 mL, and the mixture was stirred with a magnetic stirrer at 90°C. The prepared emulsion was placed in a 90°C incubator to observe the emulsification.

2.2.2 Emulsion viscosity.

Emulsion viscosity refers to the viscosity value of oil-water emulsion at a certain temperature. The unit is mPa·S. The viscosity of dehydrated crude oil at 90°C is 80 mPa·S.

2.2.3 Evaluation of plugging performance.

A sand-packed pipe model with a length of 30 cm and a diameter of 3.12 cm was used to investigate the variation law of the displacement pressure before and after the injection of the emulsifier 55# solution. The specific experimental steps are as follows: First, the formation water is saturated in vacuum, the porosity and PV volume of the sand-packing pipe are calculated, and the water phase permeability is measured. At the displacement rate of 0.23 mL/min, the water content of the oil from water flooding to the produced fluid was 98%, and the displacement pressure was stable, and the displacement pressure in the water flooding stage was recorded; After injecting 0.5 times the pore volume of the emulsifier 55# at the same displacement rate, the water flooding was continued until the water content of the produced fluid was 98%, and the displacement pressure in the subsequent water flooding stage was recorded.

2.2.4 Evaluation of oil displacement performance.

A sand-packing tube model with a length of 30 cm and a diameter of 3.12 cm was used to investigate the oil displacement performance of the injected emulsifier 55#. The specific experimental steps are: a) vacuum saturated pure water, weigh the core mass before and after saturated water, and calculate the porosity and PV volume; b) Load the core into the core holder, and measure the water permeability K; c) Saturate crude oil at a temperature of 104°C; d) Water flooding to 98% water content, and measure its water flooding efficiency; e) Inject 0.5PV 0.3% emulsifier 55# solution, continue water flooding to 98% water content, calculate the oil displacement efficiency of the emulsifier and improve the oil recovery factor.

3. Experimental results and analysis

3.1 Component Selection for Forming High Water-cut Crude Oil Water-in-oil Emulsions

The formation of water-in-oil emulsions in high water-cut reservoirs requires that the surfactant solution injected on the ground has a certain solubility. At the same time, the water-in-oil emulsions formed also have emulsification and viscosity enhancement, control the mobility of the displacement fluid, and play a role in profile control and oil increase effect.

3.2 Conditions and Influencing Factors for the Formation of High Water-cut Crude Oil Water-in-oil Emulsion Systems

3.2.1 Formation conditions.

Einstein viscosity formula:

\[ \eta = \frac{1}{1 - \sqrt{\phi}} \eta_0 \]  

Among them, \( \eta_0 \): viscosity of external phase; \( \phi \): volume fraction of internal phase; \( h \): volume factor related to the type of emulsion.

According to the Einstein viscosity formula, the viscosity increase of the emulsion is mainly related to the volume of the internal phase, that is, we need to choose a suitable emulsifier to wrap as much internal phase water as possible. To this end, under the premise of taking into account the interfacial tension and lipophilicity, it was determined experimentally that nonionic surfactants with HLB values between 6 and 8 can form water-in-oil emulsions that can drive oil. Further, amide-based surfactants containing different fatty acids and different alkanols were targeted as thickening emulsifiers.

3.2.2 Factors influencing the viscosity-enhancing performance of water-in-oil emulsions of high water-cut crude oil

3.2.2.1 Surfactant Type.

Reducing the oil-water interfacial tension is the most basic requirement of surfactants. In the experiment, the low interfacial tension system LAB with betaine as the main agent was selected, and on this basis, its emulsifying and viscosity-increasing properties were further optimized. Use different fatty acid R and alcohol amine NH \((CH_2CH_2OH)_x\) (X value is an integer of 1 to 3) composed of alkanolamide surfactants, the structure is:

\[
R-C \cdot N \left(\text{CH}_2\text{CH}_2\text{OH}\right)_x \text{OH}
\]

The compound experiment of alkanolamide surfactant and low interfacial tension system LAB was carried out. The results are shown in Table 1.
Table 1. Emulsifying and thickening properties of different surfactants and crude oil

<table>
<thead>
<tr>
<th>R</th>
<th>X</th>
<th>Solubility</th>
<th>Emulsifying &amp; thickening</th>
<th>Lower interfacial tension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stearic acid</td>
<td>1</td>
<td>√</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Oleic acid</td>
<td>1</td>
<td>√</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Lauric acid</td>
<td>1</td>
<td>√</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>coconut oil</td>
<td>1</td>
<td>√</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Palmitic acid</td>
<td>1</td>
<td>√</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
</tbody>
</table>

√ stands for Yes; - stands for No.

It can be seen from the table that ethanolamide surfactants have good water solubility, and can form a uniform emulsion after mixing with crude oil. The viscosity test results show that the emulsification and viscosity-increasing effect of diethanol amide surfactant is better than that of monoethanolamide surfactant. The viscosity enhancement of diethanolamide surfactants is largely due to the pair of polar head groups of fatty acid-ethanolamine. The viscosity increase rate has a lot to do with the matching between the two.

3.2.2.2 Moisture content.

In order to analyze the viscosity increase of water-in-oil emulsion, the effect of different water content on the viscosity of 3% emulsifier 55# emulsion was investigated under the condition of experimental temperature of 90°C. As can be seen from Figure 1, within 75% of the water content, the viscosity of the emulsion increases greatly with the increase of water content. At this time, the emulsion is mainly water-in-oil type, and the emulsification and viscosity increase rate can reach more than 400%. When the water content is greater than 80%, the internal displacement pressure of the core with permeability of 80 mD did not increase, and no strong flow resistance was established. The reason for the analysis may be that the size of the formed water-in-oil emulsion droplet does not match the size of the core pore throat, which is insufficient to establish the flow resistance of its subsequent injection; It is also possible that due to the strong heterogeneity of the core itself, a water flow channel is formed and an oil-in-water emulsion is formed, resulting in no increase in the displacement pressure.

3.2.2.3 Temperature.

Under the condition of 50% moisture content and 3% mass fraction, and the experimental temperature is 90, 100, 110, 120, 130°C, the emulsion viscosity of emulsifier 55# is 380, 370, 362, 355, 347 mPa.S respectively. The experimental results show that when the experimental temperature is 90-130°C, the viscosity of the emulsion changes within 10%. It shows that the emulsifier 55# has better temperature resistance and can be used in high temperature oil reservoirs.

3.3 Analysis of the control and flooding effect of the water-in-oil emulsion

Three groups of cores with different permeability were designed to investigate the plugging performance and oil displacement performance of emulsifier 55# with a mass fraction of 3% on the cores. In this way, the influence of the formation of the viscosifying water-in-oil emulsion on the improvement of the control and flooding effect in the later stage of water flooding reservoir development was analyzed.

3.3.1 Evaluation of plugging performance.

In order to eliminate the fluctuation effect of different cores on the displacement pressure during the displacement process, the displacement pressure is normalized. It can be seen from Figure 2 that the displacement pressure of the core with a permeability of 45 mD has been rising during the process of surfactant injection, indicating that a strong flow resistance is established in the core pores and a high-viscosity water-in-oil emulsion is formed in the core. After switching to waterflooding, with the migration of the oil-water emulsion, under the influence of the accumulation effect, the water injection pressure also continued to increase, with a maximum increase of 2.38 times. The internal displacement pressure of the core with permeability of 150 mD did not increase, and no strong flow resistance was established. The reason for the analysis may be that the size of the formed water-in-oil emulsion droplet does not match the size of the core pore throat, which is insufficient to establish the flow resistance of its subsequent injection; It is also possible that due to the strong heterogeneity of the core itself, a water flow channel is formed and an oil-in-water emulsion is formed, resulting in no increase in the displacement pressure.

![Fig. 1. Viscosity curve of emulsion with different water content](image-url)
3.3.2 Experiment of oil displacement performance.

From the experimental results, the enhanced oil recovery values of cores with a permeability of 45 mD and a permeability of 80.2 mD are similar, which are 17.93 and 15.85 percentage points, respectively, indicating that the water-in-oil emulsion formed by the emulsifier is compatible with the core pore throat and other parameters better. Among them, the core with a permeability of 150.4 mD has a low enhanced oil recovery ratio of 10.91 percentage points. The reason for the analysis should be that during the water flooding process of this group of cores, it may be that the texture of the core itself is highly heterogeneous, resulting in the formation of water flow aisle. When the viscosified emulsion enters the high water-cut water channeling channel, since the water content is 80%, the water-in-oil emulsion undergoes phase inversion at this time, mainly oil-in-water emulsion, so the final enhanced oil recovery value is low. Therefore, we also get a little understanding that it is not suitable to use the water-in-oil emulsion system to enhance oil recovery in the formation with obvious water channeling channels.

### Table 2. The experimental results of emulsifier 55# on cores with different water contents

<table>
<thead>
<tr>
<th>Core number</th>
<th>Porosity (%)</th>
<th>Oil saturation(%)</th>
<th>Penetration(mD)</th>
<th>Waterflood recovery(%)</th>
<th>System concentration(%)</th>
<th>Increased recovery(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-1</td>
<td>13.5</td>
<td>45.4</td>
<td>45.0</td>
<td>38.79</td>
<td>0.3</td>
<td>17.93</td>
</tr>
<tr>
<td>3-2</td>
<td>14.8</td>
<td>52.3</td>
<td>80.2</td>
<td>37.12</td>
<td>0.3</td>
<td>15.85</td>
</tr>
<tr>
<td>3-3</td>
<td>17.2</td>
<td>47.8</td>
<td>150.4</td>
<td>20.55</td>
<td>0.3</td>
<td>10.91</td>
</tr>
</tbody>
</table>

4. Conclusion

Under the condition of high water cut and low permeability reservoir (water cut 80%), emulsifier 55# and crude oil can form a water-in-oil emulsion-based dispersion system. Low-permeability core experiments show that the water-in-oil emulsion with the effect of expanding the swept volume can further enhance oil recovery on the basis of water flooding. At the same time, the emulsifier has good temperature resistance, which overcomes the disadvantage of polymer flooding that is easily degraded under high temperature conditions, and points out a technical approach for further improving oil recovery in low-permeability and high-temperature water flooding reservoirs.

References