The Influence of Interfacial Tension and Emulsifying Properties of Surfactant Polymer Binary Combination on Flooding Results of Low Permeability Rock

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Abstract — ASP compound flooding with alkali can result in a series of bad consequences which include dispersion and migration of clay, the reduction of reservoir permeability and decrease of permeability reservoir. A new compound system without alkali was proposed to discuss its effects on the low permeability reservoir. According to the SP flooding mechanism, the emulsifying properties and interfacial tension have a great influence on the enhancement of oil recovery in this system. Based on the emulsifying properties and interfacial tension test, this essay researches the effect of different interfacial tension and emulsifying properties of non-alkali dual recognition system in the low permeability core by using the artificial core to perform oil-displacement experiments, and the results show that after chemical flooding, recovery significantly increases in surfactant/polymer binary combination with a lower interfacial tension, systems with low or medium emulsifying ability have a great influence in the increasing range of recovery. What’s more, the injection pressure of a system with the excellent emulsification is obviously higher than that with a low or medium emulsifying ability. Compared with the system of ultra-low interfacial tension, the system of lower interfacial tension shows obvious effect of enhanced oil recovery in the condition of the same emulsifying ability.

Key words - emulsion performance; SP flooding system; low permeability core; interfacial tension

I. INTRODUCTION

The main characteristics of the low permeability reservoir include the poor reservoir property, the low permeability, the small pore throat radius, the low porosity, the high water injection pressure, the low oil recovery of conventional water flooding. Therefore, the development effect is poor[1,2]. In ASP compound flooding, the injection of alkali can result in a series of bad consequences which include dispersion and migration of clay, scale formation of formation and wellbore, decrease of polymer viscosity, etc[3-4]. It brings more serious bad consequences to the low permeability reservoir. ASP compound flooding can avoid a series of unfavorable factors caused by the alkali. Under the circumstances of choosing reasonable surfactant, the system can have lower interfacial tension and flooding effect which are close to the ternary system. Therefore, it is given attention by the researchers[5-9]. The flooding mechanism of SP system is shown by two aspects. Firstly, it relies on the polymer solution viscosity, reduces the oil/water mobility ratio, increases the macroscopic sweep efficiency, and expands swept volume so as to achieve the purpose of improving reservoir oil recovery efficiency. Secondly, it relies on the surfactants to make the crude oil get emulsion. By reducing the interfacial tension, it strips the residual oil from the rocks and forms a large number of oil-in-water tiny drops. And these tiny drops form easy flowing O/W emulsion. With emulsification capture oil emulsifying effect it is driven out of the formation so as to enhance the oil recovery. Therefore, the interfacial tension and emulsion performance of the system play an important role in the enhancement of the oil recovery. In order to explore the influence of interfacial tension and emulsion performance of SP system on the flooding effect of low permeability core, six different kinds of surfactants with interfacial tension and emulsion performance are used to carry out the SP complex system physical simulation flooding experiments on low permeability artificial core respectively.

II. THE EXPERIMENTAL PART

A. The Experimental Apparatuses

The experimental apparatuses include the chemical flooding automation core displacement system, the core displacement automatic acquisition device, UF5000 type thermostat, UITRA-TURRA type emulsion dispersion high speed agitator, TX-500C type spinning drop interface tensiometer, etc.

B. Experimental Materials

The surfactants used in the experiment: the mahogany petroleum sulfonate PS, the heavy alkylbenzene sulfonate HABS and other auxiliary surfactants. The compound system of surfactants with the code of H1~H6 mentioned above is used in the experiment. The polymer is KYPAM acrylamide polymer with comb type produced by Beijing Hengju (The molecular weight is 1700-1900 and the degree of hydrolysis is 25~30%).

The oil used in the experiment: The dehydrated crude (The density is 0.8316 g/cm3 under the condition of 50 °C) and the kerosene (The density is 0.7815 g/cm3 at normal temperature and the viscosity is 1.33mPa.s) are mixed into the simulated oil according to the ratio of 3:4. The experimental materials include the sodium chloride, sulfuric acid, sodium bicarbonate, etc.

The water used in the experiments: The total mineralization degree of simulated formation water is 11238.15mg/L.
The core used in the experiments. The parameters of artificial core can be seen in Table I.

<table>
<thead>
<tr>
<th>Core Number</th>
<th>Length (cm)</th>
<th>Diameter (cm)</th>
<th>Air Permeability $\times 10^{-3}$ µm²</th>
<th>Porosity (%)</th>
<th>Oil Saturation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>J-1</td>
<td>6.06</td>
<td>2.44</td>
<td>43</td>
<td>17.1</td>
<td>68.2</td>
</tr>
<tr>
<td>J-2</td>
<td>6.02</td>
<td>2.47</td>
<td>46</td>
<td>18.1</td>
<td>66.5</td>
</tr>
<tr>
<td>J-3</td>
<td>6.01</td>
<td>2.49</td>
<td>44</td>
<td>17.4</td>
<td>67.6</td>
</tr>
<tr>
<td>J-4</td>
<td>6.11</td>
<td>2.45</td>
<td>46</td>
<td>16.9</td>
<td>69.7</td>
</tr>
<tr>
<td>J-5</td>
<td>6.19</td>
<td>2.46</td>
<td>45</td>
<td>17.5</td>
<td>64.5</td>
</tr>
<tr>
<td>J-6</td>
<td>6.05</td>
<td>2.46</td>
<td>48</td>
<td>16.8</td>
<td>67.0</td>
</tr>
</tbody>
</table>

C. The Experimental Methods

The oil-displacement experiment methods can be carried out according to “SY/T 6424-2000 compound flooding system performance test methods” of China petroleum industry standard. The basic process of oil-displacement experiments is shown as follows. First, the formation water should be vacuumized to saturate the core. The vacuum pumping time is more than 10h. Then the simulation oil is injected till the water can’t come out of it with the constant speed of 0.1 mL/min. The residual oil saturation on the core is formed with the aging time of 24h. After the initial water flooding achieves the water cut of more than 98%, it will be transformed into the chemical flooding. Then after the chemical agent with 0.4PV is injected, it will be transformed into the water flooding. It won’t stop transforming till the water cut achieves more than 98%.

![Figure 1. The flow chart of oil displacement experiment](image)

In the process of experiment, the differential pressure, the oil recovery and oil pump capacity, the water quantity and the total fluid quantity are recorded in the intervals. They are used to calculate the recovery rate and moisture content of water flooding and chemical flooding.

III. THE EXPERIMENTAL RESULTS AND ANALYSIS

A. The Emulsion Performance Measurement of Flooding System

The emulsion strength comprehensive index is the physical quantity with the quantitative characteristics of flooding agent emulsion performance. The product of emulsifying ability and emulsion stability the unit is extracted the square root so as to get % as the unit. The emulsifying ability $f_e$ refers to the percentage of the total amount for the oil amount and the emulsified oil extracted in emulsion phase.

The calculating formula is

$$f_e = \frac{C_o \times 50 \times 50}{m \times \frac{W_o}{W_o + W_s}} \times 100 \times 100$$  \hspace{1cm} (1)

In the formula, $f_e$ — the emulsifying ability, %;
$W_o$ — the weighted crude oil quality, g;
$W_s$ — the weighted 10% surfactant solution quality, g;
$C_o$ — the oil content checked from the standard curve, g/L;
$m$ — the weighted quality of the emulsion mixture, g.

The test method can be seen in GB/T11543-2008 “Evaluation Method of Characteristic Test and Emulsifying Ability for the Surfactants with the Medium and High Viscosity”.

The emulsion stability $S_e$ refers to the size of the emulsion stability after the oil and the water are emulsified sufficiently by a certain amount of emulsifiers. The emulsion diversion ratio $S_u$ in a certain time can be used to represent $S_e$. So the relationship between the emulsion stability and the emulsion diversion ratio is

$$S_u = (1 - S_e)$$  \hspace{1cm} (2)

The relationship between the emulsion strength comprehensive index and the emulsifying ability $f_e$ and the emulsion stability $S_u$ can be shown as follows.

$$S_o = \sqrt{f_e \times S_u}$$  \hspace{1cm} (3)

In the formula, $f_e$ — the emulsifying ability, %;
$S_u$ — the emulsion stability, %;
$S_o$ — the emulsion strength comprehensive index, %.

The emulsion strength comprehensive index value is between 1 and 100. It shows that the stronger the value is, the greater the system emulsion performance is. For the tension size of screening interface, there are three kinds of lower flooding systems and three kinds of ultra-low flooding systems respectively. And the emulsion performances are excellent (The emulsion strength comprehensive indexes are 73 and 78 respectively), medium (The emulsion strength comprehensive indexes are 50 and 52 respectively) and poor (The emulsion strength comprehensive indexes are 24 and 29 respectively) respectively.

B. The Measurement of Interfacial Tension

Under 50°C, the spinning drop interfacial tensiometer with TX-500C type is used to measure the interfacial tension between the simulated oil and different flooding systems.
C. The Core Flooding Experiments

Six low permeability cores in total whose permeabilities measured with gas are all less than 50×10⁻³µm² are selected in the experiment. The mass fraction of surfactant in SP binary flooding slug is 0.3%. Polymers all adopt KYPAM. The mass fraction is 0.1%. The injection rate is 0.4PV. The results of oil displacement experiments can be shown in Table II.

<table>
<thead>
<tr>
<th>Core Number</th>
<th>Flooding Slug Number</th>
<th>Flooding Slug Composition</th>
<th>Interfacial Tension, mN/m</th>
<th>Emulsion Performance</th>
<th>Water Flooding Recovery Efficiency, %</th>
<th>Chemical Flooding Enhanced Recovery Efficiency, %</th>
<th>Eventual Total Recovery Efficiency, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>J-1</td>
<td>1</td>
<td>0.3%H1+0.1%KYPAM</td>
<td>6.89×10⁻³</td>
<td>Excellent</td>
<td>49.7</td>
<td>13.9</td>
<td>63.6</td>
</tr>
<tr>
<td>J-2</td>
<td>2</td>
<td>0.3%H2+0.1%KYPAM</td>
<td>4.33×10⁻³</td>
<td>Medium</td>
<td>42.9</td>
<td>16.1</td>
<td>59.0</td>
</tr>
<tr>
<td>J-3</td>
<td>3</td>
<td>0.3%H3+0.1%KYPAM</td>
<td>2.62×10⁻³</td>
<td>Poor</td>
<td>40.5</td>
<td>16.7</td>
<td>57.2</td>
</tr>
<tr>
<td>J-4</td>
<td>4</td>
<td>0.3%H4+0.1%KYPAM</td>
<td>4.13×10⁻²</td>
<td>Excellent</td>
<td>45.2</td>
<td>15.5</td>
<td>60.7</td>
</tr>
<tr>
<td>J-5</td>
<td>5</td>
<td>0.3%H5+0.1%KYPAM</td>
<td>4.09×10⁻²</td>
<td>Medium</td>
<td>42.1</td>
<td>18.7</td>
<td>60.8</td>
</tr>
<tr>
<td>J-6</td>
<td>6</td>
<td>0.3%H6+0.1%KYPAM</td>
<td>3.66×10⁻²</td>
<td>Poor</td>
<td>41.7</td>
<td>18.6</td>
<td>60.3</td>
</tr>
</tbody>
</table>

Figure 2. System 4 in the core displacement experiment curve

The emulsion performance is excellent. Seen from the experiment curve, after the water flooding makes the water cut of crude oil reaches 98%, the inlet pressure also has the instantaneous rise. After a period of time, it slows down gradually. The recovery efficiency of crude oil rises gradually and it won’t stop till the water cut of crude oil reaches 98%. Other five kinds of systems in the core displacement experiment curves are consistent with the trend in the above figure. It shows that after the compound binary system is injected, under the interfacial tension is lower or ultra-low condition, no matter how excellent the emulsion performances are, these all can make the recovery efficiencies of crude oil all get a certain improvement.

Seen from the experiment results, the highest chemical flooding enhanced recovery efficiency is System 5. Its interfacial tension is 4.09×10⁻² mN/m. Its emulsion performance is medium. The chemical recovery efficiency increment is 18.7%. The recovery efficiency increment of System 6 is 3.66×10⁻² mN/m. Its emulsion performance is poor. While its interfacial tension is 6.89×10⁻³ mN/m. System 1 has the excellent emulsion performance. The chemical recovery efficiency increment is 13.9%. It is the lowest in the six groups of experiments.

System 4 in the core displacement experiment curve can be seen in Fig.2.

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Among the three kinds of flooding systems with ultra-low interfacial tension, the recovery efficiency increment of System 3 with the poor emulsion performance is 2.8% higher than the recovery efficiency increment of System 3 with the excellent emulsion performance and 0.6% higher than the recovery efficiency increment of System 3 with the medium emulsion performance respectively. Among the three kinds of flooding systems with lower interfacial tension, the recovery efficiency increment of System 5 with the medium emulsion performance is 2.8% higher than the recovery efficiency increment of System 5 with the excellent emulsion performance and 0.6% higher than the recovery efficiency increment of System 3 with the poor emulsion performance respectively. Therefore, as far as the enhanced recovery efficiency of permeability core is concerned, the systems with the excellent emulsion performance are not the best choice. The systems with the medium or poor emulsion performance have stronger enhanced recovery efficiency ability. Compared with the medium and high permeability reservoirs, it has apparent difference. For the medium permeability core, the enhanced recovery efficiency of binary compound systems will increase gradually with the enhancement of emulsion performance. For the low permeability core, the enhanced recovery efficiency of systems will reduce gradually with the enhancement of emulsion performance. The enhanced recovery efficiency of the systems with the medium and poor emulsion performance is apparently higher than the systems with the excellent emulsion performance.

Although the emulsification can cause the decrease of formation permeability, the effect has not been too great for the oil reservoirs with higher permeability [10]. The reasons for that are shown as follows. When the formation permeability is higher, the pore radius is relatively larger. The emulsion liquid drop diameter formed by the systems with good emulsifying ability and crude oil is small. The crude oil emulsion formed after the emulsion can flow out of the pore throat smoothly. Therefore, in the oil reservoirs with medium permeability the systems with good emulsifying ability have more apparent effect on the enhancement of crude oil recovery efficiency.

Compared with the oil reservoirs with medium and high permeability, the oil reservoirs with low permeability have even more complex pore throat structure. In the SP system flooding process, compared with the systems with medium and lower emulsifying ability, the systems with excellent emulsifying ability can form the smaller emulsion liquid drop with the smaller particle diameter. What’s more, the produced emulsifying carrying phenomenon is obvious so as to make the rapid output of flooding system. While the SP system with medium and lower emulsifying ability can form larger particle diameter of emulsion liquid drop with the crude oil. The emulsification capture phenomenon is more obvious than the former one. The Jamin effect produced in the flooding process increases the filtrational resistance in the pore channel so as to improve the distribution of the flow field in the whole pore space and delayed the filtrational speed of oil-displacing agent along the mainstream line to a certain extent. The occurrence of large amounts of oil drops effectively expands the swept volume of the system and improves the sweep efficiency of the system flooding, and benefits the startup of remaining oil. Therefore, it has the higher recovery efficiency of crude oil.

3) The change trend of the injection pressure of each system in the core

Fig.3 is the change trend chart of injection pressure of oil displacement experiment.

![Figure 3. The change trend chart of Injection pressure](image)

Seen from the figure, for low permeability cores, after the completion of water flooding injection SP flooding system, the injection pressures are all significantly increased. For the systems with low interfacial tension, after the rise of their injection pressures their pressure values have short duration, and the influence of the emulsification system of compound system on the injection pressure is not very obvious. It shows that after the injection of flooding system it outputs quickly along the mainstream line to reduce the pressure quickly. For the systems with relatively high interfacial tension, after the rise of the injection pressure, their pressure values have longer duration. What’s more, the system has better emulsion performance, and the injection pressure has higher increasing range. It shows that the emulsion formed by the emulsification has the emulsion plugging effect on the low permeability cores.

IV. CONCLUSION

Firstly, for low permeability cores, under the condition of the same interfacial tension, viscosity and slug size of the system, the chemical flooding crude oil recovery efficiency increment will reduce with the enhancement the enhancement of emulsion performance. The systems with the medium or poor emulsion performance have significant effect on the increment range of recovery efficiency. What’s more, the injection pressure of the systems with excellent emulsion performance is apparently higher than the systems with the medium or poor emulsion performance. It shows that the emulsion performance of the system has a certain
effect on the oil displacement effect of chemical flooding systems.

Secondly, for low permeability cores, under the condition of equivalent emulsion performance, when the interfacial tension of compound flooding system reaches the ultralow status, the best oil displacement effect can’t be obtained. The degree of enhanced recovery efficiency for the systems with lower interfacial tension is larger than the systems with the ultralow interfacial tension.

Thirdly, for the low permeability oil reservoirs, based on the interfacial tension and the emulsion performance of the system the correct choice should be done in the process of choosing the compound system.

REFERENCES


