Enhanced Oil Recovery Using Polymer/nanosilica

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Abstract

Recent developments in nanotechnology illustrates that addition of nanoparticles in the polymer flooding process can improve the oil recovery factor. But there exists few researches about the polymer performance in the presence of nanoparticles. Also there is no information about the effect of silica nanoparticles on the heavy oil recovery during the polymer flooding by anionic hydrolyzed polyacrylamide (HPAM). Therefore, for the first time in this study the effect of nanosilica (NS) in the polymer flooding in the presence of salt on the oil recovery factor has been investigated in a strongly oil wet five-spot glass micromodel saturated with the heavy oil and the image processing technique was applied to analyze the displacement mechanisms and also for calculation of the efficiency in each flooding test. The oil recovery factor after one pore volume of the injected fluid has been obtained and results indicate that in the presence of NS an improvement about 10% in the ultimate oil recovery can be achieved and this is due to the viscosity enhancement of the injected fluid. Also it has been understood that nanoparticles have ability to change the wettability to water-wet in some portions of the micromodel.

1. Introduction

Enhanced oil recovery (EOR) techniques are developed to increase the oil recovery by improving the microscopic and macroscopic sweep efficiency, Sheng (2014). In other words, EOR methods reduce the mobility ratio and tendency of fingering, Chierici (2012) and also have effect on the porous media properties. Researchers found that between different materials used in EOR processes, polymers have potential to improve the mobility ratio by increasing the injected fluid viscosity and reduce the permeability of water phase, SA et al. (2010), Shi et al.
In addition, recent developments in nanotechnology illustrate that addition of nanoparticles in the polymer flooding process can enhance the oil recovery factor, Maghzi et al. (2011), Maghzi et al. (2014). But there exists few researches on the polymer performance in the presence of nanoparticles. Also, there is no information about the effect of silica nanoparticles on the heavy oil recovery during the polymer flooding by anionic hydrolyzed polyacrylamide (HPAM). Therefore, for the first time in this study the performance of HPAM/nanosilica (NS) in the presence of salt on the oil recovery factor has been investigated. Experiments were performed in a quarter five-spot glass micromodel and in order to observe the NS effect on wettability alteration of the porous medium, three flooding tests including water flooding (WF), polymer flooding (PF) and nano-polymer flooding (NPF) were performed.

2. Materials and Methods

2.1. Materials

The materials properties used in this study are illustrated in Table 1. It should be noted that SDS and DW sequently refer to sodium dodecyl sulfate and distilled water.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Molecular Weight</th>
<th>Density (gr/cm³)</th>
<th>Degree of hydrolysis</th>
<th>size</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPAM</td>
<td>16×10⁶ D</td>
<td>-</td>
<td>20-25%</td>
<td>-</td>
</tr>
<tr>
<td>SiO₂</td>
<td>60.08 gr/mol</td>
<td>2.40</td>
<td>-</td>
<td>11-13 nm</td>
</tr>
<tr>
<td>NaCl</td>
<td>58.44 gr/mol</td>
<td>2.16</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SDS</td>
<td>288.38 gr/mol</td>
<td>1.01</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DW</td>
<td>18.01 gr/mol</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Toluene</td>
<td>92.14 gr/mol</td>
<td>0.87</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

In order to supply a stable solution for the injection, different concentrations of HPAM/NS/NaCl/DW/SDS have been tested and finally the best combination of materials has been obtained. It is worthy to mention that addition of SDS was needed to control the suspension stability. To prepare the polymer solution, 3 wt.% NaCl was mixed in distilled water, then solid HAPM (0.08 wt.%) was added to brine water and the sample was slowly stirred by the mechanical stirrer in 100 rpm for 48 h. To produce the nanosuspension NS (0.5 wt.%) stirred for 30 minutes in distilled water, then SDS (0.12 wt.%) was added and mixed again for 30 minutes. After that the suspension sonicated by the ultrasonic probe (400W, 20k Hz) for 30 minutes and simultaneously solid HAPM (0.08 wt.%) was added to water with 3wt % salinity and the sample was slowly stirred by the mechanical stirrer in 100 rpm for 48 h. Finally the polymer solution was added slowly by burette to the NS solution.

2.2. Experimental Procedure

The micromodel setup (Fig. 1) includes an accurate low rate syringe pump, a micromodel holder, light source, a vacuum pump and a professional camera that is equipped with a recording system and captures photos of the EOR process in each 2 minutes. It is worthy to note that the data were analyzed with Photoshop software to calculate the recovery factor (Equation (1)).

\[ R = \frac{S_{oi} - S_{or}}{S_{oi}} \]  \hspace{1cm} (1)
where, \( R \) is the oil recovery and \( S_{oi} \) and \( S_{or} \) are initial and residual oil saturation, respectively. The heterogeneous glass micromodel (Fig. 2) was designed based on the thin section of a real porous medium by Corel Draw software and using the laser technology. The physical properties of the used model are presented in table 2.

![Fig. 1. Schematic of the micromodel setup.](image1)

![Fig. 2. The porous medium schematic used in this study.](image2)

**Table 2. Physical properties of the micromodel.**

<table>
<thead>
<tr>
<th>Dimension (cm)</th>
<th>Porosity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6×6×0.006</td>
<td>38</td>
</tr>
</tbody>
</table>

At the start of each test the horizontal glass micromodel was cleaned by toluene and then evacuated with a vacuum pump. After providing the oil-wetting condition of the micromodel it was fully saturated with the heavy oil and then the flooding process with the injection rate 0.0008 cc/min at ambient pressure and temperature was begun. It is worthwhile to note that most of the carbonate oil reservoirs are oil-wet Chilingar and Yen (1983), therefore the following procedure to alter the wettability of glass micromodel from water-wet to strongly oil-wet has been performed for each test. (1) Soaking the porous medium with sodium hydroxide for 1h; (2) Washing the micromodel with distilled water then dry it in an oven at 200°C for 15 min; (3) Preparing a dilute solution of 2% tri chloro methyl silane (TCMS) and 98% dehydrate toluene; (4) Soaking the micromodel with the dilute solution for at least 5 min. A thin film immediately coats the micro model’s internal surface making it water repellent; (5) Washing the model...
with methanol to remove excess siliconizing fluid; (6) Drying the micromodel in an oven at 100°C for 1 h to cure the silicone coating, Romero-Zeron (2004), Maghzi et al. (2011).

3. Results and Discussion

In order to investigate the influence of nanoparticles during the polymer flooding test, it is necessary to inject a stable fluid. Also the constancy should be valid during the process. In that case the stability of nanosuspension with passing time has been checked and results are presented in Fig. 3 and it is clear that after 24 h nanoparticles deposition start, so the solution begins to be unstable and a two phase condition (Fig. 3c) can be observed.

Fig. 3. Stability of nanosuspension after: (a) 0h; (b) 6h; (c) 24 h.

During the fluid injection, the amount of oil recovery was calculated by the image analysis, and results of the ultimate oil recovery after 1 pore volume of the injected fluid are presented in table 3. Also the oil recovery in terms of pore volumes of the injected fluid is plotted in Fig. 4. It is clear from table 3 and Fig. 4 that HPAM and NS compare to water enhance the oil recovery about 10% and 20%, respectively. This is due to an increase in the injected fluid viscosity that improves the oil displacement (Fig. 5) and reduces the fluid front fingering.

Table 3. Results of flooding tests.

<table>
<thead>
<tr>
<th>Test</th>
<th>Breakthrough time (min)</th>
<th>Ultimate Recovery (%)</th>
<th>Viscosity of the injected fluid (cp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WF</td>
<td>42</td>
<td>16.63</td>
<td>1</td>
</tr>
<tr>
<td>PF</td>
<td>64</td>
<td>26.32</td>
<td>8</td>
</tr>
<tr>
<td>NPF</td>
<td>84</td>
<td>35.00</td>
<td>35</td>
</tr>
</tbody>
</table>

Fig. 4. The oil recovery versus pore volume of injected fluids.
NS can react with the cations exist in the solution and also generate a network with the polymer chain. In that case in the presence of nanoparticles, viscosity of polymer solution is 35 time of water. Therefore, the mobility of the injected fluid decreases and the sweep efficiency improves. In addition, it has been obtained that NS can change the wettability condition to water-wet and improves the oil recovery because one of the important mechanism that has effect on the oil recovery is wettability of the medium. As Fig. 5 (a and b) illustrates in the oil-wet medium fingering even in the existence of HAPM happens. Because this polymer has a hydrophilic nature and it will not swell in the oil layer and has inclination to flow through the pore walls and this makes fingerings during the polymer flooding in a oil-wet medium. For better visualization of the wettability alteration, microscopic pictures from the porous medium have been investigated after the breakthrough time and results are shown in Fig. 6. As this figure illustrates by adding NS to the injected fluid, NS have more tendency to adsorb on the pore walls and make them water-wet or partially water-wet. Therefore, NS can reduce the oil layer thickness and this help polymer to adsorb on the pore walls and finally the sweep efficiency can be increased.

![Fig. 5. Oil displacement at breakthrough time for (a) WF; (b) PF; (c) NPF.](image)

![Fig. 6. Effect of NS on the wettability alteration, (a) thin layer of oil (presence of NS) and; (b) thick layer of oil (absence of NS).](image)

4. Conclusion

In this study the effect of nanosilica on the oil recovery in the polymer flooding has been investigated experimentally and it has been obtained that NS has potential to enhance the oil recovery. Because nanoparticles increase the injected fluid viscosity and also at the pore scale they are able to change wettability of the medium to water-wet or partially water-wet.

References

Chilingar, G.V.; Yen, T., 1983. Some notes on wettability and relative permeabilities of carbonate reservoir rocks, II. Energy Sources, 7, 67-75.
flooding in heavy oil reservoirs. Petroleum Science, 7, 251-256.