IMPROVEMENT OF ENHANCED OIL RECOVERY (EOR) BY FOAM FLOODING IN POROUS MEDIA

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ABSTRACT
A new and challenging technology of enhanced oil recovery (EOR) is foam flooding. Foam can improve oil recovery by increasing sweep and displacement efficiency. Internal olefin sulfonate (IOS) with different carbon chain lengths, i.e., C15-18, C19-23 and C24-28, were employed to investigate their ability to enhance oil recovery in a sand pack flooding apparatus. Two flooding techniques, namely foam and surfactant flooding, were conducted to compare the oil removal efficiency. The condition was performed at atmospheric pressure and room temperature in the presence of brine condition. The results indicated that these three surfactants can additionally recovered more oil at 5-10% of OOIP. Both foam and surfactant flooding techniques gave similar amount of additional oil; however, the surfactant flooding required higher quantities of the surfactant solution and gave slower oil breakthrough from the sand pack compared to the foam flooding.

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INTRODUCTION
Oil recovery process from primary and secondary recovery can approach 35-50% of the original oil in place under economic and technology limitations. Enhanced oil recovery plays a significant role to recover large oil resources remaining in the reservoir. Gas injection has been used as the EOR method for long period of time due to its great displacement efficiency. However, gas has considerably high mobility and low density. These properties lead to poor sweep efficiency problems due to gas segregation, channeling and early breakthrough. Foam flooding is one of the interesting methods using the gas and surfactant solution to form multiple phase fluid to help control mobility, divert injected fluid to low permeability zone and improve sweep efficiency in the oil recovery process (Sheng, 2013). However, the main problem of foam flooding is the stability of foam in existing oil and brine in the reservoir and other environmental conditions. In addition, foam generation and decay mechanism in porous medium exhibit differently compared to those of bulk foam. Not only temperature or pressure but pore size, wettability and surfactant loss on the rock surface also affect the foam and stability considerably. When the stability of foams is low, foams cannot propagate through a large distance of formation over the period of operation, causing foams to be less efficient to recover more oil. Foaming agent is an important factor which can be easily improved due to its numerous types and characteristics. Sansen et al. (2015) performed a static foam test using internal olefin sulfonate (IOS), including C15-18, C19-23 and C24-28. They found that the shortest
chain IOS, C15-18, created the most stable foam. Robin (1974) reported that polymer can be added to increase the liquid-phase viscosity to improve foaming performance. The purpose of this work is to determine the ability to enhance oil recovery of different surfactant systems with the presence of brine condition in silica sand pack column at low pressure and the temperature of 25±2 °C and to compare two techniques used in enhanced oil recovery: foam flooding and surfactant flooding.

EXPERIMENTAL

A. Materials and equipment
A schematic of the experimental apparatus is shown in Figure 1. Foams were produced by flowing gas and surfactant solutions through the column to recover the oil phase which is n-haptane in this study. The study were performed using sand pack glass chromatography column with 2.5 cm diameter and 15 cm long. Silica sand from Herosign Margeting.Co.,Ltd with 50-70 mesh (212-300 μm) is packed in the column as the porous media. The surfactants used in this work are Internal olefin sulfonate (IOS) with different carbon chain lengths as listed in Table 1. The surfactant concentration was kept constant at 10 times above the critical micelle concentration (CMC) with 0.01wt% of brine solution (NaCl:CaCl₂ weight ratio of 8:2).

<table>
<thead>
<tr>
<th>Surfactant</th>
<th>Active content (%)</th>
<th>CMC (%wt)</th>
<th>Concentration used in this study (%wt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOS C15-18</td>
<td>28.03</td>
<td>0.0047</td>
<td>0.047</td>
</tr>
<tr>
<td>IOS C19-23</td>
<td>33.38</td>
<td>0.0050</td>
<td>0.050</td>
</tr>
<tr>
<td>IOS C24-28</td>
<td>33.00</td>
<td>0.0530</td>
<td>0.530</td>
</tr>
</tbody>
</table>

The gas used in the experiment is air with 99.99% purity. Air is purged through a mass flow controller to ensure a constant flowrate. Pressure gauges and a differential pressure transmitter are installed to measure the pressure in the surfactant and gas lines and the differential pressure between inlet and outlet of the column due to pressure loss in the sand pack, respectively. The surfactant solution, oil and brine were injected into the system by a syringe pump. Produced fluids leave the column to a sample collector and the quantity of aqueous and oil phases are measured to determine the amount of additional oil recovery.

B. Experimental procedure
All experiments were conducted at ambient temperature (25±2 °C) and atmospheric pressure. The experiment of procedures are described below.

B1. Sand pack preparation
A sand pack is used to simulate as the reservoir rock. Silica sand was screened by a sieve shaker to obtain a homogenous sand pack. Dry packing was selected to pack the column by pouring the sand gradually into the column and tightening it by tapping flow adapter gently until it reached 3 inches of height.
Figure 1 Sand pack apparatus

B2. Oil recovery procedure

First, the sand pack column was flooded with oil at a rate of 1 cm$^3$/min for about 3-4 pore volume (PV). The total injected volume and the exited volume of oil were measured and calculated to determine pore volume and porosity. From this injection, both initial oil saturation ($S_{oi}$) and original oil in place (OOIP) reached 100%. The secondary oil recovery or water flooding was performed by using 1 PV of 0.01wt% of brine solution at a rate of 0.6 cm$^3$/min. Oil was displaced by brine until it reached the residual oil saturation ($S_{or1}$) when no more oil exits the column. After water flooding, surfactant solution and air were introduced to the column by using a co-injection method at a rate of 0.6 and 5.4 cm$^3$/min respectively. These flow rates produced a 90% foam quality measured at atmospheric pressure. The foam quality is defined as the fraction or percentage of the gas in total fluid volume. Foams were generated in-situ and propagate through the sand pack to displace oil. The produced fluids were collected in vials with a fraction collector. After residual oil saturation ($S_{or2}$) was reached, additional oil recovery over water flooding was calculated. Surfactant flooding also followed the same procedure (excluding gas co-injection) to compare with the foam flooding method.

RESULTS AND DISCUSSION

A. Surfactant flooding

A series of sand pack flooding experiments were conducted to study the ability to enhance the oil recovery by Internal olefin sulfonate (IOS) with different carbon chain lengths by using n-heptane as an oil phase. Surfactant flooding and foam flooding were performed to compare the efficiency. After the column was saturated with oil, the porosity of the silica sand pack was determined as 38-43%. Figure 2 compares the percentage of oil recovery by surfactant and foam flooding for all three IOSs. For all tests, the cumulative oil recovery
from water flooding was 57-65% of OOIP. 1 PV of brine was injected. After this injected volume, the effluent oil volume is less than 10% of the collected sample volume.

**Figure 2** Summary of total oil recovery of Internal olefin sulfonate (IOS) with different carbon chain lengths (C15, C19 and C24) by foam (denoted by F) and surfactant (denoted by S) flooding

**Figure 3** Cumulative of oil recovery by surfactant flooding with three different carbon chain lengths of Internal olefin sulfonate (IOS)

In surfactant flooding, the series of Internal olefin sulfonate (IOS) were introduced as liquid surfactant solution into the column. The cumulative oil recovery of n-heptane as a function of pore volume (PV) of injected fluids was presented in Figure 3. Total cumulative oil
recovery after the whole process was about 67-72% OOIP. 10-12 PV of surfactant solution was used to remove leftover oil. The amount of additional oil recovery by IOS C15-18 and C24-28 were not significantly different (6.15 and 7.84% of OOIP respectively). Meanwhile, IOS C19-23 can recover 2.27% OOIP after secondary oil recovery which is the lowest amount among all 3 IOSs. Oil breakthrough was observed at 2.36 PV or 1.36 PV after injecting surfactant solution for IOS C19-23 and no additional recovery was obtained afterward. This may occur by channeling effect. For IOS C15-18 and IOS C24-28, the oil breakthrough was observed at 3.69 PV and 4.34 PV after injecting surfactant solution and the cumulative oil recovery continually increased. However, these agreed well with Interfacial tension (IFT) data from spinning drop tensiometer measurement as shown in Figure 4. Although the surfactants were able to enhance the oil recovery, this method required many pore volumes of surfactant solution to recover more oil. In Figure 3, it can be seen that the oil breakthrough can be observed after 3-4 PV of surfactant solution were injected to the column. In addition, this required solution more than 10 PV due to channeling effect in porous media.

![Interfacial tension data of n-heptane and Internal olefin sulfonate (IOS)](image)

**Figure 4** Interfacial tension data of n-heptane and Internal olefin sulfonate (IOS)

**B. Foam-enhanced surfactant flooding**

The effect of foam injection on oil displacement by improving the sweep efficiency was demonstrated by the co-injection of air and surfactant solution into the sand pack column to generate foam in-situ. In Figure 2, the cumulative oil recovery by foam flooding was 67-70% of OOIP. 7 PV of surfactant solution, 6-9% of n-heptane was recovered by foam flooding as shown in Figure 5. The amount of oil recovery are not significantly different for among all 3 IOSs. In addition, the first oil breakthrough in foam flooding process was observed after 1-2 PV of surfactant/air solution was introduced to the column. The oil breakthrough was occurred earlier in the foam flooding as compared to the surfactant flooding. Foam is the multiphase fluid which can reduce the channeling effect in a reservoir by diverting displacing fluid from high to low permeability zone. This decreases the mobility ratio between displaced and displacing phase (Schramm, 2000). Consequently, oil can be recovered earlier in foam flooding than surfactant flooding method. The amount of
additional oil recovery from IOSC15-18 and C24-28 by foam flooding is similar to surfactant flooding. However, the additional oil recovery of IOS C19-23 has the significantly changed from 2.27 in surfactant flooding to 8.08% in foam flooding. The dominant mechanism of surfactant flooding is the solubility. The surfactant takes time to solubilize with the oil and is consumed at high injection volume. While mobility and sweep efficiency are the key mechanisms in foam flooding causing the earlier oil breakthrough and less surfactant consumption as shown in Table 2. The surfactant flooding consumed the surfactant solution 4 PV more than the foam flooding except the IOS C19-23 which only 0.68 PV of surfactant solution used because the oil could not be recovered after this injected volume.

![Percentage of oil recovery by foam flooding with three different carbon chain lengths of Internal olefin sulfonate (IOS)](figure)

Figure 5 Percentage of oil recovery by foam flooding with three different carbon chain lengths of Internal olefin sulfonate (IOS)

<table>
<thead>
<tr>
<th>Surfactant</th>
<th>Method</th>
<th>Foam</th>
<th>Surfactant</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOS C15-18</td>
<td></td>
<td>27 (1.73 PV)</td>
<td>84 (5.16 PV)</td>
</tr>
<tr>
<td>IOS C19-23</td>
<td></td>
<td>108 (6.23 PV)</td>
<td>12 (0.68 PV)</td>
</tr>
<tr>
<td>IOS C24-28</td>
<td></td>
<td>120 (7.02 PV)</td>
<td>192 (11.58 PV)</td>
</tr>
</tbody>
</table>

CONCLUSIONS

In this work, surfactant and foam flooding were compared to study the efficiency of Internal olefin sulfonate surfactants. The result showed that three different carbon chain lengths of can similarly recover the remaining oil in sand pack in both approach. However, foam flooding required the surfactant solution less than surfactant flooding. Because foam
can improve the mobility which is the dominant mechanism compared to solubility for this series of surfactants.

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REFERENCES


