Evaluation of the Impacts of using Single and Combined Low Cost Surfactants on Enhanced Oil Recovery


Chemical & Petroleum Engineering Department, Igbinedion University, Okada. Edo State, Nigeria.

E-mail: azuokwu.azubike@iuokada.edu.ng

*Corresponding author

ABSTRACT

Due to the high cost of most surfactants used in the oilfield enhanced oil recovery, this study was conducted to evaluate the impacts of using single and combined low cost surfactants (Teepol and Tween 80). In the study oil and water wet porous media were subjected to water flooding followed by surfactants.

Water flooding operations yielded an average recovery factor of 46.42 % and 52.59 % and an average displacement efficiency of 49.3% and 55.2 % for oil wet and water wet systems respectively.

After water flooding operations and subsequent surfactant flooding with Teepol (anionic surfactant), a recovery factor of 64.69% and 73.52 % and a displacement efficiency of 69.33% and 72.82% were obtained for oil wet and water wet systems respectively. The water flooding and the subsequent surfactant flooding operations with Tween 80 (nonionic surfactant) resulted to the displacement efficiencies and recovery factors of 73.27% and 76.89% and 67.60% and 77.33% for the oil wet and water wet systems respectively. The results further showed that both surfactants are good enhanced oil recovery agents however Tween 80 was better than Teepol for light oil recovery.

The displacement efficiencies and recovery factors obtained due to water flooding and the synergy of the two surfactants for the oil wet and water wet systems were 71.89% and 75.19% and 66.15% and 75.08% respectively, which showed positive synergies between anionic and nonionic surfactants.

Results further showed that both the water flooding and surfactants flooding operations were more favourable in water wet systems than in oil wet systems.

Keywords: Single and Combined Low Cost Surfactants, Water Flooding, Surfactant Flooding, Recovery Factor, Displacement Efficiency
1. INTRODUCTION

The field of enhanced oil recovery (EOR) has received more attention in recent years due to constant rise in the demand for crude oil and the corresponding depletion in conventional reserves coupled with the desire to improve oil recovery beyond primary and secondary recovery. Studies have shown that the overall recovery factors for combined primary and secondary recovery range between 35 and 45% [1-4]. The remaining oil left after primary and secondary recovery operations over long-time periods is usually distributed in pores in the reservoir, where the oil is trapped, mainly due to capillary forces and viscous forces [5-7]. EOR is oil recovery by injection of gases or chemicals and/or thermal energy into the reservoir [8]. The basic mechanisms of EOR include increasing volumetric sweep efficiency and enhancing displacement efficiency through IFT reduction and decrease in mobility ratio [9, 10].

Among the various EOR methods, Chemical Enhanced Oil Recovery (CEOR) has been used worldwide for many decades and the fundamental CEOR is the Surfactant Flooding [11]. According to [12], surfactants are chemical substances that adsorb on or concentrate at a surface or fluid/fluid interface when present at low concentrations in a system. They consist of a lipophilic portion (hydrocarbon group) and hydrophilic portion (polar group) which are the non-polar (tail) and polar (head) portions respectively [13].

Wettability and interfacial tension are significant issues in oil recovery [14-16]. Surfactant flooding enhances oil recovery through the mechanism of interfacial tension reduction, or wettability alteration, or a combination of both mechanisms [11, 17].

Several surfactants are available for enhanced oil recovery. They are majorly classified into anionic surfactants, non-ionic surfactants, cationic surfactants and zwitterionic surfactants. [18]. Surfactants can be used single or combined form during flooding operations [19-22].

Surfactant flooding has been rated as one of the effective and widely applied enhanced oil recovery process [23]. However, due cost of most surfactants, efforts have been focused on the search for alternatives, and improvement on the existing low cost oilfield surfactants [23-24, 17]. This study was therefore conducted to evaluate the impacts of using single and combined low cost surfactants on oil recovery.

2. MATERIALS AND METHODS

2.1 Materials

(a) Low Surfactants [(i) Teepol (ii) Tween 80]

Teepol is an anionic surfactant by shell and has a density of 1.03g/ml at 20°C. The teepol comprises Myristyl trimethyl ammonium bromide and hydrogen peroxide (H₂O₂)
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Tween 80 also called Polysorbate 80 is a nonionic surfactant and emulsifier. This synthetic compound is a viscous, water-soluble yellow liquid. It has a molar mass 1310 g/mol, a Chemical formula C_{64}H_{124}O_{26}, a density of 1.06-1.09 g/mol and oily liquid.

(b) Crude oil (light), 32˚API

(c) Glass Beads (Soda Lime Glass Spheres) - Class IV Soda Lime Glass Spheres from MO-SCI Speciality Products, L.L.C, A subsidiary of MO-SCI Corporation 4040 Hypoint North Rolia, MO 65401 USA were used as porous media in all flooding experiments. The Glass beads have a particle size distribution of -60+80 mesh.

(d) Others materials include Brine- NaCl, H_{2}SO_{4}, kerosene.

(e) Apparatus- Core holder (bulk volume of 112.9 cc), peristaltic pump, beakers, stop watch, measuring Cylinders, Fann Viscometer, Magnetic Stirrer, UPS, Weighing Balance and Oven

2.2 Methods

The processes involved in this work include glass beads preparation, slug preparation, Porous media preparation and flooding experiments.

Glass Bead Preparation

Glass bead of 80 microns was used all through this experiment. Water wet and oil wet beads samples were prepared and used.

100% Water Wet Glass Bead

About 1400g of dry glass bead was washed and treated with 5% of H_{2}SO_{4} solution to etch it for the removal of any organic substances attached to it. The etched glass bead was properly rinsed to remove H_{2}SO_{4} with sufficient water. Water was sieved out and dried in an oven for about 48 hours. The dry glass bead was labeled 100% water wet.

100% Oil Wet Glass Bead

About 700g of the dried water wet glass bead was measured, properly soaked and mixed in kerosene. The kerosene coats the surface of the glass beads particles increasing its affinity for oil (oil wet). Kerosene was sieved out from the glass bead. Kerosene- treated glass bead was oven dried as shown below for about 72 hours to attain a completely oil wet beads.

Reagents Preparation

(a) Brine Preparation

2% by weight of NaCl was measured and added to 98% pure water in a beaker to form the brine solution. The solution was stirred with a magnetic stirrer to form a uniform solution for about 10 minutes.
(b) Surfactant Preparation

The surface active substance used in this experiment was Teepol and Tween 80. Teepol slug and Tween 80 slug were used at a concentration of 0.9% prepared with magnetic stirrer. Thus, 0.9% by weight of surfactants, Teepol and Tween were measured into a 99.1% brine solution (2% NaCl) and stirred with a magnetic stirrer to attain a uniform surfactant solution to obtain two slugs. Also 0.45% of Teepol and 0.45% of Tween were missed together in 99.1% brine to constitute a mixture of the two surfactants.

Flooding Experimental

Six different flooding experiments were performed as shown in Table 1. Water flooding was followed by surfactants flooding. The experimental set is shown in Figure 1.

The experimental procedures are in tandem to those stated by Oluwaseun et al. [25], with some modification and are outlined below:

i. The core holder was loaded with glass bead (soda lime glass spheres) and vibrated as incremental loading takes place to remove air bubbles and ensure uniform distribution of grains in the porous media.

ii. The weight of the core holder with the glass bead is measured.

iii. Core holder was held vertically in a retort stand and completely flooded with the 2% brine solution at a flow rate of 0.8cc/min to avoid fingering. The core holder is then weighed and the pore volume calculated.

iv. Oil saturation was carried out by flooding the porous media horizontally with light dead oil at a flow rate of 2.0cc/min and the water displaced from the core holder is collected in test tubes. Drainage continues for about one hour until water cut is less than one percent. This was done to determine the initial oil saturation and residual water saturation. The effluent fluid was collected in 100ml measuring cylinders. The volume of displaced water is equivalent to the volume of oil injected (steady state).

The displacement efficiency $E_D$ was calculated as:

v. 2% brine solution was used to perform water flooding at a flow rate of 2.0cc/min. The breakthrough time was recorded. Water flooding continues until a water cut of approximately 96%. This is done to determine residual oil saturation estimated based on the volume of oil collected in the measuring cylinders.

vi. 0.7 PV of the 0.9% concentration of Teepol surfactant, Tween 80, and the mixture of the two surfactants were injected into the porous media at a flow rate of 2.0cc/min at different time. This helps to reduce the interfacial tension holding back the residual oil in the porous media after water flooding and release the trapped oil.
These procedures were followed for the six different experiments with different wettability and surfactant slugs.

The following calculations were made.

\[ PV = \left( \frac{W_{CH+\text{brine saturated glass beads}} - W_{CH+\text{dry glass beads}}}{\text{Specific Gravity of Brine}} \right) - \text{(dead volume)} \]  

Where:
Specific gravity of brine = 0.01197 and Dead Volume = 2.4cc.
W = Wight, CH = Core Holder.

The Porosity is calculated as:

\[ \text{Porosity} = \frac{\text{Pore Volume}}{\text{Bulk Volume}} \]  

The displacement efficiency \( E_D \) was also calculated as:

\[ E_D = \frac{S_{oi} - S_{or}}{S_{oi}} = 1 - \frac{S_{or}}{S_{oi}} \]  

*holder with dry glass beads*

**Figure 1.** Experimental Set-Up
Table 1. Experimental Nomenclature

<table>
<thead>
<tr>
<th>SN</th>
<th>Expt.</th>
<th>Wettability</th>
<th>Initial Flooding</th>
<th>Subsequent Surfactant Flooding</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X₁</td>
<td>Oil Wet (oil wet porous media)</td>
<td>Brine Solution</td>
<td>Teepol</td>
</tr>
<tr>
<td>2</td>
<td>X₂</td>
<td>Water wet (water wet porous media)</td>
<td>Brine Solution</td>
<td>Teepol</td>
</tr>
<tr>
<td>3</td>
<td>Y₁</td>
<td>Oil Wet (oil wet porous media)</td>
<td>Brine Solution</td>
<td>Tween 80</td>
</tr>
<tr>
<td>4</td>
<td>Y₂</td>
<td>Water Wet (water wet porous media)</td>
<td>Brine Solution</td>
<td>Tween 80</td>
</tr>
<tr>
<td>5</td>
<td>Z₁</td>
<td>OILWET (oil wet porous media.)</td>
<td>Brine Solution</td>
<td>Teepol + Tween 80</td>
</tr>
<tr>
<td>6</td>
<td>Z₂</td>
<td>Water Wet (water wet porous media)</td>
<td>Brine Solution</td>
<td>Teepol + Tween 80</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION

The results the studies are presented in Figure 2 to Figure 5.

**Figure 2. Result of Flooding Experiments**

**Figure 3. Result of Displacement Efficiency (Water Flooding)**
Figure 4: Result of Displacement Efficiency due to water flooding and Surfactant Flooding

Figure 5. Recovery Factors due Water Flooding and Surfactants Flooding

3.1. Water Flooding

For the Oil Wet porous media, the volume oil recovered after water flooding operations, were 14.8cc for Expt.X₁, 15.0 cc for Expt.Y₁ and 14.9cc for Expt.Z₁ (Figure 2). For the Water Wet porous media, the volume oil recovered after water flooding operations were 16.8cc for Expt.X₂, 17.0cc for Expt.Y₂ and 16.9cc for Expt.Z₂ (Figure 2).
For the Oil Wet porous media, the Recovery Factor after water flooding operations, were 46.25 % for Expt.X₁, 46.73 % for Expt.Y₁ and 46.27 % for Expt.Z₁. For the Water Wet porous media, the Recovery Factor after water flooding operations, were 52.34 % for Expt.X₂, 52.80 % for Expt.Y₂ and 52.65 % for Expt.Z₂. Thus the average recovery factor for the oil wet porous media obtained from water flooding operations was 46.42 % as compared to 52.59 % obtained in water wet porous media. This showed that water-wet system exhibited greater oil recovery under water flooding than oil-wet system.

For the Oil Wet porous media, the average displacement efficiency after water flooding operations was 49.3% while for the Water Wet porous media, the average displacement efficiency after water flooding operations was 55.2 %. This further showed that water flooding favoured of water wet beads pack than oil wet bead.

### 3.2. Surfactant Flooding

The injection of Teepol into the beads pack after water flooding in the oil wet beads resulted to additional oil recovery of 5.90cc (18.44% of the Initial Oil in place). The total displacement efficiency and recovery factor due to water flooding and surfactant flooding with Teepol in oil wet beads were 69.33% and 64.69% respectively. In water wet beads pack, a further 6.80cc (21.18% of the Initial Oil in Place) was recovered with Teepol. The total displacement efficiency and recovery factor due to water flooding and surfactant flooding with Teepol in oil wet beads were 72.82% and 73.52 % respectively. These results showed that flooding with the anionic surfactant was in favour of water wet systems (Figure 4 and 5).

Tween 80 recovered about 6.70cc (20.87% of the Initial Oil in place) in oil wet and 7.90cc (24.53% of the Initial Oil in place) in water wet packs after water flooding operations. The displacement efficiencies recorded due to water flooding and surfactant flooding with Tween 80 for the oil wet and water wet systems were 73.27% and 76.89% respectively. The recovery factors obtained due to water flooding and surfactant flooding with Tween 80 for the oil wet and water wet systems were 67.60% and 77.33% respectively. These results showed that flooding with the nonionic surfactant was more favourable to water wet systems (Figure 4 and 5).

Flooding with the mixture of the two surfactants resulted to a further recovery of 6.40cc (about 19.88%) for oil wet condition and 7.20cc (about 22.43%) for the water wet condition. The displacement efficiencies recorded due to water flooding and the synergy of the two surfactants for the oil wet and water wet systems were 71.89% and 75.19% respectively. The recovery factors obtained due to water flooding and the synergy of the two surfactants for the oil wet and water wet systems were 66.15% and 75.08% respectively.

The study further showed that both surfactants are good enhanced oil recovery agents however Tween 80 was better than Teepol for light oil recovery at a concentration of 0.9% (Figure 5). Tween 80 has been noted for its IFT reduction and wettability alteration abilities [26-29]. The results of the injection of mixtures of 0.45% of Tween
80 (a nonionic surfactant and emulsifier) and 0.45% of Teepol (an anionic surfactant) into the beads pack after water flooding showed a positive synergy between anionic and nonionic surfactants. The results of the synergisms between the two surfactants were more favourable to water wet systems than oil wet systems (Figure 4 and 5).

3.3. Visual Observation

Figure A1 showed the effluent from the Injection of Tween 80, while Figure A2 showed that from Teepol injection. It can be observed that the effluent of Tween 80 has a cloudy phase below the oil. This is a region of low interfacial tension and micro-emulsion, while for that of Teepol, the phase below the oil level is clearer which shows that the interfacial tension between the oil and water is higher than that of the previous.

4. CONCLUSIONS

In this study, the impacts of using single and combined low Cost Surfactants in enhanced oil recovery were determined. Teepol, an anionic surfactant and Tween 80 a nonionic surfactant were used in the study. The processes involved in this work include glass beads preparation, slug preparation, Porous media preparation and flooding experiments (water flooding followed by surfactants flooding).

Water flooding operations yielded an average recovery factor of 46.42 % and 52.59 % and an average displacement efficiency of 49.3% and 55.2 % for oil wet and water wet systems respectively. These showed that water flooding is more favourable with of water wet systems.

After water flooding operations and subsequent surfactant flooding with Teepol, a recovery factor of 64.69% and 73.52 % and a displacement efficiency of 69.33% and 72.82% were obtained for oil wet and water wet systems respectively. Thus water flooding operations and the subsequent surfactant flooding with Teepol was more favourable with water wet systems.

The water flooding operations and subsequent surfactant flooding with Tween 80 resulted to the displacement efficiencies and recovery factors of 73.27% and 76.89% and 67.60% and 77.33% for the oil wet and water wet systems respectively. These showed that water flooding operations and the subsequent surfactant flooding with Tween 80 is more favourable with water wet systems.

The study further showed that both surfactants are good enhanced oil recovery agents however Tween 80 was better than Teepol for light oil recovery.

The displacement efficiencies and recovery factors obtained due to water flooding and the synergy of the two surfactants for the oil wet and water wet systems were 71.89% and 75.19% and 66.15% and 75.08% for the oil wet and water wet systems respectively. These results showed positive synergies between anionic and nonionic surfactants. The synergisms between the two surfactants were more favourable to
REFERENCES


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Publishing © 2010 ELSEVIER Inc. pp 199.


[18] Susanna Laurén (2019): “Why is wettability important in enhanced oil recovery”? Biolin Scientific,


APPENDIX

Figure A1. The Effluent of Tween 80 Injection

Figure A2. The Effluent of Teepol Injection