Performance of Nonionic Surfactant for EOR on Various Salinity and Hardness of Water

Reno Pratiwi, Abidia Marina Saputri, Lestari Said

Abstract—Water as a surfactant’s solvent media that will be mixed with petroleum has salinity and hardness that affects the performance of the surfactant. Generally, nonionic surfactants are used as co-surfactants since they are relatively more resistant to dissolved salt and minerals in the water. The purpose of this study therefore was to analyze the process conditions for non-ionic surfactants to achieve the best performance. Compatibility, interfacial tension of oil-water, phase behavior, and thermal resistance are parameters considered. Field observations were made on variations of salinity and hardness of water. Additionally, Ca²⁺ ions were chosen as electrolytes which are widely found in surfactant solvent water. From this work, the results of nonionic surfactant have excellent compatibility in all types of solutions observed. The use of 0.5% surfactant in a solution with a salinity of 50,000 ppm and Ca²⁺ 500 ppm ion content was the best in reducing interfacial tension with a value of 2.39·10⁻⁴ dyne/cm. The phase behavior test for seven days observation shows there are similarities with type I emulsion Winsor. Result shows that nonionic surfactants have potential to dissolve under various solution, condition, and were useful in reducing interfacial tension at salinity values up to 50,000 ppm and Ca²⁺ 500 ppm concentration. The emulsion formed showed the ability of surfactants to develop oil-water emulsion. The thermal test fails to yield satisfactory results since the recommendedIFT value only lasts one day.

Index Terms—Nonionic Surfactant, Enhance Oil Recovery, Salinity, Hardness Water, Electrolyte, Phase Behavior, Chemical Flooding

1 INTRODUCTION

Increase in the acquisition of petroleum is might be achieved by manipulating the interfacial tension of oil-water trapped in the reservoir pore. Surfactants, with its polar and non-polar groups, are capable of simultaneously dissolving in the water and oil phase [1]. For this reason, they are widely used to reduce oil-water interfacial tension. The anionic ones with polar acid groups are commonly used in rock reservoirs related to sandstone while cationic with polar base groups are often adopted in carbonate reservoirs [2],[3],[4],[5],[6]. The problem faced in the use of anionic and cationic surfactants is the presence of formation water with high contain of mineral salts which affect their performance. Solutes with high concentrations might be reactive to polar surfactant groups, inhibiting the performance of the surfactant [1],[2],[5],[7]. Therefore, if use in EOR, anionic or cationic surfactants are usually accompanied by cosurfactant, which mainly serves to anticipate the high concentration of mineral salts in formation water [2],[8]. A nonionic surfactant is more effective in solutions with high electrolyte concentration since the nature of the polar group is not charged. This means it is not affected by intensity of ions in the solution[8].

In general, the study of the performance of anionic and cationic surfactants in manipulating interface tension has been carried out. One of the most observed parameters is the effect of salinity and the presence of divalent ions due to the use of formation water, on the ability of surfactants to reduce interface tension [9][10][11][12][13].

The study on the performance of nonionic surfactant, in the saline of solutions with divalent ions is still rarely carried out. The reactivity of nonionic surfactants should remain affected by the presence of electrolyte ions in solution. Therefore, this study examine the effects of salinity and hardness water, represented by the presence of divalent ions on nonionic surfactants.

2 RESEARCH METHOD

The nonionic type surfactants were derived from natural ingredients based on palm oil. The study was conducted on a laboratory scale, using an IFT measuring device such as Spinning Drop Interfacial Tensiometer as tool for observation during the study.

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2.1 Compatibility Test
Salinity and water hardness are variables which affect the performance of surfactants in reducing interface tension. For this reason, various types of solutions with concentrations of NaCl and Ca$^{2+}$ were used. The composition of these solutions depended on the conditions of formation water in the oilfield. Furthermore, observation of the effect of NaCl concentration in solution correlates with its salinity, while the influence of intensity of CaCl$_2$ in solution relates to the level of hardness in formation water.

The first parameter in observing the performance of surfactants is their compatibility in liquids. For instance, nonionic surfactants are tested for solubility in several types of solutions. These include synthetic formation water with a mineral content similar to Y oil field formation water (as shown in table 1), and a solution containing NaCl or CaCl$_2$ at various concentrations.

In general, the solution has excellent compatibility if there is no sediment at a specific temperature which is kept constant within a definite time range. The high solubility of surfactant generate low interfacial tension, thus a high oil recovery factor (RF) might be obtained [1].

<table>
<thead>
<tr>
<th>Chemical Component</th>
<th>Amount, gram</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaCl$_2$</td>
<td>0.886</td>
</tr>
<tr>
<td>MgCl$_2$.6H$_2$O</td>
<td>4.471</td>
</tr>
<tr>
<td>NaHCO$_3$.10H$_2$O</td>
<td>0.002</td>
</tr>
<tr>
<td>Na$_2$CO$_3$.10H$_2$O</td>
<td>1.894</td>
</tr>
<tr>
<td>NaCl</td>
<td>5.144</td>
</tr>
</tbody>
</table>

2.2 Interfacial Tension Measurement (IFT)

The Interfacial tension was observed to determine the best performance of the surfactant. Solutions with salinity content ranging from 5,000 to 50,000 ppm were observed for interfacial tension changes after adding nonionic surfactants at various concentration. Moreover, the addition of surfactant 0.05 to 1% into the salt solution was used to establish the effect it has on the interfacial tension. The target of observation is the surfactant concentration, which provides an interfacial value of tension in the range of up to $10^{-3}$ [1],[14]. The same is carried out for solutions with variations in the concentration of CaCl$_2$ in the range of 50 to 500 ppm.

2.3 Phase Behavior Test
The phase behavior test was carried out to determine the type of emulsion formed and the ability of the surfactant to maintain the emulsion within a particular time. Equally, the thermal resistance test determine the extent to which emulsions are formed at a certain temperature. The analysis was carried out for seven days with the temperature kept at a 60°C.

Overall research activities are shown in figure 2. The performance of surfactants was determined by compatibility, IFT, thermal resistance, and phase behavior.

3 RESULT AND DISCUSSION

In compatibility tests, nonionic surfactants showed an excellent response to various solutions. The resulting mixture does not show any turbidity or sediment, indicating the ability of a good surfactant to dissolve in water as the primary medium. Furthermore, the presence of nonionic groups inhibit them from reacting with polar solutes, preventing formation of deposits in the solution.

The IFT test was conducted to determine the best surfactant concentration in reducing interfacial tension. From the observations (Figure 3), the smallest IFT value (0.0042 dyne/cm) was obtained with the use of 0.5%. Figure 3 shows using concentrations higher than 0.5% does not result in a significant reduction in IFT. This is the value of the critical micelles concentration (CMC) of nonionic surfactants used [14]. This concentration value could be used in subsequent observations, meant to change the IFT value for various conditions of salinity and hardness of the water.

The effect of salinity on the performance of surfactants was determined using two different of solutions, one with a composition similar to formation water of Y field, and the other one with 500 ppm Ca$^{2+}$ ions.

The results obtained are shown in figure 4, where solution 2 represents the formation water solution. The IFT value is relatively higher than solution 1 with a Ca$^{2+}$ 500 ppm content.
From table 1, solution 2 used in the observation contains Ca\(^{2+}\) ion of 880ppm. This means it has more divalent ion content compared to solution 1 with. The presence of divalent ions has more influence on the performance of surfactants. Although the nonionic surfactant used is not often influenced by the presence of divalent elements, reactive ions such as Ca\(^{2+}\), at certain concentrations still affect its performance.

The effect of Ca\(^{2+}\) ions representing the hardness of the water on the performance of nonionic surfactants was observed. Without the involvement of NaCl salts in solution, the measured Ca\(^{2+}\) 300 ppm in the solution of IFT was 2.674 dyne/cm compared with the IFT value of Ca\(^{2+}\) 500ppm of 0.03365 dyne/cm. There was a significant decrease in IFT in increasing the content of divalent Ca\(^{2+}\) in solution. In this regard, the performance of nonionic surfactants is not significantly affected by the presence of Ca\(^{2+}\) ions up to a concentration of 500ppm. This is consistent with several studies on nonionic surfactants less sensitive to hydrophobic structures and salinity changes, more tolerant to validations, and insignificantly dependent on alcohol concentration. For some nonionic, pH might also be an important factor [15], [4].

Generally, If the solution used in the observation contain a certain ion divalent (Ca\(^{2+}\)) concentration with various salinity, the result should appears as shown in fig 4. The same tendency was evidence in IFT values in solutions with surfactants, Ca\(^{2+}\) and NaCl ions together. Changes in IFT values in increasing the concentration of Ca\(^{2+}\) in solutions with a salinity of 50,000 ppm can be seen in Figure 5.

The chemical structure of the non-ionic surfactants is hardly changed, even under different emulsifying conditions, due to lack of ionic groups within their molecules. However, the emulsifying capability could be affected by the pH and electrolyte concentration of the dispersing medium since they also possess protonatable groups, i.e., partially localized charges [16].

The CaCl\(_2\) molecule in the solution is ionized into positive and negative ions. The presence of these ions finally attract H\(_2\)O molecules to be hydrated. As a result, the hydroxides increase in the adjacent regions to particles. This is the surface of the charge phase of the oil particle. These results indicate the existence of electrolyte in the oil phase suspensions trigger the destabilization of the suspension, by reducing the electrical repulsive force between particles [17].

From figure 5, the increasing presence of CaCl\(_2\) lessens the performance of nonionic surfactants in lowering surface tension. The solution which also contains a large amount of salinity, which is 50,000 ppm also influences the number of dissolved ions. IFT values that continue to increase until the CaCl\(_2\) concentration of 300ppm, shows the phenomenon mentioned above.
the previous conditions. Figure 4 strengthens the above analysis, where an increase in IFT value is compared with a solution containing fewer ions [7],[4].

Nevertheless, in the solution of surfactant, the operating temperature conditions need to be considered. Generally, the surfactants are thermodynamically unstable in forming emulsion. For this reason, a thermal resistance test is carried out to determine the extent to which surfactants maintain microemulsions formed.

From the 30-days observation of solutions containing 500ppm CaCl₂, salinity was 50,000ppm and 0.5% surfactant used, the data shown in table 2 below was obtained. From the table, that use of nonionic surfactants with a concentration of 0.5% in a solution containing 500 ppm CaCl₂ and a 50,000ppm salinity cannot maintain the expected IFT value. In just 1 day the value of IFT had a significant increase. Also, observing the compatibility of surfactants at the same temperature and time, satisfactory results were obtained. The surfactant could dissolve well in the solution. Although the ability of surfactants to dissolve is still good, as shown in fig 6, its performance is still not as expected [18].

4. CONCLUSION

The tests performed on nonionic surfactants established a range of salinity and water hardness conditions, which provide optimal results in reducing IFT. Salinity with a range of 20,000 to 50,000 ppm and Ca²⁺ concentrations of 300 to 500ppm have the potential to improve the performance of surfactants in manipulating IFT. The emulsion formed from the use of this surfactant is a lower phase and tends to dissolve in water. Further research on the use of this nonionic surfactant for EOR needs to be conducted. This is since the thermal resistance test shows unsatisfactory results, where at a temperature of 60 °C, surfactants are only able to maintain IFT at a value of 10⁻³ in just one day.

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REFERENCES


