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Laboratory Evaluation of the Micellar Flooding as a Tertiary Oil Recovery Method

Amin Azdarpour
Universiti Teknologi Malaysia
Aamin22@live.utm.my

Parham Babakhani dehkordi
Universiti Teknologi Malaysia
babakhani65@gmail.com

Alireza Zare
Universiti Teknologi Malaysia
Alireza_Zare3000@yahoo.com

Abstract

After the reservoir natural drive is depleted, one of the most important methods to reduce residual oil saturation as a tertiary method is Micellar flooding. The investigations showed that around 60% of the reserve recovered by chemical flooding. Surfactant flooding can decrease Inter Facial Tension (IFT), which causes the reduction in residual oil saturation to desired value. There are three types of microemulsion systems when surfactant added to the solution depending upon the amount of salt in the process, which is classified as Winsor Type I, Winsor Type II, Winsor Type III.

In this paper, in order to investigate the impact of surfactant concentration on oil recovery, we used different Alpha Olefin Sulfonate (AOS) surfactant concentrations changing from 0.02 % to 0.1 % and 0.1 % PHPA as a polymer to control mobility. The results showed that increasing surfactant concentration has positive influence on oil recovery and improve oil recovery significantly up to 0.1% surfactant concentration. The effect of salt concentration on oil recovery and IFT were examined using different concentrations of NaCl changing from 0.02% to 0.17% representing Winsor type I and changing from 0.17% to 0.35% representing Winsor type III. The salinity in which IFT is at lowest value is called effective salinity, which gives the highest amount of oil recovery. Results showed that increasing salt concentration at Winsor type I decrease IFT and in Winsor type III, the results indicated that increasing salt concentration has reverse effects on IFT as compare to type I. The effect of salt concentration was investigated on residual oil saturation and results exhibited decreasing in residual oil saturation with increasing salt concentration in Micellar type I and increasing residual oil saturation with increasing salt concentration in Micellar type III.

Introduction

Enhance Oil Recovery (EOR) methods such as chemical flooding, miscible displacement, or carbon dioxide flooding may recover some of remain unrecovered oil originally in place in most light oil reservoirs after the waterflood and the use of thermal methods is more emphasized in heavy oil reservoirs [1]. Chemical EOR methods including polymer, surfactant, micellar, emulsion and alkaline flooding are widely investigated both in laboratory and field applications however, Although many field tests have been carried out, chemical floods have not performed as well in the field as in the laboratory, partly because the experiments are usually unsealed. Scaling criteria for chemical floods have been obtained, but are difficult to satisfy; consequently, laboratory results such as oil recovery vs. pore volumes injected, are not directly applicable to field situations [2].

Micellar flooding is known as microemulsion flooding, micellar-polymer and surfactant-polymer flooding. Generally the basic process consists in injecting a slug of a preflush, followed by the micellar slug proper, followed by a slug of a polymer solution, which is graded into a waterflood [3]. Micellar solution can be also defined as a dispersion of a surfactant in an oleic or aqueous solvent that can stabilizes large amount of water or oil to form either water in oil or oil in water microemulsions [4]. Although micellar flooding process has some limitations regarding the using of chemicals in its structures, the long term potential for the recovery of residual light oils makes this method one of the most technically applicable methods in the field scale as a tertiary recovery method for low pressure and depleted oil reservoirs. The high cost of this method is due to use of large amount of chemicals in this method, therefore the concentration of the component should be chosen carefully to maximize its effectiveness [5].

To study the compatibility of the designed slug with the reservoir fluids, it is convenient to refer to the ternary diagram drawn to study the phase behavior of the intended slug with the reservoir crude, connate water, temperature and mobility buffer solution. So for an effective recovery of oil, the multiphase region should be minimal so as to prolong the locally miscible displacement. Also, the interfacial tension should be low for an effective immiscible displacement in the multiphase region [6].

In order to show each component of the microemulsion (water, oil and surfactant), ternary diagram is used to indicate the phase behavior of the microemulsion as shown in figure 1 [7]. The model proposed by Winsor explains the simple situation by the presence of three pure components in which the multiphase region is bounded by a continuous bimodal curve. Everywhere above the binodal curve a single phase exist that undergoes transitions among various structural states as the compositional point moves about the diagram. These transitions may be gradual, reflecting an equilibrium in which there is significant coexistence of difference of different micellar configuration [8].

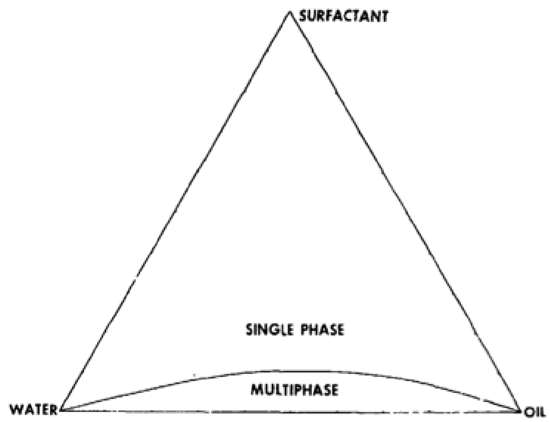

Figure 1. Ternary diagram representation of microemulsion system

In the multiphase region, the most simple, three- component system involves only two phases throughout; one is oil-external and the other water-external. In this case, the two phases lie at opposite ends of a tie line and disappear equally at a plait point. The plait point would also be a phase inversion point for compositions along the binodal curve. The problem of field application work is that, in the real world we can never find three pure components and there are always more than three pure components in the system and there is also three or more phases in equilibrium in certain portions of the multiphase region. Sometimes the structure of all these phases are not simple because these phases may contain combinations of spherical and lamellae micelles, cylindrical micelles or a dispersion of surfactant in either water or oil which make the identification of and construction of tie lines more difficult.

Winsor's Intermicellar Equilibrium Concept

S1-phase is the spherical micelles having oil cores and is dispersed in water and S2-phase is the oil external phase. And the G phase is the intermediate lamellar structure that can be a gel or liquid crystal. All these components can make equilibration with each other depending on the type of the components in which are used. Therefore using this definition, a wide variety of equilibrations can be made for example Winsor type I is the 0+S1, Winsor type II is W+S2 and Winsor type III is W+(S1,S2)+0. This structure is shown in figure 2 as well [9].

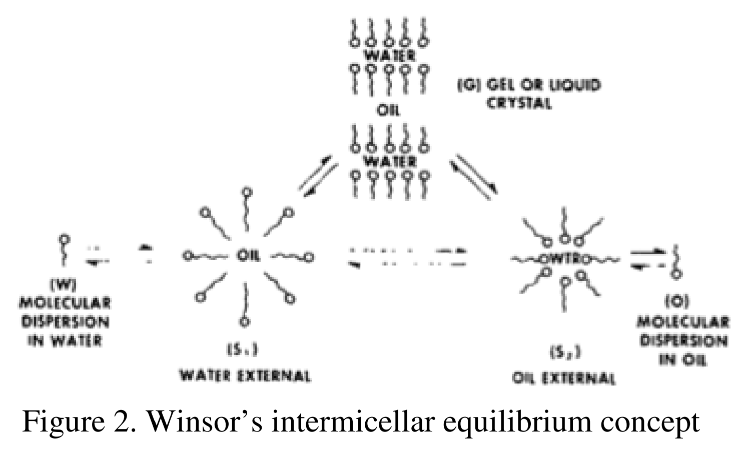

Figure 2. Winsor's intermicellar equilibrium concept

Effect Of Salt Presence On Phase Behavior

Sometimes the number of components is more than three and it is usually six components in which we have surfactant, co-surfactant, polymer, water, brine and oil. In this a pseudocomponent is defined and depending upon the type of investigation, other components would be ignored and the required phase would be emphasized. For example, Healy *et al* investigated the effect of brine on phase behavior of the system using the surfactant-cosurfactant, oil and brine [10]. Some studies investigated the systems consists of alcohol cosurfactant between pseudobrine and pseudohydrocarbon where the isopropyl alcohol (IPA) was used as cosurfactant. The use of this system is only valid if the waterflood and polymer have the same composition as the pseudobrine used in the micellar flooding [11], [12].

Effect Of Salt On Oil Recovery

A sand pack in 1-ft long and 1-inch diameter with the porosity ranges of 30-35% and permeability of 1000 md used at room temperature to find the effect of salt concentration on oil recovery in microemulsion process. Different NaCl concentrations were used as salt. NaCl concentrations changes from 0.02% to 0.17% representing Winsor type I and from 0.17% to 0.35% representing Winsor type III. In order to condition the sandpack, preflush was used as well. A set of displacement tests carried out to figure out the role of each parameter on oil recovery. The displacement sequence was first brine injection to make the sandpack fully saturated with brine. Then we used paraffin oil with the viscosity of 1.48 cp and started to inject around 4 PV to make the sandpack saturated with oil. This process continued with injecting the brine solution to the sandpack to make the residual oil saturation in the sandpack. After generating the reservoir sample, then we started to inject the micellar solution to the sandpack. 1 PV of the micellar solution was injected to the sandpack then followed by 1 PV polymer solution to control the mobility. This process was repeated for different solutions with different concentrations and in each process the oil recovery was measured respectively. In this section, we investigated the effect of different salt concentrations on oil recovery. Different concentrations of NaCl added to the solution and then for all the steps this brine solution was injected to the sandpack and then oil recovery was measured for each case. Table 1 shows the brine concentration used for Winsor type I and the oil recovery for each test as well.

Table 1. Final oil saturation for different salt concentrations in Winsor type I

N NaCl Concentration	Final Oil Saturation %
0.02	29.5
0.04	25.3
0.08	17.7
0.12	11.1
0.15	9
0.17	5.8

The effect of salt concentration on final oil saturation was also examined in Winsor type III and the results are shown in table 2.

Table 2. Final oil saturation for different salt concentrations in Winsor type III

N NaCl Concentration	Final Oil Saturation %
0.17	5.8
0.19	10
0.24	18.9
0.28	22.6
0.32	24.2
0.35	27.5

Theses results show that, increasing salt concentration in Winsor type I, has positive effect on oil recovery in which the final oil saturation is decreased and it means that oil recovery is improved and the second table also show that, increasing salt concentration in Winsor type III has negative effect on oil recovery, because increasing salt concentration increases the amount of final oil saturation which means that oil recovery is decreased. In Winsor type III, the increasing the salt concentration is not consider as a favorable process because of the negative effect on oil recovery, however in Winsor type I, this increase could be names as a favorable process in improving the oil recovery.

Effect Of Salt On Interfacial Tension

Increasing the salt concentration has positive effect on increasing the Interfacial tension, however in microemulsion, this phenomenon has different behavior in which the IFT depends on the type of microemulsion (Winsor types). To see the effect of salt concentration on IFT in Winsor type I, we used different salt concentration and then IFT was measured for each solution and the results are shown in table 3.

Table 3. IFT for different salt concentration in Winsor type I

N NaCl Concentration	Interfacial tension (mDyne/cm)
0.02	537.3
0.04	89.4
0.08	76.5
0.12	35.9
0.15	28.1
0.17	11.9

This table shows that increasing the salt concentration decreases the interfacial tension in Winsor type I, which is favorable in any microemulsion flooding. The lowest value of the IFT is referring to the highest salt concentration (0.17 N NaCl), which is the optimum salt concentration. The effect of salt concentration on IFT in Winsor type III was investigated and results are shown in table 4.

Table 4. IFT for different salt concentration in Winsor type III

N NaCl Concentration	Interfacial tension (mDyne/cm)
0.17	11.9
0.19	14.1
0.24	19.7
0.28	21.5
0.32	25.3
0.35	27.9

This table shows that, increasing salt concentration in Winsor type III does not perform a good condition for the microemulsion because increasing salt concentration results in increasing the interfacial tension. The lowest IFT is for the optimum salt concentration (0.17N NaCl) and then IFT is increased. IFT is in a direct relationship with the oil recovery and as it is shown from the results of oil recovery and IFT data, increasing the salt concentration is not compatible with the microemulsion system because the oil recovery is decreased as a result of increasing in IFT by increasing the salt concentration that is not favorable in compare with Winsor type I.

Effect Of Surfactant On Oil Recovery

The Proper design of surfactant solution play an important role in micellar flooding. There is some limitation to increasing surfactant. The adsorption phenomena into rock surface can prevent the effectiveness of surfactant. In our system, the concentration of surfactant is 0.02% to 0.1%. In all the solutions, the concentration of PHPA polymer is 0.1% to increase volumetric sweep efficiency. Table 5 shows the slug composition of the system. As it can be seen from the table, increase at surfactant concentration up to 0.1 % could result in recovering oil of 0.75 %. It is expected that 0.2 % surfactant would obtain better recovery. However, due to high adsorption in the core, 0.60 % oil recovered which can not be favorable according to the amount of surfactant spent.

Table 5. Oil recovery for different slug composition design

Test No.	C_1	C_2	C_3	C_4	Slug size (% PV)	Oil Recovery
A	0.98	0.0	0.02	0.1	15	0.46
B	0.95	0.0	0.05	0.1	15	0.51
C	0.92	0.0	0.08	0.1	15	0.59
D	0.9	0.0	0.1	0.1	10	0.75
E	0.88	0.0	0.2	0.1	5	0.60

Conclusion

One of the most important factors affecting oil recovery is the amount of surfactant injected. The amount of injected surfactant extremely depends on the level of adsorption. The size of slug is less important unless miscibility mechanism is involved in this case and higher concentration would be better design. According to several works done, one of method to prevent adsorption of surfactant is to add alkaline agents. The amount of oil recovered is significantly sensitive to the degree and amount of salt in the system. In Solution type Winsor I, by increasing salt content the oil recovery sharply reduced. However, at salt content of 0.17 N Nacl and higher, system goes into Winsor type III or middle phase resulting in higher recovered oil up to 27.5 %. Optimum salt content is to be found 0.17 N Nacl in which Interfacial tension is the lowest amount. In Winsor type 1, low concentration of salt gives high interfacial tension, which can not get the oil out of pore volumes. By adding higher values of salt, IFT shows its effect on micellar flooding processes. In Winsor type 3, IFT is the lowest value in effective and optimum salinity in which oil recovery is at its maximum state.

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