Effect of Surfactant and Nanoparticles in Low Salinity Water on Interfacial Tension and Contact Angle

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Abstract. In this study, the mixture of the surfactant, nanoparticles and brine are utilized to investigate the performance for the interfacial tension reduction and contact angle changes at various conditions. From the results, IFT decreased adversely with brine content, whereas the nanoparticles even increased IFT when in used alone in the system. In addition, the temperature and the surfactant concentration have the effects on IFT, and nanoparticles are also the key contributor of ultra-low IFT reduction with the mixture of the surfactant-brine system. Meanwhile, without even the ion changes, the brine can affect the contact angle changes between crude oil and solid surface.
Keywords: SDS, Silica Nanoparticles, Low salinity, IFT and contact Angle Reduction

1 Introduction

Owing to the vast increase in research and development of enhanced oil recovery (EOR) field, the EOR mechanisms are getting better understood. For the need to increase oil recovery, changing the interfacial tension between oil and aqueous phase and wettability alteration of the formation rock becomes the part of the main process for the enhanced oil recovery process [1, 2]. This is due to the oil displacement efficiency in the reservoir on which the capillary number acts as the direct proportional key factor. The capillary number are related to oil water interfacial tension as described in equation 1 where N_{ca} represents the capillary number and σ represents interfacial tension (IFT) [3]. Hence, lowering the IFT can lead to an increase in capillary pressure which in turn, results in good displacement efficiency. The various methods are applied to lower the interfacial tension that affects the fluid flow in the porous media, permeability, and capillary pressure. Another dominant factor on oil entrapment in reservoir is the reservoir rock wettability. The contact angle larger than 90˚ indicates the unfavorable oil wet whist the contact angle smaller than 90˚ indicates the water wet behavior of the rocks which allow the hydrocarbon to freely flow from the rock surface. Thus, the reduction in the contact angle can change the wettability which is also crucial in enhanced oil recovery process.

$$N_{ca} = \mu v/\sigma\varphi \quad (1)$$

Regarding the methods applied with the purpose of IFT reduction and wettability alteration, the chemical methods are intensively used especially the surfactant flooding as well as the polymer flooding and nanoparticles assisted chemical flooding [4]. Moreover, on account of inevitable formation salinity, low salinity water (LSW) flooding has also come into consideration of accomplishing the enhanced oil recovery mechanisms [5]. The mechanisms are responsible for the oil recovery. Hence, this paper will focus on the effectiveness of each of surfactant, nanoparticles and salinity for the reduction of the IFT and contact angle and how the combination could affect the mechanisms as well.

The surfactant has been the most conventional chemical EOR method as it can be efficiently used to reduce the IFT and can be easily accessible. The surfactant forms the micro-emulsion which reduces the oil water interfacial tension. With the combining of the nanoparticles and the surfactants in the aqueous solution, it has an impact on the IFT reduction. Vatanparast et al. [6] intensively proved that with the presence of the nanoparticles, the surfactants can induce more effective IFT reduction. Moreover, it reduces the contact angle between the oil and the rock surface that nanoparticles adsorbed by changing the surface charge on the pore walls. Therefore, the wettability of that rock surface is gradually changed from oil wet to water wet. Therefore, it is the main purpose of nanoparticles assists the surfactant in the EOR process.

At the same time, many researchers have also found out that the LSW flooding can also help achieve these two main mechanisms especially the wettability changes because of the surface charge changes or double layer expansion [7]. Also, many researchers proved that LSW alters the wettability of the rock to becomes water wet. The combinations of these chemicals and brine can promote the favorable condition to improve oil recovery. Many studies have been conducted the effect of surfactant and nanoparticles combination in improved oil recovery processes. However, very few studies have been done to investigate the enhancement of LSW to nanoparticles assisted the surfactant solutions [8].

2 Experimental section

2.1 Materials

The anionic surfactant, silica nanoparticles and brine are the main chemicals used in this study. For the anionic surfactant, sodium dodecyl sulfate (SDS), with a molecular weight of 288.38 g/mol is used and purchased from Sigma-Aldrich with >99 % purity. The silica nanoparticles (SiO2), Aerosil 200, with the molecular weight of 60.08 g/mol is obtained from Evonik Industries with >99.8 % purity. For the brine composition, two types of salts, sodium chloride and sodium bicarbonate are used to imitate the low salinity formation water and both of them are purchased from Ajax Company Ltd. All chemicals are used without any further purification or modification. The oil sample used in this study is acquired from the northern oilfield in Thailand. The salinity of the produced water is relatively low around 500-1,000 ppm.

2.2 Solution preparation

For the mixture of the surfactant-nanoparticle-brine system, Betancur et al. [9] studied the importance of nanofluid preparation for ultra-low IFT and recommended the optimal method of the nanofluid formulation. Therefore, by using their method, the two-base brine solution is mixed, and the surfactant is added, followed by the nanoparticles.

2.3 Interfacial Tension and Contact Angle Measurements

IFT and contact angle change as a consequence of different chemicals added at altering concentration and combinations are studied with the IFT 700 interfacial tension meter from Vinci Company. Due to the lower density of oil than the bulk fluid density, the rising drop method is chosen for IFT measurement, and the sessile up method is selected for the contact angle measurement. All of the measurements are conducted at the temperature from 70˚C to 90˚C.

3 Results and discussions

3.1 The result of IFT measurement

The effects of LSW on IFT are discussed. Like the work of Mahmoudi et al. [10], IFT of nanoparticles at 750 ppm provided the lowest IFT regardless of the surfactant concentrations over a range of brine concentration from 0 to 1,000 ppm are measured as presented in Figure 1. The range of salinity used in this study is adjusted according to the actual operating condition of Fang oilfield. The IFT of crude oil and brine with nanoparticles interface gradually decreases with an increasing brine concentration in the presence of the nanoparticles which provide the different results of LSW flooding that IFT reduces with lowering brine concentration [11]. From Divandari et al.'s work [12], this phenomenon is explained by experimenting over a wide range of brine concentrations. In their work, the concentration of brine was increased from 0 to 150,000 ppm from which, the results show that IFT between crude oil and brine slightly decline with increasing brine concentration and then rises again with constant rate with further increase in brine concentration. According to their finding, IFT will decrease continuously until the brine concentration is reached to 40,000 ppm as the result of oil-in-water and water-in-oil microemulsion [13].

Another explanation is that at low salinity concentrations before the turning point concentration is reached, the IFT reduction can be due to the surface-active agents and the generation of in-situ surfactants due to the reaction between the brine and acidic ingredients of oil [12, 14]. Therefore, the concentrations used in this study is still coherent with the previous research's results of IFT declines with the brine concentrations before the turning point is achieved [15]. The additional finding from the results showing in Figure 1 is that the temperature also effects on the IFT of oil and aqueous phases. An increase in the temperature would cause the increase in IFT as well.

Furthermore, the effects of the surfactant on IFT are tested in the presence of brine and brine mixed with nanoparticles as presented in Figure 2. From the figure, it could be clearly seen that adding surfactants can dramatically reduce the IFT of the systems. Another finding is that temperature has the slight effect on IFT reduction. At the crude oil and brine interface, the IFT slightly increases with the increase in temperature from 70˚C to 90˚C. The reason is largely explained from the literature [16] that IFT decreased and reached the minimum at 35˚C and above that temperature, IFT started to increase slightly due to the decrease in the number of hydrogen bonds between the surfactant head groups and surrounding water molecules. According to the results in Figure 2, IFT does not effectively decrease once the surfactant concentration is more than 2000 ppm and it can be confidently said that using the surfactant concentration beyond 2000 ppm is not necessarily required as it will not provide relatively significant reduction in IFT.

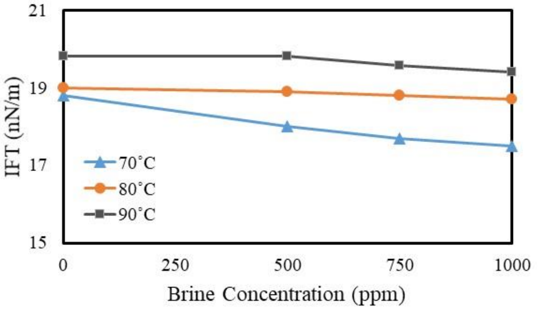

Fig. 1. Effect of salinity on IFT at different temperature.

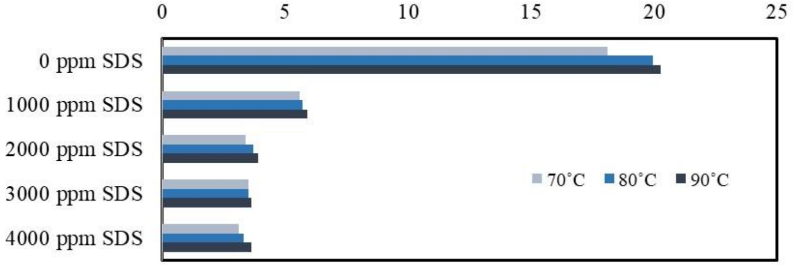

Fig. 2. Effect of surfactant on IFT in the presence of brine 750 ppm.

In addition, IFT changes of using nanoparticles in the aqueous phase and adding in the surfactant brine solution are observed. According to the results shown in Figure 3, an increase in the amount of the nanoparticles can decrease and later increase the IFT which contrasts the objective of EOR mechanisms. It can be said that using only nanoparticles in the system does not have favorable effect for EOR process and it can even worsen the condition.

However, when the surfactant and brine are mixed with the nanoparticles, it aids in the better IFT reduction rather than using only surfactant with brine in the process. The results can be seen in Figure 4 that adding the nanoparticles help reduce the IFT. IFT results of overall experiments comparing adding different combination of surfactant, nanoparticles at 2000 ppm and 750 ppm respectively with varying concentration of brine are presented. The first observation from this comparison is that at 0 ppm salinity, the notable IFT reduction caused by the nanoparticles with the surfactant can be achieved rather than nanoparticles or SDS alone in the system. Moreover, from Figure 4, it can be concluded that in order to reduce IFT for EOR purpose, the mixture of brine, SDS and nanoparticles can support the ultra-low interfacial tension.

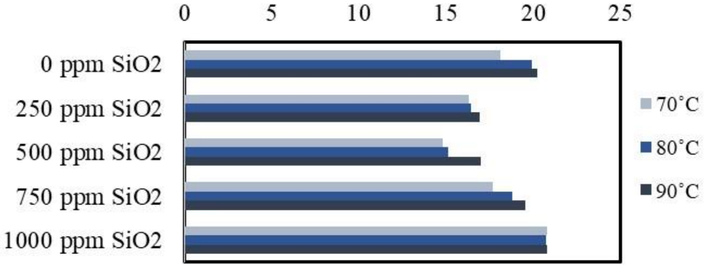

Fig. 3. Effect of nanoparticles on IFT

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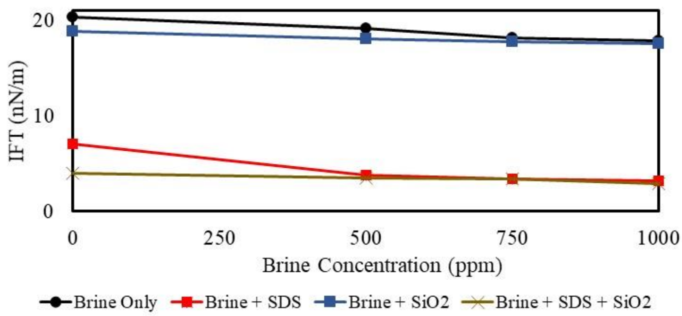

Fig. 4. Results of IFT in brine and surfactant system with and without SiO2

3.2 The result of Contact Angle measurement

The wettability of the reservoir rock surface is investigated when the adsorption of the nanoparticles or surfactants occurs on the rock surface or in such a way that the ion exchange or double layer expansion happens due to low saline water. Therefore, the contact angle measurement is performed to study the interactions of the surface charges between the rock surface and interested chemical solution. In this study, the contact angles alteration due to the different chemicals used are measured on the surface of stainless steel. Thus, the effect of ion exchange behavior between rock and aqueous phase is not considered in the changes described in Figure 5.

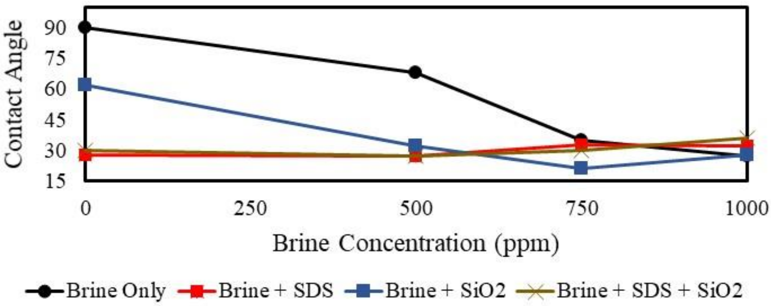

Fig. 5. Contact angle at different solutions.

According to the results, it can be said that without the mechanisms of surface charge changes, the low saline brine still has an effect on contact angle reduction on the surface which can be due to its other mechanisms such as fine particles migrations and pH changes. Moreover, when the change of adding the nanoparticles is focused, the nanoparticles do not have much effect in helping surfactants reduce the contact angle as IFT reduction and the surfactant adsorption are the only the main mechanisms of the nanoparticles.

4 Conclusion

In this study, the effects of salinity, the concentration of the nanoparticles and the concentration of surfactants on the interfacial tensions and contact angles are measured and analyzed the results. According to the results, the following observations and conclusions can be made in this research. IFT can be reduced with the increase in brine concentrations up to the point that it falls in the range of low salinity water. Using only nanoparticles in EOR cannot provide the positive effect on IFT reduction, however if used with low saline brine and surfactant together, it can yield the better effect than using the surfactant and brine themselves. The low salinity water can enhance the performance of the nanoparticles assisted with the surfactant EOR process. The optimal surfactant concentration for the effect of IFT and contact angle reduction for the field of the interest would be at 2,000 ppm in the presence of 750 ppm nanoparticles.

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