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The investigation of the Anionic and Cationic Surfactants effects on the enhanced oil recovery in Iran oil reservoir

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The oil recovery by water flooding from the carbonate reservoir is not effective because of the capillary forces in naturally fractured oil-wet carbonate formations. Alkaline/surfactant solution is recommended to enhance the spontaneous imbibition between the fractures and matrix by both wettability alteration and ultra-low interfacial tensions.
In this study the effects of anionic surfactant, from sulfate family, and a cationic surfactant, from C_nTAB family, on the interfacial tension (IFT), wettability alteration and spontaneous imbibition of oil and outcrop rock samples obtained from Aghajari reservoir were investigated. The experimental results show the effectiveness of these surfactants to be used in this Enhanced Oil Recovery scenario at very dilute concentrations.

Keyword: interfacial tension, wettability alteration, spontaneous imbibitions, surfactant

1. Introduction

The oil recovery methods commonly used are pressure depletion and water flooding. The residual oil left after water flooding in fractured oil-wet reservoir is reported to be very high [1]. This is mostly due to the preferential flow of water as the noon-wetting fluid in the fractures leaving most of the oil saturated matrixes completely unswept. The water imbibition into the matrixes is hindered by the negative capillary pressure in the matrixes.

After conventional water flooding processes, the residual oil in the reservoir as a discontinuous phase in the form of oil drops is trapped by capillary forces [2]. On average, water flooding leaves approximately two third of the original oil in place (OOIP) as residual oil which is the target of further EOR recovery [3].

Surfactants flooding system aims at producing the residual oil after secondary oil recovery with water flooding or gas injection. Producing ultra-low interfacial tension and wettability alteration are the most important mechanisms for oil recovery by surfactant flooding. Surfactant flooding for displacement of oil in the porous media and establishment of positive capillary pressure of reservoir rock were reported [4, 5, 6, 7]. Many flooding systems, especially surfactant-enhanced alkaline systems have been investigated. The alkaline addition into many flooding systems plays an important role in reducing interfacial tension. At the same time, the alkaline can react strongly with the rock in the layer. Therefore, a great quantity alkaline is consumed, and the layer is also destroyed simultaneously. If the surfactant formulation for oil recovery is properly designed and the flow of the formulation is properly controlled in the reservoir, it has a high potential for achieving maximum oil recovery [8, 9].

Liu *et al.* [10] performed a study on using alkaline/surfactant flooding of Western Canadian heavy oil reservoir. They used Na_2CO_3, NaOH as alkaline and alkyl sulfate, alpha olefin sulfonate, linear alkyl benzene sulfonate, alkyl benzene sulfonate and alkyl ether sulfate surfactants. Their experimental results showed that the dynamic interfacial tension of oil/water can be lowered by using a combination of Na_2CO_3 and NaOH solutions at very dilute concentration of surfactant [10].

Spontaneous imbibition tests in oil-wet dolomite cores carried out by Hirasaki and Zhang. No spontaneous imbibition was observed with brine for 8 months, while with alkaline/surfactant solution, spontaneous imbibition was initiated within an hour. However, no conclusion was made toward what factor contributed mostly to the differences in oil recovery observed. Their worker is committed to quantifying the effect of the important factors in alkaline/surfactant enhanced spontaneous imbibition in oil-wet carbonate formations [11].

Nedjhioui *et al.* [12] investigated the effect of using a combination of two anionic surfactants (SDS and Marlon ARL), on water soluble biopolymer (Xanthan gum) and alkaline (NaOH) at various concentrations by measuring conductivity, surface and interfacial tension. They concluded that the mixture of different compounds has an important effect on the conductivity and interfacial tension of these systems and the crude oil/water system [12].

Lorenz and Peru reported that the effectiveness of sodium hydroxide, sodium carbonate and sodium carbonate alkaline compounds for lowering interfacial tension are decreased, respectively [13].

Mohanty in a study used of anionic surfactants Alfotera, cationic surfactant DTAB and oil sample of West Texas, reservoir. He investigated wettability alteration, and imbibition. It was shown that anionic surfactants can reduce IFT more than cationic surfactant but in the wettability alteration cationic surfactant was more powerful than anionic surfactant. His results of oil recovery at core after 48 hours showed that cationic surfactant was more effective than anionic surfactant [14, 15, 16].

Thermal and miscible tertiary recovery techniques are not effective in these reservoirs. Regarding to special properties of fractured carbonate reservoirs, surfactant flooding is a promising method for enhanced oil recovery. Alkaline surfactant solutions are used to recover oil from these reservoirs by enhancing the imbibition of water between fracture and the matrix by both wettability alteration and interfacial tension reduction. Aghajari reservoir is one of these types of reservoirs. Thus, chemical flooding seems to be a suitable method for increasing oil recovery from the reservoir [17, 18, 19].

2. Experimental

2.1. Materials

The anionic surfactant, salt, and alkaline used in this study were sodium dodecyl sulfate, NaCl, NaOH and Na_2CO_3 from Merck. Cationic surfactant, C_{12}TAB, was purchased from Sigma-Aldrich. The oil and outcrop rock used to obtain from Aghajari reservoir, south of Iran.

2.2. Interfacial tension measurement

The prepared anionic solution contained anionic surfactant, 5 wt% NaCl, NaOH and Na_2CO_3, while the cationic solution only included surfactant and 5% wt salt to mimic the reservoir brine enriched with the surfactants.

In order to investigate equilibrium phase behavior of oil and surfactant aqueous solution, the prepared solutions were mixed with reservoir oil in a test tube in 1:1 volume ratio. The test tube was shaken and then left for at least five days to achieve phase equilibrium. The IFT between the top oil layer and the bottom water layer was then measured using tensiometer Kruss K11 model.

2.3. Wettability alteration and spontaneous imbibition

In order to study the effects of these two types of surfactants on wettability alteration and spontaneous imbibition; the outcrop rocks were first saturated with the reservoir oil sample. The saturated rock was then immersed in the aqueous solution at specific surfactant concentration and temperature for 48 hours. This could lead to the determination of spontaneous imbibition of the aqueous solution by measuring the amount of extracting oil from rocks.

The wettability alteration could also be verified by comparing the contact angle between the oil drop and the rock after aging the rock at the specified temperature and concentrations of the surfactants.

3. Results and Discussion

Interfacial tensions between the oil sample and water containing 0.05 %wt of SDS surfactant and 0.5 to 1.5 %wt of Na_2CO_3 at 30 ^oC for various NaOH concentrations were measured. The results obtained at 30, 50, and 70 ^oC is shown in Figures 1, 2, and 3, respectively.

Figure 1 indicates that by increasing the NaOH concentration, an initial sharp decline of IFT to a minimum value occurs. Then IFT increases slightly and finally reaches to an approximate constant level. The minimum amount of IFT was obtained at 1 and 1.5 wt% of Na_2CO_3 and 0.4 mol/lit of NaOH at 30 ^oC.

The amount of IFT decreased more at 1.5 wt% of Na_2CO_3 compared to two other concentrations. Although the trend of IFT reduction at 50 °C (Figure 2) is similar to the IFT at 30 °C (Figure 1), the amount of IFT decreased more at 50 °C compared to that at 30 °C for all concentrations of Na_2CO_3.

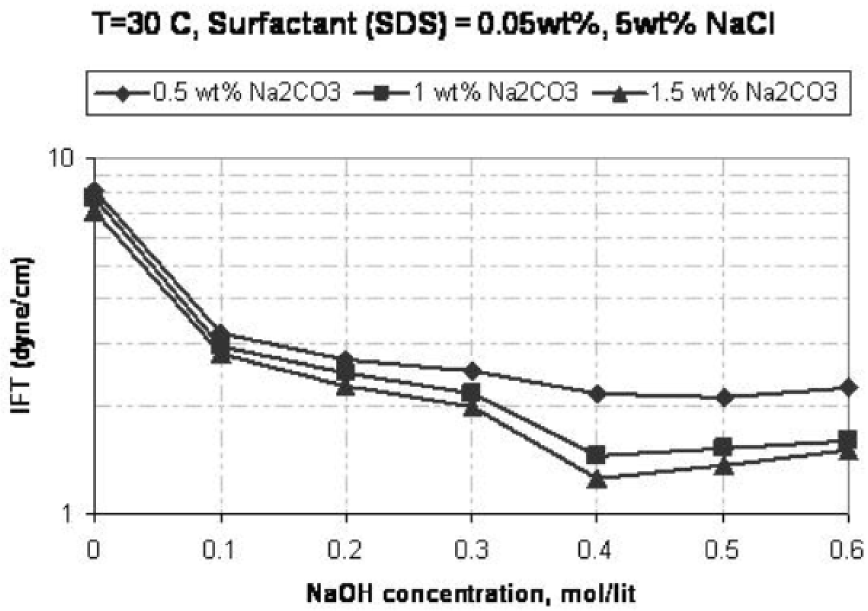

Fig 1: Oil-Water IFT reduction for the solution of 0.05 wt% SDS, 0.5 to 1.5 wt% of Na_2CO_3, and 5 wt% of NaCl and 30 °C at different NaOH concentrations

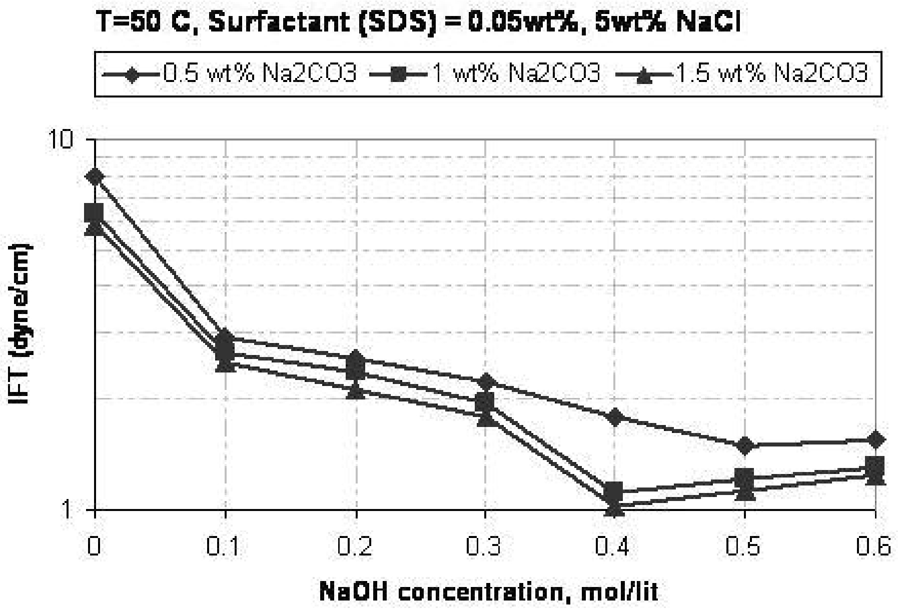

Fig 2: Oil-Water IFT reduction for the solution of 0.05 wt% SDS, 0.5 to 1.5 wt% of Na_2CO_3, and 5 wt% of NaCl and 50 °C at different NaOH concentrations

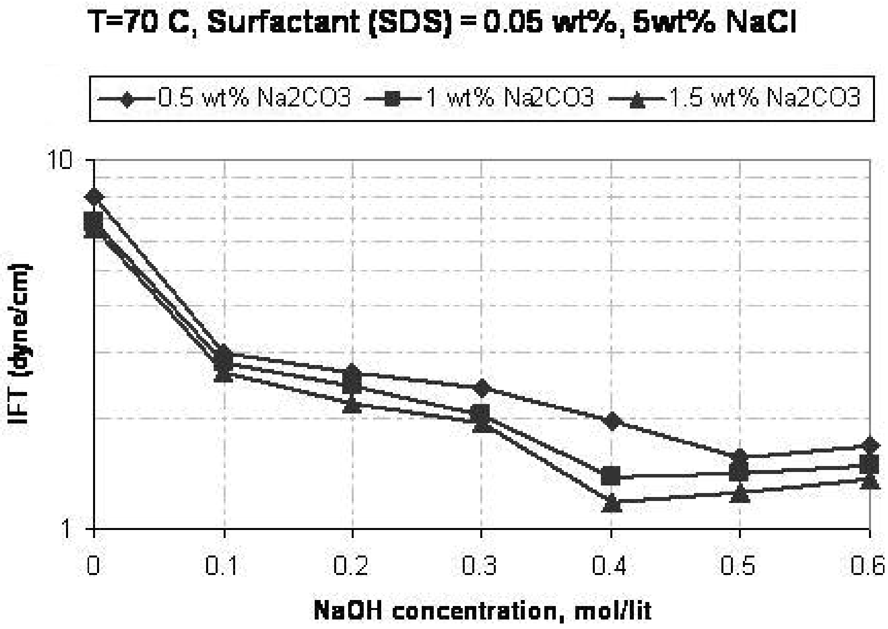

Fig 3: Oil-Water IFT reduction for the solution of 0.05 wt% SDS, 0.5 to 1.5 wt% of Na_2CO_3, and 5 wt% of NaCl and 70 °C at different NaOH concentrations

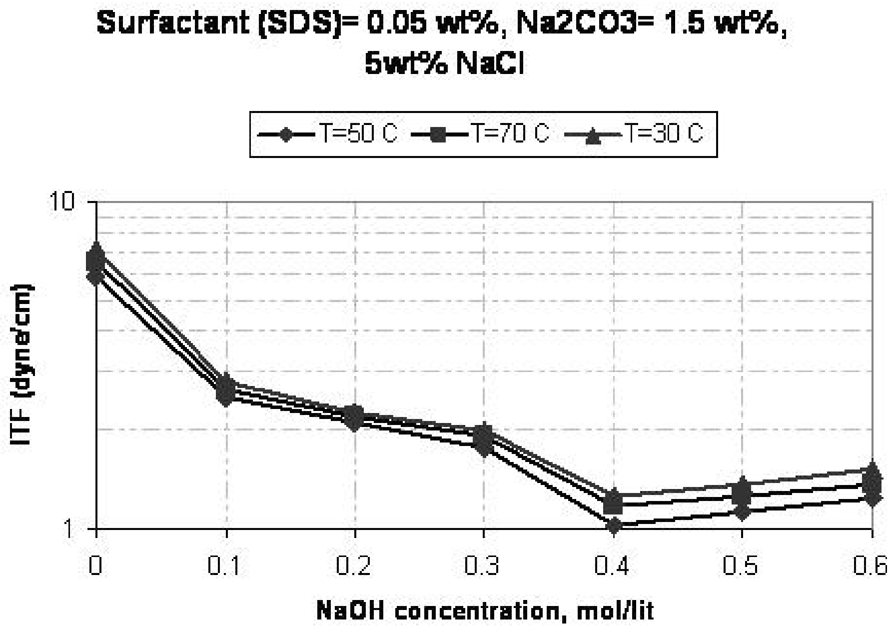

Fig 4: Oil-Water IFT reduction for the solution of 0.05 wt% SDS, 1.5 wt% of Na_2CO_3, and 5 wt% of NaCl and 30, 50 and 70 °C at different NaOH concentrations

The same results of IFT reduction at the same conditions are shown in Figure 3 for 70 °C. This indicates that the optimum temperature for the minimum IFT at the SDS concentration of 0.05 wt% at the mentioned conditions is 50 °C.

As it is shown in Figure 4, the optimum concentration of Na_2CO_3 in which the minimum amount of IFT at the mentioned conditions is 1.5 wt %.

Figures 1, 2, and 3 indicate that the minimum amount of IFT was obtained for 0.5 wt% of Na_2CO_3 at higher concentration of NaOH (0.5 mol/lit) compared with the other concentrations of Na_2CO_3. This suggests that at the higher concentrations of Na_2CO_3, the minimum amount of IFT is obtained at the lower concentration of NaOH solution. Thus NaOH is more effective than Na_2CO_3 to reduce IFT.

The effect of cationic $C_{12}TAB$ surfactant concentration on the oil-water IFT reduction was also examined at the temperatures of 30, 50 and 70 ^{o}C (Figure 5). By increasing surfactant concentration, an initial decrease of IFT to its minimum followed by slight increase was observed. The minimum amount of IFT for this surfactant was obtained for 0.3 wt% surfactant at 70 ^{o}C. Temperature of 70 ^{o}C was more appropriate in comparison with temperatures of 30 and 50 ^{o}C, however it doesn't mean this is definitely the optimum temperature for surfactant as the experiment was not carried out at higher temperatures.

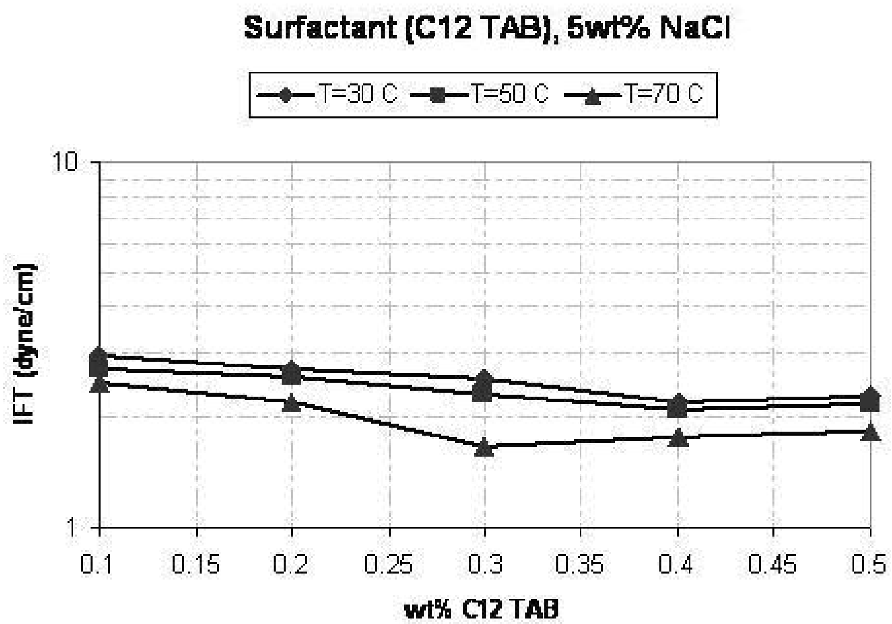

Fig 5: Oil-Water IFT reduction for the solution of 0.05 wt% $C_{12}TAB$, and 5 wt% of NaCl and 30, 50 and 70 ^{o}C

According to Figures 1, 2, 3, and 5, anionic SDS surfactant decreases the IFT at lower concentrations in comparison with $C_{12}TAB$ and therefore it is a more appropriate surfactant.

4. Wettability Alteration Measurement

4.1. Contact Angle Method

The contact angle measurement was applied to find the tendency of the specified reservoir rock for the oil and water solution. The oil and outcrop rock used in this part of study were obtained from Aghajari reservoir, south of Iran.

Figure 6 shows the contact angle of reservoir rock in the presence of brine (5 wt% of NaCl). According to droplet shape and the contact angle between brine droplet and the reservoir rock saturated with oil, the rock demonstrated as mixed wet.

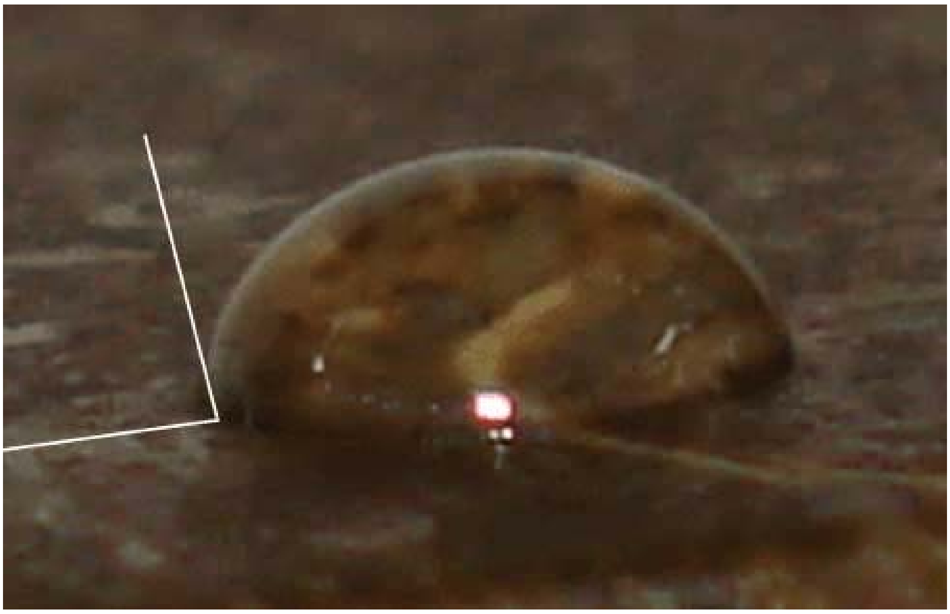

Fig 6: Wettability of reservoir rock in the presence of brine (5 wt% of NaCl)

Figure 7 shows the variation of the reservoir rock wettability in the presence of surfactant solution included 0.05 wt% of surfactant SDS, 5 wt% of NaCl, 1.5 wt% of Na2CO3 and 0.4 mol/lit NaOH at 25, 30, 50 and 70 ^{o}C, respectively. According to Figures 6 and 7, SDS surfactant solution was able to make a remarkable wettability alteration of reservoir rock to water wet. Therefore an increase in temperature had positive effect on the degree of wettability. The higher the temperature, the more the effectiveness on the wettability alteration.

Fig 7: Variation of the reservoir rock wettability in the presence of surfactant solution included 0.05 wt% of surfactant SDS, 5 wt% of NaCl, 1.5 wt% of Na_2CO_3 and NaOH 0.4 mol/lit at, (a) 25, (b) 30, (c) 50 and (d) 70 ^{o}C

Figure 8 demonstrates the reservoir wettability in the presence of surfactant solution composed of 0.3 wt% of surfactant $C_{12}TAB$ and 5 wt% of NaCl, at 25, 30, 50 and 70 ºC, respectively.

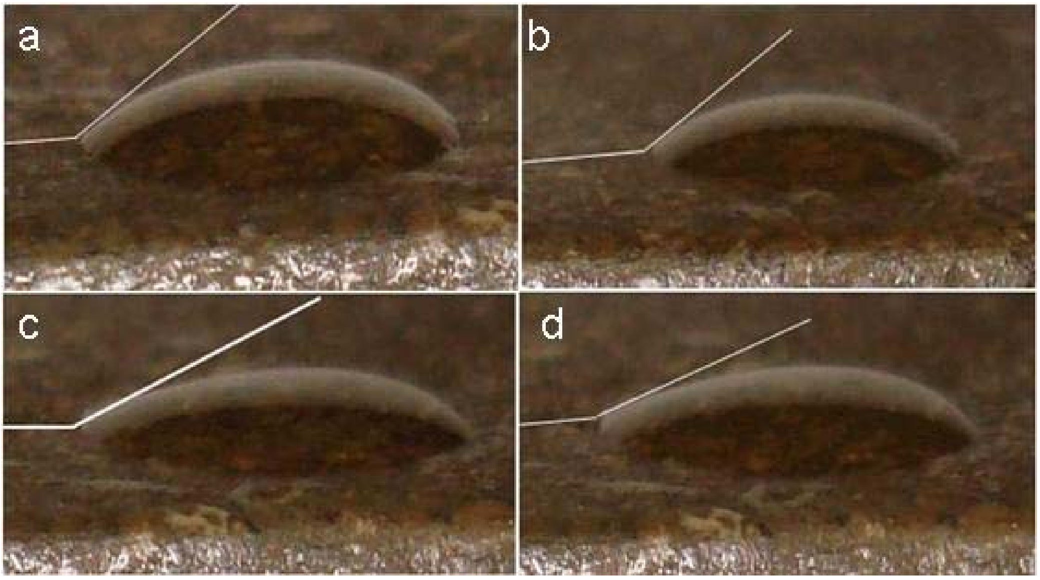

Fig 8: The degree of reservoir wettability in the presence of surfactant solution including of 0.3 wt% of surfactant $C_{12}TAB$ and 5 wt% of NaCl at, (a) 25, (b) 30, (c) 50 and (d) 70 ºC

The appearance of droplet and the contact angle between the droplet and the rock indicates that $C_{12}TAB$ has remarkably altered the reservoir rock wettability. Solution temperature also led to more alteration to degree of wettability.

According to the shape of droplet and the angle between that and the rock (Figures 7 and 8), surfactant $C_{12}TAB$ has altered the reservoir rock wettability more than SDS at the same temperature.

4.2. Spontaneous Imbibition

For indication of spontaneous imbibition and oil recovery from reservoir rock, a solution of SDS surfactant in optimum condition containing SDS surfactant (0.05 wt %), NaCl (5 wt %), Na_2CO_3 (0.05 wt %) and NaOH (0.4 mol/lit) was prepared at 50 ºC. A solution of surfactant $C_{12}TAB$ in optimum condition containing surfactant $C_{12}TAB$ (0.3 wt %), NaCl (5 wt %) at 70 ºC was also prepared and the solutions were used for spontaneous imbibition tests.

Figure 9 demonstrates the spontaneous imbibition and oil recovery from reservoir rock in the presence of a solution of SDS at 50 ºC after 48 h. While, Figure 10 shows the spontaneous imbibition and oil recovery from reservoir rock in the presence of a solution of $C_{12}TAB$ at 70 ºC after 48 h.

According to Figures 9 and 10, the rate of spontaneous imbibition and oil recovery from rock in the presence of $C_{12}TAB$ surfactant solution increased more than that of SDS surfactant solution.

Fig 9: Spontaneous imbibition and oil recovery from reservoir rock in the presence of an optimal solution of SDS at 50 ºC after 48 h

Fig 10: Spontaneous imbibition and oil recovery from reservoir rock in the presence of an optimal solution of C_{12}TAB at 70 °C after 48 h

5. Conclusion

At lower concentrations, more IFT reductions were obtained by anionic surfactant SDS compared with C_{12}TAB.

Surfactant C_{12}TAB alters the reservoir rock wettability more than SDS surfactant at the same temperatures.

The amount of oil production through spontaneous imbibition within 48 hours for the solution C_{12}TAB was higher than that of SDS surfactant solution.

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