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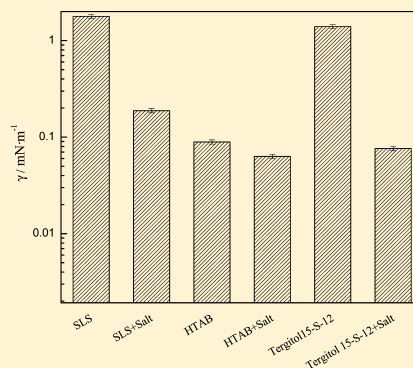
Synergistic Effect of Surfactant and Salt Mixture on Interfacial Tension Reduction between Crude Oil and Water in Enhanced Oil Recovery

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ABSTRACT: In the present paper the effect of salinity and different surfactants on interfacial tension (IFT) between crude oil and water has been investigated. Three different types of surfactants like anionic (sodium lauryl sulfate [SLS]), cationic (hexadecyltrimethylammonium bromide [HTAB]), and nonionic surfactants such as Tergitol 15-S-7, Tergitol 15-S-9, and Tergitol 15-S-12, respectively, have been used in this study. Improved efficiency of IFT reduction using a salt and surfactant mixture has been verified by measuring the IFT between oil and water. The synergism of salt and surfactant mixture on the reduction of IFT has been observed. A series of flooding experiments have been conducted to justify the effects of lowering interfacial tension and adsorption behavior of surfactants on additional oil recovery. It has been found that the additional oil recovery increases up to 24 % of the original oil in place (OOIP) when a surfactant and salt mixture has been used as the displacing fluid.



1. INTRODUCTION

The interfacial tension (IFT) between oil and water is one of the key factors in investigation of the capillary forces acting on trapped oil within the reservoir rocks. The effect of various influencing parameters and variables on IFT and consequently on oil recovery efficiency has been investigated experimentally for several decades.^{1–8} The fundamental requirement of many enhanced oil recovery (EOR) processes is to produce ultralow IFT. The oil recovery by chemical flooding is influenced by the properties of oil, fluids, and formation interfaces. The governing properties are wettability, contact angle, capillary forces, viscous forces, and IFT. A well-known relationship among the parameters with capillary number, N_C , which is an important measurement of the fluid mobilization of the trapped oil in EOR is expressed as

$$N_C = \frac{\mu V}{\gamma \cos \theta} \quad (1)$$

where μ is the viscosity of the liquid, v is the velocity, θ is the contact angle, and γ is the IFT between oil and water. This concept has been reported under several equivalent forms, and its numerical value has been correlated with the actual recovery efficiency.^{9–13} The critical value of the capillary number at which oil recovery becomes significant has been found to be in the 10^{-5} – 10^{-4} range. However at least a 10-fold increase is needed to obtain an 80 % recovery in core tests; a still higher value is probably required for field tests because of accumulated practical difficulties. Since the capillary number value is typically 10^{-6} for ordinary water flooding, an increase of at least 3 orders of magnitude is required to obtain substantially improved oil recovery. It is not practical to significantly increase the

superficial velocity because of limitations on the injection pressure. For the same reason the viscosity of the aqueous phase cannot be increased substantially because an increase in viscosity will also produce a corresponding increase in pressure drop according to Darcy's law. The viscosity increasing additives such as a polymer allow a gain of about 1 order of magnitude in the capillary number value and also provide a good mobility control but cannot alone produce the required change in IFT or capillary number.^{14–20} Thus most of the research work has been focused on reducing the IFT by several orders of magnitude with application of different surface active agents.

However, the large scattering in the reported data dealing with the correlation of oil recovery suggests that an ultralow tension might not be the unique criterion. It should be also pointed out that a low tension may be transient, and that the bulk of the reported data deal only with IFT between effluent fluids at equilibrium, which might be misleading with regard to the actual displacement mechanism. The actual shape of the pore and the contact angle or wettability of the rock might be quite important as shown by analyzing the mobilization mechanism on simplified models.^{21–24}

In the oil recovery technique, displacement by surfactant solutions is one of the important tertiary recovery methods by chemical solutions. It is well-known that the addition of surfactant decreases the interfacial tension between crude oil and formation water, lowers the capillary forces, facilitates oil

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Table 1. Detailed Physicochemical Properties of the Surfactants Employed in the Present Work Including Chemical Names of the Surfactants (CNS), Linear Formula (LF), Molar Mass (MM), Trade Name (TN), Hydrophilic–Lipophilic Balance (HLB), and Category (C)

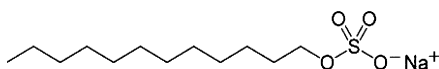
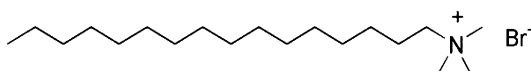
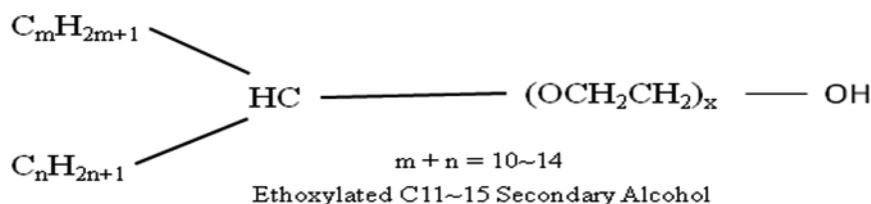
CNS	LF and MM	TN	HLB	C
sodium lauryl sulfate	$\text{CH}_3(\text{CH}_2)_{11}\text{OSO}_3\text{Na}$, MM = 0.288 kg/mol	SDS	40.0	anionic
hexadecyltrimethyl- ammonium bromide	$\text{CH}_3(\text{CH}_2)_{15}\text{N}(\text{Br})(\text{CH}_3)_3$, MM = 0.364 kg/mol	CTAB	21.4	cationic
secondary alcohol ethoxylate	$\text{C}_{12-14}\text{H}_{25-29}\text{O}[\text{CH}_2\text{CH}_2\text{O}]_x\text{H}$ EON = 7, MM = 0.515 kg/mol	Tergitol 15-S-7	12.1	nonionic
secondary alcohol ethoxylate	$\text{C}_{12-14}\text{H}_{25-29}\text{O}[\text{CH}_2\text{CH}_2\text{O}]_x\text{H}$ EON = 9, MM = 0.584 kg/mol	Tergitol 15-S-9	13.3	nonionic
secondary alcohol ethoxylate	$\text{C}_{12-14}\text{H}_{25-29}\text{O}[\text{CH}_2\text{CH}_2\text{O}]_{12}\text{H}$ EON = 12, MM = 0.738 kg/mol	Tergitol 15-S-12	14.7	nonionic

mobilization, and enhances oil recovery. The applications of a surfactant in EOR have been studied since the increase in demand of the commercial use of the crude oil. Bansal et al. (1977)²⁵ investigated the interfacial tension behavior between aqueous and oil phases. They reported that the recovery of oil is mainly dependent on miscibility and mobility control of the oil/water/rock interface. When a surfactant and alkali mixture is used in chemical flooding as a displacing fluid then synergism takes place between the produced ionized acids species from crude oil and added surfactant.^{3,6,28} Another synergism also takes place when surfactant is used with salt which has been studied in this present work.

In the present work a study on the reduction of the IFT between oil and water by different types of surfactants has been made. The effect of surfactant concentrations on IFT has also been reported. The improved efficiency of the salt and surfactant mixture has been verified by measuring the IFT between oil and water in the presence of salt and surfactant. A series of flooding experiments have been conducted to justify the effects of lowering interfacial tension and the adsorption behavior of surfactants on additional oil recovery.

2. EXPERIMENTAL SECTION

2.1. Materials Used. Three different types of surfactants such as SLS (anionic), HTAB (cationic), and three nonionic surfactants such as Tergitol 15-S-7, Tergitol 15-S-9, and Tergitol 15-S-12 were used to prepare the surfactant solutions. The nonionic surfactants are having mole fraction purity of 0.99 each. The mole fraction purities of both SLS and HTAB are 0.98. The detail properties of the surfactants have been given in Table 1. The structures of SLS, HTAB, and Tergitol surfactants have been shown in Figures 1, 2, and 3, respectively. Sodium

**Figure 1.** Molecular structure of SLS surfactant.**Figure 2.** Molecular structure of HTAB surfactant.**Figure 3.** Molecular structure of Tergitol surfactants ($x = 7$ for Tergitol 15-S-7, 9 for Tergitol 15-S-9, and 12 for Tergitol 15-S-12).

chloride (NaCl) with 0.99 mol fraction purity was used for preparation of different concentration of brines and it was supplied by Qualigens Fine Chemical, India. The crude oil sample collected from Ahmadabad oil field, India, was used in the experiment. Reverse osmosis water from Millipore water system (Millipore SA, 67120 Molsheim, France) was used for preparation of solutions. All the materials have been used without further purification.

2.2. Apparatus and Procedure. **2.2.1. IFT Measurement.** The IFT between the crude oil and water interface has been measured with a Spinning Drop Video Tensiometer (Data-Physics, model no. SVT 15N) at (313 ± 1) K. During the measurements each sample was rotated at a speed of 5000 rpm. The IFT values were recorded until the equilibrium was established. The equilibrium was considered to be obtained when successive values agreed within $0.01 \text{ mN}\cdot\text{m}^{-1}$. The equilibrium IFT was obtained from the eq 2 as follow:

$$\gamma = \frac{\omega^2 R^3 \Delta \rho}{4} \quad (2)$$

where, ω is the angular velocity, R is the radius of the drop, and $\Delta \rho$ is the difference in density between crude oil and tested solutions. The IFT of each point was repeated at least twice.

2.2.2. Experimental Apparatus and Methods for Surfactant Slug Flooding. The experimental apparatus is composed of a sand pack holder, cylinders for holding chemical slugs and crude oil, positive displacement pump, and measuring cylinders for collecting the samples. The detail of the apparatus is shown in Figure 4. The displacement pump is one set of Teledyne Isco syringe pumps. The control and measuring system is composed of different pressure transducers and a computer. The physical model is a homogeneous sand packing model with vertically positive rhythm. The model geometry size is $L = 0.35 \text{ m}$ and $r = 0.035 \text{ m}$. The core holder was tightly packed with uniform sands (60–100 mesh) and saturated with 0.01 mass fraction of NaCl. It was flooded with the brine at a pressure of $2737 \cdot 10^5 \text{ Pa}$ and the absolute permeability was calculated from the flow rate of the through sand pack. The sand pack was then flooded with the crude oil at a pressure of $2.859 \cdot 10^6 \text{ Pa}$ to irreducible water saturation. The initial water saturation was determined on the basis of mass balance. The crude oil used in the flooding experiments was collected from the Ahmedabad oil-field

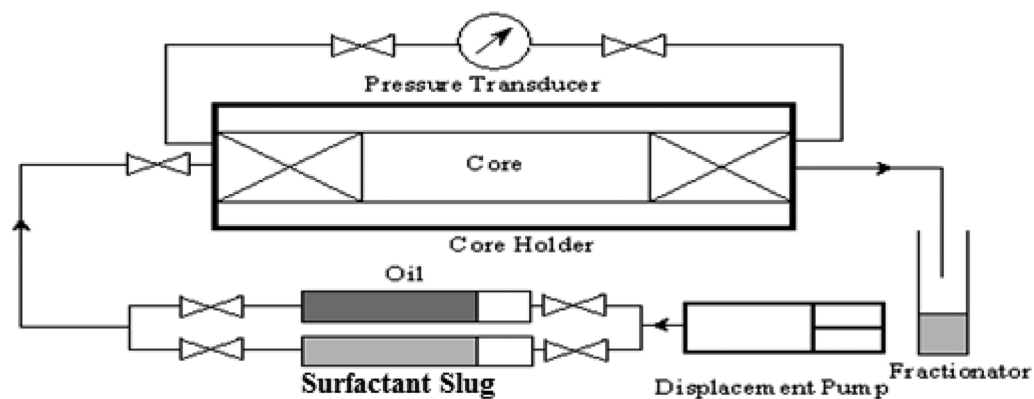


Figure 4. Schematic of experimental setup for surfactant flooding in sand packs.

(India). The oil has a total acid number of $0.038 \cdot 10^{-3} \text{ kg KOH} \cdot \text{kg}^{-1}$, density of $831 \text{ kg} \cdot \text{m}^{-3}$, and viscosity of $11.9 \text{ Pa} \cdot \text{s}$ at 303 K . Waterflooding was conducted by placing the coreholder horizontally at a constant injection pressure at $1.379 \cdot 10^6 \text{ Pa}$. After water flooding, when the water-cut reached above 95% , an approximate 1.0 pore volume (PV) of surfactant slug was injected followed by chasing water. The experiments were repeated using different surfactant slugs. The additional recoveries were calculated by material balance.

The effective permeability to oil (k_o) and effective permeability to water (k_w) were measured at irreducible water saturation (S_{wi}) and residual oil saturation (S_{or}), respectively, using Darcy's law equation. The permeability of the sand packs was assessed with the Darcy equation, eq 3, used for fluid flow in porous media. For a horizontal linear system, flow rate is related with permeability as follow:

$$q = \frac{kA}{\mu} \frac{dp}{dx} \quad (3)$$

where q is volumetric flow rate, A is total cross-sectional area of the sand pack, μ is the fluid viscosity, dp/dx is the pressure gradient, and k is permeability.

The recovery factor is obtained by summing up the amounts of oil recovered in each step (secondary and tertiary oil displacement process) and is expressed in percentage (%)

$$RF_{\text{Total}} = RF_{\text{SM}} + RF_{\text{TM}}$$

where, RF_{Total} = total recovery factor (%), RF_{SM} = recovery factor obtained by secondary method (%), RF_{TM} = recovery factor obtained by tertiary method (%).

3. RESULTS AND DISCUSSION

3.1. Effect of Surfactant Concentration on IFT. The IFT of a surfactant–crude oil system is greatly dependent on the adsorption of surfactant at the crude oil/water interface. Surfactant type, concentration of surfactant, temperature, and other factors can affect the adsorption of surfactant at the crude oil–water interface. Surfactant concentration influences the IFT variation between crude oil and the water system.^{8,26,27} In the present study IFT between crude oil and water has been found to be $48 \text{ mN} \cdot \text{m}^{-1}$ which is noticeably higher than any surfactant system. Figure 5 shows the variation of IFT with the concentrations of SLS and HTAB. Figure 6 depicts the concentration-dependent IFT of Tergitol surfactants namely Tergitol 15-S-7, Tergitol 15-S-9, and Tergitol 15-S-12. It was found from the figure that with an increase in surfactant

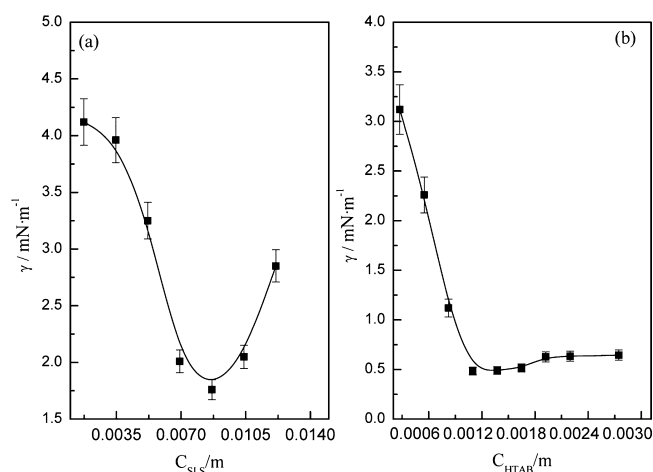


Figure 5. Effect of surfactant concentration ($C_{\text{SLS}}/C_{\text{HTAB}}$) on interfacial tension (γ) between crude oil and water at 313 K .

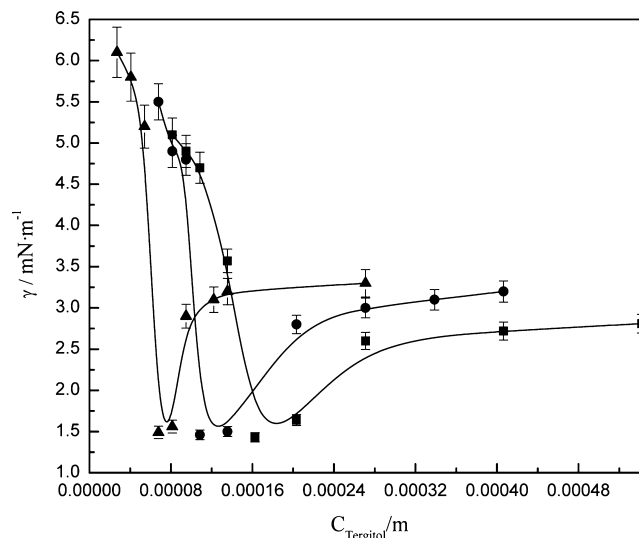


Figure 6. Effect of Tergitol surfactant concentration (C_{Tergitol}) on interfacial tension (γ) between crude oil and water at 313 K . Symbols: ■, Tergitol 15-S-12; ●, Tergitol 15-S-9; ▲, Tergitol 15-S-7.

concentration the IFT value decreases and after certain concentration again increases. At the critical micelle concentrations (CMCs) of the surfactants the IFT values were found to be minima. When surfactants were used IFT values were

found to be highly decreased compared to those of simple water or brine. SLS and Tergitol surfactants can reduce interfacial tension up to $1\text{--}2\text{ mN}\cdot\text{m}^{-1}$, whereas HTAB reduces the value up to $10^{-1}\text{ mN}\cdot\text{m}^{-1}$.

Dynamic IFT values have been depicted in Figure 7 for SLS, HTAB, and Tergitol 15-S-12 at 313 K. With an elapse of time

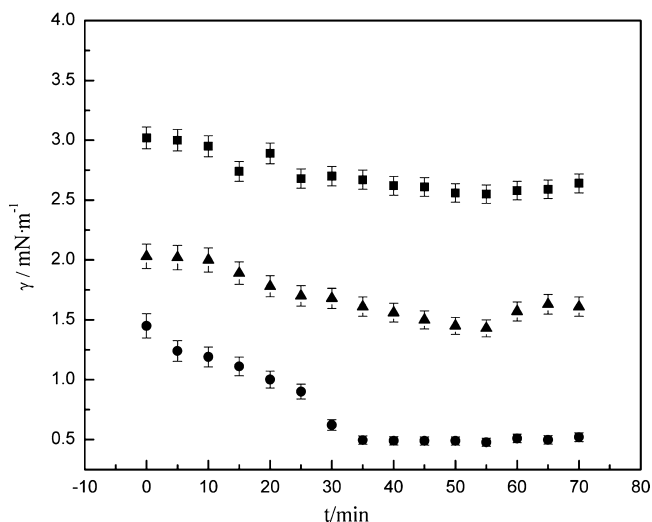


Figure 7. Dynamic interfacial tension (γ) of crude oil-surfactant solutions as a function of time (t) at CMCs of the surfactants at 313 K. Symbols: ■, SLS; ▲, Tergitol 15-S-12; ●, HTAB.

the IFT values starts to decrease and after certain time it reaches to minimum value and then again increases.^{28–30} As time increases, the adsorption of surfactant at oil–water interface increases and interracial tension decreases. After certain time the maximum adsorption of surfactant at interface takes place and when no further adsorption is possible then desorption of surfactant from the crude oil–water interface starts and then IFT again increases.

3.2. Effect of Surfactant–Salt Mixture on IFT. When surfactant is used alone the IFT values were found to be reduced up to $10^{-1}\text{ mN}\cdot\text{m}^{-1}$ to $2\text{ mN}\cdot\text{m}^{-1}$ for different types of surfactants. It is very interesting to note that when NaCl salt is added to the surfactant solution then the IFT again decreases up to a $10^{-2}\text{ mN}\cdot\text{m}^{-1}$ order of magnitude. This may be due to the influence of the synergistic effect (synergism) of the salt and surfactant mixture on the IFT.^{26,28,31} In the presence of NaCl salt, the critical micelle concentration and the surface tension of the surfactant solution decrease, and also the salt lowers the solubility limit of the surfactant. The solubility of surfactant decreases with the addition of salt and hence makes it less ionized; therefore, the surfactant molecules adsorb strongly at the oil–water interface which reduces IFT. Another important colloidal phenomenon is the liquid crystalline dispersion formation in the presence of salt in a surfactant solution. The produced aqueous dilute liquid crystalline dispersion of surfactants can also reduce IFTs against crude oil. Different studies have also shown that the liquid crystalline dispersion of surfactants in the presence of salt can produce an ultralow IFT between the crude oil and salt–surfactant mixture.^{32–34} Figure 8 shows the reduction of IFT values in the presence of surfactant and the surfactant–salt mixture. The addition of salt in a surfactant solution has a positive effect on lowering the IFT and expanding the range of optimal surfactant concentration. The photographs of oil drops during IFT

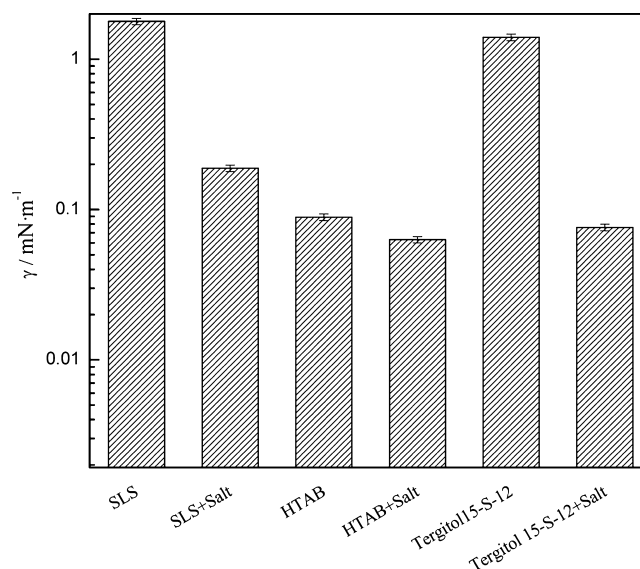


Figure 8. Interfacial tension (γ) of crude oil–surfactant system in the presence and absence of NaCl salt at CMC at 313 K.

measurements of the crude oil and brine and surfactant-salt mixture solutions are shown in Figure 9. The figure confirms

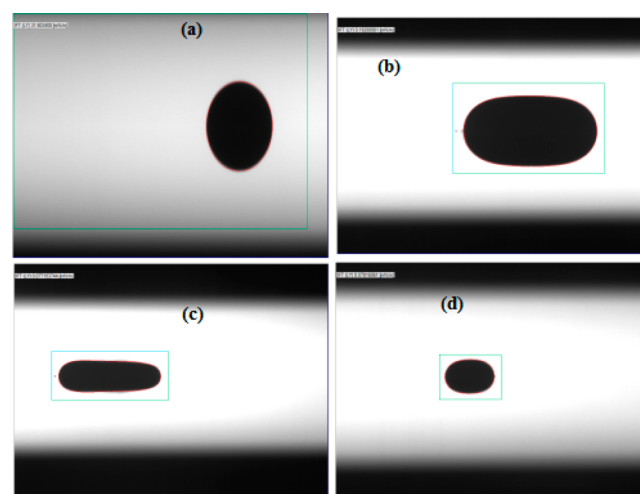


Figure 9. Photographs of the crude oil drops in 0.015 mass fraction of brine and different surfactant-salt mixture solutions: (a) 0.015 mass fraction of brine, (b) SLS, (c) HTAB, (d) Tergitol 15-S-12.

that during IFT measurement the deformation of an oil drop takes place when the IFT reduces to a very low value. As in the case of HTAB, the lowest IFT has been attained and therefore the oil drop is highly deformed and takes the stretched oval shape. Figures 10, 11, and 12 indicate the effect of the added surfactant concentration on IFT at different NaCl concentration for SLS, HTAB and Tergitol 15-S-12 respectively. It has been found from Figures 10, 11 and 12 that with addition of salt to surfactant solution the lowering of IFTs are more or less same for all the concentrations near the CMC of the corresponding surfactants. In general surfactants can reduce the IFT between crude oil and surfactant solution by adsorbing the surfactant molecules at the oil–water interface.^{4,34–36} When NaCl salt is added then again in situ surface active agent formation starts and the IFT value is highly influenced to reduce to a lower value in the 10^{-2} range. The addition of NaCl

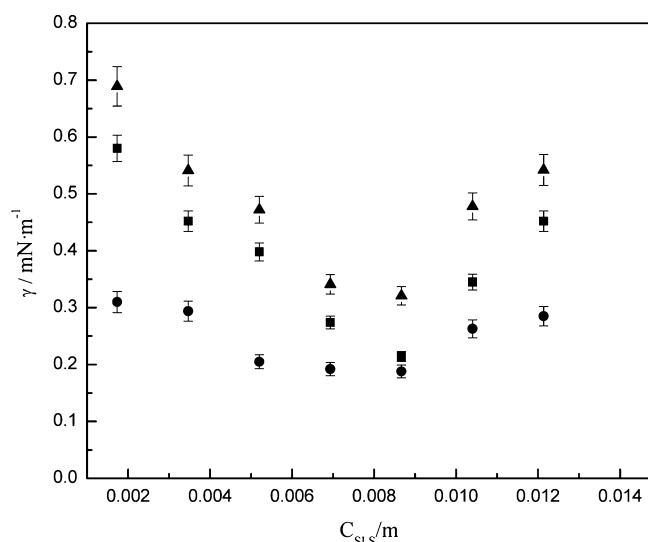


Figure 10. Effect of SLS surfactant concentration on equilibrium interfacial tension at different NaCl concentrations at 313 K. Symbols: ■, 0.04 mass fraction of NaCl; ●, 0.06 mass fraction of NaCl; ▲, 0.08 mass fraction of NaCl.

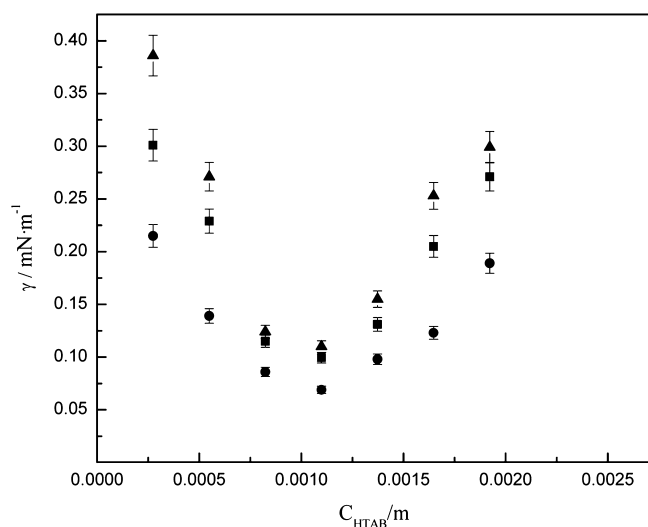


Figure 11. Effect of HTAB surfactant concentration on equilibrium interfacial tension at different NaCl concentrations at 313 K. Symbols: ■, 0.04 mass fraction of NaCl; ●, 0.06 mass fraction of NaCl; ▲, 0.08 mass fraction of NaCl.

salt to the surfactant solution influences the double electrode layer, and it thins the layer of the interface, making an arrangement of the surfactant molecule and also the produced surface active molecules at the interface together and helping the IFT to reach a lower value than that of surfactant alone.^{6,26,31} Another promising factor is the partitioning of the surfactant at the oil–water interface which has been enhanced in the presence of salt.^{37,38} This phenomenon further influences the IFT reduction between the oil–water systems.

Figure 13 shows the dynamic IFT of SLS, HTAB, and Tergitol 15-S-12 surfactant in presence of NaCl salt. As time elapses the IFT decreases, and after a certain time minimum IFT has been reached. This phenomenon could be explained on the basis of the formation rate of surface active agents from the crude oil in the presence of NaCl salt. Initially the formation rate is slow and therefore the accumulation of

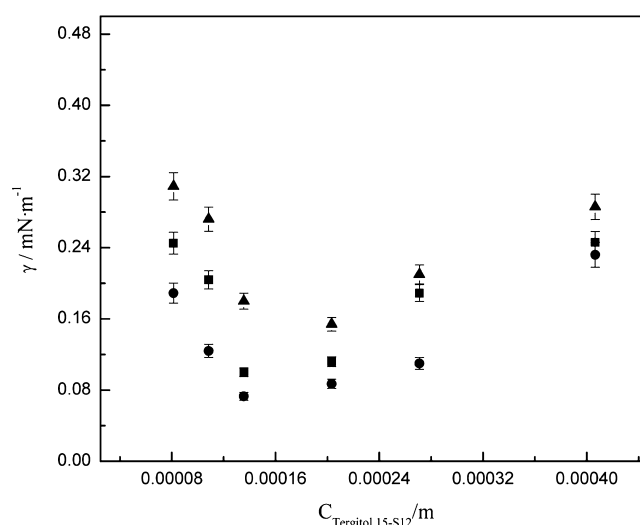


Figure 12. Effect of Tergitol 15-S-12 surfactant concentration on equilibrium interfacial tension at different NaCl concentrations at 313 K. Symbols: ■, 0.04 mass fraction of NaCl; ●, 0.06 mass fraction of NaCl; ▲, 0.08 mass fraction of NaCl.

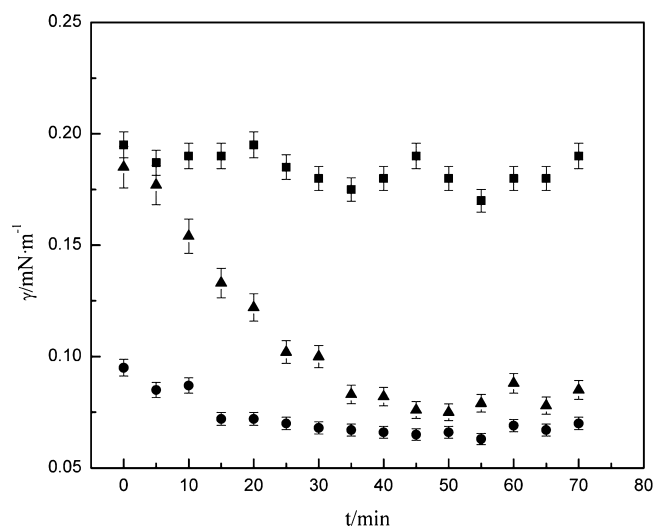


Figure 13. Interfacial tension of crude oil–brine with surfactant as a function of time at the CMCs of the surfactants at 313 K. Symbols: ■, SLS + NaCl; ●, HTAB + NaCl; ▲, Tergitol 15-S-12 + NaCl.

surfactant and surface active agent at the interface is low, and the thickening of the double layer of interface cannot properly happen. With increasing time the accumulation of surface active agent from the crude oil increases; it thins the double layer interface properly and therefore IFT decreases. When accumulation of the surface active agent more or less has been stopped then no further decrease of IFT takes place. At that point desorption of the surfactant molecules from the interface starts and IFT increases. The interaction between nonionic surfactant and salt is absent in the solution mixture. Therefore other phenomenon plays the role to reduce IFT. In the presence of NaCl salt the solubility of nonionic surfactant Tergitol has been reduced and the surfactant molecules strongly adsorb at the interface and reduce the IFT.

3.3. Surfactant Flooding and Recovery. The sand pack was flooded with surfactant and surfactant with salt after water flooding. Figures 14, 15, and 16 show the oil recovered with pore volume injected into the sand pack for SLS, HTAB, and

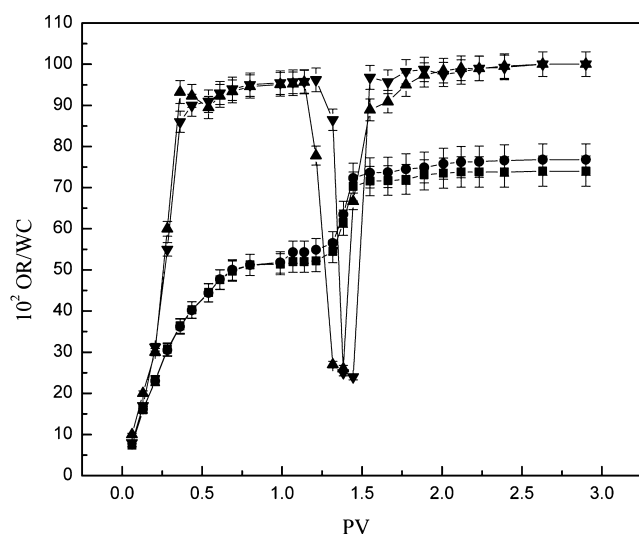


Figure 14. Oil recovery (OR) and water-cut (WC) of SLS and SLS with salt in EOR at 300 K. Symbols: ■, oil recovery (SLS); ●, oil recovery (SLS + salt); ▲, water-cut (SLS); ▼, water-cut (SLS + salt).

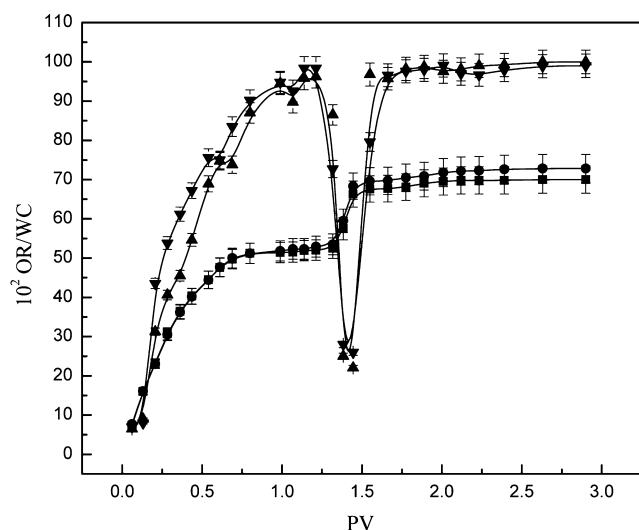


Figure 15. Oil recovery (OR) and water-cut (WC) of HTAB and HTAB with salt in EOR at 300 K. Symbols: ■, oil recovery (HTAB); ●, oil recovery (HTAB + salt); ▲, water-cut (HTAB); ▼, water-cut (HTAB + salt).

Tergitol 15-S-12, respectively. The figures of waterflood oil recovery show an early breakthrough and channel flow which caused much lower oil recovery. During injection of the surfactant slug, the water-cut declines gradually, and then again reaches 100 % at the end of flooding. After the injection of the surfactant slug, the trapped oil droplets or ganglions are mobilized due to a reduction in interfacial tension between oil and water. The coalescence of these drops leads to a local increase in oil saturation. Behind the oil bank, the surfactant now prevents the mobilized oil from being retrapped.

In the present work, the experiments were carried out in sand pack; the water flood recovers more than 50 % of the original oil in place (OOIP) because of higher porosity (~37 %) and permeability of the system. During water flooding, as the water-cut reaches above 95 %, it was subsequently flooded with surfactant slugs, followed by chase water. The recovery of oil and water-cut with pore volume (PV) injected for three

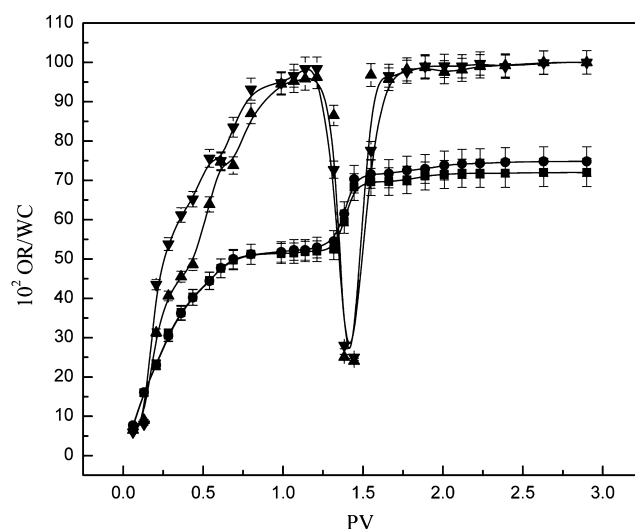


Figure 16. Oil recovery (OR) and water-cut (WC) of Tergitol 15-S-12 and Tergitol 15-S-12 with salt in EOR at 300 K. Symbols: ■, oil recovery (Tergitol 15-S-12); ●, oil recovery (Tergitol 15-S-12 + salt); ▲, water-cut (SLS); ▼, water-cut (Tergitol 15-S-12 + salt).

different surfactant systems is presented in Figures 14, 15, and 16. It has been found that water begins to break through when the injected volume of water reaches 1.15 PV, and then the water-cut sharply increases above 90 % for each case. It is clear from the Figures 14, 15, and 16 that the cumulative oil recovery by surfactant flooding is higher in the case of SLS because of significant physicochemical properties of the SLS surfactant. The mechanism results in a reduced water mobility that improves both vertical and areal sweep efficiency. The additional recovery of oil over water flooding is 23.025 %, 21.914 %, and 22.454 % when the surfactant slugs with SLS, HTAB, and Tergitol 15-S-12 were used respectively. When salt is used with a surfactant then the additional recovery increases up to 24.578 %, 23.423 %, and 23.851 % over conventional water flooding. This is due to the synergistic effect of the surfactant and salt mixture. The details of the recovery performance and sand pack properties have been depicted in Table 2. However, the proper design of the surfactant slug should be performed by feasibility analysis, considering the operating costs and market value of the crude.

The interfacial tension reduction by HTAB is higher than the other surfactants. But another governing factor that influences the recovery factor is adsorption of the surfactant on the reservoir rock surface. Because the sand pack is negatively charged in nature, the adsorption of HTAB on the sand surface is higher than that of the other surfactants.³⁹ Therefore, loss of surfactant results in a decrease in concentration which goes below the CMC value. As a result the effectiveness of the surfactant is reduced. Because of these two counter effects, the recovery by HTAB has been reduced in the sand pack flooding experiment and on the other hand SLS and Tergitol 15-S-12 show higher recovery than HTAB.

4. CONCLUSIONS

The IFTs between crude oil and water in the presence of salt and surfactant and their mixture have been studied. The results of the present study show that brine, surfactant, and salt-surfactant mixture all are able to reduce the IFT of the corresponding systems. Surfactant with salt reduces the IFT

Table 2. Recovery of Oil by Different Types of Surfactant Flooding with Salt and without Salt and Properties of Sandpack Core Including Flooding Agents (FA), Porosity (ϕ), Permeability to Water (k_w) and Oil (k_o), Oil Recovery by Water Flooding (N_{PW}), Oil Recovery by Surfactant Slugs (N_{Ps}), and Different Saturation (S)

FA	$\phi/\%$	$k/\mu\text{m}^2$		$N_{PW}/\%$ OOIP	$N_{Ps}/\%$ OOIP	S/%		
		k_w ($S_w = 1$)	k_o (S_{wi})			S_{wi}	S_{oi}	S_{or}
SLS (0.6 PV surfactant slug + chase water)	37.265	0.318	0.019	51.6471	23.025	18.52	81.48	22.963
SLS + salt (0.6 PV surfactant and salt slug + chase water)	37.265	0.299	0.019	51.522	24.578	17.29	82.71	23.827
HTAB (0.6 PV surfactant slug + chase water)	37.725	0.292	0.019	51.794	21.914	19.52	80.48	20.976
HTAB + salt (0.6 PV surfactant and salt slug + chase water)	37.415	0.282	0.019	51.452	23.423	19.45	80.55	20.452
Tergitol 15-S-12 (0.6 PV surfactant slug + chase water)	37.841	0.277	0.019	51.524	22.454	20.01	79.99	20.142
Tergitol 15-S-12 + salt (0.6 PV surfactant and salt slug + chase water)	36.948	0.280	0.019	51.583	23.851	19.79	80.21	20.451

Standard Uncertainties u are $u(\phi) = 1.0$ and $u(k_w) = 0.03 \mu\text{m}^2$.

significantly up to a range of $10^{-2} \text{ mN}\cdot\text{m}^{-1}$, whereas surfactant alone can only reduce up to $10^{-1} \text{ mN}\cdot\text{m}^{-1}$. The synergistic effect of salt and surfactant has also been confirmed when IFTs have been measured for individual salt and surfactant and also salt–surfactant together. A series of flooding experiments have been conducted to observe the additional oil recovery after water flooding using surfactant and surfactant with salt slug. The use of a very small quantity of surfactant reduces the interfacial tension of displacing fluid (water) significantly, which in turn increases the recovery by forming an oil bank. The injection of a 0.6 pore volume surfactant and surfactant–salt slug increased recovery by approximately 25 % OOIP. The recovery by HTAB has been reduced in the sand pack flooding experiment and on the other hand SLS and Tergitol 15-S-12 show a higher recovery than HTAB as two counter effects (IFT reduction and adsorption) simultaneously influence the oil recovery mechanism.

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