

Full Length Research Paper

Experimental investigation of impact of low salinity surfactant flooding for enhance oil recovery: Niger Delta field application

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Oil reserves in the Niger Delta have been gradually decreasing due to the increased production. New large field discoveries are scarce, thus there is need to improve on the production from existing reserves. Low salinity surfactant flooding (LSSF) is a potential enhanced oil recovery process to increase oil production in the Niger Delta oil fields. In this study, sodium dodecyl sulphate and ethanol were used as surfactant to study the significance of the surfactants on oil recovery. Sand packs were used as formation sample in the laboratory. This was soaked with oil of 24.36° API and specific gravity of 0.9436. Low salinity water was used as a displacing fluid in the secondary recovery mechanism. However, sodium dodecyl sulphate and ethanol (78% vol.) was introduced into the sand packs. The sodium dodecyl sulphate reduced the interfacial tension as obtained using tensiometer machine. Ethanol was used in the second case as surfactant. The result of the work shows that sodium dodecyl sulphate had oil recovery of 16.1, 16.9, 19.0 and 19.3% respectively at different surfactant concentrations 0.2, 0.3, 0.35 and 0.38% wt. respectively; while ethanol (78% vol.) had oil recovery of 1.5%. The study noted that sodium dodecyl sulphate is a good surfactant for enhanced oil recovery for crude oil with the specified API gravity. In addition, interfacial tension reduction and change in rock wettability were the working mechanisms for the sodium dodecyl sulphate to increase oil recovery from reservoirs. The work showed that sodium dodecyl sulphate maintained low interfacial tension through the flood process.

Key word: Sodium dodecyl sulphate, interfacial tension reduction, ethanol, crude oil

INTRODUCTION

Surfactant flooding is the process of injecting surfactant into the reservoir to reduce the interfacial tension. Surfactant flooding is now considered to be one of the

commercially proven enhanced oil recovery methods (Morrow and Buckley, 2011). Tang and Morrow (1999) Reported that global energy demand grows as reserves

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are depleted; this makes enhanced oil recovery (EOR) from brown fields to become exceedingly important. Use of reservoir energy and secondary recovery method can only recover one-third of the initial oil in the reservoir. This gave rise to the fact that the untapped oil in the reservoir needs to be recovered in order to meet up the global rising demand for energy (Robertson, 2007; Sheng, 2014). This remaining amount of oil unrecovered in the reservoir has drawn the responsiveness of oil and gas industries on developing new techniques to recover oil after primary and secondary mechanism has reached its economic limit. Emegwalu (2009) observed that low salinity surfactant flooding could help to improve heavy oil recovery as a result of reduction in oil viscosity. Adibhatla and Mohanty (2006) and Berg et al. (2010) reported in their work that when surfactants act on the oil/water interfaces, the surfactants could lower the oil/water interfacial tension (IFT) and/or cause wettability alteration. Dogru (2008) observed that the best surfactant performance in a surfactant flood depends on reservoir conditions and the characteristics of reservoir fluids, low retention, compatibility and aqueous stability. More so, it was noted from the work that surfactant flooding played a significant role to improve oil recovery due to interfacial tension reduction. In addition, Zhao et al. (2006) noted that LSSF should maintain adequate low interfacial tension (IFT) to mobilize the remaining oil. Adnan (2014) reported that low salinity surfactant slug injection into the reservoir can help to improve heavy oil recovery due to reduction in interfacial tension. In addition, it was observed that the rock wettability had effect on the efficiency of slugs' injection in the reservoir. Solveig (2012) conducted an experiment using four aged Bentheimer cores. It observed that low salinity injection increased oil recovery to 2% OOIP. In addition, the use of surfactant injection and low salinity water flooding resulted in appreciably increase in oil recovery of additional 26% OOIP. The work showed that LSSF could meaningfully enhance oil recovery. Abdulmecit and Farad (2021) conducted an experiment using nine crude oil aged Berea core plugs to investigate the effect of brine composition, wettability alteration, low salinity water (LSW) and low salinity surfactant (LSS) flooding on enhancing oil recovery. The result of their work showed that more than 50% of initial oil in place was produced by low salinity surfactant flooding. They work further noted that the increase in oil recovery could be wettability change from water-wet to oil-wet and reduction in oil-water interfacial tension. Shayan et al. (2015) applied UTCHEM-IPhreeqc numerical approach to investigate low salinity waterflooding and low salinity surfactant flooding. The result of their study showed that low salinity surfactant flooding can significantly improve oil recovery. Low salinity waterflooding improves oil recovery due to wettability change and reduction of residual oil saturation as reported by Ihekoronye et al. (2019). In addition, Izuwa et al. (2019) also noted that injection of low salinity

polymer flooding showed great improvement in oil recovery and determined the optimal salinity ratio that yields the highest oil recovery. With polymer concentration of 0.35% wt and water salinity of 2000 ppm, the researchers achieved 62% oil recovery.

This research paper is aimed at enhancing oil recovery in the Niger Delta region by injection of low salinity surfactant flooding (sodium dodecyl sulphate) to improve oil recovery. The work will investigate the mechanism of interfacial tension reduction during LSSF.

Surfactants

Surfactants are organic compounds that serve as surface acting agents, which are made up of amphiphilic and hydrophilic parts in the same molecule. Amphiphilic group acts as hydrophobic group whereas hydrophilic group is the polar part. Surfactant can be soluble in both organic solvents and water. It is classified into cationic, anionic, nonionic, and zwitterionic (Ottewill, 1984). The negative surface charge in anionic surfactant aids adsorption of the surfactant on sandstone rocks and mostly used in surfactant flooding. In addition, cationic surfactant can be used to change wettability from oil-wet to water-wet as a result of its affinity for sandstone. Nonionic surfactants serve as co-surfactant and are more tolerant in high salinity environment and functions well in improving oil recovery. Zwitterionic surfactant contains two active groups together that are nonionic-anionic or anionic-cationic. Some surfactant is more tolerant to temperature and salinity and also expensive (Lake, 1989).

Surfactant (sodium dodecyl sulphate) used in this research work

The kind of surfactant used in this work has amphiphilic properties and has the general formula, $\text{CH}_3(\text{CH}_2)_{11}\text{SO}_4\text{Na}$.

Characteristic of the Surfactant (sodium dodecyl sulphate) used in this research work:

1. Sodium dodecyl sulphate belongs to the family of organosulfate compounds.
2. It contains anionic "head group" and hydrocarbon tail.
3. Its amphiphilic properties allow it to form micelles.

Importance of sodium dodecyl sulphate:

1. To mobilize the residual oil saturation and decrease the interfacial tension (IFT) of the oil.
2. The reduced interfacial tension of the crude oil helps to modify the formation rock /fluid and fluid/fluid interaction to mobilize the remaining oil.



Figure 1. Sodium dedocyl sulphate.



Figure 3. Crude oil sample.



Figure 2. Ethanol.

Objective of study

The main objective of this study is to investigate the impact of low salinity surfactant flooding on interfacial tension reduction for improvement of oil recovery in the Niger Delta fields.

METHODOLOGY

Materials used in the experiment

The following materials were used in the experiment: ethanol,

Table 1. Crude oil Properties for the experiment.

Properties	Values
Specific gravity	0.9436
Density	0.8672 g/cm ²
Oil viscosity	6.273 cp
Temperature	120 -129°C
API gravity of the oil	24.36°

sodium dedocyl sulphate, core plug samples, sand, brine and crude oil.

Instrument used in the research work

The following instruments were used in the work: SRM-20 milling machine (used for pack sand in a foil), mercury thermometer, pump, beakers, foil, measuring cylinder, spatula, weighing balance and tensiometer (SITE 100).

Collection of the sample

The surfactant samples used for this experimental work were bought from the south-eastern part of Nigeria. The surfactant used was sodium dedocyl sulphate and ethanol (local surfactant). Figures 1 to 3 show the sample materials used for the experiment.

Crude oil sample used in the study

The crude oil sample used in this experimental study was gotten from Niger Delta. Table 1 shows the property of the crude oil sample. The temperature used in the experimental study ranges from 120 -129°C.

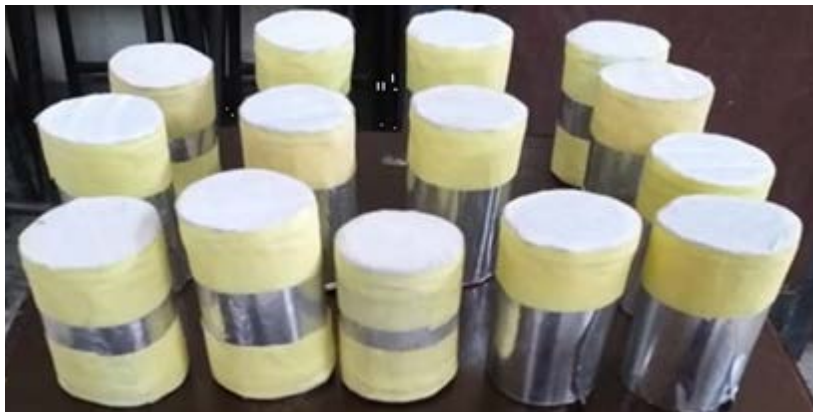


Figure 4. Core plug sample.



Figure 5. Tensiometer.

Experimental procedure

This section presents the methods applied to investigate the effect of low salinity surfactant flooding using sand packs obtained from Niger Delta oil fields.

Formulation of sand packs (cores)

Unconsolidated sand was used to form sand pack samples representing typical reservoir rock in the Niger Delta. The sand packs were dried in an oven for ten minutes at a temperature of 60°C; it was removed from the oven and packed in a foil as shown in Figure 4. Weight of both dry and wet samples was recorded. The cores were saturated with brine of 5000 ppm salinity.

Preparation of surfactant solutions

The sodium dodecyl sulphate was prepared in the laboratory by dissolving the amount of surfactant in low saline water under atmospheric condition. The dissolved amount of surfactant was mixed thoroughly at different concentrations of 0.2, 0.3, 0.35 and 0.38%wt in four different beakers. In addition, tensiometer

machine was used to quantify the interfacial tension of the crude oil in order to investigate the effects of the surfactant on oil recovery. The measured surfactants at different concentrations of (0.2, 0.3, 0.35 and 0.38%wt) were gently introduced into the sand packs containing the crude oil.

A 96% volume ethanol was purchased from a commercial vendor. The ethanol was thoroughly mixed with the saline water to obtain 78% vol. It was introduced into the saturated sand packs containing crude oil. The ethanol was used as a displacing fluid to recover oil trapped in the core samples.

Determination of the Interfacial Tension with Tensiometer

Figure 5 shows the tensiometer used for interfacial tension determination. In Figure 5, the tensionmeter machine was heated at a temperature of 22°C. Temperature of the experiment was maintained with the help of a water bath.

In addition, surfactant solution was filled in a tube and a needle with diameter of 0.6 mm was used to calibrate the DSA-2 software. After the calibration was done, the tube was filled such that gas bubbles would not be trapped at the ends of the tube. However, a drop of oil was introduced into the tube using a syringe and the tube was rotated at a speed of 2200-3800 rpm. A continuous measurement of the reduced oil interfacial tension with different spinning rate was recorded. Moreover, the measurement of each of the surfactant concentration sample was obtained.

Investigation of the effect of low salinity on Interfacial tension reduction

Sodium dodecyl sulphate was measured using a weighing balance to form different concentrations (0.2, 0.3, 0.35, and 0.38%wt). Different core samples were saturated with the low salinity brine. Solution of surfactant was prepared with the measured solute (sodium dodecyl sulphate) and low salinity water. The interfacial tension of the different surfactants concentration was tested with the tensiometer to evaluate the reduction in interfacial tension.

Low salinity waterflooding (secondary recovery mechanism)

Low salinity water flooding experiment was conducted to demonstrate the secondary production mechanism. The core flooding experiment was set up and 5000 ppm of saline water was

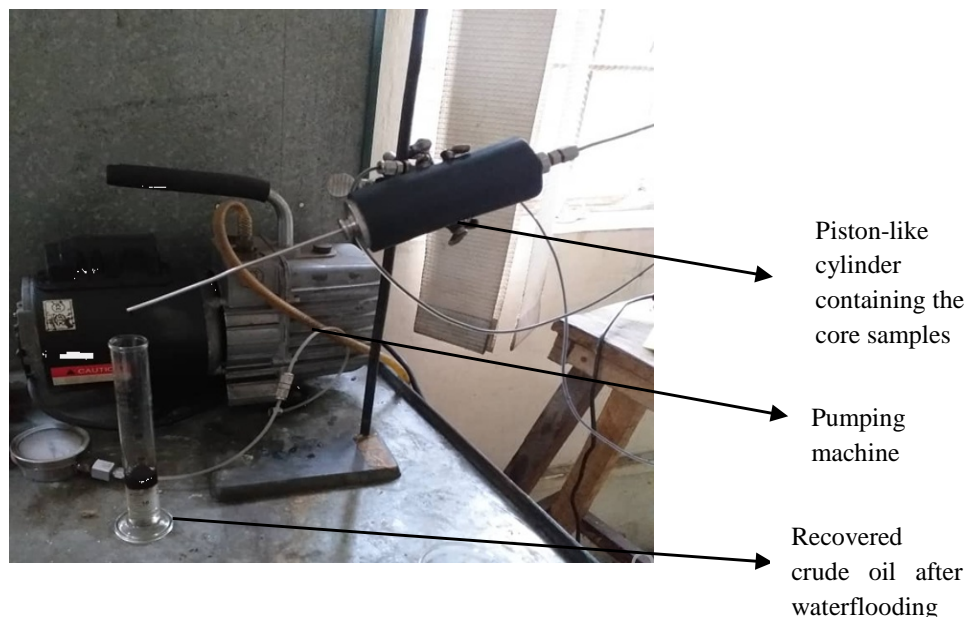


Figure 6. Experimental set-up.

Table 2. Property of the different core samples.

Core samples	Weight of dry core sample (g)	Weight of saturated core sample (g)	Density of fluid (g/cm ³) (5,000ppm brine)	Pore volume (cm ³) ($\frac{\text{weight of saturated core}}{\text{density}}$)
B ₁	20.21	24.76	1.007	24.59
B ₂	22.23	28.10	1.007	27.90
B ₃	21.21	25.62	1.007	25.44
B ₄	18.25	30.23	1.007	30.02
B ₅	20.34	28.71	1.007	28.51
B ₆	19.23	24.76	1.007	24.59
B ₇	19.98	22.34	1.007	22.18
B ₈	21.45	25.01	1.007	24.84

introduced to mimic the secondary production.

Experimental procedures of low salinity surfactant flooding

The experiments were conducted under surface condition using atmospheric pressure. In this experiment, two sets of experiments were conducted. In the first case, the low salinity brine was injected into different beakers containing core samples (B₁ - B₈). The low saline water saturates the core samples. The core samples were placed in a piston-like cylinder as shown in Figure 6. Furthermore, in the second phase, the sodium dodecyl sulphate was introduced into the formation after water flooding as the base case. The injected sodium dodecyl sulphate emulsifies the oil, forming water-in-oil emulsion. Sodium dodecyl sulphate injection helped to reduce the interfacial tension which helped the trapped oil in the formation to be mobilized. Hence, oil recovery was greatly improved. More so, the experiment was repeated for the different concentrations (0.2, 0.3, 0.35 and 0.38%wt) of the sodium dodecyl sulphate to investigate the effect of the different surfactant concentrations on oil

recovery. The same process was applied to the ethanol to investigate its effect on oil recovery. Figure 6 shows the experimental setup of the research work. It was used to study the effect of low salinity surfactant flooding in recovery of crude oil. In addition, the core plugs were noticed to be more of water-wet than oil-wet as a result of wettability change.

RESULTS

The results of the work in this study are hereby presented following the steps used in the methodology. Tables 2 and 3 depict the properties of the sand pack obtained and used as secondary data in work. Table 4 shows the result of the interfacial tension reduction and result of the secondary production is shown in Table 5.

Tables 2 and 3 show the properties of the core samples (core plugs) used in this experimental study. It can be

Table 3. Porosity and permeability of the core samples.

Sample	Core radius (cm ²)	Core sample height (cm ²)	Bulk volume (cm ²) ($\pi r^2 h$)	Pore volume (cm ²)	Porosity (%) $\left(\frac{\text{pore volume}}{\text{bulk volume}}\right)$	Permeability (md)
B ₁	1.43	7.28	46.78	24.59	0.5257 = 52.57	11.25
B ₂	1.59	6.80	54.01	27.90	0.5166 = 51.66	18.56
B ₃	1.43	6.10	39.19	25.44	0.6491 = 64.91	17.34
B ₄	1.48	5.82	40.05	30.02	0.7496 = 74.96	19.73
B ₅	1.77	6.21	61.13	28.51	0.4663 = 46.63	23.25
B ₆	1.89	4.95	55.56	24.59	0.4426 = 44.26	24.34
B ₇	1.60	5.64	45.37	22.18	0.4889 = 48.89	22.21
B ₈	1.62	6.23	51.37	24.84	0.4836 = 48.36	20.35

Table 4. Interfacial tension result.

Surfactant concentrations (%wt)	IFT (m/Nm)
0.2	10 ⁻¹ (0.1)
0.3	10 ⁻² (0.01)
0.35	10 ⁻³ (0.001)
0.38	10 ⁻⁴ (0.0001)

Table 5. Summary of result due to water flooding (secondary recovery mechanism).

S/No	Variable	Core B1 Oil (mil)	Core B2 Oil (mil)	Core B3 Oil (mil)	Core B4 Oil (mil)
1	Original oil in place (OOIP)	19.2	20.1	18.9	19.1
2	Oil recovered by waterflooding	7.5	8.2	7.8	8.0
3	% of oil recovered by waterflooding	39.1	40.8	41.3	41.9

observed from the Table 2 that the weight of dry core samples, weight of saturated core samples, and density of fluid were used to evaluate the pore volume. Similarly, Table 3 shows the measured height, bulk volume, radius of the core and determined porosity and permeability.

Table 5 shows the surfactant concentrations of (0.2 - 0.38%wt) of different core samples (Core B₁- Core B₄). The original oil in place for (Core B₁- Core B₄) at different core samples was 19.2, 20.1, 18.9 and 19.1 respectively. However, the core sample was water flooded with low saline water as a secondary recovery process as shown in the Table 5 (column 2, oil recovered by water flooding). Oil recovered due to water flooding was recorded before the introduction of the surfactant (sodium dodecyl sulphate) to different core samples and at different concentrations to assess the influence of the surfactant on oil recovery shown in Table 6 roll 3, (Core B₅- Core B₈). More so, the percentage of the total oil recovered (that is both water flooding and surfactant flooding) were recorded as shown in roll 4, Table 6. Furthermore, Figure 7 shows the sand packs after the flooding process.

Similarly, Table 7 shows the performance of the local surfactant (ethanol). The original oil in place was 26.5.

Low saline water was used as a displacing fluid; oil recovered due to water flooding was 10.2. However, ethanol was used as a tertiary recovery mechanism for enhanced oil recovery. It was observed from the table that the percentage of oil recovered due the ethanol was 1.5% OOIP which is low. This shows that ethanol does not have much appreciable effect on oil recovery.

Calculation of displacement efficiency and residual oil saturation

The displacement efficiency was calculated as:

$$\text{Displacement efficiency} = \frac{X}{S_o} \times 100\% \quad (1)$$

Where X = Amount of oil recovered bbl; S_o = oil in place

Ethanol

Total oil recovered by water flooding = 38.5%

Table 6. Summary of oil recovered due to flooding with sodium dodecyl sulphate at different concentrations (Tertiary recovery mechanism).

S/N	Variable	CORE B ₅ 0.2%wt surfactant	CORE B ₆ 0.3%wt surfactant	CORE B ₇ 0.35%wt surfactant	CORE B ₈ 0.38%wt surfactant
1	Tertiary oil recovery Core +brine+(sodium dedocyl sulphate , ml)	3.1	3.4	3.6	3.7
2	% of oil recovered sodium dedocyl sulphate solution	16.1% of OOIP	16.9% of OOIP	19.0% of OOIP	19.3
3	Total oil recovered by waterflooding and sodium dedocyl sulphate , ml	10.6	11.6	11.4	11.7
4	Total % oil recovered	$\frac{10.6}{19.2} \times \frac{100}{1} = 55.2$	$\frac{11.6}{20.1} \times \frac{100}{1} = 57.7$	$\frac{11.4}{18.9} \times \frac{100}{1} = 60.3$	$\frac{11.7}{19.1} \times \frac{100}{1} = 61.3$



Core samples after tertiary recovery process.

Figure 7. Sample of the oil-water wet rock formation.

Table 7. Summary of result for surfactant (ethanol).

S/N	Variable	Core B ₉ (mil) (ethanol)
1	Original oil in place (OOIP)	26.5
2	Core B ₁₃ +brine (waterflooding)	10.2
3	% of oil recovered by waterflooding	38.5
4	Core B ₁₃ +brine+ (ethanol)	0.4
5	% of oil recovered by (ethanol)	1.5
6	Total oil recovered (waterflooding + ethanol)	10.6
7	% Total oil recovered (waterflooding + ethanol)	$\frac{10.6}{26.5} \times \frac{100}{1} = 40.0$

$$S_{orw} = 0.82 - 0.385 = 0.435 = 0.44$$

$$\begin{aligned} \text{\% of oil recovered by ethanol} &= 1.5\% \\ &= 0.015 \times S_{orw} (0.435) = 0.006525 \end{aligned}$$

$$\begin{aligned} \text{Residual oil saturation after ethanol flood } (S_{or \text{ ethanol}}) &= \\ S_{orw} - 0.006525 &= 0.435 - 0.006525 = 0.428475 = 0.43 \end{aligned}$$

Sodium dodecyl sulphate concentration of 0.2 %wt

Total oil recovered by water flooding = 39.1%

$$S_{orw} = 0.82 - 0.391 = 0.429 = 0.43$$

$$\begin{aligned} \text{\% of oil recovered by surfactant of (0.2%wt)} &= 16.1 \\ &= 0.161 \times S_{orw} (0.429) = 0.069069 \end{aligned}$$

$$\begin{aligned} \text{Residual oil saturation after surfactant flood } (S_{or \text{ surfactant}}) &= \\ S_{orw} - 0.069069 &= 0.429 - 0.069069 = \\ 0.359931 &= 0.36 \end{aligned}$$

Sodium dodecyl sulphate concentration of 0.3 %wt

Total oil recovered by water flooding = 40.8%

$$\begin{aligned}
 S_{orw} &= 0.82 - 0.408 = 0.33456 = 0.33 \\
 \% \text{ of oil recovered by surfactant of (0.3\%wt)} &= 16.9\% \\
 &= 0.169 \times S_{orw} (0.33456) = 0.05654064 \\
 \text{Residual oil saturation after surfactant flood} \\
 (S_{or \text{ surfactant}}) &= \\
 S_{orwf} - 0.05654064 &= 0.408 - 0.05654064 = 0.35145936 \\
 &= 0.35
 \end{aligned}$$

Sodium dodecyl sulphate concentration of 0.35 %wt

$$\begin{aligned}
 \text{Total oil recovered by water flooding} &= 41.3\% \\
 S_{orw} &= 0.82 - 0.413 = 0.407 = 0.40 \\
 \% \text{ of oil recovered by surfactant of (0.35\%wt)} &= 19.0\% \\
 &= 0.190 \times S_{orw} (0.407) = 0.07733 \\
 \text{Residual oil saturation after surfactant flood} (S_{or \text{ surfactant}}) &= \\
 = S_{orw} - 0.07733 &= 0.407 - 0.07733 = 0.32967 = 0.33
 \end{aligned}$$

Sodium dodecyl sulphate concentration of 0.38 %wt

$$\begin{aligned}
 \text{Total oil recovered by water flooding} &= 41.9\% \\
 S_{orw} &= 0.82 - 0.419 = 0.401 = 0.40 \\
 \% \text{ of oil recovered by surfactant of (0.35\%wt)} &= 19.3\% \\
 &= 0.193 \times S_{orw} (0.401) = 0.077393 \\
 \text{Residual oil saturation after surfactant flood} \\
 (S_{or \text{ surfactant}}) &= S_{orw} - 0.077393 = 0.401 - 0.077393 = \\
 0.323607 &= 0.32
 \end{aligned}$$

The calculations of the displacement efficiency and residual oil saturation were shown (sections 4.1.1-4.1.5). The calculations showed the total oil recovered by water flooding before the injection of the different concentrations of sodium dodecyl sulphate. Table 9 shows the amount of oil left in the sand pack as residual oil.

DISCUSSION

Reservoir property evaluation

The properties of the sand pack were taken to represent the properties of the unconsolidated reservoir rocks found in Niger Delta. Table 2 depicts the estimated pore volume of the sand packs. Slight difference occurred with respect to porosity over estimation. The results of porosity and permeability are shown in Table 3.

Effect of surfactant concentration on interfacial tension

The surfactant solutions prepared were 0.2, 0.3, 0.35 and

0.38% wt. the impact of surfactant solution on interfacial and surface tension was investigated using different concentration of sodium dodecyl sulphate. It was observed that the higher the surfactant concentration the more the surface and interfacial tension is reduced. Results of this experiment are shown in Table 4.

Effect of low salinity water flooding on recovery

Low salinity water flooding was conducted to demonstrate secondary recovery using the sand packs. The sand packs had different pore volumes (Table 2); the recovered oil equally defers (Table 5). Oil recovery from the sand packs increased from B1 to B4. Water flooding recovered 39.1, 40.8, 41.3 and 41.9% respectively. This agrees to the fact that two-third of the oil in place is left after secondary recovery scheme. It was not only the quantity of oil in place that determined the volume recovered but also the reservoir characteristics as the cores had variable values of porosity and permeability.

Effects of low salinity surfactant flooding on oil recovery during tertiary recovery

It was observed from the study that injection of sodium dodecyl sulphate can help to improved oil recovery due to the oil-water interfacial tension reduction. Recovery from surfactant flooding increases as concentration of surfactant injected increases which indicates a good displacement efficiency of the displacing fluids. The injection of the surfactant at different concentrations played a significant role to recover untapped oil trapped in the formulated core plugs. The injection of surfactants into the formation weakens the interfacial tension forces, this makes the oil to be mobilized and move freely in the pore throat of the core plug, thereby making more oil to be recovered. In addition, the result agrees with the works of Adnan 2014 and Behruz (2014) that injection of surfactant slugs can help to improved oil recovery as a result of interfacial tension reduction and wettability change which is in agreement with this research papers.

It was observed from Figure 8 that injection of surfactant increased oil recovery at different concentration. Water flooding recovered was 39.1, 40.8, 41.3 and 41.9%, while oil recovered due to surfactant flooding was 16.1, 16.9, 19.0 and 19.3% of OOIP respectively. The research had total oil recovery of 55.2, 57.7, 60.3 and 61.2% (Table 6) respectively for the various surfactant concentrations. The result indicates that surfactant flooding showed appreciably increase in oil recovery from the experimental study carried out. Table 7 also shows the result of the ethanol flooding. It can be observed from the table that ethanol had a little effect on oil recovery. Table 7 shows the result of secondary and tertiary production using ethanol. About 40% of the original oil in place was produced while 60%

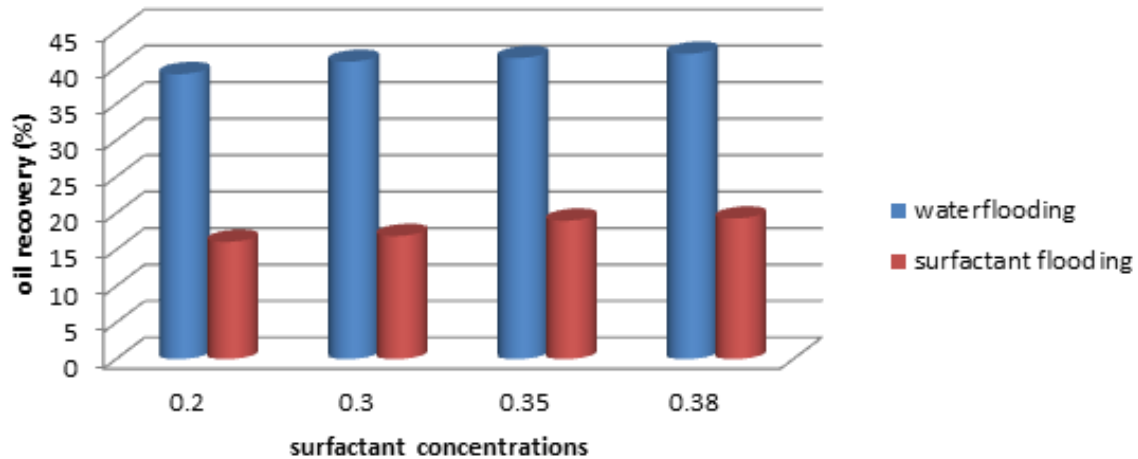


Figure 8. Graph of oil recovery against surfactant concentrations.

Table 8. Comparison of Results between the oil recovered using sodium dodecyl sulphate and ethanol.

Core sample	% of oil recovered due to sodium dodecyl sulphate	Core sample	% of oil recovered due to sodium dodecyl sulphate
Sodium dodecyl sulphate			
Core B ₅	16.1	Core B ₆	16.9
Core B ₇	19.0	Core B ₈	19.3
Ethanol			
Core B ₉	1.5		

Table 9. Effect of Surfactant concentration on residual oil after surfactant injection.

Concentration of the surfactant	Residual oil sat. after sodium dedocyl sulphate surfactant flood ($S_{or\ surfactant}$)
0.2	0.36
0.3	0.35
0.35	0.33
0.38	0.32
Residual oil sat. after ethanol flood ($S_{or\ ethanol}$)	0.43

of the oil is left in the reservoir. Oil recovered due to ethanol was 1.5% of OOIP. It was also observed that ethanol evaporates when injected into the sand packs. This could be the reason why ethanol did not recover much oil.

Abdulmecit and Farad (2021) in their work on combined injection of low salinity and surfactant for improved oil recovery obtained 9.2% of OOIP after the injection of surfactant. While this work obtained 16.1, 16.9, 19.0 and 19.3% (Table 8) after the injection of surfactant at different concentrations. This work has improved on the result of Abdulmecit and Farad. The increment in oil recovery using surfactant flooding might be interfacial

tension reduction which gave a significant effect on oil recovery at all concentrations. Table 9 showed the effect of surfactant concentration on the residual oil saturation. The table shows that the higher the concentration of the surfactant, the lower the residual oil saturation and more oil recovered.

Furthermore, Figure 8 shows the graphical comparison between the secondary recovery mechanism (water flooding) and the tertiary recovery mechanism (sodium dedocyl sulphate). Tapped oil in the cores was recovered by the injection of the surfactant into the sand packs. Figure 9 shows that as the surfactant concentrations increases, interfacial tension of the crude oil decreases.

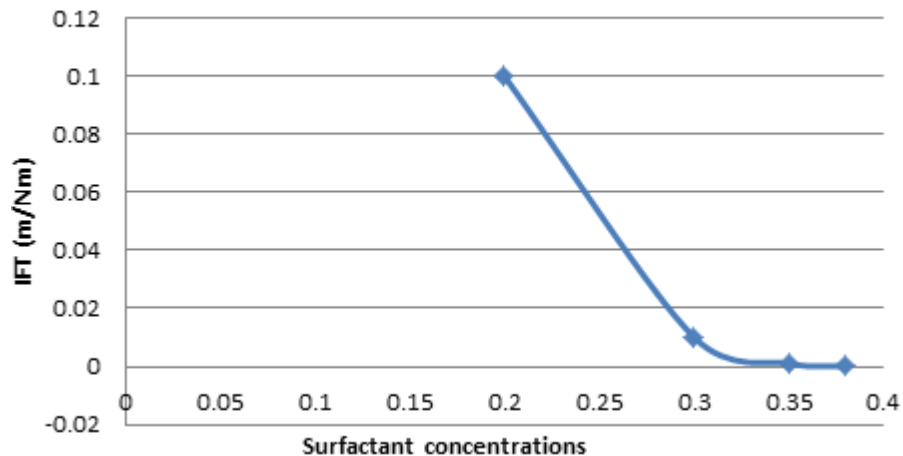


Figure 9. A graph of surfactant concentrations against IFT reduction.

Conclusion

Sodium dodecyl sulphate exhibited a positive effect on oil recovery. This is because the different concentrations played a significant role in decreasing the interfacial tension between oil and water as well as oil and rock surface. Several authors have claimed that reduction in interfacial tension and wettability alteration enhance the production of remaining oil after water flooding, this work has equally contributed to show that interfacial tension reduction aids oil recovery. These mechanisms could assist the mobilization of oil trapped in the core plugs, thereby increasing oil recovery due to injection of sodium dodecyl sulphate.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest.

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