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Effect of unconventional surfactant on wettability alteration for enhanced heavy- oil recovery in sandstone reservoirs

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Abstract

With depletion of global light oil reserves and the challenges associated of developing new wells have led to a shift in focus towards heavy crude oil as a vital component of future global energy mix. Heavy crude oil reserves are abundant and their development is crucial to meeting the increasing energy demands. The wetting condition of a crude oil/brine/rock system plays a significant role in determining transport properties and oil recovery. Research has shown that some local materials possess similar characteristics as the conventional materials. This study investigates the potentials of locally formulated non-edible surfactant in altering rock wettability and improving recovery during chemical flooding of core plugs obtained from Niger delta formation. The surfactant was screened for critical micelles concentration and aqueous compatibility and its performance in wettability alteration and oil recovery was evaluated using a conventional surfactant as a reference. Results indicates that the locally formulated agents effectively reduced the interfacial tension (IFT), altered the wettability condition from slightly oil-wet to more water-wet, resulting to increased oil recovery. The performance of locally formulated EOR (Enhanced Oil Recovery) agent (SLE) was compared with conventional surfactant (SDS) experimentally by chemical flooding, yielding a recovery of 22.5% of original oil in place (OOIP) for SLE and 24.7% of original oil in place (OOIP) for the conventional Sodium Dodecyl Sulfate, indicating a percentage difference of 8.9%. The findings suggest that SLE is a promising candidate for enhanced heavy crude oil recovery applications in sandstone reservoirs, offering a viable alternative to conventional surfactants.

Keywords: Unconventional Surfactant (SLE); Enhanced Oil Recovery (EOR); Wettability Alteration; Heavy Crude Oil; Sandstone Reservoir

1. Introduction

With the increasing challenges and cost associated with developing new oil and gas fields, attention is shifting towards optimizing production from existing reservoirs. Globally, heavy crude oil reserves are abundant and their development is crucial to meeting the increasing energy demands driven by population growth and industrialization. Heavy oil reservoirs are widely distributed in countries like Canada, Venezuela, Iran, Oman, China, Mexico, USA, Brazil, Columbia and Nigeria [13].

Altering the wettability of a reservoir has significant effect on oil recovery, mobilizing residual oil, altering the internal forces controlling the flow dynamics in the matrix allowing the fluid to flow to the wellbore.

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Chemical injection with a surfactant allows for changing the wettability from hydrophobic to hydrophilic. [4]. Surfactants are surface-active agents which are organic in nature, possess hydrophilic head and hydrophobic tail polar groups. These polarities play a significant role in the altering the surface and interfacial properties in the formation.

Conventional synthetic chemical flooding agents such as Sodium Dodecyl Sulphate, SDS, Sodium lauryl sulphate, SLS have been used to improve displacement efficiency in heavy crude oil reservoirs [5] [10] However, these synthetic chemicals have several drawbacks including environmental concerns, high cost and potential reservoir damage which has limited their effectiveness. Research had shown that local materials in our environment can be used for enhance oil recovery as they possess similar characteristics as the synthetic conventional materials. They provide salinity tolerance and are stable at high temperature when compared with synthesized chemicals. These local materials available in our environment can be used as alternatives or as well as replacement for the conventional chemicals used for chemical flooding. Their utilization will minimize production, maximize profit, convert waste to wealth and create job opportunities [10-11].

Leaf extracts contain saponins, natural bio-based surfactants providing surface -active properties suitable for enhanced oil recovery [9]. Several investigations have been carried out on locally sourced surfactants for enhanced oil recovery [1-6]. However, most of the studies have not considered non-edible local sourced material. This study investigated the effectiveness of locally sourced natural surfactant extracted from *Codiaeum Varigatus* leaves as a replacement for conventional synthetic chemical in enhanced heavy-oil recovery.

2. Materials and Methods

Apparatus or equipment used to carry out this experimental work consists among others; weighing balance, beaker, measuring cylinder, Ph meter, pump, filter paper, sieve or mesh, thermometer, core flooding unit, core holders, deionized water, distilled water, industrial salt, Amott wettability unit, drying oven, conductivity meter, viscometer, pycnometer, sodium dodecyl sulphate, brine and crude oil. The materials were obtained locally because they are readily available and cost effective. With the aim of reducing or eliminating the need to import oil field chemicals and improving their application. These materials are natural surfactant extracted from *Codiaeum Varigatus* leaves (SLE). The surfactant was incorporated into core flooding experiments to evaluate its effectiveness for enhanced heavy-oil recovery. The Crude oil used for this research was obtained from a field in Nigeria.

2.1. Brine Preparation

The brine used in the experiment was prepared in the laboratory. 30g of sodium chloride (NaCl) was dissolved in 3000ml of distilled water. The mixture was stirred continuously with a magnetic stirrer until the salt was completely dissolved yielding a homogenous solution. The resulting brine had a concentration of 3%(w/v), equivalent to 30,000ppm or 30g/L).

2.2. Surfactant preparation

2.2.1. Synthetic Surfactant

Sodium Dodecyl Sulphate (SDS) (≥99% purity) was used as reference anionic surfactant. A stock solution of 3000ppm (0.3wt%) was prepared dissolving 3.00g of SDS (weighed to 99%purity) in 30ml of deionized water in a beaker. The mixture was stirred magnetically until fully dissolved, then transferred to a 10L volumetric cylinder and diluted to the mark with additional deionized water, yielding a homogenous 3000ppm SDS solution

2.2.2. Local Surfactant

Codiaeum Varigatus leaves (SLE) were washed, air dried, shredded and grounded to paste. The paste was hand-pressed through a clean cloth to collect the liquid extract which was then filtered (Whatman No.1) to remove solid particles.3.00g of the filtered leaf extract was dissolved in 30ml of deionized water, stirred until uniform and then diluted to 10L with additional deionized water in a volumetric cylinder giving a 3000ppm leaf-extract surfactant solution.

2.3. Screening Test for the Formulated Surfactants

The surfactant solutions, SDS and SLE were subjected to screening tests, including critical micelles concentration determination and aqueous compatibility assessment.

2.3.1. Critical Micelles Concentration (CMC)

Critical Micelles Concentration is the minimum concentration of surfactant required to form micelles in solution. It is a term refers to an aggregate form of surfactant molecules dispersed in a liquid colloid [8]. The CMC of the selected surfactants in this research was determined to ensure the right concentration to flood using electrical conductivity method.

2.3.2. Aqueous Stability Test: (AQS)

This test aims to verify the suitability of surfactants with the reservoir brine. Incompatible solution may result in formation damage and plugging of pore throats. Varying concentration of brine solution was mixed with surfactant solution in a test tube. The solutions were stirred continuously to attain homogeneity. The test tubes were kept in an oven at temperature of 70^{o}C for 6hours and finally inspected virtually to ensure a clear, cloudless fluids that are devoid of precipitates.

2.4. Assessment of Wettability Alteration

The initial wettability state was established by performing a core-flooding experiment on the cleaned, dried core sample. First the core was fully saturated with brine and its pore volume (Vp) measured. Oil was then injected at a constant flow rate until irreducible water saturation (S_{wir}) was reached. The volume of water displaced and the pressure drop across the core were recorded. Next, water was injected at a constant rate, displacing oil and the volume of oil produced and pressure drop were recorded at each step. Water saturation (Sw) was calculated as:

$$S_w = \frac{Vw}{Vp} \qquad (1)$$

and relative permeabilities were computed using Darcy's law

$$k_{rw} = \frac{q_w \ \mu_w \ L}{A\Delta P} \qquad (2)$$

$$k_{ro} = \frac{q_o \ \mu_o \ L}{A\Delta P} \qquad (3)$$

where

q_w , q_0 = flow rate of water and oil respectively, μ_o , μ_w = oil and water viscosities respectively, Δp = pressure drop, L= length of core samples, A= Cross sectional area

The relative permeability curves (K_{rw}, k_{ro} versus S_w) were plotted and the intersection point of the two curves (k_{rw}=k_{ro}) was taken as the initial wettability state (cross over saturation). After determining the baseline wettability, the core sample was injected with surfactant solution and allowed to equilibrate for 12hours, the flooding procedure was repeated and the change in the cross over saturation indicated the degree of wettability alteration.

2.5. Oil Recovery Test

Oil recovery test was conducted with the cores plugs serving as the porous medium while the natural and synthetic surfactant solutions served as the chemical recovery agents. The test aimed to evaluate the recovery percentage with respect to wettability change, displacement efficiency and incremental oil recovery. The test consisted of secondary and tertiary flooding.

3. Results and Discussions

3.1. Fluid Properties

The crude oil exhibited a density of 0.931g/cm^3, °API of 20.6 at 27°C, Total Acid Number (TAN) 3.02mg KOH/g, and viscosity of 252.82cP at 150^{o}F (Table 1). These values classify the crude as heavy crude. Both the synthetic foreign surfactant (SDS) and local surfactant (SLE) exhibited similar densities of 1.01g/cm3 which suggest that SLE would exhibit similar fluid-dynamics during chemical flooding thereby validating the decision to substitute the foreign surfactant for local surfactant.

Table 1 Fluid Properties

Sample	Density g/cc
Crude oil	0.93
Brine	1.03
SDS	1.01
SLE	1.01

3.2. Critical Micelle Concentration of the Surfactants

The inflection points on the graph (Figure 1) indicates the critical micelles concentration. The points of deviations or changes in the slope could likely be attributed to the behavior of the surfactants. The result of the locally designed surfactant (SLE) is close to SDS. This implies that the locally designed surfactant can be used as substitute for synthetic surfactant considering availability and the impact (non-toxic nature) on the environment.

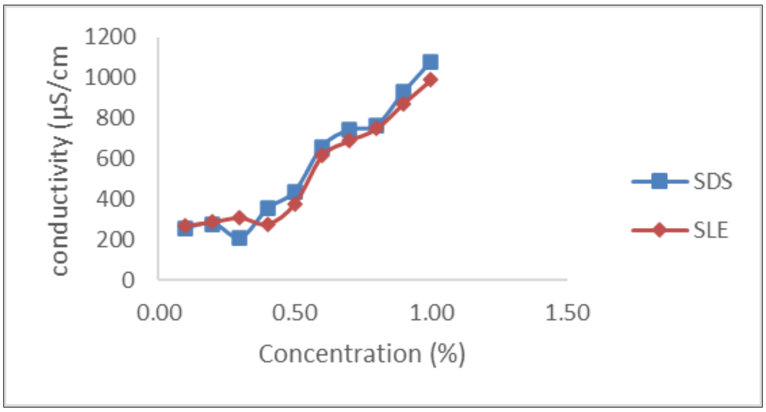

Figure 1 Critical micelle concentration of surfactants

3.3. Aqueous Compatibility Test

Compatibility test performed on the synthetic surfactant (SDS) and local surfactant in brine solution showed that both SDS and SLE produced clear, cloudless solutions devoid of precipitates at a temperature of 70°C demonstrating their thermal stability and compatibility with the aqueous phase.

3.4. Effects of the Surfactants on Interfacial Tension (IFT) Reduction

The impact of two different surfactants, SDS, synthetic and SLE, locally formulated were evaluated for their ability to reduce IFT between oil and water phases. (Figure 2). IFT reduction performance of SDS was characterized by an initial decrease from 7.20 to 1.17 mN/m as concentration increased from 0 to 0.75wt%. However further increase in concentration led to an increase in IFT at 1wt%. This behavior suggests that SDS is effective in reducing IFT at low to moderate concentration, but its performance is compromised at higher concentration which could be attributed to micelle concentrations or changes in surfactant solubility. In contrast, SLS exhibited a continuous decrease in IFT which indicates that SLE is consistent IFT reducer. The results demonstrate that surfactant structure and concentration play a crucial role in determining IFT reduction performance.

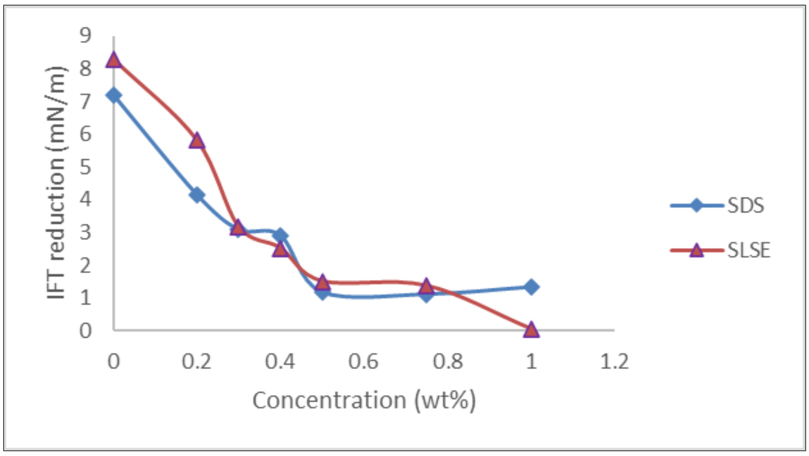

Figure 2 Effects of the Surfactants on Interfacial Tension (IFT)reduction

3.5. Impact of Surfactants on Rock Wettability

3.5.1. Wettability State Before Treatment

Prior to surfactant treatment, the initial relative permeability curves intersected at water saturation value of 0.48, as illustrated in Figure 3, indicating a mixed -wet to oil-wet condition. The intersection point suggests that the reservoir rock surface had high affinity for oil resulting in potentially lower oil recovery.

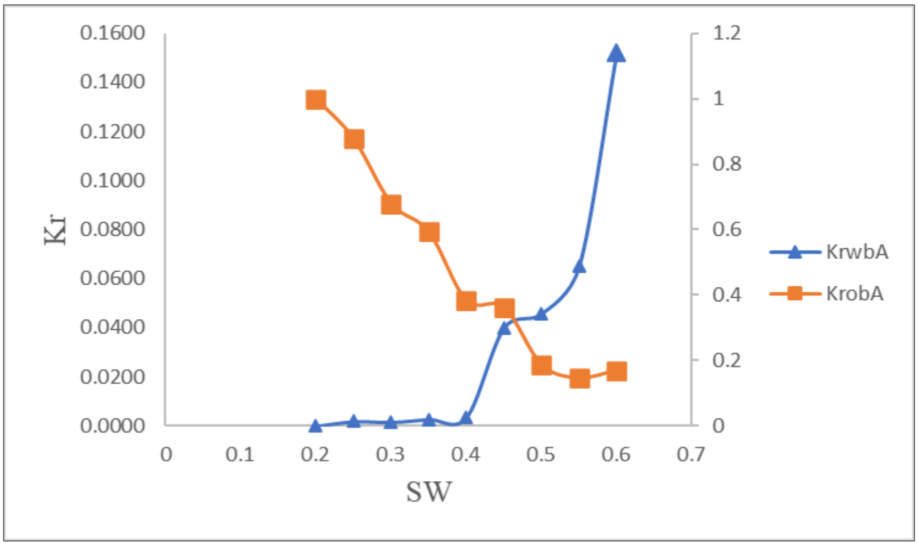

Figure 3 Initial Wettability State

3.5.2. Wettability State After Treatment

Following surfactant treatment, the intersection points of the relative permeability shifted as displayed in Figures 4-5. The application of surfactants significantly altered the wettability of the core plugs. Notably the synthetic surfactant (SDS) exhibited the most pronounced effect, shifting the intersection point from 0.48 to 0.7. In contrast, the locally prepared surfactants shifted the curve from 0.48 to 0.64. This variability in intersection points may be attributed to differences in surfactant molecular structure, concentration or interaction with rock minerals. Which is an indication that the locally prepared leaf-based surfactant can be used as viable alternatives to synthetic surfactants for wettability alteration in EOR applications.

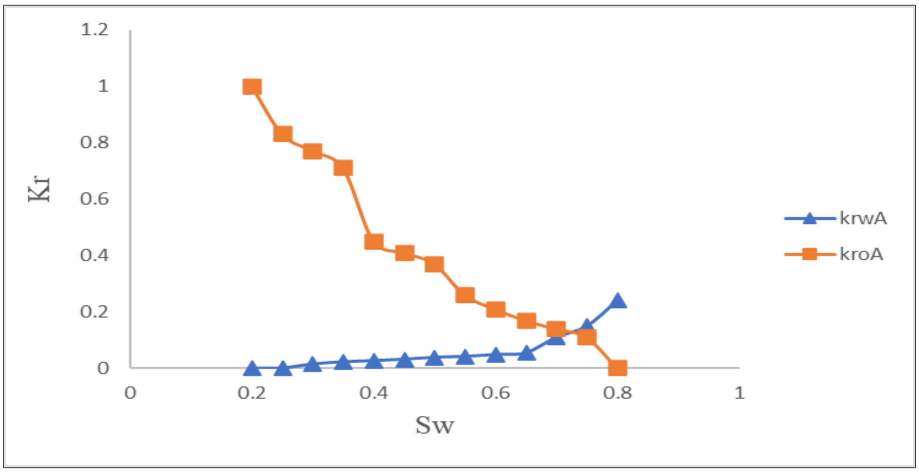

Figure 4 Wettability Alteration with Sodium Dodecyl Sulphate (SDS)

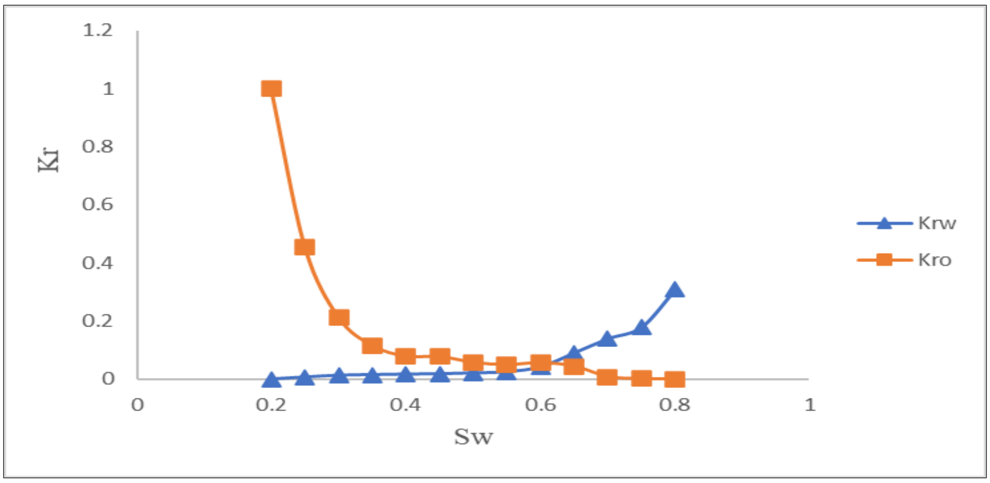

Figure 5 Wettability Alteration with *Codiaeum Varigatus* (SLE)

3.6. Oil Recovery Test

3.6.1. Secondary Recovery (Brine Flooding)

Brine was used for flooding at the secondary stage recovery process at 30,000 ppm salinity concentration. The original oil present in the core plug was 15ml. During secondary recovery, 5PV of brine was used as displacing fluid, 5.5ml of oil was recovered with 9.5ml of residual oil unrecovered implying that an average of about 65% of residual oil was yet to be recovered.

3.6.2. Tertiary Recovery (Surfactant Flooding)

Flooding with surfactants resulted in additional recoveries of 2.1ml and 1.82ml for SDS and SLE yielding a recovery of 22.5% of original oil in place (OOIP) for SLE and 24.7% of original oil in place (OOIP) for the conventional Sodium Dodecyl Sulphate, indicating a percentage difference of 8.9%.

4. Conclusion

This study investigated the potential of unconventional locally formulated surfactant, SLE for enhanced heavy oil recovery in sandstone reservoirs compared to a conventional synthetic SDS.The surfactants were screened for critical micelles concentration (CMC) and aqueous compatibility test (AQS). Their performance in wettability alteration and oil recovery was evaluated.

The results showed that both SDS and SLE surfactants exhibited good aqueous compatibility and effectively altered the rock wettability demonstrating their stability and compatibility with the aqueous phase.

The CMC values for SDS and SLE were 0.3 and 0.4 respectively indicating that SLE has a comparable surfactant efficiency to the conventional SDS as the CMC values are within the same order of magnitude.

The surfactants significantly reduced interfacial tension and altered the rock wettability from mixed wet conditions (Sw=0.48) to more water-wet condition (0.7 for SDS and 0.64 for SLE). These findings suggests that SLE is a promising candidate for wettability alteration.

Compliance with ethical standards

Acknowledgment

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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