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Performance Study of Surfactant-Assisted Electrokinetics for Enhanced Oil Recovery in the Niger-Delta

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Abstract

There is always large residual oil saturation after primary and secondary recovery phases, and this is due to unfavorable mobility ratio and capillary forces. To resolve this, enhanced oil recovery (EOR) techniques such as chemical enhanced oil recovery (CEOR) have been utilized to recover this entrapped crude oil. CEOR comprised of polymer, alkali and surfactant flooding, but surfactant flooding have gotten global attention. Though Surfactant reduces IFT between brine-oil systems, it is limited by mobility control issue due to insufficient viscosity to effectively sweep crude oil. These limitation have led to several combination techniques such Electrokinetic-enhanced oil recovery (EK-EOR). EK-EOR is a technology that involves passing low DC current through the reservoir between a subsurface anode and cathode in the producing well. In this study, the impact of electrokinetic enhanced surfactant flooding was explored for improving oil recovery. The study was carried out using interfacial tension and core-flooding. From the result the IFT test, MgO at 2wt% recorded the least IFT of 8.3mN/m while 2%wt APG recorded IFT of 12.4mN/m. From the result of the coreflooding, for sequential mode, 2%wt MgO nanoparticle recorded the highest performance with additional recovery of 37.96% while 1wt% MgO, 3wt% APG, 2wt% APG and 1wt% APG recorded additional recoveries of 34.57%, 32.10%, 31.79% and 25/93% respectively. For simultaneous mode, 2%wt MgO nanoparticle recorded the highest performance with additional recovery of 43.83%, while 1wt% MgO, 3wt% APG, 2wt% APG and 1wt% APG recorded 41.98%, 43.21%, 43.21% and 40.74% respectively.

Keywords: *Enhanced oil recovery; Electro-kinetic assisted; Surfactants; Nanoparticle.*

1. Introduction

There is always large residual oil saturation after primary and secondary recovery phases, and this is due to unfavorable mobility ratio and capillary forces. In other to continue recovering crude beyond these stages, enhanced oil recovery (EOR) techniques should be introduced. This is due to the potentials of EOR techniques in recovering about 37% of original oil in place (OOIP) [1]. Several EOR techniques exists, but chemical enhanced oil recovery (CEOR) is the most preferred globally [2-3]. CEOR is a technique where chemical substances are injected into the formation for the purpose of pushing or mobilizing the entrapped crude to the wellbore. The chemical substances could be surfactant, alkaline, polymer or hybrid system depending on the prevailing reservoir condition [2]. CEOR functions with mechanisms such as interfacial tension (IFT) reduction, wettability alteration, mobility control, polymeric viscoelasticity and permeability reduction. Surfactants have been utilized for EOR since 1970s due to their potential prospects [4]. Surfactant can be explained as surface-active agents with wide levels of application [5]. Surfactant comprises of hydrophobic (tail) and hydrophilic (head) groups which plays a significant role in both water and oil systems. The hydrophilic head of the surface-active agents determines its category. Surfactant are grouped into zwitterionic, anionic, cationic and non-ionic [6]. The nonionic and anionic surfactants, are the most recommended for CEOR [7]. Anionic is the most utilized in CEOR due its relatively low adsorption behavior to negatively charged sandstone surface and stability at high temperature [8]. In carbonate environment; anionic surface-active agents are rarely utilized due to their high rate of adsorption to the surface of the rock [9]. This phenomenon can be mitigated or reduced using sodium carbonate [10]. Nonionic are used to enhance the phase behavior and stabilize the surfactant in elevated saline environment despite failing to properly reduce IFT [11]. The best surfactant is the agent with the lowest critical micelle concentration CMC [12]. The anionic surfactants can be grouped into carboxylate, sulphate, sulfonate and phosphate while non-ionic surfactant are ether, ester, phenol, hydroxyl and amine [13-14, 29]. Both experimental test and field evaluation have shown the utilization of surfactants in EOR in reducing the residual oil saturation due to its wettability alteration and IFT reduction behaviors on the rock formation. In some cases, co-surfactant and/or alkaline are introduce to enhance the performance of the surfactant. The later in addition to lowering IFT, reacts with acidic component of the crude oil to generate in-situ soap which helps to reduce surfactant adsorption at optimal conditions of salinity, temperature and pressure [15]. Surfactants and Alkali are used to improve the effectiveness of macroscopic sweep efficiency in the reservoir [16]. Introduction of surfactant into an oil-water solution, results in the formation of micelle and reduces the IFT between the oil and water. At increasing surfactant molecule concentration, insoluble fluids become soluble and form micro-emulsion (ME), until a point in which addition of surfactant to the solution does not yield or form micelles. This concentration is referred to as critical micelle concentration (CMC). After the CMC stage, the introduction of surfactant does not further yield micelle. While surfactant reduces IFT between brine-oil systems, its inability to increase viscosity of the injected fluid, leads to early breakthrough without recovering the entrapped crude oil, particularly in high viscosity and in low permeability reservoir [17]. These limitation have led to several combination techniques such Electrokinetic-enhanced oil recovery (EK-EOR). EK-EOR is a technology that involves passing low DC current through the reservoir between a subsurface anode and cathode in the producing well. The low DC current yields hydrodynamic movement of fluid from the injection well to the producer well [18]. This technology has demonstrated several advantages, including fluid viscosity reduction, permeability enhancement, and reduced water cut [19]. The EK-EOR utilizes joule heating, electro-migration, electrophoresis (EP), electro-osmosis and electrochemically enhanced reaction for its operation [20-22].

Several EK-EOR studies have been conducted by authors such as Haroun *et al.* [23] and Chilingar *et al.* [24], but these studies have not considered its viability in the Niger-Delta.

In this study, performance evaluation of electro-kinetic (EK) approach in improving oil recovery of alkyl polyglycoside (APG) and magnesium oxide nanoparticle (MO-NPs) in the reservoir. FTIR characterization, IFT measurement and core-flooding were conducted to ascertain the EOR potentials.

2. Materials and methods

2.1. Materials

The materials utilized for the study were crude oil, alkyl polyglycoside (APG), magnesium oxide, sandstone core plug, coreflood apparatus, weighing balance, beaker, stirrer, viscometer, density bottle, tensiometer, distilled water, and industrial sodium chloride

2.2. Sourcing of materials

Alkyl polyglycoside (APG) and magnesium oxide nanoparticles (MO-NPs) were sourced from an industrial chemical store. Crude oil and core plug were sourced from a field in the Niger-Delta.

2.3. Methods

2.3.1. Evaluation of the crude oil and core sample

The crude oil was evaluated using specific gravity, API gravity and viscosity test. The specific gravity test and viscosity test depicted in Table 1, was carried out using hydrometer and cannon u-tube viscometer respectively. The core sample was evaluated using porosity determination test and results documented in Table 2

Table 1. Petro-physical properties of core plug .

Density, g/cm^3	Specific gravity	API	Type	Viscosity	Pressure, psi
0.868	0.860	31.50	light	<10cP	15

Table .2. Petrophysical properties of crude oil.

CORES	Length (cm)	Diameter (cm)	Dry weight (g)	Wet weight (g)	Bulk volume (mL)	Pore volume (mL)	Porosity (%)	OIIP (mL)
CORE A	7.20	3.60	139. 80	157. 80	73.28	18.00	24.50	16.20

2.3.2. Sample characterization

Sample characterization are necessary to decipher the present functional groups and vital features associated with the samples. The characterization of APG and MO-NPs are vital to determine the present functional groups and the type of surfactant to have a better understanding. From the literature study carried out, the FTIR characterization of APG and MO-NPs were carried out by Donat and Demirel [25] and Mirza and Makwanna [26] respectively with the outcome of their characterization outlined in the result section of the study.

2.3.3. Brine formulation

The synthetic brine was prepared by dissolving 30g of industrial sodium chloride in 1 litre of water.

2.3.4. Interfacial tension test (IFT)

IFT existing between the non-wetting (bulk fluid) and wetting (oil) phase were measured using the Fisher 20 modelled Scientific Tensiometer. The operational procedure was documented in the manual guide of the Fisher tensiometer. Experimental study was conducted on Brine, APG and MO-NPs at the different concentration depicted in Table 3.

Table 3. Samples Concentration for IFT determination test.

S/N	Samples	Concentration
1	APG	1wt%, 2wt% and 3wt%
2	MO-NPs	1wt%, 2wt% and 3wt%
3	Brine	3wt% or 30000ppm

2.3.5. Core-flooding

Oil displacement study was conducted to determine the EOR potentials of the selected surfactants and hybrid surfactants-electrokinetic assisted approach. The core plug with properties depicted in Table 2 were utilized for the oil displacement. The core plugs were introduced to the saturation system and the pressure of the system was raised to 2500psi to ensure total core saturation. These pressurized system remained constant for 48hrs before being depressurized. The depressurized core was reweighed before been placed in a core-flooding system depicted in Figure 1 at 1000psi confining pressure. Formation water was introduced at 2cc/sec to inhibit air bubble entrapment within the pores of the core, thereby retaining its perfect and air free state. Crude oil was introduced to displace the water in a drainage process until initial oil and water saturation was attained. The synthetic brine of 30000ppm was introduced to the core as a secondary recovery fluid to mobilize the oil until oil production stops. The residual saturation was derived before the introduction enhanced oil recovery process (EOR). In the EOR process, four sets of test were carried out. The first was surfactant flooding followed by the electro-kinetics, the second was nanofluid the nanofluid flooding followed by the electro-

kinetics, the third was the surfactant and electro-kinetics simultaneously, while the fourth was the nanofluid and electro-kinetic simultaneously injected.
The incremental oil recoveries from the various flooding operation were determined and documented. Figure 1 shows the schematic of the coreflood study

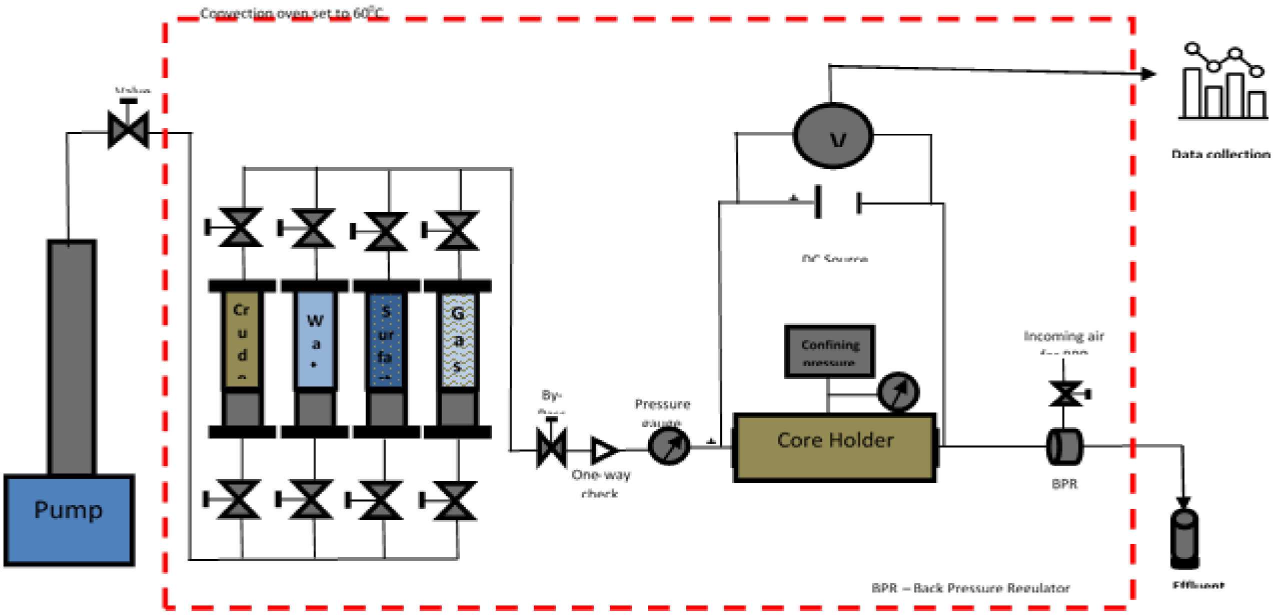

Figure 1. A Schematics Setup of an Electrokinetic Core Flooding Equipment. (FUPRE Lab).

3. Results and discussion

3.1. Sample characterization

Table 4 shows the result of FTIR characterization done on APG and MgO. As observed from the table both materials recorded the presence of hydrophilic materials such as hydroxyl group, amine, carboxylic and ester, and hydrophobic group such as alkene to record their suitability as chemical enhance oil recovery additive.

Table 4. Result of FTIR Characterization carried out on alkyl polyglycosides and magnesium oxide nanoparticles.

S/N	Alkyl polyglycosides [25]	MgO nanoparticles [26]
1	Alkene	Hydroxyl group
2	Methyl	Magnesium oxide
3	Hydroxyl	Aromatic tertiary amine
4	Carboxylic acid	Alkenes
5	Ester	Ester
6	Ether	Carboxylic acid

3.2. Interfacial tension

Figure 2 shows the IFT value of the various fluids. As shown in Figure 2, brine recorded an IFT value of 31.4mN/m. These IFT was reduced to 18.1mN/m, 12.4mN/m and 12.mN/m with the introduction of 1wt%, 2wt% and 3wt% APG respectively. When 1wt% and 2%wt of MgO was introduced to the brine-crude oil system, IFT reduced from 31.4mN/m to 11.3mN/m and 8.3mN/m respectively. Izuwa *et al.* and Dike *et al.* [8,27] studies showed that surfactant continues to reduce IFT between brine-oil system until it attains critical concentration, beyond which their addition does not reduce IFT between brine-oil system. As observed From Figure 2, APG obtained critical surfactant concentration.at 2wt% and is in-line with Izuwa *et al.* [8] and Dike et al [27] study.

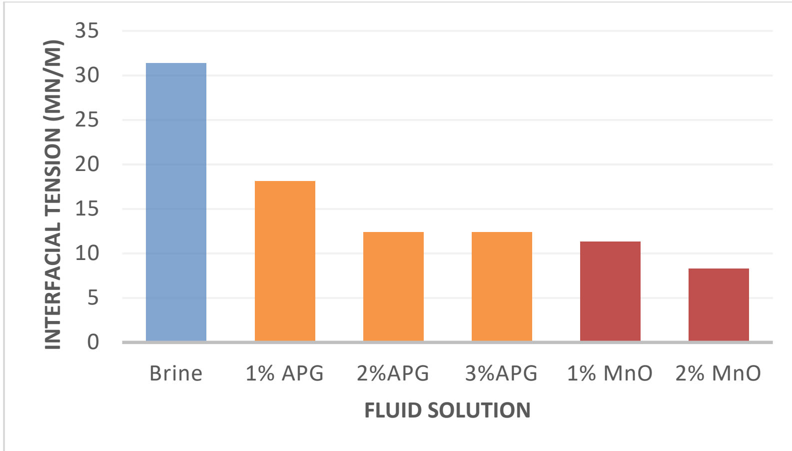

Figure 2. Interfacial tension value of the APG and MgO-NPs.

3.3. Core-flood result

Figure 3 shows the oil-recovery performance of surfactant-assisted electrokinetic approach in sequential mode. As shown in Figure 3, 1wt% of APG recorded additional 20.37% crude oil recovery before it cease to produce. Further surfactant flooding after introduction of 2V, 4V, 6V and 8V to the core yielded additional 2.47%, 3.7%, 4.94% and 5.56% respectively. 2wt% of APG recorded additional 24.88% crude oil recovery, before the introduction of 2V, 4V, 6V and 8V increase additional recovery by 1.67%, 3.52%, 4.75% and 6.91% respectively. For 3wt% APG, the EOR process recovered additional 24.07%, while introduction of 2V, 4V, 6V and 8V increased recovery by 1.85%, 3.7%, 5.86% and 8.02% respectively. At 1wt% concentration, MgO yielded additional 29.63% crude oil recovery. Introduction of 2V, 4V, 6V and 8V increased the EOR of the nanoparticles by 0.62%, 1.85%, 3.7% and 4.94%. When the concentration of MgO was increased from 1wt% to 2wt%, additional recovery increased from 29.63% to 31.48%. Further introduction of 2V, 4V, 6V and 8V of power, increased CEOR recovery by 1.23%, 3.09%, 4.94% and 6.48% respectively. As observed in Figure 3, the CEOR performance of APG recorded the maximum recovery at 2%wt, while further increase in concentration yielded lesser crude oil recovery. Comparing Figure 3 with Figure 2, the highest CEOR value at 2%wt is attributed to its least IFT value, and is in-line with Kerunwa [28] study.

The reduced CEOR at 3wt% concentration is attributed to adsorption. The additional recovery due to introduction of 2V, 4V, 6V and 8V of electricity can be attribute to heat generation of the injected current which reduces the viscosity of the crude oil to allow ease displacement after the surfactants had reduced IFT between the brine-oil systems. As observed too, MgO nanoparticles yielded better recovery than APG. This is attributed to the action of MgO nanoparticles to in reducing the viscosity of crude oil, while lowers IFT between brine-oil systems. Figure 4 shows the oil-recovery performance of surfactant-assisted electrokinetic approach in simultaneous mode. As shown in Figure 4 the simultaneous flood of 1wt% APG with 2V, 4V, 6V and 8V recorded 27.78%, 33.33%, 37.65% and 40.74% additional recoveries respectively. At 2wt% APG with 2V, 4V, 6V and 8V recorded 32.72%, 37.04%, 40.74% and 43.21% additional recoveries respectively. At 3wt% APG with 2V, 4V, 6V and 8V recorded 36.42%, 38.89%, 40.74% and 43.21% additional recoveries respectively. At 1wt% MgO with 2V, 4V, 6V and 8V recorded 31.48%, 35.19%, 38.27% and 41.98% additional recoveries respectively. At 2wt% MgO with 2V, 4V, 6V and 8V recorded 38.89%, 41.36%, 42.59% and 43.83% additional recoveries respectively. Comparing Figure 3 with Figure 4, the simultaneous mode electrokinetic approach yielded better oil recovery compared to sequential flooding. This is attributed to the constant reduced viscosity of the crude oil and reduced IFT performance of the surfactant compared to sequential flooding which crude oil viscosity is not constant.

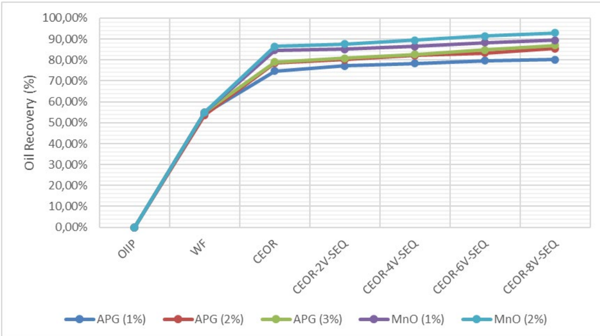

Figure 3. Surfactant-assisted electrokinetic approach in sequential mode.

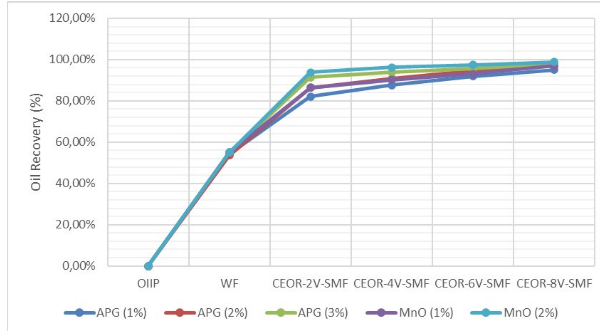

Figure 4. Surfactant-assisted electrokinetic approach in simultaneous mode.

4. Conclusion

From the result of the interfacial tension test (IFT) carried out, increase in surfactant concentration reduces IFT till critical surfactant concentration. MgO at 2wt% recorded the least IFT of 8.3mN/m while 2%wt APG recorded IFT of 12.4mN/m. The introduction of electrokinetic approach enhanced the performance of the selected materials. Electrokinetic approach for enhance oil recovery is more effective in simultaneous flooding than in sequential flooding. In sequential flooding, 2%wt MgO nanoparticle recorded the highest performance with additional recovery of 37.96% while 1wt% MgO, 3wt% APG, 2wt% APG and 1wt% APG recorded additional recoveries of 34.57%, 32.10%, 31.79% and 25/93% respectively. In simultaneous flooding, 2%wt MgO nanoparticle recorded the highest performance with additional recovery of 43.83%, while 1wt% MgO, 3wt% APG, 2wt% APG and 1wt% APG recorded 41.98%, 43.21%, 43.21% and 40.74% respectively.

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