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Performance Evaluation of Agro-Materials for Surfactant-Polymer Flooding

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Abstract

Conventional surfactants and polymers are costly, limited by adsorption and retention problems which reduces their effectiveness within the pore spaces of the reservoir rock. In this study, experimental evaluation of EOR potentials of agro-polymers and surfactants when utilized for surfactant- polymer (SP) flooding was carried out. Fourier transform infrared (FTIR) spectroscopy, IFT determination, phase behavior and core flooding were conducted on these materials. From the results, the local agro-polymers: *Araucaria columnaris* exudate (ACE), *Terminalia mantaly* exudate (TME) possess the same functional groups as the conventional Xanthan gum (XG) and are therefore polysaccharides. Similarly, the agro-surfactants: *Carica papaya* extracts (CPE), *Vernonia amygdalina* extracts (VAE) also had the same functional groups as the conventional Sodium lauryl sulphate (SLS) and with ether and hydroxyl group, the agro-surfactant can be said to possess nonionic and anionic properties as SLS. For the IFT, SLS recorded lower IFT value of 6.95mN/m among the surfactants while CPE and VAE recorded 11.35mN/m and 9.98mN/m respectively. The blend of SLS-XG recorded least IFT value of 6.92mN/m while the blend of CPE-TME had low IFT value of 8.58mN/m in comparison with CPE-ACE, VAE-TME and VAE-ACE agro-slugs which had 10mN/m, 9.06 and 10.15mN/m respectively. The polymer showed colloidal phase with water. SLS and CPE recorded Winsor Type I system while VAE recorded Winsor Type III. From the flooding, ACE yielded 15.91% additional oil recovery while XG and TME yielded 14.09% and 13.18% oil recoveries respectively. The performance of ACE over XG and TME, is tied to its viscosity which gave rise to favorable mobility control thereby yielding increased oil recovery. SLS performed better than the agro-surfactants (VAE and CPE) with 16.74% additional oil recovery while for SP flooding, CPE-ACE slug performed better than other slugs as it yielded 19.09% additional oil recovery. The EOR performance of CPE-ACE blend is tied to combined mechanisms of mobility control and IFT reduction. Evidently, the agro-polymers and surfactants have shown adequate EOR potentials to be used for EOR operations and to serve as substitute to the conventional polymers and surfactants.

Keywords: *Surfactant; Polymer; Interfacial tension; Chemical enhanced oil recovery.*

1. Introduction

Materials such as polymer, surfactant, alkaline and/or their hybrid solutions are utilized after secondary recovery to enhance oil production [1]. These materials when injected improves displacement and sweep efficiencies using mechanism such as mobility ratio reduction between mobilizing and mobilized fluids, rock and/or fluid wettability modification, permeability reduction, polymeric viscoelasticity and interfacial tension (IFT) reduction. About 37% of the original oil in place (OOIP) could be recovered by this approach and commonly referred as chemical enhanced oil recovery (CEOR) [2]. Of the various CEOR approaches, polymers and surfactants have shown unique features, high effectiveness and potentials [3]. Surfactants are surface active chemicals with varieties of application [3-4]. When injected into the reservoir using a carrier fluid (fresh water or brine) in phenomenon called surfactant flooding, the surface-active chemical reduces the IFT between the wetting and non-wetting phases [4-5]. In addition to lowering IFT, surfactants flooding also alter the wettability of porous formation

from oil-wet to water-wet. Surfactants generally comprises of hydrophobic (tail) and hydrophilic (head) groups which influence its mode of operation in oil-injectant rock system. The hydrophilic head of the surface-active agents determines its grouping. Surfactant are grouped into cationic (+vely charged), non-ionic (neutrally charged), anionic (-vely charged) and zwitterionic (combination of +ve and –ve charges) [6]. The anionic and non-ionic surfactants are the most widely utilized for CEOR [7]. Anionic surfactants are widely used in CEOR due to its very low adsorption behavior to the negatively charged sandstone surface [8]. Non-ionic surfactants are used to improve phase behavior of the system and possesses stability in higher saline conditions despite its inability to adequately lower IFT in comparison to anionic surfactant. Surfactants, however are plagued with challenges such as high adsorption [9], which limits their effectiveness in the reservoir. The utilization of viscosity increasing reagent called polymers in enhancing oil recovery is referred to "polymer flooding". Polymer flooding on the other hand is more widely utilized for CEOR than surfactant flooding, and this is due to its ability to yield a favorable mobility ratio between the mobilized and mobilizing fluids and also prevent viscous fingering. Polymer CEOR is best applicable for reservoirs with viscosity <100cp, temperature <72^{o}C and moderate to low salinity environment [10]. Polymer can be derived biologically or synthetically, though previous works have shown biologically based polymer as better polysaccharide than synthetic polymers [11]. Hydrolyzed polyacrylamide (PAM) (synthetic polymer) and xanthan gum (XG) (biopolymer) are the most utilized polymeric material for CEOR [12], and this is due to their relative abundance, low cost and unique features. Polymer propagation in porous media is affected by retention problems; which is influenced by its adsorption, mechanical entrapment and hydrodynamic retention [13]. The limitations of polymers and surfactants when flooded independently have given rise to the design of surfactant-polymer (SP) hybrid solution aimed at maximizing the mechanisms and benefits associated with each CEOR approach. SP flooding utilizes combined mechanisms of the individual approaches. The success of these SP hybrid formulations in CEOR process is dependent on the compatibility between the surfactant and polymer agents [11].

2. Literature review

Recent studies have shown the prospects of locally sourced agro-materials (polymers and surfactants) in improving oil recovery. Osuji *et al.* [14] confirms the effectiveness of these agro-materials in improving oil production and their prospects in substituting conventional EOR materials when modified. Abdulraheem *et al.* [15] conducted a comparative EOR study between locally sourced polymer, to wit: modified gum arabic and natural gum Arabic, and conventional polymers, viz: hengfloc and XG. The modified gum arabic performed better than the other polymers as it yielded 41% recovery while natural gum arabic, XG, and hengfloc, yielded 28.81%, 23.96% and 28.51% oil recoveries respectively. Uzoho and Onyekonwu [16] compared the EOR performance of okro and PAM. From their study, okro performed better by yielding additional 18.7% recovery and 99.1% displacement efficiency while PAM yielded additional 12.73% recovery and 94.56% displacement efficiency. Obuebite *et al.* [17] evaluated the performance of *Terminalia mantaly* (TM), pectin and PAM as CEOR agents. From their study, TM performed better than both PAM and pectin as it yielded 90% recovery while PAM and pectin recorded 81% and 79% recovery respectively. Uzoho *et al.* [18] conducted an experimental EOR study on agro-surfactants, to wit: local gin, cocos nucifera, VAE, CPE, and conventional sodium dodecyl sulphate (SDS). From their result, SDS performed better than the agro-surfactants with 97.8% displacement efficiency, while CPE, cocos nucifera, VAE and local gin yielded 94.1%, 93.7%, 92.4% and 87.5% displacement efficiency respectively. They reported that the result has lend credence to the potentials of these agro-materials. Abraham *et al.* [19] investigated the impact of castor oil extracts (COE) and methyl ester sulfonate (MES) on oil recovery from sandstone formation. From their result, COE had better performance than MES as it yielded 46.42% additional recovery while MES yielded 37.93% additional recovery. Ikeagwu *et al.* [20] compared the EOR potentials of starch and palm wine blend with the respective individual solutions. From their study, the starch-palm wine blend yielded 26.67 displacement efficiency while individually starch yielded 2.5% displacement efficiency and palm

wine yielded 21.43% displacement efficiency respectively. Ogolo *et al.* [21] compared the EOR prospects of SDS-PAM blend with soya bean-*Irvingia gabonensis* blend in light and medium crude. From their result, SDS-PAM blend had better performance with displacement efficiency of 90% in light crude than the individual floods of SDS with 20% displacement efficiency, PAM with 35% displacement efficiency, soya bean with 20% displacement efficiency, *Irvingia gabonensis* with 37% displacement efficiency and soya bean-*Irvingia gabonensis* blend with 40% displacement efficiency respectively. Contrarily, soya bean-*Irvingia gabonensis* blend had better performance with displacement efficiency of 75% in medium crude while SDS-PAM blend had 60% displacement efficiency. In this study, 2 locally sourced agro-surfactant materials, to wit: *Carica papaya, Vernonia amygdalina*, 2 locally sourced agro-polymer materials, viz: *Terminalia mantaly* and *Araucaria columnaris* 1 conventional surfactant, namely: sodium lauryl sulphate and 1 conventional polymer, namely: xanthomas spp) were used as EOR agents in sand-pack oil displacement flood test under laboratory conditions. The extracts of *Carica papaya* and, *Vernonia amygdalina* were used in the surfactant flood test while the exudates of *Terminalia mantaly* and *Araucaria columnaris* were used in the polymer flood test and subsequently a combination of these were used in the surfactant-polymer flood test. The results of individual agro-surfactant, agro-polymer and agro-surfactant-polymer flood test were compared with those of the conventional surfactant, polymer and surfactant-polymer flood test.

3. Materials and methods

3.1.Materials

The material used for the study includes: CPE, VAE, SLS, ACE, TME, xanthan gum, crude oil, weighing balance

3.2.Methods

3.2.1 Crude oil

The crude oil for this study was sourced from Niger Delta oil field. The crude oil has specified gravity of 0.84, API gravity of 36.95^{o}API and dynamic viscosity@60^{o}F as 3.1149cP.

3.2.2. Preparation of the polymers

The TME was obtained from its habitat. TME was recovered from the incised section of *Terminalia mantaly* tree and prepared using Michael *et al.* [22] approach. The TME-biopolymer was extracted from the incised spot of the tree and dried for 5 days. The dried TME was cleansed with deionized water to eliminate impurities. The washed exudate gum was dried in an oven at 50^{o}C temperature for 48hrs to remove the moisture content of the exudate. The dried exudate was then soaked in chlorofoam-water hybrid solution for 5 days to soften the exudate before tedious task was carried out to remove the viscous phase from the exudate. Thereafter the exudate was precipitated with ethanol and washed with 100mLs of dimethyl ether, before being oven dried again at 45^{o}C temperature for 48hrs. The dried exudate was crushed to powdered form and then sieved and stored in airtight container. *Araucaria columnaris* exudates were collected from the stem of the tree and was dissolved in deionized water for 20hrs, to remove impurities. The washed exudate was dried in an oven at 50^{o}C temperature for 48hrs to remove the moisture content of the exudate. The dried exudate was then grinded into powder and then sieved and stored in airtight container. Xanthan gum was purchased from an industrial store in Owerri, Nigeria. The properties of the polymers are highlighted in Table 1.

3.2.3. Preparation of the surfactant

The *Carica papaya* leaf and *Vernonia amygdalina* leaf were recovered from their respective tree, washed three times with fresh water to remove unwanted materials and then dried for 20hrs. The dried leaves were cut into small sizes and then crushed in water to form solutions of the extracts. The extracts of *Carica papaya* and *Vernonia amygdalina* were filtered out with filter paper. The conventional surfactant, sodium lauryl sulphate (SLS) was purchased from industrial store in Owerri, Nigeria. The properties of the surfactants are shown in Table 1.

Table 1. Properties of the surfactants and polymers.

	Concentration	Density (g/cm^3)	Dynamic viscosity (cP)	pH
Surfactant				
Sodium lauryl sulphate (SLS)	1%	1.0014	0.8719	6.2
Vernonia amygadlina extracts (VAE)	1%	1.0016	0.8582	5
Carica papaya extract (CPE)	1%	1.0014	0.8668	6.2
Polymer				
Xanthan gum (XG)	0.5%	1.0018	1.1005	9.6
Terminalia mantaly exudates (TME)	0.5%	0.9996	0.8596	6.4
Araucaria columnaris exudate (ACE)	0.5%	1.0018	0.8907	5

3.2.4. Preparation of synthetic brine

The synthetic brine was prepared by dissolving 5g of industrial sodium chloride in 1 litre of water. The properties of the brine solution are shown in Table 2.

Table 2. Properties of synthetic brine solution.

	Concentration (ppm)	Density (g/cm^3)	Dynamic viscosity (cP)	pH
Synthetic Brine	5000ppm	1.0041	0.9050	7.9

3.2.5. Sample characterization

Fourier Transform Infrared (FTIR) spectroscopy was utilized to characterize the surfactant and polymer samples. M530 modelled bulk scientific infrared was used for the FTIR experimental analysis. The prepared solution (comprising of the samples, potassium-bromide and nujol) was introduced into an apparatus were wavelength of 600-4000cm^{-1} was used to derive spectra heights. The spectroscopy yielded a chart in absorbance spectra form, which shows the type of chemical bond and molecular structure in the samples. The analytical spectra determined for each material was compared with the reference library of the instrument utilized to determine the present functional group.

3.2.6. IFT test

Attension Sigma 702/702ET Tensiometer was used for IFT derivation. The procedure utilized was as documented in the Attensio Sigma 702/702ET Tensiometer manual. Experiment was conducted on brine solution with the surfactants and polymer in the presence of surfactant at varying concentration.

3.2.7. Polymer phase behavior

Polymers with concentration as shown in Table 1 was mixed in brine solution of Table 2, was introduced into sealed test-tubes before visually checked. The cloudy solutions containing precipitates was not considered compatible and failed as cloudless and clear fluids were selected.

3.2.8. Surfactant phase behavior

Surfactants with concentration in Table 1 was mixed into brine solution with concentration depicted in Table 2 in a beaker and allowed to stabilize for an hour. 30mL of the resultant surfactant solutions and 30 mL of the crude oil were introduced to an airtight test-tube before agitation process was carried out for 10 minutes. After thorough agitation, the airtight tube were kept on a plastic stand for 2 minutes before quantitative evaluation was conducted on the resultant solution to determine the phase behavior

3.2.9. Core flooding

Oil displacement study was conducted to determine the EOR potentials of the selected surfactants, polymers and surfactant-polymers hybrid solution as depicted in Table 1. Core with average length of 7.28 cm and diameter of 3.36 cm were used for the oil displacement. The

cores were then introduced to the saturation system and the system was pressurized to 2500psi to achieve completion saturation. The system was depressurized after 48hrs and the core reweighed before been placed in core flooding system shown in Figure 1 at 1000psi confining pressure. Formation water was introduced at 2cc/sec to prevent entrapment of air bubbles within the pores core, thereby retaining their perfect state. Crude oil was utilized to displace water out of the core until the first droplet of crude oil was observed. The volume of brine displaced is used to derive the oil originally in place. (OOIP). Synthetic brine with properties depicted in Table 2 was used as secondary recovery fluid to displace the crude oil until oil recovery ceases. The residual oil saturation was derived before the CEOR agents were deployed for the core flood study. In the CEOR study, three sets of tests were carried out on the core. The first was polymer flooding, derived by introduction polymer into synthetic brine, the second was surfactant flooding, derived by the introduction surfactant into synthetic brine while the third was surfactant-polymer (SP) flooding, derived by introduction of surfactants slug chased with polymer slug. The EOR fluids were introduced until residual oil saturation was achieved. Fig 1 shows the schematic of the experimental setup.

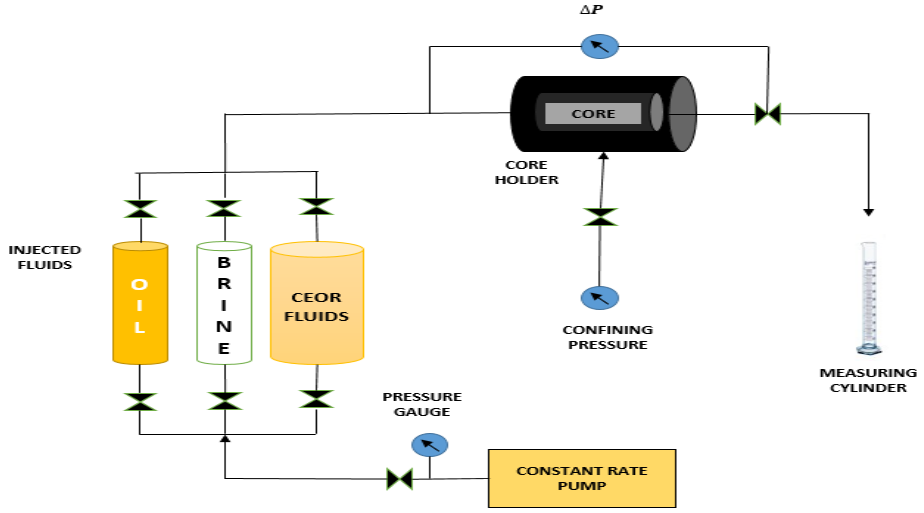

Figure 1. Schematic of the experimental setup.

4. Results and discussions

4.1. Samples characterization

The FTIR characterization of the polymer; ACE, TME and XG showed the presence of alcohol, methylene, nitriles, carboxylic acid, ester, ethene and chloro compounds at 3804.874cm^{-1}, 2854.287cm^{-1}, 2538.784cm^{-1}, 1883.881cm^{-1}, 1419.007cm^{-1} and 806.2237cm^{-1} wavelengths respectively. TME showed the presence alcohol, methylene, nitriles, carboxylic acid, ester, amine, ethene and ether at 3697.053cm^{-1}, 2890.022cm^{-1}, 2481.688cm^{-1}, 2037.26cm^{-1}, 1899.214cm^{-1}, 1624.910cm^{-1}, 1382.281cm^{-1} and 1181.947cm^{-1} wavelengths respectively and, XG showed the presence of alcohol, methylene, ester, ketones, carboxylic acid, acetate and glycoside compounds at 3227.9cm^{-1}, 2124.6cm^{-1}, 1625.1cm^{-1}, 1580.4cm^{-1}, 1401.5cm^{-1}, 1021.3cm^{-1} and 868.5cm^{-1} wavelengths respectively. As observed by Gilani *et al.* [23], commercial XG comprises of chemical groups such as acetyl, carbonyl, hydroxyl and carboxyl. Evidently, the local agro-polymers possesses the same functional groups as XG and are therefore polysaccharides and can be utilized as substitute for all CEOR operations that XG can be used for the FTIR characterization of the surfactants; CPE, VAE and SLS. CPE indicated the presence of alcohol, methylene, nitriles, carboxylic acid, amine, ethene, ether and chloro compounds at 3835.602cm^{-1}, 2804.268cm^{-1}, 2451.513cm^{-1}, 2134.756cm^{-1}, 1631.035cm^{-1}, 1361.936cm^{-1}, 1069.077cm^{-1} and 664.7313cm^{-1} wavelengths respectively. VAE indicated the presence of alcohol, methylene, nitriles, carboxylic acid, ester, amine, ethene, ether and chloro compounds at 3827.917cm^{-1}, 2652.666cm^{-1}, 2434.026cm^{-1}, 2086.688cm^{-1}, 1853.267cm^{-1}, 1448.506cm^{-}

^{1}, 1315.664cm^{-1}, 1113.992cm^{-1} and 702.6527cm^{-1} wavelengths respectively while SLS indicated the presence of alcohol, thiocyanate, methylene, nitrilies, carboxylic acid, amine, ethene, ether, chloro and bromo compounds at 3620.29cm^{-1}, 2924.56cm^{-1}, 2623.676cm^{-1}, 2463.6cm^{-1}, 2068.031cm^{-1}, 1624.910cm^{-1}, 1235.15cm^{-1}, 935.598cm^{-1}, 845.598cm^{-1} and 708.385cm^{-1} wavelengths respectively. The locally sourced agro-surfactants had similar hydrophilic group: carboxylic, ester, amine and hydroxyl as SLS, while in the case of hydrophobic group, the agro-surfactants and SLS also shared similar group viz: ethene and methylene. The agro-surfactant having ether and hydroxyl group, can be said to possess nonionic and anionic properties in-line with Ahmed *et al.* [24] report on surfactant grouping, and can also be excellent candidates for sandstone formation and high saline environment as reported by Tadros *et al.* [8].

4.2. IFT determination

Figures 2-3 depicts the IFT for surfactants and surfactant-polymers hybrid solution. From Figure 2, SLS recorded least IFT among the surfactants with IFT value of 6.95mN/m while CPE and VAE recorded 11.35mN/m and 9.98mN/m respectively. The IFT performance of the SLS is tied to its anionic nature defined from its FTIR characterization. The introduction of surfactant to various polymer solution as shown in Figure 3 yielded difference responses. The blend of SLS-XG recorded IFT value of 6.92mN/m, while blend of local formulations: CPE-TME, CPE-ACE, VAE-TME and VAE-ACE recorded 8.58mN/m, 10mN/m, 9.06 and 10.15mN/m respectively. From Figure 2 and Figure 3, the blend of SLS-XG yielded lower IFT value than that of SLS, the blend of CPE-TME and CPE-ACE recorded lower IFT value than that of the CPE while VAE-TME had lower IFT value than VAE and VAE-ACE recorded higher IFT value than the individual formulations of VAE and ACE. The effect of surfactant presence in polymer caused IFT reduction and this is in agreement with the Izuwa *et al.* [25] which reported that surfactant presence in polymer could also reduce IFT at certain concentrations. The results are also in agreement with Abhijit *et al.* [26] study which discussed about the interactions between surface active agents and polymers in reducing IFT at certain concentrations.

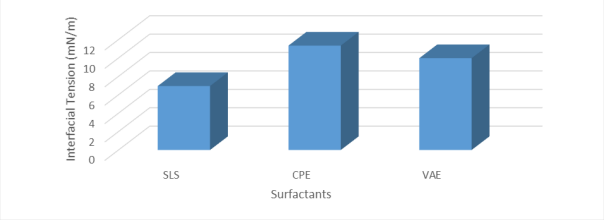

Figure 2. IFT of the surfactants.

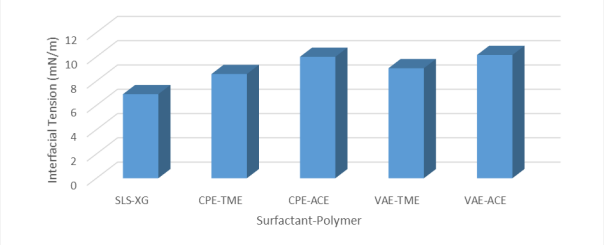

Figure 3. IFT of the surfactant-polymer formulations.

4.3. Polymer phase behavior

Table 3 depicts the polymer phase behavior. As shown as in Table 3, debris formation was observed at the bottom of the solution at 29^{o}C, but when the temperature of the solution was increase to 80^{o}C, a clear and compatible colloid was observed. This confirmed the ability of the agro-polymer to form colloidal phase with water at high temperature and as such cannot plug off the pore channels of the reservoir rock when injected.

Table 3. Polymer phase behavior.

Polymer	Concentrations %	Result@ 29^{o}C	Result@ 80^{o}C
ACE	0.5	Solution contains debris at the bottom	Clear and compatible solution
TME	0.5	Slight formation of particles at the bottom of solution	Clear and compatible solution
XG	0.5	Cloudy yellow solution with slight particles at the base	Clear compatible solution

4.4. Surfactant phase behavior

Figure 4 shows the phase behavior of the surfactant. As shown in Figure 4, CPE recorded a Winsor Type I system with 20.5mL oil and 39.5mL microemulsion. VAE recorded a Winsor Type III system with 25.5mL oil, 10.8mL microemulsion and 23.7mL water. SLS recorded a Winsor Type I with 3.5mL oil and 56.5mL microemulsion. The high microemulsion volume of SLS over CPE and VAE is due to its anionic surfactant characterics and lower IFT value compared to CPE and VAE. The close Winsor Type I relationship between SLS and CPE is due to the similar hydrophilic group present in both.

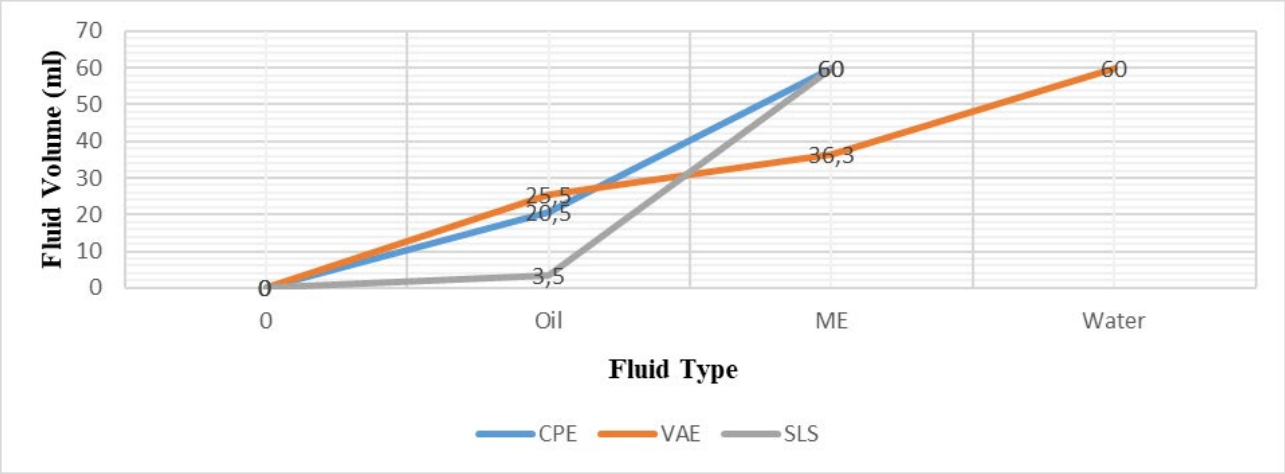

Figure 4. Phase behavior of the surfactant.

4.5. Core flooding

Figures 5-7 depict the additional recovery of the polymer, surfactant and SP hybrid solution. As shown in Figure 5, ACE yielded 15.91% additional recovery, XG yielded 14.09% additional recovery while TME recorded 13.18% additional recovery respectively when I-PV of CEOR fluids were injected. Comparing Figure 5 with Table 1, the performance of ACE over TME and XG is tied to favorable mobility ratio which gave rise to increased recovery. From Figure 6, SLS performed better than the agro-surfactants (VAE and CPE) with 16.74% additional recovery while CPE and VAE recorded 15.64% and 13.90% additional recoveries respectively when 1-PV of CEOR were injected. The CEOR performance of the SLS over CPE and VAE is due to its anionic hydrophilic head which reduces adsorption compared to CPE and VAE which have been identified to be nonionic surfactants, and possesses the ability to reduce IFT in brine-oil system better than CPE and VAE. The performance of CPE over VAE in CEOR despite having a higher IFT is due to lesser adsorption of CPE on the rock surfaces compared to VAE. For the SP flooding, the following SP slugs were flooded: SLS-XG, VAE-ACE, VAE-TME, CPE-ACE and CPE-TME. From Figure 6, SLS-XG, VAE-ACE, VAE-TME, CPE-ACE and CPE-TME recorded 16.82%, 12.73%, 17.50%, 19.09% and 17.27% additional recoveries respectively at 1-PV CEOR fluid injection. Comparing Figure 7 with Figures 5-6, VAE-TME, CPE-ACE and CPE-TME slug formulation performed overwhelmingly better than their individual formulations, SLS-XG slug formulation slightly performed better than their individual formulations while VAE-ACE did not perform better than their individual formulations. The excellent performance of VAE-TME, CPE-ACE and CPE-TME is attributed to their ability to reduce IFT in brine-oil system and effectively displace oil out of the rock. The performance of VAE-ACE is attributed to its inability to reduce IFT in brine-oil system and thus could not effectively displace crude oil out of the rock. CPE-ACE slug recorded the best recovery.

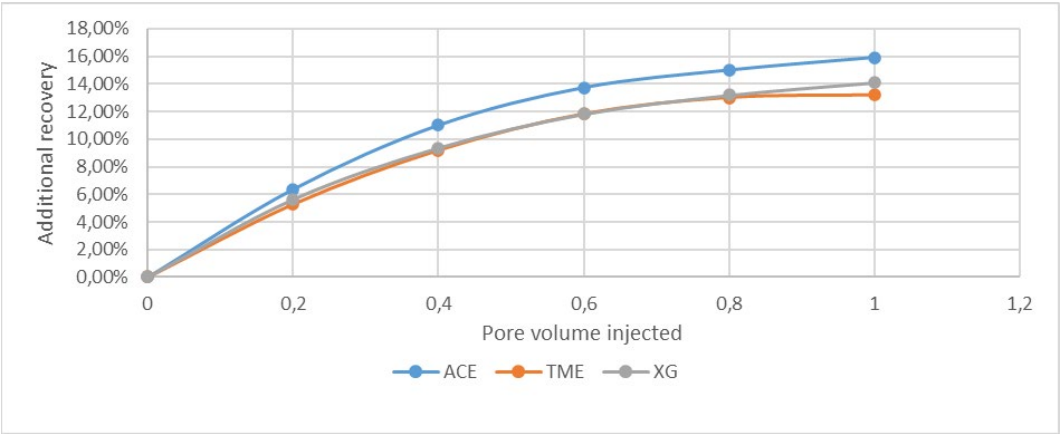

Figure 5. Additional recovery of conventional and local agro-polymer.

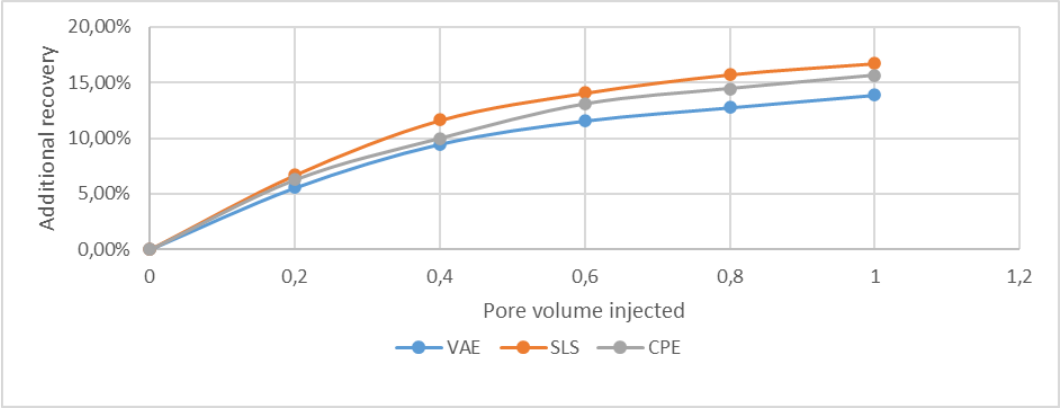

Figure 6. Additional recovery of conventional and local agro-surfactants.

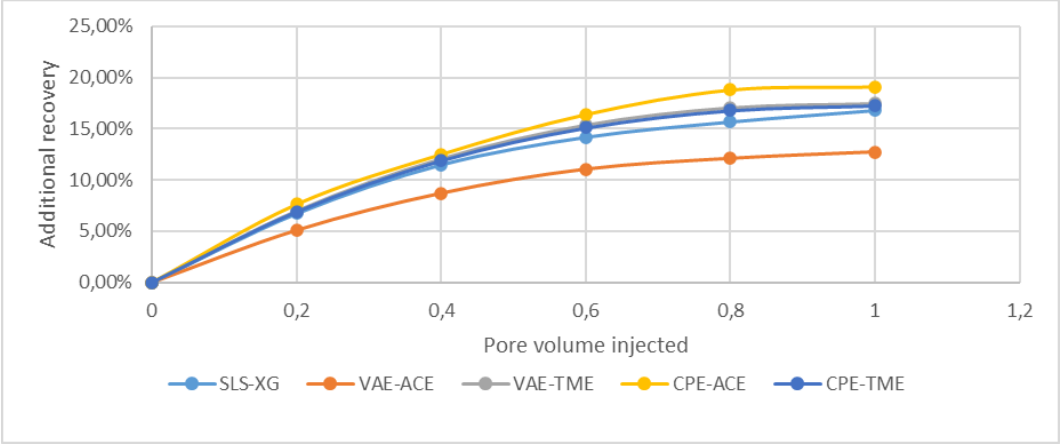

Figure 7. Additional recovery of both conventional and local agro-based sp formulations.

5. Conclusions

The agro-surfactants and agro-polymers shared similar functional groups with the conventional surfactant and polymer. Surfactants presence in polymers greatly affected the IFT values. SLS-XG blend recorded least IFT value of 6.92mN/m of all the scenarios while CPE-TME slug recorded 8.58mN/m of all the agro-SP scenarios. ACE agro-polymer had better Oil Recovery of 15.91% than the conventional XG which yielded 14.09% oil recovery while for the SP flooding, CPE-ACE blend had the best performance of 19.09%% additional recovery of all

the SP flood scenarios. The EOR performance of CPE-ACE blend is tied to combined mechanisms of mobility control and IFT reduction. The performance of VAE-ACE and SLS-XG show the importance of effective IFT reduction and mobility control for increased oil recovery using SP Flooding. The agro-surfactants and agro-polymers have shown adequate EOR potentials to be used for surfactant, polymer and SP flooding.

Nomenclature

CEOR	*Chemical enhanced oil recovery*
EOR	*Enhanced oil recovery*
IFT	*Interfacial tension*
OOIP	*Original Oil in Place*
SP	*Surfactant-polymer*
CPE	*Carica papaya extracts*
VAE	*Vernonia amygdalina extracts*
TME	*Terminalia mantaly exudate*
ACE	*Araucaria columnaris exudate*
SLS	*Sodium lauryl sulphate*
XG	*Xanthan gum*

Reference

[1] Mandal A. Chemical Flood Enhanced Oil Recovery: A Review, Int. Jour. Oil, Gas and Coal Technology, 2015; 9(3): 241-264.

[2] Odo JE, Ohia NP, Nwogu N, Oguamah I, Ekwueme S, Ezeh SC. Laboratory Experiment on Enhanced Oil Recovery Using Nanoparticles (NPs) and Permeability Alteration Due to Their Retention in Porous Media, American Journal of Engineering and Technology Management, 2020; 5(1): 18-26. doi:10.11648/j.ajetm.20200501.13

[3] Azam MR, Tan IM, Ismail L, Mushtaq M, Nadeem M, Sagir M. Static adsorption of anionic surfactant onto crushed Berea sandstone, Journal of Petroleum Exploration and Production Technology, 2013; 3(3): 195- 201

[4] Kerunwa A. The Impact of Core Firing on EOR of Low Salinity-Surfactant Flooding, Open Journal of Yangtze Oil and Gas, 2020; (5): 103-116. https://doi.org/10.4236/ojogas.2020.53009

[5] Izuwa NC, Williams CC, Ihekoronye KK, Okereke NU, Onyejekwe MI. Experimental Investigation of Impact of Low Salinity Surfactant Flooding for Enhance Oil Recovery: Niger Delta Field Application, Journal of Pet mand Gas Eng, 2021; 12(2): 55-64. https://doi.org/10.5897/JPGE2019.0333

[6] Schramm L. Surfactants fundamental and application in petroleum industry, Cambridge University Press, 2000.

[7] Coung D, Long N, Ngoc N, Zhangxin C, Chaodeng Y, Wisup B. A Comprehensive Alkaline-Surfactant-Polymer Flooding and Hybrid Process For Enhanced Oil Recovery, SPE Paper, 2017, SPE-187132-MS.

[8] Tadros TF. An Introduction to Surfactants, (2014). AnWalter de Gruyter GmbH, Berlin/Bo University of Bristol, 2013. Surfactant Catalog. K. http://www.bristol.ac.uk/ chemistry/research/eastoe/what-are-surfactants/ (accessed 17 August 2023)

[9] Paria S, Manohar C, Khilar KC. Experimental Studies on Adsorption of Surfactants onto cellulose surface and its relevance to detergency, Journal of the Institution of Engineers Singapore, 2003; 43: 2.

[10] Uzoho CU, Onyekonwu M, Akaranta O. Formulation of Local Alkaline-Surfactant-Polymer (ASP) for Enhanced Oil Recovery in Niger Delta: A Review, SPE NAICE Paper, 2015, SPE-178300-MS.

[11] Gbadamosi AO, Radzuan J, Muhammad AM, Agi A, Yusuf AS. An overview of chemical enhanced oil recovery: recent advances and prospect, International Nano Letters, 9, 2019, pp 171-202

[12] Obuebite AA, Onyekonwu MO, Akaranta O. Effect of Salinity and Divalent ions on Local Bio Polymers, SPE NAICE Paper, 2018, SPE-193450-MS.

[13] Agi A, Junin R, Gbonhinbor J, Onyekonwu M. Natural Polymer Flow Behavior in Porous Media For Enhanced Oil Recovery Applications: A Review, Journal of Petrol. Expl. and Prod. Tech., 2018; 8: 1349-1362.

[14] Osuji C, Onyekonwu M, Using Alkaline Surfactant Polymer Flooding to Improve Recovery. Master's Thesis, University of Port Harcourt, Nigeria, (2012).
[15] Abdulraheem M, Hamisu T, Abdullahi G, Taiwo O, Bello K, Mohammed I, Olafuyi O. Comparative Analysis on Rate Dependent Polymer Flooding using Bio and Synthetic Polymers, SPE NAICE Paper, 2018, SPE-193529-MS.
[16] Uzoho CU, Onyekonwu M. Comparative Analysis of Local and Conventional EOR Agents, SPE NAICE Paper 2018, SPE-203777-MS
[17] Obuebite AA, Gbonhinbor JR, Onyekonwu M, Akaranta O. Comparative Analysis of Synthetic and Natural Polymer for Enhanced Oil Recovery, Int. Jour. of Sci. and Eng. Invest., 2021; 10(133): 2-7.
[18] Uzoho CU, Onyekonwu M, Akaranta O. Chemical Flooding Enhanced Oil Recovery Using Local Alkali- Surfactant-Polymer, World Journal of Innovative Research, 2019; 7(1): 16-24.
[19] Abraham D, Orodu O, Efeovbokhan V, Okro E, Ojo T, Keshinro L. Experimental Studies on the Performance of Bio Based and Industrial Surfactant in Enhanced Oil Recovery, SPE NAICE Paper, 2020, SPE-203759.
[20] Ikeagwu C, Nyah FJ, Onyekonwu M, Ogolo NA, Ubani C. Study of Alcohol Mixtures for Enhanced Oil Recovery SPE NAICE Paper, 2013, SPE-167547
[21] Ogolo NA, Ogiriki SO, Onyiri VID, Nwosu CT, Onyekonwu M. Performance of Foreign and Local Agents for Enhanced Oil Recovery of Nigeria Crude, SPE NAICE Paper, 2015, SPE-178305-MS.
[22] Michael AO, Babatunde MO, Oluyemisi AB, Native and microwave modified Terminalia Mantaly gums as sustained-release and bio-adhesive excipients in naproxen matrix tablet formulations, Polymers in Medicine, 2017; 47(1): 35-42.
[23] Gilani SL, Najafpour GD, Heydarzadeh HD, Zare H. Kinetic models for Xanthan Gum production using Xanthomonas Campestris from molasses, Chemistry Industry & Chemical Engineering Quarterly, 2011; 5(10): 855-859
[24] Ahmed FB, Khaled AE, Syed MM, Nazliah NZ, Saeed A, Osman S, Eldin H. The Effect of Surfactant Concentration, Salinity, Temperature and pH on Surfactant Adsorption for Chemical Enhanced Oil Recovery: A Review, Jour. of Petrol. Explr. and Prod. Tech, 2019, https://doi.org/10.1007/s13202-019-0685-y
[25] Izuwa NC, Nwankwo IV, Nwachukwu A, Ohia NP, Uwaezuoke N, Duru UI., Obah B, Ekwueme ST. Suitability Evaluation of Locally Sourced Surfactants for Enhanced Oil Recovery (EOR) in the Niger Delta, Int. Jour. of Oil, Gas and Coal Engineering, 2021; 9(5): 71-82.
[26] Abhijit S, Keka O, Ashis S, Ajay M. Surfactant and Surfactant-Polymer Flooding for Enhanced Oil Recovery, Petroleum Exploration and Development, 2011; 2(1): pp 13-18.

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