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An Experimental Approach to Low Cost, High-Performance Surfactant Flooding

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Abstract— **Surfactant flooding plays a key role in chemical enhanced oil recovery due to its ability to reduce interfacial tension between the aqueous and oleic phases, thereby mobilizing the trapped oil droplets into a flowing oil bank which invariably reduces the amount of residual oil saturation thus accounting for additional oil recovery of about 20%. However, the cost of surfactant chemicals has made surfactant flooding less attractive. Interestingly, recent experimental studies have reported that certain local materials capable of acting as surface active agents can effectively recover residual oil. This has attracted more interest due to their low cost, availability and eco- friendly nature. This paper reviews the oil displacement efficiency of different local surfactants in comparison with synthetic surfactant.Commonly used synthetic surfactant, Sodium dodecyl sulphate (SDS) and three different local surfactants namely AlkaSurf X (a plant extract), Palm kernel oil (Elaeis guineensis) and Moringa leaf (Moringa oleifera) was evaluated in the laboratory using various concentration in a bid to compare their performance. To simulate actual formation brine, brine samples were prepared in the laboratory using sodium chloride and potassium chloride with Total Dissolved Solids (TDS) of 30000ppm. Critical Micelle Concentration (CMC) was calculated to ascertain the right concentration to flood with. Sandstone oil displacement experiments using core plugs with porosity values ranging from 22%-23% was carried out on medium crude oil to ascertain the effectiveness of the selected local surfactants in recovering oil. Results showed high compatibility of the brine with all the selected local surfactants. As the brine salinity increased, the pH of the surfactant concentration increased. In line with the results obtained from the CMC plot, the synthetic surfactant performed best at 0.2wt.% while the local surfactants performed best at a higher concentration of 0.4wt%. Of the three local surfactants, AlkaSurf X gave the highest additional recovery of 22.7%OOIP while the synthetic surfactant gave an additional recovery of 20%OOIP.This study underpins the oil displacement efficiency of these local surfactants. Moreover, AlkasurfX can be replaced with synthetic surfactant Sodium dodecyl sulphate (SDS) due to its availability, performance and reduced cost.**

Index Terms— **Enhanced Oil Recovery, Surfactants, Recovery Factors, Phase Behaviour.**

I. Introduction

The process of oil recovery involves the use of mainly water and gas flooding as a secondary oil recovery measure to increase the amount of oil initially recovered during primary oil recovery. This secondary oil recovery method accounts for about 20% production of the original oil in place, OOIP (Alagorni*et al*, 2015). Water flooding as a secondary recovery method accounts for over 50% of the world's oil production (Nunez *et al.*, 2010). However, an appreciable amount of oil is left unrecovered after water flooding due to the capillary forces. Experimental studies reveal that the amount of this unrecovered oil also referred to as residual or immobile oil can be reduced with a corresponding increase in capillary number. One of the methods to achieve an increase in capillary number is to reduce the interfacial tension between the wetting and non-wetting phase (Sheng,2013). This can be achieved through the use of surfactants. Surfactants are surface active agents that are amphiphilic in nature because they have both hydrophilic and hydrophobic groups. Based on their hydrophilic nature, surfactants are generally grouped into four types namely; Anionic, Cationic, Non-ionic and Zwitterionic surfactants (Sheng, 2011). The main function of a surfactant is to reduce the interfacial tension between a fluid and a solid or between immiscible fluids such as oil and water such that an emulsion phase is created to allow for continuous flow (Hirasaki*et al.*, 2008). When the interfacial tension (IFT) is low, it annihilates the capillary forces that originally trapped the residual oil thereby causing the oil globules to coalesce together forming a continuous flowing oil bank.The use of surfactants either in laboratory studies or field tests such as the Yates Field in Texas and Semoga Field in Indonesia have been proven to significantly reduced interfacial tension to about 10^{-3}mN/m thereby increasing the capillary numbers by over a thousand times and invariably reducing the amount of residual oil saturation. This has made surfactant flooding a very attractive chemical enhanced oil recovery method.Negatively charged anionic surfactants such as Sodium Dodecyl Sulphate (SDS) are the most commonly used surfactant type in the oil industry because of their low adsorption rate and relative stability on sandstone reservoirs. Studies have reported that surfactants are easily adsorbed onto the rock surface thereby reducing the amount of injected surfactant (Sheng, 2011). This has proven uneconomical in most field cases owing to the fact that these synthetic surfactants are very costly. Since surfactants are very expensive, the development of an effectivechemical enhanced oil recovery technology using surfactants depends on how much surfactant can be sacrificed economically while recovering additional crude oil from a reservoir. Due to the dwindling crude oil prices which makes surfactants even more expensive than the produced crude oil, recent studies on the use of alternative options such as the use of local materials that act as surfactants have gained increasing attention. More so, the associated toxic effect of these synthetic surfactants has proven to be dangerous to the environment, aquatic and human lives. Thus, in line with ensuring standard practices of a clean, green environment, it

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is important to formulate a surfactant slug that is environmentally friendly (Rahman *et al.*, 2000). Several researchers (Uzoho*et al.*, 2016: Ojukwu *et al.*,2013,Aggrey-Tams*et al.*, 2012, Chiabuotu*et al.*, 2012) have carried out experimental studies on the use of certain local materials which act as surfactants.They ascertained the effectiveness of these local surfactants in enhancing oil recovery. Local materials such as Soybeans, Palm wine, *Carica papaya* leave extract, Local detergent,local bar soap, *Cocos nucifera*, *Vernonia amygdalina* extractwere used to perform surfactant flooding in the laboratory. Aggrey Tams *et al.*, (2012) reported that local detergent is a better surfactant than a bar soap or liquid soap probably owing to its various sodium content. Uzoho*et al.*,(2016)in their work decided to use local agricultural waste devoid of any chemical and then compared the displacement efficiency of some of these local surfactants with the synthetic surfactant, SDS. They reported that these local surfactantsdid not perform as well as the synthetic surfactant but if refined and modified they can replace the synthetic surfactants as noted by (Ogolo*et al.*, 2015).The use of these local surfactants can be considered to be a suitable replacement being that they are more readily available, less expensive and environmentally friendly.For this study, three different local materials that are primarily plant waste namely; Alkasurf X, *Elaeis guineensis* oil and *Moringa oleifera* leaveswere used in comparison with a synthetic surfactant, Sodium Dodecyl Sulphate; SDS. These three local surfactants are readily available in most countries of the world such as Nigeria.Alkasurf X is a plant extract containing several chemical compositions such as saponins (a glucoside with foaming characteristics),phenolic, plant acids, polysaccharides (Hans-Walter *et al.*, 2011).*Elaeis guineensis* oil, locally referred to as Palm Kernel oil is also made up of similar chemical composition as Alkasurf X.Leaves of*Moringa oleifera* also contain bioactive components such as saponins (foaming characteristics), tannins (binding characteristics), phenolic acids (Vergara-Jimenez *et al.*, 2017).The chemical composition of these local surfactants ascertains their ability to act as surfactant especially due to the foaming ability. This study seeks to analyse certain local agricultural waste that acts as surfactants, determine their oil displacement efficiency in comparison to the synthetic surfactant, SDS and design a low cost, environmentally friendly, high-performance surfactantslug for chemical flooding.

II. MATERIALS AND METHOD

Materials/ Equipment

Apparatus used in this laboratory study includes weighing balance, stirrer, borosilicate pipette, beakers, test tubes, pH indicator, conductivity meter, density bottle, viscometer, glass electrode, core flood equipment.

Commonly used synthetic surfactant, SDS and three different local surfactants namely AlkaSurf X (a plant extract), Palm kernel oil (*Elaeis guineensis*) and Moringa leaf (*Moringa oleifera*) were used in this experimental study. The local surfactants were locally sourced from the market, air-dried, pulverized and kept in an airtight container. Chemicals for brine preparations were purchased from local suppliers. Synthetic brine was prepared in the laboratory to simulate actual formation brine. The brine contained varying concentrations of sodium chloride and potassium chloride with total dissolved solids of 30,000ppm and a salinity of 3.0%. The crude oil used during this study was a medium crude from an oil field in the Niger Delta region of Nigeria. The non-aqueous phase titration method was used to determine the acid number of oil used in this study and then calculated using(1) and (2) below. The physical properties of the crude oil sample are shown in Table I.

Table I: Properties of Crude Oil sample

Density @ 27°C	$0.92g/cm^3$
API Gravity	23.3°
Viscosity	44.45cP@ 30.5°C
Colour	Brownish black
Total acid number	0.5mg KOH/gram

$$KOH\ vol.\left(\frac{mol}{l}\right) = \frac{(KHP\ solution.grams) * (KHP\ concentration)}{KOH\ Concentration} \quad (1)$$

$$Acid\ number = (A - B) * M * \frac{56.1}{W} \quad (2)$$

Where,

A = volume of KOH solution used in the titration to the last inflection endpoint, mL

B = Volume corresponding to A for blank titration, mL

M = KOH Concentration, mol/L

W = Mass of oil Sample, grams.

Table II shows the properties of the core sample used during the experiment. Well sorted, fine-grained, moderately cemented cylindrical sandstone core samples with an absolute porosity value of 22% provided for the porous medium.

A series of phase behavior test was conducted for the surfactant -brine system to ascertain the compatibility of the system under varying ionic strength (concentration) and salinity using glass test tubes. The conductivities of the surfactants were measured and their CMC calculated. Phase separation (Pipette) test was carried out on the aqueous and oleic phases to determine optimal salinity and the presence of Type III microemulsion which is indicative of an ultralow interfacial tension.

Table II: Properties of Core sample

Length of Core (cm)	Diameter of Core (cm)	Bulk Volume (cm^3)	Pore Volume (cm^3)	Porosity (%)
5.2	3.7	55.98	12.35	22.9

The displacement apparatus used for the flooding experiment was assembled in the laboratory. A sandstone core flooding experiment was performed to compare the oil displacement efficiency between the local and imported surfactants when used as anenhanced oil recovery agent.

III. EXPERIMENTAL PROCEDURES

The following procedures were carried out in preparing synthetic brines in the laboratory. Table III shows the concentration of the various chemicals used in the brine preparation.

Procedures for Preparation of Brine solution:

- Using a weighing scale, measure varying grams of sodium and potassium chloride, gradually add into a beaker filled with 800ml of distilled water.
- Stir the solution continuously using a magnetic stirrer until the solution is completely dissolved and clear
- Filter brine solution using a filter paper
- Transfer the filtered-brine solution into a 1litre volumetric flask using a glass rod, adding more distilled water to fill up the 1litre mark.
- Label appropriately.

Aqueous Stability Test

To analyse fluid compatibility, an aqueous stability test was performed between the selected surfactants and the brine solution to determine the presence of any non-homogeneity such as cloudiness and precipitation in the aqueous phase. Varying concentration of the selected surfactants (0.2%, 0.3%, 0.5%) was mixed into a 100ml beaker of synthetic brine, sealed to avoid evaporation and visually inspected. Only clear, cloudless fluids devoid of precipitates were selected.

Table III: Brine Composition

Composition of Synthetic Brine	Concentration. (ppm)
NaCl	25,000
KCl	5,000
TDS	30,000

Critical Micelle Concentration (CMC)

CMC is a principal characteristic of surfactants and can be determined from the physical properties of a surfactant such as electrical conductivity, surface tension, density, etc. The CMC of the selected surfactants was determined to ensure the right concentration to flood with. The electrical conductivity of the surfactants was measured using a conductivity meter and a variation of conductivity values against surfactant concentration was plotted. The point of inflection on the plot was taken to be the Critical Micelle Concentration (CMC).

Salinity Scan Test

Further tests were carried out to determine the salinity tolerant of the selected surfactants at varying electrolyte concentration. Surfactant concentration obtained from the CMC was kept constant, while brine salinity was varied. The experiment was conducted using a glass test tube each containing a total volume of 10ml. The solution was mixed based on molarity calculations using (3).

$$C_1V_1 = C_2\,V_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where,

C_1= Initial concentration (%);

C_2= End concentration (%);

V_1= Start Volume (ml);

V_2= Total Volume (ml)

Sample Calculation for Surfactant, SDS:

With an initial concentration of 0.5%wt., a final concentration of 0.2% wt. or any concentration obtained from the CMC result and a total volume of 10ml, the start volume of SDS for the salinity scan was calculated:

$$C_1V_1 = C_2\,V_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots. (4)$$

$$0.5 \times V_1 = 0.2 \times 10 \ldots\ldots\ldots.. (5)$$

$$V_1 = \frac{0.2 \times 10}{0.5} \ldots\ldots\ldots\ldots\ldots\ldots.. (6)$$

$$V_1 = 4ml \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (7)$$

Thus, 4ml of SDS was kept constant in each test tube, while brine and distilled water (calculated using the same formula) at varying salinities were used to make up the total volume.

Phase Separation (Pipette) Test

Phase separation (pipette) test was carried out to determine phase interaction. Compatible surfactant- brine and oil system were injected into an array of 5ml borosilicate pipettes. Each pipette contained 2ml of surfactant- brine solution at varying salinities and an equal volume of oil. Samples were tightly sealed to avoid evaporation or inflow of oxygen and carefully inverted to allow a mix of the two phases. Fluid interfaces were recorded and samples in the pipette were observed under laboratory conditions for the presence of micro-emulsions in the surfactant-brine +oil system. Solutions will either form Type I, II or III micro-emulsions. Solutions containing type III micro-emulsions is indicative of an ultra-low interfacial tension. After visual assessment of the formed microemulsion, in solutions with Type III micro-emulsions, level readings for aqueous, oleic and microemulsion was recorded at different equilibration times, their individual volumes, as well as oil and water solubilisation ratio versus salinity, was calculated in order to obtain optimal salinity.

Oil Displacement Test procedures

Sandstone core flooding was conducted in order to assess the displacement efficiency of local surfactant flooding on residual oil recovery as well as compare the oil displacement efficiency using the local and synthetic surfactants. A chemical recovery flood is used to evaluate the recovery rate from chemicals with respect to permeability change, displacement efficiency, and incremental oil recovery. The displacement tests consisted of two sequential experiments; Secondary and Tertiary flooding.

Core flood procedures

- Weigh the dried core sample using a measuring scale
- Using Vernier callipers, measure the diameter and length of the core.
- Immersed sample in brine and leave in a vacuum pump for 2days to ensure full saturated.
- Reweigh core sample and record the difference in weight which determines the pore volume (PV)
- Insert the core sample into the core holder
- Fill up the accumulators with each of these fluids: Oil, brine and surfactant.
- Connect the one end of the accumulator (injection point) to the inlet and the other end (production point) to the outlet.
- Brine displacement by oil to determine irreducible

water saturation and relative permeability to oil.

- ❖ Secondary recovery usingbrine to determine residual oil saturation.
- ❖ Surfactant flooding as a tertiary recovery method.

Drainage

The sandstone cores were saturated for 3mins in brine using a saturator after which, drainage experiment was performed using oil as the displacing fluid at 1.4PV. It was used to displace brine until no more brine was produced. The volume of brine displaced was collected into burettes. The experiment continued until the first drop of oil was seen. The volume of brine collected was measured. Original oil in place (OOIP) alongside irreducible water saturation was determined.

Imbibition (Secondary Flooding)

The synthetic brine was used to displace oil to residual oil saturation simulating a water-wet reservoir (10PV). The volume of oil displaced was collected into burettes. The experiment continued as drops of oil and occasionally brine was collected and was terminated with no more drop of oil. Collected oil volume was measured and residual oil saturation was calculated.

Tertiary (Surfactant)Flooding

A surfactant solution 2PV was injected continuously into the slug and used as a displacing fluid to enhance oil recovery. The experiment was continued until an oil cut of less than 1% was achieved.

IV. RESULTS AND DISCUSSION

Results of the various experimental work carried out are discussed in this section.

Aqueous Stability Test

Compatibility test performed on the synthetic surfactant (SDS) in the brine produced clear solutions devoid of precipitates. Similar compatibility test was performed on the three local surfactants. Both Alkasurf X and Moringa oleifera produced clear, cloudless, compatible solutions.

Table IV: Compatibility Test of selected Surfactants in Brine

Surfactant types	Concentration (%)	Results/observation
Sodium Dodecyl sulphate (SDS)	0.1, 0.2, 0.3, 0.5	Clear, completely dissolved solution at all concentrations
AlkaSurf X	0.1, 0.2, 0.3, 0.5	Clear, completely dissolved solution at all concentrations
Moringa oleifera	0.1, 0.2, 0.3, 0.5	Clear, completely dissolved solution at all concentration
Elaeis guineensis oil	0.1, 0.2, 0.3, 0.5	Only 0.1% solution produced clear solution, higher concentrations produced cloudy solutions.

Elaeis guineensis (Palm kernel) oil produced a clear solution only at 0.1% concentration, higher concentrations (0.2-1%) produced cloudy solutions. This shows incompatibility of brine with higher concentrations of *Elaeis guineensis*(palm kernel) oil and such incompatible solutions results in precipitation or phase separation which causes plugging of production wells during oil recovery thereby reducing permeability. Due to the incompatibility of *Elaeis guineensis* (palm kernel) oil with the brine, further tests were not conducted on the system.

The electrical conductivity for the threecompatible surfactants in brine at varying concentrations was determined using a conductivity meter. Other properties such as viscosity and pH value were also measured. The viscosities of the local surfactants were slightly lower than that of the synthetic surfactant, SDS. However, one of the local surfactants; Alkasurf X has a higher pH value than SDS, implying that Alkasurf X has higher alkalinity than SDS. Valdya and Fogler (1992) noted that a pH of 9 is most suitable during chemical flooding because a higher pH greater than 9 results in permeability impairment and a pH above 11 results in a drastic decline in permeability due to clay dispersion. The pH of a solution is amore important parameter in surfactant flooding than viscosity, due to its role in altering the wettability of the rock and reducing surfactant adsorption.Alkasurf X with a pH of 9 is a better candidate for surfactant flooding than Moringa oleifera and SDS.

The conductivities values were used in determining the CMC. Fig. 1 and Fig. 2 shows the critical micelle concentration for SDS and Alkasurf X derived from the plot of conductivity values against surfactant concentration.

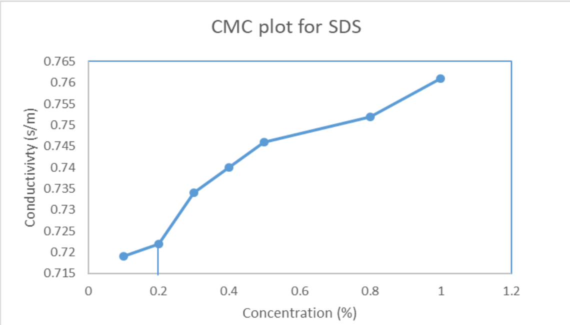

Fig 1:Critical Micelle Concentration for SDS

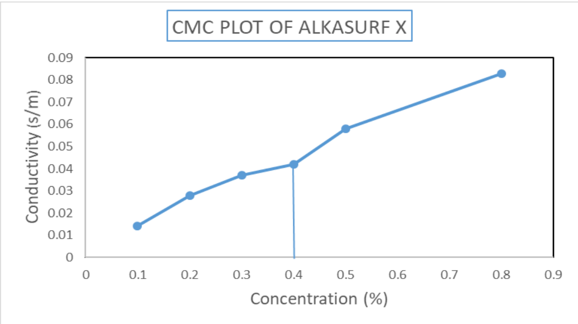

Fig 2: Critical Micelle Concentration for Alkasurf X

It is reported that a surfactant solution with a lower CMC is more effective being that it requires only a little concentration to effectively reduce interfacial tension. TableV below shows the critical micelle concentrations for the three surfactants. From the table, SDS has a lower CMC value than the surfactants. This implies that a lesser quantity of SDS will be needed to be followed byAlkasurf X and then Moringa oleifera. However, considering the cost and availability of both the synthetic and local surfactants, Alkasurf X (a plant extract) is a better option because of its availability, non-toxic nature and far less cost.

Table V: Critical Micelle Concentration of Selected Surfactants

Surfactant type	Concentration (%)
Sodium Dodecyl sulphate	0.2
Alkasurf X	0.4
Moringa oleifera	0.5

2.

3. Salinity Scan Test

Further tests on the compatibility of the surfactant-brine system were carried out to determine the effect of salinity on the selected surfactants. Surfactant concentration at their individual micelle concentration was kept constant as brine salinity varied. No precipitation occurred at both high and low salinity for all selected surfactant. It was observed that the brine salinity increased as the pH value of the solution increased.

4. Phase Separation Test

Phase separation or pipette test was carried out between the oleic and aqueous phases. The crude oil formed the oleic phases while the aqueous phase consisted of the surfactant in brine.The concentration of the surfactants used was determined from the result obtained from the CMC. Pipette test for each of surfactant-brine-oil system producedWinsor Type Imicroemulsion as such could not achieve optimum salinity.This is because the salinity is lower than the optimum salinity causing the surfactant to partition into the aqueous phase, this renders the interface under-optimized and unable to produce a Type III microemulsion which is indicative of low interfacial tension.Thus, further calculations to obtain solubilization ratios and optimal salinity was not performed. This result of the pipette test further affirms the report of Liu *et al.*, (2008) that only the mixture of a synthetic or injected surfactant and an in-situ surfactant obtained from the reaction of an alkali with the carboxylic acid found in crude oil can achieve optimum salinity of Type III microemulsion.

5. Oil displacement Test

Tertiary recovery using surfactants as the recovery agents was conducted to recover residual oil left behind after water flooding (secondary recovery). Core flooding experiments were run to determine the effects of surfactant flooding on sandstone reservoir using unsteady state measurement where one phase is displaced by another as well as compare the performance of local surfactants over synthetic surfactant. Core flood results produced an irreducible water saturation of 0.16 ml or 16.69% at the start of the test during drainage. Oil effective and relative permeability was calculated to be 5196.3mD and 2.01mD.

Sodium Dodecyl Sulphate (SDS): Oil cut during secondary flooding was high and reduced at the late stage with 11.4ml of oil produced alongside a recovery of 71.29% after an injection of 10PV of brine.Residual oil of 4.6ml from an OOIP of 16ml representing about28.8% was retained. Surfactant flooding using SDS 0.2wt.% concentration and salinity of 3.0wt.% resulted in an additional recovery of 3.2ml indicating a recovery factor of20% OOIP and a total oil recovery of 91.29%.

Alkasurf X (a plant extract): The original oil present in the core plugwas 10ml of oil. During secondary recovery using brine as the displacing fluid, 7.3ml of oil was recovered with 2.7ml of residual oil unrecovered implying that about 27% of residual oil was yet to be recovered. Surfactant flooding using Alkasurf X 0.4wt.% and 3.0wt.% brine salinity gave an additional recovery of about 2.3ml out of 2.7ml residual oil representing a recovery factor of 22.7% OOIP and a total oil recovery of 96%.

***Moringa oleifera* (a plant extract):** Original oil in place initially present in the reservoir was 12ml of oil. Oil cut during secondary flooding was high and reduced at the late stage with 8.9ml of oil produced with a recovery of 74.0% after an injection of 10PV of brine. Residual oil of 26.0% of residual oil was left. Chemical flooding using a surfactant slug of Moringa 0.5wt.% and 3.0wt.% brine salinity resulted in an additional recovery factor of 18.8% and a total oil recovery of 92.8%. Table VI shows the various surfactants and their respective recovery factors.

Table VI: Recovery Factor for selected surfactants

Surfactant Type	Concentration (%)	Secondary Recovery (%)	Additional Recovery (%)
SDS	0.2	71.29	20
Alkasurf X	0.4	73.3	22.7
Moringa oleifera	0.5	74	18.8

Generally, these results further prove that these local surfactants are capable of recovering residual oil in line with the findings of Ojukwu *et al.*, (2013). From the results outlined in Table VI, local surfactant extracted from a plant, Alkasurf X gave the highest additional recovery of 22.7% after secondary recovery as opposed to commonly used synthetic surfactant, SDS with an incremental recovery of 20% after water flooding. This is due to the higher pH solution of greater than 9which is associated with Alkasurf X. A high pH creates a negatively charged environmentwhich gets adsorbed onto the rock surface thereby reducing the amount of surfactants adsorbedand also causes repulsion at the interface of the oil-brine thereby altering the wettability of the rock surface to water-wet.Furthermore, the present cost of SDS is about fifteen thousand naira per kilogram, this is much higher than Alkasurf X which cost about four thousand naira per kilogram. Alkasurf X being a locally grown plant is readily available, less expensive and non- toxic to the environment.Alkasurf X can be replaced with synthetic surfactant Sodium Dodecyl Sulphate (SDS) due to its availability, performance and reduced cost.

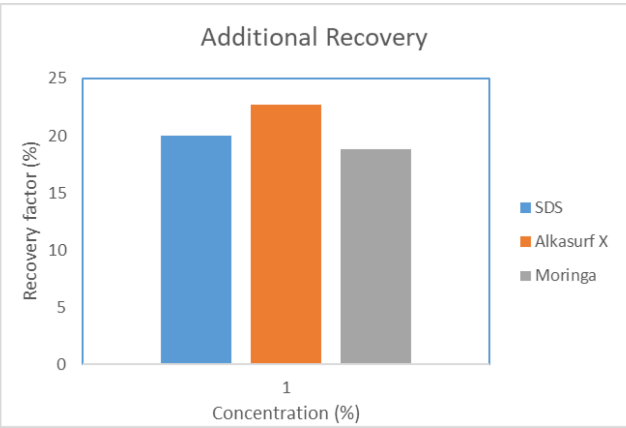

Fig3: Incremental recovery factor of selected surfactants.

V. CONCLUSION

The following conclusions were drawn from this experimental study:

- All selected surfactants showed a high solubility in brine at all concentrations except Elaeis guineensis oil which produced aclear solution only at 0.1wt.% and cloudy, incompatible solutions at higher concentrations.
- The viscosity of the synthetic surfactant, Sodium Dodecyl Sulphate (SDS) is slightly higher than that of the selected local surfactants.
- A more important parameter for surfactant flooding is the pH value of the solution, of which, Alkasurf X solution showed a higher pH than Sodium Dodecyl Sulphate (SDS) and Moringa oleifera.
- The Critical Micelle Concentration for the selected surfactants was determined with Sodium Dodecyl Sulphate (SDS) having the lowest critical micelle concentration compared to the selected local surfactants.
- Salinity scan test conducted on the selected surfactants produced compatible solutions at high and low concentration with an increase in pHvalue as the brine salinity increased.
- Phase separation test resulted in Type I microemulsion.
- The oil displacement results showed that these local surfactants are capable of recovering residual oil in line with the findings of Ojukwu *et al.*, (2012).
- Local surfactant, Alkasurf X gave a higher additional oil recoveryof 22.7% than commonly used synthetic surfactant, Sodium Dodecyl Sulphate at 20%.
- Alkasurf X can be considered as a novel surfactant for chemical enhanced oil recovery.

VI. RECOMMENDATION

The following are recommendations made from this experimental work;

- For these local surfactants to be used convincingly in enhancing oil recovery, they need to be subjected to reservoir temperatures and pressure to ascertain their performance.
- A combination of Alkaline-Surfactant-Polymer (ASP) flooding using Alkasurf X as the surfactant is important.
- A field pilot test to be conducted using Alkasurf X as the surfactant agent.

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REFERENCES

[1] Aggrey-Tams, A. and Onyekonwu, M. (2012): "Experimental Study of Enhanced Oil Recovery using local Surfactants". Department of Petroleum and Gas Engineering, University of Port Harcourt.

[2] Alagorni, A., Yaccob, Z., Nour, A. (2015): "An Overview of Oil Production Stages: Enhanced Oil Recovery Techniques and Nitrogen Injection. International Journal of Environmental Science and Development. 6. Pp. 693-701.

[3] Chiabuotu, A. and Onyekonwu, M. (2012): "Experimental Study of using Local Surfactant for EOR". Department of Petroleum and Gas Engineering, University of Port Harcourt

[4] Hans-Walter, H., Birgit, P. (2011): Phenylpropanoids comprise a multitude of plant secondary metabolites and cell wall components. Plant Biochemistry. 4th Edition. Pp. 431-449.

[5] Hirasaki, G., Miller, C., Puerto, M. (2008): Recent Advances in Surfactant EOR. *SPEJ* 115386-MS.

[6] Liu, S., Zhang, D., Yan, W., Puerto, M., Hirasaki, G., Miller, C. (2008) Favourable Attributes of Alkaline-Surfactant-Polymer Flooding. *SPEJ* **13** (1): pp.5-16.

[7] Nunez, V., Marcio da Silveira, C., Basante, V. (2010): Effect of Capillary Number on the Oil Recovery Using Oil-Water Emulsion Injection in Core Flooding Experiments. Congress of Thermal Sciences and Engineering.

[8] Ogolo, N.A., Ogiriki, S.O., Onyiri, V.I., Nwosu, T.C., Onyekonwu, M.O. (2015): Performance of Foreign and Local Agents for Enhanced Oil Recovery Nigerian Crude. SPEJ 178305, pp 6.

[9] Ojukwu, C., Onyekonwu M.O., Ogolo N.A., Ubani C. (2013): Alkaline Surfactant Polymer (Local) Enhanced Oil Recovery: An Experimental Approach. SPEJ 167529, pp 2-5.

[10] Sheng, James. (2013): A Comprehensive Review of Alkaline-Surfactant- Polymer (ASP) Flooding. SPE Western Regional & AAPG Pacific Section Conference,California, USA.

[11] Sheng, J. (2011): Modern Chemical Enhanced Oil Recovery; theory and practice. Gulf Professional Publishing, pp. 501-520.

[12] Uzoho, C.U., Onyekonwu, M.O., Akaranta, O. (2016): Studies on the use of Local Materials for Alkaline Surfactant Polymer Enhanced Oil Recovery. African Centre for Oilfield Chemical Research, University of Port Harcourt.

[13] Vaidya, A., Fogler, H. (1992): Fines Migration and Formation Damage: Influence of pH and Ion Exchange. SPE Production Engineering. 7. Pp. 325-330.

[14] Vergara-Jimenez M.,Almatrafi, M., Fernandez, M. (2017): Bioactive Components in Moringa oleifera Leaves Protect against Chronic Disease. Dietary Antioxidants and prevention of Non-Communicable Diseases. Vol. 6 (4).

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