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Suitability study of locally sourced surfactants for chemical enhanced oil recovery

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ABSTRACT

The need for this project is centred around economic issues encountered during production operations of oil and gas. The need to recover more oil after the reservoir's natural energy is depleted lead to enhanced oil recovery methods. During enhanced oil recovery using surfactants, the cost of surfactants has also become as issue thus the need to use locally available materials to synthesize formulas good enough to replicate the work of these conventional surfactants. In this study, suitability evaluation was conducted on locally sourced surfactants for chemical enhanced oil recovery. The local materials were as follows: local bar soap (LBS), a blend of aloe vera extract and almond leave extract (AVALE) while sodium lauryl sulphate (SLS) was utilised as conventional surfactant. Fourier transform spectroscopy (FTIR), critical micelle concentration (CMC), adsorption tests and core flooding was carried out on both the local and conventional surfactants. From the result of the FTIR study, LBS, AVALE recorded similar functional groups with SLS. From the CMC tests, SLS and AVALE recorded its CMC at 0.5%wt while the LBS was at 0.75%wt. From the adsorption test results, AVALE recorded its best rate at 0.75%wt, LBS at 0.25%wt while SLS was at 0.75%wt. After core flooding, SLS the conventional surfactant returned as the best surfactant with a peak displacement efficiency of 64.29%

while LBS returned as the best alternative at 62.5%. AVALE blend returned a displacement efficiency of 60%.

1. INTRODUCTION

Oil reservoir's recovery process involves three phases: primary, secondary and tertiary recovery. During primary recovery phase, oil is produced due to natural reservoir energy (compaction drive, solution gas drive, water drive, gas cap drive, gravity drive). Secondary recovery methods are water or gas injection for reservoir pressure maintenance or/and production increase. Tertiary methods called 'Enhanced Oil recovery methods' (EOR) are mostly applied in mature oil fields with declining production trend after primary and secondary methods or immediately after primary production phase. These 'Enhanced Oil Recovery' methods (EOR) imply injection of gases or fluids to mobilize residual oil captured in reservoir rock due to presence of strong viscous and capillary forces and high value of interfacial tension between fluid and rock.

The recovery factor for primary recovery ranges from 10-30%, it's between 10-20% additional recovery using secondary recovery and an added 15-25% using tertiary recovery as well as 10-25% extra for residual oil (Muggeridge et al, 2013). The selection of the suitable EOR method for implementation depends on the screening and the evaluation of reservoir properties and conditions as well as the economic feasibility (Green and Willhite 1998). Enhanced oil recovery is thus classified into gaseous (injection of miscible and immiscible gases to drive fluid), chemical (use of polymers, surfactants, alkaline fluids or a combination of fluids) and thermal methods (use of electromagnetics, cyclic vapour, continuous vapour or in-situ combustion to drive fluid).

The mechanisms involved in chemical oil recovery includes wettability alteration, interfacial tension reduction, mobility control, permeability reduction. Wettability alteration is a process that transforms the surface characteristics of rock grains by interactions with chemical agents achieved through physical adsorption or reaction with rock minerals. When wetting phase is imbibed into rocks, it can lead to the entrapment of less or non-wetting phases in multiphase reservoirs. By modifying wettability properties, this mechanism releases trapped hydrocarbons, enhancing their relative permeabilities. This particular recovery mechanism has been proposed for low-permeability gas-liquid reservoirs where gas is experiencing choked-flow due to liquid drop out (Wu and Firoozabadi, 2010; Li et al., 2011).

Interfacial tension (IFT) reduction involves introducing surface-active chemicals into pore spaces containing multiphase fluids acts to diminish interfacial adhesion forces, resulting in a reduction of capillary pressure. In reservoir rocks, the most prevalent conditions are either water wetting or mixed wetting. Surfactant flooding into the reservoir is a common choice for lowering interfacial tension. This approach effectively alters rock-fluid interactions, thereby contributing to an overall enhancement in reservoir performance. Mobility control process is usually associated with enhanced oil recovery using polymers. In chemical enhanced oil recovery, increasing the resistance to flow of the displacing phase by agents like polymers prevents viscous fingering which could lead to poor sweep of the targeted reservoir section

(Funsho Afolabi, 2015). Polymers (long chain molecules) are added to injection fluids to increase their ability to flow. This increased viscosity helps in controlling the mobility ratio (ratio of displacing fluid to the displaced fluid) thereby moderating fluid movement and consequently avoiding the bypassing of oil-rich zones. This regulated flow enhances sweep efficiency, ensuring a better interaction with the reservoir thereby increasing oil recovery.

One popular chemical enhanced oil recovery method is surfactant flooding into the reservoir. Surfactant flooding is injection of one or more liquid chemicals and surfactants. The injection effectively controls the phase behaviour properties in the oil reservoir, thus mobilizing the trapped crude oil by lowering IFT between the injected liquid and the oil thereby ensuring further production (Sandersen, Sara Bülow, 2012).

Surfactants work by forming micelles (tiny structures that encapsulate oil droplets, making them more mobile in the water phase). This facilitates the detachment of oil from the rock surfaces, reducing the capillary forces that hold the oil in place. Surfactant flooding is also effective in reducing viscous fingering, a phenomenon where injected water tends to channel through the reservoir, leaving oil behind. By reducing interfacial tension, surfactants help in achieving a more uniform sweep of the reservoir by ensuring greater contact with the oil-bearing zones. Surfactants have both hydrophilic (water-attracting) and hydrophobic (water-repelling) parts, which allow them to interact with both water and non-water substances. It is the balance between the hydrophilic and hydrophobic parts of the surfactant that generates the characteristics of the surface-active agent (Sandersen Sara Bülow, 2012).

According to the nature of the hydrophilic head group, surfactants are classified into different types, and this classification of surfactants is made based on the charges of the polar head group of the surfactant molecule. Surfactants are therefore divided into the classes: anionics (negative charge), catatonics (positive charge), non-ionic (no charge), and zwitterionic (negative and positive charge), (Bera and Belhaj 2016). Anionic surfactants are not usually tolerant of harsh environments such as salinity and temperature, and are not readily used as corrosion inhibitors (Chandrabhan et al, 2023). Cationic surfactants can be used to improve the spontaneous imbibition rate of water into preferentially oil-wet carbonate (Standnes & Austad, 2002). (Gupta and Mohanty, 2007) indicts that nonionic surfactants mostly play a crucial role as co-surfactants to enhance surfactant effectiveness. Zwitterionic are types of surfactants that carries both positive and negative charges on their hydrophilic head. Therefore, they can be anionic, nonionic, anionic-cationic or nonionic-cationic (Ahmed Fatih Belhaj et al, 2019).

Surfactant flooding is posed with a lot of problems of which the most popular is the adsorption of surfactants into rock pores and crevices as well as other undesirable portions of the reservoir. Surfactant adsorption on rock pores results in loss and decrease in surfactant concentration, thereby, reducing the quantity of surfactant molecules available for the interfacial tension reduction of oil–water interface, and consequently reduces the economic feasibility of the EOR method (Amirianshoja et al., 2013).

There are several factors that affect surfactant adsorption into rock pores. The most notable ones are surfactant concentration, salinity of environment, temperature and pH of the environment. Practically, surfactant adsorption can't be completely eradicated. Modifying the conditions of this reservoir can better the effectiveness of the use of surfactants by reducing adsorption to rocks thus save money for the project. Also, cosurfactants improve surfactant ability. The performance of the surfactant flooding process will be improved, and good recovery efficiency can be achieved only if the process is economically optimized by reducing surfactant adsorption (Park et al. 2015). Surfactant concentration significantly impacts the success of

surfactant flooding in EOR. A decrease in surfactant concentration during injection may diminish its efficiency in reducing oil-water interfacial tension, potentially leading to economic waste. Generally, adsorption increases with an increase in surfactant concentration. Salinity plays a significant role in influencing surfactant adsorption especially when anionic surfactants are involved. Generally, the presence of salt improves the adsorption of anionic surfactants on a negatively charged solid surface. Adsorption increases with the increase in temperature at low ionic strength while it decreases at high ionic strength with the temperature decrease (Ziegler and Handy, 1981).

Previous researchers have evaluated different types of surfactants at different environmental conditions thereby arriving at slightly different results and conclusions. Baviere et al. (1988) worked with alpha-olefine sulphate at salinity conditions of 600 ppm – 80000 ppm and temperatures of 30 ºC - 50 ºC concluding that alpha-olefine sulphate is stable in low-high salinity and low-high temperature conditions. Ingrid Hov (2014) worked with sodium dodecylbenzylsulfonate at 1169 ppm- 11688 ppm salinity and observed a decrease in adsorption in medium and low salinity conditions thereby implying the surfactant isn't good for high salinity reservoir conditions. Mannhardt et al. (1993) worked with Diphenyletherdisulfonate/ alpholfnsulfonate (DPES/AOS) blend in salinity range of 21000 ppm - 147000 ppm sandstone formation and discovered that the lower the salinity, the lower the adsorption rate in a sandstone formation. Tabary (2013) worked on olefin sulfonates at conditions of 220000 ppm salinity and 120 ºC temperature found that in high temperature conditions (up to 120 °C) good oil recovery can be achieved therefore recommended it to be used alongside adsorption inhibitors as it works in high temperature conditions.

2. MATERIALS AND METHODS

2. 1. Materials

The materials involved in this CEOR work include: a conventional anionic surfactant, sodium lauryl sulphate {SLS} to serve as a standard in analysing the effectiveness of the locally. sourced surfactants, locally sourced nonionic surfactant, Aloe vera gel/almond leave {AVALE} extract 1:1 ratio blend, a locally sourced nonionic surfactant, local bar{black} soap (LBS), an industrial salt used in brine preparation, Crushed core samples sieved to replicate that which is obtainable in the Niger delta zones.

The apparatus used in this research work include: the mechanical sieve shaker, a magnetic stirrer, the hydraulic mixer, a weighing balance, beakers, graduated cylinders, funnels, filter vernier callipers, saturator and accumulators, etc.

The local bar soap, LBS was sourced from a community market in Ihiagwa, Owerri west local government area of Imo state, Nigeria. The aloe vera from which the gel was extracted as well as the almond leave extract was sourced from FUTO market, Owerri Imo State, Nigeria. The crushed core samples were locally sourced from Otammiri river banks, FUTO Owerri, Nigeria. The industrial salt used in brine preparation was sourced from a chemical store in Douglas market, Owerri, Imo State, Nigeria.

2. 1. 1. Preparation of Materials

Aloe vera gel/ almond leave extract: the materials were washed and gloves were worn, the aloe vera was gently cut open and the gel scooped using a spoon, the almond leaves were

blended and sieved with a mesh, leaving behind the juice, both extracts were stored in container and kept in a cool environment to prevent aging and temperature effects.
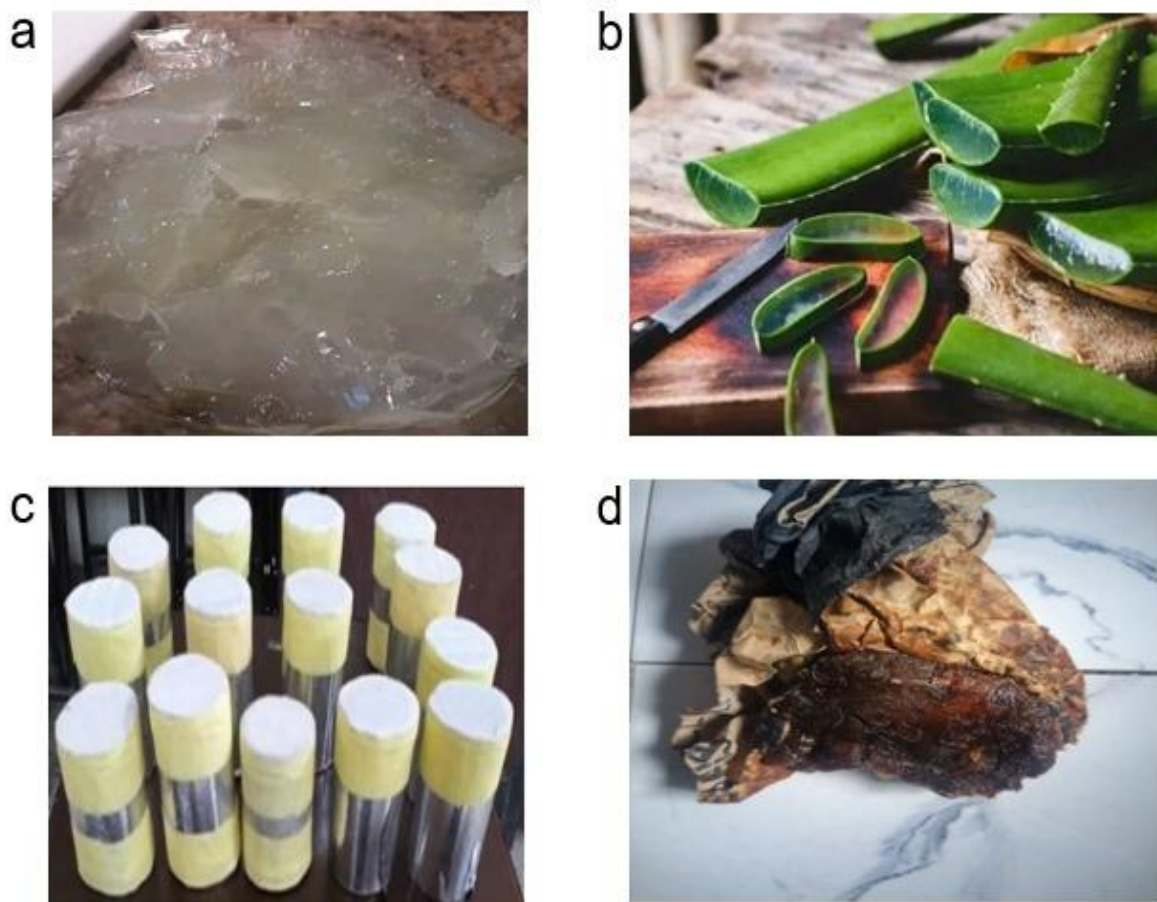

Fig. 1. (**a**) Aloe vera extract, (**b**) Aloe vera, (**c**) Core samples, (**d**) Local bar (black) soap.

2. 2. Methods

2. 2. 1. FTIR Characterization of Surfactants

This academic work utilized the Fourier transform infrared (FTIR) spectroscopy, which relies on infrared lights to analyse samples and observe their bond properties. FTIR instruments have catalogues which interpret the test results and generates a graph known as absorbance spectrum. This graph depicts the unique bonds and molecular structure of the sample. Compared to other types of characterization analysis, FTIR is quite popular. This characterization analysis is quite rapid, good in accuracy, and relatively sensitive (Jaggi and Vij, 2006).

The peak of this graph indicates the components present and indicates the functional groups such as alkanes, alkenes, ketones, ethers, carboxylic acids. Etc. Finally, the analytical spectrum is compared to reference elements to determine its best match and consequently characterize(group) it rightfully into the type of surfactant it is.

Table 1. Surfactant materials and type as indicated by FTIR.

MATERIAL	SURFACTANT GROUP
Sodium lauryl sulphate {SLS}	Typically, Anionic
Almond leave extract	Nonionic, slightly amphiphilic
Local bar soap (LBS)	Nonionic
Aloe vera extract	Nonionic

2. 2. 2. Critical Micelle Concentration Tests (CMC)

The crushed core samples were put into topmost mesh of the mechanical sieve shaker and put on to carefully sieve until the desired mesh size {30) is achieved. Measurements of 25g, 50g, 75g, 100g, 125g of the brine was put into 100 ml of water to get 2500, 5000, 7500, 10000 and 12500 ppm brine respectively. Each of the 0.25g, 0.50g, 0.75g, 1.00g and 1.25g samples was injected into the different brine concentrations and mixed vigorously. The conductivity of each mixture was taken and recorded. A plot of the different conductivities against surfactant concentration was made and at the point of inflection, the critical micelle concentration is defined.

2. 2. 3. Adsorption Tests

The mixtures were passed through 20g (Cf) of the core samples and stirred using a magnetic stirrer and then each was passed through a sized filter paper. After adsorption, the conductivity of each mixture was taken using a conductivity meter. The adsorption rates of each mixture were calculated using the formula:

$$q = \frac{(c_o - c_f) \times m_b}{m_c} \times 10^{-3} \quad \text{(Obuebite et al, 2024)}$$

where q = amount of the surfactant adsorbed on the core surface (mg/g), C_O = initial concentration of the surfactant solution before equilibration with the core sample (ppm), C_f = final concentration of the surfactant solution after equilibration with the core sample (ppm), M_b = total mass of solution in original bulk solution (g), and m_c = total mass of the crushed core sample (g).

After calculations, a plot of the adsorption rates against surfactant concentration was made. The closest adsorption rate to zero, above the critical micelle concentration is regarded as potentially the best concentration for surfactant flooding.

2. 2. 4. Surfactant Flooding

The Weight of the dried core sample was taken using a measuring scale while vernier callipers was used to measure the diameter and length of the core. The samples were immersed

in brine and left in a vacuum pump for 2days to ensure full saturation. The weight of each saturated core sample was taken and the difference between dry and saturated recorded as the pore volume. The core samples were fixed into the core holders and the accumulators were filled up with Oil, brine and surfactant, this was done for each surfactant sample differently. One end of the accumulator (injection point) was connected to the inlet and the other end (production point) to the outlet. 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. During imbibition, 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. 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.
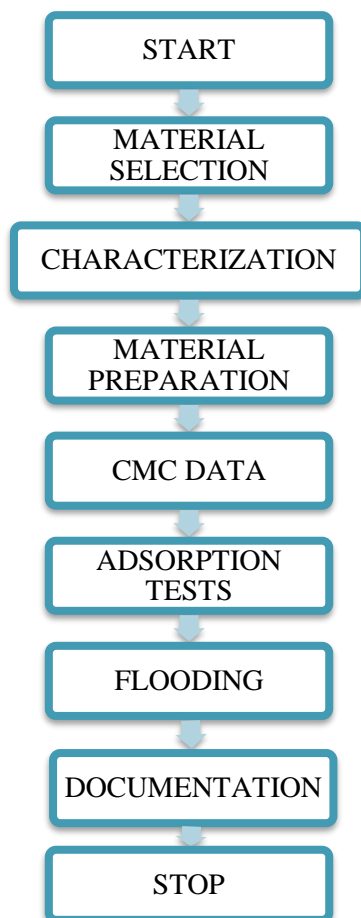

Fig. 2. Flow chart of experiments

3. RESULTS AND DISCUSSIONS

3. 1. Functional Groups Test

Fourier Transformed Infrared (FTIR) technique is an important tool used to identify the characteristic functional groups, which are instrumental in determination of functional groups and organic compounds inherent in any given sample. Results of the FTIR spectra is presented below.

As shown in Fig. 3, ALE contains the following functional groups at the corresponding wavelengths: Aromatics (C-H) with a wavelength of 737.2429 cm^{-1}, Aromatics (C-H) with a wavelength of 846.4747 cm^{-1}, Aliphatic amine stretch (C-N) with a wavelength of 1041.886 cm^{-1}, Alkyl halides C-H (-CH2X) with a wavelength of 1297.166 cm^{-1}, Aromatic stretch (in ring) (C-C) with a wavelength of 1405.544 cm^{-1}, 1^0 amine bend (N-H) with a wavelength of 1606.047 cm^{-1}, Anhydride stretch (C=O) with a wavelength of 1834.378 cm^{-1}, Allene stretch (C=C=C) with a wavelength of 1973.859 cm^{-1}, Isothiocyanate stretch (N=C=S) with a wavelength of 2039.59 cm^{-1}, Carbodiimide stretch (N=C=S) with a wavelength of 2142.907 cm^{-1}, Nitrile stretch (C≡N) with a wavelength of 2259.914 cm^{-1}, Carboxylic acid stretch (O-H) with a wavelength of 2518.083 cm^{-1}, Carboxylic acid stretch (O-H) with a wavelength of 2656.518 cm^{-1}, Aldehydes stretch (H-C=O:C-H) with a wavelength of 2816.506 cm^{-1}, Alkenes stretch (=C-H) with a wavelength of 3005.58 cm^{-1}, Alcohols, phenols stretch (O-H) with a wavelength of 3236.25 cm^{-1} 1^0, 2^0 amines, amides stretch (N-H) with a wavelength of 3335.175 cm^{-1}, Alcohols, phenols stretch (O-H) with a wavelength of 3426.466 cm^{-1}, Alcohol stretch (O-H) with a wavelength of 3535.734 cm^{-1}, Alcohol stretch (O-H) with a wavelength of 3684.386 cm^{-1}, and Alcohol stretch (O-H) with a wavelength of 3817.227 cm$^{-1.}$.

As shown in Fig. 4, AVE contains the following functional groups at the corresponding wavelength s : Alkynes bend (-C≡C-H: C-H) with a wavelength of 6907.7953 cm^{-1}, Aromatics (C-H) with a wavelength of 853.9798 cm^{-1}, Aliphatic amine stretch (C-N) with a wavelength of 1133.505 cm^{-1}, Alcohols, carboxylic acids, esters, ethers stretch C-O with a wavelength of 1318.672 cm^{-1}, 1^0 amines bend (N-H) with a wavelength of 1613.978 cm^{-1}, Anhydride stretch (C=O) with a wavelength of 1829.055 cm^{-1}, Allene stretch (C=C=C) with a wavelength of 1962.824 cm^{-1}, Isothiocyanate stretch (N=C=S) with a wavelength of 2054.088 cm^{-1}, Thiocyanate stretch (S-C≡N) with a wavelength of 2173.728 cm^{-1}, Carboxylic acid stretch (O-H) with a wavelength of 2457.542 cm^{-1}, Carboxylic acid stretch (O-H) with a wavelength of 2527.403 cm^{-1}, Carboxylic acid stretch (O-H) with a wavelength of 2644.871 cm^{-1}, Aldehydes stretch (H-C=O:C-H) with a wavelength of 2715.564 cm^{-1}, Aldehydes stretch (H-C=O:C-H) with a wavelength of 2825.524 cm^{-1}, Alkanes stretch (C-H) with a wavelength of 2990.84 cm^{-1}, Alcohol stretch (O-H) with a wavelength of 3171.713 cm^{-1}, Aliphatic primary amine stretch (N-H) with a wavelength of 3261.533 cm^{-1}, Alcohol stretch (O-H) with a wavelength of 3456.634 cm^{-1}, and Alcohol stretch (O-H) with a wavelength of 3793.272 cm^{-1}.

As shown in Fig. 5, LBS contains the following functional groups at the corresponding wavelengths: 1^0 , 2^0 amines wag (N-H) with a wavelength of 854.1979 cm^{-1}, Nitro compound stretch (N-O) with a wavelength of 1340.69 cm^{-1} 2^0, 1^0 amines bend (N-H) with a wavelength of 1605.982 cm^{-1}, Anhydride stretch (C=O) with a wavelength of 1864.057 cm^{-1}, Allene stretch (C=C=C) with a wavelength of 1971.229 cm^{-1}, Isothiocyanate stretch (N=C=S) with a wavelength of 2116.35 cm^{-1}, Alkyne stretch (C≡C) with a wavelength of 2203.554 cm^{-1}, Carbodioxide stretch (O=C=O) with a wavelength of 2458.455 cm^{-1}, Carboxylic acid stretch (O-H) with a wavelength of 2614.944 cm^{-1},
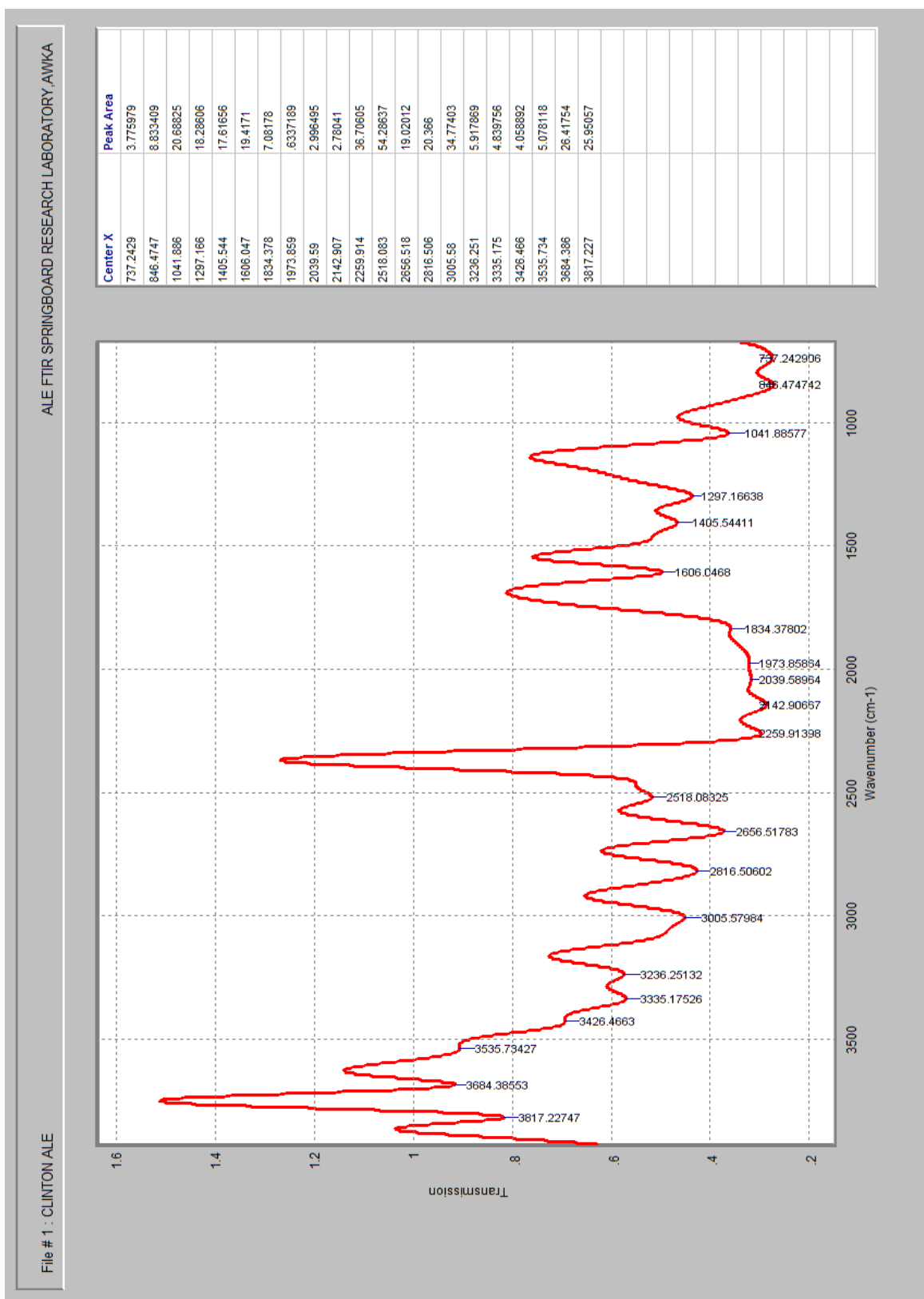
ALE FTIR SPRINGBOARD RESEARCH LABORATORY, AWKA

File # 1 : CLINTON ALE

Center X	Peak Area
737.2429	3.775979
846.4747	8.833409
1041.886	20.68825
1297.166	18.28606
1405.544	17.61656
1606.047	19.4171
1834.378	7.08178
1973.859	.6337189
2039.59	2.996495
2142.907	2.78041
2259.914	36.70605
2518.083	54.28637
2656.518	19.02012
2816.506	20.366
3005.58	34.77403
3236.251	5.917869
3335.175	4.839756
3426.466	4.058892
3535.734	5.078118
3684.386	26.41754
3817.227	25.95057

Fig. 3. FTIR result for almond leaf extract (ALE)

Center X	Peak Area
690.7953	.08206641
853.9798	40.28328
1133.505	1.431671
1318.672	105.8511
1613.978	32.4179
1829.055	28.31146
1962.824	1.190756
2054.088	4.50831
2173.728	64.65923
2457.542	17.05531
2527.403	1.626598
2644.871	1.034055
2715.564	13.25454
2825.524	3.447348
2990.484	24.46549
3171.713	1.886832
3261.533	18.30654
3456.634	47.33876
3793.272	11.42606

AVE FTIR SPRINGBOARD RESEARCH LABORATORY,AWKA

File # 2 : CLINTON AVE

Fig. 4. FTIR result for aloe vera extract (AVE)
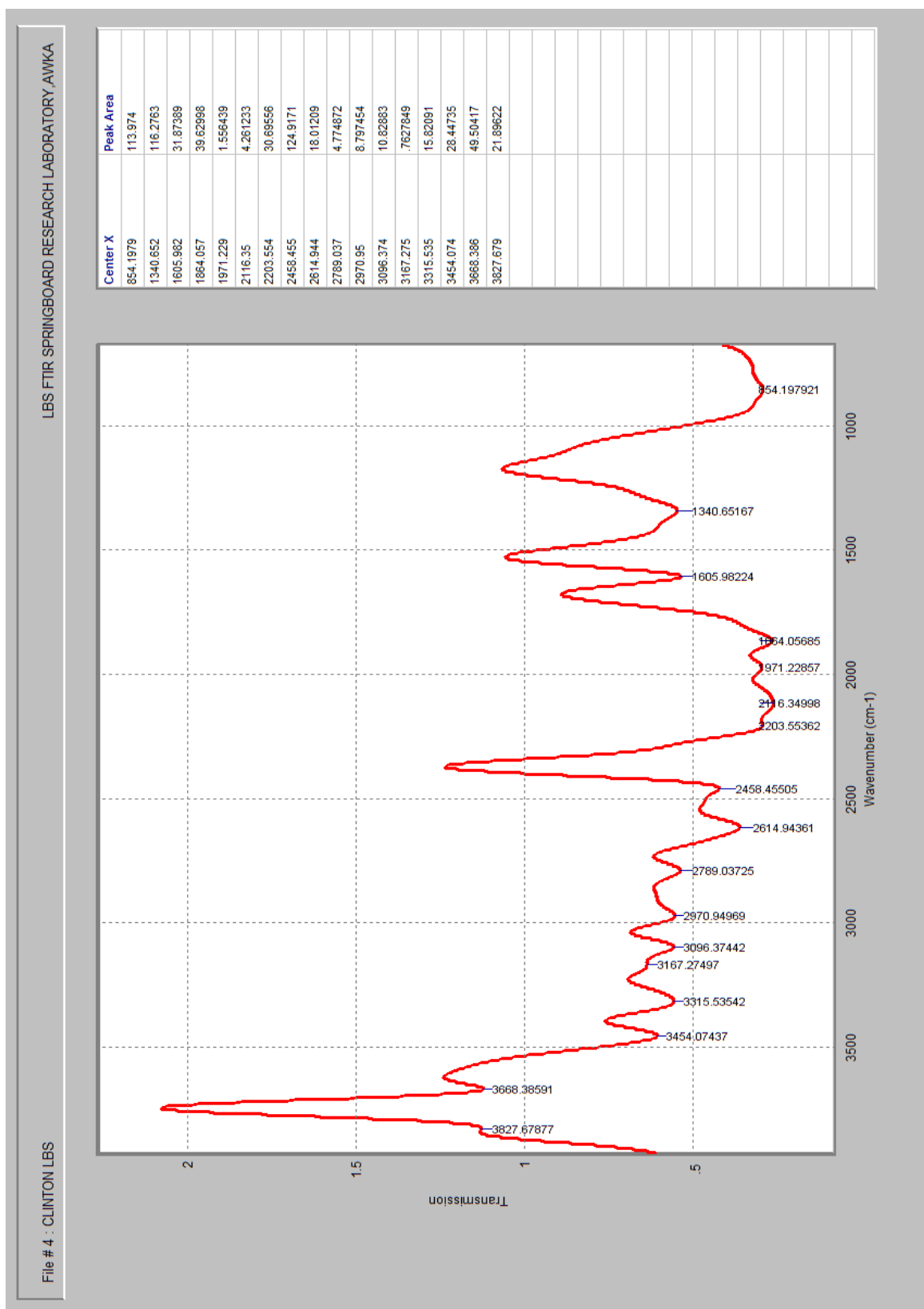
Fig. 5. FTIR result for local bar soap (LBS)
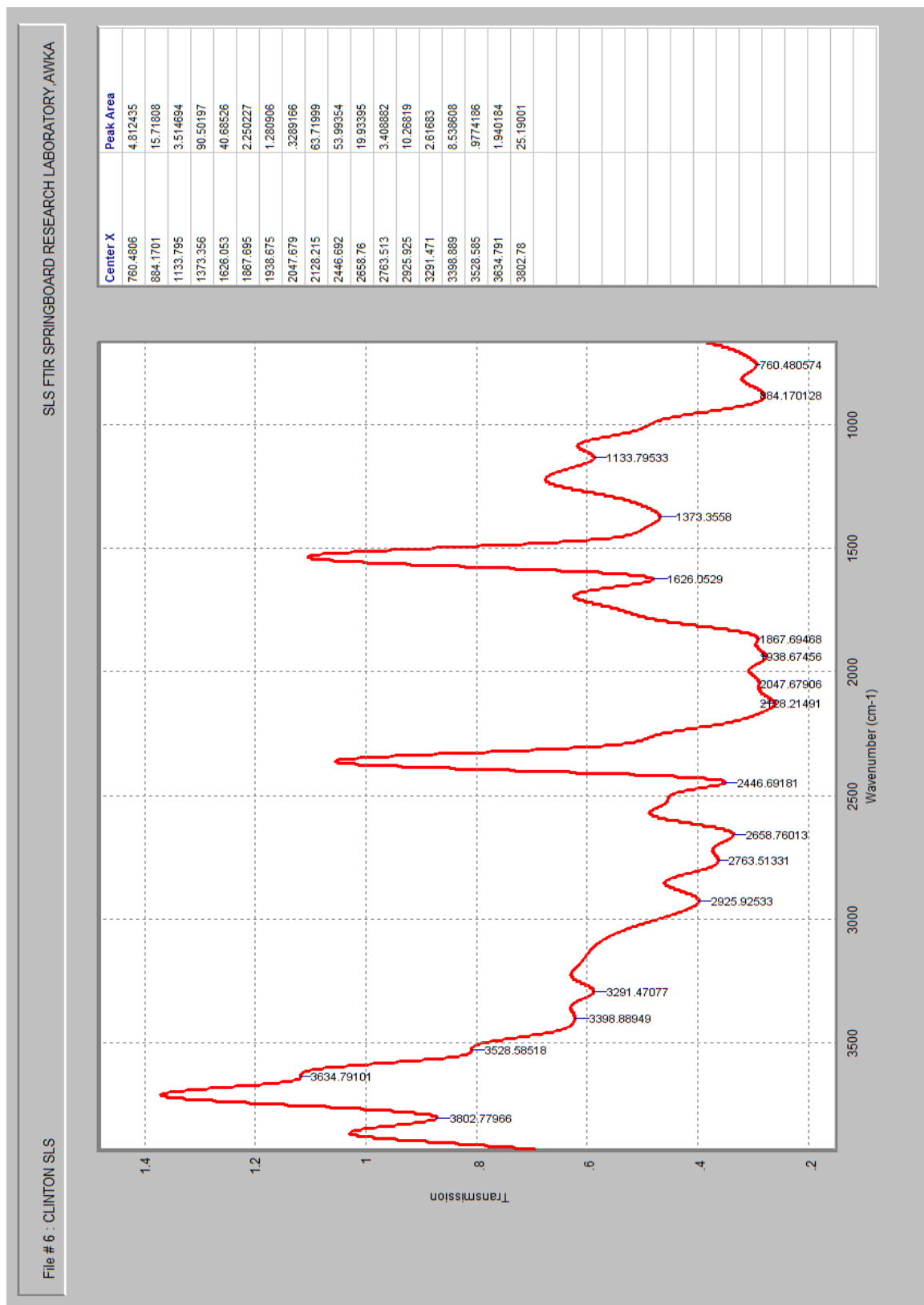
Fig. 6. FTIR result for sodium lauryl sulphate (SLS)

Alcohol stretch (O-H) with a wavelength of 2789.037 cm^{-1}, Alkane stretch (C-H) with a wavelength of 2970.95 cm^{-1}, Alkene stretch (C-H) with a wavelength of 3096,374 cm^{-1}, Alcohol stretch (O-H) with a wavelength of 3167.275 cm^{-1}, Aliphatic primary amine stretch (N-H) with a wavelength of 3315.535 cm^{-1}, Alcohol stretch (O-H) with a wavelength of 3454.074 cm^{-1}, Alcohol stretch (O-H) with a wavelength of 3668.386 cm^{-1}, and Alcohol stretch (O-H) with a wavelength of 3827.679 cm^{-1}.

As shown in Fig. 6, SLS contains the following functional groups at the corresponding wavelengths: Alkyl halides (C-Cl) with a wavelength of 760.4806 cm^{-1}, Aromatics (C-H) with a wavelength of 884.1701 cm^{-1}, Aliphatic amine stretch (C-N) with a wavelength of 133.795 cm^{-1}, Phenol bend (O-H) with a wavelength of 1373.356 cm^{-1}, Cyclic alkene stretch (C=H) with a wavelength of 1626.053 cm^{-1}, Anhydride stretch (C=O) with a wavelength of 1867,695 cm^{-1}, Allene stretch (C=C=C) with a wavelength of 1938.675 cm^{-1}, Isothiocyanate stretch (N=C=S) with a wavelength of 2047.679 cm^{-1}, Azide stretch (N=N=N) with a wavelength of 2128.215 cm^{-1}, Carbodioxide stretch (O=C=O) with a wavelength of 2446.692 cm^{-1}, Carboxylic acid stretch (O-H) with a wavelength of 2658.76 cm^{-1}, Aldehyde stretch (C-H) with a wavelength of 2763.513 cm^{-1}, Amine salt stretch (N-H) with a wavelength of 2925.925 cm^{-1}, Alcohol stretch (O-H) with a wavelength of 3291.471 cm^{-1}, Aliphatic primary amine stretch (N-H) with a wavelength of 3398.889 cm^{-1}, Alcohol stretch (O-H) with a wavelength of 3528.585 cm^{-1}, Alcohol stretch (O-H) with a wavelength of 3634.791 cm^{-1}, and Alcohol stretch (O-H) with a wavelength of 3802.78 cm^{-1}

The above surfactants based on their hydrophilic and hydrophobic compounds are non-ionic surfactants, all having alcohol present as a functional group.

ALE is majorly amphiphilic as it contains both hydrophobic and hydrophilic functional groups, AVE is classified as a nonionic surfactant typically containing polar groups as well as non-polar hydrocarbon chains, LBS is a mixture of nonionic and amphiphilic surfactants as it contains alcohol, carboxylic acids and ethers (typical nonionic surfactants) and functional groups like amines, alkenes and alkynes (typical amphiphilic surfactants), SLS is primarily nonionic containing functional groups like alcohols, aromatics and aldehydes which are typical of nonionic surfactants.

The most common hydrophobic group in all the samples is the allene stretch, while the most common hydrophilic groups present in all the samples are aliphatic amine stretch, carboxylic acid stretch and alcohol stretch which generally classifies the samples as nonionic.

3. 2. Critical Micelle Concentration

Figures 7-9 depict the conductivity of AVALE, LBS and SLS at varying concentrations. From Figure 8, LBS recorded 455 us/cm, 721 us/cm, 912 us/cm, 1462 us/cm, 1462 us/cm at 0.25% wt, 0.5% wt, 0.75% wt, 1% wt and .25%wt respectively.

From Figure 9, SLS recorded 930 us/cm, 1349 us/cm, 1898 us/cm, 2000 us/cm, 2000 us/cm at 0.25% wt, 0.5% wt, 0.75% wt, 1% wt and 1.25% wt respectively. As observed from Figures 7-9, AVALE recorded its CMC at 0.5 and 0.75. LBS recorded its CMC at 0.75 and 1.00, while SLS recorded its CMC at 0.5 and 0.75.

Using CMC tests alone, AVALE and SLS are the best surfactants having recorded the its CMC values (0.5). Uzoho et. al 2012 says that the surfactant with the least CMC value is the best.
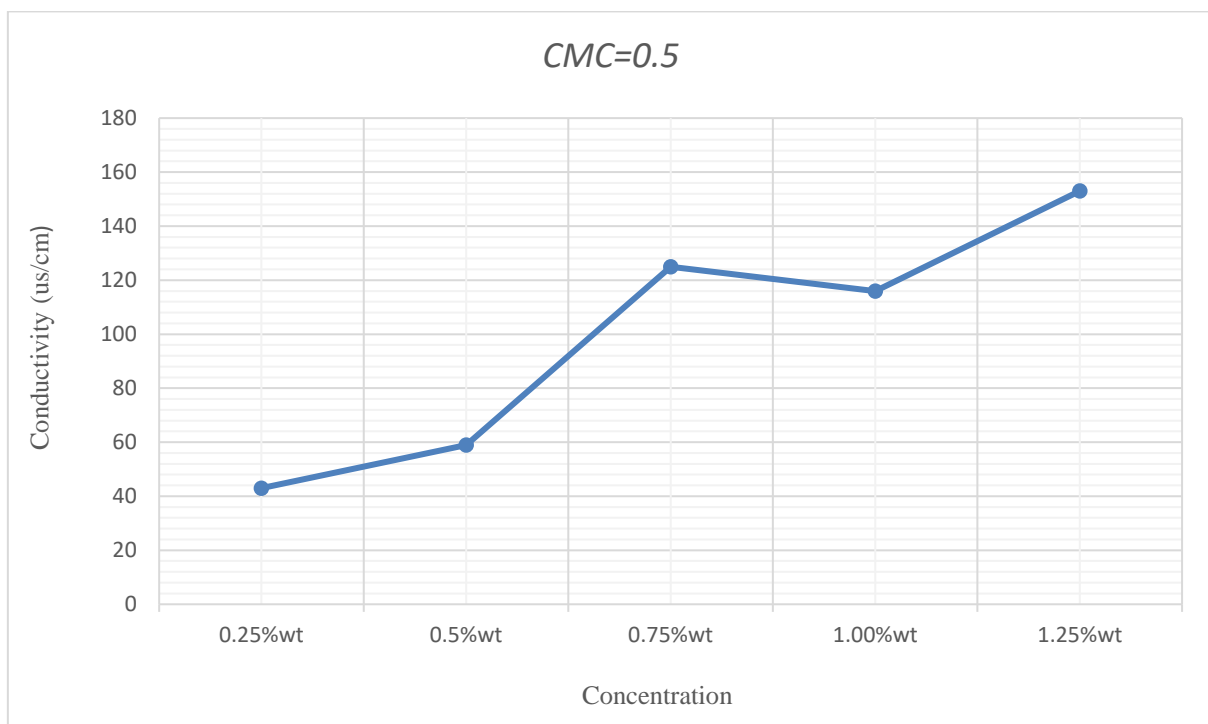
Fig. 7. Plot of conductivity against surfactant concentration to determine
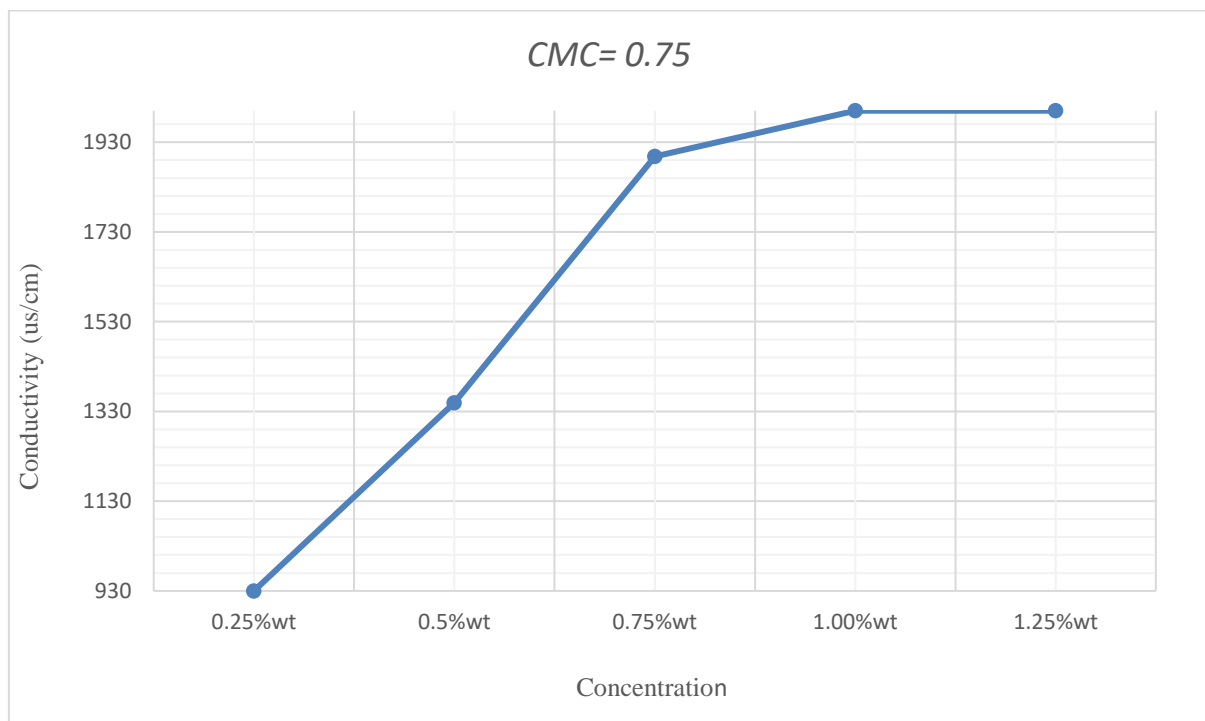the CMC of AVALE blend.

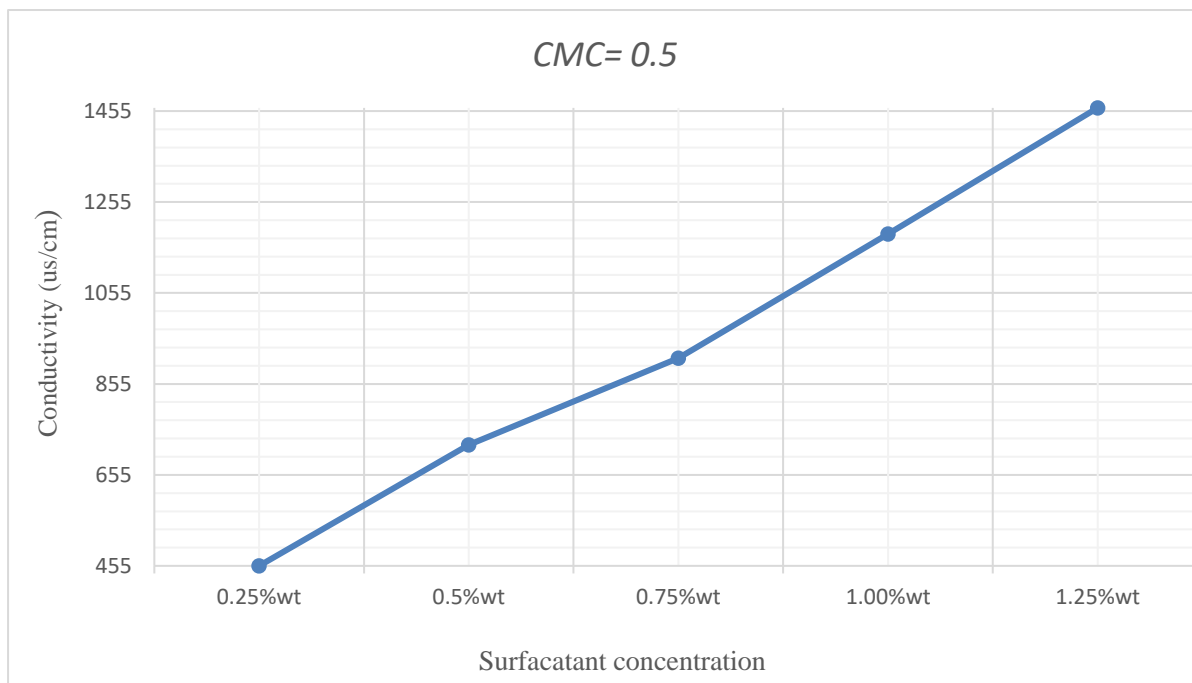**Fig. 8.** Plot of conductivity against surfactant concentration of LBS.

Fig. 9. Plot of conductivity against surfactant concentration of conventional surfactant, SLS.
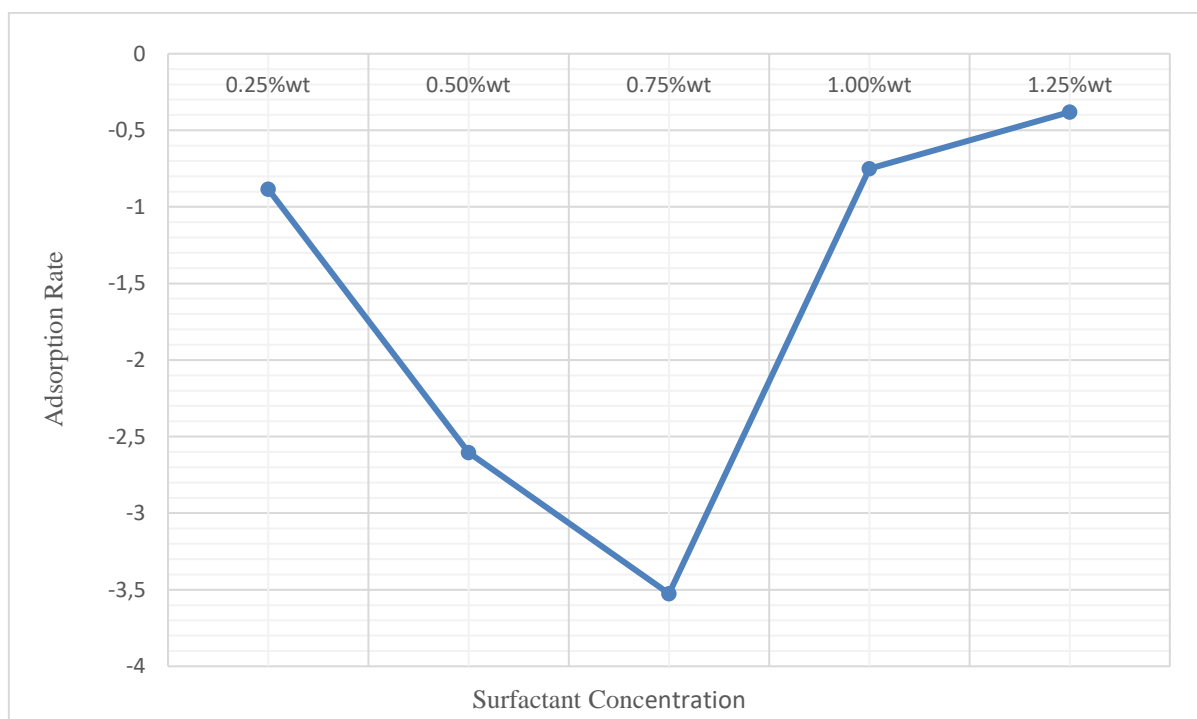
3. 3. Adsorption Tests

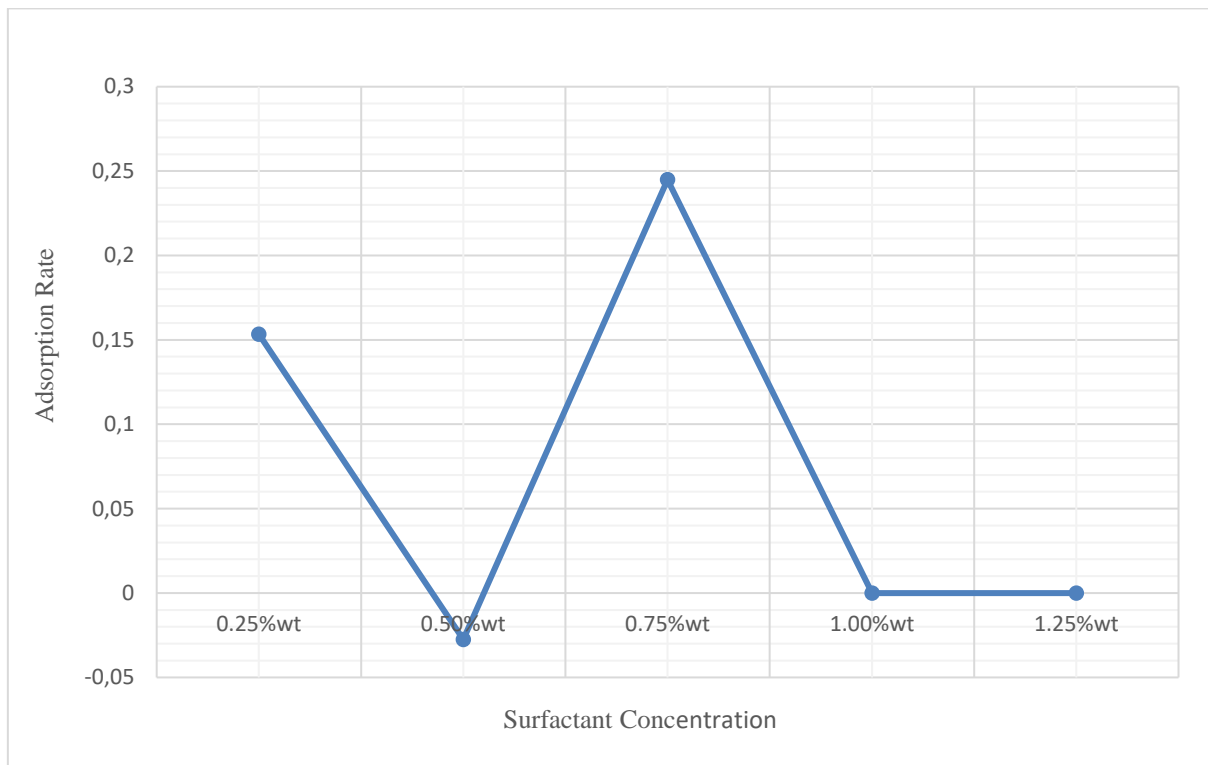**Fig. 10.** Adsorption rate of AVALE blend

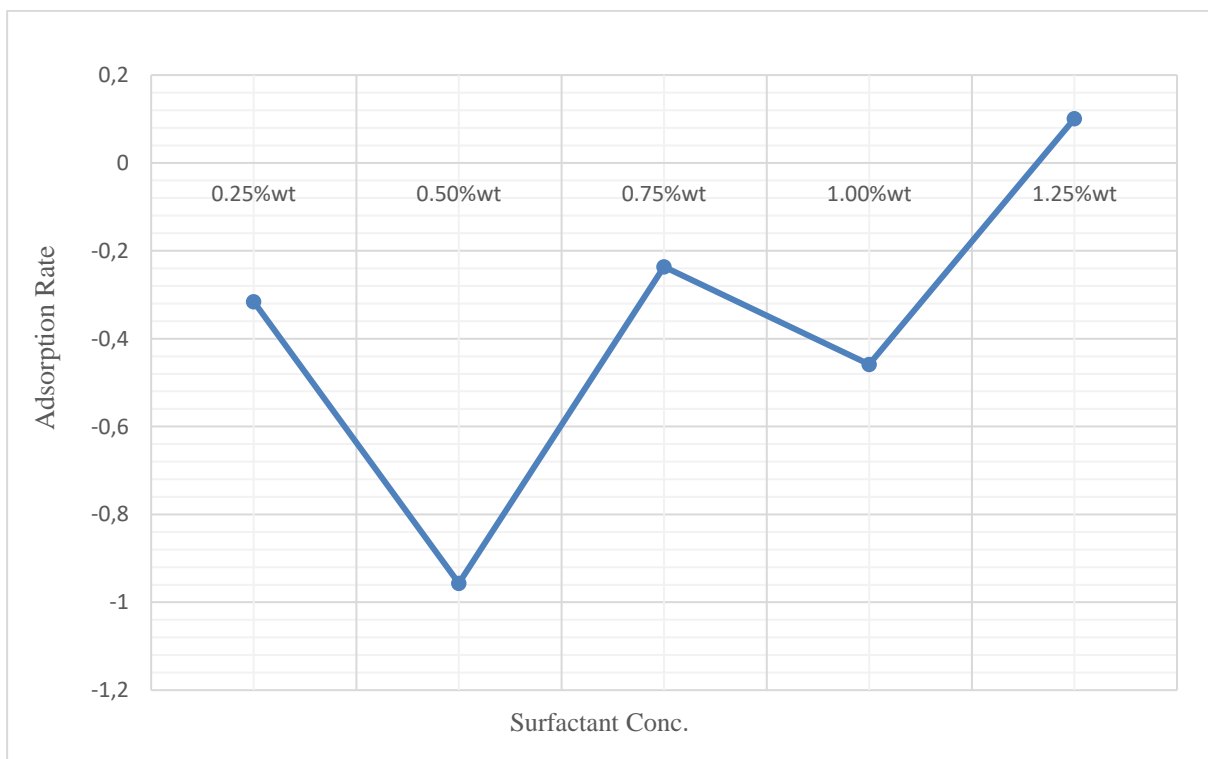**Fig. 11.** Adsorption rate of LBS.

Fig. 12. Adsorption rate of conventional surfactant, SLS.

From Figures 10-12, the adsorption rates of AVALE, LBS, SLS are du**ly** represented. In Fig. 10, AVALE gave adsorption rates of -0.8885 mg/g, -2.6039 mg/g, -3.5256 mg/g, -0.7508 mg/g, -0.3810 mg/g at concentrations of 0.25% wt, 0.5% wt, 0.75% wt, 1% wt and 1.25% wt respectively.

In Fig 11 LBS showed adsorption rates of 0.1534 mg/g, -0.0275 mg/g, 0.2449 mg/g, 4.6370 mg/g at varying concentrations of 0.25% wt, 0.5% wt, 0.75% wt, 1%wt respectively. In Fig. 12, conventional surfactant SLS resulted in adsorption rates of -0.3156 mg/g, -0.9567 mg/g, -0.02362 mg/g, -0.4584mg/g and -0.1007 mg/g at varying concentrations of 0.25% wt, 0.5% wt, 0.75% wt, 1% wt and 1.25% wt respectively.

3. 4. Surfactant Flooding

Table 2. Surfactant flooding results

| PLUG S/N	CONCENTRTION OF EOR FLUID	OIIP (ml)	SEC. REC (ml)	DISP. EFF	EOR (ml)	ADD. REC.
AVE/ALE 1	Brine (5000 ppm) / AVALE 0.25%	24	16	60.00%	4.80	20.00%
AVE/ALE 2	Brine (5000 ppm) / AVALE 0.5%	24	16	47.06%	3.76	15.69%
AVE/ALE 3	Brine (5000 ppm) / AVALE 0.75%	24	16	42.86%	3.43	14.29%
AVE/ALE 4	Brine (5000 ppm) / AVALE 1.00%	24	16	29.00%	2.32	9.67%
AVE/ALE 5	Brine (5000 ppm) / AVALE 1.25%	24	16	28.57%	2.29	9.52%
LBS 1	Brine sol (5000 ppm)/ LBS 0.25%	24	16	40.00%	3.20	13.33%
LBS 2	Brine sol (5000 ppm)/ LBS 0.5%	24	16	41.18%	3.29	13.73%
LBS 3	Brine sol (5000 ppm)/ LBS 0.75%	24	16	62.50%	5.00	20.83%
LBS 4	Brine sol (5000 ppm)/ LBS 1.0%	24	16	61.11%	4.89	20.37%
LBS 5	Brine sol (5000 ppm)/ LBS 1.25%	24	16	59.00%	4.72	19.67%
SLS 1	Brine sol (5000 ppm)/ SLS 0.25%	24	16	52.86%	4.23	17.62%
SLS 2	Brine sol (5000 ppm)/ SLS 0.5%	24	16	57.14%	4.57	19.05%
SLS 3	Brine sol (5000 ppm)/ SLS 0.75%	24	16	64.29%	5.14	21.43%
SLS 4	Brine sol (5000 ppm)/ SLS 1.0%	24	16	63.24%	5.06	21.08%
SLS 5	Brine sol (5000 ppm)/ SLS 1.25%	24	16	62.32%	4.99	20.77%
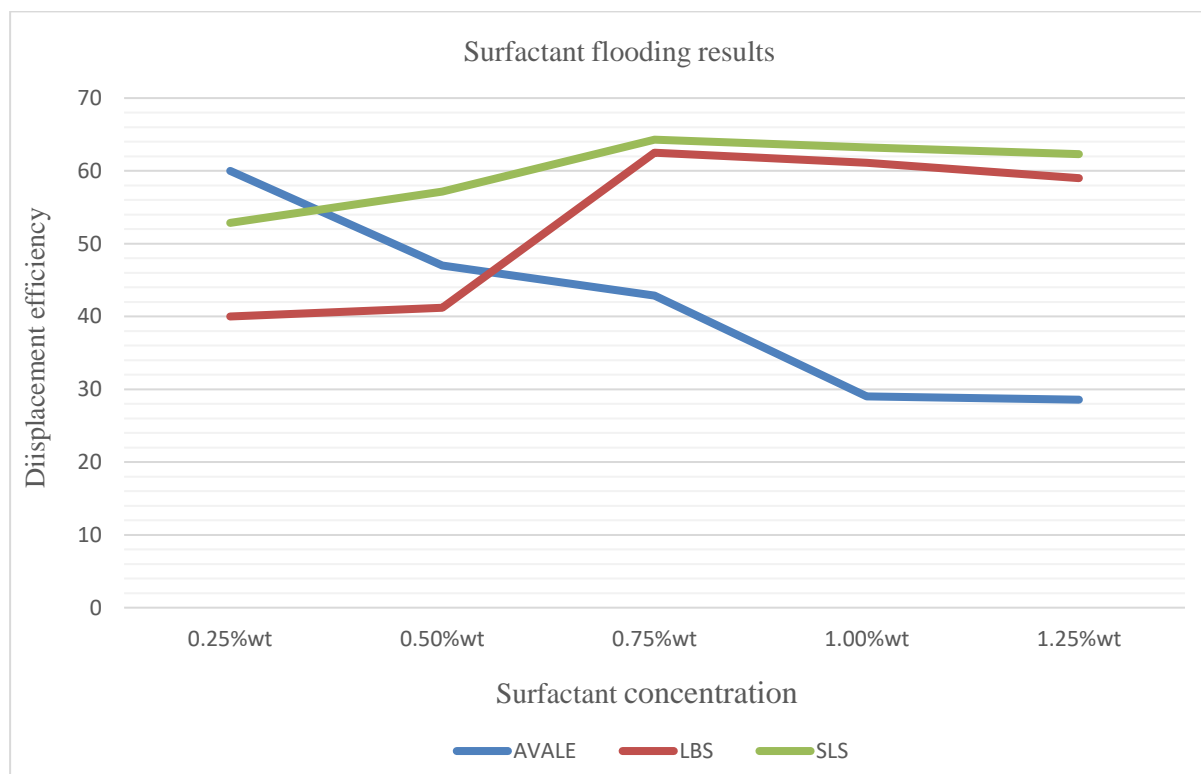
Fig. 13. Surfactant flooding results

From Fig. 13, SLS of course, proved to be the best surfactant showing a peak 64.29% displacement efficiency at 0.75%wt. the displacement efficiency afterward drops slightly with increasing concentration showing that the CMC has been reached and adsorption rates increased. This could also be as a result of slight decline as the production rate drops. The LBS impressively returned a 62.50% displacement efficiency at 0.75% wt. The displacement efficiency also drops afterwards with increasing concentration indicating CMC have been surpassed as adsorption rate also increases. This result leaves the LBS as a very good alternative with the only problem as discovered during the flooding being the length of time it took to displace the oil due to it high sulfonating content. Also from Fig. 13, AVALE showed a peak 60.0% displacement efficiency at 0.25% wt. The peak displacement efficiency at a lower concentration makes it possibly, a viable alternative in the economic analysis considering the amount required to displace the oil.

4. CONCLUSIONS

The main objective of this research which is to find local surfactants that'll compete the imported surfactants both in efficiency, ability to work in temperate and saline regions as well as better the imported ones economically have been achieved to an extent. Some points were noted down after this research work: The presence of both hydrophobic and hydrophilic groups in the locally sourced surfactants show that they offer more versatility in formulations, have

great stability in a wide range of temperature and pH conditions and are more environmentally friendly than the imported surfactants. Also, with a better treatment process, locally sourced surfactants would compete effectively with the conventional surfactants. As seen in this work, LBS competed effectively with the SLS but fell short due to its high sulfonating content which caused a lot of foaming and consequently more amount of time to perform its job. Local surfactants for the value they give, costs less than the conventional surfactants. However, because oil well drilling and production is costed at the high-end, the optimum measures to recover oil should be adopted till local surfactants are near perfect for the job. Salinity and temperature are critical factors to be considered in surfactant flooding. A slight change in this factor can result in a massive overall change in the flooding results. The use of local surfactants for enhanced oil recovery should be looked into more critically. Local surfactants have shown to almost replicate almost same oil recovery as the imported surfactants which cost way higher. However, laboratory tests and usage on the field might differ thus the need to practically use them to confirm the laboratory results. Also, this work is limited to certain conditions which can render this work less feasible and workable. Other research areas that could be looked into includes further treatment of local surfactants before usage, commercial production of local surfactants, evaluation of the abilities of local surfactant blends.

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