# Synthesis, Characterization, Physical and Thermodynamic Properties of an Anionic Surfactant Derived from Linum Usitatissimum

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## ABSTRACT

Chemically synthesized surfactants are very effective in breaking the boundary tensions between the trapped oil and injected fluid but of recent, the use of synthetic surfactant is limited owing to its high cost of production and the associated toxic effects which have proven to be harmful to the environment. Therefore, the new focus of the oil and gas industry is the development of cost-effective bio-degradable surfactants that are environmentally friendly. The study discusses the production of bio-based surfactant via saponification from Linseed oil and its application in enhanced oil recovery. The surfactant was characterized using FTIR, SEM-EDX analysis, foam ability, emulsion stability and static adsorption test. From the produced surfactant, 6 concentrations in parts per million (ppm) (500ppm, 1000ppm, 2000ppm, 4000ppm, 8000ppm, 1200ppm) were prepared and subjected to characterization and performance tests. Effect of electrolyte concentrations (0wt. %, 2wt. % and 5 wt. %) on the emulsion and foam characteristics of the surfactant solutions were equally analyzed.

It is expected from the FTIR analysis that the surfactant will be an ester and the EDX is expected to show a high percentage of sodium with no impurities. The conductivity of surfactant increases with increase in concentration and salt content. The foam height of the surfactant was a function of the concentration of the surfactant and the more the salt, the more stable the foam. The surfactant formed mainly Type I microemulsion. The adsorption density of the surfactant increased as the concentration of the surfactant increased until it got to equilibrium point which was 400ppm where it remained constant at 0 wt %, 2wt % and 5 wt %.

Linseed oil surfactant showed good potential for enhanced oil recovery application.

## INTRODUCTION

There is a constant increase in the demand for energy, yet, the amount of conventional oil fields being discovered are steadily decreasing, hence there is need for oil reservoirs to be redeveloped using modern technologies in order to increase production life (JestrilEbaga-Ololo and Bo Hyun Chun, 2017). The remaining oil in the reservoir which is about 70% of the original oil in place, continues to be trapped in a discontinuous process by capillary forces after traditional methods have been applied, this includes both primary and secondary recovery methods (AchintaBera and Ajay Mandal, 2015). To improve the efficiency of the recovery, we make use of Enhanced Oil Recovery processes which are done after secondary recovery methods and they refer to means of recovering oil that deviates from the usual techniques which are primary and secondary methods. It is usually done to extend the economic life of a reservoir (Zahra Bachari et al, 2019).

Surfactants are surface-active substances. (surface-acting chemicals), that lower the surface area between the residual oil and the aqueous surfactant solution. They are often employed in the detergent, paint, cosmetic, and glue industries. However, more recently, they have been used into the oil recovery process. Because of its propensity to reduce the interfacial tension between the displacing fluid and the fluid to be displaced and change

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the reservoir rock's wettability from oil-wet to water-wet, it is currently employed in oil recovery. Its potential is influenced by the permeability, wettability, capillary pressure, and interfacial tension. The major concern with most of the surfactants used in the industry include, the high-cost, they are synthetic, they are harmful to the environment and non-biodegradable in nature majority. Natural surfactants made from natural resources like plants, vegetable oil and seed oils, have been discovered to be an applicable alternative to synthetic surfactants and they are inexpensive, eco-friendly and biodegradable. Natural surfactants employed in chemical EOR are divided into non-ionic, cationic, anionic, and amphoteric kinds, just as chemical surfactants (Zahra Bachari1 et al 2019).

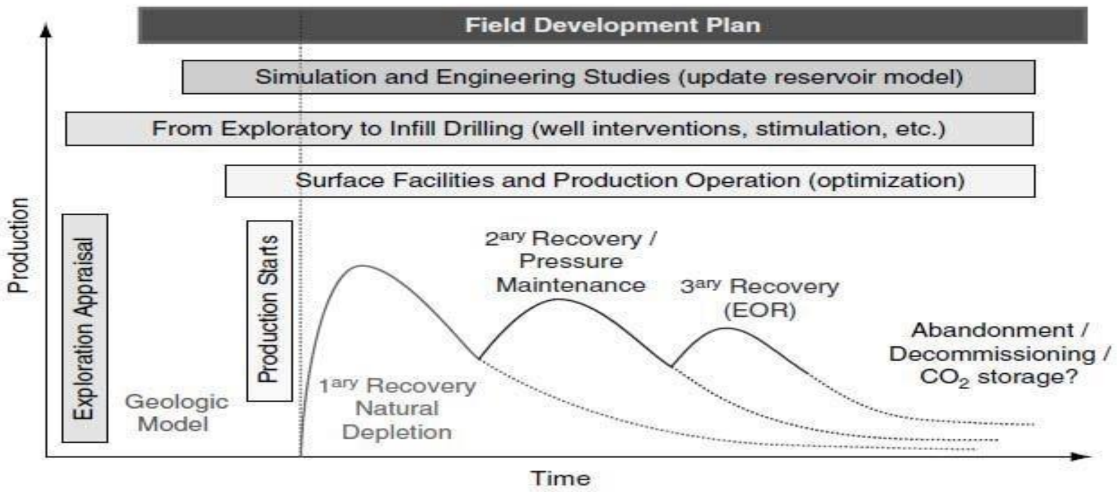


Figure1: Enhancing Production with Time

EOR techniques may be roughly divided into two categories: thermal and non-thermal techniques. Non-thermal approaches are more frequently utilized since thermal techniques cannot be used in deep water or in thin pay zones. Chemical techniques are considered to be the most promising non-thermal technologies because to their superior performance, technical and economic sustainability, and cheap cost. They are also excellent at reducing interfacial tension and modifying the wettability of rocks to increase microscopic efficiency. Alkaline injection, surfactant flooding, and polymer flooding are the three different forms of chemical flooding. Due to their effectiveness in displacing the trapped oil in the reservoir, polymer and surfactant flooding are more often utilized.

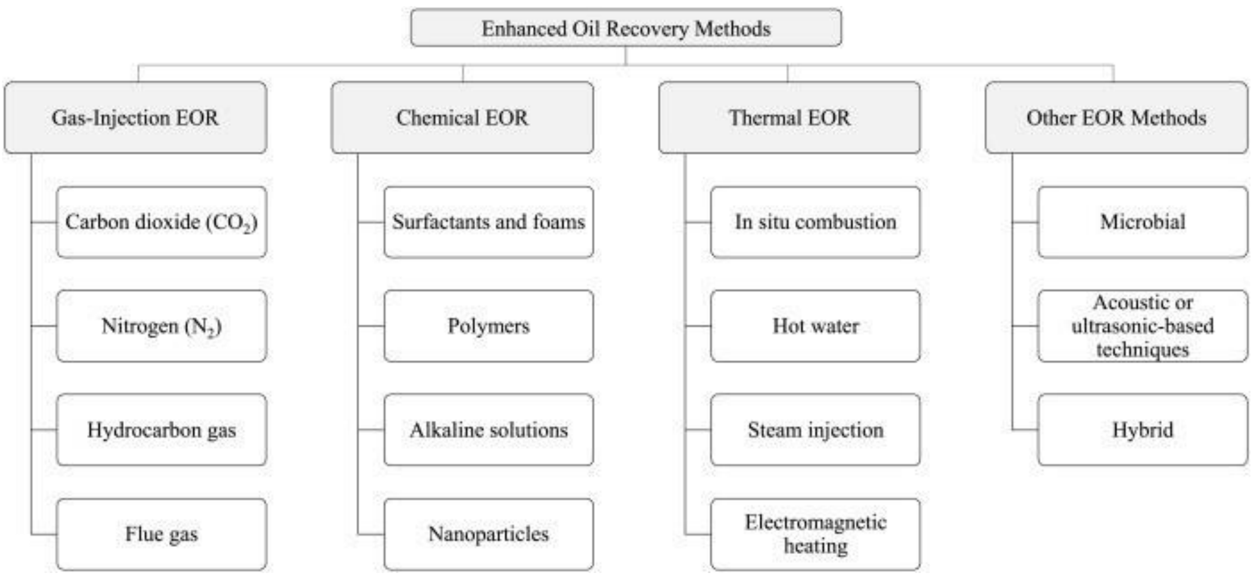


Figure2: Main methods of EOR

The Major classifications of oil recovery are:

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Primary recovery- Oil recovery through pressure decline

Secondary recovery- •Oil recuperation by injection of aqueous fluid or gas

Tertiary recovery- Oil recuperation using confined oil's mobilization

This study focuses on developing a natural surfactant from seed oil, characterizing it and testing it for its emulsification property, foaming ability and static adsorption. Therefore this research aims.

The objective of this study is:

To extract bio surfactant from Karanja seed oil

To determine its composition using FTIR and SEM-EDX analysis

To test the static adsorption tendencies of the surfactant at different concentrations of salt

To test the surfactant for its foaming ability and emulsion stability

The current study is focused on formulating biodegradable surfactant that is ecologically friendly for use as chemical additive during enhanced oil recovery (EOR) application process. The objective is to formulate a bio surfactant from Linseed oil (Linumusitatissimum)via transesterification and sulfonation process while the effectiveness of the formulated natural surfactant will be evaluated by observing the boundary forces (surface and interfacial tensions) that exist between the immobile hydrocarbon and the injected natural surfactant solution produced, examining the potential of the produced bio-surfactant to induce a change in wettability at the rock-brine interface and by evaluating the ability of the surfactant to form stable emulsion at various concentrations.

Hence, the scope of this research is limited to characterizing the properties of the surfactant, testing its ability to achieve ultra-low interfacial tension, its adsorption tendencies and its ability to form stable foam and emulsions.

**Background on Surfatant Flooding**

Surfactant flooding is a technique for improving recovery of oil in which a watery fluid is pumped to wash the reserve while surfactant, a surface acting chemical, is also added. The surfactant in the injected fluid improves the mobility of the oil by reducing the interfacial tension between the injected fluid and the oil and by changing the reservoir rock's wettability.

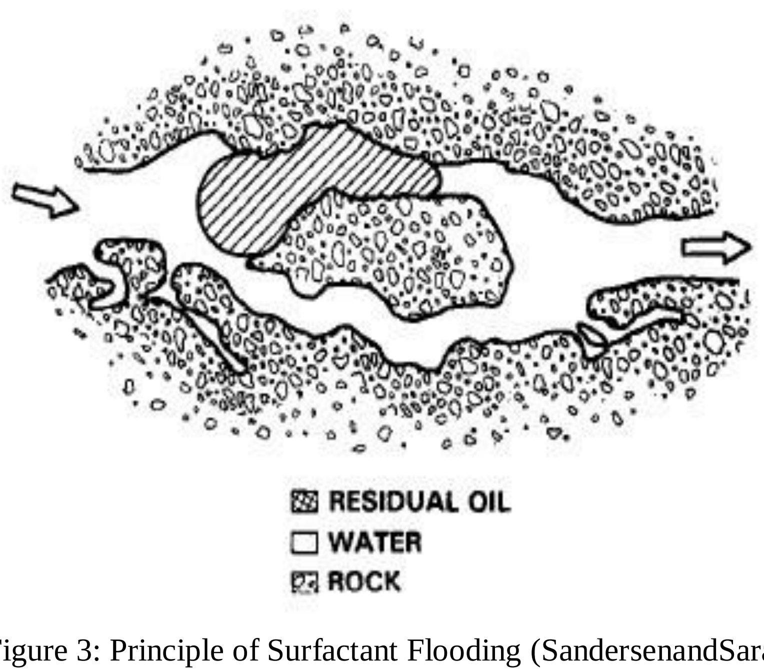


Figure 3: Principle of Surfactant Flooding (SandersenandSaraBülow, 2012)

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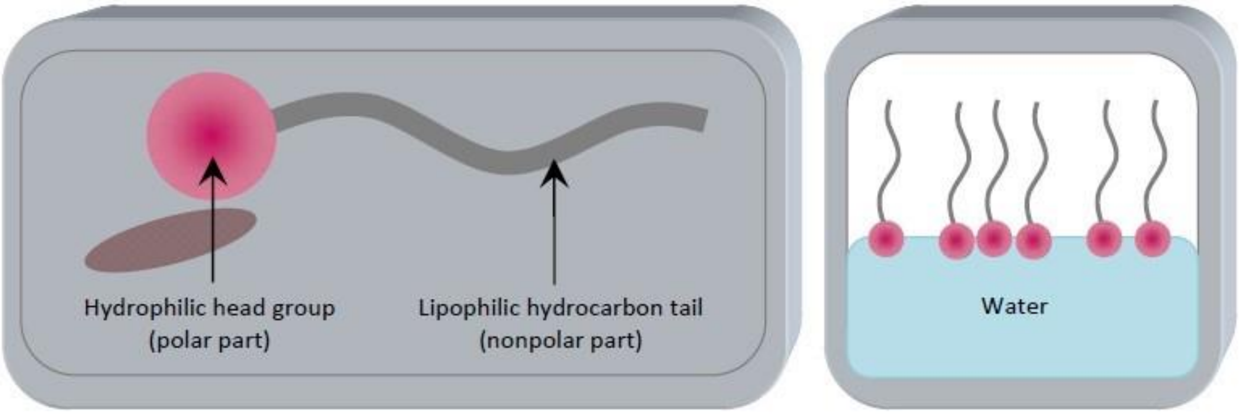


Figure 4: Surfactant Molecule and its orientation in water (Sandersen, n.d.)

Because oil is non-polar and water is polar, water and oil are immiscible. In order to recover oil from the reservoir, we inject a surfactant solution comprising surface-acting agents to lower the interfacial tension between the displacing fluid and the trapped oil in the reservoir. in order to recover oil from the reservoir. This causes the trapped oil and the injected fluid to move as one thereby improving the recovery efficiency. Co-surfactants can also be added to the surfactant solution to augment its efficiency in terms of pressure, temperature and salinity. The mechanism behind surfactant flooding is to increase displacement efficiency at the pore-scale level by:

- Reducing interfacial tension- Water cannot displace oil on its own. This is because the capillary forces that are trapping the oil in the reservoir are very high. Capillary forces are measured by capillary number as shown below:

- $N_c =^{\mu . v}$……………………….Equation 1

$\sigma.Cos\theta$

Where μ= viscosity of displacing fluid, v= velocity of displacing fluid, ***σ***= interfacial tension between oil and displacing fluid and **Ɵ**= contact angle. An increase in capillary number, $N_c$, would cause an increase in oil recovery. From the capillary number equation, this can be done by either increasing viscosity, increasing velocity or reducing interfacial tension. Of all three methods, reducing the interfacial tension is the best and this is done with the aid of surfactant. Surfactants are amphiphilic in nature, meaning that they are hydrophilic (water soluble) and hydrophobic (non-polar).

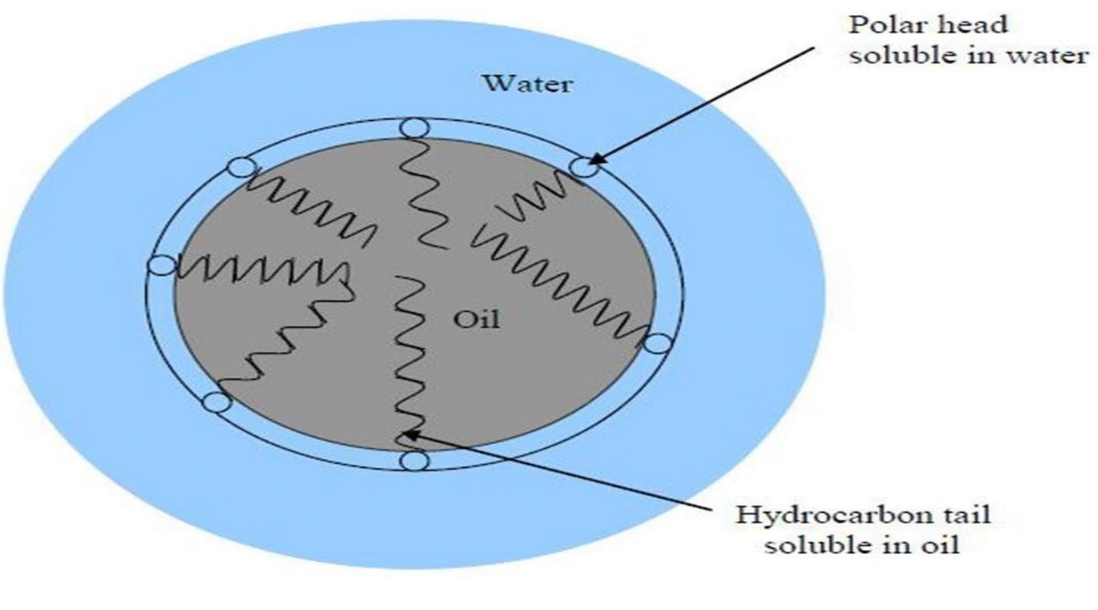


Figure 5: Surfactant adsorption at the oil/water interface (Gbadamosi et al., 2019)

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Changing the reservoir rock's wettability- Wettability, which governs the placement, distribution, and movement of fluid in a reserve, is the capacity of a fluid to adhere to the surface of a solid while other non-mixing fluids are present. Reservoirs can be classified as being oil-wet, water-wet, or mixed-condition wet. The wettability of the rock is assessed using the contact angle, or the point at which water and oil interact with the reservoir rock. When the temperature is greater than 90 degrees and lower than 90 degrees, the substance is moist with oil. If the reservoir rock's wettability were switched from oil to water, the capillary force in the reservoir would be decreased and oil recovery would be enhanced.


Figure 6: Improved permeability due to wettability alteration (Gbadamosi et al., 2019)

Table 1: Types of Surfactant flooding(Sandersen, n.d.)

| **Types of Surfactant Flooding** | **Method** | **Comment** |
|---|---|---|
| Micelle/Polymer Flooding | The reservoir is injected with a mixture of surfactant, cosurfactant, alcohol, brine, and oil. | It produces a displacement efficiency of nearly 100% in the laboratory |
| Microemulsion Flooding | To reduce interfacial tension, a mixture of surfactant, cosurfactant, alcohol, and brine is pumped into the reservoir. | It can be modified to perform in conditions where polymer or alkali would not work like high temperature and high salinity areas |
| Alkaline/Surfactant/Polymer Flooding | Alkaline chemicals are added to reduce interfacial tension at lower surfactant concentration | Less cost of chemicals due to the fact that lower surfactant concentration is involved |

A good surfactant should be; effective at low concentrations, thermally stable at reservoir temperatures, tolerant to reservoir salinity, able to reduce interfacial tension under reservoir condition. Also, surfactants must be able to enhance foam generation, reduceinterfacial tension, wettability alteration, emulsification. Microemulsions refers to a clear, thermodynamically stable isotropic mixture usually made of oil, water and surfactant.

## METHODOLOGY

The methodology and apparatus utilized in the laboratory experiment for synthesizing a natural surfactant, characterizing it, and assessing its usefulness in enhanced oil recovery are discussed here.

**Materials utilized include the following:**

Linseed oil- It is gotten from the dried, ripened seeds of flax plant (LinumUsitatissium). It has an unusually large amount of linolenic acid, and has long carbon chains.

Sodium hydroxide- This was used in the trans-esterification process of making the surfactant.

Phosphoric acid- This was used in the trans-esterification process of making the surfactant.

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Distilled water- This was used in the trans-esterification process of making the surfactant.

Tetrachloromethane- This was used in the synthesis of the surfactant.

Chlorosulfuric acid- This was used in the synthesis of the surfactant.

Sodium bicarbonate- This was used in the synthesis of the surfactant.

Sodium chloride- This was used in preparing salt solutions.

Deionized water- This was used to prepare solutions.

EQUIPMENTS utilized include: Three-necked flask, Separating funnel, Magnetic rod, Reflux tube, Magnetic stirrer, Beaker, Heating mantle, Weighing, Spatula, Test tubes, Measuring cylinder, Retort stand, Conductivity meter, Rotary evaporator, Fume Cupboard.

Table 2: Procedure for Surfactant Preparation and Testing

| **Analytical Procedure** | **Process** |
|---|---|
| Trans-esterification of Linseed Oil | Transesterification is the process which involves the reaction of an ester with alcohol in order to replace the alkoxy group. The presence of a catalyst increases the reaction rate and yield. Excess alcohol is used to shift equilibrium to the product side because the reaction is reversible. |
| Fourier Transform Infrared Spectroscopy (FTIR) Analysis | FTIR offers quantitative and qualitative studies for materials that are both organic and inorganic. |
| Scanning Electron Microscopy and Energy Dispersive X-Ray Analysis (SEMEDX) | It is also possible to obtain quantitative compositional data and elemental identification using an Energy Dispersive X-Ray Analyzer (EDX or EDA |
| Preparation of Different Surfactant Solutions | Further testing, various solutions of the surfactant were formed at different concentrations. |
| Physiochemical Properties of The Surfactant Solution | The 20 solutions were tested for their physiochemical properties using the CDS 107 pH, Conductivity, Total Dissolved Solids (TDS) and Salt meter |
| Foam Ability | The foam ability was done using Bartschtest to measure of the stability of foam. |
| Emulsion Stability | This was done using visual analysis |
| Static Adsorption | The surfactant's adsorption on the sandstone reservoir rock was determined using batch equilibrium testing, and fluctuations in surfactant concentration were determined using the conductivity technique. This method is based on comparing the surfactant concentration in the aqueous phase before and after adsorption to measure surfactant adsorption on the surface of solids like sandstone rocks. |

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# RESULTS AND DISCUSSION

## Physiochemical Properties of Linum Usitatissimum

Table 3: Physiochemical Properties of Linseed oil

| Properties | Mean value |
|---|---|
| Refractive index | 1.469 |
| Iodine value (g $I_2$/100g oil) | 177 |
| Saponification value (mg KOH/g oil) | 190 |
| Acid value (mg KOH/g oil) | 0.80 |
| Peroxide value (meq$O_2$/kg oil) | 0.95 |

Table 4: Fatty Acid Composition of Linseed oil

| Fatty Acid | Content (%) |
|---|---|
| Palmitic acid | 6.58 |
| Stearic acid | 4.43 |
| Oleic acid | 18.51 |
| Myristic acid | 0.05 |
| Linolenic acid | 53.21 |
| Linoleic acid | 17.25 |

## Physical Properties of Crude Oil

### Viscosity of crude oil

The viscosity of the oil was gotten using the Brookfield viscometer using a 6inch diameter spindle and rotating at various speed as shown in the results below:

Table 5: Viscosity of Crude oil at varying speeds

| Speed (rpm) | Viscosity (cp) | Torque (%) |
|---|---|---|
| 1.0 | 10000 | 1.0 |
| 5.0 | 6600 | 3.3 |
| 10 | 3800 | 3.8 |
| 12 | 3580 | 4.3 |
| 20 | 2750 | 5.5 |

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| | | |
|---|---|---|
| 30 | 2370 | 7.1 |
| 50 | 2220 | 11.1 |
| 60 | 2120 | 12.7 |
| 100 | 1970 | 19.7 |

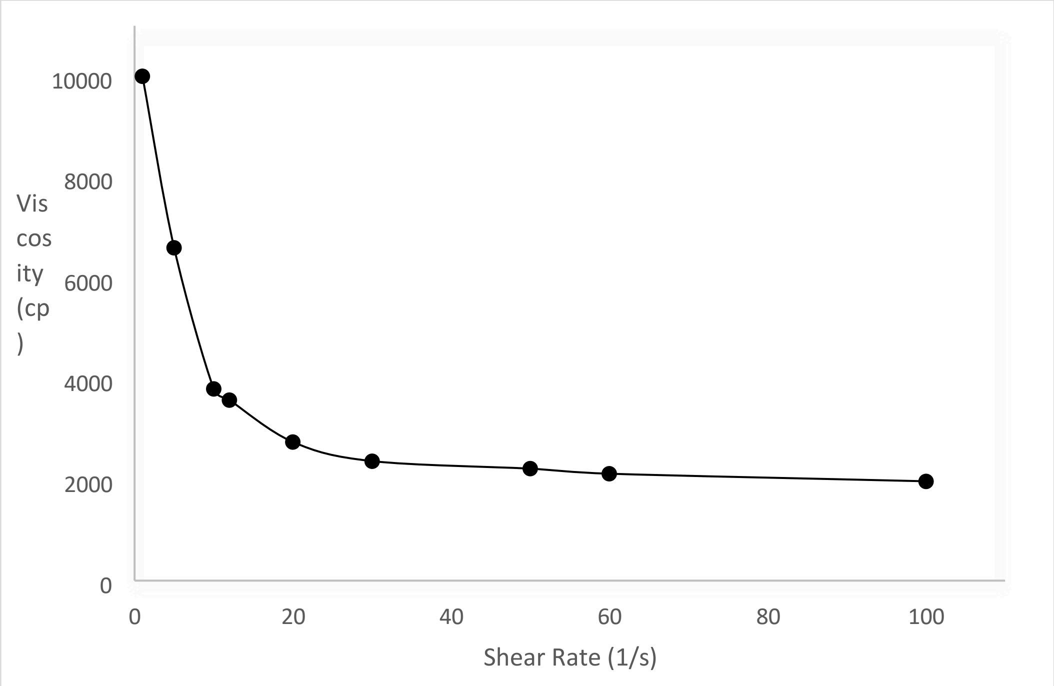


Figure 7: Plot of viscosity against Shear Rate

Density of Crude oil

The density of the crude oil was determined using a density bottle.

Weight of empty bottle= 32g

Weight of bottle + oil= 72g

Volume of bottle= 50ml

$mass$

$Density$ = Equation 6

$volume$

4.4= $\frac{(72-32)}{50}$=0.8g/ml

= $49.9 lb/ft^3$

= $800 kg/m^3$

Specific gravity of oil=$\frac{\rho oil}{}$…………….Equation 7

$pw$

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$= \frac{49.9}{62.4} = 0.8$

API= $\frac{141.5}{\rho oil}$ – 131.5……………. Equation 8

$= \frac{141.5}{0.8} - 131.5 = 45.$

**Characterization of the Surfactant**

FTIR Analysis

Figure 7 below shows the IR spectrum of the saponified surfactant synthesized from Linseed oil

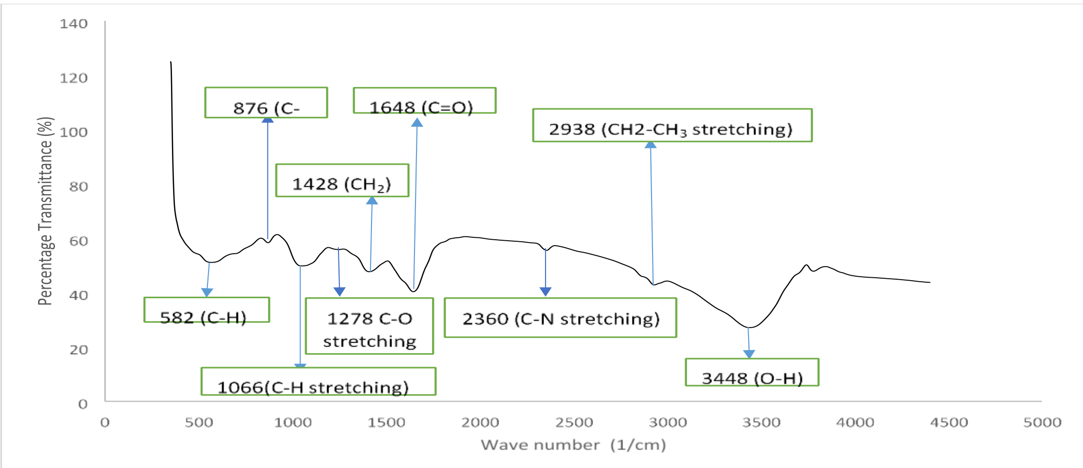


Figure 8: IR spectrum showing functional groups present in the surfactant

SEM-EDX Analysis

SEM-EDS analysis of Linseed oil surfactant was done to study surface morphology at varying magnifications as depicted in Figure 8.

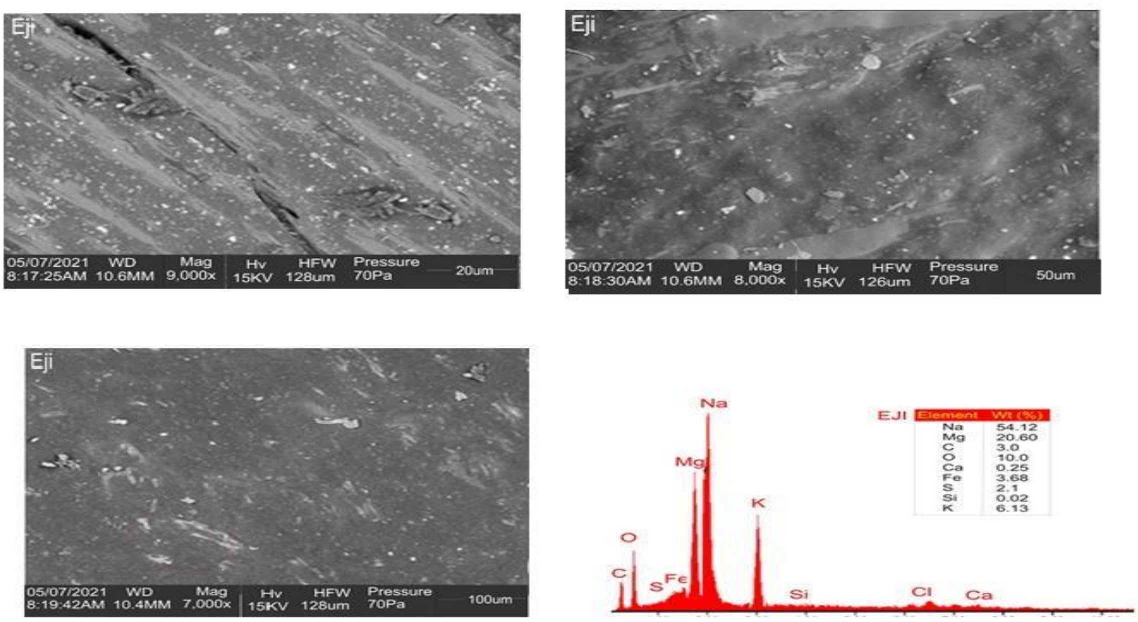


Figure 9: a) SEM image at 20µm b) SEM image at 50µm c) SEM image at 100µm d) EDS analysis

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**Physiochemical Properties of the Surfactant Solutions 0wt% Concentration**

Table 6: Physiochemical properties of surfactant solution with no salt

| Surfactant concentration (ppm) | PH | Conductivity (µs) | TDS (ppm) | Salt (ppm) |
|---|---|---|---|---|
| 500 | 4.08 | 52.2 | 37.7 | 20.6 |
| 1000 | 3.68 | 96.8 | 64.0 | 37.1 |
| 2000 | 3.47 | 149.7 | 100.9 | 62.0 |
| 4000 | 3.23 | 273 | 183.0 | 114.0 |
| 8000 | 2.96 | 525 | 346.0 | 231.0 |
| 12000 | 2.82 | 714 | 471.0 | 321.0 |

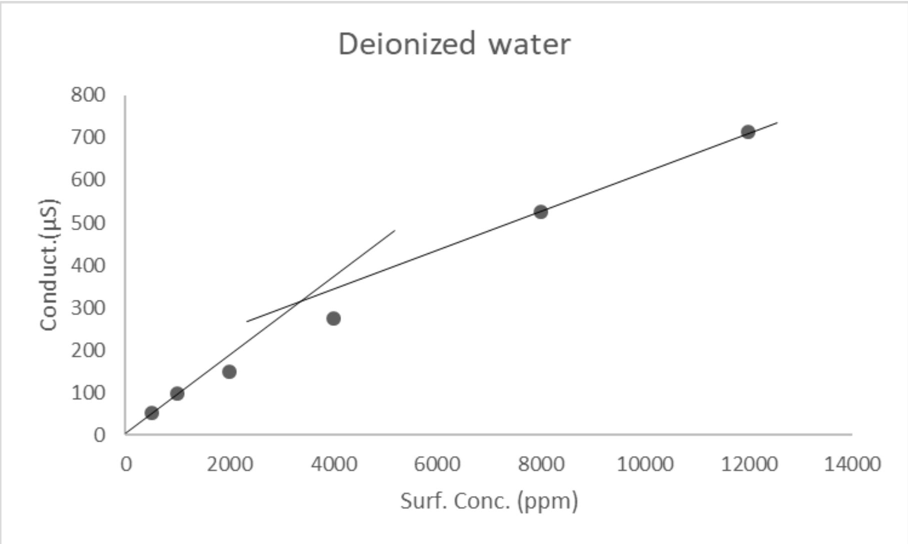


Figure 10: Graph of Conductivity against Concentration at 0 wt. % salt

**2wt% concentration**

Table 7: Physiochemical properties of surfactant at 2wt% concentration of NaCl

| Surfactant concentration (ppm) | PH | Conductivity (µs) | TDS (ppt) | Salt (ppt) |
|---|---|---|---|---|
| 500 | 4.08 | 31900 | 21.0 | 20.0 |
| 1000 | 3.68 | 32100 | 21.3 | 20.2 |
| 2000 | 3.47 | 32200 | 20.3 | 19.4 |
| 4000 | 3.23 | 32100 | 21.1 | 20.1 |
| 8000 | 2.96 | 32600 | 22.1 | 21.1 |
| 12000 | 2.82 | 33600 | 20.7 | 19.9 |

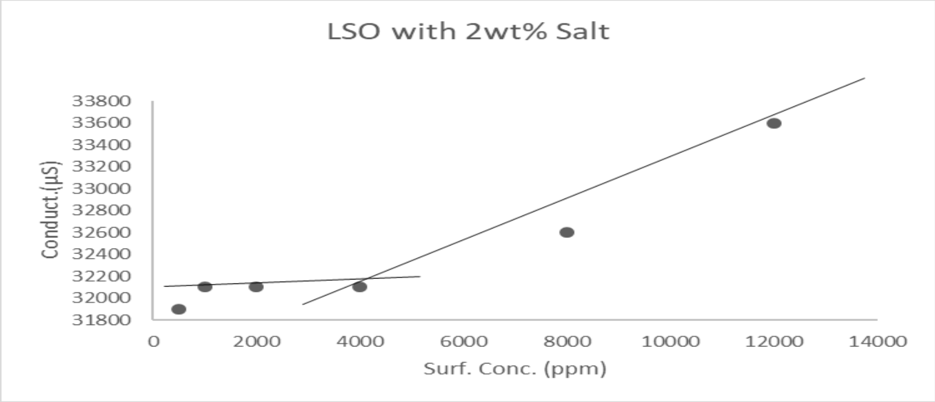


Figure 11: Plot of Conductivity against Concentration at 2wt% salt

**5wt% concentration**

Table 8: Physiochemical properties of surfactant solution at 5wt%

| Surfactant concentration (ppm) | PH | Conductivity (µs) | TDS (ppt) | Salt (ppt) |
|---|---|---|---|---|
| 500 | 4.08 | 71100 | 46.9 | 48.2 |
| 1000 | 3.68 | 60600 | 39.6 | 40.3 |
| 2000 | 3.47 | 69700 | 46.1 | 46.7 |
| 4000 | 3.23 | 71100 | 46.9 | 48.4 |
| 8000 | 2.96 | 68800 | 45.4 | 46.2 |
| 12000 | 2.82 | 70500 | 46.5 | 47.9 |

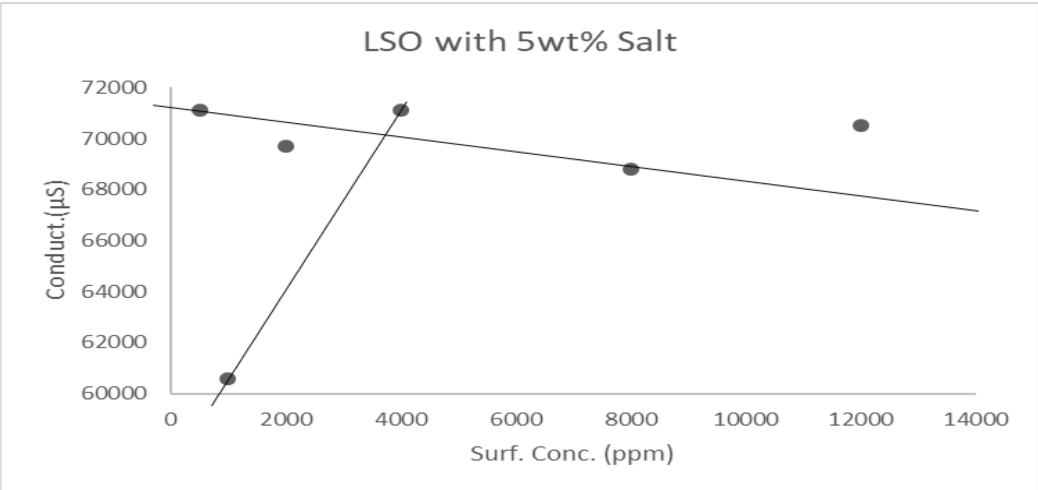


Figure 12: Plot of Conductivity against concentration at 5wt%

**Determination of Optimal salinity for various surfactant concentrations**

The salinity that allows for the formation of a microemulsion with equimolar IFTs between the microemulsion phase and the surplus oil or additional water cycle is known as the optimal salinity. The smallest IFT that can be achieved in laboratory testing for IFT readings, according to more study, is the IFT recorded at the optimum salinity (Hirasaki et al., 2011) The optimal amount of salt for boosting oil recovery is one that causes a buildup of biosurfactant at the oil-water interface, which is typically the circumstance that yields extremely low IFT (Fernandes et al., 2016).

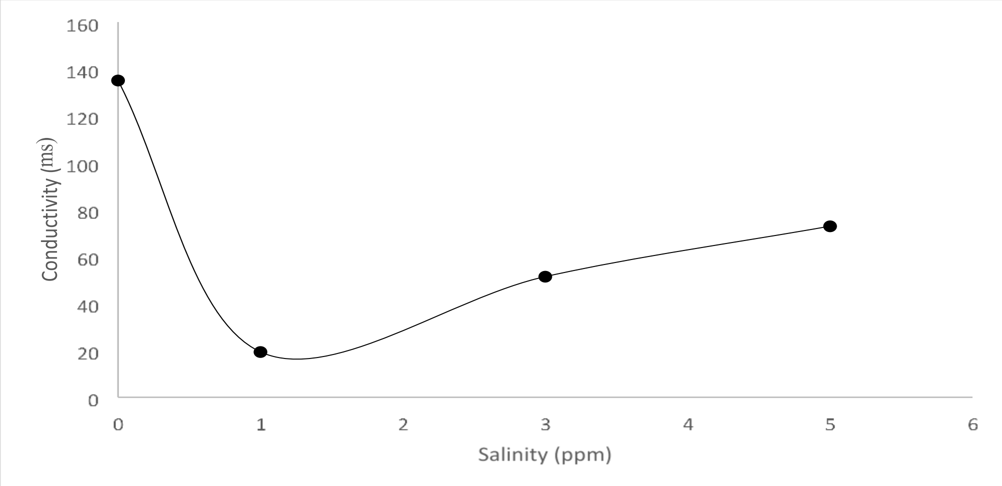


Figure 13: Conductivity against salinity at 500ppm

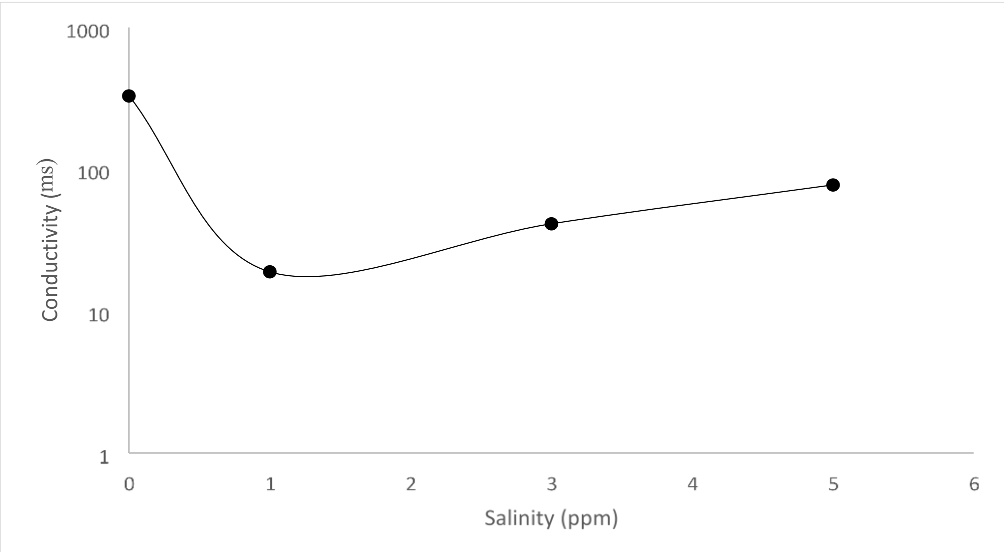


Figure 14: Conductivity against Salinity at 1000ppm

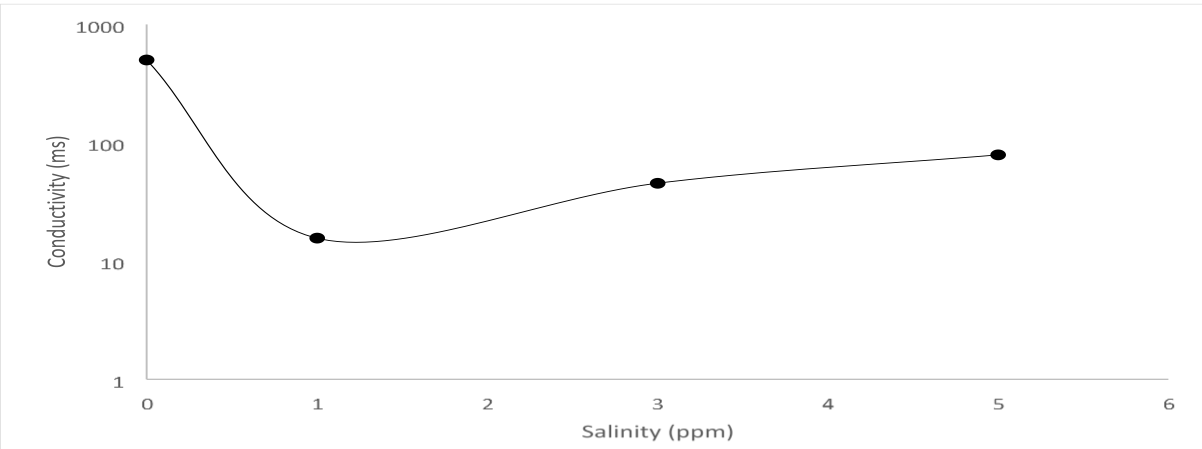


Figure 15: Conductivity against Salinity at 2000ppm

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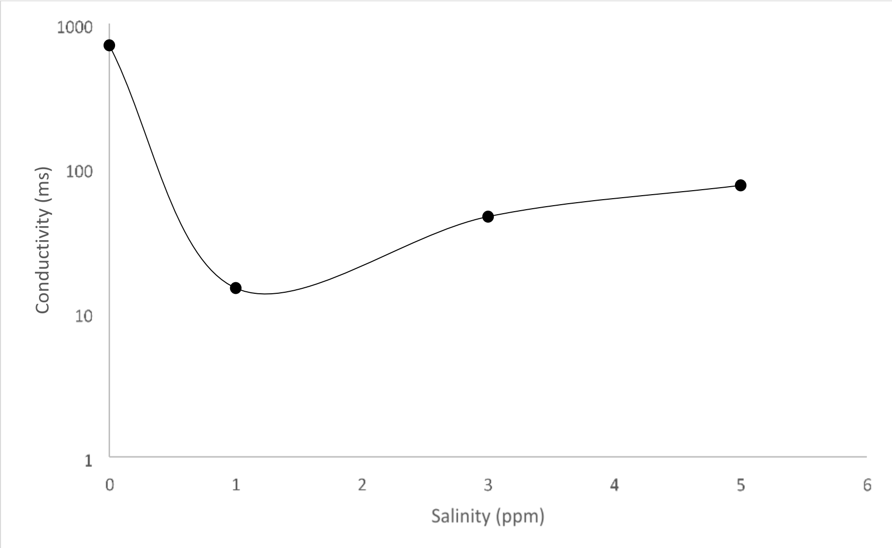


Figure 16: Conductivity against Salinity at 4000ppm

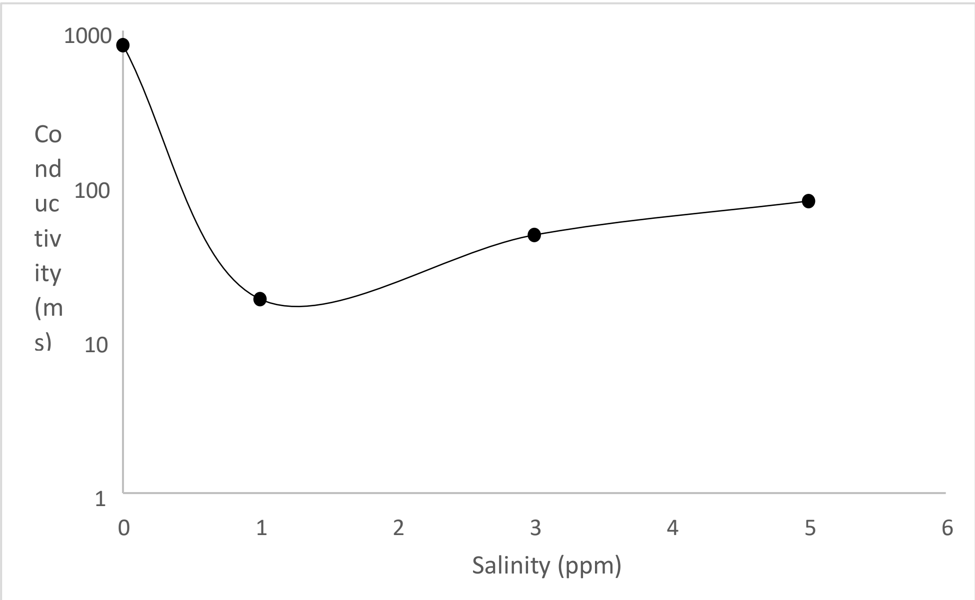


Figure 17: Conductivity against Salinity at 8000ppm

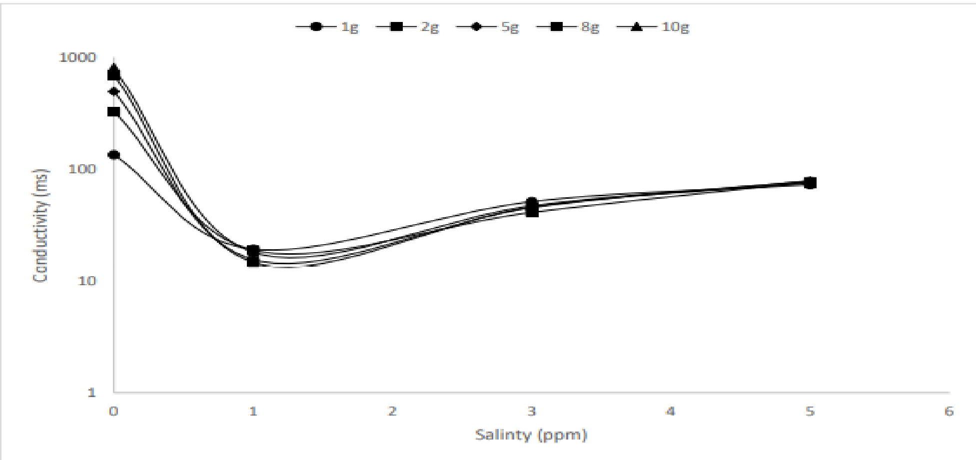


Figure 18: Optimal salinity

**Foam Ability**

Table 9: Foam Decay over time for 0wt% Surfactant solution

| Time(min) | 500 (PPM) | 1000 (PPM) | 2000 (PPM) | 4000 (PPM) | 8000 (PPM) | 12000 (PPM) |
|---|---|---|---|---|---|---|
| 0 | 8.5 | 12 | 10.00 | 19 | 21 | 18 |
| 2 | 3.5 | 2.5 | 1 | 0.5 | 1 | 1 |
| 4 | 3 | 1 | 0.5 | 0.5 | 0.5 | 0.8 |
| 6 | 3 | 0.5 | 0.4 | 0.3 | 0.4 | 0.8 |
| 8 | 3 | 0.4 | 0.3 | 0.2 | 0 | 0.5 |
| 10 | 3 | 0.3 | 0 | 0 | 0 | 0 |
| 12 | 3 | 0.2 | 0 | 0 | 0 | 0 |
| 14 | 3 | 0 | 0 | 0 | 0 | 0 |
| 16 | 2 | 0 | 0 | 0 | 0 | 0 |
| 18 | 2 | 0 | 0 | 0 | 0 | 0 |
| 20 | 2 | 0 | 0 | 0 | 0 | 0 |
| 22 | 1.8 | 0 | 0 | 0 | 0 | 0 |
| 24 | 1.5 | 0 | 0 | 0 | 0 | 0 |
| 26 | 1.5 | 0 | 0 | 0 | 0 | 0 |
| 28 | 1.5 | 0 | 0 | 0 | 0 | 0 |
| 30 | 1.5 | 0 | 0 | 0 | 0 | 0 |
| 32 | 1.5 | 0 | 0 | 0 | 0 | 0 |
| 34 | 1 | 0 | 0 | 0 | 0 | 0 |
| 36 | 1 | 0 | 0 | 0 | 0 | 0 |
| 38 | 1 | 0 | 0 | 0 | 0 | 0 |
| 40 | 1 | 0 | 0 | 0 | 0 | 0 |
| 42 | 1 | 0 | 0 | 0 | 0 | 0 |
| 44 | 0.8 | 0 | 0 | 0 | 0 | 0 |
| 46 | 0.5 | 0 | 0 | 0 | 0 | 0 |
| 48 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 0 | 0 | 0 | 0 | 0 | 0 |
| 52 | 0 | 0 | 0 | 0 | 0 | 0 |
| 54 | 0 | 0 | 0 | 0 | 0 | 0 |

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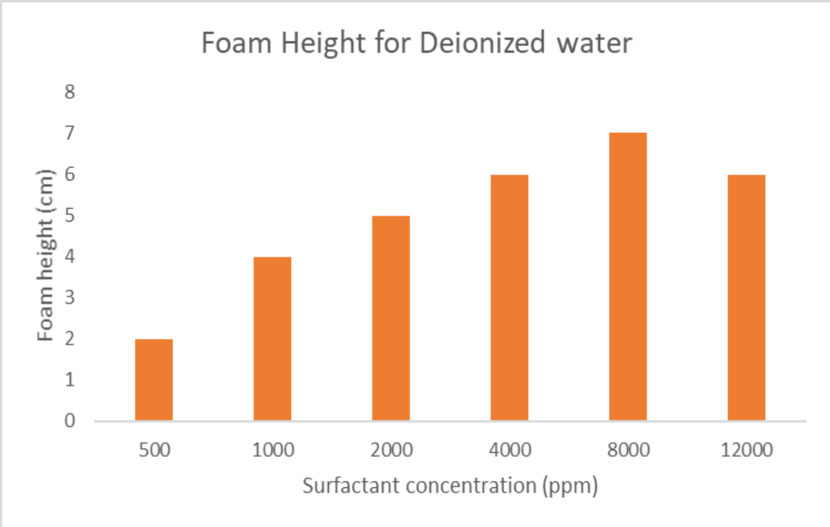


Figure 19: Initial foam height for different surfactant solutions in deionized water, 0wt%

## EMULSION STABILITY

Table 10: Emulsion Stability at 2day interval for 0wt% salt

| | 24hrs | | | | 48hrs | | | |
|---|---|---|---|---|---|---|---|---|
| **Concentration (ppm)** | **Emulsion height** | **Total height** | **Microemulsion Type** | **Emulsifying index (%)** | **Emulsion height** | **Total height** | **Microemulsion Type** | **Emulsifying index (%)** |
| 500 | - | 30 | No emulsion | 0 | - | 30 | No emulsion | 0 |
| 1000 | 14 | 30 | Type 1 | 46.7 | 14 | 30 | Type 1 | 46.7 |
| 2000 | 12 | 30 | Type 1 | 36.7 | 12 | 30 | Type 1 | 36.7 |
| 4000 | 13 | 30 | Type 1 | 43.3 | 13 | 30 | Type 1 | 43.3 |
| 8000 | 17 | 30 | Type 1 | 60 | 17 | 30 | Type 1 | 60 |
| 12000 | 15 | 30 | Type 1 | 50 | 15 | 30 | Type 1 | 50 |

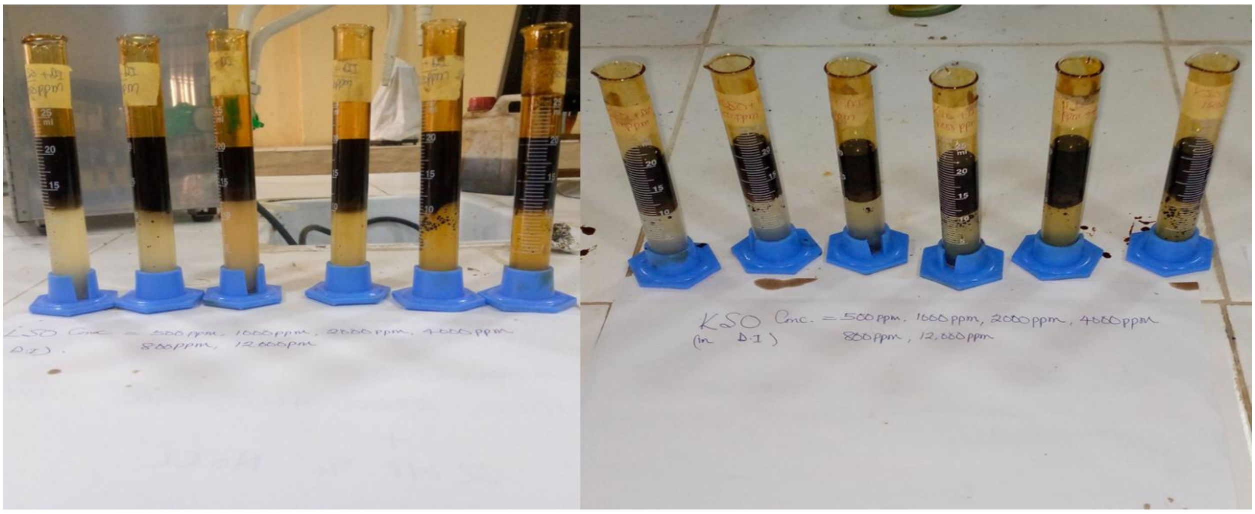

Figure 20: a) Emulsion stability after 24hrs b) Emulsion stability after 48hrs

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**Static Adsorption**

Table 11: Conductivity after 12days for 0wt% Nacl

| Day | Cond.(µS) @500ppm | Cond.(µS) @1000ppm | Cond.(µS) @2000ppm | Cond.(µS) @4000ppm | Cond.(µS) @8000ppm | Cond.(µS) @12000ppm |
|---|---|---|---|---|---|---|
| 0 | 342 | 470 | 410 | 525 | 800 | 1525 |
| 1 | 320 | 400 | 380 | 502 | 700 | 1182 |
| 2 | 300 | 300 | 340 | 446 | 600 | 1000 |
| 3 | 290 | 270 | 300 | 400 | 560 | 950 |
| 4 | 270 | 250 | 280 | 374 | 520 | 900 |
| 5 | 250 | 225 | 265 | 345 | 480 | 820 |
| 6 | 220 | 205 | 247 | 310 | 450 | 725 |
| 7 | 190 | 180 | 233 | 280 | 400 | 600 |
| 8 | 170 | 150 | 205 | 240 | 340 | 520 |
| 9 | 150 | 130 | 180 | 210 | 300 | 460 |
| 10 | 140 | 110 | 148 | 190 | 250 | 400 |
| 11 | 135 | 105 | 120 | 178 | 217 | 335 |
| 12 | 132 | 103 | 115 | 174.6 | 218 | 329 |

Table 12: Conductivity after 12days for 2wt% Nacl

| Day | Cond.(µS) @500ppm | Cond.(µS) @1000ppm | Cond.(µS) @2000ppm | Cond.(µS) @4000ppm | Cond.(µS) @8000ppm | Cond.(µS) @12000ppm |
|---|---|---|---|---|---|---|
| 0 | 34050 | 40290 | 35620 | 34300 | 36680 | 38680 |
| 1 | 33700 | 34850 | 33120 | 33950 | 35330 | 35000 |
| 2 | 33500 | 34600 | 32200 | 32700 | 34600 | 34100 |
| 3 | 33100 | 34600 | 32100 | 32600 | 34500 | 34000 |
| 4 | 31500 | 32000 | 30120 | 31100 | 32350 | 32100 |
| 5 | 26120 | 26900 | 24800 | 25700 | 26800 | 27000 |
| 6 | 21800 | 22000 | 20000 | 21200 | 22200 | 22100 |
| 7 | 19060 | 18440 | 16560 | 18200 | 18950 | 18460 |
| 8 | 16850 | 16980 | 15200 | 15850 | 17550 | 17000 |
| 9 | 15650 | 16680 | 14200 | 14430 | 16270 | 15880 |
| 10 | 14000 | 15030 | 12750 | 13310 | 14820 | 14000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 11 | 10000 | 10000 | 8400 | 9500 | 10450 | 10700 |
| 12 | 9600 | 9850 | 8000 | 9050 | 10200 | 10200 |

Table 13: Conductivity after 12days for 5wt% Nacl

| Day | Cond.(µS) @500ppm | Cond.(µS) @1000ppm | Cond.(µS) @2000ppm | Cond.(µS) @4000ppm | Cond.(µS) @8000ppm | Cond.(µS) @12000ppm |
|---|---|---|---|---|---|---|
| 0 | 78350 | 76670 | 98450 | 84740 | 83990 | 88700 |
| 1 | 76810 | 74200 | 94640 | 80150 | 80400 | 86200 |
| 2 | 72200 | 68700 | 85200 | 73800 | 74600 | 76300 |
| 3 | 70500 | 65500 | 80000 | 71500 | 71800 | 74000 |
| 4 | 69200 | 64100 | 76300 | 68600 | 69300 | 70500 |
| 5 | 54300 | 48200 | 53100 | 51300 | 52300 | 51600 |
| 6 | 45700 | 40200 | 43200 | 41900 | 44700 | 41100 |
| 7 | 40300 | 35900 | 38300 | 36100 | 40000 | 35400 |
| 8 | 35900 | 30600 | 33700 | 30100 | 34600 | 30100 |
| 9 | 33200 | 26400 | 29500 | 26800 | 30600 | 25800 |
| 10 | 27800 | 21800 | 25300 | 21600 | 25700 | 20600 |
| 11 | 20900 | 15410 | 21300 | 15230 | 18530 | 15310 |
| 12 | 20700 | 14900 | 21000 | 15000 | 17200 | 15150 |

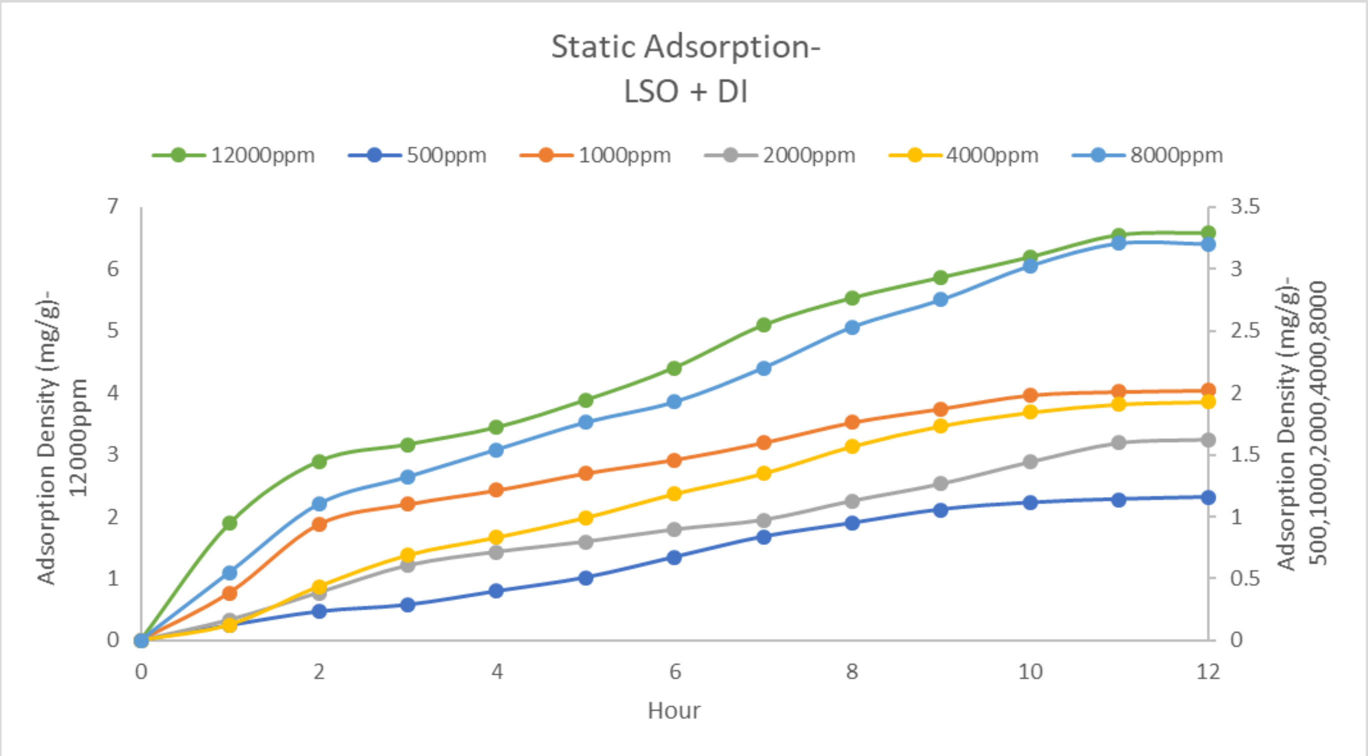


Figure 21: Adsorption density vs different surfactant concentration for 0wt%

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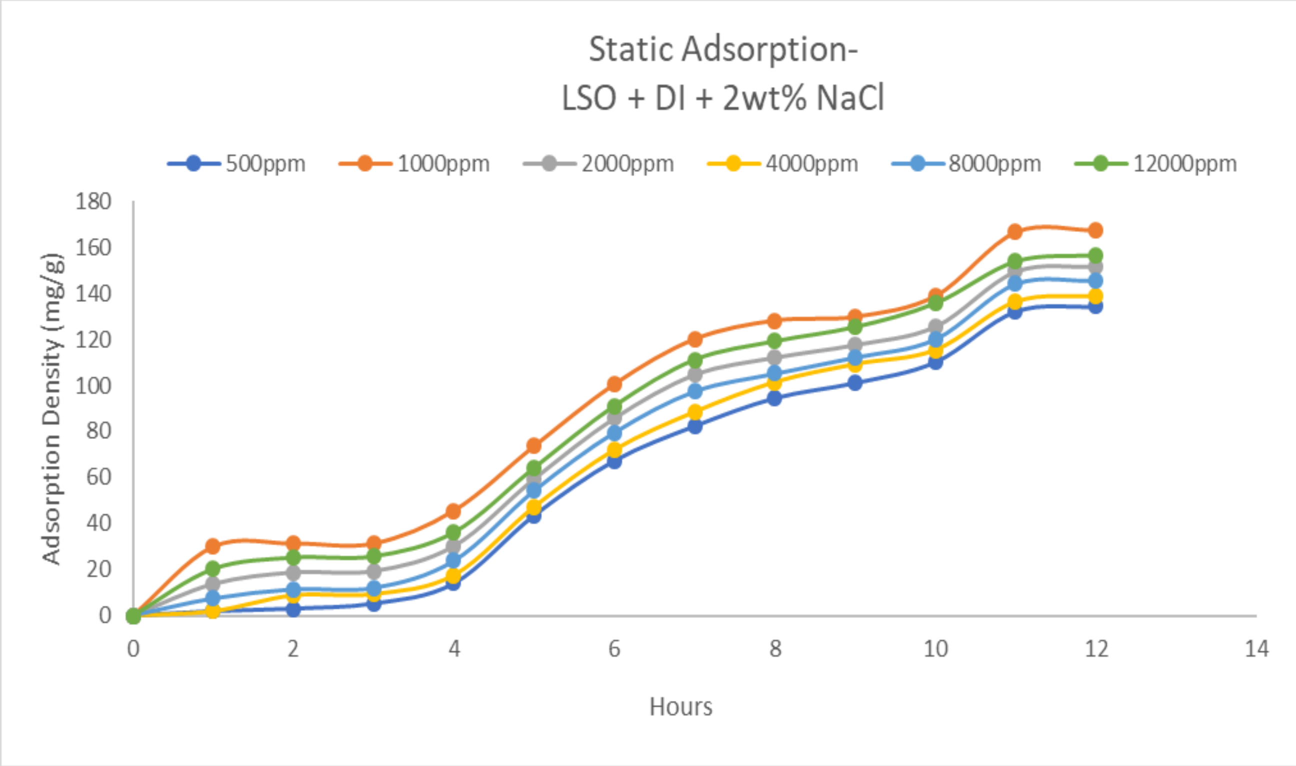


Figure 22: Adsorption density vs different surfactant concentration for 2wt%

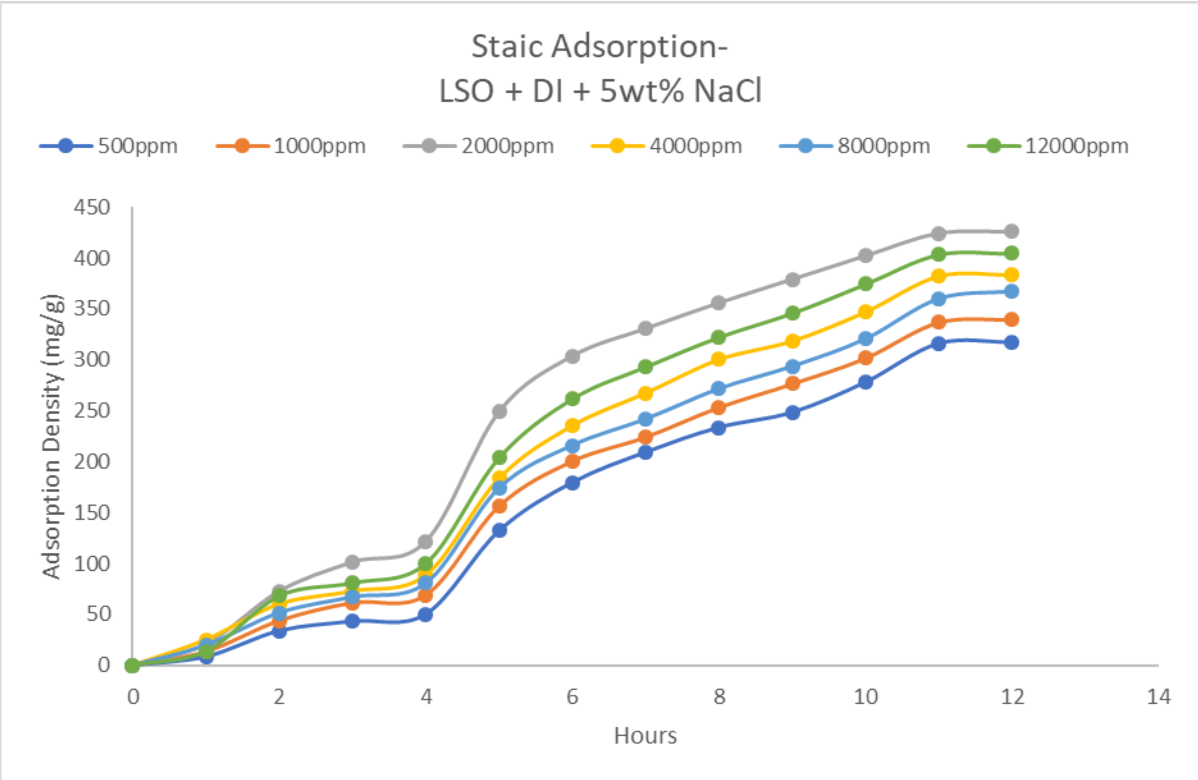


Figure 23: Adsorption density vs different surfactant concentration for 5wt%

## DISCUSSION

### Properties of crude oil

The decrease in viscosity as shear rate increases is characteristic of a non-Newtonian fluid and the API gravity of 45° and density of 800kg/m$^3$ falls within the range of light crude oil.

### Surfactant characterization

### Physiochemical properties of the surfactant

From the result gotten, it can be inferred that as the concentration of surfactant increased from 500ppm to 12000ppm in either the solutions with distilled water or the solutions with some amounts of NaCl, there was an increase in conductivity which is expected due to increasing ionic concentration. Increasing the amount of NaCl in a surfactant concentration caused a decrease in the optimal salinity and a corresponding decrease in interfacial tension of the concentration as seen in Figure 4-7, Figure 4-8, Figure 4-9, Figure 4-10 and Figure 4-11 until the optimum point was reached where there was an increase in IFT. It was observed that interfacial tension is lowest at the point of optimum salinity for each surfactant concentration (Saxena et al., 2019).

### Foam Ability and Stability

Surfactants are able to form stable foam because of their hydrophilic-hydrophobic nature. It was observed from Figure 4-13 that the initial foam height increased with increase in surfactant concentration with 12000ppm having the highest initial foam height. The higher the surfactant concentration, the more stable the foam.

Emulsion Stability

The emulsification index was derived to examine the synthetic biosurfactant's capacity to emulsify crude oil. The emulsification capacity increases with increasing EI. The EI of different surfactant solutions with crude oil ranges from 50 to 60 percent, which is consistent with the results obtained from sodium lauryl sulfate.

### Static Adsorption

According to the study's findings, the surfactant's ability to bind to the sandstone and accumulate there until it achieves CMC increases with surfactant concentration. Surfactant adsorption levels must be below 1 mg/g of rock for EOR procedures to be cost-effective (Kamal et al., 2017), which is in accordance with the adsorption level of the surfactant made from linseed oil.

## CONCLUSION AND RECOMMENDATIONS

### Conclusion

In this report, the synthesis of a surfactant from Linseed oil via trans-esterification was carried out and its application in enhanced oil recovery was studied and investigated. Different concentrations of the synthesized surfactant were individually mixed with different concentrations of deionized water plus wt% NaCl. Physiochemical tests were carried out on all the concentrations to establish their pH, Salt content, total dissolved content and conductivity. The Interfacial tension (IFT) between different surfactant concentration solutions diluted in deionized water plus wt% NaCl, and heavy crude oil was measured by the CSC-Du NUOY tensiometer. Performance evaluation tests of the synthesized surfactant/ deionized water and wt% NaCl /crude oil system were carried out namely, foaming ability, emulsion stability test and static adsorption tests. In conclusion:

The introduction of surfactants was found to have helped lower the interfacial tension (IFT) between heavy crude oil and the displacing fluid (deionized water plus wt% NaCl).

The ratio of interfacial tension to surfactant concentration and temperature rises. The created surfactant was able to reduce the IFT in systems including heavy crude oil, deionized water, and wt% NaCl, demonstrating its superior surfactant characteristics.

In the presence of NaCl, the surfactant/water/oil system creates an intermediate state microemulsion. The outcome shown that the microemulsion (ME) reduced as surfactant concentration values fell. The surfactants mostly constituted the Type I microemulsion phase of Winsor.

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