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The Importance of Microemulsion for the Surfactant Injection Process in Enhanced Oil Recovery

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Abstract

Microemulsion is the main parameter that determines the performance of a surfactant injection system. According to Myers, there are four main mechanisms in the enhanced oil recovery (EOR) surfactant injection process, namely interface tension between oil and surfactant, emulsification, decreased interfacial tension and wettability. In the EOR process, the three-phase regions can be classified as type I, upper-phase emulsion, type II, lower-phase emulsion and type III, middle-phase microemulsion. In the middle-phase emulsion, some of the surfactant grains blend with part of the oil phase so that the interfacial tension in the area is reduced. The decrease in interface tension results in the oil being more mobile to produce. Thus, microemulsion is an important parameter in the enhanced oil recovery process.

Keywords: enhanced oil recovery, emulsion, middle-phase emulsion, microemulsion, surfactant

1. Introduction

The general oil production activity is categorized into three phases: primary, secondary and tertiary. The primary recovery is limited to activities that naturally cause hydrocarbon to rise toward the surface with artificial technology, such as a submersible pump. Secondary recovery is conducted by utilizing water and gas injections that fill lower layers of oil and drive them into the surface. In secondary recovery, the refineries are often found unable to produce although they possess relatively large saturation levels between 30% and 40% of their initial reserves. These oils are trapped inside the reservoir and are unable to move. This situation often happens because oil grains rest on the surface of rocks and produce high interface tension levels. Enhanced oil recovery (EOR) chemical injection is aimed at freeing these trapped oil grains in the reservoir. EOR is a tool to produce oil in the third phase, also known as tertiary recovery effort. At this stage, a lot of effort is made to improve oil production after primary recovery and secondary recovery efforts. The way to further increase oil production is through the tertiary recovery method or EOR. Although more expensive to employ on a field, EOR can increase production from a well to up to 75% recovery.

EOR is the main concentration of petroleum engineering that is related to higher level of oil recovery based on physics principles through different techniques utilization. A number of formulas are utilized to improve oil recovery that involves important parameters such as injection rate, oil production rate, movement efficiency, mobility, and reservoir characteristics and fluids [1]. EOR process is determined to enhance the ability of oil to move toward the well by injecting water, chemical compound or gas into the reservoir that would alter oil's physical nature. Its main goal is to produce optimum amount of oil after primary and secondary productions are implemented. EOR process includes thermal, chemical and miscible methods. EOR process is designed to recover the remaining amount of oil after primary and secondary recovery by enhancing oil movement and volumetric sweeping efficiency [2].

Chemical EOR is an efficient oil recovery technique to improve oil flow and to produce oil trapped in the reservoir. This EOR method is implemented by using chemical injection to improve oil recovery levels [3]. The implementation of this method is by inserting a long molecular chain, such as polymer or surfactant, through injection into the reservoir in order to improve waterflooding efficiency or to improve surfactant effectiveness, which acts as a sweeper that lowers interface tension level that prevents oil from flowing toward the reservoir.

EOR process that involves injecting into the reservoir is aimed at forming middle-phase emulsion in order to lower interfacial tension level. This condition will allow oil grains to move easily and to flow into production wells to be produced.

2. Methodology

Observation on mixed-phase behavior of reservoir fluid and injection fluid can be categorized as lower-phase emulsion, microemulsion (middle-phase emulsion), upper-phase emulsion and sediment. Mixed phase that forms microemulsion represents miscible displacement condition. Meanwhile, mixed phase that forms upper or lower phase represents immiscible displacement condition. Emulsion is a system of two phases, where one of the liquids is dispersed in another liquid in the form of small droplets [4].

Emulsion can be defined as droplet dispersion from one liquid to another one that is immiscible. These droplets, also known as the dispersed phase, drop into a second liquid called the continuous phase. To create a stable emulsion, the droplets should be kept in dispersed condition by adding surfactant or co-surfactant [5, 6]. Generally, in terms of the phase, two microemulsion types are often produced, namely water in oil (w/o) and oil in water (o/w). The two types of microemulsions imply that w/o emulsion describes that water acts as the dispersed phase, while w/o emulsion clearly implies that oil is the dispersed phase. Based on the size of the dispersed droplets, microemulsion and macroemulsion can be specifically identified, 5–100 nm for microemulsion and >100 nm for macroemulsion. The other difference is that microemulsions are often categorized as a thermodynamically stable system, while macroemulsions are the kinetically stable ones. The colors of the two types are also different, transparent with low viscosity on microemulsions and opaque with high viscosity on macroemulsions. The unique characteristics make the utilization of these two types of emulsions a vital part of the study.

Emulsions from immiscible mixtures are often results of stable and even ones. Salinity, temperature, oil type and surfactant used are the most determining factors that drive the mixture to become stable. There are two types of emulsions based on the type of liquid that serves as an internal or external phase, namely:

- a. Emulsion type O/W (oil in water) is an emulsion consisting of oil droplets dispersed into water, oil as the internal phase and water as the external phase.
- b. Emulsion type W/O (water in oil) is an emulsion consisting of water droplets dispersed into the oil, water as the internal phase and oil as the external phase.

According to [7] microemulsion phase, behavior is very much complex and highly depends on several determining parameters, which include the type and concentration of surfactant, co-solvent, hydrocarbon, salinity of salt water, temperature and low level of pressure. There is no formula to describe simple microemulsion. Based on that, phase behavior on a microemulsion system must be experimentally observed. Generally, to present microemulsion-phase behavior, ternary diagram is used as the main tool, although the pressure and temperature are considered at a constant level. Ternary diagram is a highly benefitting tool due to its ability to simultaneously and wholly represent phase composition and the relative numbers. **Figure 1** shows the schemes of ternary diagram. On ternary diagram, water, oil and surfactant are represented on a triangle-shaped model, with each concentration level represented on units of molar, mass or volume. The system can exist in a phase where the solubility ratio of water and oil is high. **Figure 1** shows ternary diagram of microemulsion system [9]. **Figure 1** also shows that there are two areas where oil can be recovered; in single-phase area that is dominantly filled with oil and in a number of parts or multiphase that includes a mixture of a number of phases, oil, water and surfactant.

Surfactant is a molecule that usually contains both head and tail poles [10]. Surfactant molecule arranges itself based on a number of intermolecular and intramolecular forces. For example, when surfactant is mixed with oil and water, surfactant is formed on oil and water interface, which leads to a thermodynamically benefitting condition [11]. Oil in water emulsion can happen in two ways: where oil molecule is incorporated in a micelle or in between surfactant tail, or it can also be incorporated in the hydrophobic core, as illustrated in **Figure 2**.

Microemulsion (multiphase part) is divided into three categories, namely lower phase (l), upper phase (u) and middle phase (m), in equilibrium with oil phase, water phase or both. Microemulsion, as observed by Winsor [13], shows the phenomenon when water (or brine) and organic compound (both mixed and single compounds) can be mixed with a suitable number on surfactant equilibrium system. There are four main types of equilibrium systems: type I, II, III and IV, as shown in the following **Figure 3**.

Figure 3 shows that Winsor I is a dominant emulsion formed in the water phase, where surfactant is mostly mixed with water. Winsor II is an emulsion formed of oil phase, where surfactant is mostly mixed with oil. Meanwhile, Winsor III is a

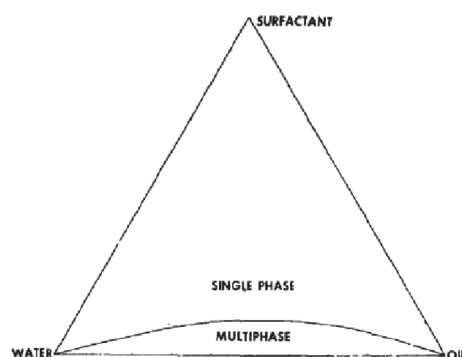


Figure 1.
 Ternary diagram of micro-emulsion system [8].

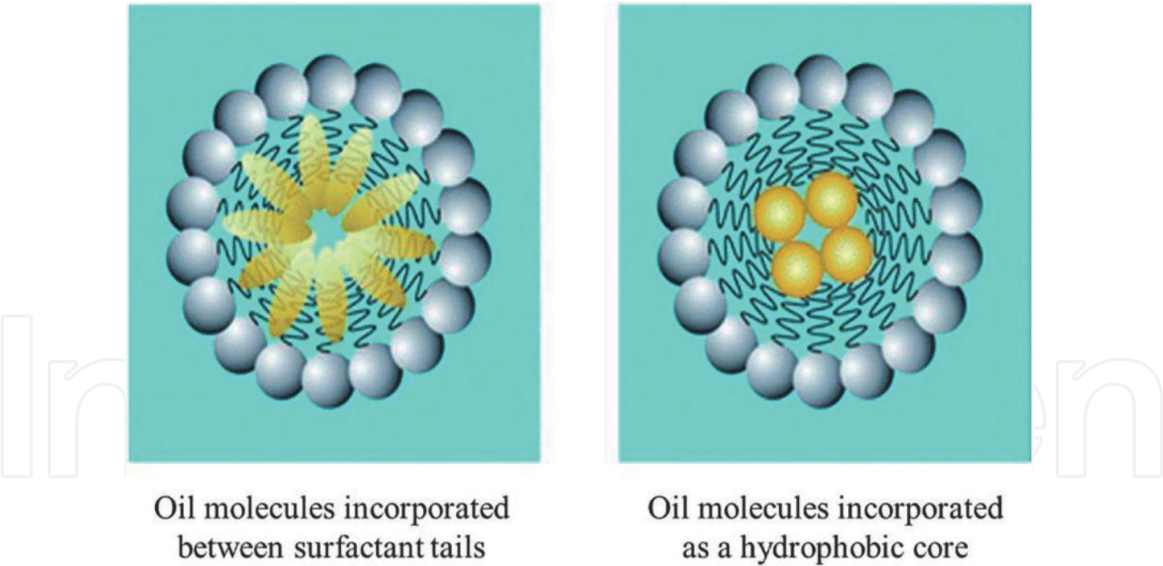


Figure 2.
Surfactant molecule and oil molecule [12].

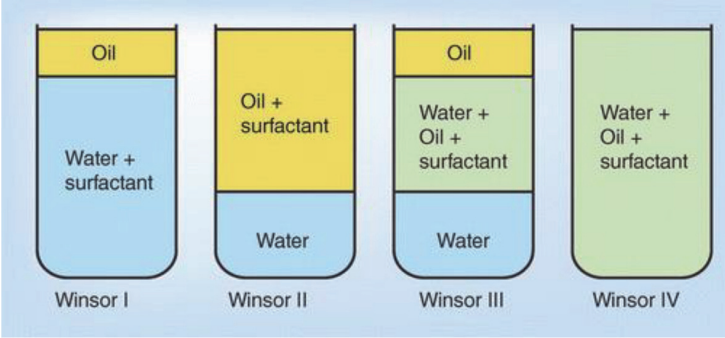


Figure 3.
Development of microemulsion [14].

middle-phase emulsion where surfactant is mixed with both oil and water. Winsor III is the expected result on surfactant injection mechanism. Microemulsion phase formed during this level of balance is known as the middle-phase emulsion. In this condition, organic and water phases are located in the phase that holds all three components [13, 14]. In Winsor I and II, the tie horizontal line should be at a similar level. Behavior formed by Winsor III can be seen in **Figure 4**; the polyphonic area includes three zones that are surrounded by the other two zones. Meanwhile, the

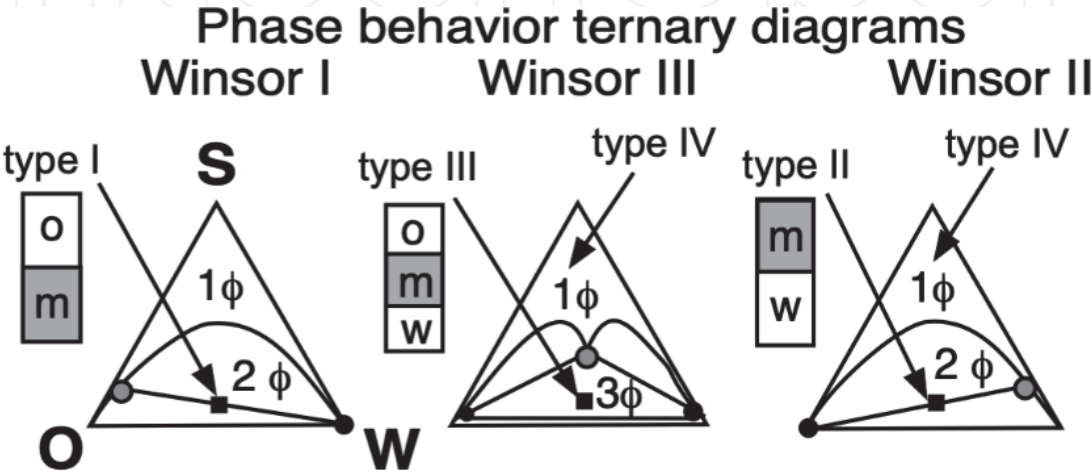


Figure 4.
Winsor I, II, III diagrams [15].

composition system of the phase is formed in three different phase zones, namely surfactant middle phase emulsion, and the other two phases, which basically consist of liquid and oil. This phase is also known as the middle phase because it is formed between oil and water due to its medium-density level. These three-phase systems are extensively studied in order to achieve better oil recovery level [15]. Based on that, Winsor III emulsion is preferred to improve oil recovery. The microemulsion formation mechanism of the three emulsion types of equilibrium phases can be seen in the following figures.

Single-phase area is located in the zone with high level of surfactant concentration, the three-phase area in the middle zone, and the lobe of two phases are located at the upper right and left areas of the triangle. There is a third two-phase area located on the lower surfactant under the three-phase area. Winsor III ternary phase behavior itself is included in areas close to saltwater/oil axis limited by the triangle. Winsor III is also known as Winsor type III.

Between type I and II, a horizontal tie line with similar surfactant condition between the two phases is expected. The type III phase behavior can be seen in **Figure 2**. The polyphonic area includes three types of zones, which are surrounded by two-phase zones. The composition system is actually located in the three-phase zones, which are categorized into surfactant-rich area (shaded area), oil and water. This phase is called as middle phase due to its location, which is in the middle of oil and water. Due to its accurate identification, the system is studied in an extensive manner in order to achieve better oil recovery level [1]. Based on that, to improve oil recovery level, type III emulsion is preferred (**Figure 5**). The type of O/W emulsion shown in **Figure 5** can be seen in general system microemulsion in **Figure 6**, where this microemulsion will release oil trapped in the rock grains as shown in **Figure 7**.

In microemulsion system, there is a rapid exchange of individual components between different types of environments and also a consistently fluctuated interface film. In microemulsion, there are two main phases that highly depend on its composition, which are the droplet phase and the bi-continual phase [19]. Droplet phase occurs in high concentration water; microemulsion contains oil droplets that are covered by the interface layer, which consists of co-surfactant part and freely dispersed surfactant in continuous phase, which is the water phase and forms o/w microemulsion. However, when water concentration is limited or lower, reverse situation occurs where water droplets get dispersed in oil and form w/o

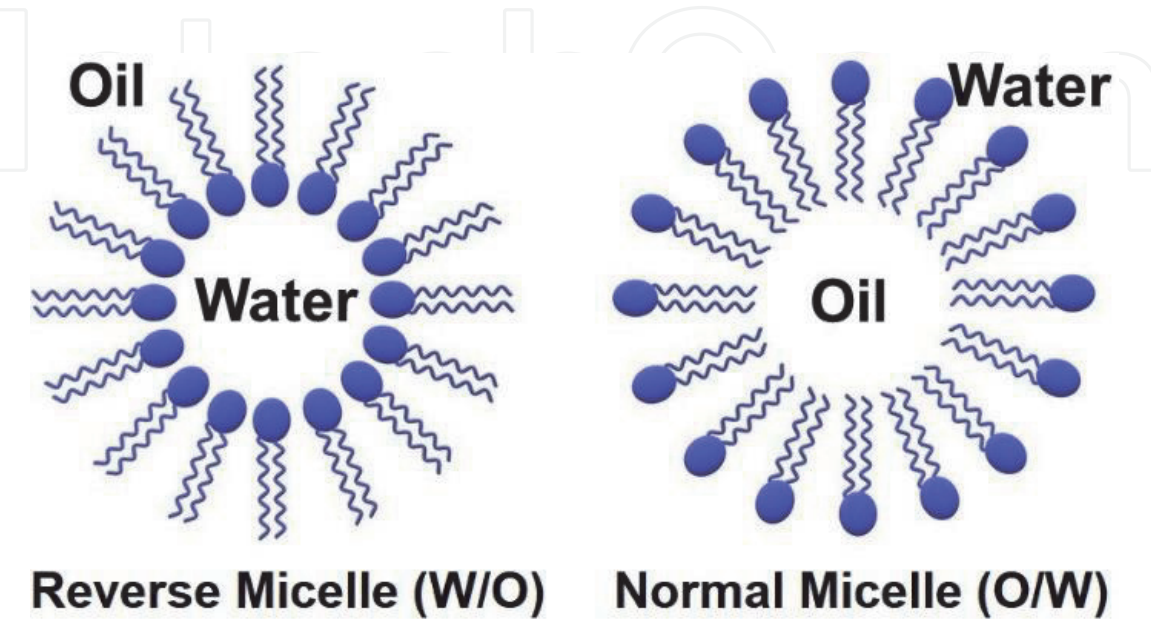


Figure 5.
Microemulsion formation mechanisms [16].

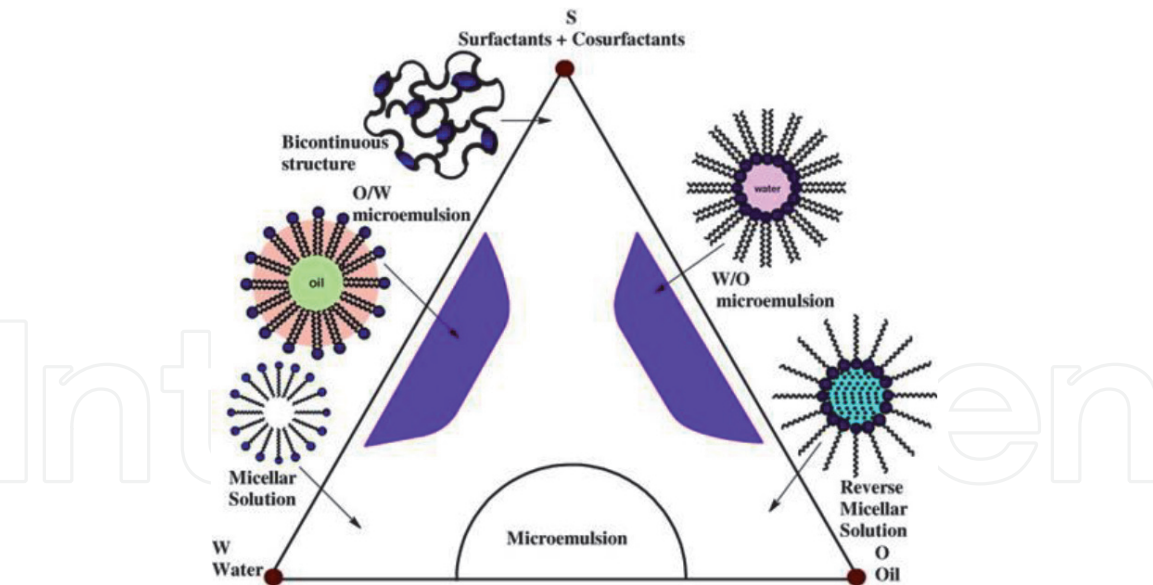


Figure 6. Microemulsion systems of oil (o), water (w) and surfactant + co-surfactant (S) [17].

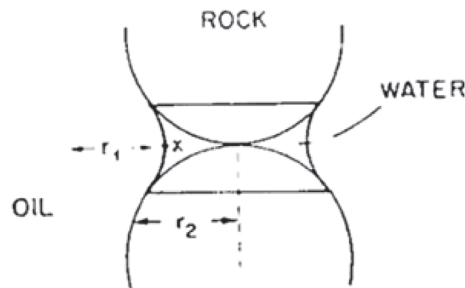


Figure 7. Water trapped between two grains of sand on water-wet reservoir [18].

microemulsion [20]. Meanwhile for bi-continual phase, the transition is more stable than o/w to w/o microemulsion alteration system by changing the amounts of oil and water. The area formed in the middle possesses more or less similar fraction of water and oil. Generally, it contains bi-continual or thin structures where the two phases continually fluctuate until they almost reach zero [21, 22].

With the surfactants, water and oil mixed, emulsification, which can reduce the water-oil interfacial tension, occurs, so the capillary pressure in the pore narrowing area decreases. Because the capillary pressure is reduced, the resistance to oil flow will also be reduced and the oil will move more easily to be produced. Capillary pressure (P_c) is defined as the difference in pressure that exists between the surfaces of two immiscible fluids (liquid-liquid or liquid-gas) as a result of the interface between them. The pressure difference between these two fluids is the pressure difference between the “non-wetting phase” (P_{nw}) fluid and the “wetting phase” (P_w) fluid. In general, reservoirs are water-wet, so water tends to stick to the rock surface, while oil lies between the water phases. The character of oil-wet in reservoir rock conditions is not expected to occur because it will cause the amount of oil left in the reservoir rock when produced to be greater than water-wet. A liquid is said to wet a solid if the adhesion stress is positive ($\theta < 90^\circ$), which means the rock is water-wet, whereas if the water does not wet the solid, then the adhesion stress is negative ($\theta > 90^\circ$), meaning the rock is oil-wet. This wettability has an important role in the behavior of the reservoir because it will cause capillary pressure, which will provide an impetus so that oil or gas can move. In the reservoir, water is usually the wetting phase, while oil and gas are the non-wetting or non-wetting phases.

Capillary pressure in pored rocks depends on the size of pores and the type of fluid. Quantitatively, the relationship can be formulated as follows:

$$P_c = P_o - P_w = \sigma \left(\frac{1}{r_1} + \frac{1}{r_2} \right) \tag{1}$$

- P_c = capillary pressure (pressure unit)
- σ = interfacial tension
- r_1 & r_2 = curve radius on interface area
- P_o & P_w = pressure on oil and water phases

Capillary number theory is considered to be the basic theory in chemical injection in the EOR process. The basic mechanism of chemical flooding in EOR can be summarized into mobility control based on increasing sweep efficiency and based on capillary number theory, which increases displacement efficiency. In surfactant injection, changes in wettability and imbibition will occur in some cores that have heterogeneity at the pore scale. The heterogeneity in question is the difference in wettability; if the difference is greater, the imbibition will be more visible [23]. These factors affect the displacement efficiency (E_d), in addition to the capillary number (N_c) and the emulsion effect that occurs when surfactant injection. Emulsion will change the behavior of the permeability and wettability phase so that imbibition will occur.

For the purposes of exploration and exploitation of petroleum, water-wet formations are easier to perform oil recovery. This is because the water-wet formation has a high oil saturation, which means that water wets and fills the smallest pores in the rock grains and the oil is above the water so that it is easier for oil to move and spill because there is no adhesion force to the surface of the rock. This situation allows the increase in oil recovery in formations with sandstone reservoirs by injection of water into the formation so that it can increase the volume of water and encourage oil to come out and be produced. Carbonate reservoirs, which are oil-wet, require EOR by chemical injection with the aim of changing the chemical structure of the rock surface so that oil no longer wets the rock surface.

The application of the concept of wettability to reservoir rocks can be seen in the following description. The wettability of rock is influenced by the chemical composition of its constituents. So the concept of chemical element bonds greatly affects the wettability of a rock surface against water or oil. Wettability classification based on rock lithology is shown in the following table (**Table 1**).

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Lithology	Wettability
Sandstone	Neutral-wet—water-wet
Clay	Neutral-wet
Carbonate	Neutral-wet—oil-wet

Table 1.
Wettability classification based on its lithology [24].

Wettability is one of the important parameters that affect the distribution of fluid in the reservoir and has a great influence on the spontaneous imbibition process. Wettability is defined as the ability of a fluid phase to wet certain solid surfaces while also facing another immiscible fluid [25]. The fluid is called as wetting phase and the other one is called the non-wetting phase. Wettability is a vital concept in oil recovery process because of its significant impact toward distribution ability, location determination and level of oil and water movements in the reservoir. In a water-wet system, water is expected to penetrate and stay inside narrow pores and drive oil out of the pore in the form of droplets. The opposite condition occurs in the oil-wet reservoir. This wettability can be determined based on the measurement results of the angle of contact; if it is from 0° to 75° , it is defined as water-wet, while if the angle is at 105° – 180° , it is defined as oil-wet, which makes angle range of 75° – 105° as neutral-wet system [26].

Capillary pressure is a pressure difference that occurs on interface of two unmixed fluids, where one fluid wets the surface of rock more than the other.

IFT also influences capillary pressure and will influence fluid distribution and flow. The ratio between viscosity and capillary forces is represented by capillary number (N_c) in the following formula:

$$N_c = (v\mu)/(\sigma) = (\text{viscous forces})/(\text{capillary forces}) \quad (2)$$

where:

v = average speed of fluid in pores (ft/D)

μ = viscosity of driving fluid (cP)

σ = interfacial tension system between water and oil (dyne/cm)

Surfactants can lower the IFT of oil-water, which results in the increase of N_c . IFT also acts as a guidance for miscibility; high IFT indicates immiscible fluid and low IFT indicates miscible fluid. The clear difference of low and ultralow IFT on surfactant flooding is detected on its emulsification approach. However, both w/o or o/w emulsions are formed on pored media, specifically on the angle of contact, in the form of droplets [27]. The contact angle observed during unmixed movement is not mixed in pored media, is arranged by equilibrium of capillary and viscosity forces, and escalates as the number of capillary increases. On surfactant injection with low IFT level in water-wet reservoir, the capillary number is inadequate to increase contact angle at a significant level, which creates a state where oil remains on non-wetting phase and leads to o/w emulsion formation (**Figure 1a**). On surfactant injection with ultralow IFT in water-wet reservoir, the high number of capillaries increases the angle of contact by more than 90° (**Figure 1c**) and creates w/o emulsion instead of o/w emulsion during movement (**Figure 1d**). The formation of a thick w/o emulsion on surfactant inundation with ultralow IFT leads to increased pressures and swiping efficiency, which eventually create an effective and improved crude oil production.

Surfactant injection is used to significantly decrease capillary forces in order to be able to mobilize the remaining oil after water injection. As the surfactant is injected into the reservoir, the tail of the surfactant will interact with oil residual; meanwhile, the head will interact with brine, which leads to lower IFT level [28]. Low IFT in the reservoir will eventually lead to reduced flow resistance and increased oil mobilization. Selection of the right surfactant is an important factor that causes reduced IFT and helps in the recovery of 10–20% of the original oil reserve.

The formation of microemulsions in surfactant injection in chemical flooding is very important to create effective injection. Microemulsion can be produced both through surfactant-oil mixing and surfactant injection to create in situ microemulsion.

A homogeneous mixture of oil and water while surfactant is present will increase oil movement in the reservoir. The effect will be lower IFT between oil and water, which leads to lower capillary pressure and mobilizes oil residual [29]. Under normal conditions, the reservoir is water-wet, so water tends to stick to the rock surface, while oil lies between the water phases. This is a normal condition where oil can flow by itself to be produced to the surface. In the case of tertiary recovery conditions, where oil is trapped in rock pores and cannot move on its own, in general the reservoir is oil-wet. In an oil-wet system, oil occupies a narrow pore and is present as a film on the pore wall, while water is present as water droplets in the middle of the pore. In this condition, the so-called oil droplets stick to the pore walls. To release the oil attached to the pore wall, a surfactant is needed, which functions to reduce the interfacial tension between the oil grains on the pore wall. In an oil-wet reservoir, oil residual stays inside rock pores, which makes it difficult to be mobilized except with high level of energy release. Surfactants act as an altering agent to change the wettability into water-wet [30]. The nature of SLS surfactant as an o/w emulsification allows it to convert oil-wet into water-wet.

Wettability is an important factor in EOR. After the wettability change occurs, the detachment energy is significantly reduced, making it easier to mobilize the remaining oil. Wettability is an important factor that determines the pattern of oil-water transfer in porous media. "Wettability" is a term to describe the relative adhesion of two fluids to a solid surface. In porous media filled with two or more immiscible fluids, wettability is a measurement of which fluid can wet (spread or adhere to) the surface. In a water-wet system (wet water), rocks filled with oil and water, water occupies the smallest pores and wets most of the surface in the larger pores. In areas that have high oil saturation, the oil is held above the wet water and spread on the surface. If the rock surface tends to be water-wet and the rock is saturated with oil, water fills the smallest pores, displacing oil when water enters the system. If the rock surface tends to be oil-wet, it is saturated with water; oil enters and wets the smallest pores in place of water. A rock saturated with oil means water-wet (wet water), and vice versa if the rock is saturated with water means oil-wet. By lowering the oil/water interfacial tension and changing the wettability from oil-wet to a water-wet condition, the recovery rate of the remaining oil can be increased successfully. The combined effect of wettability-IFT shows a better potential for EOR, compared to the reduction in interfacial tension alone under oil-wet conditions [31].

3. Results and Discussion

In this research, we utilized SLS surfactant synthesized from bagasse. SLS surfactant is anionic, which makes it popular in surfactant injection processes. The function is to drive middle-phase emulsion and lower IFT level of oil so that it can be mobilized and produced [28, 32]. Lignosulfonate is a derivative of lignin that contains hydrophilic groups, namely sulfonates group, hydroxyl alcohol, phenyl hydroxyl and hydrophobic groups [33]. That is the reason why this type of surfactant is categorized as anionic.

The phase behavior test was carried out to see changes in behavior from the condition of the crude oil sample, before and after being mixed with surfactant. The phase test was carried out in 2 mL of SLS surfactant mixed with 2 mL of crude oil sample in a 5 mL test tube. After entering the two types of fluid, the tubes are shaken slowly. The phase behavior test was carried out for 21 days at a constant temperature in the oven. In **Figure 8A**, there is still a clear boundary between the surfactant at the bottom and crude oil at the top. After being shaken slowly, in **Figure 8B** it can be seen that there is a mixture between the surfactant part and the

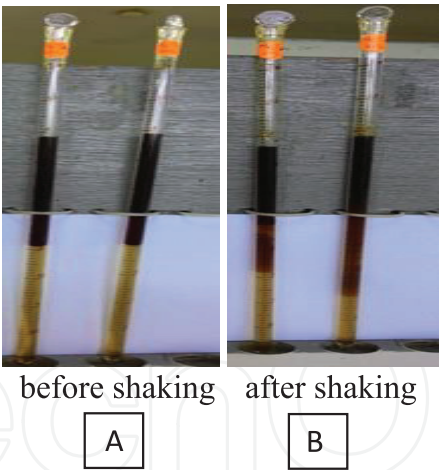


Figure 8.
Phase behavior test before and after shake.

crude oil part. This is referred to as a microemulsion or middle-phase emulsion, because of the mixing that occurs at the boundary between the surfactant and crude oil. **Figure 8B** is the Winsor III phenomenon, as expressed in the microemulsion formation mechanism [14, 16]. The following figures picture phase behavior test before and after shaking.

The spontaneous emulsification shows that oil grains can be mixed with surfactant grains. Emulsion between sugarcane bagasse SLS surfactant and light oil shows the existence of a system that includes two liquid phases dispersed as small grains (**Figure 9**). The emulsion that forms in the middle of the pipette has shown the occurrence of Winsor III emulsion.

The phase behavior test results of a number of samples show that sugarcane bagasse SLS surfactant is able to form microemulsion with crude oil, as seen in the following figure.

Figure 10a shows phase behavior test on light crude oil sample; **Figure 10b** shows phase behavior test result on intermediate crude oil; and **Figure 10c** shows phase behavior test result on heavy crude oil samples. Sugarcane bagasse SLS surfactant will only form emulsion with light crude oil. The emulsion is not formed at all on intermediate and heavy crude oil samples. The phase behavior test result on light crude oil is continued with a number of different formation water salinity compositions (**Table 2**).

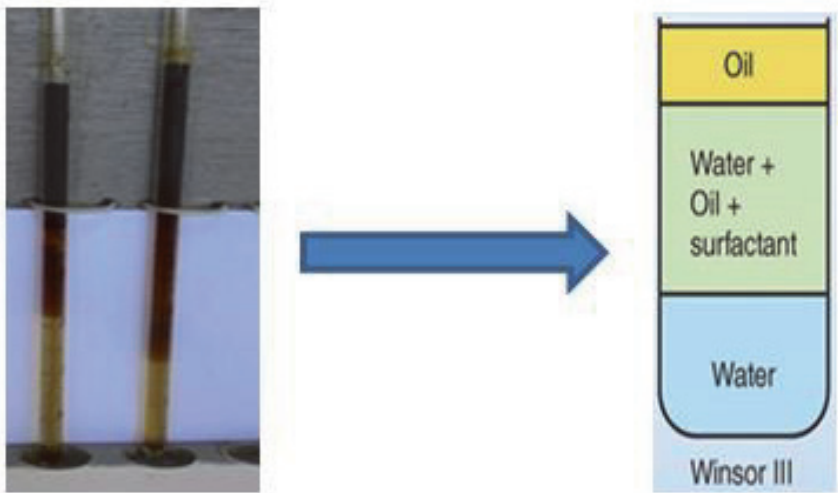


Figure 9.
Microemulsion formation (middle-phase emulsion).

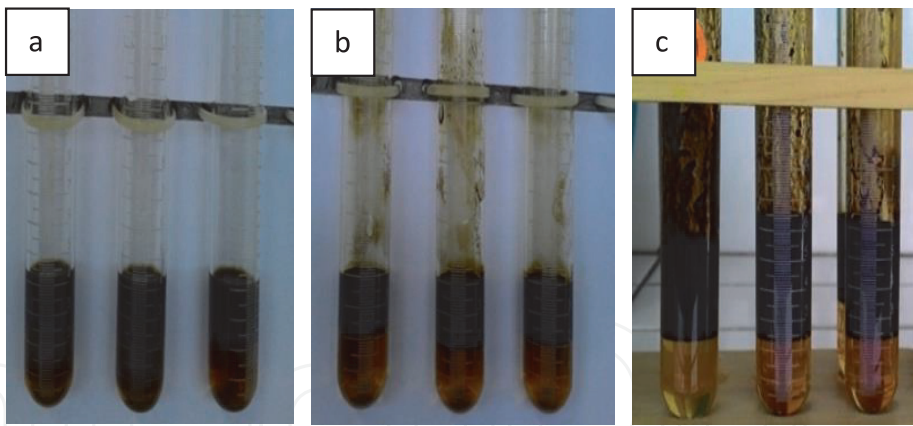


Figure 10.
Phase behavior test on a number of crude oil samples.

No.	Salinity (ppm)	Stability emulsion (%)	Type emulsion
1.	5000	10.00	Middle phase
2.	10,000	8.75	Middle phase
3.	20,000	5.00	Upper phase
4.	40,000	6.25	Middle phase
5.	80,000	1.25	Upper phase

Table 2.
Phase behavior test results on a number of salinities.

In some compositions with certain salinity, emulsions are formed in the middle and upper phases. Middle-phase emulsion or microemulsion occurs in the composition of sugarcane bagasse SLS surfactant with salinity of 5000 ppm, 10,000 ppm and 40,000 ppm, while the emulsion of the upper phase occurs at the composition of salinity of 20,000 ppm and 80,000 ppm. This is in accordance with the theory that states that the behavior of the microemulsion phase is very complex and depends on a number of parameters, including the type and concentration of surfactants, co-solvents, hydrocarbons, salinity of brine, temperature and much lower pressure levels [7]. In this case, formation water salinity influences microemulsion formation.

The formation of the mid-phase emulsion by the SLS surfactant is actually related to the components contained in the SLS surfactant. The results of the synthesis of SLS surfactants from bagasse have been analyzed using the Fourier transform infra-red (FTIR) test and the nuclear magnetic resonance (NMR) test. FTIR spectrophotometric measurements were carried out on the lignosulphonate surfactant product that had been produced from this lignin sulfonation process to determine the functional groups that corresponded to the expected lignosulphonate structure. The results of the FTIR test showed that the functional groups in the lignosulphonate structure of SLS bagasse consisted of —C=C— alkene groups, S=O sulfonates, C=O carboxylate groups and S—OR ester groups. This component complies with the standard lignosulphonate used as a comparison.

Furthermore, by using NMR, monomer test was carried out to determine the molecular formula of the sugarcane bagasse SLS surfactant. Based on the structure of the lignosulphonate monomer obtained from the NMR spectrum analysis, we can determine the lignosulphonate monomer by noticing the presence of specific atoms, namely C, O, H and S inside its structure. From the results of the NMR spectrum analysis, the number of atoms $\text{C} = 11$, $\text{O} = 8$, $\text{H} = 16$ and $\text{S} = 1$, so the empirical

Classification	Groups	Amount
Lipophilic group	=CH—	3
	—CH ₂ —	3
	—CH ₃	2
Hydrophilic group	—SO ₃ Na	1
	—OH	3

Table 3.
Sugarcane bagasse SLS surfactant function group classification.

formula for lignosulphonate monomer is (C₁₁H₁₆O₈S)_n. Functional groups in their structure can be grouped as hydrophilic groups or lipophilic groups. The grouping can be seen as in the following table (**Table 3**).

By knowing the lipophilic group and the hydrophilic group, the value of the Hydrophilic-Lipophilic Balance (HLB) can be calculated. The HLB value can be used to estimate the properties of the SLS surfactant. The calculation of the HLB value refers to the Myers theory [34] with the following formula:

$$HLB = 20 \times (M_h)/(M_l + M_h) \tag{3}$$

where

M_h = weight of hydrophilic molecule group

M_l = weight of hydrophobic or lipophilic molecule groups

Based on the data from **Table 4**, we can calculate the weight of hydrophilic and lipophilic molecule groups.

$$M_h = (SO_3Na) + (OH) \times 3 = (32 + 48 + 23 + 51 = 154) \tag{4}$$

$$M_l = (CH) \times 3 + (CH_2) \times 3 + (CH_3) \times 2 = 111 \tag{5}$$

Based on that, the HLB value is at:

$$HLB = 20 \times 154/(111 + 154)) = 11.62 \tag{6}$$

HLB value of 11.62 is compared to Myers and Akzo Nobel tables as follows (**Table 4**).

The HLB value of this bagasse SLS bagasse surfactant, after being matched with the Myers and Azko tables, turned out to be in the o/w emulsification range. Thus, it can be said that the SLS sugarcane bagasse surfactant is perfect for its use as an o/w emulsion. In the injection process, surfactant is dissolved in formation water

Application	Range HLB	
	Myers	Azko Nobel
Defoaming of aqueous systems	—	1–3
W/O emulsification	2–6	3–6
Wetting and spreading	7–9	7–9
O/W emulsification	8–18	8–28
Detergency	3–15	12–15
Solubilization	15–18	11–18

Table 4.
Surfactant function category [34, 35].

and then injected into the reservoir in order to mobilize trapped oil on rock pores. In addition to its function as a driving force for oil in rock pores, this SLS surfactant will change the properties of the oil by reducing interfacial tension. The results of this study have proven that there is a decrease in IFT in the sugarcane bagasse SLS surfactant system to light crude oil as a continuation of the results of the phase behavior and microemulsion stability tests (**Table 5**).

From the results of this IFT test, the lowest value of the IFT measurement was formed in the composition of the SLS sugarcane bagasse surfactant with a salinity of 10,000 ppm, namely 2.73 mN/m. This sample of crude oil X comes from an oil field that has 11,000 ppm formation water. The initial IFT measurement of formation water without SLS surfactant was at 12.43 mN/m. The following **table 5** describes the changes in IFT measurement results without surfactant and with SLS bagasse surfactant. This measurement shows that the surfactant function can reduce IFT from 12.43 to 2.73 mN/m. This condition is in accordance with the theory that states that when surfactant is injected into the reservoir, the hydrophobic surfactant tail will interact with the residual oil and the hydrophilic head will interact with the saltwater, as shown in **Figure 4**. It is this hydrophobic and hydrophilic interaction with water and oil that causes a strong decrease in IFT (**Figure 11**) [28].

The picture shows a mixture of oil and water, forming a new arrangement, as occurs between a mixture of sugarcane bagasse SLS surfactants and crude oil X. This new molecular arrangement involves interactions between the hydrophobic components of the surfactant and oil on one side of the interface, and water on the other. This mechanism occurs in the mixing of sugarcane bagasse SLS surfactant with the light crude oil sample used. The hydrophilic group of sugarcane bagasse SLS surfactant consisting of SO₃Na + and OH⁻ interacts with saltwater and the

No.	Solution composition	IFT (mN/m)
1.	Light oil with formation water (without sugarcane bagasse SLS surfactant)	12.43
2.	Light oil with sugarcane bagasse SLS surfactant of 5000 ppm salinity	6.81
3.	Light oil with sugarcane bagasse SLS surfactant of 10,000 ppm salinity	2.73
4.	Light oil with sugarcane bagasse SLS surfactant of 20,000 ppm salinity	4.13
5.	Light oil with sugarcane bagasse SLS surfactant of 40,000 ppm salinity	4.11
6.	Light oil with sugarcane bagasse SLS surfactant of 80,000 ppm salinity	3.61

Table 5.
IFT test results of light oil X—sugarcane bagasse surfactant SLS 1.5% on salinity variations.

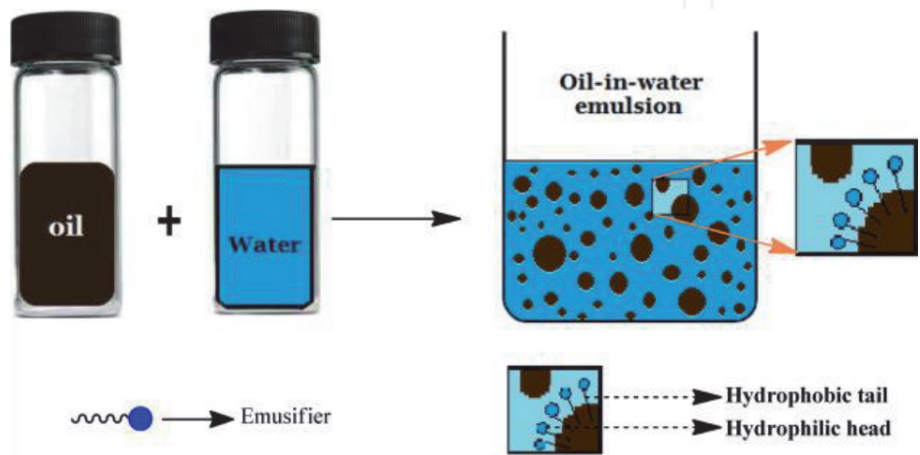


Figure 11.
O/W emulsion [36].

hydrophobic group consisting of $=CH-$, $-CH_2-$ and $-CH_3$ interacts with oil [36, 37]. With the result, we can say that oil-water interface is highly stronger than water-oil interaction prior to surfactant addition, which decreases IFT level [38, 39].

With the decrease in interfacial tension, the capillary pressure in the area of narrowing of the pores will decrease. Because the capillary pressure is reduced, the resistance to oil flow will also decrease so that the oil will move more easily to be produced [40, 41]. As the interfacial tension decreases, the capillary pressure decreases so the grain-fluid contact angle and the rock wall will also change. This has an impact on the wettability. Changes in wettability play a very important role in the mobilization of residual oil. In porous media filled with two or more immiscible fluids, wettability is a measurement of which fluid can wet (spread or adhere to) the surface [42]. In a water-wet system where the rocks are filled with oil and water, water will occupy the smallest pores and wet most of the surface in the larger pores. In areas that have high oil saturation, the oil will be held above the wet water and spread on the surface. If the rock surface tends to be water-wet and the rock is saturated with oil, water will fill the smallest pores, displacing oil when water enters the system [43]. If the rock surface tends to be oil-wet, it will be saturated with water, oil will enter and wet the smallest pores in place of water. A rock saturated with oil means water-wet (wet water) and vice versa if the rock is saturated with water means oil-wet. The wettability of a system can be classified in the very water-wet or oil-wet range depending on the water-oil interaction with the rock surface. The function of surfactants in the microemulsion formation mechanism will ultimately change the wettability of the reservoir system from water-wet to oil-wet.

4. Conclusions

Based on studies conducted on bagasse along with its utilization as a novel and stronger product, we can say that lignin content plays an important role that enables it to be produced as SLS surfactant that can be utilized on injection-based EOR process. This fact is also supported by laboratory test results, which evidently revealed that SLS surfactant contains four important compounds; alkenes, carboxylic acids, sulfonic acids and esters. As an addition, the liquid possesses HLB (-Hydrophilic-Lipophilic Balance) value of 11.62, which indicates its ability to dissolve in water and to form surfactant solution. The idea of SLS surfactant bagasse utilization is to create emulsion that would lower IFT level and mobilize oil better. That is why bagasse is highly potential to be utilized as main material of SLS surfactant production.

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