Investigation of Alpha Olefin Sulfonates Microemulsion Performance without Addition of Cosurfactant under Different Types of Salinity and Temperature

by

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16576

Dissertation submitted in partial fulfillment

of the requirements for the

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(Petroleum)

MAY 2015

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CERTIFICATION OF APPROVAL

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Petroleum Engineering Programme
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BACHELOR OF ENGINEERING (Hons)
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Approved by,

(Nur Asyraf Bt Md Akhir)	(Dr. Sia Chee Wee)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
MAY 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

HARASHTA HANIFA

ABSTRACT

Surfactant is one of the chemical widely used in enhanced oil recovery (EOR) process to reduce the interfacial tension (IFT) between oil and water to ultralow, thus improve the displacement efficiency. It was also known for its ability to change the wettability of a rock from oil-wet to water-wet, depending on the type of surfactant used. Despite all of its beneficial use, the stability and economic of a surfactant flooding is a major issue in its application. A good understanding of the microemulsion phase is important in implying the project. Microemulsion phase, which consists of oil, water, surfactant and co- surfactant plays an important role in the performance of surfactant flooding. Addition of cosurfactant is frequently added to enhance the microemulsion performance. Several factors such as brine salinity, surfactant type and concentration as well as the temperature within the system also affects the performance of microemulsion. Understanding the behavior of microemulsion phase is an important step in designing surfactant flooding processes. The project evaluates the feasibility of anionic surfactant namely alpha olefin sulfonate (AOS), which is frequently used in surfactant flooding due to its economical friendly price and good stability under high temperature. The AOS microemulsion were tested under different range of salinity, concentration and temperature without the addition of alcohol or any cosurfactant. In this project, the behavior of AOS cosurfactant-free microemulsion and the feasibility on an EOR project had been evaluated

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CHAPTER 1

INTRODUCTION

1.1 Project Background

A performance of a reservoir is often complex and influenced by several factors. One of the most important factor that most engineers focused on while developing a field is pressure depletion, which often resulted in a recovery less than 50% of the OOIP (Shindy *et al.*, 1997). This might lead the company to apply improved oil recovery method, such as waterflooding which is conducted primarily for a pressure support. However there are some issues that might be faced by company when applying waterflooding on a field, such as water breakthrough or water bypassing unswept oil. This condition occurs due to the high interfacial tension between oil and water, influencing the behavior of water injected which has lower mobility than oil to bypass the oil and leading to early water production. In an improved recovery project this condition is unlikely to be faced since it decreases the efficiency of improved oil recovery. Some other factor that affects the recovery efficiency in oil reservoirs as well as the flow behavior is wettability (Abeysinghe *et al.*, 2012). When the reservoir rock is considered as oil-wet rock, the sweeping performance of a displacing fluid might be not effective due to the tendency of oil adsorbing on the rock. These two major issues are some of the factors to be tackled by introducing a tertiary method of oil recovery, or commonly known as enhanced oil recovery (EOR).

The main objective of EOR is to improve the capillary number of a field after primary or secondary recovery is inefficient to be conducted. Ding & Kantzas (2007) defined capillary number as ratio of viscous forces to capillary forces. Capillary number can be improved by increasing viscosity of displacing fluid or decreasing interfacial tensions (IFT) between displacing and displaced fluid. Usually EOR methods are classified into several types; such as thermal, chemical and miscible injection. This project focuses on one of the chemical flooding method known as surfactant/microemulsion flooding. Mitchell *et al.* (2014) mentioned that monitoring the efficiency of EOR processes is an important step in the screening of new chemical agents, and the screening process begins at laboratory scale. This project is a preliminary study investigating one of the factors that influence the performance of surfactant flooding, which is the addition of cosurfactant in the mixture

1.2 Problem Statement

Throughout the years, surfactant flooding has been applied as one of the EOR methods that has a potential in improving a significant oil recovery by the surfactant’s ability in altering wettability and reducing the IFT (Kumar *et al.*, 2008). In a surfactant flooding, combination of surfactants, cosurfactant, hydrocarbon, water and electrolytes creates a new phase called microemulsion solutions (Sandersen, 2012). The performance of surfactant flooding is dependent on the microemulsion phase which is strongly influenced by the characters of the surfactant itself such as surfactant concentration and surfactant types. Besides that, Tavassoli *et al.*, (2015) mentioned that the surfactant phase behavior depends on parameters such as oil characteristics, brine composition, temperature, and pressure. According to Sandersen (2012) there are currently no predictive model to describe phase behavior due to the presence of surfactants and salts.

Sandersen (2012) classified surfactants into anionic, cationic, non-ionic and zwitterionic based on the behavior of “head” part of surfactant. Anionic surfactant is one of the most used surfactant in EOR process due to its temperature tolerance as well as economical-friendly cost. Most of the studies on anionic surfactant microemulsion mentions the addition of cosurfactant to the surfactant mixture to improve the microemulsion behavior. However, the addition of cosurfactant might also influence the detrimental impact of applying surfactant flooding method, both environmentally and economically.

This study focuses on one of the most used anionic surfactant in microemulsion namely alpha olefin sulfonate (AOS), which had been considered as one of the most favourable anionic surfactant used due to its good microemulsion performance and reasonable price. However, most of the anionic surfactant used in surfactant flooding was added with an addition of cosurfactant such as alcohol or fatty acid (Lohateeraparp *et al.*, 2003). Sandersen (2012) also mentioned that cosurfactant is often blended into the liquid surfactant solution in order to improve the properties of the surfactant solution. However previous study mentioned that addition of cosurfactant such as alcohol might impact the project outcome environmentally. This research was conducted to investigate the performance of microemulsion formed by AOS without the addition of cosurfactant in the solution, evaluating the impacts on both the IFT and optimum salinity. The effects of different types of salinity, temperature, and surfactant concentration were also examined.

1.3 Objectives and Scope of Study

The objectives of this study are as follow:

a) To evaluate the optimum salinity as well as minimum IFT of AOS microemulsion without the presence of cosurfactant.
b) To evaluate the effectiveness of AOS microemulsion performance without the presence of cosurfactant.
c) To investigate the effect of temperature on the optimum salinity of AOS microemulsion.

The project is relevant to the industry and feasible to be carried out. It is considered to be a preliminary study of anionic surfactant AOS performance in microemulsion flooding, when applied without addition of cosurfactant. This project is feasible to be done within the scope of study and time given. Throughout the time scope given, clear overview on how the project will be conducted was learned from several consultations with supervisor as well as studying previous conducted studies and subsequently all the related activities in completing this project were planned as efficient as possible. The project is relevant to the development of EOR techniques which is crucial lately in the oil and gas industry

CHAPTER 2

LITERATURE REVIEW

2.1 Enhanced Oil Recovery (EOR)

Often after several years of production from the field, the pressure depletion disable any further natural recovery. While secondary recovery technique such as water flooding can be applied, it still leaves significant portion of oil initially in place (OIIP) in the reservoir. Previous journals (Mai & Kantzas, 2009; Ali & Thomas, 1989) had mentioned that around 65% of OOIP might remain unswept in the reservoir. On the other hand, Alkafeef & Zaid (2007) stated that primary and secondary recovery can only recover estimately 45% of the oil in place while Tunio *et al.* (2011) stated that EOR techniques can increase the recovery up to 60-65%. This means that the increase from EOR application is quite significant, improving the production of a field by around 20% of remaining residual oil.

EOR is usually designed specifically to recover residual oil, which is due to wettability and pressure depletion usually could not be produced by primary and/or secondary recovery techniques. Sheng (2011) mentioned in his study that EOR refers to any reservoir process to change the existing rock-fluid interaction in reservoir while Bahan *et al.* (2012) stated that EOR basically consists of injecting fluids to a reservoir with the objective of displacing residual oil out of the reservoir. Sandersen (2012) furtherly mentioned that the main objectives of EOR method is to alter the mobility of the remaining residual oil. In the broader scope, EOR focuses on specific concept on how a reservoir performance can be improved, such as capillary number which is a function of viscosity and interfacial tensions. In conclusion from previous studies, EOR is applied by injecting new fluid to change the rock and fluid interaction in reservoir and/or alter the mobility of remaining oil. The capillary number, can be improved by increasing the injected fluid's viscosity or reducing the interfacial tensions (IFT) between the rock-fluid and/or fluid-fluid interactions. In EOR methods, reducing the IFT is one of the most important aspect which will impact the sweeping efficiency and prevent by-passing process.

Throughout the application, EOR is considered as an expensive method. It also deals with complex reservoir fluid-specific data, therefore EOR project must be evaluated thoroughly before being applied. Hite & Bondor (2004) mentioned that some of the selection of EOR methods including geologic analysis and modeling, project economics, project design, pilot testing and project implementation and surveillance. On the other hand, Moreno *et al.* (2014) stated that seven parameters need to be evaluated as a key on identification and ranking of applicability of an EOR methods which are; oil gravity, oil viscosity, reservoir depth, reservoir temperature, porosity, permeability, and formation type. Objectives of EOR method were classified by Hite & Bondor (2004) into two categories: to improve volumetric sweep efficiency or to improve displacement efficiency. Currently, there are several methods of EOR available in industry such as thermal, chemical and miscible injection.

2.2 Chemical Enhanced Oil Recovery (CEOR)

According to Othman *et al.* (2013) Chemical EOR projects were very active during 1980's, however due to the low oil prices and technical challenges the interest in chemical EOR had decreased since 1990's. Although nowadays the oil price had become low again, chemical EOR shows a promising future since most of the fields developed will be in need of tertiary recovery method. According to Sandersen (2012) chemical EOR is a chemical processes which is performed by injection of a specific liquid chemical mainly to create desirable phase behavior properties in order to improve the oil displacement. It can be classified into three main categories which are surfactant flooding, polymer flooding and caustic flooding. Furthermore, Sheng (2011) mentioned in his study that there are also combination of these processes. The mechanisms of oil displacement by surfactant is based on the formation of ultra-low interfacial tensions (IFT), which is lower than 0.001 mN/m. A chemical EOR is really sensitive to the uncertainties in the input parameters. Othman *et al.* (2013) mentioned that some of the important uncertainties to be considered such as reduction in IFT and residual oil saturation, adsorption of chemicals, trapping numbers and emulsion formation and its behavior. Thus, it is really important for a chemical EOR to be studied microscopically before applying it on the field and a good understanding of both liquid-liquid as well as liquid-rock interactions is necessary (Michell *et al.*, 2014).

2.3 Surfactant Flooding

Surfactant flooding is one of the type of chemical EOR processes, which uses small amount of surfactant to the fluid injected primarily to improve the sweep efficiency. Surfactant flooding creates microemulsion solutions, which may contain different combinations of surfactants, cosurfactant, hydrocarbon, water and electrolytes (Green and Willhite, 1998). The injections of one or more liquid chemical and surfactant swept the oil by decreasing the IFT to ultra-low IFT, therefore improving the displacement efficiency of the flooding. The criteria in applying surfactant flooding is to maximize the amount of oil recovered, while minimizing the chemical cost. While it is necessary to reach low IFT for the surfactant system, it is not the only criteria for surfactant flooding to be conducted since the project might not be efficient if the chemical cost is more than the residual oil recovered. Sandersen (2012) also mentioned that attention to the optimum salinity is crucial to be studied during application of surfactant flooding. Lohne and Fjelde (2012) mentioned that some of the mechanisms that should be evaluated in a surfactant flooding focuses on micro-scale mechanisms which are reduced residual oil saturation and altered relative permeability; macro-scale mechanisms including capillary trapping due to the presence of heterogeneities and segregated flow due to gravity; and lastly the wettability alteration which affects the flow on both scales.

2.4 Surfactant

Surfactant is an abbreviation of surface active agent, which is a chemical substance that adsorb at the surface or fluid interface. The surface can be an interface of solid and liquid, air and liquid or liquid with different immiscible liquid. Surfactant molecules are amphiphilic, which is a term used for chemical compound that contains both hydrophilic and hydrophobic molecules, as shown in *Figure 2.1*. The hydrophilic part is known as the head part of surfactant, and the hydrophobic part is known as the tail. Due to the polar molecules that the head consisted of they tend to interact with water/brine which also has a polar bond. On the other hand, the tail consists of non-polar molecules which attract them with oil that is composed of non-polar bond. Sheng (2011) also mentioned that surfactant is amphiphilic organic compounds that consists of hydrocarbon chain which are hydrocarbon group (water-loving) and hydrophilic group (water-hating). According to Schramm (2010) surfactants are divided into different categories based on the basis of the head part; anionic, cationic, nonionic and zwitteronic/amphoteric surfactants. Among the types of surfactant, anionic is widely used in enhanced oil recovery due to their low adsorption on reservoir rocks compare to other types.

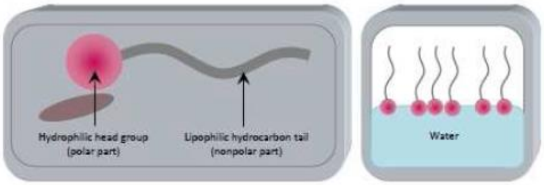

Figure 2. 1 : Schematic representation of surfactant

2.5 Microemulsion

When surfactant is dissolved at low concentration, the molecules are dispersed as monomers. As the concentration is increased, surfactant molecules will start to aggregate and at a specific concentration known as critical micelle concentration (CMC), surfactants will form into micelles and any further addition of surfactant will form into micelles (Sandersen, 2012). The presence of micelle will solubilize two immiscible phases such as water and oil, known as microemulsion system. It is a clear, transparent and thermodynamically stable isotropic liquid mixtures of oil, water and surfactant.

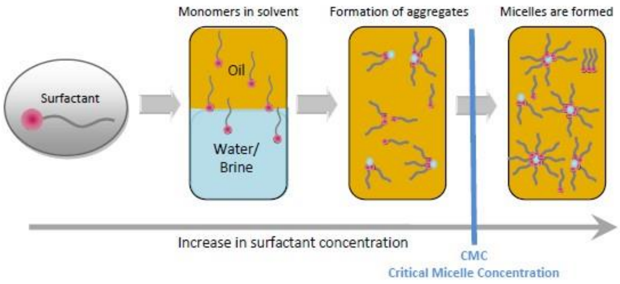

Figure 2. 2 : Formation of micelle and critical micelle concentration adapted from (Sandersen, 2012)

Depending on the phase behavior of the mixture, there are three types of microemulsion form (Winsor, 1954; Reed and Healy, 1977; Nelson and Pope, 1978; Prouvost *et al.* 1985). Winsor (1954) classified microemulsion containing oil, water and surfactant as Type I, Type II and Type III. The surfactant-water-oil phase behavior is strongly affected by brine salinity (Mwangi, 2010). For low brine salinities, surfactant will exhibit a good aqueous phase solubility and poor oil-phase solubility thus forming a microemulsion phase in water where oil is solubilized in aqueous phase. This type is known as Winsor Type (I). Where the brine has a high salinity, water tend to be solubilized in oleic phase, known as Winsor Type (II). In this condition, the hydrophilic part of surfactant molecules are shielded and surfactant has high affinity to oil. The third type is termed Winsor Type (III) or also known as middle-phase microemulsion. For the mobilization and displacement of oil, Winsor Type III is considered the optimum regime because of the ultralow IFT between the microemulsion phase and the excess oil and water phases (Tavassoli *et al.*, 2015).

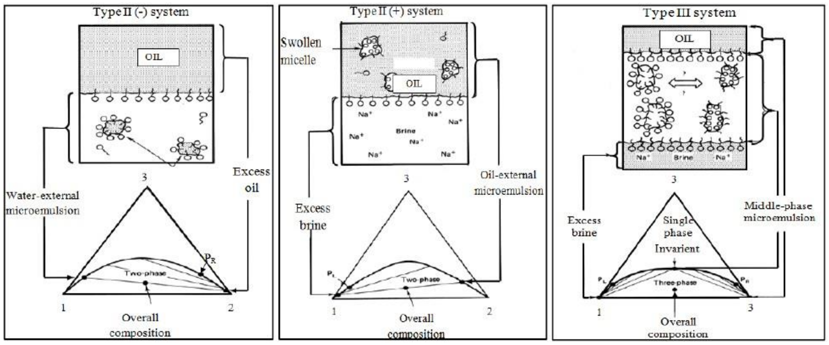

Figure 2. 3 : Schematic representation of Winsor Type I (left), Winsor Type II (middle) and Winsor Type III (right) adapted from (Mwangi, 2010)

2.6 Effects of Salinity

The effects of salinity towards surfactant solubility remains questionable. According to Healy *et al.* (1976), increase in salinity causes microemulsion transitions to occur from lower to middle to upper phase. Cai *et al.* (1996) showed in their research that increment of salt concentration increase the IFT but insensitive with the salt species. Okasha and Al-Shiwaish (2009) found out in their study that the presence of gas in live oil system resulted in lower IFT decrement compare to dead oil system. On the other hand, Alotaibi and Nasr-EL-Din stated that lowering NaCl concentration does not necessarily reduce the IFT, thus there is a critical salt concentration at which a minimum IFT between brine and oil could be obtained. On the bigger picture, Zhang *et al.* (2007) investigated the effect of using low salinity brine and high salinity brine on oil recovery, the result shows that low salinity brine increase the oil recovery in both secondary and tertiary mode In addition, surfactant concentration also impact the behavior of microemulsion transition. Liu *et al.* (2008) also mentioned that when a salinity scan test is conducted at low surfactant concentrations, equilibrium phase behavior appears to go from the lower-phase to an upper-phase over a narrow salinity range. A system of surfactant-oil-water is highly sensitive to the salinity, therefore must be evaluated thoroughly in a various range to evaluate the optimum salinity.

2.7. Influence of Alcohol/Co-surfactant

In surfactant flooding, cosurfactant is often used to stabilize the microemulsion over a wide range of surfactant concentrations. During microemulsion flooding, surfactant often is mixed with cosurfactant such as alcohol, fatty acid, or binary anionic surfactant Sandersen (2012) mentioned in her study that cosurfactant often are blended into the liquid surfactant solution in order to improve the properties of the surfactant solution Throughout the use in fields, alcohol is one of the most used cosurfactant to be added to surfactant solution. However, alcohol has certain detrimental effects. Noll (1991) mentioned that at higher temperature, alcohol only influence a little effect on critical micelle concentrations. This might lead to a non-beneficial extra cost which is a major issue in EOR project. In addition, alcohol can impact the environment when performing a surfactant flooding due to its properties.

Hsieh and Shah (1977) found out in their study that the volume of middle phase of surfactant is always smaller at higher alcohol concentration, unless the surfactant concentration is increased. The increasing alcohol concentration indicate that there exists an optimum alcohol concentration which can produce ultra-low IFT and solubilize maximum amount of oil and brine, and they mentioned that the optimum alcohol concentration depends on the brine salinity.

According to Lelanne-Cassou *et al.* (1983) the addition of alcohol is just one of many methods that can be used to bring oil/water/surfactant systems into the microemulsion regime. The conceptually simplest method is to elevate temperature, but for a given oil reservoir temperature is fixed. A second method could be to lower the salinity, however both of these is dependent on reservoir conditions.

2.8 Effects of Temperature

Zheng (2012) investigated the effect of temperature towards anionic and nonionic surfactant effects to interfacial tension under room temperature (22 °C) and reservoir temperature (~98.9 °C). The result showed that nonionic surfactant is significantly affected by temperature change, where nonionic surfactant display a better temperature tolerance. Although anionic surfactant IFT decrement reduce when tested in higher temperature, it does not decrease significantly compare to nonionic surfactant. Skauge and Fotland (1990) stated that increase in temperature results in an increase of optimal salinity, on the other hand Gupta and Mohanty (2010) showed that for most of the surfactants they tested at higher temperature the optimal salinity may decrease or remains unchanged. This inconsistency illustrate the complexity of surfactant systems where the phase behavior will be both component and composition dependent (Sandersen, 2012).

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 Research Methodology

The methodology used in completing this project can be seen in *Figure 3.1* below. The project started by gathering information about the topic throughout literature review, research papers and consultation with supervisors. After that, the chemicals and materials needed for the experiment were gathered. Subsequently, chemical screening of the results was conducted and optimum salinity was evaluated. After all of the experiments were conducted, author finished the report analyzing the results and followed by presenting the project results to the internal and external evaluators. Further details will be explained in the next section.

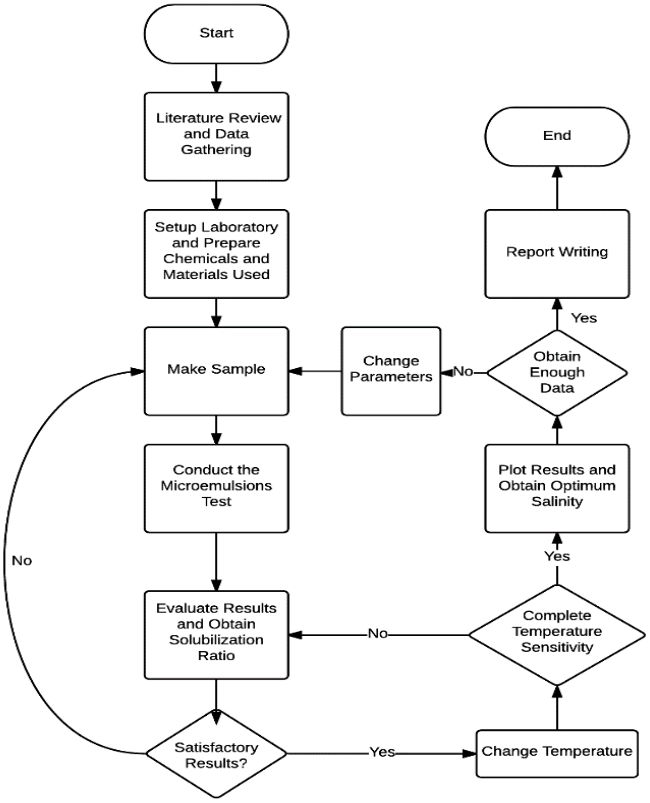

Figure 3. 1 : Research Methodology Workflow

3.2 Experimental Methodology

The methodology of the experiment consists of brine and surfactant preparation, oil preparation, microemulsion experiment and solubilization ratio as well as IFT calculation. Further details will be explained on the next section.

3.2.1 Brine and Surfactant Preparation

The brine was prepared using sodium chloride (NaCl) by calculating the weight of the NaCl required to make the desired salinity using the dilution equation:

$$C_1V_1 = C_2V_2 \qquad \text{(Eq. 1)}$$

Where C_1 and V_1 are the concentration and volume of the first solution while C_2 and V2 are the concentration and volume of the new solution, respectively. The equation was first used to estimate the amount of NaCl needed to prepare a 35,000 ppm brine in 1 L beaker glass. The desired weight of NaCl was weighed on weighing scale to ensure the accuracy of the weight. After being weighted out, NaCl was put on 1 L beaker glass and distilled water was added. The brine solution subsequently is stirred using a magnetic stirring until the solid salt totally dissolved. Once the solution is ready, it is divided again into various salinity varying from 889 ppm to 35,000 ppm using the same method and put in 100 ml beaker glasses. There are a total of 15 different salinities prepared for the experiment.

The surfactant solutions were prepared using alpha olefin sulfonate (AOS) surfactant the same method used for preparing brine. However, the calculation is slightly different considering that the surfactant was already liquid. Distilled water was also added after the desired concentration and required volume was estimated. There are three surfactant solutions prepared in a 100 ml beaker glasses which are 0.5, 1.0 and 1.5 wt%.

3.2.2 Oil Preparation

The oil sample used in this research is a light oil named Tapis oil. It has an API gravity of 45.2°. Before mixing with the sample, the oil was filtrated using filter paper to remove impurities.

3.2.3 Microemulsion Experiment Procedure

The microemulsion experiments were conducted by thoroughly putting the desired brine solution, surfactant, as well as oil in a measuring tubes using syringe to ensure accurate volume was put. The water oil ratio (WOR) used is 1, and the composition of surfactant is varied to evaluate the performance of surfactant without addition of cosurfactant. After that, the measuring tubes were closed and shaken mildly for several minutes to mix and allow the complete phase separation to occur. It was subsequently left at room temperature for at least 24 hours to reach equilibrium. Every input was recorded in *Table 3.1* and evaluated after that to measure the solubilization ratio and interfacial tensions.

Table 3. 1 : Samples Input Data

Sample ID	Brine salinity, ppm	Brine Volume (%)	Surfactant Volume (%)	Oil Volume (%)
ME1	35,000.00	45	10	45
ME2	26,923.08	45	10	45
ME3	20,710.06	45	10	45
ME4	15,930.81	45	10	45
ME5	12,254.47	45	10	45
ME6	9,426.52	45	10	45
ME7	7,251.17	45	10	45
ME8	5,577.82	45	10	45
ME9	4,290.63	45	10	45
ME10	3,300.49	45	10	45
ME11	2,538.84	45	10	45
ME12	1,952.95	45	10	45
ME13	1,502.27	45	10	45
ME14	1,155.59	45	10	45
ME15	888.92	45	10	45

3.2.4 Solubilization Ratio and IFT Measurement

After mixture had reached equilibrium, the microemulsion phase was observed visually and tabulated in table to simplify the evaluation. Firstly, the type of Winsor formed was determined and the microemulsion volume of each sample was measured. After that, the excess volume and excess water phase is measured. One of the assumption used is that all the surfactants were present in the microemulsion phase when calculating the solubilization parameters. Excess volume in here is the extra volume after the sample reached equilibrium, therefore in Winsor Type I the excess water volume will be zero. On the other hand when Winsor Type II was present, the excess oil volume will be zero. Next, the V_o and V_s are calculated by deducting the excess V_o or V_w from initial V_o and/or V_w inputted. It has to be noted that all the volume calculated here was measured in percentage. The solubilization ratio of oil (V_o/V_s) and water (V_w/ V_s) was calculated by dividing the V_o and/or V_w by the volume of surfactant are all tabulated. All the experiments results were tabulated in a table, as shown in *Table 3.2* which shows the results for AOS 0.5 wt% experiment at 25 °C. After that the solubilization ratio of oil and water were used to calculate the IFT between oil-surfactant and water-surfactant. The salinity vs solubilization ratio (SR) was afterward plotted on the graph to see the trend and obtain the optimum salinity of the sample. To calculate the IFT and solubilization ratio, *Equation 2* and *Equation 3* are used.

$$IFT = \frac{0.3}{SR^2} \qquad \text{(Eq. 2)}$$

$$SR = \frac{Volume\ of\ Solubilized\ Phase}{Volume\ of\ Surfactant} \qquad \text{(Eq. 3)}$$

Table 3. 2 : Microemulsion Test Evaluation for AOS 0.5% wt at 25 °C

Sample ID	Salinity, wt%	Winsor Type	ME Volume	Excess Vo (%)	Excess Vw (%)	V_o (%)	V_w (%)	V_o / V_s	V_w / V_s	IFTos, mN/m	IFTws, mN/m
ME1	3.50	Upper	66	0	34	45	11	4.5	1.1	0.0148	0.2479
ME2	2.69	Upper	69	0	31	45	14	4.5	1.4	0.0148	0.1531
ME3	2.07	Upper	71	0	29	45	16	4.5	1.6	0.0148	0.1172
ME4	1.59	Middle	66	7	27	38	18	3.8	1.8	0.0208	0.0926
ME5	1.23	Middle	57	18	25	27	20	2.7	2	0.0412	0.0750
ME6	0.94	Middle	53	24	23	21	22	2.1	2.2	0.0680	0.0620
ME7	0.73	Lower	75	25	0	20	45	2	4.5	0.0750	0.0148
ME8	0.56	Lower	74.8	25.2	0	19.8	45	1.98	4.5	0.0765	0.0148
ME9	0.43	Lower	74	26	0	19	45	1.9	4.5	0.0831	0.0148
ME10	0.33	Lower	70	30	0	15	45	1.5	4.5	0.1333	0.0148
ME11	0.25	Lower	69	31	0	14	45	1.4	4.5	0.1531	0.0148
ME12	0.20	Lower	68	32	0	13	45	1.3	4.5	0.1775	0.0148
ME13	0.15	Lower	67	33	0	12	45	1.2	4.5	0.2083	0.0148
ME14	0.12	Lower	66	34	0	11	45	1.1	4.5	0.2479	0.0148
ME15	0.09	Lower	65	35	0	10	45	1	4.5	0.3000	0.0148

3.3 Tools and Materials Used

The tools and materials used in this study are listed on the *Table 3.3* below.

Table 3. 3 : List of Tools and Materials Used

No	Chemicals/Materials/Tools	Description
1	Alpha Olefin Sulfonate	Anionic surfactant used in the experiment.
2	Sodium Chloride (NaCl)	Used to make brine sample.
3	Tapis Oil	Selected crude oil from field to be evaluated.
4	Syringe	Used to ensure accuracy of volume inputted in sample.
5	Measuring Tubes	To evaluate and store the microemulsion samples.
6	Beaker Glass	To store brine and surfactant samples, and to store the filtered oil.
7	Distilled Water	To make surfactant and brine solutions.
8	Magnetic Stirrer	To stir the solution prepared.
9	Weighting Balance	To weigh NaCl and AOS prepared.

3.4 Key Milestones

The key milestones of this project, starting from January 2015 to August 2015, are as listed on *Table 3.4* below.

Table 3. 4 : Key Milestones

Project Key Milestones	Date
Extended proposal submission	16th January – 20th January 2015
Progress draft report submission	6th April – 10th April 2015
Progress report submission	13th April – 17th April 2015
Progress report submission	29th June – 3rd July 2015
Pre-SEDEX	20th July – 24th July 2015
Draft report submission	27th July – 31st July 2015
Soft bound dissertation submission	3rd August – 7th August 2015
Technical paper submission	3rd August – 7th August 2015
Oral presentation	10th August – 14th August 2015
Hard bound dissertation submission	24th August – 28th August 2015

3.5 Gantt Chart

The complete Gantt chart for the activities of this project can be seen on *Table 3.5* on the next page.

Table 3. 5 : Gantt Chart

■ Process X Milestone

Remarks	Week																												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Selection of topic	■	■																											
Research/preliminary studies on surfactant and microemulsion			■	■																									
Literature review			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Proposal writing			■	■	■																								
Submission of extended proposal						X																							
Preparation for proposal defense							■																						
Proposal defense and revision							■	■	■																				
Data gathering for chemicals and materials used								■	■	■	■	■	■	■	■	■	■												
Interim report writing										■	■	■	■																
Submission of interim draft report													X																
Submission of interim report														X															
Laboratory booking														■	■	■	■	■											
Gathering materials																■	■	■											
Conduct experiment for AOS 0.5 wt%																		■	■	■	■	■							
Preparation of progress report																				■	■	■							
Submission of progress report																						X							
Conduct experiment for AOS 1 and 1.5 wt%																						■	■	■	■	■			
Preparation for Pre-SEDEX																						■	■	■					
Pre-SEDEX																								X					
Preparation of final report and technicalpaper																								■	■	■			
Submission of final report draft																									X				
Submission of dissertation soft printed and technical paper																										X			
Viva																											X		
Submission of project dissertation hardbound																													X

CHAPTER 4

RESULTS AND DISCUSSION

4.1 RESULTS

The results of microemulsion test for AOS 0.5, 1 and 1.5 wt% at room temperature are plotted on *Figure 4.1*, *Figure 4.2* and *Figure 4.3* respectively. Also the effects of temperature changes for the optimum salinity and IFT are plotted on the graphs on *Figure 4.4* and *Figure 4.5*.

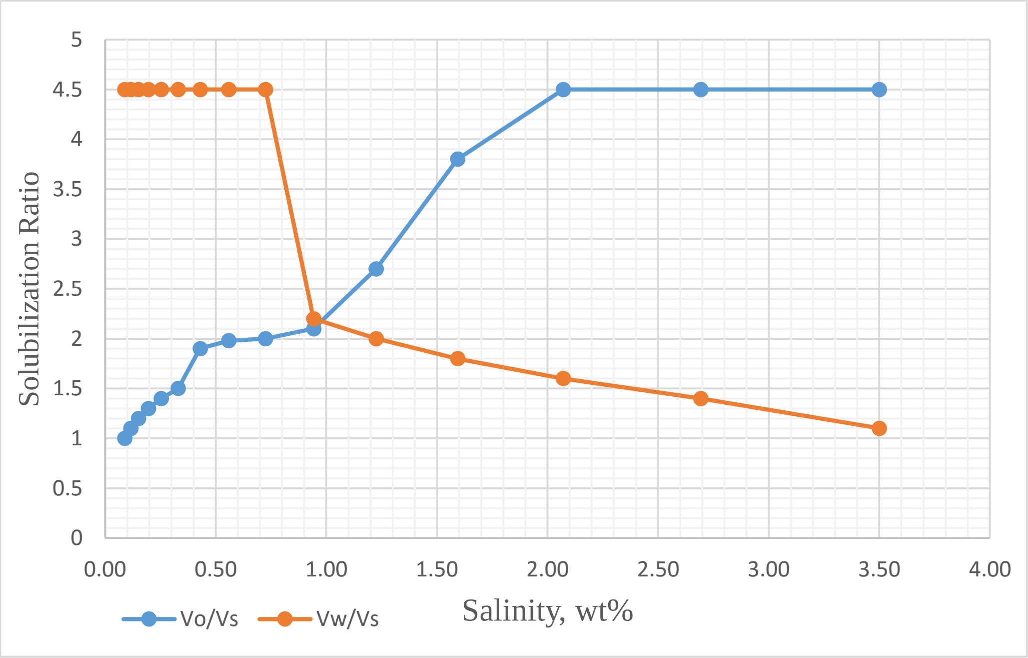

Figure 4. 1 : Salinity vs Solubilization Ratio for AOS 0.5 wt% at 25° C

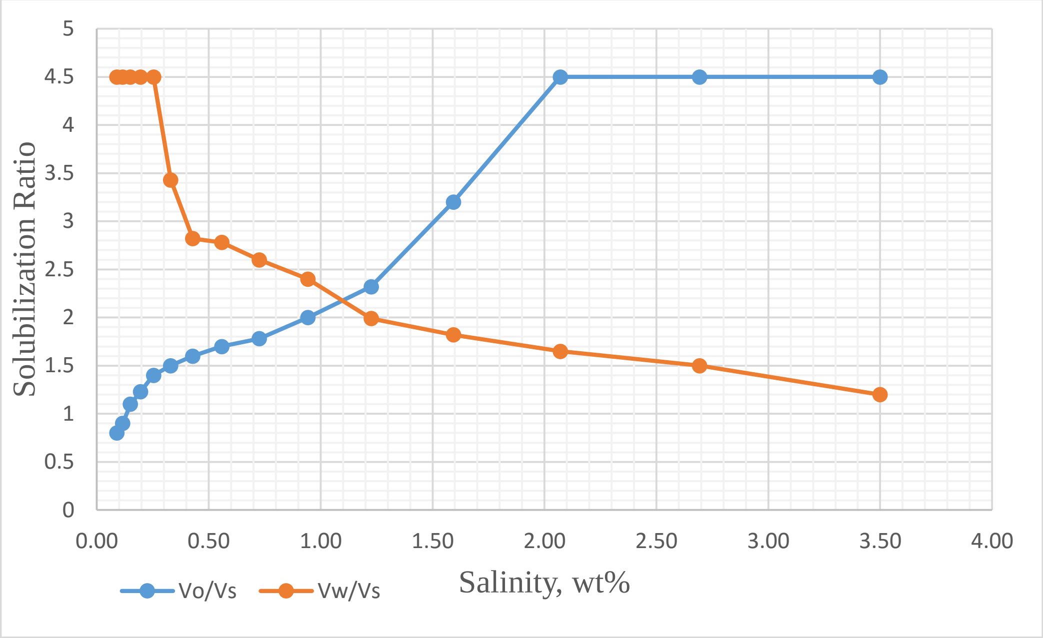

Figure 4. 2 : Salinity vs Solubilization Ratio for AOS 1.0 wt% at 25° C

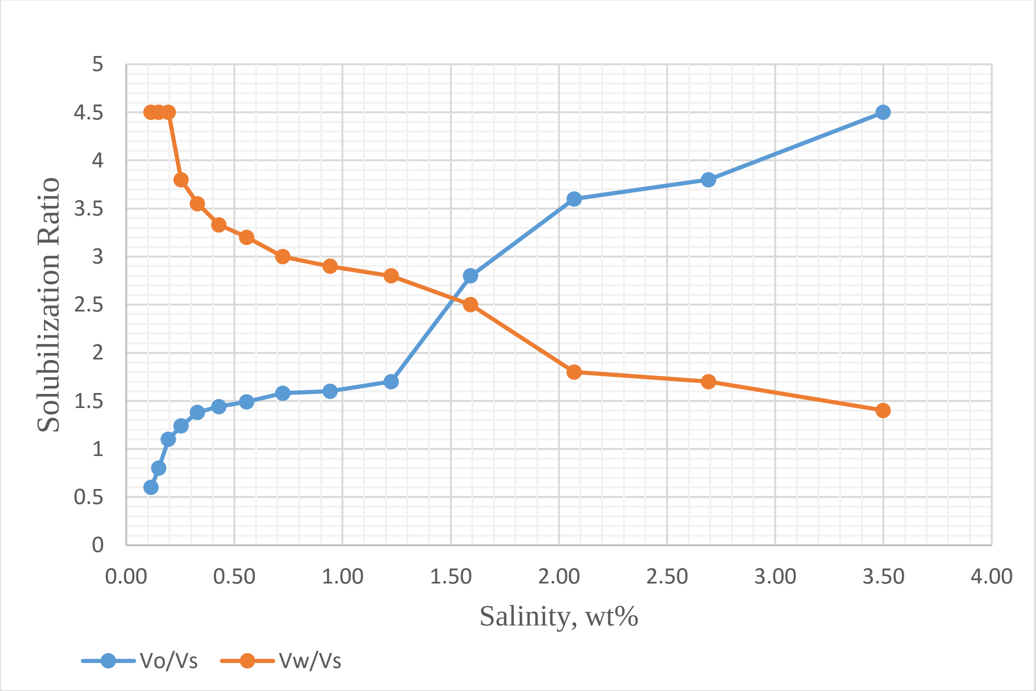

Figure 4. 3 : Salinity vs Solubilization Ratio for AOS 1.5 wt% at 25° C

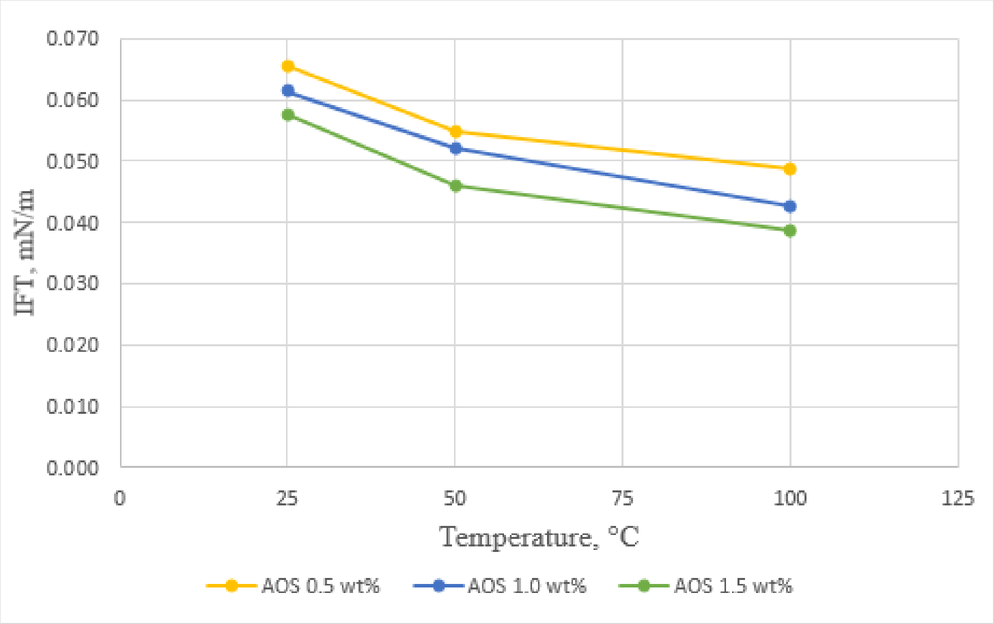

Figure 4. 4 : Temperature vs IFT of AOS 0.5, 1.0 and 1.5 wt%

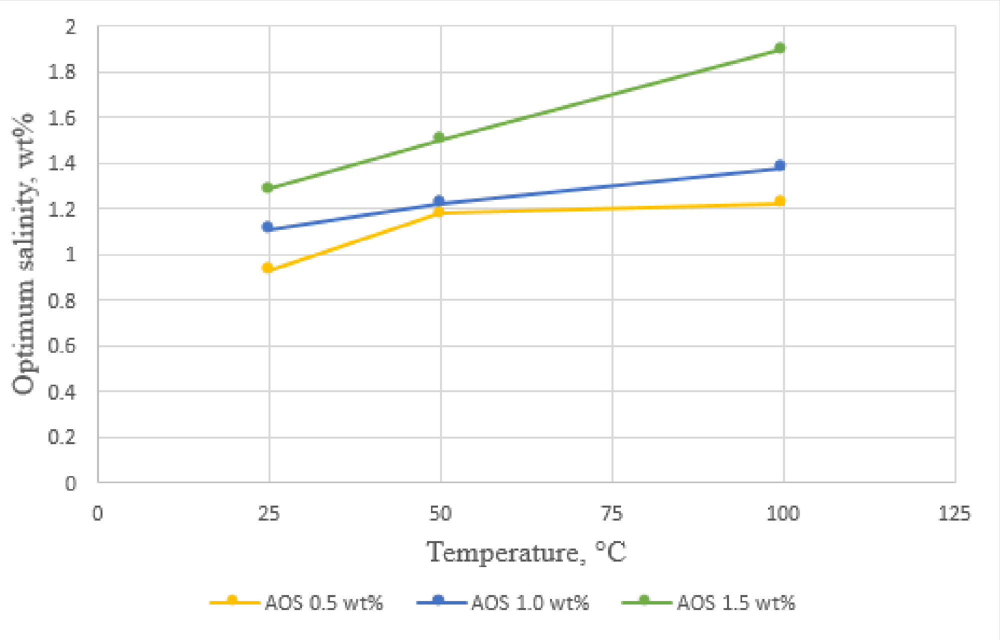

Figure 4. 5 : Temperature vs Optimum Salinity of AOS 0.5, 1.0 and 1.5 wt%

4.2 DISCUSSION

Fifteen (15) samples of each surfactant concentration with various salinity was prepared and evaluated. The phase presence in the sample can be observed from the graph, the upper phase is shown by constant solubilization ratio of oil at 4.5 and varying solubilization ratio of water. This is due to the microemulsion phase formed in the oil phase, therefore the excess oil volume will be zero and excess volume of water will vary. The lower phase is shown by solubilization ratio of water at 4.5 and varying solubilization ratio of oil. In lower phase microemulsion, the microemulsion formed in water phase therefore the varying results will be from the excess oil volume. Lastly, the middle phase can be seen from variation of both phases solubilization ratio since in middle phase the microemulsion attract both oil and water to be miscible. Therefore the solubilization ratio will not stay at 4.5.

Based on *Figure 4.1*, AOS 0.5 wt% samples undergo the transition between upper-phase to lower-phase microemulsion abruptly. Only the sample with NaCl salinity of 0.94, 1.23 and 1.59 wt% shows the presence of middle phase microemulsion. The volume of oil solubilized happen to be changing significantly from salinity of 0.94 to 1.23 wt%. According to the literature review, optimum salinity is defined as a salinity where the volume of oil solubilized (V_w/V_s) is equal to the volume of oil solubilized (V_o/V_s), which can be obtained by the intersection between V_w/V_s and V_o/V_s. This condition can be achieved when microemulsion present is Winsor Type III or middle phase microemulsion, since in this type of microemulsion surfactant solubilizes both oil and water in the microemulsion phase. For the 0.5 wt% AOS, the optimum salinity was found to be at 0.93 wt%. In a higher surfactant concentration, more middle phase microemulsion are presence. As shown in *Figure 4.*2 in AOS 1 wt% experiment, there were four (4) more samples showing middle phase microemulsion compare to OS 0.5 wt% experiment. Samples that shows middle phase microemulsion were ME 4 to 10, which consists of salinity ranging from 0.33, 0.43, 0.56, 0.73, 0.94, 1.23, and 1.59 wt%. The intersection of V_o/V_s and V_w/V_s on *Figure 4.2* is found between ME 10 and ME11, and the optimum salinity was found to be 1.11 wt%. This shows that as the surfactant is increased, the optimum salinity required to achieve the minimum IFT will be increased too. This statement was clarified furthermore after evaluating the results from AOS 1.5 wt% experiment shown in *Figure 4.3*, where the optimum salinity increased to 1.29 wt%.

One more thing to be considered is the solubilization of the phases. As surfactant concentration increased, it can be seen that the volume of oil solubilized is decreased where the volume of water solubilized is increased. This might be due to the behavior of surfactant which became more hydrophilic as the surfactant concentration is increased. In addition, increase in surfactant affects the presence of middle phase on wider salinity range. This was observed from the results of AOS 0.5 wt% having three samples with middle phase and increased to seven samples when the surfactant concentration is increased to 1 wt%. Also when the surfactant concentration is increased to 1.5 wt%, there existed ten samples showing middle phase microemulsion. One more thing to be added is that the upper microemulsion presence seem to be decreasing from three samples on 1 wt% AOS to one sample only at 1.5 wt% AOS. This confirmed more on the decrement upon the volume of oil solubilized as the surfactant concentration is increased.

Salinity plays an important role in the behavior of microemulsion phase. As salinity increased, the microemulsion undergo transition from lower to middle to upper phase. As the brine salinity is increased, solubility of surfactant in brine is decreased due to the increase in electrolyte concentration which drives surfactant out of brine. The effects of temperature on the behavior of microemulsion were also conducted, ranging from room temperature 25 °C, 50 °C and lastly 100 °C to evaluate the feasibility of surfactant in a field temperature which frequently found to be 100 °C and above. The value of IFT in this experiment was calculated using Chun Huh's equation. From *Figure 4.4* it can be seen that the IFT at optimum salinity decrease as the surfactant concentration increased. The effect of increasing the temperature on AOS microemulsion resulted in a decrease on optimum IFT, which is favourable for surfactant application. However, the decrease is not significant and the IFT did not achieve the ultra-low IFT which is desired in the application of surfactant flooding. This is one of the important point observed, which is most probably occurred due to the absent of cosurfactant in microemulsion. As shown in *Figure 4.4*, the decrement in IFT from 0.5 wt% to 1 wt% was steady but not significant. Increasing the concentration to 1.5 wt% shows a decrease on IFT comparing to 0.5 wt%, however this behavior shows that more concentration of surfactant is required to attain the ultra-low IFT. Increase on temperature also affects the optimum salinity required to attain the minimum IFT. Based on the results on *Figure 4.5*, the optimum salinity of AOS 0.5 wt% lies at 0.93 wt% at 25 °C. It increased up to 1.29 wt% at AOS concentration of 1.5 wt%. As the temperature was increased to 100 °C, optimum salinity of 0.5 wt% AOS was found to be 1.22 wt% where at AOS concentration of 1.5 wt% found to be 1.9 wt%. This shows that as the temperature is increased, optimum salinity will increase too.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Throughout the application, surfactant has shown a very promising application in increasing oil recovery. However, due to the low oil prices in recent years, surfactant flooding had not been applied often on fields. It is considered as a complex method due to the behavior of phases and strongly influenced by the economic factors. Some of the important factors that affect both, such as temperature, salinity, as well as surfactant concentration was evaluated throughout this study. Anionic surfactant such as AOS had always been considered to be economic-friendly and shows a good tolerance in terms of temperature. The results from this study shows that optimum salinity increase as temperature and surfactant concentration increased. The most optimum salinity was achieved from 1.5 wt% AOS at 100 °C which lowers the IFT down to 0.039 mN/m. However, this was not enough to be applied in a field application due to the desirable ultra-low IFT on practicing surfactant flooding. This shows that although Alpha Olefin Sulfonate is one of the most promising surfactant candidate in surfactant flooding, the addition of co-surfactant is required to attain more IFT decrement. The results of this study shows that increase in surfactant concentration also decrease the IFT, however it might not be economically applicable if the surfactant concentration requires to be increased further.

5.2 RECOMMENDATION

The optimum salinity and IFT for three different concentrations of AOS are obtained from the experiments. There were several errors that can be occurred during the experiment that must be considered. First, is the systematic error is due to the random error in conducting experiment. The oven sometimes did not give the desired temperature, slightly lower from the expected. Also during the weighing of materials using the weighting balance, air from surrounding movement might impact the reading, since it is quite a sensitive instrument. Human error is also one important factor to be considered. The measurements of solubilization ratios were observed visually by student, which can affect the reading to be slightly higher or lower from the exact measurement.

For future work regarding this study, it is recommended to evaluate the comparison of using co-surfactant to evaluate further on the impact of eliminating the presence of co-surfactant in AOS microemulsion performance. Also the interfacial tensions measured from Chun Huh’s equation can be compared by spinning drop method or pendant drop to evaluate the accuracy and compare the IFT results and further evaluate the applicability of Chun Huh’s IFT equation. Furthermore, higher surfactant concentration should be evaluated to observe at which concentration Alpha Olefin Sulfonate can achieve the condition of ultra-low IFT. Lastly, the effect of pressure might be required to evaluate AOS performance and further clarify this project.

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