This Is For You
Emak and Abah,
Mariam Hj Bujang & Saharudin Jamian

Thank you
My SV
Mr Iskandar Dzulkarnain

Thank you
UTP

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.

SITI KHAIRUN NISYAK SAHARUDIN

ACKNOWLEDGEMENT

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It has been a great pleasure to do Final Year Project.

Thank you.

CHAPTER 1

INTRODUCTION

1.1 Project Background

1.1.1 Enhanced Oil Recovery

The demand of crude oil in this era keep on increasing, so as the prices. Due to this situation, people in oil and gas industries come out with a lot of way to improve their ways of extracting oil from the reservoir and keep fulfill the demands from human nature. A lot of research have been done to solve the problem. One of them is Enhanced Oil Recovery. There are some method introduced which is similar meaning, except they are also applied to primary and secondary method. The method called Improved Oil Recovery (IOR) and Advanced Oil Recovery (AOR).

Enhanced Oil Recovery or EOR is the processes involve the injection of a fluid or fluids of some type into the reservoir. EOR refers to the recovery of oil that is left behind after primary and secondary recovery methods are either exhausted or no longer economical. The injected fluids and injection processes supplement the natural energy present in the reservoir to displace oil to a producing well. Plus, the fluid that has been injected will interact with the reservoir rock or oil system to create condition that suitable for oil recovery. From the injection, the interaction might give result in lowering IFT's, swelling of oil viscosity reduction, modification of wettability, or favorable phase behavior.

Traditionally, oil recovery has been divided into three stages which are primary, secondary and tertiary. Primary recovery is the use of natural energy that existed in a reservoir as the main source of energy for the displacement of oil to producing wells. Most of the time, reservoir would have gas cap drive, solution gas drive and natural water drive. Secondary recovery would be come from augmentation of natural energy through of water or gas to displace oil towards producing wells. The injection is based on the natural of the reservoir's energy. Gas injection for instance, is either into a gas cap for pressure maintenance and gas-cap expansion. Figure 1 shows the mechanism for oil recovery in a form of chart. Primary followed by secondary and tertiary always be in sequence in the recovery and related to each other.

a) Primary production is the first oil out, the 'easy oil'. Once a well has been drilled and completed in a hydrocarbon bearing zone, the natural pressures at that depth will cause oil to flow through the rock towards the lower pressure wellbore, where it is lifted to the surface. Recovery is usually between 10-15% of original oil in place.

b) Secondary recovery methods are used when there is insufficient underground pressure to move the remaining oil. The most common technique is water flooding, which uses injector wells to introduce large bodies of water into the reservoir for pressure maintenance and sweeping of oil encountered by water as it moves through the reservoir. The recovery is between 10-30% of original oil in place.

c) Tertiary process which is obtained after secondary recovery uses miscible gases, chemicals and/or thermal recovery to displace additional oil after the secondary recovery process become uneconomical.

The idea of EOR process is about the efficient microscopic and macroscopic displacement. Microscopic displacement relates to the displacement or mobilization of oil at the pore scale. It is reflected in the magnitude of the residual oil saturation, *Sor*, in the region contacted by the displacing fluid. While macroscopic displacement efficiency is the effectiveness of the displacing fluid in the contacting the reservoir in a volumetric sense.

Alternative term conveying the same general concept are sweep efficiency and conformance factor. In equation form,

$$E = E_d \times E_v$$

Where,

E =overall displacement efficiency

E_d = microscopic displacement (fraction)

E_v = macroscopic displacement (fraction)

Factors affecting the microscopic displacement are miscibility between fluids, decreasing IFT between fluids, oil volume expansion and reducing viscosity. While for macroscopic displacement is controlled by mobility ratio. This ratio can contribute in improvement of sweep efficiencies.

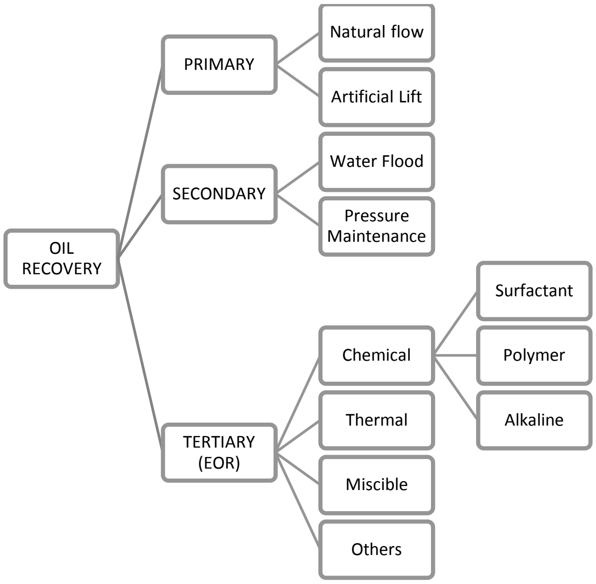


FIGURE 1 Oil Recovery Mechanism

1.1.2 Classification of EOR Process

Apart from the conventional, we have Enhanced Oil Recovery, which consist of mobility-control process, chemical, thermal, miscible and others like microbial, mechanical and so on.

a) **Mobility-Control Process**

It is a typical application whereby a solution of partially hydrolyzed polyacrylamide polymer in brine, at a concentration of a few hundred to several hundred ppm polymer, injected to displace oil towards the production wells. Partially hydrolyzed polyacrylamide polymer will affect the mobility in twi different ways which are solution of polymers have apparent viscosities that are larger than water and polyacrylamide polymers adsorb on porous media and mechanically entrapped as a result of their large physical size.

b) **Chemical Process**

Chemical processes target the reduction of IFT between the displacing liquid and oil. It comes from the injection of specific liquid chemicals which through their phase behavior leads to displacing of more oil. Surfactants and polymer have shown more potential for a higher EOR than any other method. In this process, a solution which contains surfactants is pumped in followed by polymer. The surfactant injection can only be justified when oil prices are relatively high and if the residual oil saturation after water-flooding process is high. This is because surfactants are expensive.

c) **Thermal Process**

This type of processes may be subdivided into hot-water floods, steam processes, and in-situ combustion. This is a single well method in which steam is injected into a production well for a specific period of time and the well is closed for a while. And when the well is opened for production, it will continue flow date diminish to a point when the entire procedure is repeated.

Production is increased through a combination of mechanisms, including viscosity reduction, steam flashing, oil swelling, and steam stripping. But the major problem with this method is control of the movement of the combustion front.

d) **Miscible Process**

The objective is to displace oil with a fluid that is miscible with oil at the conditions existing at the interface between the injected fluid and the oil bank that has being replaced. There are two major variations which are first-contact-miscible (FCM) and multiple-contact-miscible (MCM).

1.1.3 Surfactant

Surfactants are widely used and find a very large number of applications because of their remarkable ability to influence the properties of surfaces and interfaces. In petroleum industry, surfactant can be used for a few functions (Schramm, 2000).

TABLE 1 Function of Surfactant in Petroleum Industry

Type of System	**Function of surfactants**
Gas/Liquid Systems	▪ Producing oil well and well-head foams ▪ Oil flotation process froth ▪ Distillation and fractionation tower foam
Liquid/Liquid Systems	▪ Emulsion drilling fluids ▪ Enhanced Oil Recovery ▪ Heavy oil pipeline emulsions
Liquid/Solid Systems	▪ Reservoir wettability modifier ▪ Reservoir fines stabilizer ▪ Drilling mud dispersant

1.1.4 Hard Water

Hard water isn't water that's hard as rock. Instead, it's water that contains dissolved substances called minerals. These minerals contain the elements calcium or magnesium. Hard water does not harm human being but it is not suitable to be drinking water as it taste salty.

The minerals exists in the hard water will alter the composition in the surfactant solution. Thus, surfactant used must resist the impact or can deal with the difference.

1.2 Problem Statement

Surfactant is needed in EOR as to deal with the hydrocarbons and the fluids inside the reservoir. The function is to reduce the IFT inside the system. But, surfactant perform in its favorable condition. The performance of surfactant flooding is depends on the temperature, type of surfactant, concentration of surfactant, purity and hardness of water. Hard water adversely affects the water solubility of surfactants and can hamper the performance and produce precipitation. Without proper control of these factors, the surfactant might end up functionless and might affect the reservoir.

Hardness of water is the main problem as most of the seawater is considered as hard water. Thus, to prevent the form of precipitation, an optimum concentration of surfactant and salinity of the hard water need to studied.

1.3 Objectives

The objectives of this research are:

a) To investigate the phase behavior of surfactant in hard water and identification the suitable surfactant.
b) To find the parameter that contribute in maximizing the effectiveness and efficiency of surfactant.
c) To study the optimum salinity of the hard brine water, giving no precipitation in reaction with surfactant.

1.4 Scope of Study

This research is in EOR field. This project is begins with finding the information regarding surfactants and behavior of them. The behavior of surfactant is the mechanism that being the manipulating factor of the function of surfactant. The phase behavior will be used to estimate optimum concentration of surfactant that react with formation water/brine water and give no precipitation as result. For this project, the area covered are:

a) Optimum concentration of aqueous solution and salinity of brine water.
b) Characterization of emulsion
c) Emulsion retention of oil-in-water emulsion
d) Wettability alteration of reservoir rock though direct and indirect methods

1.5 Relevancy of Project

In Malaysia, the fields are located offshore which is in deep sea and have high salinity of water. In high salinity of water, it have high magnesium, calcium and iron ions. Thus, it is relevant to have further study on the phase behavior of surfactant flooding.

1.6 Feasibility of Project

Every final year students is given an exact 2 semesters to complete their Final Year Project (FYP). The project will be breaks into two parts which is FYP 1 and FYP 2. In the first semester, which are 14 weeks given, the author need to do research and literature review on the project. While in second semester, the author will do some the experiment parts to prove the research done in the first semester, and observes the result of the experiements.

CHAPTER 2

LITERATURE REVIEW

In this project, student will focused more on chemical processes which is surfactant flooding. In order to drives chemical process, a number of liquid chemicals are used such as surfactants, polymers and hydrocarbon solvents. This process involves the injection of specific liquid chemical that effectively displace oil to reduce the IFT between the displacing oil and liquid. Among chemical flooding methods, surfactant flooding processes are particularly effective for recovering a large fraction of conventional oil (25° API or higher) left in the reservoir after water flood – which could be as much as 60% of the original oil in place. The basic principle behind the use of surfactant flooding is to recover the capillary-trapped residual oil remaining after water flooding by injecting surfactant solution; the residual oil can be mobilized through a strong reduction in the interfacial tension (IFT) between oil and water. If the interfacial tension can be reduced between the oil and water, the resistance to flow is definitely reduced. If surfactants are properly selected, a reduction in interfacial tension could be as much as 10-3 dynes/cm, a recovery of 10-20% of the original oil in place, when not producible by other technologies, is technically and economically feasible by surfactant feasible by surfactant flooding.

Surfactant is a short term for surface active agents. These chemical substances adsorb or concentrate at a surface or fluid/fluid interface when present at low concentration in a system (M.J, 1978). Surfactants are wetting agents that lowered the surface tension of a liquid and allowing for easier spreading. Surfactant molecule is amphiphilic, that is, it has a polar water-soluble group attached to a non-polar insoluble hydrocarbon chain. This dual nature of the surfactants makes them reside at the interface between aqueous and organic phases thereby lowering the interfacial tension. Figure 2 is the simplified sketch of the surfactant molecule. The tail group is the hydrocarbon portion while the head group is the ionic portion. The hydrocarbon portion can be either straight chain or branched. The entire molecule is called as an amphiphile because it contains the nonpolar and polar moieties. To characterized the surfactants, it is commonly is hydrophilic/lipophilic balance (HLB) (Garret, 1972) which it indicates the tendency to solubilize in oil or water and thus the tendency to form water-in-oil or oil-in-water emulsion. High HLB numbers are tend to be less soluble in oil and to form water-in-oil emulsion. Surfactant may be classified into ionic nature of the head group itself as anionic, cationic, nonionic and zwitterionic. The description as follows (Ottewill, 1984):-

a) Anionic: have negative charge of head group. Example sodium dodecyl sulfate
b) Cationic: have a positive charge of head group. Example dodecyltrimethylammonium bromide
c) Nonionic: does not ionize, and the head group is larger than the tail group. Example dodecylhexaoxyethylene glycol monoether
d) Zwitterionic: has two groups of opposite charge. Example 3-dimethyldodecylamine propane sulfonate

The most common used surfactant would be sulfonated hydrocarbons. Most of the time, anionic and nonionic surfactants are used in EOR processes. Anionic surfactants are the most preferable as they have good surfactant properties, stable and exhibit relatively low adsorption on reservoir rock. Furthermore, anionic surfactant can be produced economically. However, nonionic have been used as to improve the behavior of surfactant systems but it is not as good as anionic. Unlike cationic, it is less used as they absorb strongly on reservoir rock. For non-ionic have been used primarily as co-surfactant to improve the behavior of surfactant system and much more tolerant of high salinity brine. More or less, the reaction to reduce IFT is not as good as anionic.

Surfactants have been widely used because they are effective at attaining low IFT, relatively cheap, and chemically stable (Salter, 1986). Surfactants can be considered practical for EOR applications have solubility in water. Sulfonates are soluble due to its structure that have ionic sulfonate group SO_3^-. Thus, with this condition, they tend to precipitate or become primarily oil-soluble in brines that have high salinity content which is high in calcium or magnesium ion content. Magnesium and calcium sulfonates are oil-soluble. And so as tail of hydrocarbon, affects the solubility. High salinity will affects the water solubility of surfactants and can alter the performance. In general, increasing salinity of an aqueous phase (brine) decreases the solubility of an ionic surfactant. Surfactant is driven out of brine as the electrolyte concentration increases. According to Baviere, the alpha olefin sulfonates are more tolerant of salinity than typical petroleum sulfonates (Baviere, Bazin, & Noik, 1988).

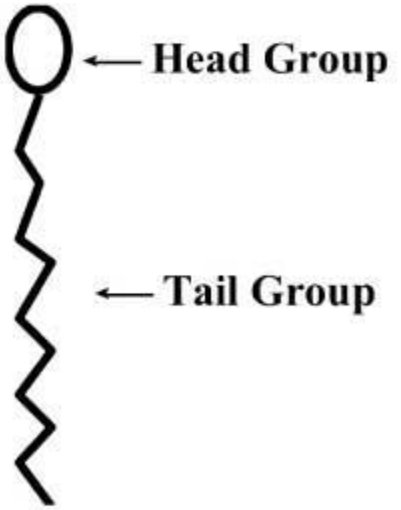


FIGURE 2 Schematic of surfactant molecule

2.2 Mechanism

A few mechanism were identified to be the parameters and condition for surfactants to performs.

a) **Microemulsion/Micelles Flooding**

Microemulsion is stable emulsion of hydrocarbons and water in the presence of surfactants and co-surfactants. They are described by spontaneous formation, ultra-low interfacial tension and thermodynamic stability. The wide-spread in microemulsion and use in industrial application is based on their high capability in solubilization capacity for both hydrophilic and lipophilic compound. (Schramm, 2000)

As with the alkali or surfactant or polymer formulations, micro emulsion are injected to the reservoir as part of EOR and to lower the interfacial tension (IFT) for mobilize residual oil trapped in the reservoir after water flooding. And there is strong correlation exists between phase behavior of a micro emulsion system and IFT. A number of variables affect the phase behavior thus IFT, including temperature; types of ion in the brine phase, alcohol and oil; water oil ratio; surfactant structure; addition of polymer to solution; and yet pressure.

b) Capillary Number

Capillary number can be defined as the ratio of the viscous forces and local capillary forces. It can be calculated by using the equation below:

$$N_c = \frac{\vartheta\mu}{\sigma}$$

ϑ = Effective Flow rate

μ = Viscosity of displacing fluid

σ = Interfacial Tension

Figure 3 shows an illustration of the Capillary Desaturation Number relates with capillary number to the residual oil saturation.

An increase in capillary number implies a decrease in residual oil saturation and thus an increase in oil recovery. In order to achieve an increase in the capillary number, an increase in the viscosity of the displacement fluid or an increase in the velocity of displacement may not be effective on a field scale. However, a high N_c can be achieved by reducing the interfacial tension between water and oil by the use of surfactants

Critical capillary numbers, NC_{ri} is a point which correspond to break the desaturation curve. To improve the oil recovery relative to water flooding by using chemicals, the capillary number must be significantly higher than the critical capillary pressure. The factors that control the desaturation curves and critical capillary number depend on pore size distribution, ration of body to pore throat diameter and wettability of the reservoir.

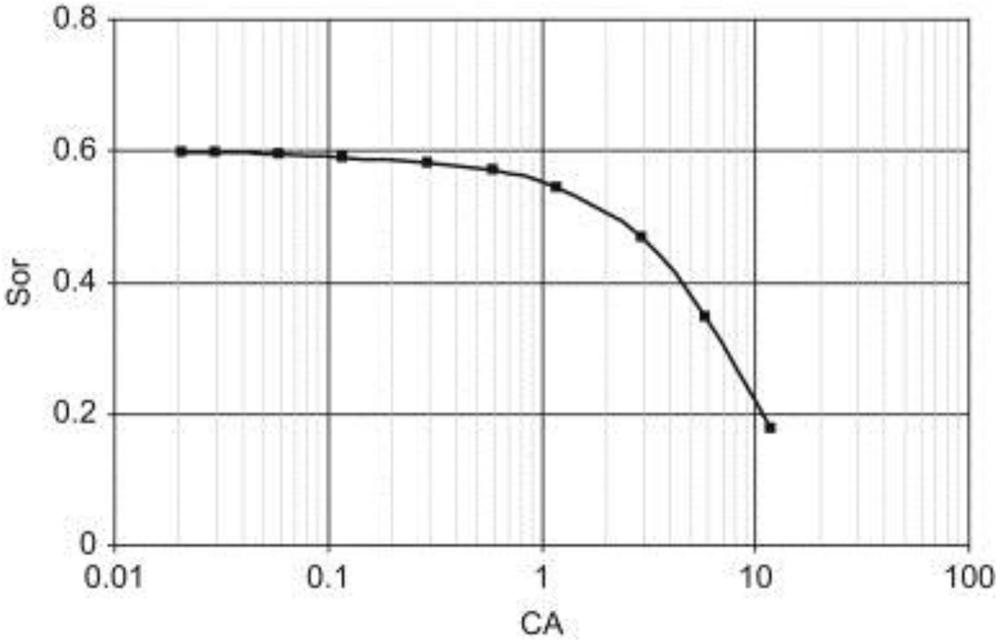


FIGURE 3 Graph of residual oil saturation

c) Volumetric Sweep Efficiency

In volumetric displacement, it is always favorable to have mobility ratios less than one ($M < 1$) for better sweep efficiency. In surfactant flooding, for successful displacement of the oil bank towards the producing well, the mobility ratio should be as low as possible. A low mobility slug improves the volumetric sweep efficiency by ensuring that the injected fluids get into low permeable layers and into the interior parts of the reservoirs that are far from the injection and production wells. The importance of mobility ratio in layered reservoir is made more evident by simulation studies of surfactant floods in such reservoirs. Performance of surfactant flooding is independent on the size of slug (small or large) injected.

d) Interaction Between Surfactant and Rock (Retention)

Retention of surfactant has being regarded as one of the main factors for the unfavorable economics of surfactant flooding. Retention, which at times could be as much as 90% of injected surfactant, could be by precipitation, phase trapping and adsorption. Precipitation and phase trapping could however be prevented by using salt tolerant surfaces (S.M, 1992). Unfortunately, the solution to adsorption is far from being solved as adsorption will always occur at solid-liquid interface.

2.3 Phase Behavior of Surfactant Flooding

The main concept in surfactant flooding is that surfactants are injected into the reservoir to control the phase behavior properties inside the oil reservoir. The aim of this process is to lower the IFT between oil and water thus displace or mobilize the trapped oil (Sara Billow Sandersen). Among the critical parameter surfactant based Enhanced Oil Recovery (EOR), some must be investigated at an early stage in the decision and evaluation process. It is obviously the case of reservoir geological parameter including: temperature, rock type, oil properties and etc. another criteria concerns the brine composition. During flooding, surfactant solubility, interfacial properties, adsorption could be strongly impacted by major changes in brine composition along the process (B. Bazin, 2011). Microemulsion system can be designed that have ultralow IFT values with either aqueous or hydrocarbon phase which is about 10^{-3} dynes/cm. This property makes micelles solutions, or microemulsion, attractives for use as oil recovery agents. Ultralow IFT's correlates with high solubilization of oil and water by microemulsion system (R. N. Healy, Reed, R. L., and Stenmark, D. G., June 1976).

2.3.1 Effect of Brine Salinity on Phase Behavior

In general, surfactant flooding performances has been demonstrated using soft brines/moderate salinities as the surfactant make up water. Rare exception included costly microemulsion fluids in hard brines. (Santanna, 2009).

Theoretically, increasing salinity of aqueous phase (brine water) decrease the solubility of an ionic surfactant. Surfactant is driven out of a brine as the electrolyte concentration increases. Thus, we can conclude that brine salinity has significant effect on phase behavior. The system can be shown like in the Figure 4 below.

At relatively low brine salinity, solutions at concentration with multiphase region divide into a water-external microemulsion and an excess-oil phase. The microemulsion is saturated with oil at that composition and temperature.

At intermediate salinity, the system is more complex. At lower surfactant concentrations, a three-phase region exist. Solutions with overall concentration within this region separate into microemulsion, water and oil phases.

While at high salinity, the system separates into an oil-external microemulsion (hydrocarbon or oleic phase) and an excess, denser brine water. This is called as upper-phase microemulsion. At this system, precipitate will formed and affect microemulsion's performance. This condition must be avoided.

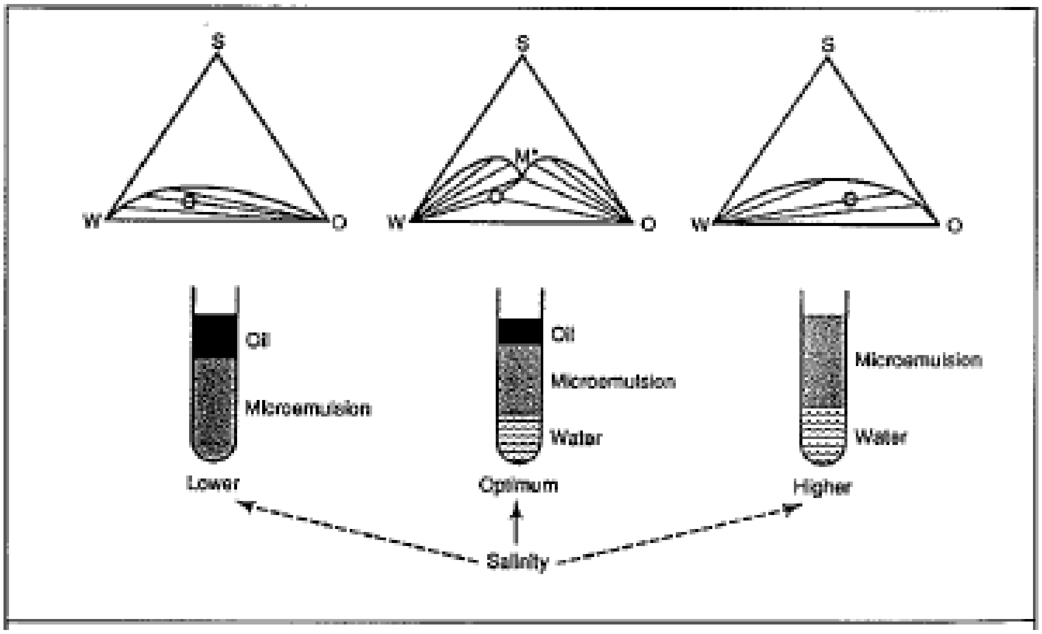


FIGURE 4 Effect of salinity on microemulsion phase behavior (R. N. Healy, Reed, R. L., and Stenmark, D. G., June 1976)

2.3.2 Effect of Type of Oil on Phase Behavior

Type of oil also give different impact to the system. Oil can be categorized as aromatic, paraffin and etc. When paraffin oil is used, the optimal salinity is increased (R. N. Healy, Reed, R. L., and Stenmark, D. G., June 1976) while using aromatic oil, the optimal salinity and the IFT at the optimal salinity is decreased. The effect of oil type on phase behavior can be unpredictable. Thus, each oil will gives different type of phase behavior and optimal salinity.

2.3.3 Effect of Type of Surfactant on Phase Behavior

Type of surfactant play role in phase behavior as the ion inside the surfactant will react with the brine water in the sea. High performance surfactants for chemical EOR are mostly anionic surfactants. These surfactants typically exhibit limited tolerance to high salinity brines. Divalent cations are also known to strongly impact surfactant adsorption. Therefore, designing surfactant formulation with high salinity or hardness is challenging (R. Tabary, 2013).

2.3.4 Effect of Temperature on Phase Behavior

Increase in temperature causes solubilization parameter V_o/V_s and V_w/V_s to decrease at optimal salinity, increasing the IFT and shifting the optimal salinity for a given system to a higher value (Don W. Green, 1998). In this project, the author will keep the temperature constant.

2.3.5 Solubilization Parameters

From phase behavior, we could determine solubilization ratio. The volume of oil and brine that can be solubilized by microemulsion is of interest in characterizing a surfactant system. The solubilization ratio is amount of oil and water solubilized by unit surfactant in terms of solubilization parameters (R. N. Healy, Reed, R. L., and Stenmark, D. G., June 1976).

Solubilization parameters are defined as follows (Bourrel, 1988):-

$$P_o = \frac{V_o}{V_s} = \frac{volume\ of\ oil\ in\ microemulsion\ phase}{volume\ of\ surfactant\ in\ microemulsion\ phase}$$

$$P_w = \frac{V_w}{V_s} = \frac{volume\ of\ water\ in\ microemulsion\ phase}{volume\ of\ surfactant\ in\ microemulsion\ phase}$$

This equation is important in phase behavior. The value of V_s is the volume of surfactant in the system and includes no co-surfactant. The surfactant is assumed to be in the microemulsion phase and not in the excess-oil or –water phases.

The salinity at which the parameter are equal is called optimal salinity for phase behavior.

2.4 Interfacial Tension of Surfactant Flooding

Interfacial Tension (IFT) is one of the parameter to measure the effectiveness of surfactant flooding. And function of using surfactant is to reduce the IFT of the microemulsion and recover more oil in production.

2.4.1 Interfacial Tension using Chun-Huh Equation

The solubilization ratio and Interfacial Tension at the middle phase can be predicted using the Chun-Huh equation (Khalid Kanan, January 2012) (S. Liu, 2008):

$$\sigma_{mo} = \frac{c}{(V_o/V_s)^2}$$

$$\sigma_{mw} = \frac{c}{(V_w/V_s)^2}$$

Where,

σ_{mo} = IFT between the oil phase and surfactant phase

σ_{mw} = IFT between the water phase and surfactant phase

c = constant, 0.3 mN/m

2.4.2 Interfacial Tension using Spinning Drop Tensiometer

Interfacial Tension nowadays can be measured using an equipment called Spinning Drop Tensiometer. By using this equipment, IFT can be measured accurately and can be done many times. This equipment is easy to use.

2.4.3 Correlation of IFT and Solubilization Parameters

The value of salinity at which $\sigma_{mo} = \sigma_{mw}$ is called the optimal salinity for IFT (R. N. Healy, Reed, R. L., and Stenmark, D. G., June 1976). This salinity usually very close to the optimal salinity for phase behavior previously defined as the salinity for which $V_o/V_s = V_w/V_s$.

The fact that optimal salinity for phase behavior is essentially equal to optimal salinity for IFT has an important result. IFT is relatively difficult to measure when tensions are ultralow. Instrument and equipment such as pendant drop or spinning drop must be used (Cayias, 1975). However, measurement of solubilization parameters is relatively easy. Thus, for a specific system under consideration, one can first determine optimal salinity by relatively easy phase measurement.

One correlation that describes the data of Healy is in this section of the form (R. N. Healy, Reed, R. L., April 1977):

$$\log(\sigma_{mo}/\sigma'_{mo}) = \frac{a}{m_o(V_o/V_s) + 1}$$

$$\log(\sigma_{mw}/\sigma'_{mw}) = \frac{b}{m_w(V_w/V_s) + 1}$$

Where a, b, m_o, m_w are constants and $\log \sigma'_{mw}$ and $\log \sigma'_{mo}$ are intercept values obtained from experimental data. The constant for both equations are specific to the surfactant and oil used to generate the phase behavior and interfacial data and to the temperature.

2.5 Field Application of Surfactant Flooding

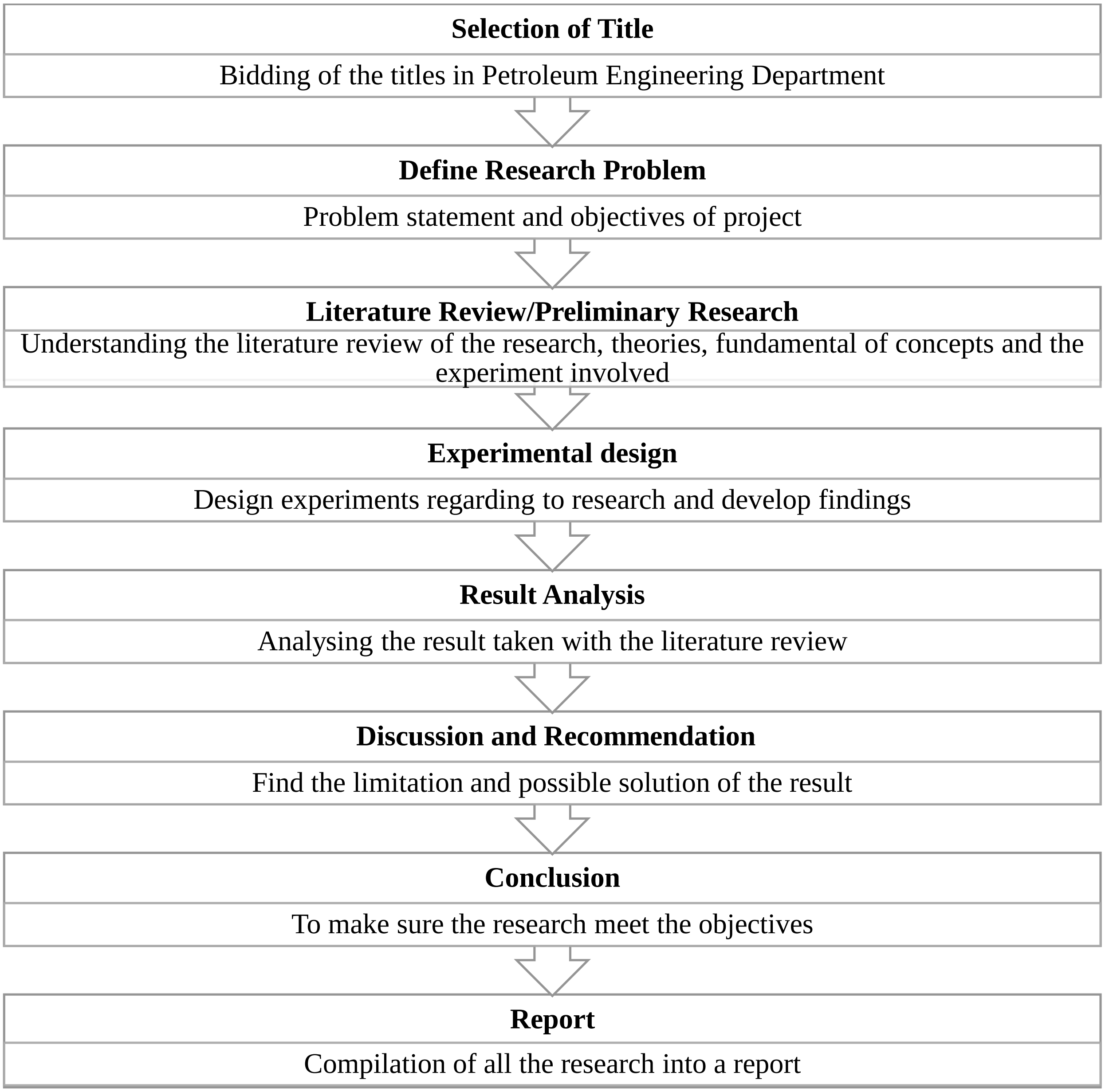
a) In new research, new anionic surfactants for EOR application had been discovered, named Gemini surfactant (Bo Gao, 2012). Gemini surfactants have been used in many different applications in the past. This surfactant consist covalently linked "conventional" surfactant via a spacer. It can consist a rich of variety of anionic and cationic surfactants. The tail of the hydrocarbon part is vary in length; the spacer itself can be flexible or rigid, hydrophilic or hydrophobic; and the polar group can be anionic, cationic, nonionic and zwitterionic. Gemini surfactant investigated were synthesized using two step reaction scheme (Gao, 2012) adopted from reported procedures. The chemical structure of the Gemini Surfactant is prepared by weighing the surfactant in distilled water and stirring using a magnetic stirrer at the desired experimental temperature.

b) In a research this year, a few experiments had been done to discover the phase behavior in order to overcome the challenging condition. Usually, the problem are hard brines and high temperatures (Oukhemanou-Destremaut, Douarche, Moreau, Bazin, & Tabary, 2013). When hard brine is used as surfactant make-up brine (injection brine), chemical adsorption is high using conventional injection strategies. This makes the overall process limited. Same goes as high temperature, which is more than 80ºC. So far, the proven method to handle hard brines is the water treatment itself. It is to reduce the level of divalent cations. However, it brings significant logistic issues related to the disposal of huge volume of calcium carbonates muds.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology



Selection of Title

Bidding of the titles in Petroleum Engineering Department

Define Research Problem

Problem statement and objectives of project

Literature Review/Preliminary Research

Understanding the literature review of the research, theories, fundamental of concepts and the experiment involved

Experimental design

Design experiments regarding to research and develop findings

Result Analysis

Analysing the result taken with the literature review

Discussion and Recommendation

Find the limitation and possible solution of the result

Conclusion

To make sure the research meet the objectives

Report

Compilation of all the research into a report

3.2 Key Milestone

TABLE 2 FYP I Gantt Chart

Detail/Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**
Project Title Selection	■	■						**M**							
Literature Review		■	■	■	■			**I**							
Extended Proposal Submission						■		**D**							
Study fundamental concepts related to the projects				■	■	■	■	**S**	■	■	■				
Proposal Defense								**E**	■	■					
Lab and Experiment								**M**			■	■	■		
Preparation of Interim Report														■	
Submission of Interim Report															■

TABLE 3 FYP II Gantt Chart

Detail/Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Progress Work Continuities	■	■	■	■	■	■	■	**M**								
Submission of Progress Report						■		**I**								
Project Work Continuities								**D**	■	■	■	■	■			
Pre-SEDEX								**S**			■					
Submission of Draft Report								**E**				■				

Submission of Dissertation (soft bound)								**M**					🟧			
Submission of Technical Paper													🟧			
Oral Presentation														🟧		
Submission of Project Dissertation (Hard Bound)																🟧

TABLE 4 Project Gantt Chart for FYP I

Detail/Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**
Project Title Selection	🟩	🟩						**M**							
Literature Review of Project			🟩	🟩	🟩	🟩	🟩	**I**	🟩	🟩	🟩				
Extended Proposal Report Submission						🟩		**D**							
Preparing Approval Letter for Using Laboratory								**S**	🟩	🟩					
Proposal Defense								**E**	🟩	🟩					
Requesting Apparatus for Lab and Experiment								**M**	🟩	🟩	🟩				
Preparing Chemicals and Solutions for Lab and Experiment										🟩	🟩	🟩			
Start the Experiments													🟩	🟩	🟩
Submission of Interim Report															🟩

TABLE 5 Project Gantt Chart for FYP II

Detail/Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Experiment 1 Aqueous Solubility Test	🟩	🟩	🟩												
Collecting Result of Experiment 1	🟩	🟩	🟩												
Experiment 2 Microemulsion Phase Behavior Test				🟩		🟩									
Submission of Progress Report						🟩									
Collecting Result of Experiment 2					🟩		🟩								
Experiment 3 IFT Measurement Test								🟩	🟩	🟩					
Collecting Result of Experiment 3								🟩	🟩	🟩					
Pre- SEDEX										🟩					
Submission of Draft Report											🟩				
Submission of Soft Bound and Technical Paper												🟩			
Oral Presentation													🟩		
Submission of Hard Bound															🟩

3.3 Project Activities

The author has managed to study on research papers that has related with the topic. From the studies and research, the author has come out with a lot of findings about the concepts, mechanism and theories related to the surfactant in EOR.

The author has to find the experiment of phase behavior of surfactant in EOR. The chemical used such as sodium dodecyl sulfate (SDS), Alcohol Alkoxy Sulfate (AAS), Sodium Chloride (NaCl), Magnesium Chloride ($MgCl_2$) can be found in the lab.

3.4 Experiment

3.4.1 Aqueous Solubility Test

TABLE 6 Procedure of Aqueous Solubility Test

<table>
<tr><th>Experiment Title</th><th colspan="2">Aqueous Compatibility Test</th></tr>
<tr><td>Objective experiment</td><td colspan="2">To find the optimum salinity aqueous solution using Sodium Dodecyl Sulfate (SDS) and Alcohol Alcoxy Sulfate (AAS) with hard water.
This experiment to show any presence of precipitate in the solution.</td></tr>
<tr><td>Theory of the Experiment</td><td colspan="2">The experiment was done to evaluate the aqueous solubility limitation by mixing the surfactant whether SDS or AAS with hard water solution in a range of salinity.
Expected result of this experiment is with increasing of salinity solution, the aqueous solution have chance to turn cloudy. While decreasing with salinity will turn aqueous to separate in phase.</td></tr>
<tr><td>Methodology</td><td>Equipment/Apparatus</td><td>10 ml measuring cylinder, weighing scale, spatula, convection oven, pipette</td></tr>
</table>

	Material/Chemical	Distilled Water, Sodium Chloride, Magnesium Chloride, Sodium Sulfate, Calcium Chloride, Potassium Chloride, Sodium Dodecyl Sulfate, Alcohol Alcoxy Sulfate
Identification of Hazard	All the chemicals are volatile. Alcohol Alkoxy Sulfate contain alcohol which is hazard if in contact.	
Procedure	Preparation of stock solution - Surfactant stock solution: surfactant of SDS and AAS mixed with distilled water until diluted. - Hard water: prepared by mixing Sodium Chloride, Magnesium Chloride, Sodium Sulfate, Calcium Chloride, Potassium Chloride in distilled water using the respective formula; $\frac{x\ \%}{100\ \%} \times 100ml\ of\ solution = y\ g\ of\ solute$ **x = percentage of solution **y = chemical substances	
	Procedure of testing 1. Stock solution of hard water and surfactants were prepared according to their respecting percentages. 2. From the stock solution, the hard water component with SDS were calculated according to their proportion. 3. After calculate the proportion needed for every sample, the solution is prepared in the measuring cylinder using pipette.	

4. Once all the component added, the measuring cylinders were gently shaken and set inside the convection oven at the temperature of 60°C.
5. After equilibrium reached (24 hours), the measuring cylinder were checked visually. The cloudiness and phase separation occurred were recorded.
6. The procedure is repeated for AAS with concentration 1% and 2%.

Data

Solution		**Precipitation**	**Cloudiness**
SDS 2%	Brine Water (%)		
	0.50		
	1.00		
	1.50		
	2.00		
	2.25		
	2.50		
	2.75		
	3.00		
	3.25		
	3.50		
	3.75		
	4.00		

<table>
<tr><td></td><td><table><tr><td></td><td>4.25</td><td></td><td></td></tr><tr><td></td><td>4.50</td><td></td><td></td></tr></table></td></tr>
<tr><td>Expected Result</td><td>All the data recorded in the table above. Then it will be interpreted by observing the solution after equilibrium.</td></tr>
<tr><td>Conclusion</td><td>The equilibrium solutions should be a single and clear phase at the optimum salinity.
After the optimal salinity determined, the salinity will be used for micro emulsion compatibility test.</td></tr>
</table>

3.4.2 Microemulsion Phase Behavior Test

TABLE 7 Procedure of Microemulsion Phase Behavior Test

Experiment Title	**Microemulsion Compatibility Test of Surfactant Solution**	
Objective	To find the optimum concentration and salinity aqueous solution using Sodium Dodecyl Sulfate (SDS) and Alcohol Alkoxy Sulfate (AAS) with crude oil and brine water (NaCl) or distilled water to avoid precipitation of micro white particle.	
Theory	Brine water has different hardness which is depend on the ions of particles. The reaction of surfactant might produce precipitation. This experiment will test the compatibility of surfactant with the brine water.	
Methodology	**Equipment/Apparatus**	Test tube, graduated cylinder, weighing scale, convection oven
	Material/Chemical	Distilled Water, Sodium Chloride, Magnesium Chloride, Sodium Sulfate, Calcium Chloride, Potassium Chloride, Sodium Dodecyl Sulfate, Alcohol Alcoxy Sulfate, crude oil
Hazard Identification	All the chemicals involved are volatile. Inhalation can cause irritation to the lungs and will cause irritation to the skin.	
Experiment procedure	**Preparation** 1. The mass of Sodium Dodecyl Sulfate needed is calculated using the following formula: Mass = (volume x mass percentage) / (100 - mass percentage)	

*For example, to make a 1 percent solution using 60 mL of distilled water, this equation used to determine the amount of sodium hydroxide to be used:

Mass = 60 x 1 / (100 - 1) = 0.6 g

2. The calculated amount of Sodium Dodecyl Sulfate (SDS) is weighed on the scale. Distilled water of 60 mL is poured into the test tube, and add Sodium Dodecyl Sulfate (SDS). The solution is mixed with the spoon or gently swirl the test tube until the salt dissolves completely.
3. Then, the mass of sodium chloride is calculated using above formula for example 1% solution in 60 mL then add into test tube.
4. About 40mL crude oil is measure and added into test tube to make the solution 100 mL.
5. The samples were placed in a convection at temperature 70^{o}C.
6. The experiment is continue with the same step by using different type of surfactant which is Alcohol Alkoxy Sulfate.

Sample testing

The test tube is shacked and waits for several minute to see whether precipitation occurs or not. If the precipitation occurs, above step is repeated until there is no precipitation using different percent of Sodium Chloride.

Data Recording

Salinity	2% SDS			1% AAS			2% AAS		
	V_o	V_s	V_w	V_o	V_s	V_w	V_o	V_s	V_w
0.5									
1.0									
1.5									
2.0									
2.5									
3.0									
3.5									
4.0									

Expected Results

Calculation	Mass = (volume x mass percentage) / (100 – mass percentage)

Data interpretation :

Data recorded will be interpreted by observing the stability of emulsion formed.

Conclusion

Through this experiment, the optimal concentration of surfactant and brine will be determined.

3.4.3 Interfacial Tension Measurement Test

TABLE 8 Procedure of Interfacial Tension Measurement Test

Title	**IFT measurement test using spinning drop method for given duration period.**
Objective	To make correlation between dynamic IFT and retention of emulsion.
Material	Crude oil, surfactant (Sodium Dodecyl Sulfate and Alcohol Alkoxy Sulfate) containing brine solution.
Apparatus	Test tube, syringes
Machine	Spinning Drop Tensiometer with FALCON software
Procedure	1. Open the application – SVT20 2. Set the temperature 3. Insert tube inside the equipment and make sure the tube is set static. 4. Set rotational speed(rpm for the tube to spin) around 1200 5. Set the density, RI (Phase 1 denser fluid, Phase 2 less dense fluid) 6. Inject crude (1 drop) – pull out the syringe as soon as possible. 7. Adjust rpm to get the horizontal diameter of the drop to be at least 3 times the vertical diameter of the drop, or more 8. Adjust the camera to focus to the wanted drop image 9. On screen : Drop type : Full Mode : Profile Fit (L-Y / VG) Vertical scale : adjust to fit if the size of the drop is not ok)

	10. On the image : Put the square on the drop Calibrate (3 run) Extract profile When the wanted shape is found, fix the camera For Static IFT a) Set single measurement b) Hold drop c) Take the IFT reading on the image d) Save result 11. Stop rotation 12. Take out the tube and clean

3.5 Tools, Materials and Softwares

a) Measuring Cylinders

10 mL measuring cylinders are used in the microemulsion phase behavior experiment. The scale on the measuring cylinder is used to measuring the height of water, oil, emulsion and precipitates formed after equilibrium state of phase behavior.

b) Weighing Scale

Used to measure the weight of solid chemicals to make solutions in aqueous compatibility and microemulsion phase behavior experiment. The weighing scale must be accurate in order to make accurate concentration of solution.

c) Convection Oven

For incubation purposes. The temperature is set to be fixed throughout the experiments.

d) Spinning Drop Tensiometer

A machine used to measure interfacial tension (IFT). The machine is supported with a software called FALCON. The machine operated by spinning the samples inside heavy-glass tube. FALCON software used to captures the image of the samples in big size and measure the IFT of samples.

e) Microsoft Office

This software is used to make the reports, calculations, graphs, and presentation. The software used are Microsoft Words, Microsoft Excel and Microsoft PowerPoint.

f) EndNote

This software used to make citation of each research done in the report. The citation used for the referencing.

CHAPTER 4

RESULT AND DISCUSSION

Author had done a few experiment for the phase behavior of the surfactant based on the parameters covered. The experiments are:

- Aqueous Solubility Test
- Microemulsion Phase Behavior Test
- Interfacial Tension Measurement Test using Spinning Drop

4.1 Aqueous Solubility Test

This experiment is to test the homogeneity and thermodynamic stability of the solution. This is also one way of screening the salinity of brine water and concentration of surfactant that will give good result. For this project, the author only used anionic surfactant. Anionic surfactant have been most widely used because they have good surfactant properties, are relatively stable, exhibit relatively low adsorption on reservoir rock, and can be manufactured economically.

4.1.1 Aqueous Solubility Test using 2% Sodium Dodecyl Sulfate

At first, Aqueous Test is conducted by using Sodium Dodecyl Sulfate (SDS) as the surfactant.

TABLE 9 Result of Aqueous Solubility of 2% SDS

Solution		**Precipitation**	**Cloudiness**
SDS **(2%)**	**Brine Water (%)**		
	0.50	No	Clear
	1.00	No	Clear
	1.50	No	Clear
	2.00	No	Clear
	2.25	No	Clear
	2.50	No	Clear
	2.75	No	Clear
	3.00	No	Clear
	3.25	No	Clear
	3.50	No	Clear
	3.75	No	Clear
	4.00	No	Clear

After run all the salinity, the author found that there is no reaction even at high salinity solution. The author assumed due to poor performance, Sodium Dodecyl Sulfate would not be able to give any reaction. SDS does not strongly influence the reaction. This could be due to several effect:

1. The SDS has such a low density that it perturbs only a tiny amount of the salinity molecules. The signal change that results from SDS and salinity interaction is below the author detection limit.
2. The SDS is not interacting strongly with the oil molecules.

Thus, SDS result is rejected and need to be replaced with another anionic surfactant.

4.1.2 Aqueous Solubility Test using Alcohol Alkoxy Sulfate

- **Aqueous Solubility Test using 1% Alcohol Alkoxy Sulfate**

TABLE 10 Aqueous Solubility Test of 1% AAS

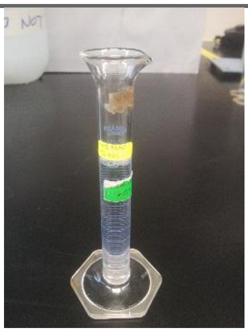
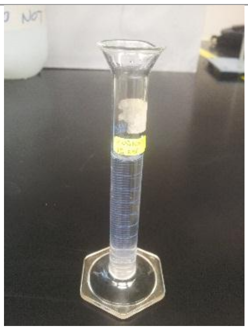
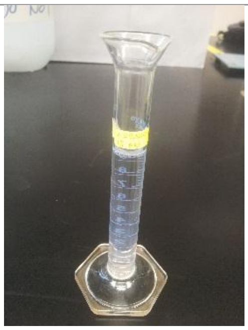
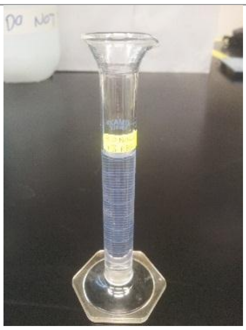
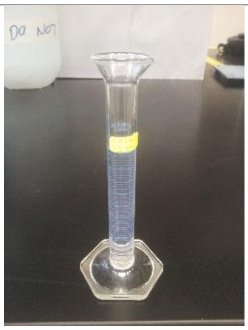
1% of Alcohol Alkoxy Sulfate		
		
0.5 % Brine Water	**1.0 % Brine Water**	**1.5 % Brine Water**
		
2.0 % Brine Water	**2.5% % Brine Water**	**3.0 % Brine Water**
		
3.5 % Brine Water	**4.0 % Brine Water**	

TABLE 11 Result of Aqueous Solubility Test of 1% AAS

Solution		**Precipitation**	**Cloudiness**
AAS (1%)	**Brine Water (%)**		
	0.50	No	Clear
	1.00	No	Clear
	1.50	No	Clear
	2.00	No	Clear
	2.50	No	Clear
	3.00	No	Cloudy
	3.50	No	Cloudy
	4.00	Yes	Cloudy
	4.50	Yes	Cloudy

From this experiment, according to Table 10, the solution of the surfactant react well and some of them give different reaction. Table 11, shows the result of the experiment. Reaction on 0.5% until 2.5% of salinity shows no changes. But, from 3.0% of salinity onwards, the solution turn cloudy and produced some precipitate. Apart from this experiment, we could make a screening phase for Aqueous Solubility Test to find better salinity (Zaitoun, Fonseca, Berger, Bazin, & Monin, 2003).

The author make deduction that higher the salinity, the aqueous tend to turn cloudy and produced precipitate. The salinity that produced precipitate and cloudy solution is not favorable condition for surfactant performance.

- **Aqueous Solubility Test using 2% Alcohol Alkoxy Sulfate**

TABLE 12 Aqueous Solubility Test of 2% AAS

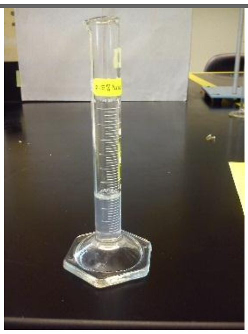
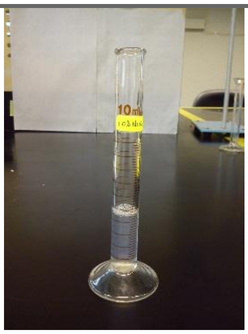
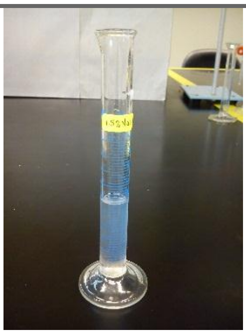
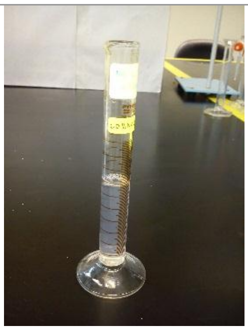
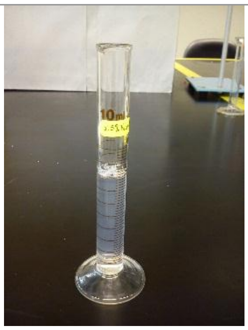
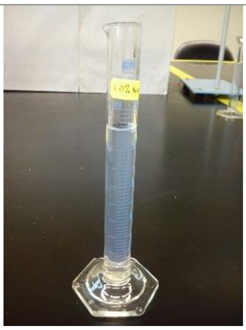
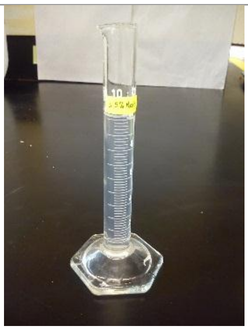
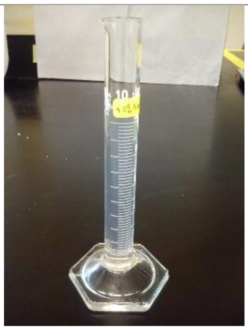
2% of Alcohol Alkoxy Sulfate		
		
0.5 % Brine Water	**1.0 % Brine Water**	**1.5 % Brine Water**
		
2.0 % Brine Water	**2.5% % Brine Water**	**3.0 % Brine Water**
		
3.5 % Brine Water	**4.0 % Brine Water**	

TABLE 13 Result of Aqueous Solubility Test of 2%

Solution		**Precipitation**	**Cloudiness**
AAS **(2%)**	**Brine Water (%)**		
	0.50	No	Clear
	1.00	No	Clear
	1.50	No	Clear
	2.00	No	Clear
	2.50	No	Clear
	3.00	No	Cloudy
	3.50	No	Cloudy
	4.00	Yes	Cloudy
	4.50	Yes	Cloudy

As expected, from this experiment, according to Table 12, the solution of the surfactant react well and some of them give different reaction. Table 13, shows the result of the experiment. Reaction on 0.5% until 2.5% of salinity shows no changes. But, from 3.0% of salinity onwards, the solution turn cloudy and produced some precipitate. Apart from this experiment, we could make a screening phase for Aqueous Solubility Test to find better salinity (Zaitoun, et al., 2003).

Same like the experiment before, the author make deduction that higher the salinity, the aqueous tend to turn cloudy and produced precipitate. The salinity that produced precipitate and cloudy solution is not favorable condition for surfactant performance.

After the test using two different concentration of Alcohol Alkoxy Sulfate and done the observation, the author detect difference occur to the solution. As we can see from the result, at high salinity, the solution turns to be cloudy and produce precipitate. At low salinity of brine water, the solution did not produce any precipitate and the solution was clear. Thus, salinity at 3.0% and above are not favorable for surfactant to perform effectively.

In general, increasing salinity of an aqueous phase (brine water) decrease the solubility of an ionic surfactant. Surfactant is driven out of a brine as the electrolyte concentration increases, thus, brine salinity has a significant effect on phase behavior. This is the reason why salinity increasing will produce precipitate.

4.2 Microemulsion Phase Behavior Test

- **1% of Alcohol Alkoxy Sulfate**

TABLE 14 Figure of Microemulsion Compatibility Test 1% after 96 hours

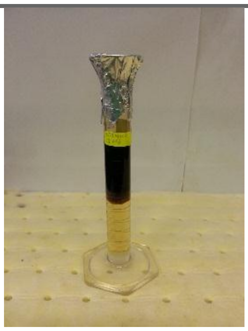
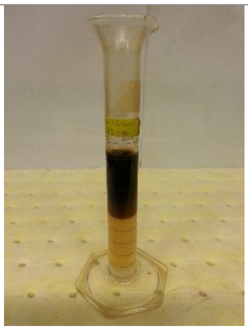
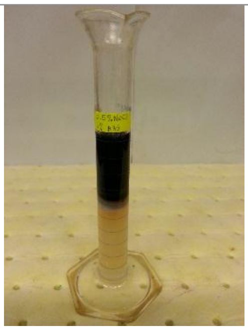
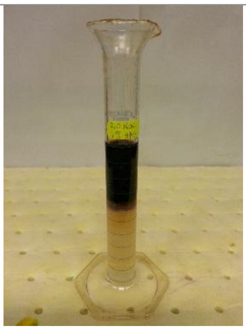
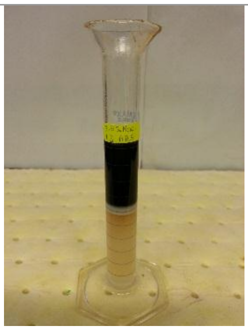
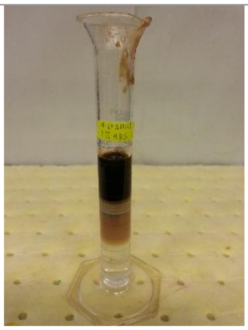
1% of Alcohol Alkoxy Sulfate		
		
0.5 % Brine Water	**1.0 % Brine Water**	**1.5 % Brine Water**
		
2.0 % Brine Water	**2.5% % Brine Water**	**3.0 % Brine Water**
		
3.5 % Brine Water	**4.0 % Brine Water**	

TABLE 15 Result of Microemulsion Compatibility Test 1% AAS at 96 hours

Salinity	**Microemulsion Volume (ml)**	**Precipitate Volume (ml)**	**Excess Oil Volume (ml)**	**Excess Water Volume (ml)**	**Volume of Oil V_o (ml)**	**Volume of Water V_w (ml)**	V_o/V_s	V_w/V_s
0.5	0.7	**0.0**	**4.0**	**5.7**	**0.0**	**-0.3**	**0**	**0**
1.0	**0.5**	**0.0**	**4.0**	**5.5**	**0.0**	**-0.1**	**0**	**0**
1.5	**0.6**	**0.0**	**4.0**	**5.2**	**0.0**	**0.2**	**0**	**0**
2.0	**0.5**	**0.0**	**3.1**	**5.3**	**0.9**	**0.1**	**1.5**	**0.019**
2.5	**0.1**	**6.0**	**3.8**	**0.0**	**0.2**	**5.4**	**0.33**	**1**
3.0	**0.4**	**5.8**	**3.6**	**0.0**	**0.4**	**5.4**	**0.67**	**1**
3.5	**0.005**	**6.0**	**3.8**	**0.0**	**0.2**	**5.4**	**0.33**	**1**
4.0	**0.005**	**6.0**	**2.8**	**4.0**	**1.2**	**1.4**	**2**	**0.185**

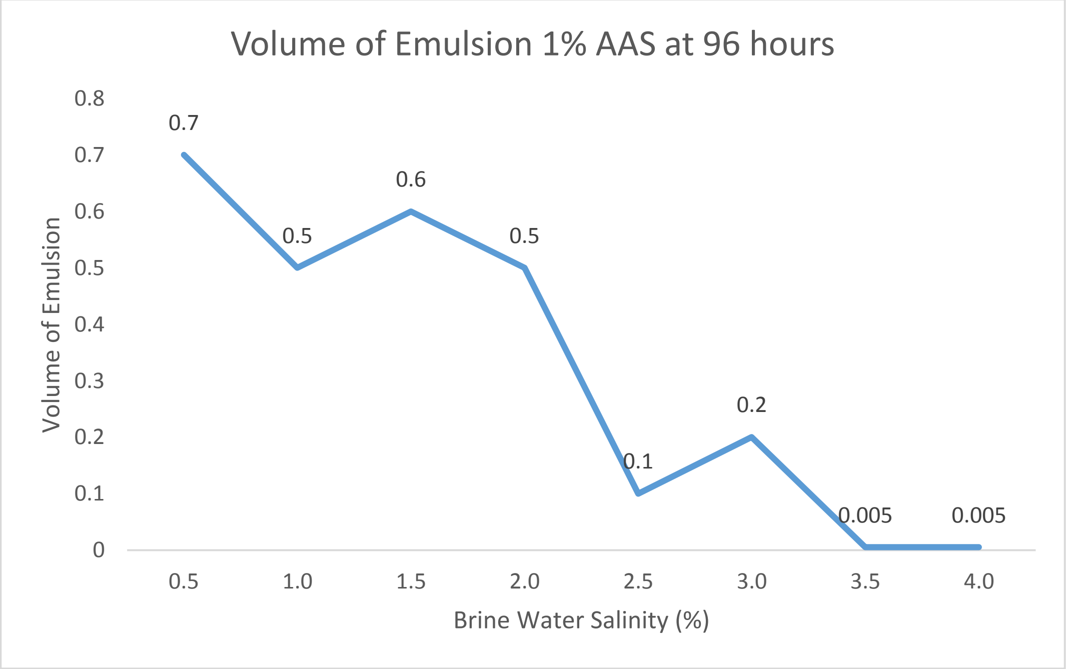


Figure 5 Volume of Emulsion 1% AAS at 96 hours

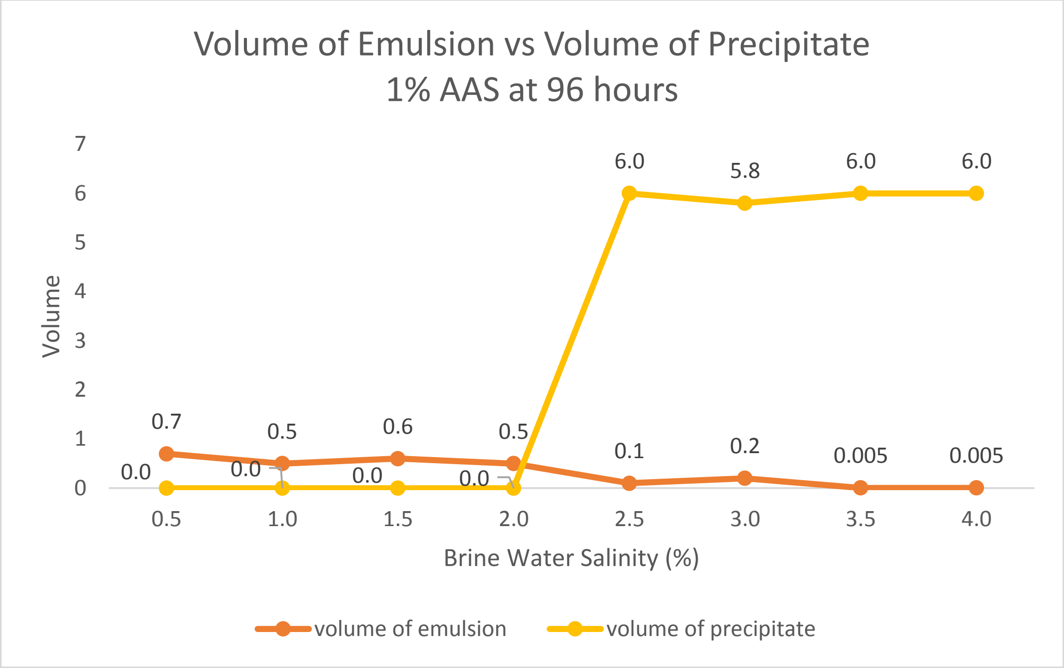


Figure 6 Volume of Emulsion vs Volume of Precipitate 1% AAS at 96 hours

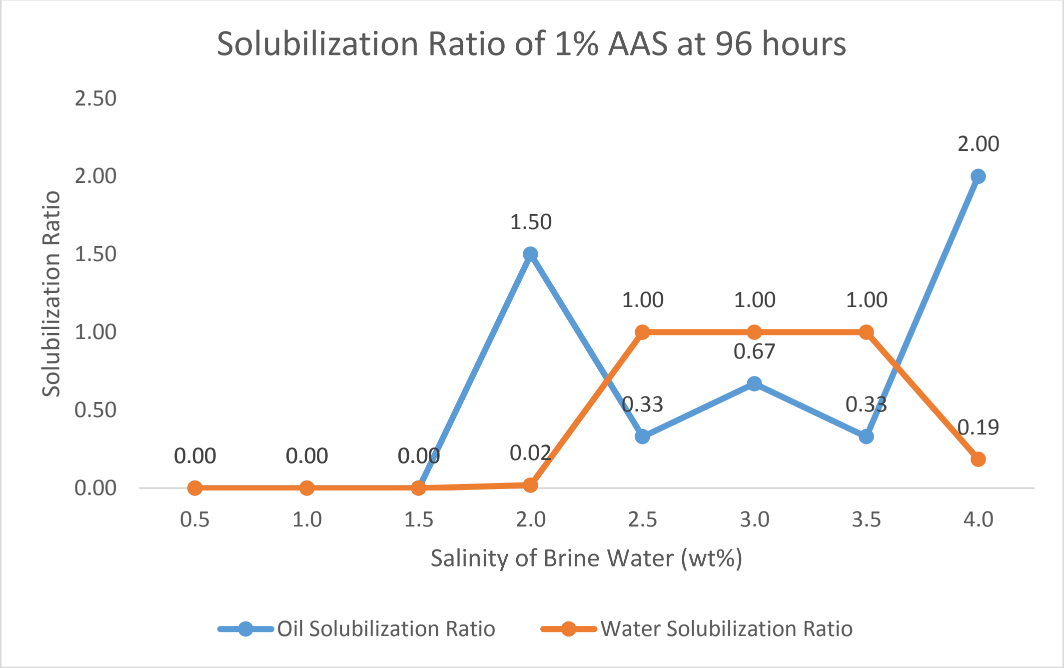


Figure 7 Solubilization Ratio 1% AAS at 96 hours

The composition of microemulsion compatibility test of 1% Alcohol Alkoxy Sulfate contain of 4 ml of crude oil which is from Dulang Field, 5.4 ml of brine water solution and 0.6ml of surfactant which is Alcohol Alkoxy Sulfate. From the composition of the sample, student able to calculate the solubilization ratio and plot the graph of Figure 7 to find optimum salinity.

The interaction between 1% of surfactant Alcohol Alkoxy Sulfate (AAS) with the crude oil will form microemulsion. According to the observation done in Table 14 the emulsion is in brown in colour. The emulsion is needed to reduce the interfacial tension between oil and rock. The Table 15 above shows the volume of each layer formed in the solution for each samples. For sample contain 0.5%, 1.0%, 1.5% and 2.0% salinity of brine water contain no precipitate. While sample with 2.5%, 3.0%, 3.5% and 4.0% salinity of brine water produced layers of precipitate.

From Figure 6, it shows the volume of emulsion versus volume of precipitate 1% AAS at 96 hours. As it shown, the volume of microemulsion decrease with increase of salinity while precipitation volume increase. The volume of precipitate start to increase at 2.5% of salinity.

From the observation, the excess volume of the oil and water can be used to calculate solubilization ratio between oil-surfactant and water-surfactant. The optimal salinity here is 2.30% that can be shown in Figure 7 which is the solubilization ratio graph.

Thus, from this experiment, it shows that the best salinity is the 2.3% as in can maintain high volume of emulsion in 96 hours and produce no precipitate.

- **2% of Alcohol Alkoxy Sulfate**

TABLE 16 Figure of Microemulsion Compatibility Test 2% after 96 hours

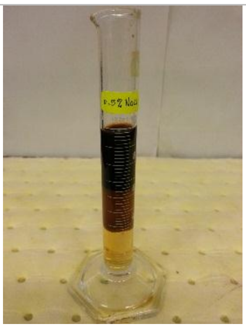
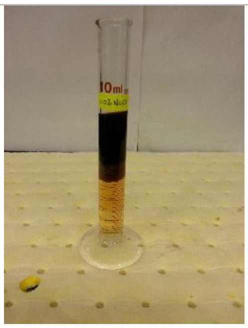
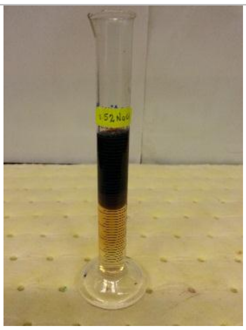
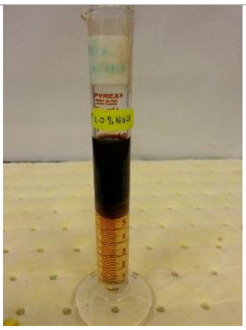
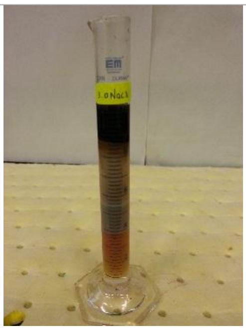
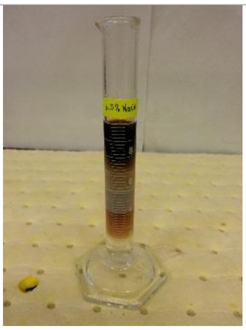
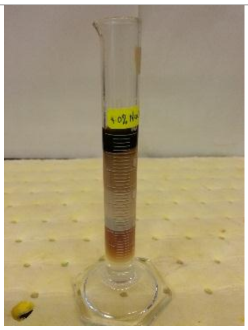
2% of Alcohol Alkoxy Sulfate		
		
0.5 % Brine Water	1.0 % Brine Water	1.5 % Brine Water
		
2.0 % Brine Water	2.5% % Brine Water	3.0 % Brine Water
		
3.5 % Brine Water	4.0 % Brine Water	

Table 17 Result of Micro Emulsion Compatibility Test at 2% after 96 hours

Salinity	**Microemulsion Volume (ml)**	**Precipitate Volume (ml)**	**Excess Oil Volume (ml)**	**Excess Water Volume (ml)**	**Volume of Oil V_o (ml)**	**Volume of Water V_w (ml)**	V_o/V_s	V_w/V_s
0.5	0.8	0.00	3.6	5.6	0.4	-0.8	0.33	-0.67
1.0	0.8	0.00	3.6	5.8	0.4	-1.0	0.33	-0.83
1.5	0.6	0.00	3.6	5.6	0.4	-0.8	0.33	-0.67
2.0	0.5	0.00	3.7	5.8	0.3	-1.0	0.25	-0.83
2.5	0.1	0.10	4.0	5.8	0.0	-1.0	0.00	-0.83
3.0	0.0	5.80	2.2	0.5	1.8	4.3	1.5	3.58
3.5	0.0	4.50	3.0	2.0	1.0	2.8	0.83	2.33
4.0	0.0	5.20	2.6	1.8	1.4	3.0	1.17	2.50

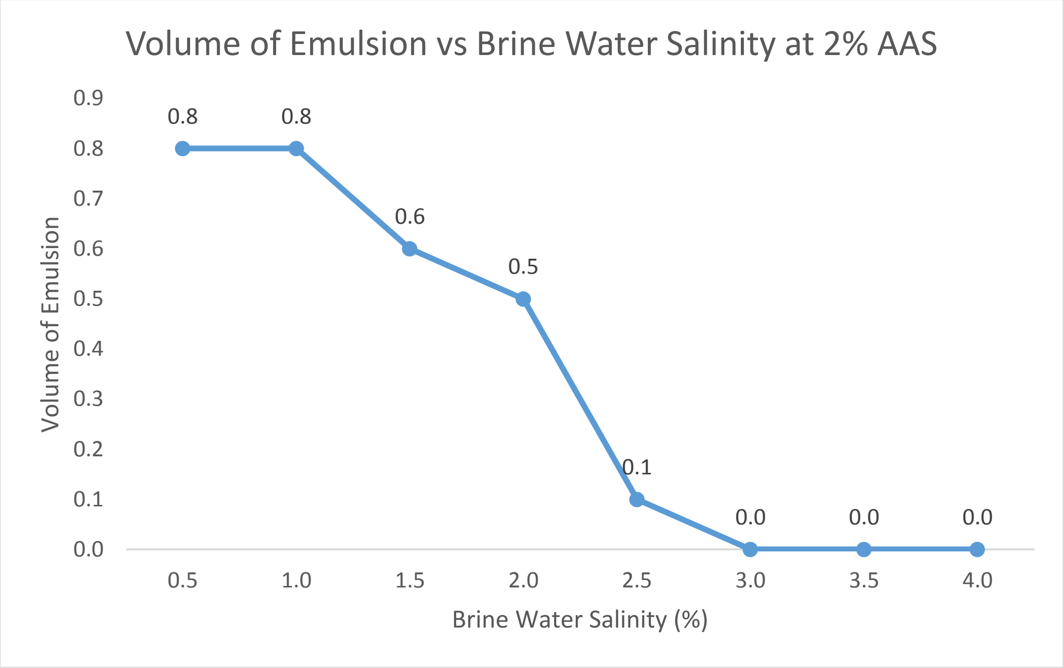


Figure 8 Volume of Emulsion vs Brine Water Salinity at 1% AAS

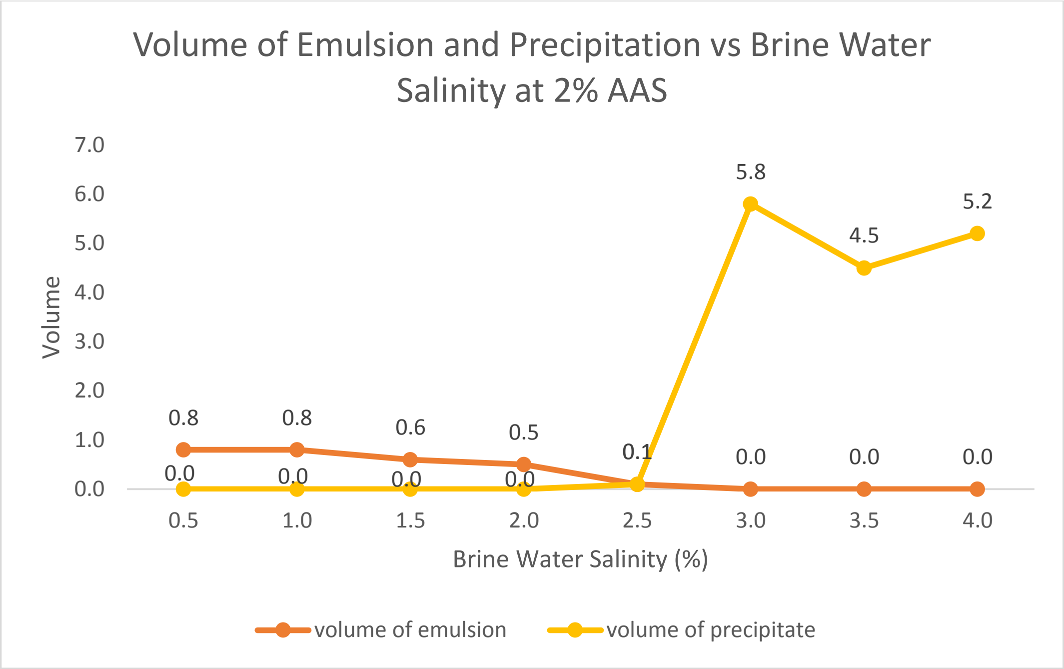


Figure 9 Volume of Emulsion and Precipitate vs Brine Water Salinity at 1% AAS

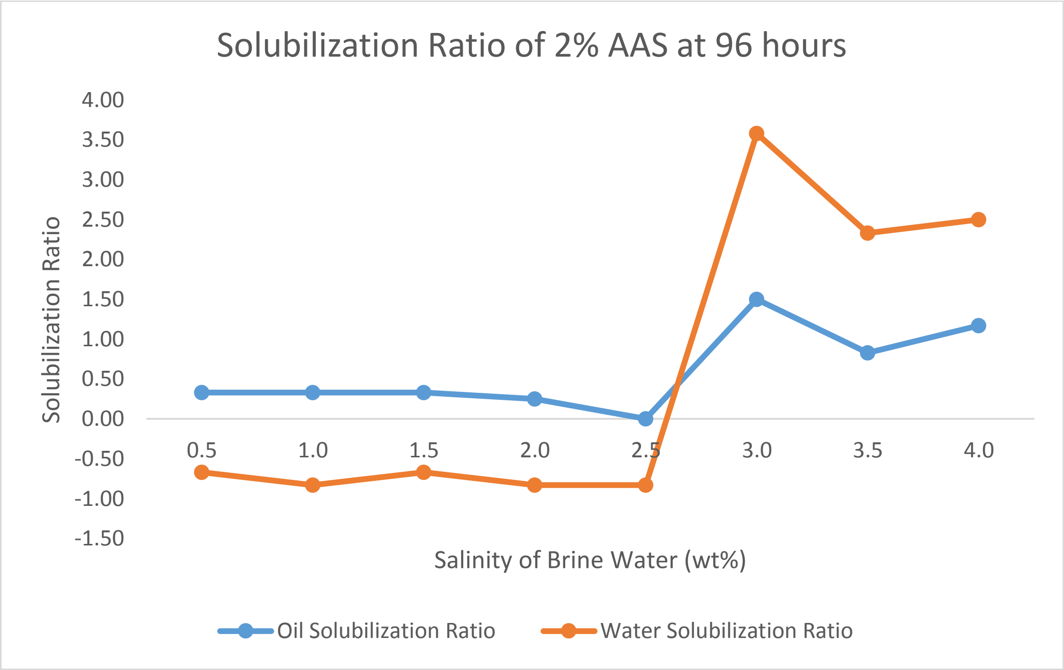


Figure 10 Solubilization Ratio of 2% AAS at 96 hours

The composition of microemulsion compatibility test of 2% Alcohol Alkoxy Sulfate contain of 4 ml of crude oil which is from Dulang Field, 4.8 ml of brine water solution and 01.2 ml of surfactant which is Alcohol Alkoxy Sulfate. From the composition of the sample, student able to calculate the solubilization ratio and plot the graph of Figure 10 to find optimum salinity.

The interaction between 2% of surfactant Alcohol Alkoxy Sulfate (AAS) with the crude oil will form microemulsion. According to the observation done in Table 16 the emulsion is in brown in colour. The emulsion is needed to reduce the interfacial tension between oil and rock. The Table 17 and Figure 8 above shows the volume of each layer formed in the solution for each samples. For sample contain 0.5%, 1.0%, 1.5% and 2.0% salinity of brine water contain no precipitate. While sample with 2.5%, 3.0%, 3.5% and 4.0% salinity of brine water produced layers of precipitate.

From Figure 9, it shows the volume of emulsion versus volume of precipitate 1% AAS at 96 hours. As it shown, the volume of microemulsion decrease with increase of salinity while precipitation volume increase. The volume of precipitate start to increase at 2.5% of salinity.

From the observation, the excess volume of the oil and water can be used to calculate solubilization ratio between oil-surfactant and water-surfactant. The optimal salinity here is 2.60% that can be shown in Figure 10 which is the solubilization ratio graph.

Thus, from this experiment, it shows that the best salinity is the 2.60% as in can maintain high volume of emulsion in 96 hours but at this salinity, it will produce precipitate. This graph might be the indication of the optimum salinity, student deduced that the optimum salinity of the solution must be 2.3% to ensure no precipitate produced.

From this experiment, the author could conclude that

- Sodium Dodecyl Sulfate is not suitable surfactant to be used in surfactant flooding. This is due to poor performance of the surfactant.
- For 1% of Alcohol Alkoxy Sulfate, the optimum salinity is 2.3 wt%. At this salinity, it perform no precipitate and give high volume of microemulsion.
- For 2% of Alcohol Alkoxy Sulfate, the optimum salinity if 2.6 wt%. But at this salinity, the solution will formed precipitate. Thus, the author deduced that the suitable salinity is 2.3 wt% as it will form microemulsion and no precipitation occur.

4.3 Interfacial Tension Measurement Test using Spinning Drop

- **1% of Alcohol Alkoxy Sulfate**

Table 18 IFT Result of 1% Alcohol Alkoxy Sulfate

Salinity of Brine Water (%)	**Refractive Index**	**Density of the Brine Water**	**Interfacial Tension (mN/m)**
0.5	1.33571	1.000	0.3506381
1.0	1.33650	1.003	0.28990065
1.5	1.33688	1.006	0.63803775
2.0	1.33716	1.008	0.095583174
2.5	1.33808	1.013	0.084604598

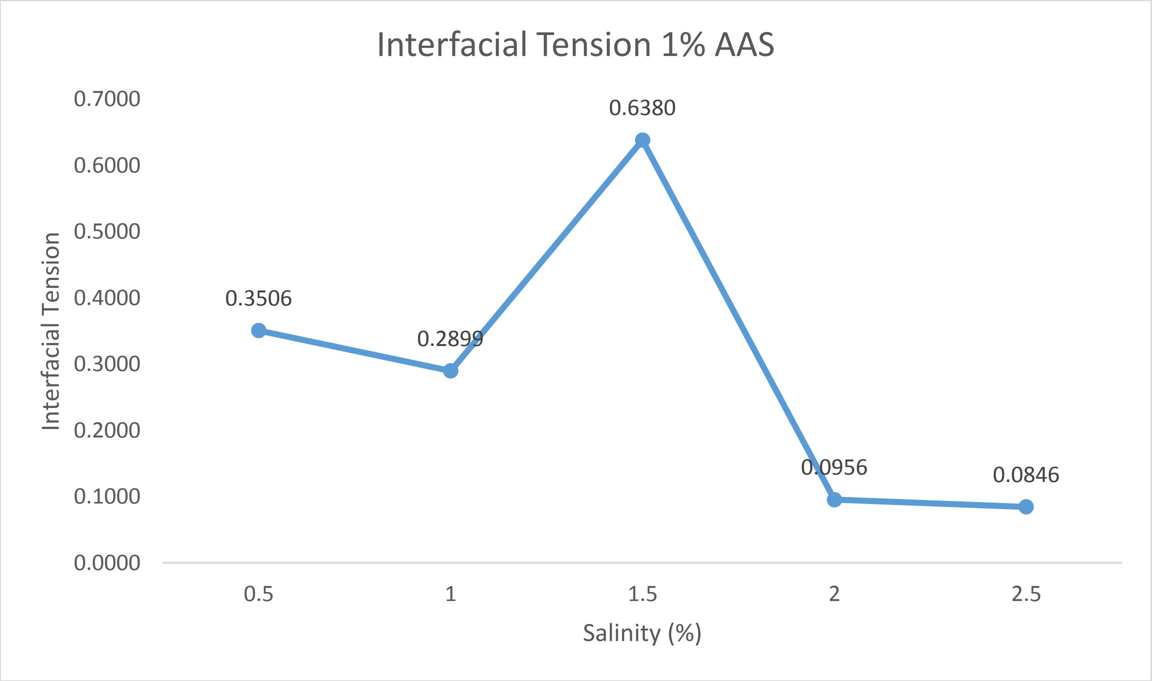


Figure 11 Interfacial Tension of 1% AAS vs Salinity using Spinning Drop

- **2% of Alcohol Alkoxy Sulfate**

Table 19 IFT Result of 2% Alcohol Alkoxy Sulfate

Salinity of Brine Water (%)	**Refractive Index**	**Density of the Brine Water**	**Interfacial Tension (mN/m)**
0.5	1.33771	1.003	4.1950704
1.0	1.33810	1.006	14.374764
1.5	1.33868	1.009	0.12109764
2.0	1.33949	1.012	0.19901035
2.5	1.34068	1.015	0.19944593

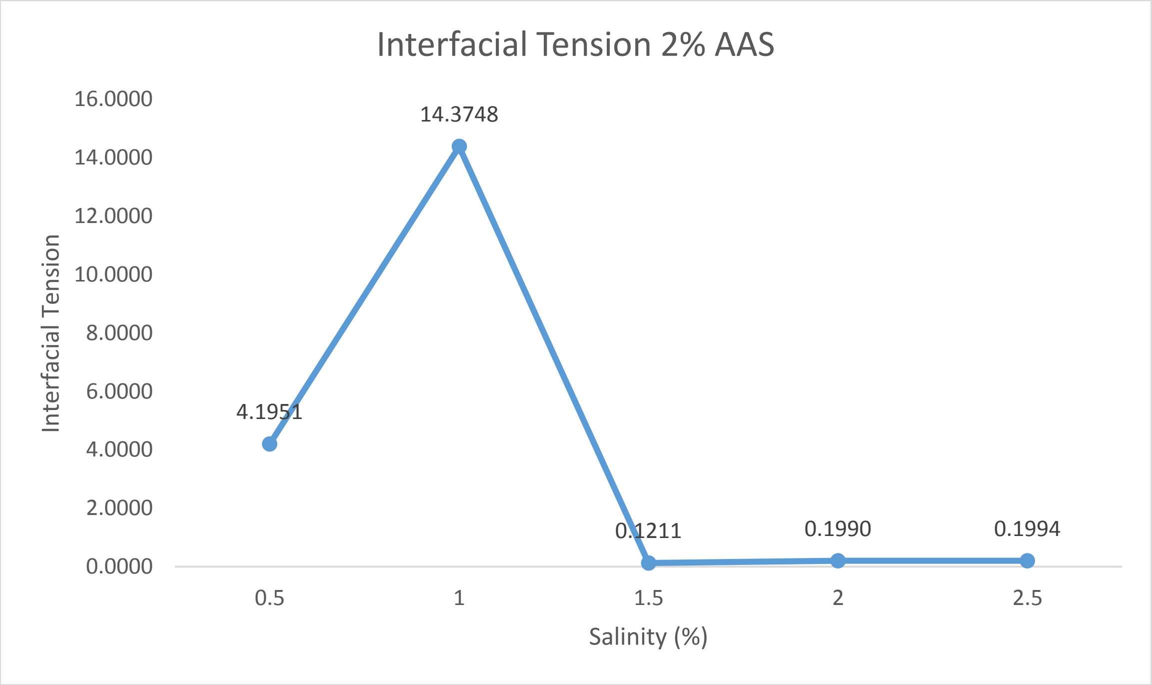


Figure 12 Interfacial Tension of 2% AAS vs Salinity using Spinning Drop

Based on the experiment, each samples have low IFT. Thus, all the samples can be used for the surfactant. For this experiment, error might occur due to human error. Thus the reading must be taken more than 3 times in order to have accurate results.

From all the experiment, the author would choose 2.3% of salinity in 1% of AAS and 2% of AAS. This is because, at 2.3% salinity, the solution do not turn cloudy, the emulsion is thick and no precipitation formed.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Phase Behavior Study of Surfactant Flooding in Hard Water has achieved it targets which is to identify the surfactant which giving more high microemulsion. At this phase, student able to identify the temperature of mixtures that will not produce any precipitate. The study of literature review helps student a lot in order to find information and the field application in oil and gas field nowadays.

The project entitled Phase Behavior of Surfactant Flooding in Hard Water has able to achieve the objectives which is to investigate the phase behavior od surfactant in hard water and identification to suitable surfactant, to find the parameter that contribute in maximizing the effectiveness and efficiency of surfactant and lastly to study the optimum salinity of the hard brine water, which giving no precipitation in reaction with surfactant.

Based on the experiment conducted in Aqueous Compatibility Test, the author could detect the suitable surfactant that can be used within this project. Two types of surfactants used which are Sodium Dodecyl Sulfate and Alcohol Alkoxy Sulfate. But, Sodium Dodecyl Sulfate turn the result down and this project was continue only with Alcohol Alkoxy Sulfate.

From experiment Microemulsion Phase Behavior Test, the author could identify the suitable concentration of surfactant and salinity of brine water to be used which giving maximum performance. The optimum salinity from both 1% and 2% of Alcohol Alkoxy Sulfate is 2.3 wt% of salinity. And IFT Spinning Drop Experiment, the author could deduced that the surfactant can be used as the IFT is low and acceptable.

5.2 Recommendation

There are some recommendations that student find that could improve the experiments and research.

- Experiments must be in right procedures.
- Accuracy of the mixtures and solution in the test tube.
- Choosing the right apparatus. Eg: test tube that have scale
- Expert in handling equipment such as Spinning Drop Equipment.

With these recommendations, student will be able to improve and find more solution from these problems.

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APPENDICES

TABLE 20 1% Alcohol Alkoxy Sulfate of Microemulsion Test

1% of Alcohol Alkoxy Sulfate				
Salinity of brine water (%)	**Partition**	**48 hours**	**72 hours**	**92 hours**
0.5	Oil	3.8	4.0	4.1
	Emulsion	0.8	0.7	0.7
	Water	5.6	5.6	5.6
1.0	Oil	4.0	4.0	4.0
	Emulsion	0.6	0.6	0.5
	Water	5.4	5.4	5.5
1.5	Oil	3.8	4.0	4.0
	Emulsion	0.6	0.6	0.6
	Water	5.4	5.2	5.2
2.0	Oil	3	3	3.1
	Emulsion	0.6	0.6	0.5
	Water	5.4	5.2	5.3
2.5	Oil	3.8	3.8	3.8
	Emulsion	0.4	0.1	0.1
	Precipitate 1	0.8	0.6	0.6
	Precipitate 2	0.8	0.6	0.6
	Precipitate 3	4.4	4.4	4.8
3.0	Oil	3.6	3.6	3.6

	Emulsion	0.4	0.4	0.4
	Precipitate 1	0.4	0.6	0.6
	Precipitate 2	1.0	0.6	0.6
	Precipitate 3	4.4	4.6	4.6
3.5	Oil	3.8	3.8	3.8
	Emulsion	0.01	0.005	0.005
	Precipitate 1	0.4	0.4	0.4
	Precipitate 2	1.6	-	-
	Precipitate 3	4.2	5.6	5.6
4.0	Oil	2.8	2.8	2.8
	Emulsion	0.01	0.005	0.005
	Precipitate 1	0.6	0.8	0.8
	Precipitate 2	1.8	1.2	1.2
	Water	3.8	4	4

TABLE 21 2% Alcohol Alkoxy Sulfate of Microemulsion Test

2% of Alcohol Alkoxy Sulfate				
Salinity of brine water (%)	**Partition**	**48 hours**	**72 hours**	**92 hours**
0.5	Oil	3.5	3.6	3.6
	Emulsion	2.2	1.0	0.8
	Water	4.2	5.4	5.6
1.0	Oil	3.6	3.8	3.6
	Emulsion	1.2	1.0	0.8
	Water	4.6	5.6	5.8
1.5	Oil	3.6	3.8	3.6
	Emulsion	1.0	0.8	0.6
	Water	5.4	5.4	5.6
2.0	Oil	3.6	3.7	3.7
	Emulsion	0.8	0.6	0.5
	Water	5.6	5.7	5.8
2.5	Oil	3.6	3.9	4.0
	Emulsion	0.1	0.1	0.1
	Precipitate 1	0.1	0.1	0.1
	Water	6.2	5.6	5.8
3.0	Oil	1.6	2.2	2.2
	Emulsion	0.00	0.0	0.0
	Precipitate 1	0.6	0.6	0.2
	Precipitate 2	2.2	0.6	0.2
	New Precipitate		0.2	0.4
	Precipitate 3	0.2	1.0	1.0
	Precipitate 4	1.4	1.4	1.4
	Precipitate 5	3.8	2.6	2.6

	Water	0.5	0.5	0.5
3.5	Oil	2.0	2.8	3.0
	Emulsion	0.00	0.0	0.0
	Precipitate 1	0.6	0.2	0.2
	Precipitate 2	1.0	0.1	0.0
	New Precipitate	-	0.1	0.1
	Precipitate 3	0.1	0.8	0.6
	Precipitate 4	1.4	1.4	1.6
	Precipitate 5	2.2	1.8	2.0
	Water	2.0	2.0	2.0
4.0	Oil	1.8	2.4	2.6
	Emulsion	0.0	0.0	0.0
	Precipitate 1	0.4	1.0	0.1
	Precipitate 2	0.8	0.0	0.0
	New Precipitate	-	-	0.1
	Precipitate 3	1.2	2.2	0.4
	Precipitate 4	0.8	1.0	2.4
	Precipitate 5	2.2	2.1	2.2
	Water	1.8	1.6	1.8

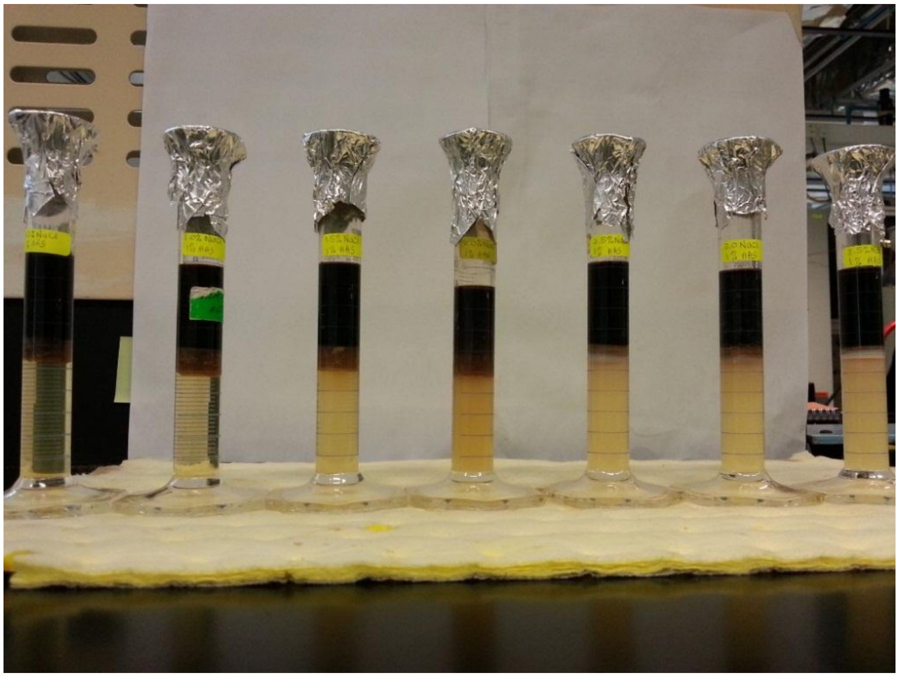


FIGURE 13 Figure of Phase Behavior of 1% AAS at 96 hours

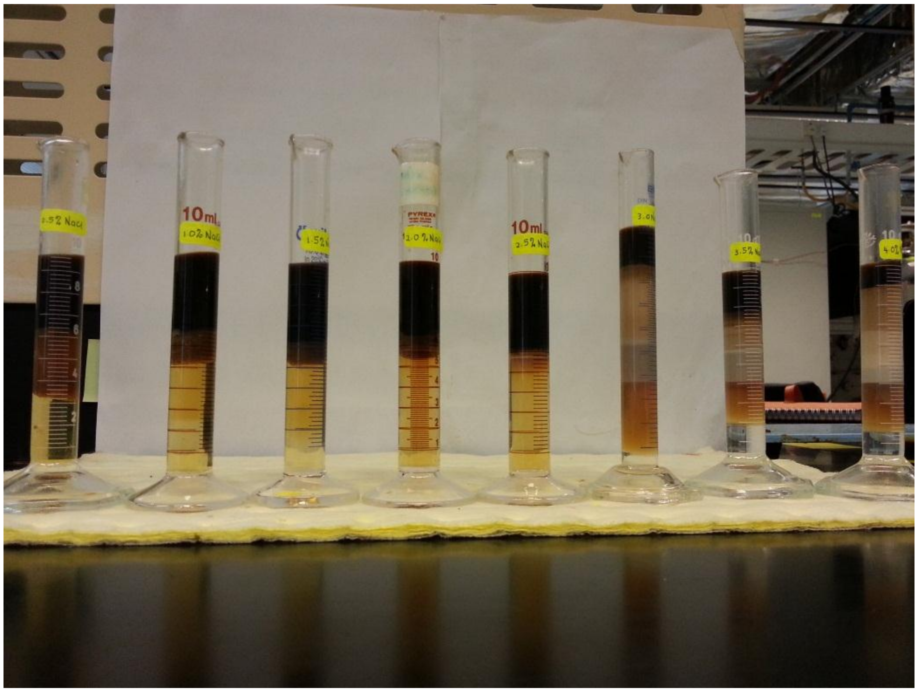
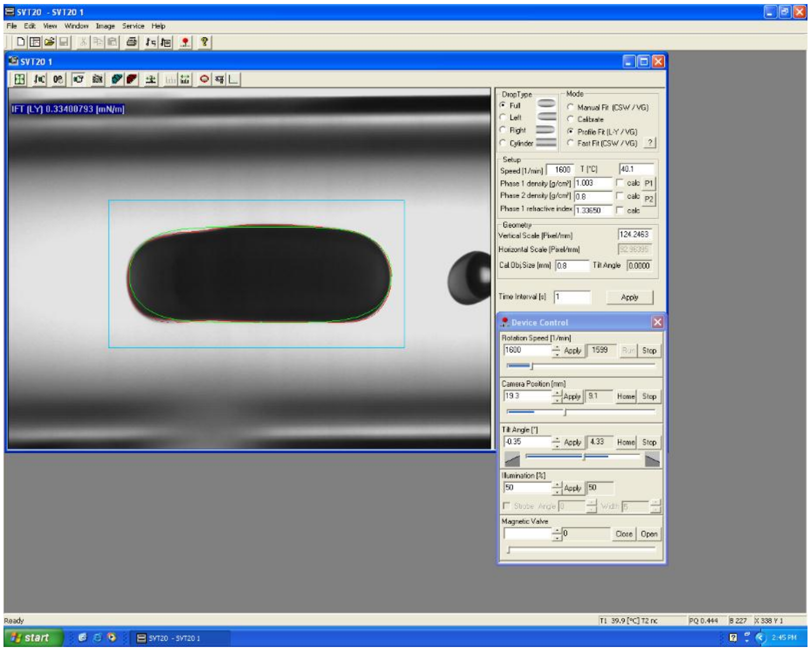


FIGURE 14 Figure of Phase Behavior of 2% AAS at 96 hours

FIGURE 15 Spinning Drop Equipment



IFT [LY] 0.33400793 [mN/m]

DropType
● Full
○ Left
○ Right
○ Cylinder

Mode
○ Manual Fit (CSW / VG)
○ Calibrate
● Profile Fit (L-Y / VG)
○ Fast Fit (CSW / VG)

Setup
Speed [1/min] 1600
T [°C] 40.1
Phase 1 density [g/cm³] 1.003 ☐ calc P1
Phase 2 density [g/cm³] 0.8 ☐ calc P2
Phase 1 refractive index 1.33650 ☐ calc

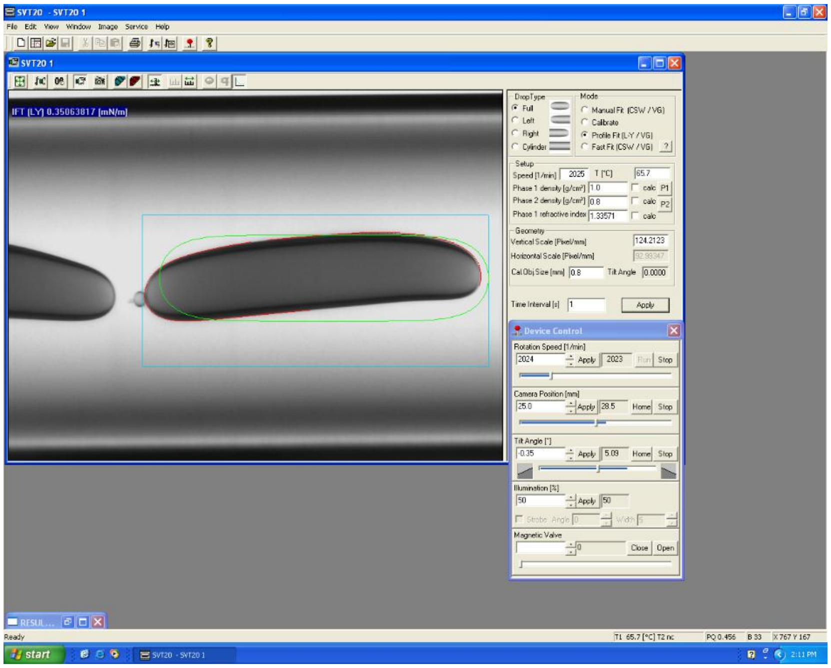
Geometry
Vertical Scale [Pixel/mm] 124.2463
Horizontal Scale [Pixel/mm] 92.96395
Cal.Obj.Size [mm] 0.8
Tilt Angle 0.0000

Time Interval [s] 1

Device Control
Rotation Speed [1/min] 1600 1599
Camera Position [mm] 19.3 9.1
Tilt Angle [°] -0.35 4.33
Illumination [%] 50 50
☐ Strobe Angle 0 Width 5
Magnetic Valve 0

Ready
T1 39.9 [°C] T2 nc
PQ 0.444
B 227
X 338 Y 1

FIGURE 16 Spinning Drop Test using Falcon software



IFT (LY) 0.35063817 [mN/m]

DropType
● Full
○ Left
○ Right
○ Cylinder

Mode
○ Manual Fit (CSW / VG)
○ Calibrate
● Profile Fit (L-Y / VG)
○ Fast Fit (CSW / VG)

Setup
Speed [1/min] 2025
T [°C] 65.7
Phase 1 density [g/cm³] 1.0 ☐ calc
Phase 2 density [g/cm³] 0.8 ☐ calc
Phase 1 refractive index 1.33571 ☐ calc

Geometry
Vertical Scale [Pixel/mm] 124.2123
Horizontal Scale [Pixel/mm] 92.99347
Cal.Obj.Size [mm] 0.8
Tilt Angle 0.0000

Time Interval [s] 1

Rotation Speed [1/min] 2024 2023
Camera Position [mm] 25.0 28.5
Tilt Angle [°] -0.35 5.09
Illumination [%] 50 50
☐ Strobe Angle 0 Width 5
Magnetic Valve 0

Ready
T1 65.7 [°C] T2 nc
PQ 0.456
B 33
X 767 Y 167

FIGURE 17 Spinning Drop Test using Falcon software