Surfactant Interfacial Tension in Varying Salinity and Temperature Condition

by

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13760

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Petroleum)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Petroleum Engineering Programme

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(PETROLEUM)

Approved by,

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(Dr. Rashidah Mohd Pilus)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2014

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 reference and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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NABIHATI HASNA BT HASMI

ABSTRACT

Chemical flooding has been studied as an efficient Enhanced Oil Recovery (EOR) method for years and the used of surfactant in the process is one of the promising Chemical EOR methods. Recently, newly designed surfactants known as CL 10 and IL 10 have been proposed in EOR but unfortunately their performance and behaviors are still unknown. Therefore, this project will investigate their behavior with the crude oil and their ability in reducing Interfacial Tension (IFT) to ensure an efficient CEOR. Even though there are several parameters that can affect the surfactants behavior, temperature and salinity are the most sensitive parameters which effects will be determined in this project. Since IFT is very significant to show the behavior and performance of surfactants, the pendant drop tensiometer is used to determine the IFT between the surfactant and the crude oil thus getting the results for the project. For the effect of salinity, both CL10 and IL10 have tolerant to the high salinity while for the effect of temperature, only CL10 show better tolerant to high range of temperature. In conclusion, CL10 is better surfactant that IL10 in reducing IFT to the lowest.

ACKNOWLEDGEMENT

First of all, I would like to praise to Allah for giving me strength and His Blessing to successfully complete my Final Year Project with ease for this whole semester at Universiti Teknologi PETRONAS. There were many individuals and parties in which without hesitation I can say that my project could not be completed successfully without their generous assistance.

Special thanks to my supervisor, Dr. Rashidah Mohd Pilus. The supervision, support and constructive comments that she gave truly help the progression and smoothness of the project. The co-operation is much indeed appreciated. Besides that, a big thank I gave to Mdm Nurul Fasihah bt Idaham as a Research Officer of PETRONAS Ionic Liquid Centre (PILC). She assisted and gave training to me on how to use OSA20 pendant drop tensiometer which contributes a lot to complete my project.

Last but not least, I would like to thank to all technicians of Core Flooding Laboratory at Block 15 and also my friends especially Asyimah who is also working on same procedures with my project.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Chemical flooding has been studied for more than 30 years as an efficient enhanced oil recovery (EOR) technique after primary and secondary oil recovery leave approximately two-third of the original oil in reservoir. The recent development of chemical flooding includes alkaline flooding (A), surfactant flooding (S), polymer flooding (P) and the combination of those either AS flooding, SP flooding or ASP flooding, while surfactant flooding has been proposed as promising chemical EOR (CEOR) process to enhance oil recovery.

Surfactant which is classified as anionic, cationic, nonionic and zwitteronic is used in oil recovery due to its ability to lower interfacial tension between residual oil and displacing fluid. The reduction of the interfacial tension between the trapped oil and flooding medium has been proven by many studies and can be considered as crucial mechanism to improve oil recovery efficiency by reducing capillary forces that causes the oil to be trapped in the pores.

Nevertheless, there are several factors that can affect the surfactant's behavior which are salinity, temperature, pH, concentration, reservoir characteristics injection speed and many more. It is impossible to do test for all the factors to find out the synchronize effect on the surfactant so they are investigated solely. As for this paper, the focus is only on the effect of salinity and temperature on the new surfactant designed in reducing interfacial tension.

1.2 PROBLEM STATEMENT

In order to get the lowest or ultra-low interfacial tension (IFT), the behavior of surfactant must be known and understood first to ensure the efficiency of surfactant in reducing IFT. Unfortunately, the ability of these new surfactants used in this research are still not fully investigated and no information is available for its behavior. Other than that, since the salinity has some effect on surfactant in reducing interfacial tension (IFT), irregular distribution of salinity in the reservoir can be one of the problems in maintaining the ability of surfactants to mobilize the residual oil. Besides that, surfactants need to form stable emulsion to move the trapped oil into the well and also to be easily separated at the surface. Nevertheless, the high temperature in the reservoir affects surfactant's ability in forming stable emulsion.

1.3 OBJECTIVES AND SCOPE OF STUDY

a) To investigate the ability of the new surfactant in reducing IFT.
b) To find out the IFT between surfactant and the crude oil in varying salinity.
c) To investigate the effect of different temperature on the IFT.
d) Only focus on two new surfactants designed to reveal their behavior and performance.
e) Only evaluate IFT in varying salinity and also the effect of different temperature on the surfactant effectiveness in reducing IFT

This project is relevant and feasible to be carried out. First and foremost, to study whether this project will work and feasible to be done within the scope of study and time, the author studied many research papers and books like books titled Modern Chemical Enhanced Oil Recovery written by James J. Sheng regarding Chemical EOR and specifically about the surfactant flooding. The author will then have clear overview on how the project will be conducted and able to plan the related activities efficiently. Besides that, the project is relevant since it will help in development of EOR techniques which is crucial recently.

CHAPTER 2

LITERATURE REVIEW AND/OR THEORY

2.1 ENHANCED OIL RECOVERY (EOR)

Enhanced Oil Recovery (EOR) is generic term for techniques for increasing the amount of crude oil that can be extracted from an oil field. There are actually several ways to define EOR. Sanderson (2012) has clarified the concepts of IOR and EOR in practice are often mixed. Apparently, it has been agreed among petroleum professionals that IOR is a general term that implies improving oil recovery by many means; EOR is more specific in concept and can be considered a subset of IOR.

Therefore according to Sheng (2011), EOR refer to any reservoir process to change the existing rock/oil/brine interaction in the reservoir while Sanderson (2012) generally identified that EOR processes involve injection of gas or fluids into the oil reservoir and displacing crude oil from the reservoir toward a production well. In the meantime, enhance oil recovery processes have their objective to increase oil recovery from reservoir depleted by secondary recovery (Donaldson et al., 1989) while Sanderson (2012) clarified that their primary goals are to displace or alter the mobility of the remaining oil in the reservoir.

For EOR processes, Donaldson et al. identified that they can be divided into three major categories which are chemical processes, thermal processes and miscible processes. But Sheng (2011) added microbial processes and claimed that the classification could never be satisfactory because several processes can be combined.

2.2 CHEMICAL ENHANCED OIL RECOVERY (CEOR)

Chemical EOR or chemical processes has been defined by Sanderson (2012) as injection of a specific liquid chemical that effectively creates desirable phase behavior properties, to improve oil displacement. It can be divided into three main categories which are surfactant flooding, polymer flooding and caustic flooding while Sheng (2011) did mentioned them but instead of caustic, he stressed on the combination of these processes. The mechanism of oil displacement by surfactant and caustic flooding is based on the formation of ultra-low interfacial tension (Donaldson et al., 1989). The formation of these surfactants result in ultra-low interfacial tension thus surfactant flooding is being focused in Chemical EOR.

The principles of chemical flooding are illustrated in Figure 2.1. From the picture below, the complexity rises as several additional tasks such as preflush of the reservoir and injection of additional fluids must be applied to accomplish an efficient process.

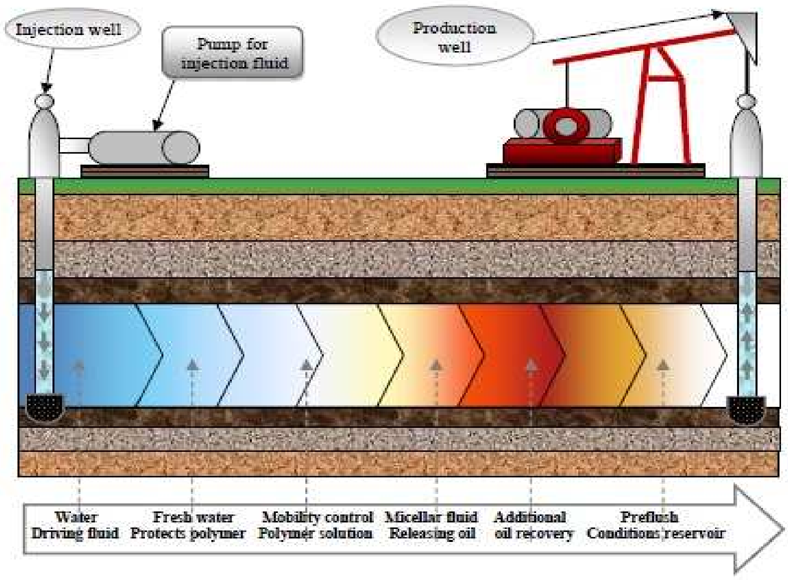


Figure 2.1: Illustration of Surfactant Flooding

2.3 SURFACTANT FLOODING

Surfactant flooding is one of the chemical EOR processes in which small amount of surfactant is added to an aqueous fluid injected to sweep the reservoir. Since very low oil/water interfacial tension (IFT) is required to move the oil through narrow capillary pores, this injection of one or more liquid chemical and surfactant mobilize the trapped crude oil by effectively regulate the phase behavior properties in the oil reservoir and lowering IFT between the injected liquid and oil. Figure 2.2 below show the principle of surfactant flooding.

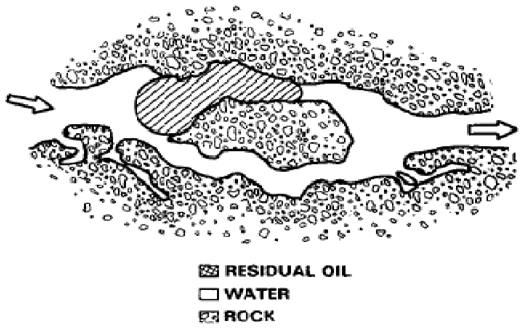


Figure 2.2: Principle of Surfactant Flooding

For this liquid surfactant solution, co-surfactants are blended to improve the properties of the surfactant solution. However the combination of multiple components in the surfactant solution does not work well in practice as chromatographic separation occurs in the reservoir (Sanderson, 2012). The surfactant may also losses due to certain physical characteristics of the reservoir. Besides that high temperature and high salinity are well known as sensitive factor for the surfactant system thus it is advised to use surfactants that can resist these conditions.

2.4 DEFINITION OF SURFACTANTS AND ITS CLASSIFICATION

As in surfactant flooding uses a blend of surface acting agents that lower the IFT between the liquid surfactant solution and the residual oil, a brief introduction and basic mechanism of surfactant should be known. Both Sheng (2013) and Schramm & Marangoni (2010) define surfactants as an amphiphilic organic compunds that consist of hydrocarbon chain (hydrophobic group) and hydrophilic group. The structure is shown is Figure 2.3.

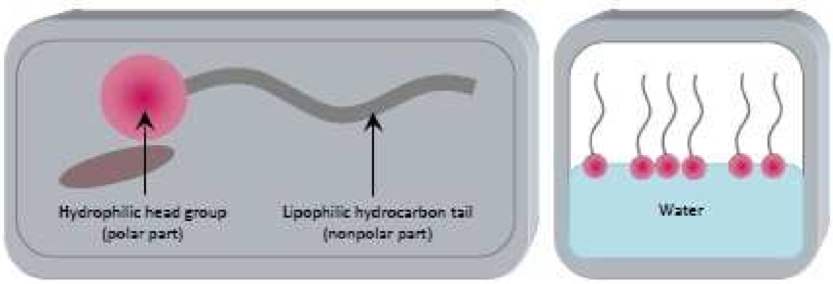
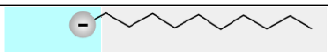
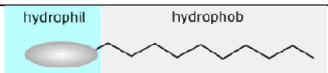


Figure 2.1: Structure of Surfactant

If the surfactant contains a hydrocarbon chain with less than 12 carbon atoms, it is called water soluble because the polar head group drags the entire molecule in water. However, when the hydrocarbon chain length is greater than 14 carbon atoms, the compounds are called water-insoluble surfactants, because they do not dissolve in water due to the long hydrocarbon chains. While Schramm (2010) stated that these molecules show surface activity like lowering the interfacial tension and surface tension in which they are dissolved by forming oriented monolayers at interfaces. He also added that it is the nature of the polar head group which is used to divide surfactants into different categories; anionic, cationic, nonionic and zwitteronic/amphoteric surfactants as Table 2.1.

Table 2.1: Categories of Surfactants

Categories	Examples	Structures
Anionic	Sodium dodecyl sulfate (SDS)	
Cationic	Cetyltrimethylammonium bromide (CTAB)	
Nonionic	Polyethylene oxides	
Zwitterionic/ Amphoteric	Dodecyl betaine	

Among this types, anionic surfactants are widely used in enhanced oil recovery due to their lower adsorption on reservoir rocks as compared to other types of surfactants (Donaldson et al., 1989). Sheng (2011) added that anionic surfactants exhibit relatively low adsorption on sandstone rocks whose surface charge is negative while cationic surfactants can strongly adsorb in sandstone rocks and being used in carbonate rocks to change wettability from oil-wet to water-wet. As for nonionic surfactants, it acts as cosurfactants to improve system phase behavior. Therefore, anionic and cationic is usually mixed together to increase the tolerance to high salinity. Zwitteronics surfactants or also known as amphotheric contain two active groups either nonionic-anionic, nonionic-cationic or anionic-cationic. Even they are temperature- and salinity tolerant, but they are expensive.

For the surfactant, there are several methods to characterize surfactants:

a) Hydrophile-Lipophile Balance (HLB)

HLB is number that indicates relatively the tendency to solubilize in oil or water and thus the tendency to form water-in-oil or oil-in-water emulsions. Low HLB numbers are assigned to surfactants that tend to be more soluble in oil and to form water-in-oil emulsions. When the formation salinity is low, a low HLB surfactant should be selected. Such a surfactant can make middle-phase micro-emulsion at low salinity. When the formation salinity is high, a high HLB surfactant should be selected. Such a surfactant is more hydrophilic and can make middle-phase micro-emulsion at high salinity.

b) Critical Micelle Concentration (CMC) and Kraff Point

CMC can be defined as the concentration of surfactants above which micelles are spontaneously formed. Upon introduction of surfactants or any surface active materials into the system, they will initially partition into the interface, reducing the system free energy by lowering the energy of the interface calculated as area time surface tension and removing the hydrophobic parts of the surfactants from contact with water. One parameter related to CMC is Kraff temperature, or critical micelle temperature. This is the minimum temperature at which surfactant from micelles. Below the Kraff temperature, there is no value for the critical micelle concentration because micelle does not form.

c) Solubilization Ratio

Solubilization ratio for oil/water is defined as the ratio of the solubilized oil/water volume to the surfactant volume in the micro-emulsion phase. Solubilization ratio is closely related to IFT. When the solubilization ratio for oil is equal to that for water, the IFT reaches its minimum.

2.5 SURFACTANTS IN ENHANCED OIL RECOVERY

About 60% to 70 % oil is still remained in the reservoir even after primary and secondary recovery like water flooding. The chemical flooding especially surfactant flooding has been suggested by many researchers to recover the remaining oil to increase the recovery. Thomas *et.al* (1999) stated that Mobility Ratio and Capillary Number are two important principles for oil recovery, introducing surfactant in reservoir is an effective enhanced oil recovery. This method has been supported by Bryan *et.al* (2007), Khosravi (2010), Zeidani *et.al* (2013) and Feng *et.al* (2012) who further stated that this surfactant has the ability to reduce or lower interfacial tension between two fluids and through which they can increase the Mobility ratio of Oil/Water and the Capillary Number thus allow the residual oil to flow.

The ability of surfactants on different type of reservoir depends on the type of surfactant to reduce the IFT.

2.5.1 Anionic Surfactants

Most of the sandstone reservoir use anionic surfactant for EOR. They are a lot of anionic used in EOR for this type of reservoir like Petroleum sulfonates, Alpha Olefin Sulfonate, Alkyl Benzene sulfonate, Alkyl Aryl Sulfonate and Synthetic Alkyl Sulfonate. Besides that, the commercial anionic surfactant known as sodium alkane sulfonate (Bio-Terge PAS-8S) has been used in heavy oil studies in the past. The petroleum sulfonate for example has been used in Loma Novia Field Low-Tension Waterflooding in the mid-1960.

2.5.2 Cationic Surfactants

For the cationic surfactant, it has been used to improve water wetness of carbonate reservoir (limestone, dolomite) from oil-wet to water-wet. Type of cationic surfactant used as mentioned in literature is alkyl trimethyl ammonium. However, the cationic surfactant is not usually used in surfactant flooding.

2.5.3 Nonionic Surfactants

This kind of surfactant is usually used in carbonate reservoir like dolomite and limestone. Nonionic ethoxy sulfate for example has been used together with anionic ethoxy sulfate and injected into the Yates field in Texas. Other than that, nonionic POA alone has been injected into Cottonwood Creek field in Wyoming for EOR.

2.6 EXISTING SURFACTANTS USED

Surfactant can be classified into four categories which are anionic, cationic, nonionic and zwitterionic surfactant as stated by Schramm (2010). While for Bryan *et.al* (2007), anionic surfactant was used in their Enhanced Heavy Oil Recovery research known as sodium alkane sulfonate which has been used in heavy oil studies in the past. From some researchers' experiences, they found that sulfonated surfactants are mostly used because they are more thermally stable at high temperature than hydrolytically susceptible sulfates. Petroleum sulfonates, Alpha Olefin Sulfonate, Alkyl Benzene sulfonate, Alkyl Aryl Sulfonate and Synthetic Alkyl Sulfonate are some examples of sulfonated surfactant commercially used for oil recovery. As for Khosravi (2010), he used internal olefin sulfonate (IOS) because he believed the high amount of C makes it a good surfactant. He added that the high level carbon in this surfactant can demonstrate superior phase behavior even with the presence of asphaltenes, high viscosity and paraffin content. Nevertheless, Feng *et.al* (2012) did not encourage introducing single surfactant system as the results showed that it could not reduce the Interfacial Tension to the ultra-low. Therefore they decide to either mixing the surfactants or design new surfactant.

2.7 PROBLEMS WITH SURFACTANTS AND FACTORS AFFECTING IT

The use of surfactant in oil industry is widely accepted as an effective enhanced oil recovery method. Unfortunately, there some challenges and problems in applying surfactant into the reservoir. Thomas *et.al* (1999) revealed some limitation of using surfactants in oil recovery in their research. One of them is the dilution of surfactant in water at the point it is not effective to reduce IFT anymore. Besides, the loss of surfactant due to its adsorption and reaction with minerals are also a problem. As the reservoir possess high temperature, the surfactant become unstable in the reservoir and probably produce unstable emulsion at downhole reservoir condition which then difficult to break on surface. This concludes that there are several parameters that can affect the performance of surfactant in reducing IFT among which are temperature and salinity.

2.8 EFFECT OF SALINITY ON IFT

Reducing IFT is one of the main mechanisms for surfactant-related EOR and it is closely linked to water and oil solubilization, best known as phase behavior. Since the salinity of brine gives strong impact to the surfactant solution phase behavior, it also affects the IFT. The oil-microemulsion phase/interfacial tension decreases as the salinity increases.(Bansal & Shah, 1978). This has been proven from experiment conducted by Karnanda, Benzagouta, AlQuraishi, & Amro, (2012) showing the existence of salt in brine at fixed concentration of surfactant relatively reduces IFT values compare with IFT value of surfactant solution in pure water. Sheng (2013) added that generally increasing salinity of brine decreases the solubility of surfactant in brine which means the surfactant can perform better. Nevertheless, Austad & Milter, (2010) claimed that as the salinity increases in the three phase region (III) (favourable to form ultra-low IFT) approaching optimal salinity, suddenly it turns into II (+) system (not favorable to form ultra-low IFT). These conclude that the salinity definitely affect the IFT.

2.9 EFFECT OF TEMPERATURE ON IFT

Many studies reported that IFT decreased as temperature increased which has shown in Aoudia, Al-Shibli, Al-Kasimi, Al-Maamari, & Al-Bemani, (2006) research. In their research, two surfactants have been investigated in the range 45-80°C in which the IFT very rapidly decreased first until reaching a minimum at T=60°C but then increased above that temperature. They explained that this occurred due to increasing temperature that reduces viscosity. Reducing viscosity causing the surfactant increasingly migrate to the interface thus reduce IFT. While in term of phase behavior claimed by Austad & Milter, (2010), the system moves toward the II(-) [water external microemulsion which has potential to reduce IFT to ultra-low] state as the temperature increased. The literatures proved the IFT is indeed affected by temperature.

2.10 INTERFACIAL TENSION

Interfacial tension can be defined as interface between two immiscible liquid. In oil recovery, Donaldson et al. (1989) stated that an ultra-low interfacial tension between crude oil and brine phases is required to ensure easy flow of trapped oil. It is because it can reduce the work of deformation needed for oil to move through narrow neck of pores. Many studies has shown that in order to displace residual oil from the reservoir, the desirable interfacial tension must be lowered to the range of 10^(-2) to 10^(-1). Besides previous study (Donaldson et al., 1989), have shown that relatively small concentration of petroleum sulfonates (surfactant) can create quite low interfacial tension between crude oil and brines.

There are some methods used to measure interfacial tension as Figure 2.4 and spinning drop is one of the ideal techniques used for Interfacial tension test to define chemical mixtures that have potential to produce incremental oil. Drelich et al. 2002 claimed in his research that the spinning drop method has been very successful in examination of ultralow interfacial tension down to 10^(-6) mN/m.

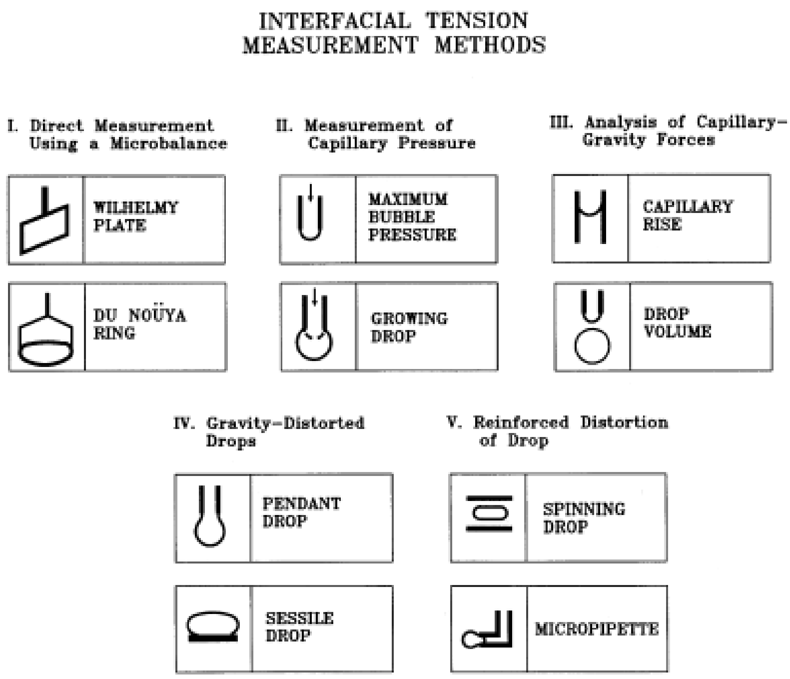


Figure 2.4: Interfacial Tension Measurement Methods

CHAPTER 3

METHODOLOGY/PROJECT WORK

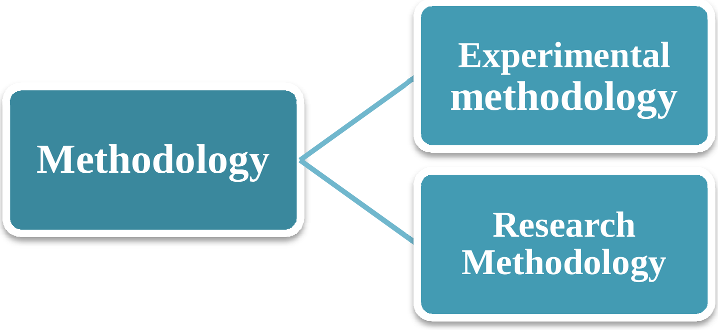


Figure 3.1: Division of Methodology

In this project, the methodology is divided into experimental and research methodology to complete the project successfully.

3.1 EXPERIMENTAL METHODOLOGY

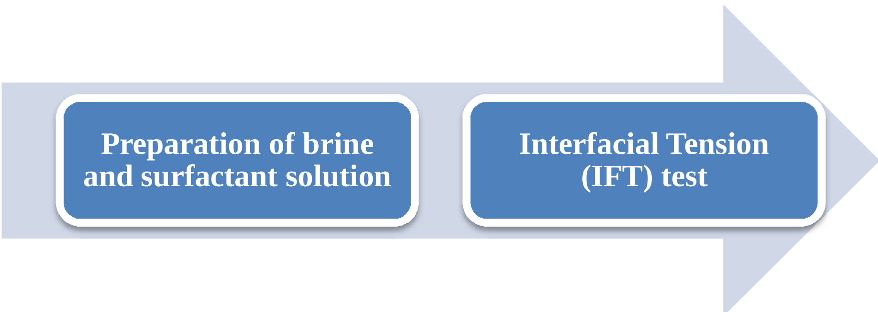


Figure 3.2: Schematic Diagram of Experimental Methodology

As shown in figure above, there are actually two main processes in conducting this project which are preparation of brine and surfactant solution and interfacial tension test. Most of the methodologies involved are in lab experimental methods using several equipments and materials in order to achieve the project's objectives.

3.1.1 Preparation of Brine and Surfactant Solution

a) To prepare the brine, stock solution of sodium chloride (NaCl) was prepared by weighting out the salts (NaCl) and then distilled water was added. The brine was stirred till the solid salt totally dissolved.

b) While for surfactant solution of two different types of surfactant; Surfactant IL 10 and Surfactant CL 10 were prepared in the lab based on the calculated formula according to desired concentration of surfactant.

c) Then, the stock solution, surfactant solution and distilled water were mixed together accordingly.

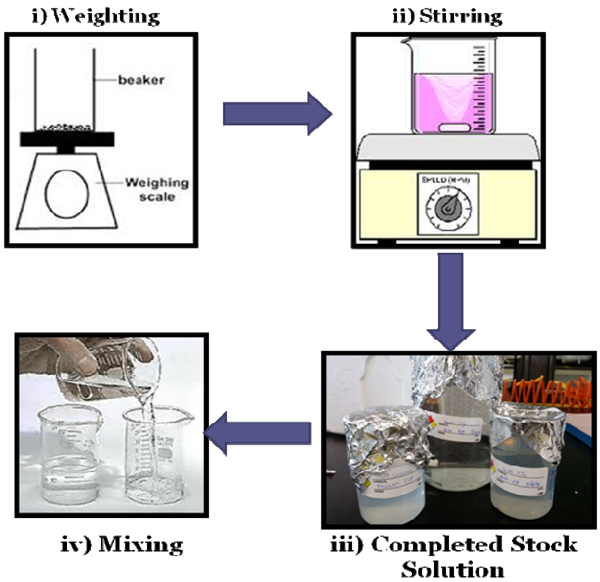


Figure 3.3: Solution Preparation

3.1.2 IFT Test

OSA20 Pendant Drop Tensiometer (Figure 3.5) is used to measure the Interfacial Tension for this project. The equipment is not only able to measure IFT but also can measure contact angle and surface tension. In measuring interfacial tension (IFT), it applies pendant drop method.

The pendant drop method is probably the most convenient, versatile and popular method to measure interfacial tension. The pendant drop method involves the determination of the profile of a drop of one liquid suspended in another liquid at mechanical equilibrium. The profile of a drop of liquid suspended in another is determined by the balance between gravity and surface forces. The interfacial tension is then calculated from the following equation

$$\gamma = \frac{\Delta\rho g D^2}{H}$$

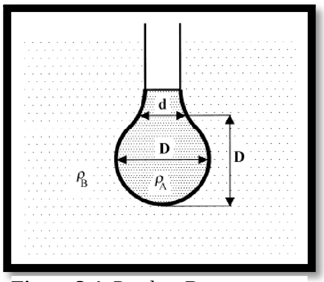


Figure 3.4: Pendant Drop

Where $\Delta\rho$, g, D and H are the density difference between solution and crude oil, gravitational constant, drop diameter, and correction factor related to the shape factor of the pendant drop respectively. A typical pendant drop apparatus consists of three parts: an experimental cell, an illuminating and a viewing system to visualize the drop and a data acquisition system to infer the interfacial tension from the pendant drop profile.

There are several steps and precautions that should be taken to measure IFT using OSA20 Pendant Drop Tensiometer. The steps are as below:

1. Crude oil is placed as the rising drop liquid since it has lower density than water while surfactant solution was placed as bulk liquid.
2. The temperature is set to 90°C before generating an oil rising bubble in the cell like in Figure 3.6.
3. The bubble image is captured using a live camera connected to a computer and then analyzed and calculated using OSA20 software.
4. For the calculation, densities for both crude oil and surfactant solution are required as input data in software and measured using Density meter.
5. Five measurements of different oil bubbles are recorded and an average IFT are calculated as final results.

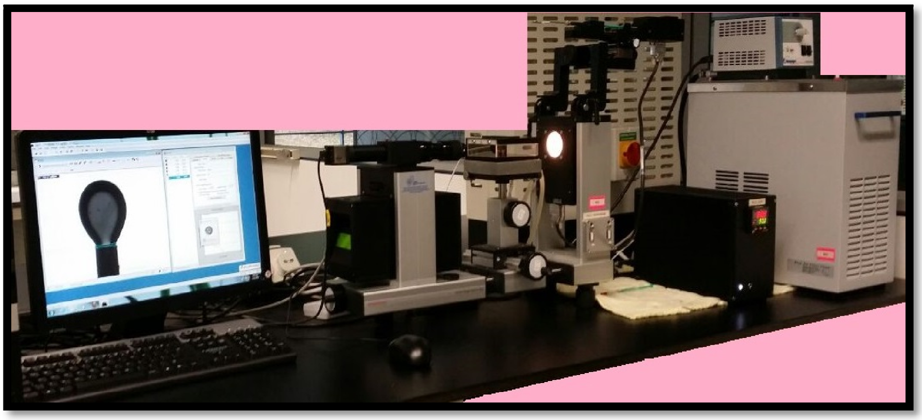


Figure 3.5: OSA20 Pendant Drop Tensiometer

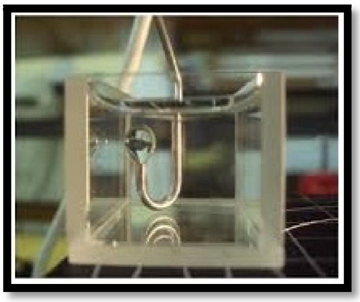


Figure 3.6: Inverted Drop

Figure 3.7: Density Meter

i. By using OSA20 Pendant drop tensiometer, the IFT between surfactant used and crude oil are measured at different salinity with fixed temperature at 90°C and concentration of 1.0 % as table below:

Table 3.1: IFT in Varying Salinity

Surfactants Name	Salinity (wt %)	IFT (mN/m)
CL 10	2.3	
	2.5	
	2.7	
	3.0	
IL 10	2.3	
	2.5	
	2.7	
	3.0	

ii. Then the IFT are measured at different temperature with fixed concentration of 1.0 wt% and 3.0 wt% salinity as table below:

Table 3.2: IFT in varying Temperature

Surfactants Name	Temperature (°C)	IFT (mN/m)
CL 10	25	
	40	
	60	
	80	
	90	
IL 10	25	
	40	
	60	
	80	
	90	

3.2 CHEMICAL AND TOOLS

Table 3.3: List of Chemicals and Tools

No	Chemicals/Materials/Tools	Description
1	Sodium Chloride (NaCl)	Used to make brine
2	Surfactants	Two new surfactant used; CL 10 and IL 10
3	Crude Oil	Selected crude oil from a field to be tested
4	Laboratory Glassware	Glassware like beakers, conical flask and measuring cylinder are used to make brine and surfactant solution.
5	Glass storage bottles	To store the 15 samples prepared to be tested
6	Distilled Water	To make brine and surfactant solution
7	OSA20 Pendant Drop Tensiometer	An equipment to measure Interfacial Tension (IFT)
8	Magnetic Stirrer	To stir the solution prepared
9	Weighting balance	To weight the sodium chloride and surfactants
10	Density meter	To measure the density of samples

3.3 KEY MILESTONES

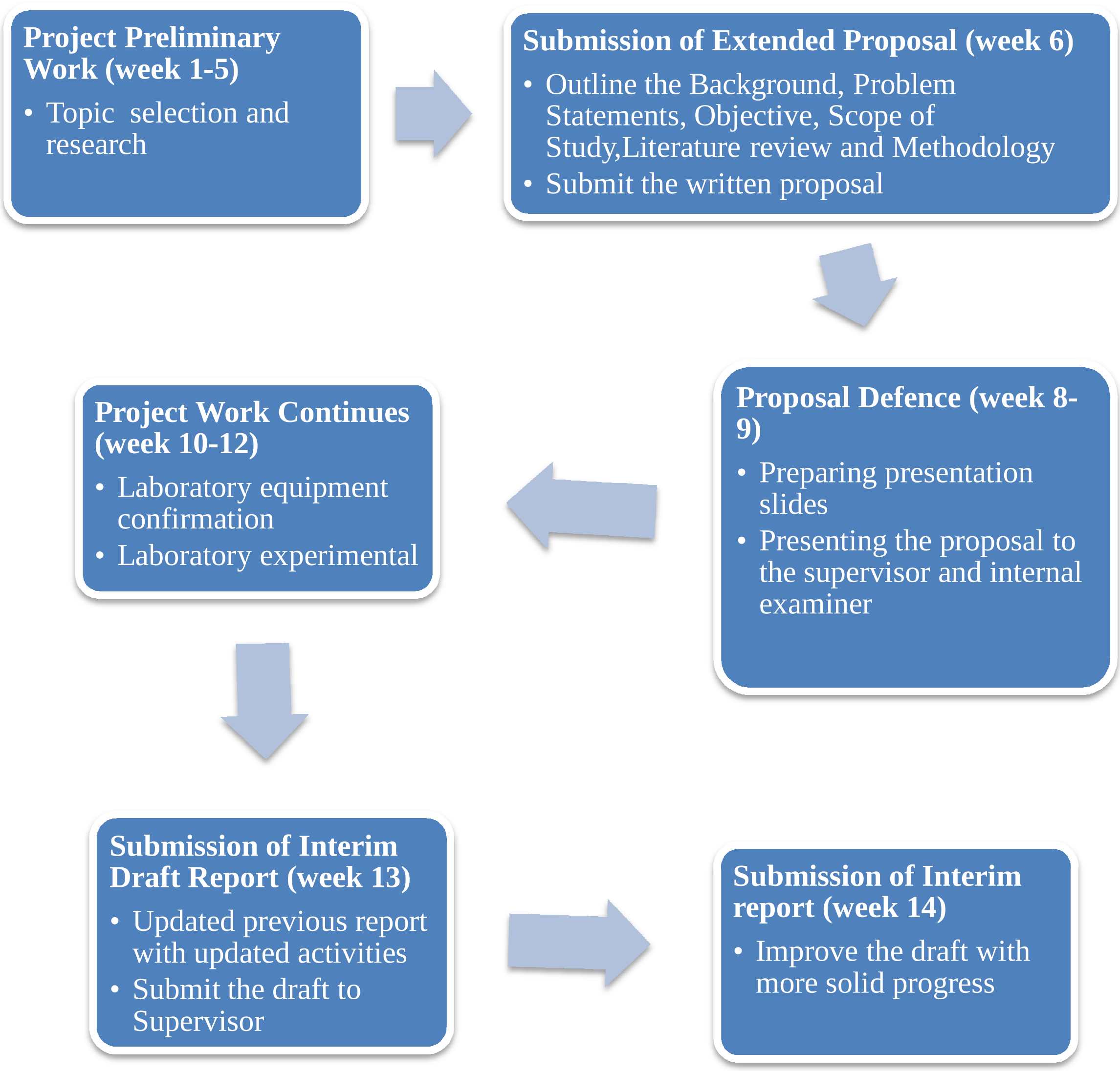


Figure 3.4: Key Milestones of Project (FYP 1)

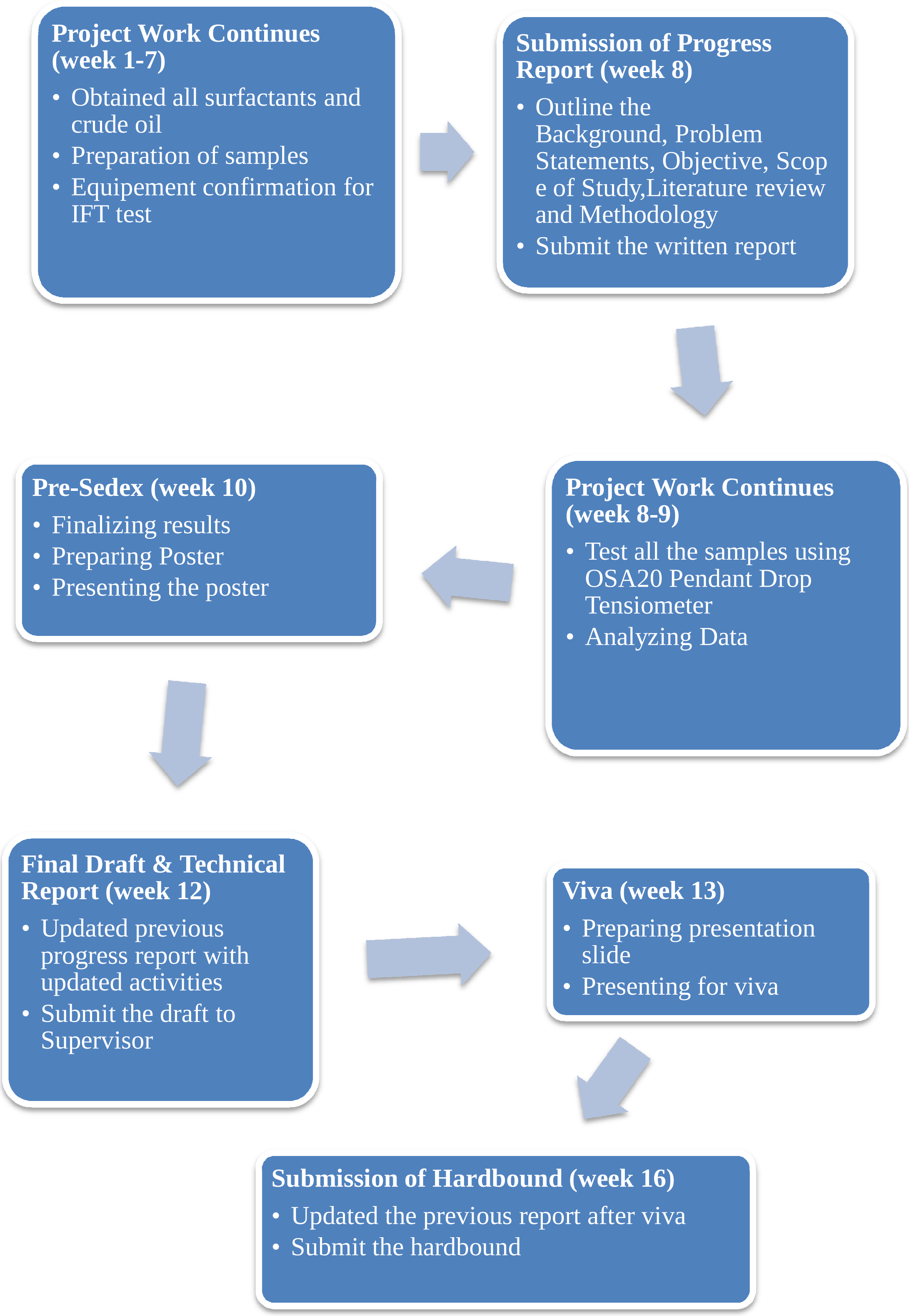
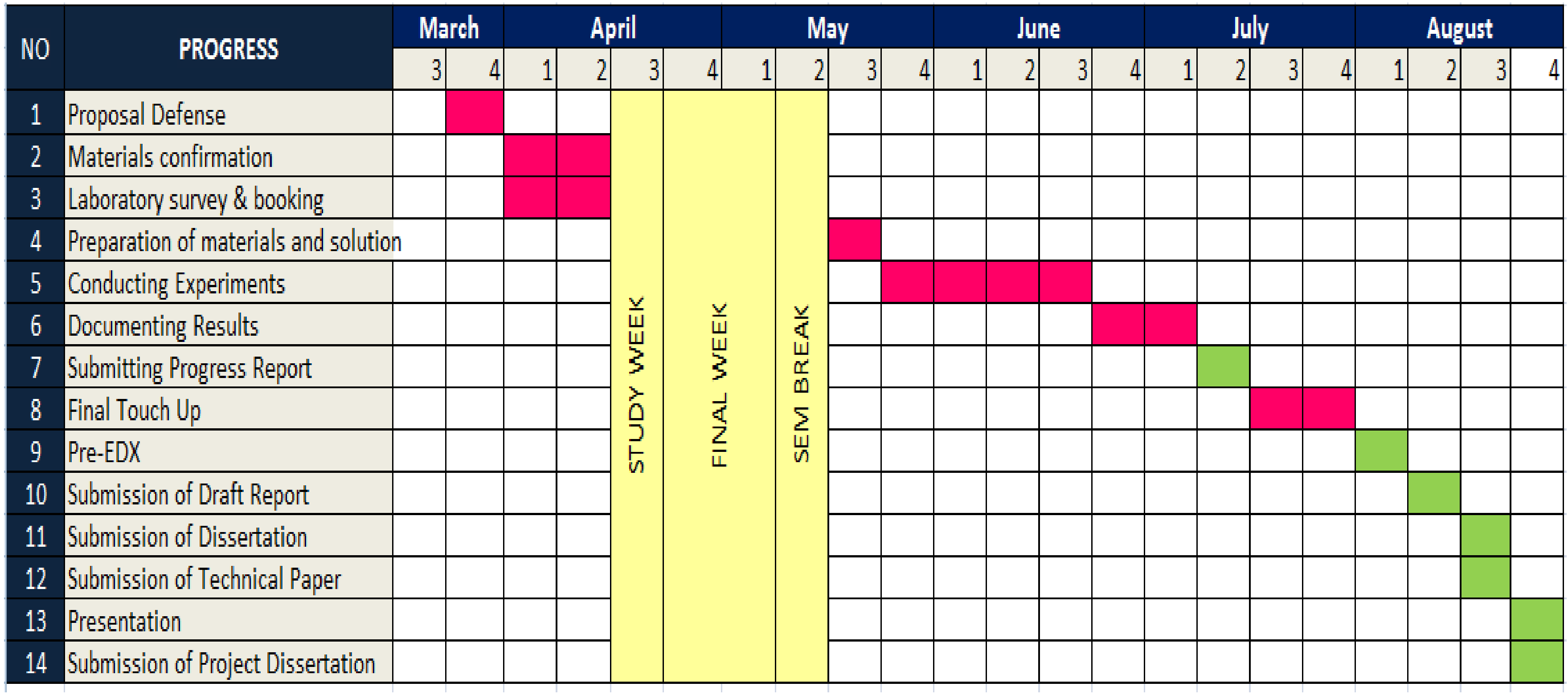


Figure 3.5: Key Milestone of FYPII

3.4 GANTT CHART



CHAPTER 4

RESULTS AND DISCUSSION

4.1 RESULTS

The interfacial tension (IFT) test result for both CL10 and IL10 in different salinity and temperature are summarized and presented in the graph.

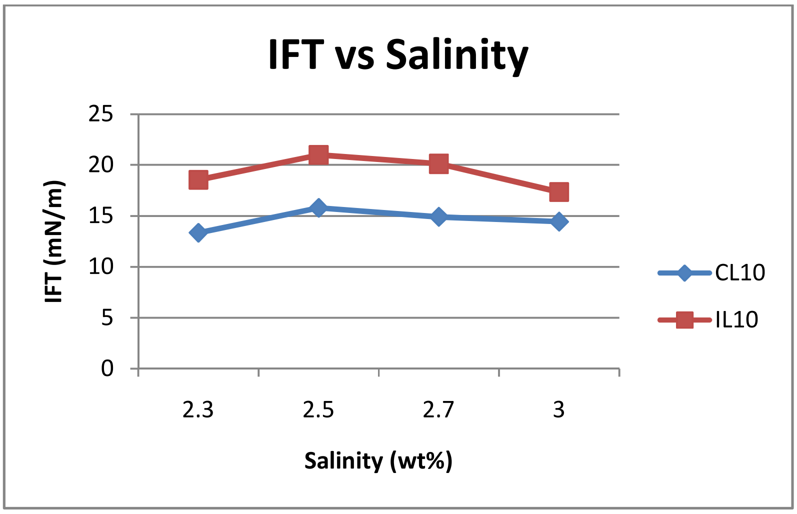


Figure 4.1: Graph of IFT against Salinity

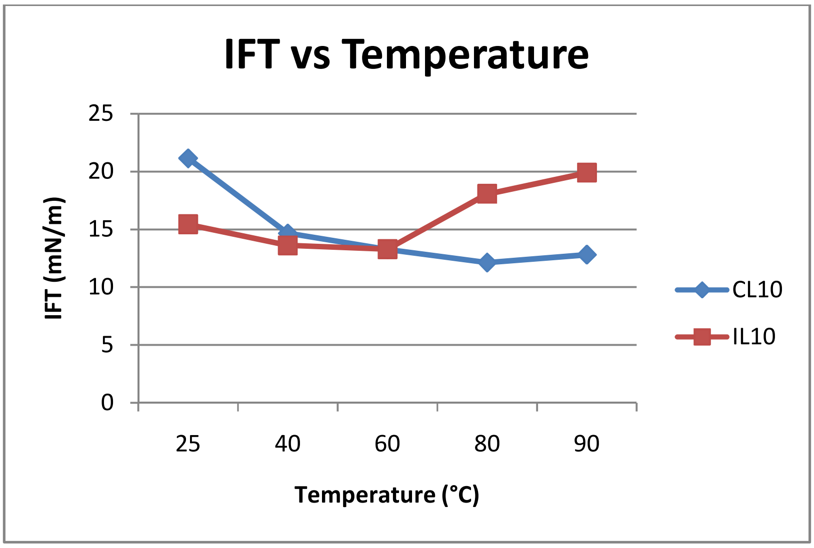


Figure 4.2: Graph of IFT against Temperature

4.2 DISCUSSIONS

There are several errors can occur throughout the experiment either it is systematic error or random error. Systematic error is caused by the way in which the experiment was conducted while random error is caused by unknown and unpredictable changes in the experiment like parallax error.

One of the systematic errors is the temperature indicator of OSA20 Pendant Drop Tensiometer. The indicator which made up of steel rod is located in the closed box that only detects the temperature of surrounded air, not directly into the sample. Therefore, even temperature is set up to 90°C, it cannot ensure that the temperature of samples tested is same as that temperature. So for every sample, it is placed for about 10 minutes in the closed box with the hot plate as the base before start the test.

The random errors can occur especially during the preparation of solution since a lot of measurement is involved. One of those is while reading the scale of the measuring cylinder to measure the liquid to be mixed. The eyes of student might not be parallel to the scale and cause the reading to slightly high or low from the exact measurement. Besides that, the error can occur during weighting of substances using the weighting balance which is quite a sensitive instrument. The air surrounding movement might let unwanted elements like powder to be on the weighting balance which can affect the reading.

After two weeks starting the last semester and dealing with equipment's and lab booking, the experiment eventually can be started. The experiment to test the IFT by using spinning drop tensiometer begins with different salinity of CL 10 which are 2.3 wt%, 2.5 wt%, 2.7 wt% and 3.0 wt%. The experiments for all four samples by spinning drop tensiometer are set at 90°C and takes about 4 hours to complete. The test for a sample actually only consume about 15 to 30 minutes but due to some errors and mistakes occur before and during the experiment lead the total time to be longer as 3 to 4 hours.

Unfortunately due to the unavailability of the spinning drop tensiometer, the test cannot be proceeded further to other surfactants and parameters for the third week of this semester. Nevertheless, another equipment for IFT test known as OSA20 Pendant Drop Tensiometer has been successfully booked and can be used on 6^{th} week of semester. Four samples of CL 10 with different salinity need to be re-run by OSA20 Pendant Drop Tensiometer because the result from spinning drop becomes invalid since it has been decided to use another method. So that the final results for all samples are standardized.

In order to prove that the surfactants used have the ability to reduce IFT, IFT test between crude oil and distilled water only is conducted. The result obtained for that as reference is 25 mN/m. Based on Figure 14, the interfacial tension for CL10 is reduced from 25 mN/m to about 14 mN/m while for IL10 is to about 18 mN/m at 2.5 wt% salinity. These reductions of IFT indicate that the surfactants used are able to reduce IFT for this type of crude oil. Besides that, the graph of IFT against salinity in Figure 4.1 also indicates that the different salinity give different value of IFT which suggest the salinity affect the surfactant IFT. The effect of salinity on IFT is important to be found out because the salinity of brine in the subsurface of oil reservoir may vary in both areal and vertical extent. This is more significant when the mature field that have been undergone several water flooding will experience substantial differences in salinity for instance the salinity of injected water is contrast to the original formation brine. Therefore, this IFT test with different salinity will assist the formulation design of these two surfactants for CEOR in future.

Both CL10 and IL10 show same trend of IFT against salinity line in which that IFT is increasing at first from 2.3 wt% to 2.5 wt% salinity. But from salinity at 2.5 wt% to 3.0 wt%, the IFT keep decreasing for both CL10 and IL10 until 14.42 mN/m and 17.35 mN/m respectively. From the results obtained, both surfactants have tolerance to high salinity since they have low IFT at highest salinity of 3.0 wt%. This behavior of surfactants is favorable for surfactant flooding. The decreasing of IFT as the salinity increases can be explained in term of solubility. As the salt concentration increases, the solubility of surfactant will be reduced which then allow the surfactant to migrate into interface increases. This kind of trend is supported by various researchers like Bansal & Shah (1978).

The effect of temperature on IFT between crude oil and water is investigated for two surfactants (CL10 and IL10) at reservoir conditions. The graph of IFT against Temperature from Figure 4.2 summarized how the temperature range from 25°C to 90°C affects the surfactants performance on IFT. From the graph plotted, both CL10 and IL10 lines are decreasing first and then increasing but they have different turning point. For CL10, the IFT starts to increase from 80°C after decreasing rapidly from 25°C. While for IL10, the IFT stop decreasing when it reach 60°C and increases to high IFT which is 19.89 mN/m. CL10 maintain low IFT about 21 mN/m to 12 mN/m in wide range of temperature (25°C-80°C) and can be considered to have good tolerance to high temperature. Instead for IL10, the IFT only decreasing until 60°C only and the lowest IFT is only 13 mN/m.

This kind of trend against temperature is also resulted and supported from research of Aoudia *et.al*, 2006. The decreasing of IFT with increasing of temperature can be explained in two terms which are solubility and viscosity. In term of solubility, increasing in temperature reduce the solubility of surfactant in which more surfactant can react at interface. While in term of viscosity, the viscosity is decreasing with temperature increasing. The reduction of viscosity causes surfactant migration to interface increases.

From the results obtained with respect to temperature, CL10 is a good surfactant to reduce IFT due to it can withstand with high temperature and achieve low IFT in wide range of temperature including high temperature. This is of great importance in the actual EOR process by surfactant flooding, owing to the facts that the temperature in many reservoirs is not uniform because of infiltration of hot water from underlying strata and that a slight decrease in the formation temperature occurs during injection that may alter the IFT.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Surfactant has become a very promising application in increasing oil recovery. Thorough researches about surfactant are necessary to know better about its behavior and performance in lowering interfacial tension. Temperature and salinity which are the most sensitive factors affecting the surfactants' behavior require some experiment to reveal the effect of those parameters on the interfacial tension especially by using new surfactants designed. From this project, it has been proved that both temperature and salinity have major effect on surfactant in reducing IFT. The results obtained for both surfactants tested show significantly changes of IFT in varying salinity and temperature. For the effect of salinity, both surfactants show tolerant to high salinity while for the effect of temperature, CL10 has better tolerant in the range of high temperature. Other than that, it can be concluded that CL10 is better surfactant than IL10. It can be observed by its performance to reduce IFT to the lower than IL10 is able.

5.2 RECOMMENDATION

After completing this project, it is suggested to have further study on the formulation design of both surfactants so that they can reduce IFT to the lowest about 10^-2 mN/m. Hopefully by this project, the new surfactants designed are capable to be used in Chemical EOR by showing good reaction with oil in reducing the interfacial tension to increase the oil recovery and eventually lead to effective EOR. Last but not least, it is advisable to develop the new and effective surfactants over time and widen the application of it.

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