Interfacial Tension Behavior and Oil Recovery Efficiency of Ionic Liquid As Surfactant

by

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CERTIFICATION OF APPROVAL

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(PETROLEUM)

Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2014

CERTIFICATION OF ORIGINALITY

This is to certify 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 and persons.

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NUR ASYIMAH BINTI MD ASRI

ABSTRACT

Depletion and high demand of crude oil had inspired the oil producers to explore other efficient enhanced oil recovery (EOR) methods. This enhancement process is the tertiary recovery method applied even after primary and secondary recovery methods take placed. By conducting this enhancement process, the extraction of oil will increase. However, exploration and further exploitation of old oil reservoirs become one of the most challenging activities in the petroleum industry. Surfactants are well known in the literature which plays the role in improving oil recovery that will affect the EOR performance. They affect the performance by reducing the interfacial tension (IFT) between water and oil besides changing the matrix wettability from mixed or oil wet to water wet and to reduce the capillary pressure thus allow the residual oil to flow. However, in term of surfactant itself, there are some factors which have impact on it. Temperature, salinity, concentration of surfactant is a few example of the parameter that should be taken into account. The effects of each parameter are investigated in most of the studies. In this study, various concentration of different ionic liquid based surfactant will be used as new candidate in order to measure the IFT. Based on the experiment, the other critical parameter of surfactant behaviour can be determined. The critical micelle concentration (CMC) is known as surfactant concentration in the large amount at which formation of micelle started. Although concentration of surfactants increased however it will not affect the IFT anymore that means the value of IFT cannot be reduced. Therefore, from the graph of ionic liquid concentration versus interfacial tension, the capability of surfactant to reduce the surface tension can be proven.

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ABBREVIATIONS AND NOMENCLATURES

CMC	Critical Micelle Concentration
EOR	Enhanced Oil Recovery
IFT	Interfacial Tension
IL	Ionic Liquid
Ppm	Parts per million
R&D	Research and Development

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

This project aims to come out with a new type of surfactant instead of the existing one in order to create a more efficient enhanced oil recovery (EOR) method. This hopefully will become a motivation to the oil producers in meeting high energy demand. The chart in Figure 1 shows that unconventional resources are much larger than conventional one. Only 30% from them are from conventional oil reserves. According to Hezave et al. (2013), it is estimated more than two-third of the original oil is trapped in the reservoirs after the conventional oil produced. In order to overcome this problem, a wide range of investigations were carried out and chemical flooding became one of the initiatives for efficient enhanced oil recovery method. At the same time, difficulties in finding new oil reservoirs and the high cost have forced the oil industry to explore for methods to enhance oil recovery from trapped oil in the depleted reservoirs.

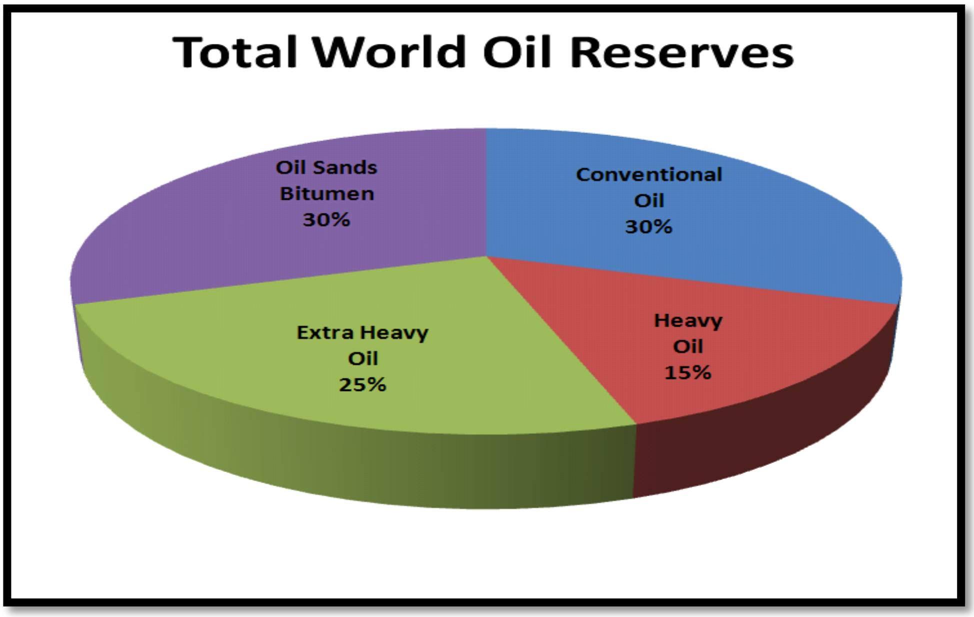


Figure 1: Total World Oil Reserves

Figure 2 shows several enhanced oil recovery methods, however this project will focus on chemical flooding where surfactant will be used. From some researchers' experiments, surfactants are the chemicals that can reduce the interfacial tension between water and oil. Therefore, oil displacement can be improved. Surface active agents or in short is called surfactants has polar and amphiphilic molecules. There are four categories of surfactant, classified as anionic, cationic, nonionic and amphoteric. Anionic is commonly used in many industrial applications even in EOR. There are also problems in applying surfactant into the reservoir. For this project, an experiment is conducted in order to get new candidates of surfactant which can enhance the efficiency of oil recovery.

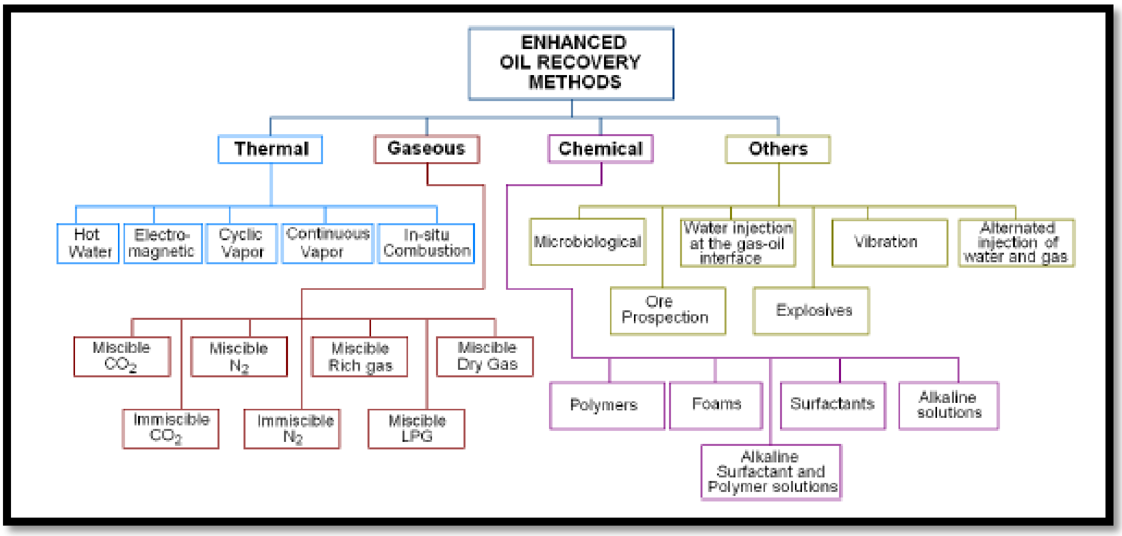


Figure 2: Several Enhanced Oil Recovery Methods

1.2 PROBLEM STATEMENT

Enhanced oil recovery (EOR) is the tertiary recovery method which is applied after primary and secondary recovery stages when there are still oil trapped in the reservoirs. In order to sustain the production of crude oil, efficient enhanced oil recovery methods need to be explored. Chemical flooding can be considered as an efficient EOR method. One of which is surfactant flooding. Surfactant is used in order to reduce the interfacial tension between water and oil which lead to the increment of mobility ratio. The purpose of this project is to study and propose a new candidate of surfactant which could be effective and economical which is made from ionic liquid. This study will also focus on critical micelle concentration (CMC) to be much lesser or economical than CMC of the existing surfactants. In order to come out with the best ionic liquid as surfactant, experiment will be run and analysis of data will be conducted. A suitable surfactant is the one that can reduce the oil and water interfacial tension sufficiently, besides being compatible with reagents and process involved in EOR.

1.3 OBJECTIVES

Chemical flooding can be one of the efficient enhanced oil recovery methods. Since surfactant flooding is one of the chemical flooding methods proposed to be efficient in enhancing oil recovery, it will be studied further in this project.

The objectives of the project are:

1. To study the relationship between IFT and concentration of the new surfactant
2. To determine the critical micelle concentration (CMC) point of the new surfactant
3. To compare the IFT reduction capability of new surfactant with the existing surfactants

1.4 SCOPE OF STUDY

The scopes of study of the project are:

1. Study on the new designated surfactants
2. Setting up a laboratory experiment to determine IFT of surfactants
3. Determine the critical micelle concentration (CMC) point for each surfactant

1.5 RELEVANCY OF THE PROJECT

This project is a relevant project since it may give a new idea regarding the suitable candidate of surfactant to be used in EOR process. The surfactant should be able to increase the efficiency of oil recovery. Instead of using common surfactant, ionic liquid based surfactant with various concentrations will be studied since there are some papers revealed its effectiveness to lower the IFT thus become a new candidate for IFT reduction. Based on the relationship between concentration and interfacial tension, critical micelle concentration (CMC) point can be plotted. Again, the suitable concentration of the surfactant can be estimated.

1.6 FEASIBILITY OF THE PROJECT

The interfacial tension experiment is suitable for a laboratory scale project since the equipment, tools, chemicals and accommodation can be set up. The time frame given to run this experiment is also sufficient. It is possible to finish both study and experiment within the time frame.

CHAPTER 2

LITERATURE REVIEW

The high demand of crude oil leads to enhancement of oil recovery from depleted reservoir nowadays. Tertiary recovery method is applied when there is no potential for primary and secondary methods to be carried out but only when the oil can still be extracted profitably. There is still two-thirds of crude oil trapped in the oil reservoirs after primary and secondary recovery stages which become the main concern for the oil producers to do some research and investigation to overcome this problem (Hezave et.al, 2013). Enhanced oil recovery or sometime is called tertiary recovery method will increase the extraction by increasing the mobility of oil. Carcona A. (1992) mentioned that elimination or reduction of capillary and interfacial forces of the oil-water system is one of the intentions of EOR methods which can improve the displacement efficiency. This goal can be achieved through the application of chemical injection methods such as surfactant flooding, where residual oil saturations is reduced in the laboratory and the field far below those values obtained by a water flooding process (Flaaten 2008; Lake 1996). Therefore, chemical flooding is the most selected method for EOR process. Many researchers had mention that surfactant flooding is the one of chemical EOR process which commonly used in order to enhance oil recovery from depleted reservoirs with low pressure. Again, according to Delshad et al. (2009), in order to improve the oil recovery, chemicals and heats can be used where they can reduce the interfacial tension (IFT) between water and oil; and change the matrix wettability from mixed oil wet to water wet. Surfactant flooding is usually expensive due to high cost of the chemical. However, this is not a problem for oil producers to invest since the additional oil recovery can pay back the cost. This can be established by designing optimum injection scheme based on current crude oil prices (Bryan and Kantzas, 2007).

Surfactants, short for surface active agents, are polar and amphiphilic molecules which can decrease the interfacial tension (IFT) between liquid surfactant solution and the residual oil. They are classified on the basis of the charge of the hydrophilic group present in them. Mainly four categories existed such as anionic, cationic, non-ionic and amphoteric. Anionic are commonly used for various industrial application and also in enhanced heavy oil recovery studies. Enhancement oil recovery method had been done in low matrix permeability and high matrix porosity fractured reservoirs in order to achieve maximum production. In recent years, injection of surfactant solution into naturally fractured reservoirs has gained a great deal of attention. According to Seethepalli et.al (2004), anionic surfactants have been identified as surfactant which can change the wettability of the calcite surface to intermediate or water wet condition better than cationic surfactant dodecyl trimethyl ammonium bromide (DTAB). In the other paper, non-ionic surfactant solution is said to be good since it can increase the recovery rate and ultimate recovery of heavy-oil in water-wet sandstone compared to the brine imbibition. Hence, each category has its own application based on different situation.

Surfactants usages are very well known in oil and gas industry whether in the petroleum recovery or processing industry. There are several papers discussing the function of surfactant in helping enhanced oil recovery process [3], [11], [21]. Bryan J., & Kantzas A. (2010) points out that surfactants are special molecules that are both hydrophilic and hydrophobic, thus the most stable configuration for them is at the interface between the water and oil. By arranging themselves in this manner, surfactants can lead to dramatic reductions in the oil-water interfacial tension. There is less capillary trapping of oil when the reduction of IFT occurs. It has been shown both experimentally and theoretically. Delshad et al. (2009) also mentioned that surfactants change the wettability that increases the oil recovery by increasing the imbibition of the water into the matrix rock. Therefore, it proved that surfactant has the ability to reduce interfacial tension, reduce wettability alteration and mobility ratio.

Austad et al. (1998) carried out imbibition experiments in nearly oil-wet, low-permeable (1 to 2 md) rocks with and without surfactant present. A 1 wt% cationic dodecyltrimethyl-ammonium bromide surfactant solution was used. Their results indicated a sudden increase in oil recovery when surfactant was present. Laboratory experiments using Yates San Andres reservoir core indicate that the injection of dilute non-ionic surfactants resulted in an improved oil recovery compared to injection of brine. The studies mentioned above indicate that surfactants play roles in enhanced oil recovery. Unfortunately, there are also disadvantages or challenges in applying surfactant into the reservoir. Beyond the critical micelle concentration

(CMC) point, the interfacial tension cannot be reduced anymore even though there is increment in surfactant concentrations (Khrosravi, 2010). The trend agrees well by other study [15]. Besides, according to Thomas S., Scoular J.R., & Farouq S.M. (1999), they also stated a few problems and limitations of surfactant in their research paper. The first one is the interaction between surfactant and minerals due to its absorption, and second is its loss to the rock matrix through several mechanisms.

Since the surfactant itself had problems therefore it is a must to study in details regarding this chemical. There are some factors which have impact on it. Temperature, salinity, concentration of surfactant is a few example of the parameter that should be taken into account. The effects of each parameter are investigated in most of the studies. This is because interfacial behavior is the main concern in oil recovery. Hezave et.al (2013) says that the extent of residual oil trapped in the reservoir pore structure is dominated by capillary and interfacial forces. The residual oil will be mobilized if the capillary forces are reduced because of IFT reduction during surfactant flooding into the reservoirs. Due to this reason, the relationship between IFT and the parameters should be studied. To come out with a good surfactant, experiments must be conducted since different surfactant behaves differently. The objective is to identify the best surfactant in terms of performance yet applicable at more economical conditions. For this project, ionic liquid is proposed as a new candidate for IFT reduction process. Ionic liquids (ILs), organic salts that are composed of organic cations with organic or inorganic anions, which are liquids within room temperature, have received considerable attention recently as potential “green” alternate to surfactants [13].

In term of concentration parameter, studies have been conducted using low concentration of surfactant in order to improve oil recovery (Spinler, 2000). It was found that, when added at low concentration (100 to 500 parts per million of active surfactant) to the imbibition water, reduced the residual oil saturation over imbibition tests conducted without surfactant. This study also showed the possibility to have an economic surfactant process at low surfactant concentrations. This finding is supported by other study [19]. However, different type of surfactant will give different readings on the effect of concentration with interfacial tension measurement which lead to experimental work. Besides, formulation of appropriate chemicals is also needed in order to generate solution with great performance based on low cost including challenging problematic reservoir properties. Economic prospective of surfactant injection is very important due to the cost since the chemicals required can be expensive. Thus, optimum injection design is needed [15].

CHAPTER 3

METHODOLOGY

3.1 PROJECT ACTIVITIES

The methodology used for this project is by research and experimental method. As this project is quite similar to research and development (R&D) field therefore the results obtained from this research can be compared with the existing one under similar scope of study. The Figure 3 below shows the flow of the project that will be implemented.

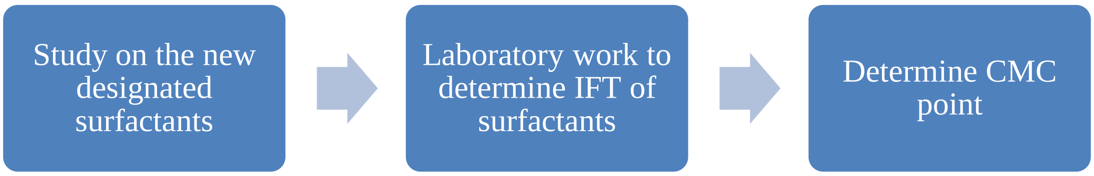


Figure 3: The Schematic Diagram of Project

Based on the interfacial tension experiment, measurement of interfacial tension can be made where several type of surfactant are used. By having several surfactant concentrations, the effect of surfactant concentration on IFT and the critical micelle concentration point will be determined.

<u>Theories</u>

Surfactant

Surfactant are polar and amphiphilic molecules which can reduce the interfacial tension (IFT) between the liquid surfactant solution and the residual oil. In enhanced oil recovery with surfactant flooding, the hydrophilic head interacts with water molecules or has higher affinity for water while the hydrophobic tail interacts with the residual oil or afraid of water. Figure 4 shows the surfactant molecule and its orientation in water.

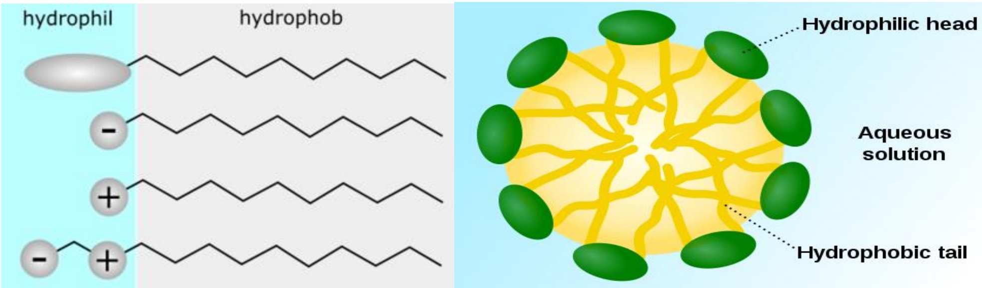


Figure 4: Surfactant molecule and orientation in water

There are a few categories of surfactant such as anionic, cationic, non-ionic and amphoteric. They can be classified based on the basis of the charges. For anionic surfactants, hydrophilic group carries a negative charge. They are commonly used for various industrial applications and enhanced oil recovery (EOR). For cationic surfactants, hydrophilic group carries a positive charge. During the synthesis to produce cationic surfactants, they undergo a high pressure hydrogenation reaction, which is in general more expensive compared to anionic surfactants. As a direct consequence cationic surfactants are not widely used as non-ionic and anionic surfactants. The other type of surfactant is non-ionic surfactants. The hydrophilic group carries no charge which is also used in EOR mainly as co-surfactants to promote the surfactant process. Their hydrophilic group is of a non-dissociating type, not ionizing in aqueous solutions. Besides, amphoteric is the other type of surfactant wherein molecule carries a positive and negative charge.

IFT Measurement

Interfacial tension (IFT) is a measurement of the excess energy present at an interface arising from the imbalance of forces between molecules at an interface. Chemical screening by IFT test is to determine the best surfactant to be used and the optimum surfactant concentration (wt%). If the surfactant concentration increases, IFT decreases rapidly. This process continues until the point of CMC is reached. After CMC, little change is observed in the IFT. By using pendant drop or spinning drop method, interfacial tension between the oil and solution in contact with the oil can be determined. This equipment was designed to measure the interfacial tension. Crude oil which has lower density than water was placed as the rising drop liquid while surfactant solution or brine was placed as bulk liquid. After setting the temperature at defined value, an oil rising bubble was generated in the cell. The shape of the liquid drop can be seen in the computer with the help of connected camera to the computer in order to derive the interfacial and contact angle properties. Densities for bubble phase and bulk phase at measurement temperature are required as input data to calculate the IFT. The methodology of measuring IFT is explained in the procedure below:

1. Prepare the solutions to be injected.

2. Check the device is clean, and then start the assembly process for the fluid chamber covers and injection needle.

3. Turn on the PC and startup the device; check the camera and the fluid chamber.

4. Start the IFT software on the desktop of the connected computer.

5. Through the software, the other setup process such as focusing would be completed.

6. Fill up the liquid chamber and adjust the required pressure and temperature.

7. Start creating a drop in the chamber and controlling it by using the injection pump and monitor through the PC camera's window.

8. After creating the drop, the measurements setups should be done.

9. Lastly, the measurements can be read through Microsoft Excel and HTML files.

10. Clean the device and the other equipment used.

Note: The experiment is repeated for different surfactant and its concentration. The samples are tabulated in the Table 1 below:

Table 1: IFT Measurement Readings

	Surfactant Type	Surfactant Concentration (ppm)	Brine	IFT (mN/m)
OIL	IL 10	100	**Xxx ppm Brine**	
		200		
		400		
		1000		
		2000		
		3000		
		5000		
	CL 10	100		
		200		
		400		
		1000		
		2000		
		3000		
		5000		

In order to find CMC point, IFT of the IL solution at different concentration were measured and plotted versus concentration of solution.

Critical Micelle Concentration (CMC)

Critical micelle concentration is the surfactant concentration in the bulk at which micelles start forming. CMC is an important characteristic of surfactant which is measured based on IFT between surfactant solution and oil sample. Before reaching the CMC, the surface tension changes strongly with the concentration of the surfactant. However, after reaching the CMC, the surface tension remains relatively constant or changes with a lower slope. Micelle is an aggregate of surfactant molecules dispersed in a liquid colloid. It is only form above critical micelle temperature. When the surface becomes saturated, the addition of the surfactant molecules will lead to formation of micelles.

3.2 CHEMICALS AND APPARATUS NEEDED

In the experiments that are going to be conducted, several chemicals, materials and apparatus are needed. List of the chemical and apparatus used in this research study is given in the Table 2, Table 3 and Figure 5.

Table 2: List of Chemical and Materials

Chemicals/Materials	Amount (g)	Purpose
CL 10	1.2	Preparing bulk solution: -CL10 solution, IL10 solution, brine
IL 10	1.2	
Sodium Chloride	42	
Distilled Water	450	
Crude oil	10	To be inject with the CL10 and IL10
Cleaner Degreaser	1 bottle	To clean the cube after each experiment

Table 3: List of Apparatus/ Equipment

Apparatus/ Equipment	Amount
Sample bottle	14
Beaker	3
Measuring Cylinder	3
Magnetic stirrer with heater	1
Micropipette	1
Syringe	3
Needle	3
Weighting Equipment	1
Density meter	1
Pendant Drop Tensiometer (IFT)	1

Pendant drop tensiometer, provided with all the necessary equipment.

Features:

- IFT standard measurement: 0.01 to $2x10^3$ mN/m
- Temperature: Ambient to 180^oC
- Accuracy: 0.01 mN/m
- Pressure: 700 bar(10,000 psi)
- Power supply: 220 VAC 50 Hz
- High performance 6-fold power zoom lens

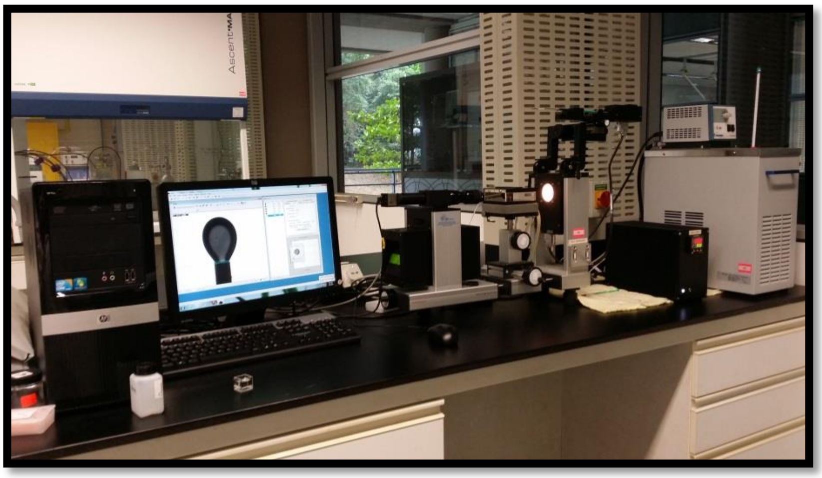


Figure 5: IFT Measurement Equipment

3.3 KEY MILESTONES

Key milestones should be achieved for every project in order to meet the objective of the project. Below are the key milestones for this project:

Problem Statement and Objective of the project

Identifying the purpose of this project

↓

Literature Review

Gathering as much information as possible from various sources such as journals and websites in order to know the background of this project

↓

Experiment Design

Identifying the subjects that need to be investigated and the experimental procedures, as well as the chemicals needed and the collection of results

↓

Data Analysis and Interpretation

The findings obtained are analyzed and interpreted critically. Comparison with other literature readings will also be done.

↓

Documentation and Reporting

The whole research project will be documented and reported in detail. Recommendations or aspects that can be further improved in the future will also be discussed.

Figure 6: Key Milestones for the Project

3.4 GANTT CHART

	Final Year Project- I														Final Year Project- II													
Detail/ Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Identify the purpose of this project and gather as much information																												
Study the experimental procedure and check the availability of equipment. Prepare the samples that will be used																												
Run the experiment on IFT measurement at different surfactant concentration with several types of surfactant																												
Analyze the result and proceed with determination of CMC point																												
Compile all the documentation including the discussion based on the results obtained in the report																												

CHAPTER 4

RESULTS AND DISCUSSION

4.1 DATA GATHERING AND ANALYSIS

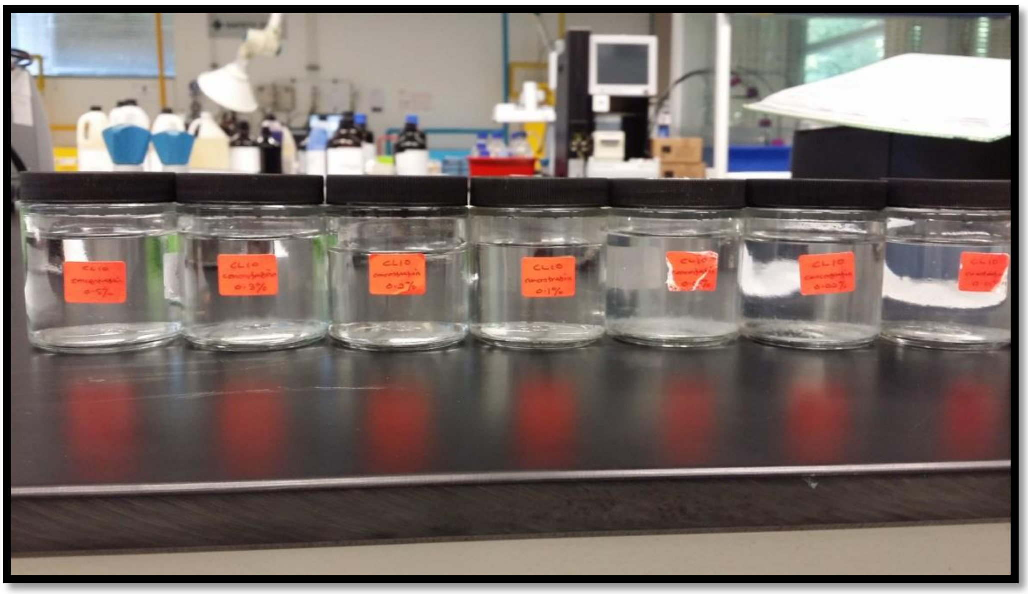


Figure 7: CL10 and IL10 Solution Samples with Various Concentrations

The Figure 7 above shows a few samples of ionic liquid solutions that have been prepared in the laboratory which is CL10 and IL10 solution with various concentrations. The selected surfactant concentrations were varied in parts per million based on weight of chemicals used. The concentrations prepared were 100, 200, 400, 1000, 2000, 3000 and 5000ppm. Basically, to come out with these solutions, bulk solution need to be prepared based on the calculation. In weight percent, the surfactant solutions were 0.01, 0.02, 0.04, 0.1, 0.2, 0.3 and 0.5wt%. The salinity and temperature is constant parameter which is 3wt% or in parts per million equal to 30 000ppm salinity and 90^0C temperature. The procedure to prepare bulk solution and sample was divided into several basic steps as below:

Step 1: Need to know the amount for each chemical used such as CL10, IL10, sodium chloride powder and distilled water in unit gram and measure using weighting equipment as per Attachment 1 and 2 in appendices.

Step 2: Mix each chemical with distilled water based on required amount using heater and magnetic stirrer in order to form a solution. Refer Figure 8 below and Attachment 3 in appendices.

Step 3: Then, start preparing the samples with different surfactant concentration according to the mixing volume using equipment as per Attachment 4 and Figure 7.

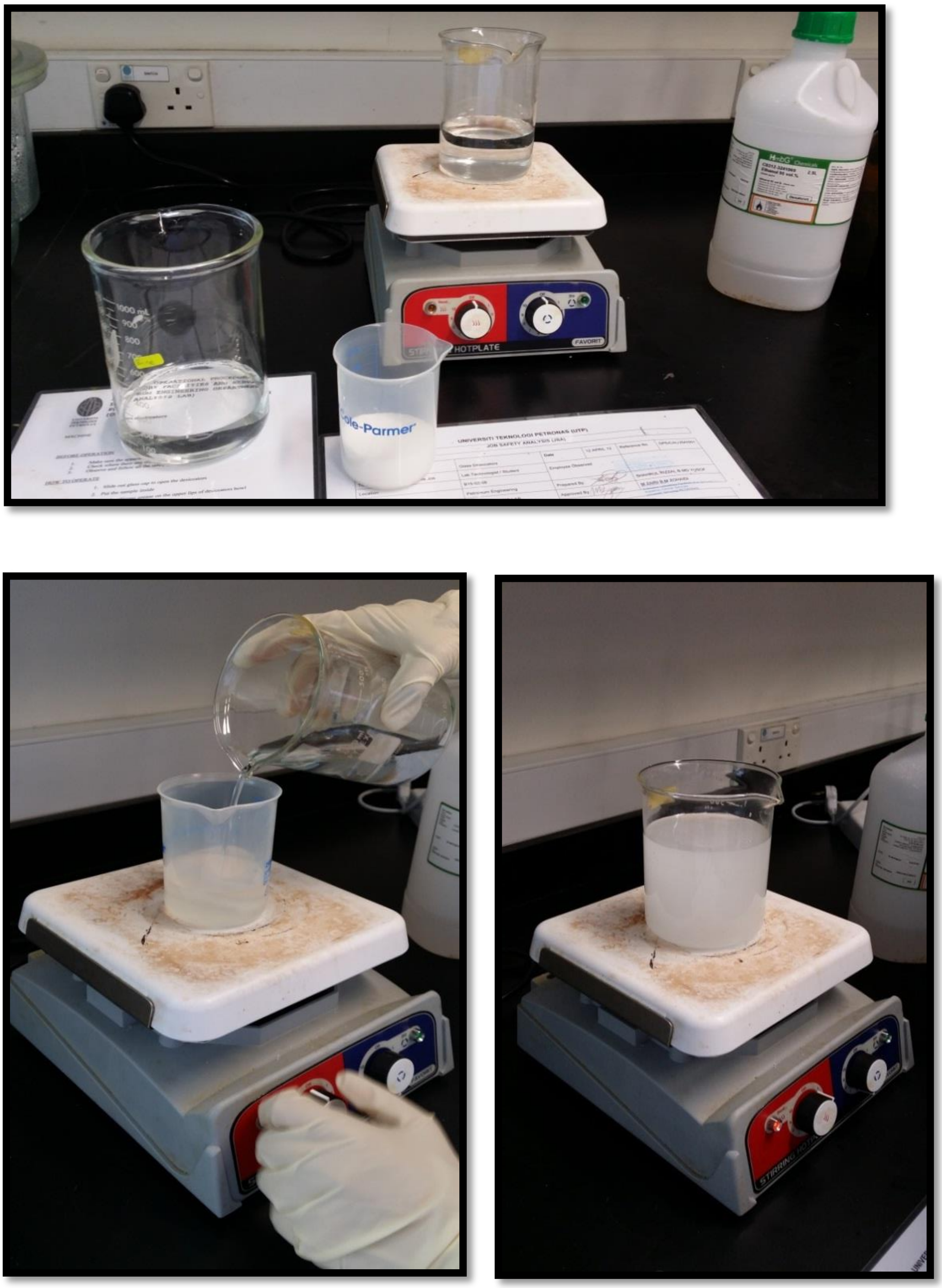


Figure 8: Mixing chemical using heater to form a solution

Before run the experiment, densities for bubble phase and bulk phase at measurement temperature are required as input data in the software in order to calculate the IFT. Refer Attachment 5 for density meter. From the data, IFT experiment can be run. Ionic liquid solution is placed as bulk liquid while crude oil was placed as the rising drop liquid.

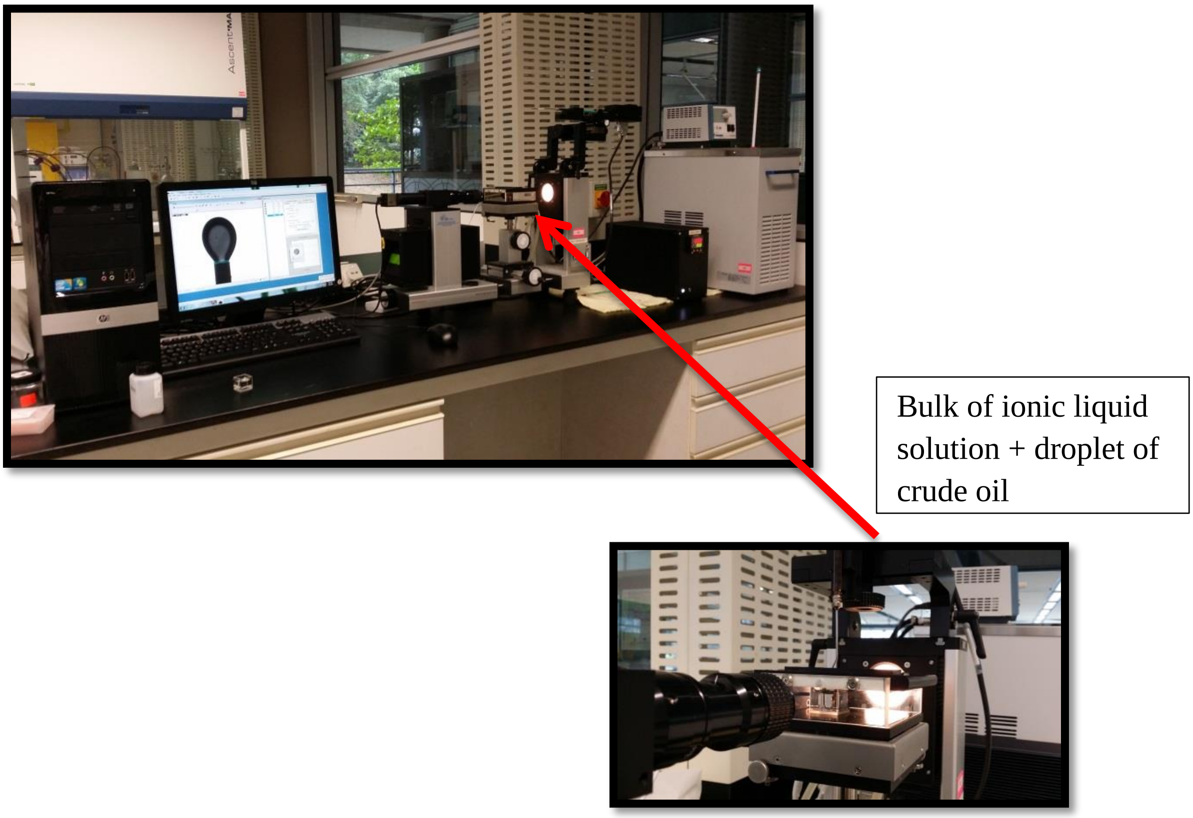


Figure 9: Running the IFT Experiment

4.2 RESULTS AND DISCUSSION

There are several parameters that affected the IFT behavior such as concentration, temperature and salinity. Concentration parameter is the only focus for this project. The salinity and temperature is constant for every experiment which is 30 000ppm or equal to 3.0wt% salinity and 90^0C in temperature. Two type of surfactant at different concentration were prepared and their IFT values with crude oil were measured.

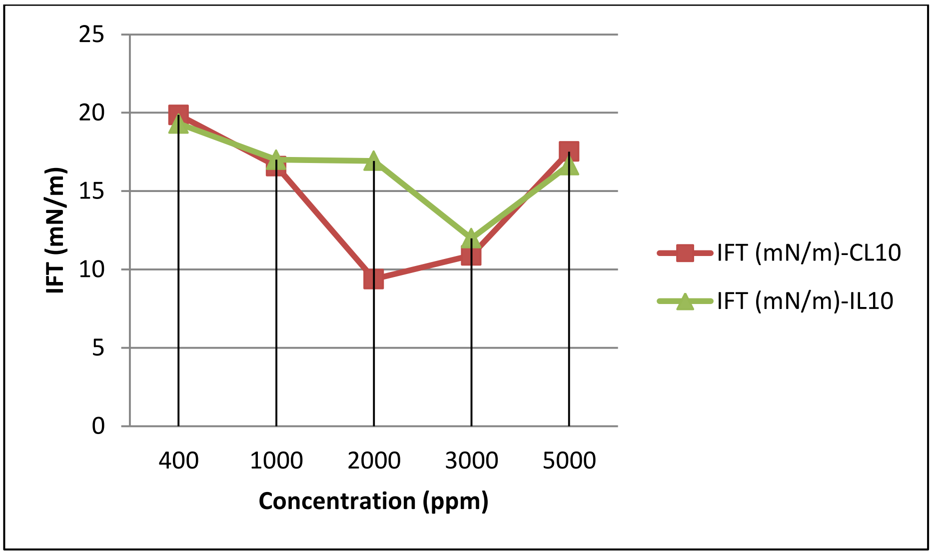


Figure 10: IFT vs Concentration Graph 1

From Figure 10, it indicates that both CL10 and IL10 have same trend of result which is IFT reduces as concentration increases. However, after certain concentration of surfactant, IFT cannot be reduced anymore. This turning point is referred as CMC point. It can be said that CMC point for CL10 is at 2000ppm while CMC point for IL10 is at 3000ppm of the concentration. It is important to identify the lowest concentration to use to reach desired IFT since it will reflect the most economical concentration for surfactant flooding. This trend of IFT reduction with different concentration is supported by other papers [15], [16]. Beyond CMC point, IFT cannot be reduced anymore even though there is increment in surfactant concentration. Besides, surfactant ability to reduce the IFT is different [15]. For example, at the given condition of temperature (90^0C), increasing CL10 surfactant concentration from 1000 to 2000ppm has more effect on IFT with reducing IFT the most reduction of about 7 mN/m. Hence, it can be a good candidate at the given condition. The least IFT reduction was seen when IL10 surfactant was used.

Comparing both surfactant types, it was observed that CL10 was more efficient than IL10 at the same surfactant concentration and reservoir conditions.

Furthermore, the reason that lead to reduction of IFT with increasing surfactant concentration is because surface tension will decrease sharply since there is an excess concentration of surfactant molecules at the interface, it increase the mixing ability of the two liquid thus lowers the interfacial tension between them. So it is easier to stretch the surface of the interface. However, when they start saturating the system, the surfactant dissolution in system changes, reverse the distribution coefficient thus change fluid-fluid interaction and reverse the effect. Therefore, determination of CMC point for each type of surfactant is important since CMC known to be the economical concentration for surfactant flooding. Economic perspective of surfactant injection is very important which optimum injection design is needed.

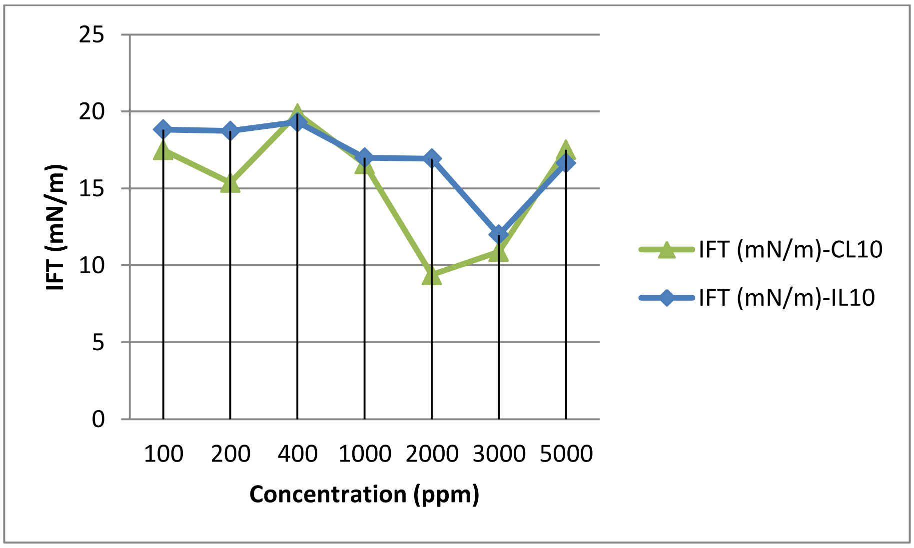


Figure 11: IFT vs Concentration Graph 2

Range selection for surfactant is important. Figure 11 shows that IFT for both CL10 and IL10 produced same trend of result when started with low surfactant concentration which is from 100ppm. It shows fluctuating result. It could be due to the very low concentration with high margin of errors. Maybe 100ppm is too small concentration and not sufficient enough for the surfactant to reduce IFT. From the previous studies, authors always start with lower surfactant concentration in order to improve oil recovery [20]. It showed the possibility to have an economic surfactant process at low surfactant concentrations. This finding is supported by other author [19]. For this project, the selected range is from 400ppm to 5000ppm of the concentration. The reason of choosing this range is because there is possibility to test other parameters such as temperature, pressure and salinity later in order to identify the best surfactant in terms of performance yet applicable at more economical conditions.

During the experiment, there are some factors and errors that should be considered which will affect the result. Parallax error should be avoid by make sure the eye in the right position while taking readings. Besides, by using appropriate equipment can give accurate measurement such as using micropipette to measure small volume of solution. Accuracy of the reading such as density and IFT also depends on the cleanliness of the equipment itself. It is important to make sure the equipment is totally clean before proceeding with the other samples. For example, the cube for placing the bulk surfactant solution need to be clean using cleaner degreaser to make sure there is no more chemical left. Surfactant solution is the other factors that need to be consider carefully in initial screening. In pendant drop method, the bulk phase must be clear and transparent to enable the camera to capture the drop image. Other than that, the bubble must have sufficient contrast with the bulk phase to allow the image processing software to differentiate them. A boundary line was created and hence IFT value can be calculate based on the bubble size. Figure 12 shows the image of bubble formed for one of the sample.

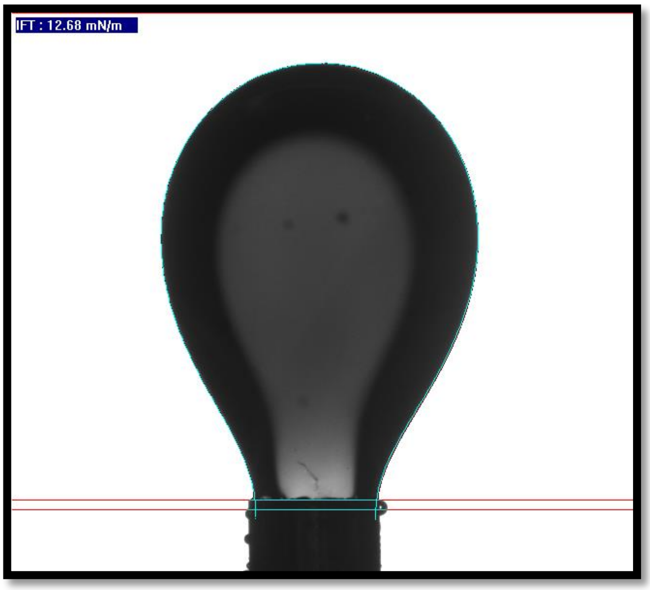


Figure 12: Image of Bubble Formed

Figure 13 shows the mechanism of interfacial tension which gives impact to capillary forces. This is because the interfacial tension between the water and oil would be the most important parameter that should be considered where minimization of IFT helps in reduction effect of capillary forces. Surfactant concentration with the lowest CMC will be chosen while surfactant solution with the lowest IFT is the best.

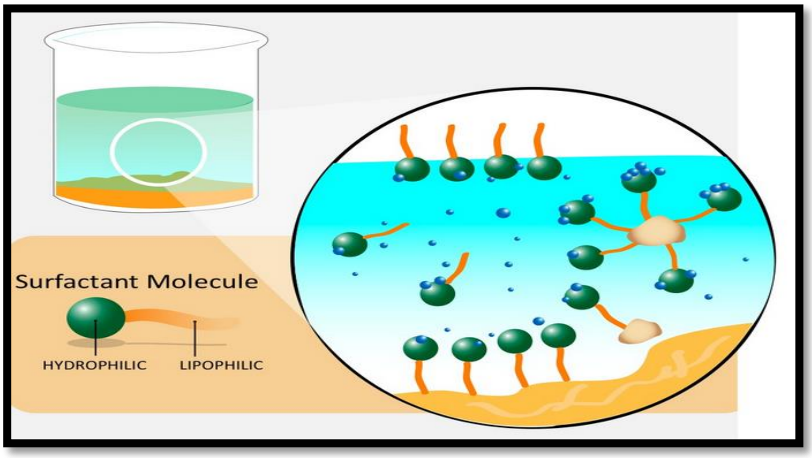


Figure 13: Mechanism of Interfacial Tension

CHAPTER 5

CONCLUSION AND RECOMMENDATION

CONCLUSION

Concentration is one of the parameters that can affect the IFT measurement. Based on the experiment conducted, IFT tends to decrease with increasing surfactant concentration. CMC is determined in order to have economical concentration for surfactant flooding. CMC point for CL10 is at 2000ppm of the concentration while for IL10 is at 3000ppm of the concentration. Therefore, CL10 is more efficient that IL10 at the same reservoir conditions. However, further study need to be done by using the selected range to test other parameters. Hopefully, this IFT result on the new surfactants can be compared with the existing surfactants later in order to investigate the reduction capability between them since this study on new surfactants has opportunity in increasing the efficiency of EOR process.

RECOMMENDATION

For the recommendation or future work, this project should have continuation since this is a new investigation that needs to be studied in order to search more efficient enhanced oil recovery (EOR) methods where many of the studies are focusing on it due to high demand of crude oil. The objective is to identify the best surfactant in terms of performance yet applicable at more economical conditions. Core flooding experiment can be the next step of this project. However, before run core flooding experiment, there are some parameters that should be considered such as temperature, pressure and other related parameters. Therefore, it is compulsory to study the effect of each parameter on IFT measurement first. Besides, further modification on formulation of appropriate chemicals can generate solution with great performance.

REFERENCES

[1] Babadagli, T. (2003). *Analysis of Oil Recovery by Spontaneous Imbibition of Surfactant Solution*. Published by Society of Petroleum Engineering.

[2] Barnes, J.R., Smit, J.P., Smit, J.R., Shpakoff, P.G., Raney, K.R., & Puerto, M.C. (2008). *Phase Behaviour Methods for the Evaluation of Surfactants for Chemical Flooding at Higher Temperature Reservoir Conditions*. Published by Society of Petroleum Engineering.

[3] Bryan, J., & Kantzas, A. (2007). *Enhanced Heavy-Oil Recovery by Alkali-Surfactant Flooding*. Published by Society of Petroleum Engineering.

[4] Carcoana, A. (1992). *Applied Enhanced Oil Recovery*. Prentice Hall, New Jersey.

[5] Critical Micelle Concentration. Retrieved February 10,2014, from http://en.wikipedia.org/wiki/Critical_micelle_concentration.

[6] Delshad, M., Najafabadi, N.F., Anderson, G.A., Pape, G.A., & Sepehrnoori, K. (2009). *Modelling Wettability Alteration by Surfactants in Naturally Fractured Reservoirs*. Published by Society of Petroleum Engineering.

[7] Delshad, M., Najafabadi, N.F., Anderson, G.A., Pape, G.A., & Sepehrnoori, K. (2006). *Modelling Wettability Alteration by in Naturally Fractured Reservoirs*. Published by Society of Petroleum Engineering.

[8] Enhanced Oil Recovery. Retrieved February 5,2014, from http://en.wikipedia.org/wiki/Enhanced_oil_recovery.

[9] Flaaten, A.K. (2008). *A Systematic Laboratory Approach to Low-Cost, High-Performance Chemical Flooding*. Published by Society of Petroleum Engineering.

[10] Gurgel, A., Moura, M.C.P.A., Dantas, T.C., Barros Neto, E.L., & Dantas Neto, A.A. (2008). A Review on Chemical Flooding Methods Applied in Enhanced Oil Recovery. *Brazillian Journal of Petroleum and Gas, 2*(2), 83-95. Retrieved from http://www.portalabpg.org.br/bjpg.

[11] Han, C., Delshad, M., Pope, G.A., & Sepehrnoori, K. (2009). *Coupling Equation-of-State Compositional and Surfactant Models in a Fully Implicit Parallel Reservoir Simulator Using the Equivalent-Alkane-Carbon-Number Concept*. Published by Society of Petroleum Engineering.

[12] Hirasaki, G.J., Miller, C.A., & Puerto, M. (2011). *Recent Advances in Surfactant EOR*. Published by Society of Petroleum Engineering.

[13] Hezave, A.Z., Dorostkar, S., Ayatollahi, S., Nabipour, M., & Hemmateenejad, B. (2013). Investigating The Effect of Ionic Liquid (1-dodecyl-3-methylimidazolium chloride on the water/oil Interfacial Tension as a Novel Surfactant). *Colloids and Surfaces A: Physicochemical and Engineering Aspects, 421,* 63-67.

[14] Interfacial Tension. Retrieved February 5,2014, from http://petrowiki.org/Interfacial_tension.

[15] Karnanda, W., Benzagouta, M.S., AlQuraishi, A., & Amro, M.M. (2013). Effect of Temperature, Pressure, Salinity, and Surfactant Concentration on IFT for Surfactant Flooding Optimization. *Arab J Geosci, 6, 3535-3544.*

[16] Krosravi, V. (2010). *Developing Surfactant to Increase the Production in Heavy Oil Reservoirs*. Published by Society of Petroleum Engineering.

[17] Lake, L.W. (1996). *Enhanced Oil Recovery*. 1st edn. Prentice Hall, Englewood Cliffs, NJ.

[18] Laurier L.Schramm. *Surfactants: Fundamental and Applications in the Petroleum Industry*. Cambridge University Press: UK. 2000.

[19] Seethepalli, A., Adibhatia, B., & Mohanty, K.K. (2004). *Physicochemical Interaction During Surfactant Flooding of Fractured Carbonate Reservoirs*. Published by Society of Petroleum Engineering.

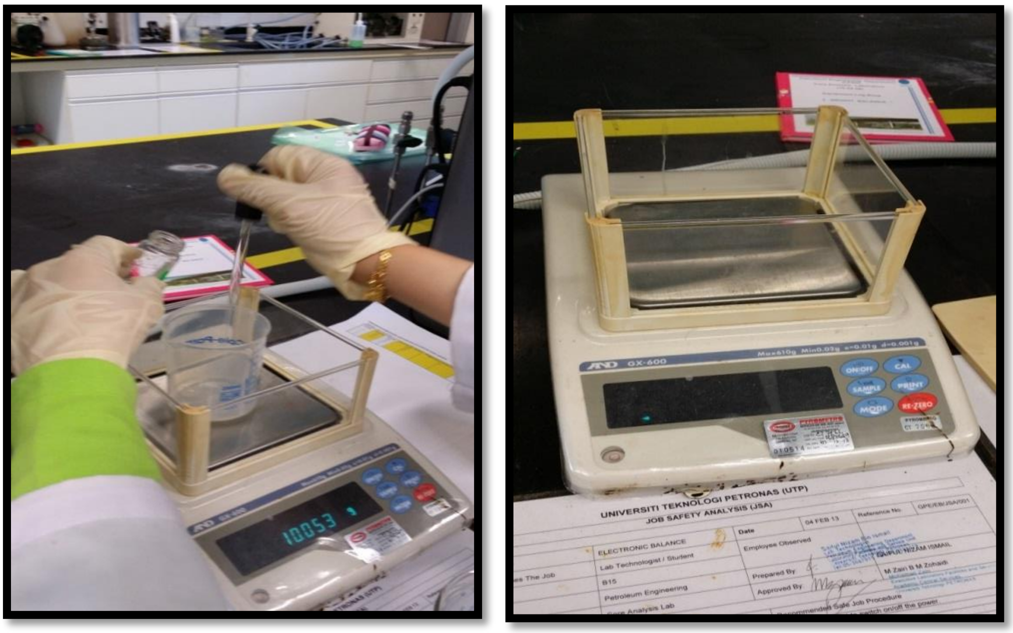
[20] Spinler, E.A., Zornes, D.R., Tobola, D.P., & Moradi, A. (2000). *Enhancement of Oil Recovery Using a Low Concentration of Surfactant to Improve Spontaneous and Forced Imbibition in Chalk.* Published by Society of Petroleum Engineering.

[21] Srivastava, M., Zhang, J., Nyugen, Q.P., & Pope, G.A. (2009). *A Systematic Study of Alkaline-Surfactant-Gas Injection as an EOR Technique.* Published by Society of Petroleum Engineering.

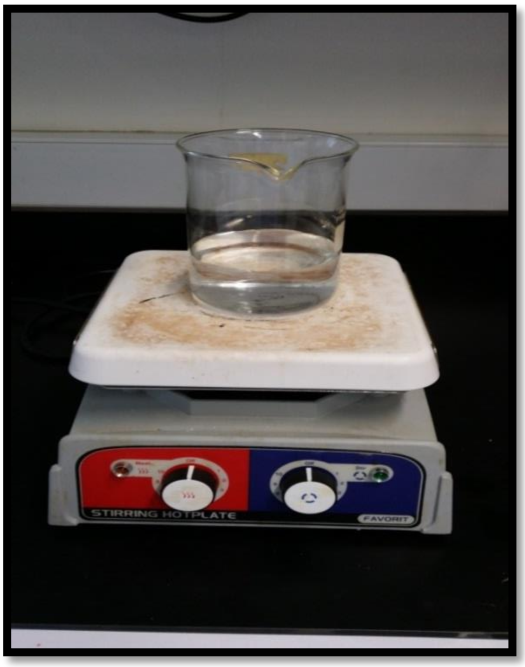
[22] Thomas, S., Scoular, J.R., & Farouq S.M. (1999). *Chemical Methods for Heavy Oil Recovery*. Published by Society of Petroleum Engineering.

APPENDICES

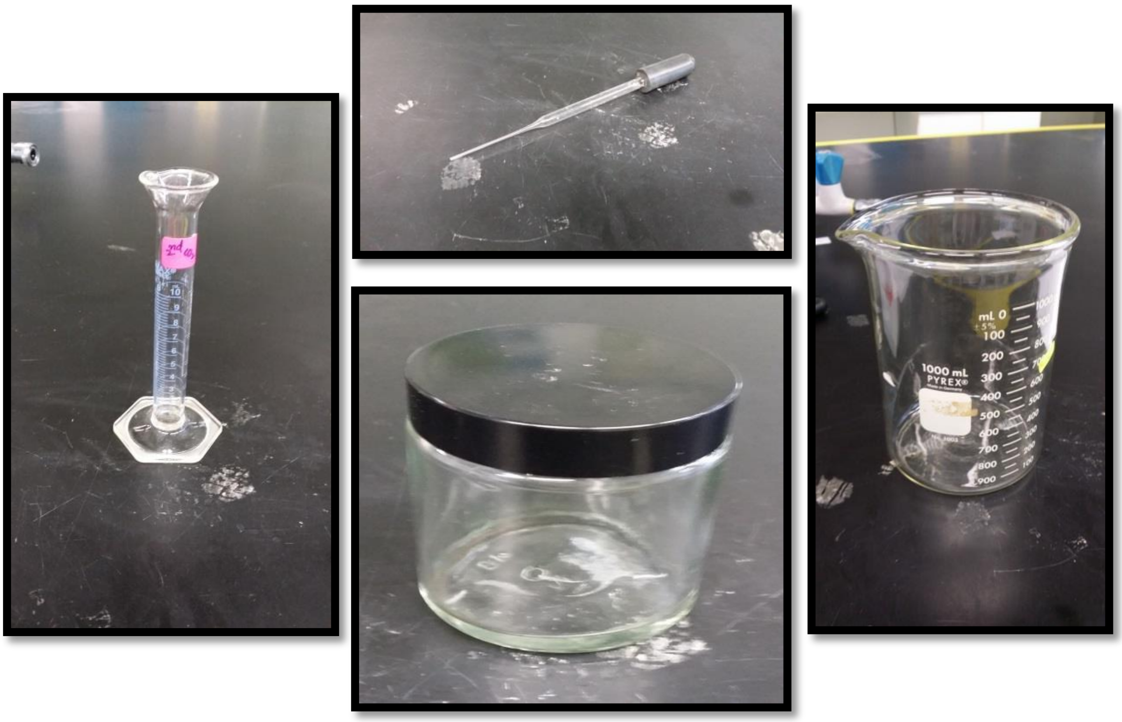
Attachment 1: Chemicals - CL10, IL10, Sodium Chloride



Attachment 2: Weighting Equipment



Attachment 3: Heater



Attachment 4: Equipment used for preparing the samples

Attachment 5: Density Meter